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STUDY OF URBAN SPRAWL IMPACTS ON WETLAND ECOSYSTEM USING REMOTE SENSING AND GIS

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ABSTRACT

Developing countries like India are experiencing huge growth in urban population which may force to cause uncontrolled urban expansion resulting in urban sprawl. With increasingly rapid urbanization, wetlands are being threatened by direct conversion to urban areas and watershed-related impacts of urban development. The wetlands of Kerala are under the constant threat of pollution, eutrophication, encroachment, reclamation, mining, biodiversity loss etc and can be treated as the by-products of uncontrolled urban sprawl. In order to conserve the existing wetlands and prevent its further loss, it is inevitable to monitor wetlands and adjoining areas. The latest geospatial techniques like remote sensing and GIS have immense potential for inventorying and monitoring wetlands. It offers a cost-effective and time-saving alternative for delineating wetlands over a large area compared to conventional field mapping methods. The objective of this paper is to quantify wetland dynamics and estimate wetland loss due to urban sprawl in the study area by using an integrated approach of remote sensing and geographic information system techniques. This study also examine how urban sprawl leads to environmental changes mainly through wetland degradation.

KEYWORDS: Urban sprawl, wetland, remote sensing, GIS, change detection

1. INTRODUCTION

The cities in India are urbanizing at an alarming rate like several other developing countries around the world. The UN World Urbanization Prospects 2018 report specified that about 34% of India's population now lives in urban areas and it is projected to escalate around 54% by 2050. This massive urbanization is a direct result of globalization which brings about drastic changes in population, ecology, social and economic aspects (Ramachandra, 2012). This may result in uncontrolled, unplanned, unauthorized and uncoordinated growth of urban areas away from the city center which can be defined as urban sprawl. Urban sprawl is considered as one of the potential threats for sustainable development.

Urban sprawl is caused and catalyzed by numerous demographic, economic, geographic, social and technological factors. Some of them are population growth, industrialization, economic growth, speculation about future growth, land hunger attitude, individual preferences favoring low-density development, natural barriers to contiguous urban development, lack of affordable housing, lack of proper planning policies etc. (Bhatta2010, OECD Report 2018). It will ultimately result in the destruction of green space and open space, environmental damage, loss of surface water, rise in traffic, contributes to air pollution, depletion in groundwater, loss of biodiversity, increased congestion and has got serious impacts on the urban ecosystem and on the sustenance of natural resources.

Urban sprawl has been shown to have significant environmental consequences ranging from destruction of green space and open space, loss of biodiversity, rise in pollution load, impacts on the urban ecosystem and on the sustenance of natural resources. This paper focuses on the wetland loss due to urban sprawl. Wetlands are areas where water is the primary factor controlling the environment and the associated plant and animal life. They occur where the water table is at or near the surface of the land, or where the land is covered by water (Ramsar, 2016). They are the world's most productive environment. The multiple roles of wetland ecosystems and their value to humanity have been increasingly understood and documented in recent years. This has led to large expenditures to restore lost or degraded hydrological and biological functions of wetlands mainly due to uncontrolled urban growth and human encroachment. Recent developments and urban sprawl have caused the destruction of many wetland ecosystems of international importance.

In order to conserve the existing wetlands and prevent its further loss, it is inevitable to monitor wetlands and adjoining areas. Geographic Information Systems (GIS) and Remote Sensing (RS) data are appropriate tools for monitoring of the wetland distribution area and spatial-temporal dynamic multiplicity (Emadi, 2010). For inventorying and monitoring wetlands, satellite remote sensing has many advantages. Satellite data has repeat coverage so that wetlands can be monitored seasonally or yearly. They can also provide information on surrounding land uses and their changes over time. Current information on the uplands surrounding wetlands is important because land use practices in uplands cause loss of wetland functions, goods, services and values. Satellite data are in digital format and relatively easy to integrate into a Geographic Information System (GIS). Using satellite remotely sensed data for land cover classification is less costly and less time-consuming than aerial photography for large geographic areas. Satellite remote sensing can be especially appropriate for wetland mapping and monitoring in developing countries, where funds are limited and where little information is available on wetland areas, surrounding land uses, and wetland losses over time (Ozesmi, 2002., Mwita, 2012).

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Ghobadi et al., (2012) applied multi temporal remote sensing data and GIS techniques in Hoor Al Azim wetland to detect the changes in wetland before and after dam construction and its factors. Assessment of results showed that the wetland system was changed dramatically due to the increase in agricultural activity, climate change to some extent and engineering project caused surface area reduction in Hoor Al Azim wetland. In this study, four Landsat images were used for 1985 (Landsat MSS), 1999 (Landsat ETM+), 2002 (Landsat ETM+) and 2011 (Landsat ETM+). The results showed that there is a spatial reduction in the wetland ~72% due to increase in the agricultural land, increases in water demands and also anthropogenic activities in the upstream areas of wetland. Soliman and Soussa (2011) used the maximum likelihood supervised classification and the post-classification comparison change detection in order to monitor the wetlands by assessing and quantifying the wetland cover changes in the Nile swamps of southern Sudan, called the Sudd, by using the ERDAS IMAGINE software. Three multispectral satellite imageries, acquired in the wet season from 1986 to 2006 by Landsat TM and Landsat ETM+ images, are classified into five main land cover classes namely water, vegetation, urban, wetland-vegetation, and wetland-no vegetation, by using the maximum likelihood supervised classification. A pixel-by-pixel comparison is then performed over the classified thematic map images. The post-classification change detection results show a 3.69% decrease in the wetland-vegetation areas and a 2.68% decrease in the wetland-no vegetation areas within the period 1986 to 1999.

2. STUDY AREA

The study area consists of Ashtamudi wetland and the Sasthamkotta Lake in the Kollam district, Kerala, India together with three-kilometer buffer area around them. Ashtamudi Lake (8°52'53" to 9°1'17" N Latitude, 76°31'49" to 76°40'40" E Longitude) is the second largest and deepest wetland ecosystem, a palm-shaped (also called octopus-shaped) extensive water body, next only to the Vembanad estuary ecosystem of the state. Ashtamudi means 'eight coned' (Ashta = 'eight'; mudi = 'coned') in the local language of Malayalam. This name is indicative of the lake's topography: a lake with multiple branches. All the arms converge into a single outlet at Neendakara near Kollam, to enter the Arabian Sea. The lake is also called the gateway to the backwaters of Kerala. Ashtamudi wetland is included in the list of wetlands of international importance, as defined by the Ramsar Convention for the conservation and sustainable utilization of wetlands. It is declared as Ramsar site on 19/08/2002 with Ramsar site no: 1204. Like fingers of the palm, it has multiple branches viz. AshtamudiKayal, KumbalathuKayal, KanjirakottuKayal, KandanchiraKayal and KaripuzhaKayal. (Wikimedia Commons. (n.d)).

The Sasthamkotta Lake (9°01'32" to 9°03'23" N Latitude, 76°36'38" to 76°38'59" E Longitude) also categorized as a wetland, is the largest rain-fed freshwater lake in Kerala situated on the right bank of Kallada river in Kollam district of Kerala. The lake is named after the ancient Sastha temple (a pilgrimage center) located on its bank. The source of water is from the underground springs. It meets the drinking water needs of half million people of the Kollam district and also provides fishing resources. The lake is a designated wetland of international importance under the Ramsar Convention since 19th August 2002 with Ramsar site no: 1212. The study area is shown in Figure.1.

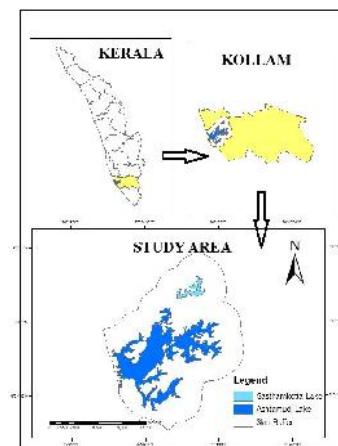


Figure 1. Study Area

3. DATASETS AND SOFTWARES

The collected data for the study comprises of Survey of India (SOI) toposheet of 1967 (scale, 1:50,000, No.58C/12 and 58D/9), Landsat imageries of 1990, 2000 and 2018 and SRTM DEM data of 90m resolution for deriving the drainage network. Table 1 shows the details of Landsat Imageries used for the study.

Image	Path/Row	Resolution(m)	Date of Acquisition
Landsat TM	144/54	30	25 February 1990
Landsat 7 ETM+	144/54	30	28 January 2000
Landsat 8	144/54	30	21 January 2018

Table 1. Details of Landsat Imageries

Data processing, extraction of information and analyses were performed using various software like ERDAS (Earth Resources Digital Analysis System) Imagine 2011, ArcGIS 9.3(ESRI) and DNR Garmin. The ground truth data points are collected using Garmin handheld GPS receiver. Google Earth application is used for getting information and land-use of historic imageries and locations which are inaccessible during field visit.

4. METHODOLOGY

The present study deals with the mapping and change detection of Ashtamudi and Sasthamkotta wetland over the past 40 years using SOI toposheet of the year 1967, Landsat TM of 1990, Landsat ETM+ of 2000 and Landsat 8 image of 2018. The general methodology adopted is as shown in Figure.2.

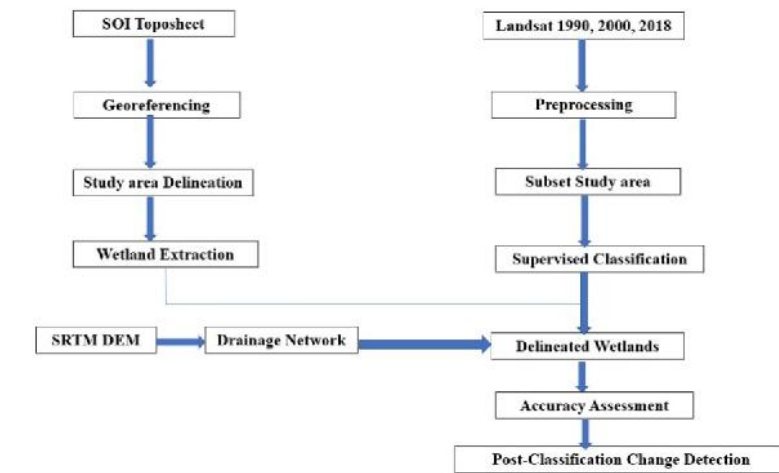


Figure 2. Flow-chart of General Methodology

4.1 Extraction of Wetlands from Toposheet

The Survey of India toposheet of 58C/12 and 58D/9 (Scale 1:50,000) were scanned using map scanner and the scanned image was stored in JPEG format. Using ArcGIS 9.3 software, toposheets were brought to WGS 1984 Universal Transverse Mercator zone 43N. Georeferencing was done by selecting control points to make it comparable with the real world with minimum RMS error. Then the study area boundary was delineated by manual heads-on digitization using polygon tool. Finally, the wetland areas in the toposheet like paddy fields, flooded areas and lake/waterbodies was to be delineated by on-screen digitization.

4.2 Image Pre-Processing

Three satellite images which were used for the study include 1990 Landsat TM, 2000 Landsat TM and 2018 Landsat 8. At first, some pre-processing such as atmospheric and geometric correction should be done on the SOI toposheets which were selected as reference map and geometrically correct it and register it to the UTM map coordinate system zone 43 North, Datum WGS-84. Then all satellite images (1990, 2000 and 2018) were registered (map to image) according to the SOI toposheet. ERDAS Imagine 2011 was used for all image analysis and image processing.

4.3 Study area extraction from imageries

Images were geo-referenced and study area is extracted in ERDAS IMAGINE 2011 using the subset option. The 3km buffer area which is stored in ArcGIS as shapefile is converted to .aoi file and with the aid of this .aoi file the study area is subset successfully in all the three images of 1990, 2000 and 2018. Image to image georeferencing is done by identifying common points/features in the reference image and the satellite image selected.

4.4 Delineation of Drainage Network

Drainage network is delineated using ArcHydro tool in ArcGIS software. This involves a step-by-step procedure in which flow direction, flow accumulation, and stream network are derived in respective order. The DEM is corrected by filling up the sinks using the tool 'fill' in ArcGIS. This ensures that water will flow without any stagnation. The 'Flow Direction' and 'Flow Accumulation' tools are used in respective order and these two layers were then used to generate the stream network. This process is automated and rapidly delineates the drainage networks.

4.5 Supervised Classification

Supervised classification is more closely controlled by the user than unsupervised classification. In this process, the user selects pixels that represent patterns the user recognizes or that the user can identify with help from other sources. Knowledge of the data, the classes desired, and the algorithm to be used is required before the beginning of selecting training

samples. By identifying patterns in the imagery, the user can train the computer system to identify pixels with similar characteristics. By setting priorities to these classes, the user supervises the classification of pixels as they are assigned to a class value. If the classification is accurate, then each resulting class corresponds to a pattern that the user originally identified. Maximum likelihood classification (MLC) is the classification approach used for analyzing the image using supervised classification method. In this study, the study area is classified into seven classes: lake/waterbody, waterlogged areas, mangroves, paddy, barren land, built-up and vegetation.

4.6 Ground Truth Data

Ground truth information is required in the training stage of supervised classification and also for accuracy assessment. The overall objective of training process is to assemble set of statistics that describe the spectral response pattern for each land cover to be classified in the image. Therefore, ground truth information of the study area is acquired using GPS.

The ground truth survey was conducted from 14th February 2018 to 17th February 2018. A hand-held GPS survey was carried out to determine the positions of the land use classes. Garmin eTREX with a positioning accuracy of 3m is the hand-held GPS that is used for conducting the survey. The positions were given by the GPS in terms of latitude and longitude. Structured field survey forms were used in data recording. The data points were collected for various land-use features like lake/waterbody, waterlogged areas, paddy, mangroves, built-up, vegetation and barren land. Some areas which are not assessable can be collected from Google Earth application. Figure.3 shows the ground truth points obtained from hand-held GPS survey.

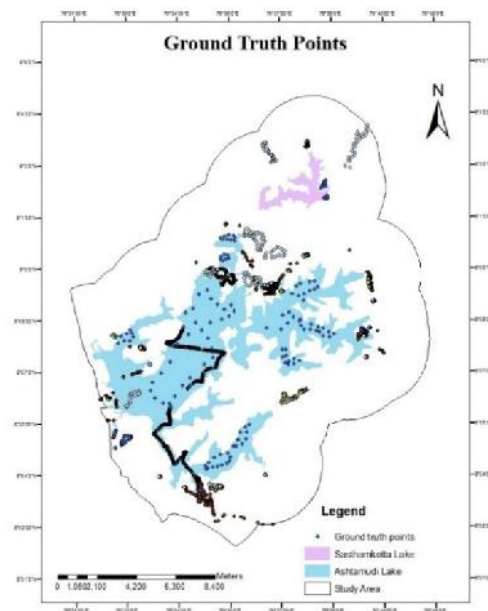


Figure 3. Ground Truth Point Locations

4.7 Post Classification Change Detection

The images from different dates are independently classified using supervised classification. The maps are then compared pixel-by-pixel basis. This method avoids the difficulties in change detection associated with the analysis of images acquired by different sensors, thereby minimizing the problem of radiometric calibration across dates. One disadvantage is that every error in the individual date classification maps is also present in the final change detection map.

5. RESULTS AND DISCUSSION

5.1 Extraction of Wetlands from Toposheet

After fixing the study area boundary, all the wetland areas are manually digitized from the toposheet using heads-up digitization method. From the legend of the toposheet we can clearly identify lake/ waterbodies, paddy fields and usually flooded areas. These areas are together grouped under wetlands. The digitization is being done on the screen of the computer monitor. Therefore, it is also known as on-screen digitization. The digitization process thus requires the use of appropriate software. For this purpose, ArcGIS Editor, ArcView are used in this study. The wetland features are extracted using the polygon geometry type. Figure 4 shows the wetland areas mapped from SOI toposheet of 1967. From the figure, the wetland areal extent which comprises of the Lakes, waterbody, paddy fields and flooded areas is found to be 169.50 sq.km and the other areal extent is 120.45 sq.km. The total study area approximates 289.95 sq.km.

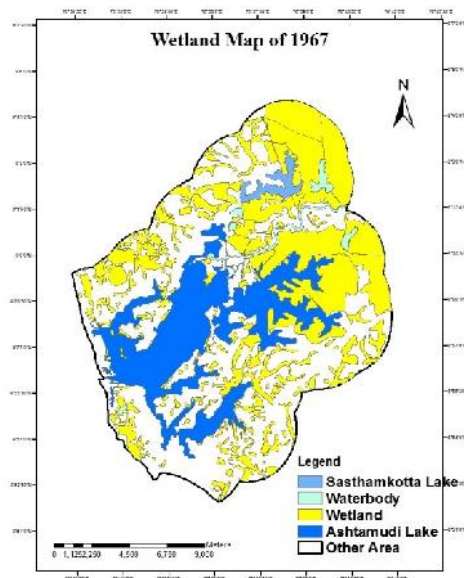


Figure 4. Wetland Area Map from Toposheet

5.2 Drainage Network Delineation

The drainage network of the study area is prepared from the SRTM (Shuttle Radar Topographic Mission) derived DEM (Digital Elevation Model). The study area is first clipped from the DEM (Figure 5). It is then given as input to ArcHydro tool of ArcGIS. The DEM is then corrected by filling the sinks using the 'Fill' tool' available in ArcHydrotoolbox. Then this filled DEM is used to derive stream network through a step by step procedure. This process is automated and rapidly delineates the drainage networks as shown in Figure 6.

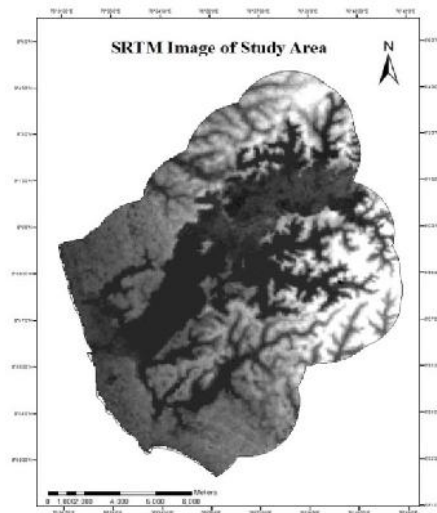


Figure 5. SRTM DEM of Study Area

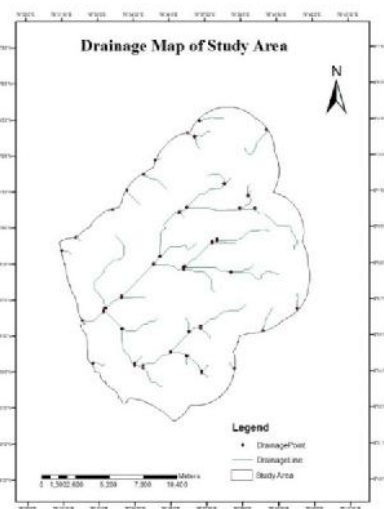


Figure 6. Drainage Map of Study Area

5.3 Supervised Classification

A supervised land use classification is done using the Landsat image of the study area. Each land use type generally has a unique spectral signature. The areas of interest (AOI) were created from the ground truth survey. Then the AOI polygons were converted into parametric files presenting the spectral signatures of the training data. In this study, the study area is classified into seven classes –lake/water body, waterlogged areas, paddy, mangroves, built-up, barren land and vegetation. Accuracy assessment has been carried out using ground truth survey points. Figures 7-9 shows the landuse map of 1990, 2000 and 2018 prepared from supervised classification respectively.

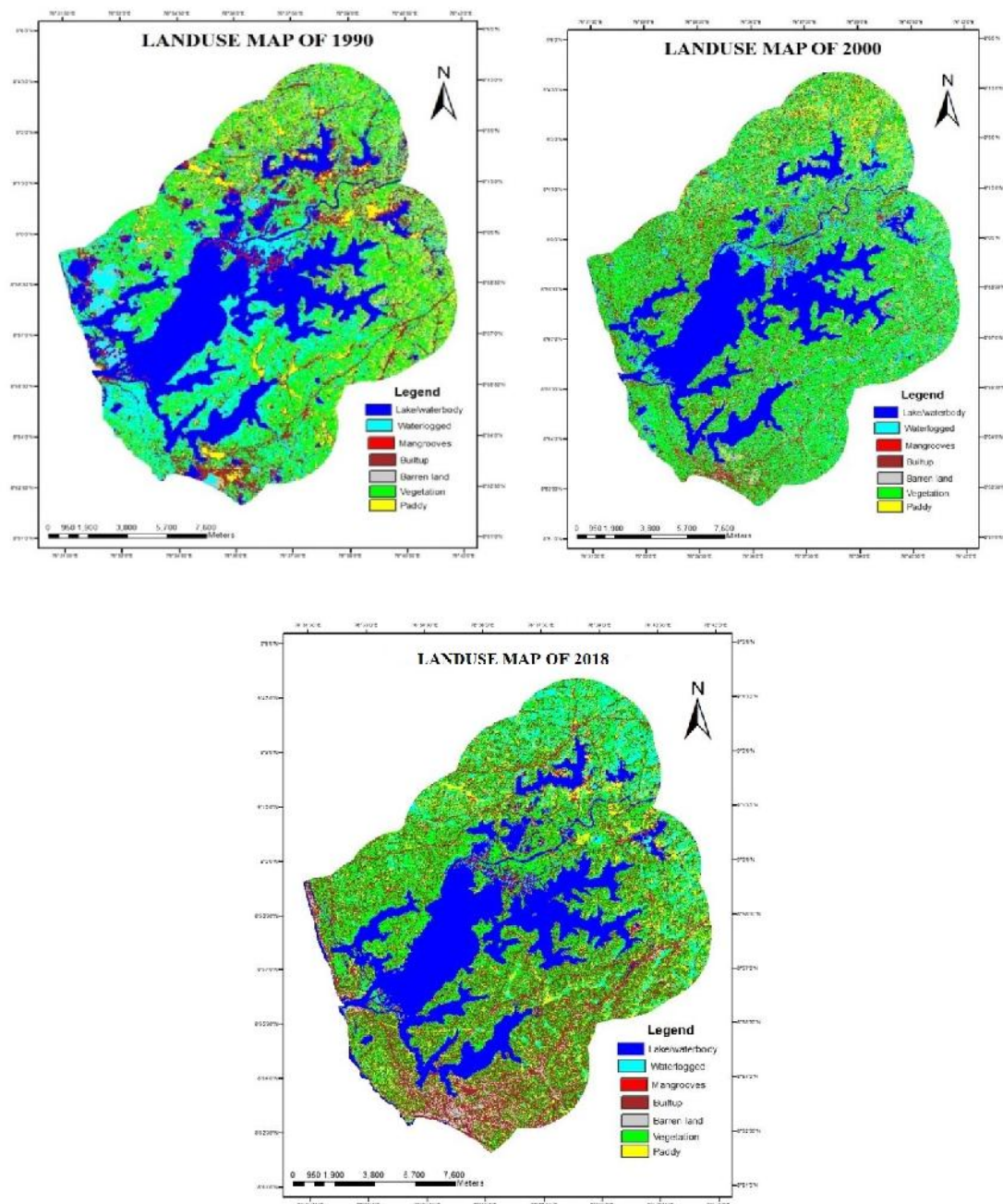


Figure 7-9. Land Use Map of 1990, 2000 and 2018 by Supervised Classification

After performing supervised classification on the 1990, 2000 and 2018 imageries, seven different land use classes were obtained. They are lake/waterbody, waterlogged areas, mangroves, paddy, barren land, built-up and vegetation. The first four categories can be grouped under wetlands and the remaining three can be grouped under other areas. The area statistic obtained from supervised classification of 1990, 2000 and 2018 is shown in Table 2.

Table 2. Area Statistics from Supervised Classification Results

Landuse Type	Area in 1990(sq.km)	Area in 2000(sq.km.)	Area in 2018(sq.km)
Lake	73.46	68.90	59.6
Waterlogged	27.57	53.36	16.07
Mangrooves	14.017	10.29	3.12
Paddy	31.006	24.45	13.31
Other area	143.891	162.94	197.85
Total Area	289.95	289.95	289.95

Next accuracy assessment of supervised classification was carried out using ground truth survey locations obtained from handheld GPS survey. The results showed 93.30% producers accuracy and 91.06% users accuracy for mapping various wetland classes. The overall accuracy for mapping wetland was found to be 88.91%, and it is more accurate compared to other methods of wetland mapping because it involves training area identification using field visits. Also using supervised classification, we can easily predict the changes that happened to particular land cover to the newly changed one. It can easily demarcate between the various wetland classes. But it is tedious and time consuming and is not that appropriate for global scale wetland studies.

5.4 Post-Classification Change Detection

Change gives us the changes of specific features within a certain time interval. For a given research purpose, when the remotely sensed data and study areas are identified, selection of an appropriate change detection method has considerable significance in producing a high-quality change detection product. Now, after obtaining detailed wetland area information from supervised classification, change detection analysis is done by using four data sets to find out the changes that have taken place between the years 1967 to year 2018. Area (in sq.km and %) occupied by wetland and other areas for all the data sets of the study area shown in the Table 3.

Table 3. Area Statistics from Post-classification Comparison

	1967		1990		2000		2018	
Feature name	Area(sq.km.)	Area(%)	Area(sq.km.)	Area(%)	Area(sq.km.)	Area(%)	Area(sq.km.)	Area(%)
Wetland	169.50	58.21	146.063	50.37	127.014	43.80	92.1	31.76
Other areas	120.45	71.79	143.89	49.63	162.940	56.2	197.85	68.24
Total	289.95	100	289.95	100	289.95	100	289.95	100

The following bar diagram shows the changes in wetland area that occurred from 1967 to 2018 (Figure 10).

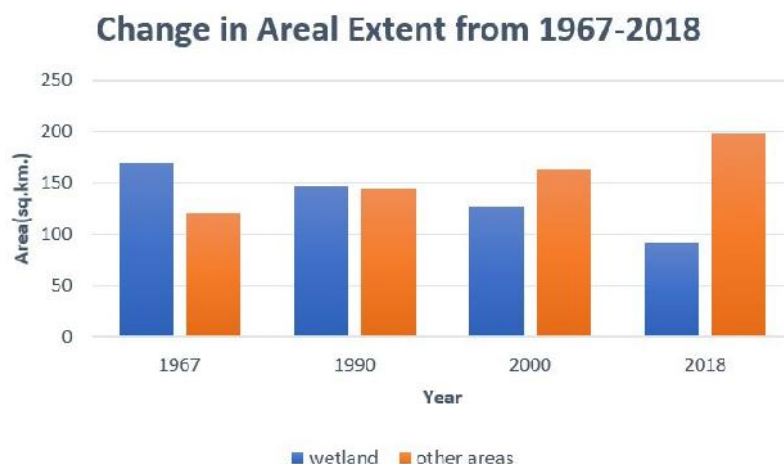


Figure10. Bar chart showing the changes in study area over years

From 1967 to 1990, almost 13.82% reduction in the wetlands occurred in the study area. When it reaches 2000, the reduction in wetland area approximates 25.06%. Almost 46% reduction in wetland area occurred from 1967 to 2018. Large change in the wetland area has been witnessed during 2000 to 2018, almost 27.48% of wetland area is converted to other areas. The major reason for this loss is found to be uncontrolled urban sprawl mainly due to agricultural expansion, and reclamation of lake for developmental purposes, encroachment etc. The surrounding areas are thickly populated and urbanized to a greater extent, leading to excessive human interferences and subsequent environmental degradation. Most of the cultivable paddy fields in the past are now turned into built-up and barren land. The mangroves in the study area decreased in an alarming way from 1990 to 2018. Nearly 77% reduction in the mangrove areas can be witnessed from 1990 to 2018. The mangroves in Asramom and Munroe islands are in peril.

6. CONCLUSION

The study investigated the mapping and changes of Ashtamudi and Sasthamkotta wetland over the past 50 years using Landsat TM, Landsat ETM+, Landsat 8 and SOI toposheet. After performing the supervised classification and post-classification change detection for all dates of imagery, it can be concluded that the wetland area is found to be diminishing in an alarming rate in the study area. Approximately there occurred 46% decrease in the wetland extent from 1967 to 2018. The major reasons for the decrease in the wetland extent in the study area are uncontrolled urban sprawl because of population/ household growth & urbanization, industrial development, infrastructure development, agriculture expansion, mining and deforestation etc. So proper care has to be taken for the wellbeing of Ashtamudi and Sasthamkotta wetland.

Encroachment and pollution due to human activities should be checked effectively. Unless some conservation mechanism is undertaken, the trend of urban sprawl would have undeniable impact on the wetland ecosystem of the area. The principles of Smart Growth strategies can be taken as a means to preserve the wetland areas of the region. Therefore, rapid increases in both urban/built-up expansions led to dramatic changes in land use and land cover, which were witnessed by sharp decreases in wetland areal extent, mangrove vegetation etc.. Care should be taken to devise planning policies for providing a sustainable environment and thus, rational urban planning policy must be made to decrease the adverse effects of urban sprawl and can make the wetland useful for the present and future generations for numerous products and services.

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SWIR BAND SYNTHESIS AT SPATIAL RESOLUTION OF LISS-4 MX DATA USING LISS-3

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ABSTRACT

Short Wave Infrared (SWIR) wavelength finds its uses in many applications like snow and ice discrimination, urban feature identification, mineral exploration, wildfire response, soil moisture estimation etc., due to its advantages like High sensitivity, can see through the smoke and penetrate thin clouds, less effect of atmospheric aerosols on SWIR wavelengths etc. With three-tier imaging capability Resourcesat-2 series, provides unique combination of payloads consisting of three solid-state cameras, viz., LISS-4, LISS-3 and AWiFS. LISS-3 sensor operates in four spectral bands providing a spatial resolution of 23.5m and covering a swath of 141 Km and LISS-4 sensor operates in three bands providing a spatial resolution of 5.8m and covering a swath of 70 Km. Three tier imaging facilitates, for each LISS-4 scene coverage there will also be coverage by LISS-3, which is taken advantage in SWIR band synthesis. This paper presents a novel method of generating synthesised SWIR band at the spatial resolution of LISS-4, adopting block based spectral transformation with multiple regression, by using the spectral knowledge of SWIR band present in LISS-3. A spectral transformation method is used to establish a relationship between the Band-2, Band-3, Band-4 and Band-5 (SWIR) images provided by LISS-3 sensor. A scene-based transformation function is fitted by selecting radiometric control points between Band-2, 3 and 4 as a function of Band-5 of LISS-3 along the line of geometric registration to find a set of coefficients to be used for simulating a SWIR band for Liss-4. The synthesised LISS-4 SWIR band will be validated by comparing it with LISS-3 SWIR band, with results of radiometric target analysis covering different terrain feature for their spectral response.

KEYWORDS: Short wave infrared, Three tier imaging, Spectral transformation, Multiple regression

1. INTRODUCTION

Images acquired in SWIR wavelength finds applications compared to visible wavelength acquired images particularly in discriminating wet earth from dry earth, and in geology (rocks and soils that look similar in other bands often have strong contrasts in SWIR). SWIR band discriminates moisture content of soil and vegetation and is also useful in areas like: mining/geology, oil spill detection etc. Keeping in view of the numerous applications of SWIR band, there is a strong need to have high resolution SWIR band images at the spatial resolution of LISS-4. This is achieved by synthesising SWIR band at spatial resolution of LISS-4 using the knowledge of SWIR band present in LISS-3. The three-tier imaging ability of Resourcesat-2 ensures that for every LISS-4 scene coverage there will also be coverage by LISS-3, which is utilised to generate scene based spectral transformation coefficients using LISS-3 data to generate synthesised SWIR band for LISS-4. Resourcesat-2 has a three-tier imaging capability (Figure 1) which ensures LISS-3 coverage for every LISS-4 coverage, the sensor characteristics are given in Table-1.

Table 1: LISS-3 and 4 Spectral Bands Characteristics

	LISS-3 Bands	LISS-4 Bands
Spectral Bands	Spectral Wavelength (nm)	Spectral Wavelength (nm)
B2	520-590	520-590
B3	620-680	620-680
B4	770-860	770-860
B5	1550-1700	Not present

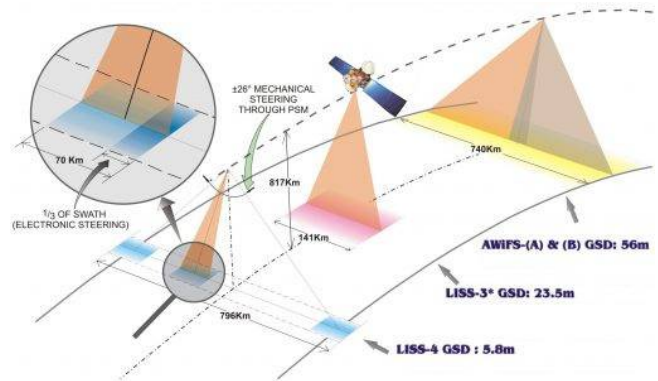


Figure 1: Three Tier Imaging in Resourcesat-2

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2. METHODOLOGY

The steps used in synthesising the SWIR band are:

1. Image registration between LISS-3 and LISS-4 Images
2. Spectral transformation using block based multiple regression by writing Band 5 as a function of Bands 2, 3 and 4 to derive band coefficients.
3. Radiometry normalisation of LISS-4 Bands 2,3,4 with LISS-3 Bands 2, 3, 4 respectively.
4. Usage of normalised LISS-4 bands 2, 3 and 4 with the derived band weights to generate SWIR band.

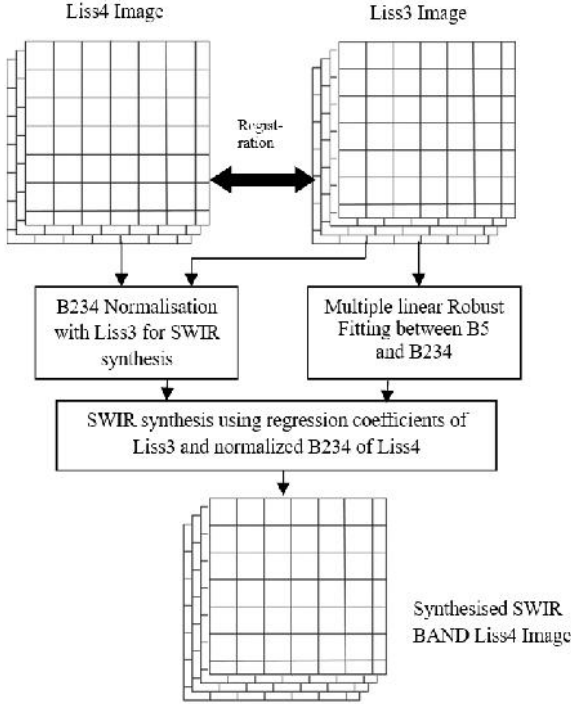


Figure 2: Block diagram showing the SWIR band synthesis procedure

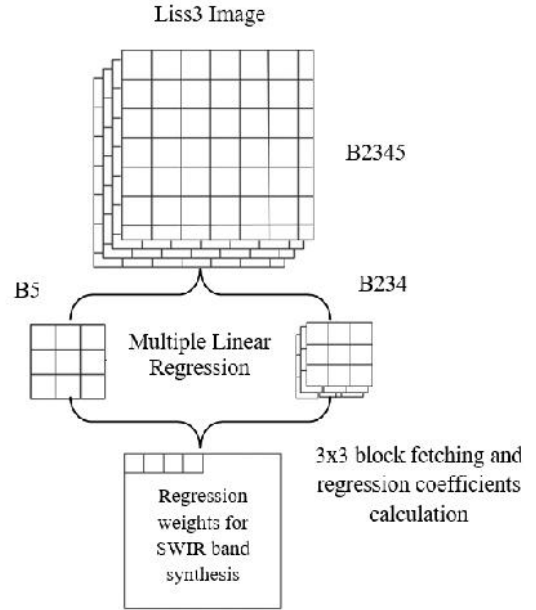


Figure 3: Block regression for band weights

2.1 Image Registration

Image registration is the process of matching two images so that corresponding coordinate points in the two images match the same physical region of the scene between the images. Image registration between two remote sensing images is a very important image pre-processing step for band synthesis, data fusion and change detection applications and its accuracy has a key impact on post-processing. Hence the LISS-3 and LISS-4 images are orthorectified and co-registered to sub pixel accuracy. The sub pixel accuracy registered images are used in post processing to derive regression coefficients for SWIR band synthesis.

2.2 Spectral Transformation using Block based Multiple Linear Regression

In spectral registration, the transformation method is similar to commonly used geometric transformation, except that geometric coordinates are replaced with spectral values. The purpose is to transform a given arbitrary band coordinate system into a pre-defined reference band coordinate system. In the spatial registration, the geometry of the scene can be computed, whereas, in spectral registration, the spectral values of the scene can be inferred⁴.

The information available in the bands can be used to write a particular band (for example Band 5) as a function of other three bands (for example Bands 2, 3 & 4). Given a radiometric control points in two image pairs (Bands 2,3,4 and Band 5 images) $[(x_i, y_i), (u_i, v_i)], i=1 \dots n$, the mapping functions that register the images can be formulated in the following way

$$\begin{aligned} X_i &= f(u_i, v_i) \\ Y_i &= g(u_i, v_i) \end{aligned}$$

Where (x_i, y_i) corresponds to a point in the reference image (SWIR band image) and (u_i, v_i) corresponds to a point in the multiband image (Band 234 image). The transformation function maps the spectral nature of points in the reference image to the corresponding

nature of the input image. The transformation function using all the three bands (Near Infra-red, red, green) to derive SWIR band is given by the following equation:

$$\text{SWIR} = a + bG + cR + d\text{IR} \text{-----}(1)$$

Where, G for pixel value in green band,
R for pixel value in red band,
IR for pixel value in near infrared band,
a, b, c, d for transformation coefficients,

In this spectral transformation, one needs to find few control points, which will be exploited to determine global radiometric mapping function.

Linear regression using the radiometric control points is a global regression method considering the points across the image with spectral accuracy achieved limited by the selection of the radiometric control points representing all the thematic class features in the scene under consideration. Whereas Block-based regression is a technique based on multiple linear regression of block regions to generate block wise regression coefficients. Implementation of the block-regression provides two advantages. One is that the block-regression based technique drastically decreases the amount of computation, whereas regression of the whole image is almost impossible. The other, most important, advantage is that adjustment of regressed block size can result in different emphasis between preservation of spectral characteristics and enhancement of textural content. The larger the regression block, the more the textural details are enhanced. In contrast, the smaller the regression block, the more the spectral features are preserved⁶.

The following steps are used in generating the block wise regression coefficients between Liss3 Bands 234 and Band 5:

- 1 A block and its neighbours are fetched from the Liss3 B234 and B5 images.
- 2 Linear multiple parameters are calculated according to Equation-1 given below, directly through multiple linear regression between the 3×3 blocks fetched from B5 image and the 3×3 blocks fetched from B234image.

$$B5 = C_1 * B2 + C_2 * B3 + C_3 * B4 \text{-----} (2)$$

Where C_1 , C_2 and C_3 are block regression coefficients.

- 3 The resultant values are saved to compute the values for the rest of the blocks.
- 4 Then steps (1) to (3) are repeated until the last block is completed. If the block size is equal to image size the regression will become multiple linear regression. A block size for 512 was used in the present study for best results and easier computation.

3. DATASETS USED AND PROCESSING

3.1 Data Used

To verify the accuracy of synthesised SWIR band, several data sets of LISS-3 and LISS-4 from Resourcesat-2A satellite covering various land features were chosen for analysis. The data sets used were covering the areas of Bengaluru, Rameswaram, Kashmir, Malanjkhanda mines, Goa and Jaisalmer. The details of scene centre latitude and longitudes and date of pass etc. (Table-2).

Table 2: LISS-3 and LISS-4 data sets used

S.No	DOP	LISS-3 Path/Row	LISS-4 Path/Row	Area covered
1	22-Feb-18	101/57	101/57/A	Malanjkhanda
2	21-Feb-18	096/61	096/61/C	Goa
3	20-Feb-18	091/52	091/52/C	Jaisalmer
4	05-Jan-17	100/64	100/64/C	Bengaluru
5	03-Feb-18	102/67	102/67/D	Rameswaram
6	01-Feb-18	092/47	092/47/B	Kashmir

3.2 Processing

In this work, we have selected the block size of 512 and used all the pixels of LISS-3 as radiometric control points to generate block wise regression coefficients with SWIR band image as an arithmetic sum of images from bands 2, 3, 4. The transformation function is fitted using equation-2.

The evaluated coefficients are used to transform Band 234 image of LISS-4 to simulate SWIR band image. The images in Figure 4(a) represents the LISS-3 image (B543) at spatial resolution of 23.5m in actual pixels with a portion covered by LISS-4 image (marked yellow rectangle); Figure 4(b) is the corresponding synthesised SWIR band LISS-4 image (B543) at spatial resolution of 5m.

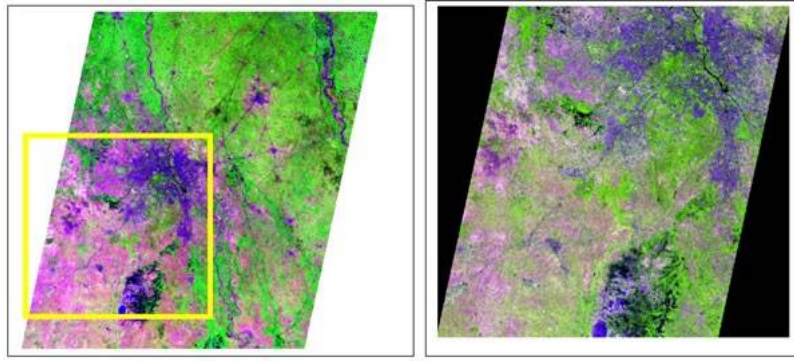


Figure 4: Delhi and Surroundings Path/Row: 96/51, DOP: 29Sep2015
(a) Input LISS-3 Image (B543) (b) Synthesised LISS-4 Image (B543)

4. RESULTS

The regression coefficients calculated for various scenes using LISS-3 bands 2, 3, 4 and 5 are tabulated below:

Table 3: Values of Regression coefficients and RMSE and R^2 achieved

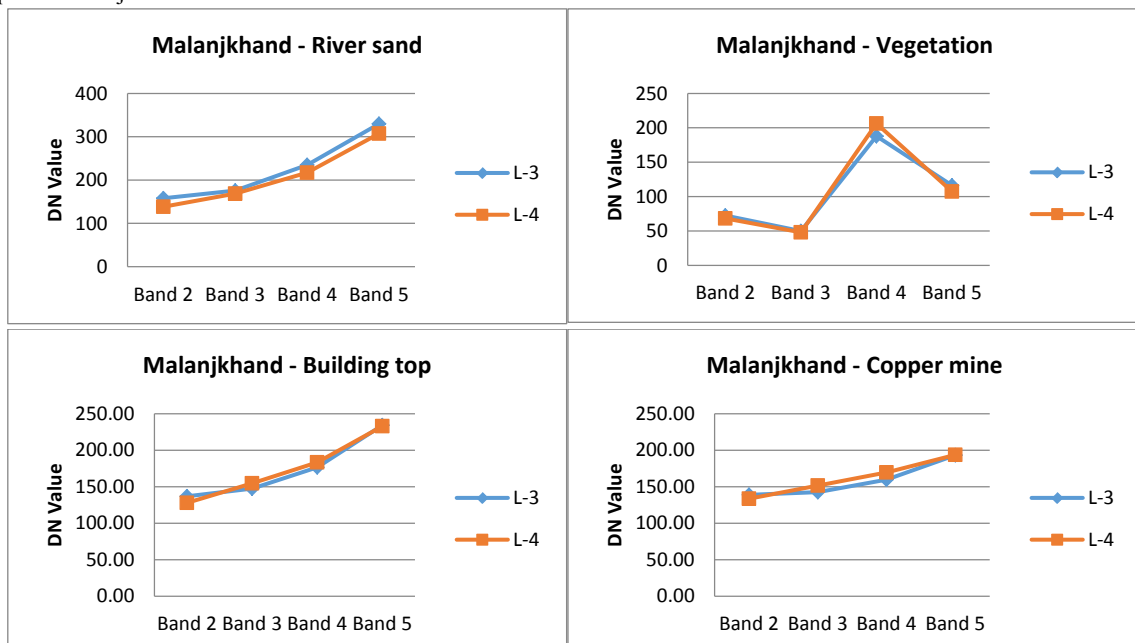
Image area	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	RMSE	R^2
Malanjkhanda	-1.0685	2.8607	0.29308	1.6346	5.41	0.967
Goa	-2.2497	3.7935	0.39386	-0.3541	7.13	0.947
Jaisalmer	-0.3749	1.7196	0.09258	0.08597	3.72	0.994
Bengaluru	-0.41819	2.0882	0.23433	0.2343	6.56	0.964
Rameswaram	-0.01421	0.02542	0.28355	0.01244	2.696	0.996
Kashmir	-2.5109	3.0974	0.51279	0.08131	4.22	0.991

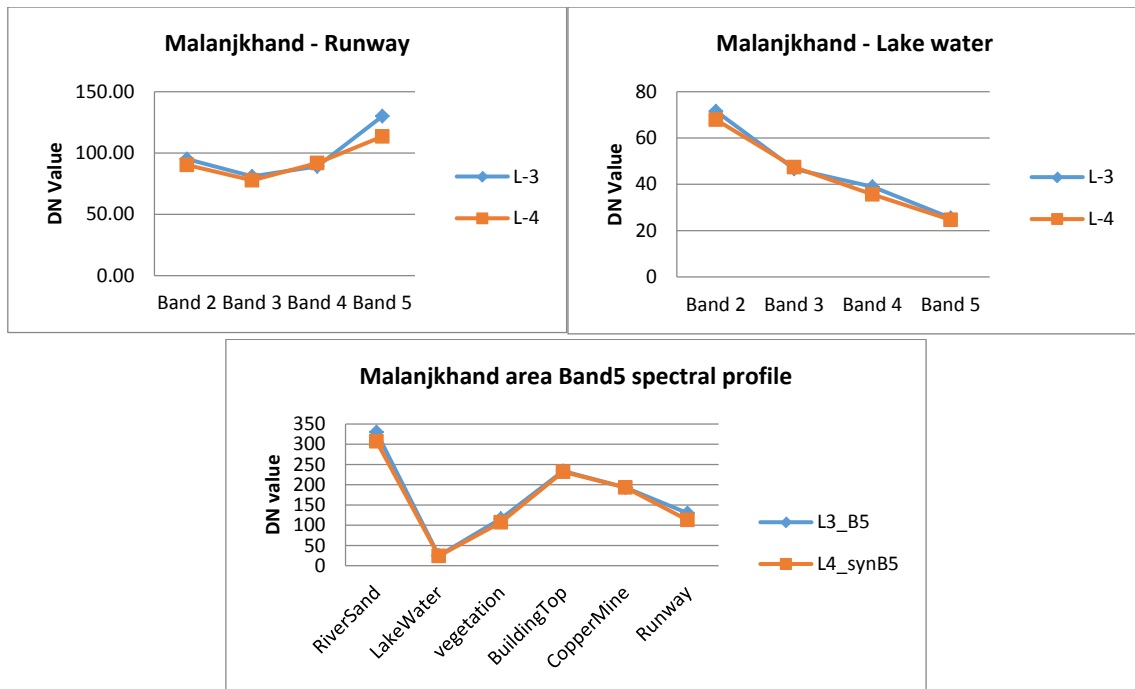
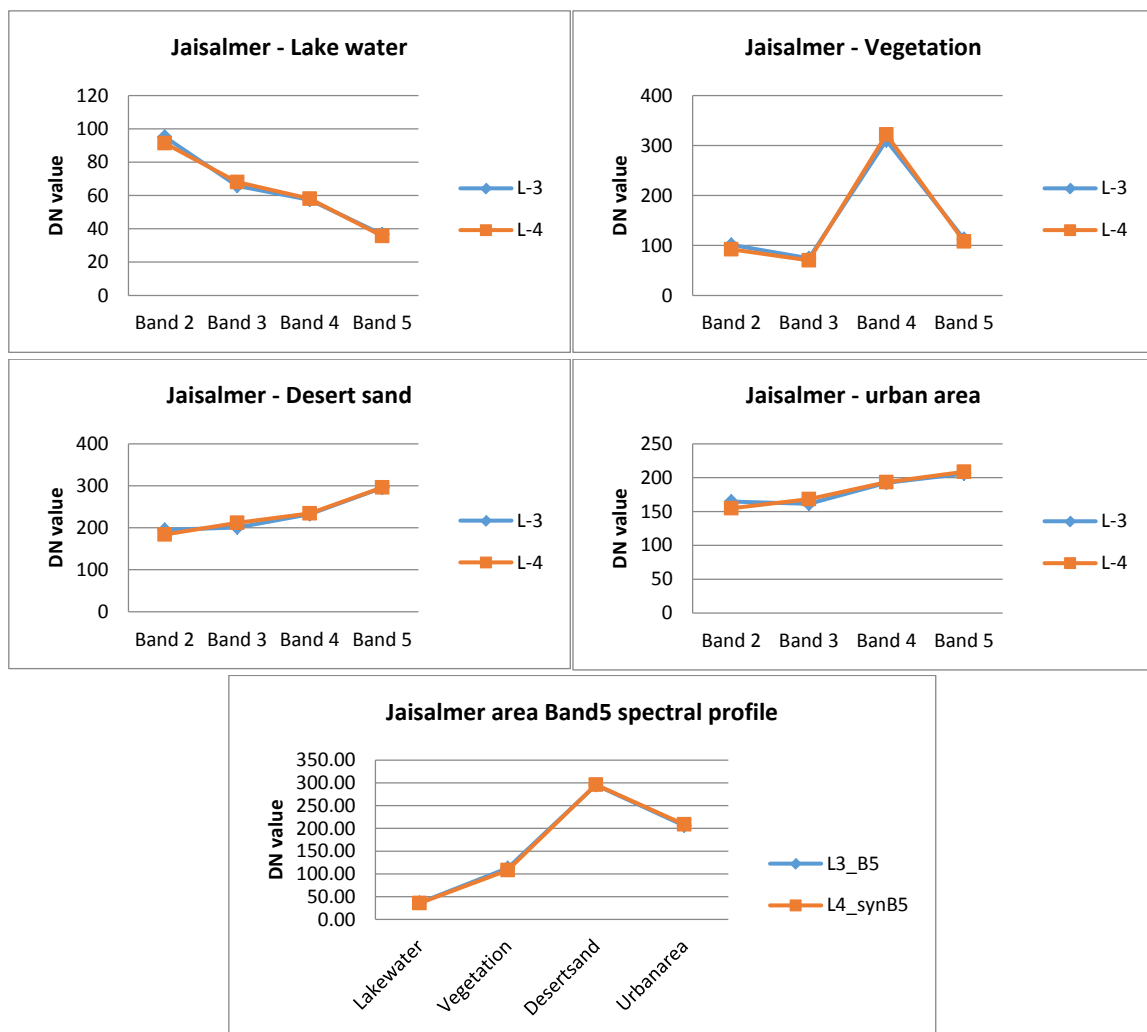
As can be seen from the results the RMSE achieved for 10-bit radiometry is less than 1% with R^2 more than 0.95.

4.1 Spectral Response Analysis

Resourcesat-2A, LISS-3 and LISS-4 data sets were selected on various terrain features. Input data sets used for analysis were given in Table-1. Few sample targets like river sand, lake water, vegetation, building top, deep sea water, desert sand were selected in the data sets to study the spectral response.

Example 1: Malanjkhanda Area



**Example 2: Jaisalmer Area**

On Malanjkhanda area, various types of area targets are identified to study the spectral response from synthesized Band-5 data as shown in Example-1 plots. Spectral profile of mean DN value of lake water, river sand, vegetation, copper mine area, building top and runway area targets were plotted for LISS-3 band-2345 and LISS-4 band-234 including synthesized band-5. Synthesized LISS-4 band-5 Spectral signatures of above targets are following the LISS-3 band-5 spectral signatures. Maximum mean difference between LISS-3 and LISS-4 on river sand is less than 8% and a minimum mean difference is 4% on lake water. Similar trend was observed on Rajasthan desert targets i.e., desert sand, vegetation, lake water, urban area targets shown in Example-2 plots. From the above spectral signatures, it can be observed that the synthesized LISS-4 Band-5 is following the spectral signatures as expected in the original SWIR band of LISS-3.

5. CONCLUSION

We have developed a spectral transformation method to synthesise LISS-4 SWIR band using knowledge from LISS-3 data. The proposed method enables the use of a unique set of transformation coefficients to generate a high-resolution SWIR band. The method worked well for images taken at different times, seasons, and classes, which are typical to remote sensing. Thus, the proposed method can be applied in different applications if the accuracy achieved is suitable for the given application.

ACKNOWLEDGEMENTS

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ESTIMATION OF RESIDENTIAL PROPERTY VALUES AS A FUNCTION OF ITS LOCATION USING GEOINFORMATICS - A CASE STUDY OF GOTRI AREA OF VADODARA, GUJARAT, INDIA

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ABSTRACT

Residential property value and its assessment is a complex and challenging task since it involves the consideration of a variety of underlying factors of the market and the way they affect the value of the property at a given time. It is also commonly accepted that properties are spatially unique and this means that location is an intrinsic attribute of a dwelling that directly determines housing quality and market value. The present study is aimed at estimating the residential property values as a function of its location using hedonic Multiple Regression Analysis (MRA) and geostatistical kriging in Gotri area of Vadodara city, India. Data on more than 30 parameters related to structural, locational and amenities were collected for 300 residential properties selected through stratified random sampling method in the study area. The data on per square feet value of the residential properties were also collected from the respondents and were normalized based on inputs received from property experts. In hedonic MRA, the location is being modeled as several accessibility variables along with structural variables. MRA is run on property value (dependent variable) and fifteen explanatory variables (structural and accessibility) to understand the relationship between variables and to estimate the residential property prices. Also, geostatistical kriging is used to estimate the residential property prices in the study area. Results are presented in the form of interpolated surfaces, graphs and tables.

KEYWORDS: Residential Property Value, Multiple Regression Analysis, Geostatistics, Semivariogram, Ordinary Kriging.

1. INTRODUCTION

Residential property price estimation is a complex and challenging field. Variation in residential properties as well as their prices is so high and diverse that it becomes difficult to analyze which variables will be suitable for modeling and will have greater or lesser impact on residential property prices. The property market is shaped by complex spatial and non-spatial processes which exert a combined effect on market value (Munroe, 2007). Each residential unit has a unique bundle of attributes such as accessibility to work, public transport, amenities, structural characteristics, neighbourhood, and environmental quality (Evans, 1973; Kain and Quigley, 1970; Muth, 1969; Ridker and Henning, 1967; So et al., 1997; Stegman, 1969).

From the list of attributes, location is arguably the most important component affecting property values. It is also commonly accepted that properties are spatially unique and this means that location is an intrinsic attribute of a dwelling that directly determines housing quality and market value. However, modeling locational factors in understanding property values has proved difficult because of the wide range of spatially defined attributes, which may or may not affect value at a particular time and location.

The accessibility to services, facilities and amenities is an essential locational factor affecting the residential property development. In many regions, urban plans ensure that individuals have some minimal levels of accessibility to the public sector facilities, such as schools, emergency services, and recreation amenities. At the same time, an essential element of location strategy for housing development is to avoid proximity to noxious facilities (For e.g., waste disposal sites, gas depots, and chemical factories) or noise producing facilities (For e.g. party plots, marriage halls etc.).

The hedonic model based on Multiple Regression Analysis (MRA) is considered a classical and traditional technique for explaining and predicting property values. In implementing MRA, a dependent variable and set of explanatory variables need to be identified and measured in quantitative form. This task becomes more complicated when the location influence in the form of accessibility on property values need to be explicitly identified and modeled. The failure of MRA is related to spatial autocorrelation and heteroscedasticity, the two spatial effects inherent in property data (Fletcher et al., 2000; Mark and Goldberg, 1988). Spatial autocorrelation means that the residuals are spatially correlated.

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The main aim of present study is to quantify the locational parameters and understanding its effects on residential property values. The location is modeled in terms of accessibility from residential properties to various facilities/amenities available in the neighborhood.

2. STUDY AREA

Gotri area located in the western part of Vadodara City, India is selected as a case study for understanding the effects of accessibility on residential property values (Fig. 1). Gotri, situated some 5 km west of central transport hub of the city, was once considered a small village situated in the outskirts of the city, it is now being considered as a developing counterpart of Alkapuri, one of the posh locality within Vadodara city. The study area is situated 5 km away from railway station/central bus depot and 9 km from the airport. Gotri is considered as one of the fastest developing reality market of the city. At the same time, the study area is developing fast in terms of social and physical infrastructure. Gotri offers a maximum number of apartments with respect to other residential areas of the city along with other types of residential units. Several schools, hospitals, banks, sub-markets etc. are located within the study area. People have easy access to malls, restaurants and movie theatres situated around race course circle which is only 2 km away from the Gotri. All type of residential options from apartments to bungalows to villas is catering to the middle income, upper middle and higher income groups.

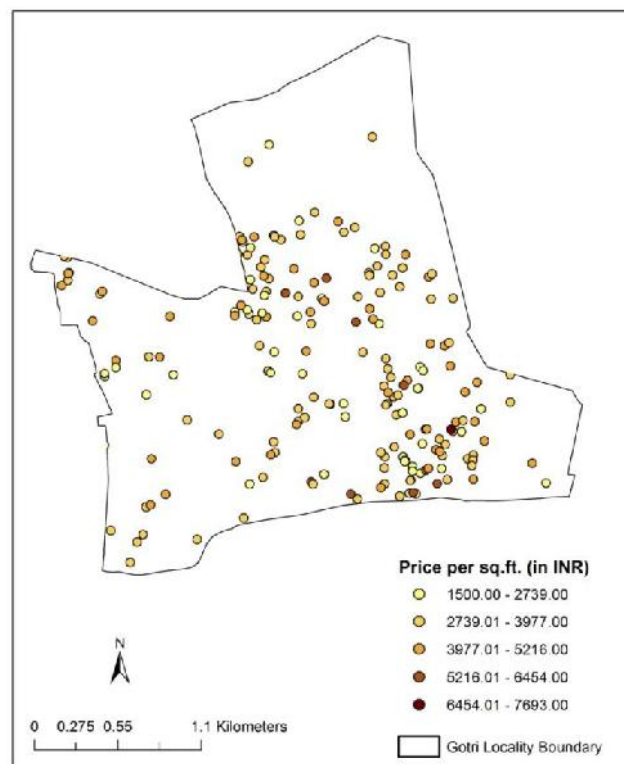


Figure 1. Location of Sample Residential Properties, Gotri Area, Vadodara City (Gujarat, India)

3. DATABASE AND METHODOLOGY

Primary data through structured schedule on more than 30 parameters related to structural (type of property, carpet area, super built- up area, age of the property, no. of bedrooms etc.) locational (location of the property, distance to nearest major road, market, public transport facility, public health service, recreational areas, central bus depot/railway station, central market, noise producing facilities etc.) and amenities were collected for 300 sampled residential properties from the study area. The sample properties were selected through stratified random sampling method and in proportion with the number of type of residential properties in the study area. The type of residential properties was considered based on classification used by Vadodara Municipal Corporation for collecting property tax. These types are Flat / Apartment, Apartment Penthouse Flat, Tenement, Row House, Bungalow, Villas, Duplex, Individual Building, Gamtal house (house in original village Gotri), Pole House (old houses in congested locality), Cabin, Chali House (old houses in congested lanes) and Hut. The data on assessed residential property value per square feet were collected from the property valuers and were normalized based on inputs received from property experts. Also, the contribution of land value to the total

property value for each of types of residential property varies greatly and therefore it was adjusted based on property valuer's judgement. Eleven accessibility variables quantifying the location effects are identified as given in Table 1.

In calculating accessibility, distance was considered with negative impedance i.e. larger the distance from residential properties to selected accessibility variables via a road network, lower is the accessibility and vice versa. An exception is the distance from residential properties to noise producing facilities. Here, lower distance is considered as negative impedance. The distances were calculated based on ArcGIS network model. The "near" function in ArcGIS software was used to find out nearest facility/amenity with a distance from sample residential properties.

Also, four structural variables namely property age (*pay*), carpet area (*casf*), super built-up area (*sba*) and number of bedrooms (*bedr*) are included as explanatory variables. Carpet area is the area enclosed within the walls and it is the actual area which can be put to any use within any residential unit. On the other hand, super built-up area is inclusive of carpet area, walls with their thickness and area under common spaces like the lobby, staircase, lift, security room etc.

Average residential property value is INR 3,410/ sq. ft. calculated from 300 sampled properties. Total average cost of the residential property derived from sample statistics is INR 49,49,307 in the Gotri area of Vadodara city. This total average cost seems higher, mainly depends on the type of property which decides the share of the cost of land in overall property value.

All variables were transformed before entering into the estimations. This was due to the skewed distribution for dependent and all explanatory variables. Natural log transformation of all selected dependent and explanatory variables has also been incorporated for Multiple Regression Analysis (MRA) using OLS (Ordinary Least Square) method. Multiple correlation analysis is attempted to understand the correlation between property value and selected explanatory variables and among explanatory variables themselves. Variables with high correlation among explanatory variables were omitted and Multiple Regression Analysis (MRA) was attempted on the remaining variables.

Sr. No.	Variables	Mean	1st Quartile	3rd Quartile	Standard Deviation
Dependent Variable					
1	Property Value in INR (per sq. ft.) (<i>rpvsf</i>)	3410	2644	4000	1046
2	Property Value in INR (Total) (<i>rpvt</i>)	49,49,307	31,50,000	61,35,000	30,69,030
Explanatory Variables - Structural					
3	Property Age (in Years) (<i>pay</i>)	11	3	15	10
4	Carpet Area (in sq. ft.) (<i>casf</i>)	1016	700	1213	499
5	Super built-up Area (in sq. ft.) (<i>sba</i>)	1440	1000	1725	680
6	No. of Bedrooms (<i>bedr</i>)	3	2	3	1
Explanatory Variables - Accessibility					
7	Distance to nearest major road (<i>disnmr</i>) (in m)	169	59	247	137
8	Distance to nearest market (<i>disnm</i>) (in m)	869	398	1172	653
9	Distance to nearest school (<i>disns</i>) (in m)	595	265	736	474
10	Distance to nearest public transport facility (<i>disnptf</i>) (in m)	387	196	477	315
11	Distance to nearest recreational facility (<i>disnrecf</i>) (in m)	637	335	762	450
12	Distance to nearest public health service (<i>disnphs</i>) (in m)	868	402	1087	640
13	Distance to central transport facility (<i>disctf</i>) (in m)	4381	3520	5250	969
14	Distance to central market (<i>discm</i>) (in m)	7494	6590	8461	1001
15	Distance to highway (<i>dish</i>) (in m)	7371	6750	7818	867
16	Distance to nearest exit point (<i>disnep</i>) (in m)	2023	1406	2806	880
17	Distance to nearest noise producing facility (<i>disnnpf</i>) (in m)	696	435	820	428

Table 1. Descriptive Statistics of Sample Residential Properties (Source: Author's calculations)

Ordinary Kriging, a geostatistical method is attempted on dependent variable i.e. residential property value to produce a continuous interpolated output for understanding the spatial variation in residential property prices across the Gotri area of Vadodara city. Geostatistical kriging uses the spatial structure of correlation to explain the housing price. Kriging and other geostatistical methods are used to create interpolated maps of variable under study. Residential property price estimation is important for the appraisal companies, bureaus, investment banking and administration for speeding up the mass appraisal and to draw up continuous maps of residential property price (Chica-Olmo et al., 2010). These maps reflect patterns in the spatial distribution of housing price within the study area. In hedonic regression the number of variables that influence house prices is both large and heterogeneous. Furthermore, identifying all relevant neighborhood characteristics within the city is difficult (Tse, 2002). Also, the correlation between the explanatory variables causes serious multi collinearity problems in the regression model.

Ordinary Kriging assumes the following model (Cressie, 1991).

$$Z(s) = \mu + \delta(s)$$

where: μ is the unknown constant-mean and $\delta(s)$ is the spatially auto correlated error, intrinsically stationary.

Ordinary Kriging is an estimation method that uses the spatial dependence of a second-order stationary variable. The spatial dependence between Z and the separation vector distance (h) and the direction (θ) is expressed by a variogram (semivariogram or direct-variogram) $\gamma(h)$ (Matheron, 1965). The model fitted depends on three parameters: nugget effect, range and sill. The nugget effect is a measure of spatial continuity; range is the distance where the model levels out and sill is the value that the variogram model attains at the range. The sill equals to the sum of partial sill and nugget.

4. RESULT AND DISCUSSION

4.1 Multiple Correlation Analysis

Multiple correlation analysis is performed by calculating correlation matrix to understand the degree of association between dependent variable i.e. residential property value and explanatory variables and among explanatory variables themselves. Karl Pearson's product moment correlation co-efficient were calculated and tabulated in the form of multiple correlation matrix (Table 2). As expected, property value is positively correlated with property age, carpet area, super built-up area and number of bedrooms and negatively correlated with distance to major road, distance to nearest market, distance to nearest school and other accessibility variables. Only accessibility variable showing unexpected negative correlation is distance to nearest noise producing facility (disnnpf). Ideally, increasing distance should result in increasing residential property prices but, the negative correlation shows otherwise. This is may be due to the fact that any noise producing facility has temporary local effect up to very limited distance and therefore, its relation with residential property values may not be linear. Variables having more than ± 0.70 correlation co-efficient were identified. The correlation co-efficient values revealed that there is higher positive correlation exist between carpet area and super built-up area (+0.99), distance to central transport facility and distance to central market (+0.98) and between distance to nearest school and distance to nearest public health services (+0.78). Also, high negative correlations were observed between distance to central market and distance to nearest highway exit point (disnep) (-0.81) and between distance to central transport facility and disnep (-0.71). In order to remove multicollinearity/data redundancy, highly correlated variables were considered for their possible exclusion from the multiple regression analysis. Between carpet area and super built-up area of the residential property, super built-up area was considered more appropriate for inclusion as the per sq. ft. price of the property is generally arrived at using super built-up area and not carpet area for most builders in the Vadodara city. However, recent guidelines under the provisions of the Real Estate (Regulation and Development) Act, 2016 (RERA), it is now the duty of the developer, to make buyers aware of the carpet area and quote prices based on this and not the super built-up area. High correlation is also observed distance to central transport facility (disctf) and distance to central market (discm). They both vary together in a similar fashion with respect to distances from sampled residential properties. In general, central market plays more important role than central transport facility hence, distance to central market is retained for multiple regression analysis. Between distance to nearest school (disns) and distance to nearest public health services (disnphs), the higher correlation is may be by chance otherwise, they both are not related at all. For removal of one of the variables, disns need to be retained because nearness to school may be given more weightage than public health service by individual residential property buyers. Similarly, between distance to central market and distance to nearest highway exit point (disnep) (-0.81), distance to central market is retained.

<i>Variables</i>	<i>rpvsf</i>	<i>pay</i>	<i>casf</i>	<i>sba</i>	<i>bedr</i>	<i>disnmr</i>	<i>disnm</i>	<i>disns</i>	<i>disnptf</i>	<i>disnrecf</i>	<i>disnphs</i>	<i>disctf</i>	<i>discm</i>	<i>dish</i>	<i>disnep</i>	<i>disnnpf</i>
<i>rpvsf</i>	1															
<i>pay</i>	0.14	1														
<i>casf</i>	0.06	-0.25	1													
<i>sba</i>	0.05	-0.25	0.99	1												
<i>bedr</i>	0.23	-0.21	0.66	0.66	1											
<i>disnmr</i>	-0.16	0.00	0.02	0.04	0.02	1										
<i>disnm</i>	-0.22	-0.35	0.16	0.17	0.11	0.41	1									
<i>disns</i>	-0.19	-0.28	0.21	0.21	0.08	0.19	0.73	1								
<i>disnptf</i>	-0.26	-0.29	0.17	0.18	0.08	0.45	0.79	0.68	1							
<i>disnrecf</i>	-0.30	-0.29	0.13	0.15	0.09	0.47	0.84	0.53	0.75	1						
<i>disnphs</i>	-0.22	-0.35	0.17	0.18	0.10	0.38	0.92	0.78	0.79	0.77	1					
<i>disctf</i>	-0.15	-0.43	0.17	0.18	0.11	0.21	0.76	0.53	0.54	0.68	0.67	1				
<i>discm</i>	-0.11	-0.41	0.17	0.18	0.11	0.13	0.68	0.45	0.46	0.58	0.54	0.98	1			
<i>dish</i>	-0.19	-0.05	-0.04	-0.03	-0.02	0.45	0.39	0.35	0.36	0.53	0.56	0.12	-0.07	1		
<i>disnep</i>	-0.04	0.26	-0.10	-0.10	-0.08	0.10	-0.17	0.09	0.02	-0.16	0.02	-0.71	-0.81	0.42	1	
<i>disnnpf</i>	-0.26	-0.15	0.05	0.06	-0.01	0.41	0.63	0.71	0.66	0.63	0.73	0.36	0.24	0.59	0.31	1

Note: Highlighted cells shows correlation coefficient higher than ± 0.70

Table 2. Multiple Correlation Matrix (Source: Author's calculations)

4.2 Multiple Regression Analysis

Initially, Multiple Regression Analysis using Ordinary Least Square method was run on real data of residential property value (per sq.ft.) and fifteen explanatory variables related to structural characteristics and accessibility. Multiple R value of 0.44 with R^2 of 0.20 (Table 3) was achieved, which shows that selected explanatory variables are moderately able to explain the variation in dependent variable i.e. residential property value. Natural log transformed data of dependent and all explanatory variables were used for applying MRA. The multiple R value slightly improved to 0.48 with R^2 of 0.23. After removing three explanatory variables namely carpet area, distance to nearest public health service and distance to central transport facility, the MRA results showed no improvement over the use of all fifteen explanatory (structural and accessibility) variables. Residential property prices tend to be auto correlated for two reasons. First, nearby properties tend to be developed at the same time, so neighborhood properties have similar structural characteristics such as dwelling size, interior and exterior design features and so on. Second, neighborhood residential properties share location facilities/amenities (Basu and Thibodeau, 1998). For example, the same public transport facility point is used by neighborhood residential properties and neighborhood children have access to the same public schools. In order to understand the spatial autocorrelation in residential property prices, Moran's I was calculated. The Moran's I achieved was 0.46 (Manhattan distance) and 0.44 (Euclidean distance) suggesting moderate spatial autocorrelation among data points. The z-score value of 5.39 indicated that, there is less than 1% likelihood that this clustered pattern could be the result of random chance. The z- value found to be significant at 0.01. Since, residential property prices are auto correlated, it is possible to apply kriging to estimate prices at unsampled locations.

	Real values – all fifteen explanatory variables	Natural log of all fifteen explanatory variables	Natural log of twelve explanatory variables
Multiple R	0.44	0.48	0.47
R Square	0.20	0.23	0.22
Standard Error	961	0.27	0.27

Table 3. Multiple Regression Analysis Results (Source: Author's calculations)

4.3 Geostatistical Kriging

Ordinary Kriging is implemented using Geostatistical Analyst toolbox in ArcGIS software. The log transformation is used to make the variances more constant throughout the study area and the data closure to being normally distributed. The model parameters, partial sill and others are optimized using cross validation with focus on the estimation of the range parameter. The semi-variogram is modeled as given in figure 5. The weighted least square algorithm is used to estimate the values of nugget and partial sill. The estimated value of nugget is 0.025 and partial sill is 0.059. The derived range value is 406.

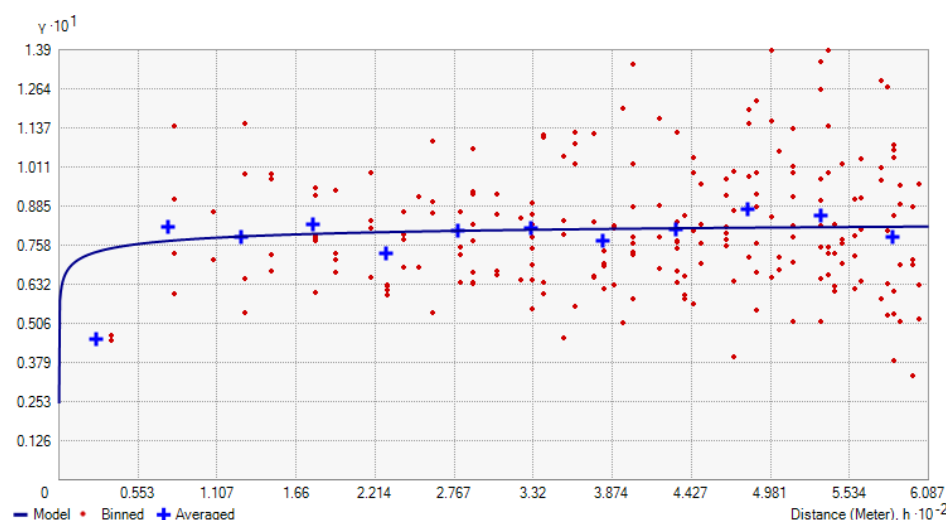


Figure 5. Semivariogram Model for Residential Property Values

Using all parameters, two outputs of Ordinary Kriging i.e. prediction map and prediction standard error map are generated. The prediction map shows different zones of residential property prices estimated based on Ordinary Kriging. The residential property prices are classified into ten classes with minimum price being INR 1,500 per sq.ft. to INR 7,693 per sq.ft (Figure 6). Around 50% of the study area is classified under moderate property prices between INR 3,246 to 3,649 per sq.ft. Western part of Gotri has comparatively lower house prices starting from INR 1,500 per sq.ft. The south western and central part of the

study area represents higher property prices ranging between INR 3,649 and INR 5,009 per sq.ft. The prediction standard error maps suggest some interesting patterns (Figure 7). Overall, the prediction error ranges from INR 480 to INR 1,194 per sq.ft. The prediction error is higher in all peripheral areas of Gotri. This might be due to the neighborhood effect of surrounding localities where average property prices are higher than Gotri. The central and western part has the lowest prediction error ranging between INR 480 to INR 798 per sq. ft. Prediction error is high for higher residential property price areas and low for lower house price areas. This suggests that this method may be more applicable for low valued properties than for high valued properties.

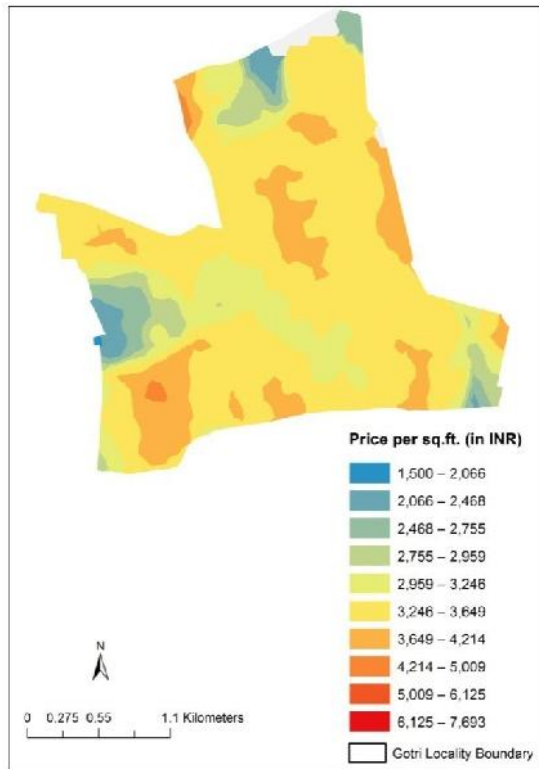


Figure 6. Prediction Map using Ordinary Kriging
(Note: Light grey area at the top shows no output generated due to insufficient neighbors)

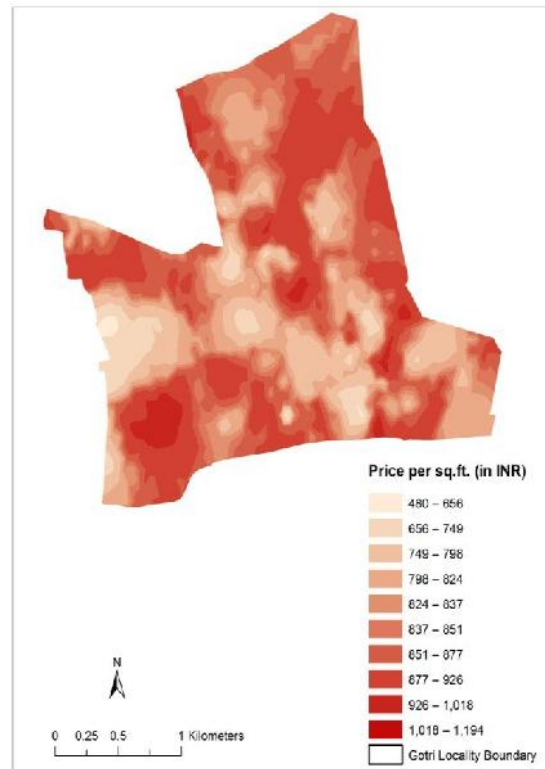


Figure 7. Prediction Standard Error Map
(Note: Light grey area at the top shows no output generated due to insufficient neighbors)

5. CONCLUSION

Hedonic modeling based on multiple regression analysis using ordinary least square technique and ordinary kriging methods are used for estimation of residential property prices. Location in the form of accessibility to various amenities/facilities is used for understanding the effects of location on residential property prices and its variation within the study area. Multiple R value of 0.44 with R^2 of 0.20 suggests that selected structural and accessibility explanatory variables are moderately able to explain the variation in dependent variable i.e. residential property value. Natural log transformation of dependent and all explanatory variables resulted into slight improvement in multiple R value to 0.48 with R^2 of 0.23. The Moran's I calculated was 0.46 (Manhattan distance) and 0.44 (Euclidean distance) suggesting moderate spatial autocorrelation among data points. Since, residential property prices are auto correlated, it is possible to apply kriging to estimate residential property prices at unsampled locations. Ordinary Kriging showed better results than MRA technique. The advantage with ordinary kriging is that it gives spatial output in the form of smooth surface showing variation in residential property prices. Also, it does locational modeling directly based on sampled residential property prices without using accessibility or any other location parameters. Another advantage with kriging is computation of prediction standard error map which can give idea about how prediction error is distributed across the area under study. The prediction error results showed the average standard prediction error of INR 837 per sq. ft. which is lower than standard error in MRA (INR 961 per sq. ft.).

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A NEW METHOD FOR DETERMINING MIN-MAX VALUE IN HISTOGRAM FOR SMART ENHANCEMENT OF REMOTE SENSING SATELLITE IMAGERY

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ABSTRACT

Remotely sensed image's visual quality depends on imaging conditions, acquired dynamic range, and scene illumination. A human eye cannot perceive, differentiate and separate the features in images in its raw form. To enable the images for better visual perceptibility various histogram stretching techniques are being used. User prefers the methods which are having less user interaction. A linear stretch with two percentage cumulative histogram is widely used for this purpose. This methodology saturates the 2% gray-level data in low and high gray level bins. Due to this the important features in low and high ranges of the gray levels get saturated. Presence of clouds and large water bodies mislead the 2% stretch methods and causes poor contrast. To overcome this problem a new method is developed which finds the true min, max value in the image histogram. The method achieves best visual quality post enhancement as compared to 2% stretch. The distribution slope of histogram is traversed in left and right direction from the middle value of the major peak. The min, max values are the end value of left and right traversal respectively. Our technique achieves good visual quality without saturating or losing finer details in the dark and bright areas.

KEYWORDS: Image Contrast Enhancement, Linear Stretch, Peak Detection, Adaptive Enhancement, Satellite Imagery, Remote Sensing

1. INTRODUCTION

As imaging technique was developed using ground-based camera in its early days and latter this was extended to aerial and space-based platforms. In the same manner image enhancement techniques like contrast enhancement, brightness enhancement (Jain, 1989), are also extended for aerial and space-based imagery (Joseph?). These methods work better on the terrestrial camera imagery as these are of high dynamic range. Whereas applying these methods on remotely sensed images straightway does not fulfill the user need. It reduces the image visual distinguishability in low and high gray-level areas of the images.

1.1 Image Enhancement

Image enhancement is basically improving the interpretability or perceivability of information in images for analyst or viewers and providing better input for other automated image processing techniques. The principal objective of image enhancement is to modify attributes of an image to make it more suitable for a given task and a specific observer. During this process, one or more attributes of the image are modified. The choice of attributes and the way they are modified are specific to a given task. Moreover, observer specific factors, such as the human visual system (Jain et. al., 1995) and the observer's experience, will introduce a great deal of subjectivity into the choice of image enhancement methods. There exist many techniques that can enhance a digital image without degrading the quality. In this proposal we are discussing the contrast enhancement in spatial domain.

1.2 Image Contrast Enhancement in Spatial Domain

In spatial domain technique we directly handle image pixel values. The pixel values are manipulated to achieve desired enhancement. These enhancement operations are performed in order to modify the image brightness, contrast and gray level distributions. It means transforming an image f into image g using transformation function T as in Equation (1).

$$S = T(r) \quad (1)$$

Where S is the value of pixel in g and r is the value of same pixel location in image f As show in Fig (1).

The output results are mapped within the grey scale range $[0, L-1]$ of the digital images, where $L = 2^k$, k is the number of bits in image. For example, an 8 bit image will have gray levels between 0-255, while a 10-bit image will have 0-1023 gray levels. The enhancement methods can broadly be divided in to the following two categories:

- Objective approach based methods
- Subjective approach based methods

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1.3 Objective Approach based Conventional Methods

These methods are automatic in nature. User input or user interaction in the enhancement process are not required. These methods are designed to provide a moderate and acceptable output. Linear 2% (Jain, 1989) is the widely used procedure in this category.

1.3.1 Linear 2% Min-Max Stretch Method

It is applied to images with ‘Gaussian’ (Jain, 1989) or ‘near-Gaussian histogram’, where all the brightness values fall within a narrow range of the histogram. The minimum and maximum brightness values in the image, denoted by $r_{\min}$ and $r_{\max}$ are generated in a predefined manner which is generated from Linear 2% cumulative histogram. Histogram of the image between $r_{\min}$ and $r_{\max}$ is stretched to the full gray range limit ($L_{\min}$ and $L_{\max}$) show by Equation (2).

$$s = \left\{ \frac{L_{\max} - L_{\min}}{G_{\max} - G_{\min}} \right\} * r \quad (2)$$

where

s = Transformed gray value

r = Input gray value

$L_{\max} = 2^{\text{bits}-1}$ and $L_{\min} = 0$

$r_{\min}$ and $r_{\max}$ are 2% cumulative threshold from low and high gray level range.

The Fig 1 (a) represents the linear stretching method where the output histogram is stretched linearly and the original curve of input image is equally translated in output.

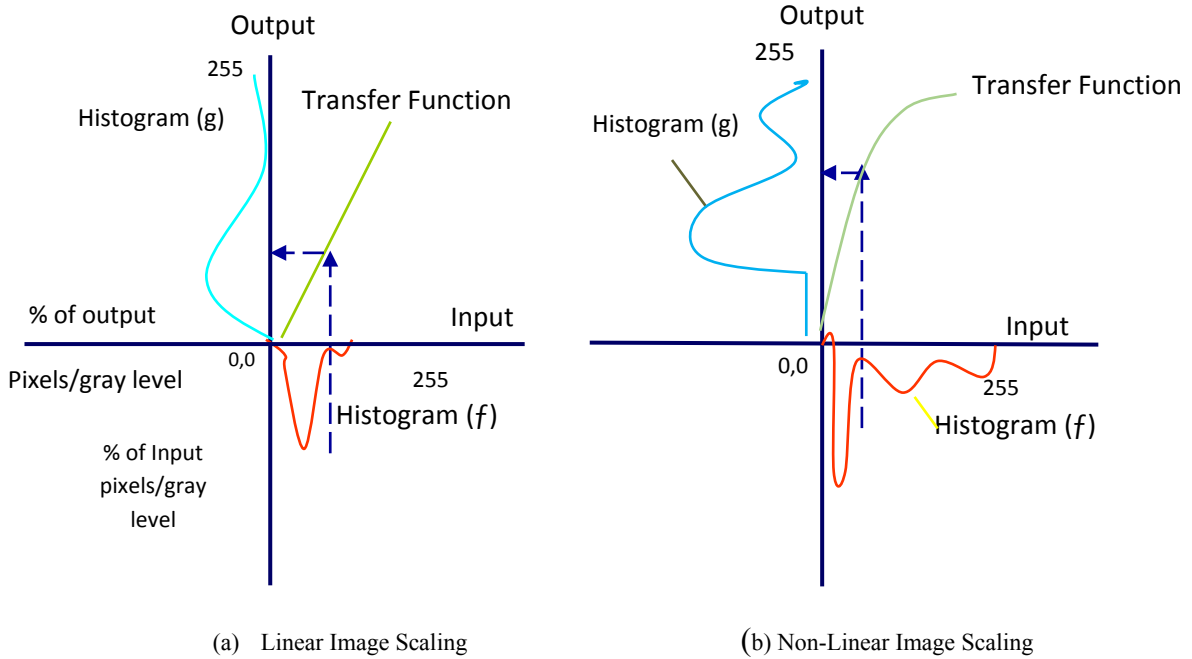


Figure 1: Transformation Function

1.4 Subjective Approach based Conventional Methods

These methods are very subjective in nature. Analyst selects the best method with appropriate parameters, which gives most acceptable results. It can be categorized in linear and nonlinear methods.

Linear methods	Nonlinear methods
Piecewise linear	Logarithmic
Histogram Equalization	Power-law
Histogram specification	Square-root

Table 1. Linear and Nonlinear Methods

The non-linear technique is diagrammatically depicted in Fig1(b). Here, nonlinear stretching method modifies the output histogram in such a way that the bins in original curve of input image is nonlinearly translated and distributed over gray level bins in output.

1.4.1 Logarithmic and Square Root

This technique takes into account human brightness perception characteristics. It involves the scaling of input data logarithmically. Images with more pixel area in low brightness or lower gray level range are good candidate for this method.

$$S = c \log(1 + r) \quad (3)$$

Where c is a constant, r input pixel values, S output pixel values.

1.4.2 Power Law

This method gives better enhancement in high intensity imagery. Images with more urban areas are good candidate for this method. It is defined as following.

$$G(j, k) = [F(j, k)]^n \quad (4)$$

where (j, k) is output pixel value at j and k location
F(j, k) is input pixel value location
n is power law variable, it is a square function for n = 2

2. METHODOLOGY

To enhance the contrast of satellite imagery in an objective manner the following information are required to be generated in an automatic fashion.

- a. Number of Peaks
- b. Major Peaks, Minor Peaks
- c. Peak Width
- d. Smart Min, Smart Max of the histogram

To detect the peak in the image histogram following methods are developed. These methods are suitable in high dynamic range images generated by terrestrial cameras whereas for low dynamic range images a new approach is required to be developed.

2.1 Conventional Peak Detection

2.1.1 Shape based Peak Detection

This category of methods achieves thresholding based on the shape properties of the histogram. Basically two major peaks and an intervening valley is searched for using such tools as the convex hull of the histogram, or its curvature and zero crossings of the wavelet components. Other authors try to approximate the histogram via two-step functions or two-pole autoregressive smoothing. These are popular methods.

- a. Rosenfeld Shape based Peak Detection (Pal et al, 1988a), (Rosenfield, 1984a)
- b. Sezan Shape based Peak Detection (Sezan, 1985a)
- c. Olivo Shaped based Peak Detection (Olivo, 1994a)
- d. Ramesh Shape based Peak Detection (Ramesh et al. 1995a)

2.1.2 Entropy based Thresholding Methods

This class of algorithms exploits the entropy of the distribution of the gray levels in a scene. The maximization of the entropy of the thresholded image is interpreted as indicative of maximum information transfer. Other authors try to minimize the cross-entropy between the input gray-level image and the output binary image as indicative of preservation of information. Pal, King, Hashim were the first to study Shannon entropy-based thresholding.

- a. Pun Entropy based Thresholding (Pun, 1980a)
- b. Kapur Entropy based Thresholding (Kapur, 1985a)
- c. Li Entropy based Thresholding (Li, 1993a)
- d. Shanbag Entropy based Thresholding (Shanbaug, 1994a)
- e. Yen Entropy based Thresholding (Yen, 1995a)

2.2 Proposed Peak Detection Method

A curvature-based technique is developed to find the above parameter in image histogram.

2.2.1 Curvature based Peak Detection

We are proposing a technique for detecting peaks in image histogram using histogram curvature. A window of defined size is moved upon the full gray-level range. Response of the window center with respect to the other window element is checked. A continuous increase and decrease in gray count are marked as gradient ascent continuity and gradient descent continuity.

2.2.2 Smart Min-Max of the Histogram

Smart min-max is generated based on true range of present gray levels in images. Histogram is presented in a two directional plane, where x direction is gray level, and y direction is pixel count in corresponding gray level. Major Peaks are the candidate peaks for smart min-max generation. To find the smart min, a window with defined size is moved in left direction from the min value of first detected peak. Moving window is stopped when the average pixel count is less than defined ratio of pixel count between adjacent gray level bins. The same way to find smart max, a moving window with defined size is moved in right direction from max value of last detected peak. Window is stopped when the average pixel count is less than defined ratio of pixel count between adjacent gray level bins.

Figure 2 is the process flow diagram for generating peaks and then deriving smart min (new min) and smart max (new max) in the histogram.

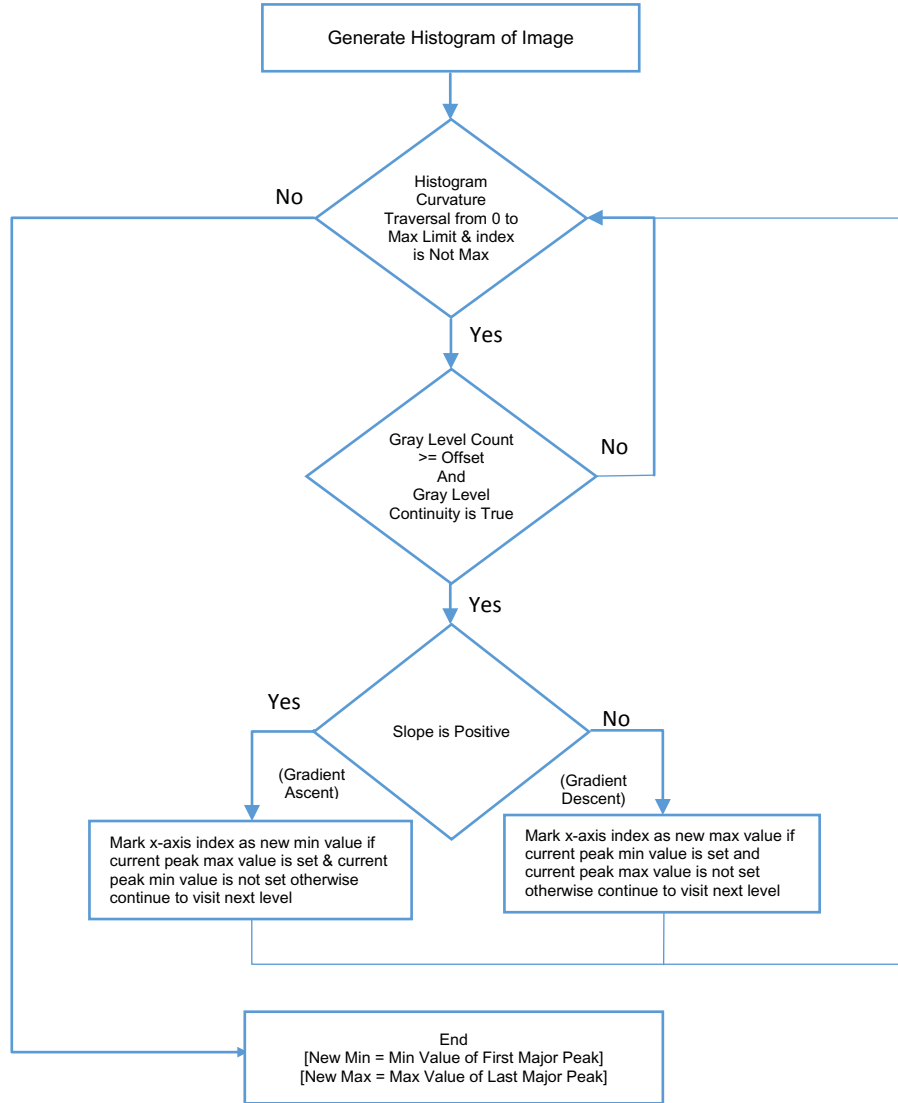


Figure 2: Process Flow Diagram

Figure 3 represents the location of smart min and smart max w.r.t. to Standard 2% linear min and max values. As visible in Figure 3 the new min and new max values will always cover and protect the darker and brighter regions in image from getting saturated.

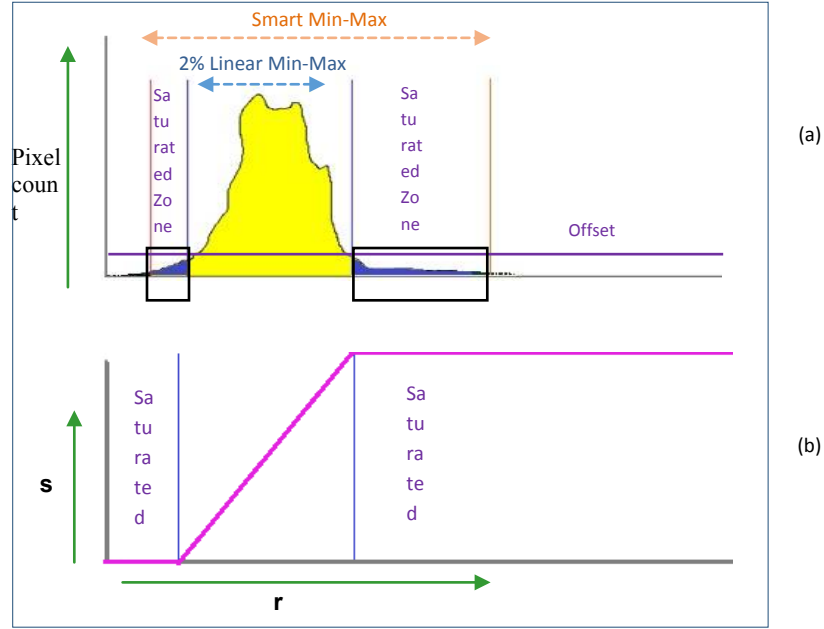
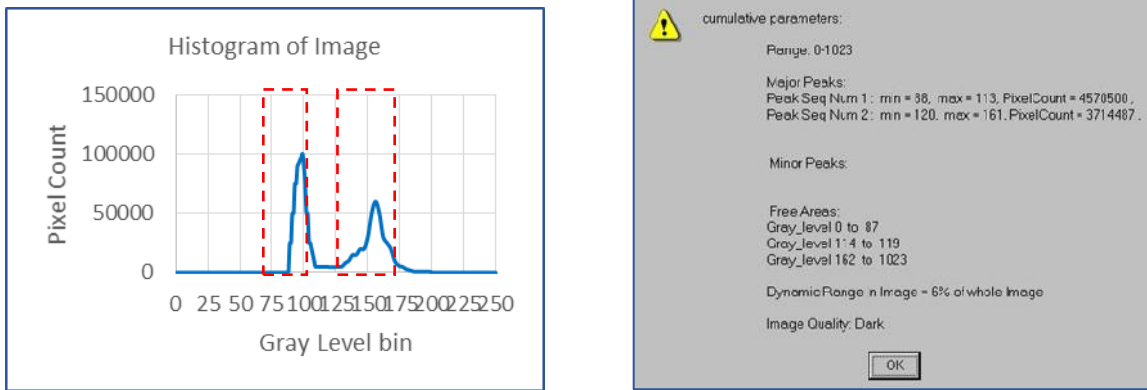


Figure 3: Smart Min (New Min) and Smart Max (New Max)

As can be seen in Fig 3 (a), the blue bars are representing the min and max generated by conventional Linear 2% method. The region shaded in blue color will be discarded and saturated as these values will go beyond the permissible gray level range in conventional method. The number of gray levels discarded will be fewer with proposed method and it will avoid the saturation. The red bars are detected by the proposed method using curvature-based technique and represent the True Min and Max as denoted by Smart Min-Max in the Fig 3 (a). The corresponding change in the linear mapping function can be seen in the Fig. 3(b) where saturated zone in both lower side and higher side of histogram is shown as text.

2.2.3 Number of Peaks

The total number of peaks in image histogram vary based on the image contents. In this method histogram curvature is followed for the complete range of gray-level. The method generates the number of peaks dynamically from images. In Fig4(a) the two major peaks are detected and highlighted with red dashed line boxes. Fig. 4 (b) depicts the detailed histogram analysis result where the Major Peak, Minor Peak, Free gray level zones are detected and displayed.



(a) Histogram of input image with Major Peaks

(b) Image Statistics generated from Peak finding Method

Figure 4: Image Histogram & Statistics

2.2.4 Major Peaks and Minor Peaks

The primary requirement for a peak is that its population should be above a preset offset as can be seen in Fig 4 (a). The detected peaks in this method are called as Major peak as it contains the most significant portions in the image whereas gray level peaks adjoining the Major peaks are defined as Minor peaks. Major peaks are detected based on gray level spread in the dynamic range with a necessary condition that its population is higher compare to other peaks. In other words, peaks generated by large water bodies and clouds may have high population but will not qualify as major peak because gray level spread is very narrow in the dynamic range.

2.2.5 Merits of Smart Min-Max in Satellite Imagery

Smart min max solves the following practical problems in satellite imagery.

- Images having significant water bodies (Joseph) are better enhanced because ripple peak due to water is isolated and narrow enough to not be considered as major peak in histogram analysis
- Zero padded ortho images (Joseph) are also enhanced in an efficient manner as single gray level and isolated peaks are not considered as major peak
- Images with cloud and snow (Joseph) are better enhanced when cloud and snow are narrow in gray level range
- Suitable to print large photo prints of the scenes with good contrast and without saturation in bright and dark areas

2.2.6 Applying Linear Stretch Using Smart Min-Max

After finding the smart min, max threshold, the conventional linear stretch is applied in a linear form. This is the reason this method is called as Adaptive enhancement using smart min-max.

$$s = \left\{ \frac{L_{\max} - L_{\min}}{\text{Smart}_{\max} - \text{Smart}_{\min}} \right\} * r \quad (5)$$

Where s = Transformed gray value

r = Input gray value

$L_{\max} = 2^{\text{bits}-1}$ and $L_{\min} = 0$

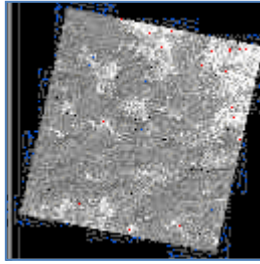
$\text{Smart}_{\max}$ = New true Max Value

$\text{Smart}_{\min}$ = New true Min Value

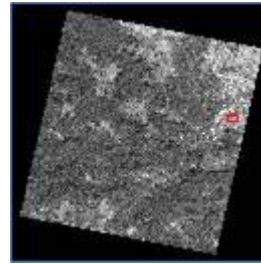
3. RESULTS

We have experimented the proposed method and highlighted the result as image clipboard. Proposed method's results are being compared with linear 2% standard deviation method. Fig 5(a, b) shows the subsample view of the enhanced image by conventional and proposed method. Figure 6 (a, b) highlights the change in histogram output after applying both methods. The output histogram (yellow color bar) in Fig 6 (a) generated by conventional method have more pixel count at gray level 0 and 1023 due to saturation. The pixel count at same gray level in output histogram in Fig 6 (b) is comparatively less which prevents saturation.

3.1 Subsample View of Large Enhanced Image Set-1



(a) Using Conventional Method

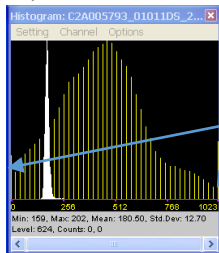


(b) Using Proposed Method

Figure 5. Enhanced Image – Set-1

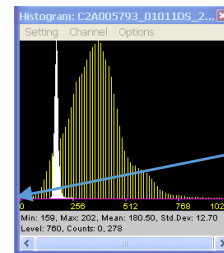
3.2 Input and Output Image Histogram Image Set-1

(White peak is original Input Histogram, Yellow-green peak is Enhanced Histogram)



(a) Using Conventional (Linear 2% Method)

Saturated at 0 and 1023



(b) Using Proposed Method

Less Saturation at 0 and 1023

Figure 6. Image Histogram- Set-1

3.3 Zoomed Portion-1 in Enhanced Image Set -1

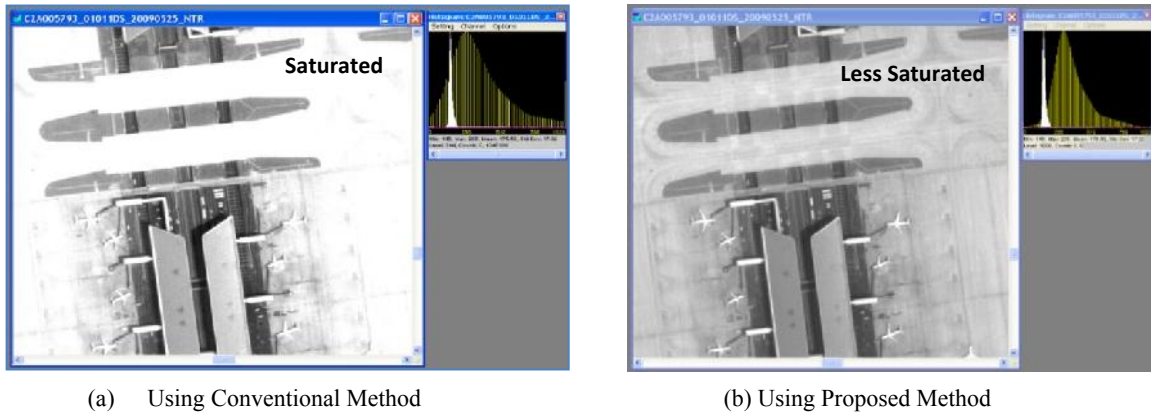


Figure 7. Enhanced Image-Set-1

In Figure 7 (a) a high resolution Cartosat imagery is shown. The features like taxiway and aircraft objects are mixed together due to saturation imposed in high gray level values by conventional method whereas in Figure 7 (b) all features are intact, preserved and perceivable after enhancement by new proposed method.

3.4 Enhanced Image Set -2

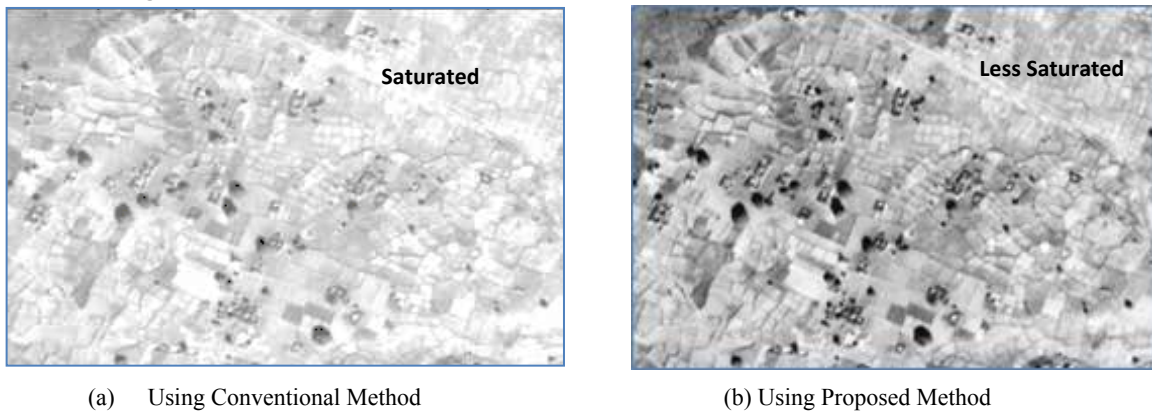


Figure 8. Enhanced Image- Set -2

Figure 8 (a) is a low resolution Cartosat imagery. Image Set-2 in this picture is having features like large patches of farm and barren land as well linear features like roads. These features are highly reflective hence pixels in these zones are covered by very low and very high gray level values. The conventional methods again create output which is not visually appealing and interpretable. The proposed method's result in Figure 8 (b) shows that it has low saturation impact as its inherent nature.

3.5 Enhanced Image Set-3

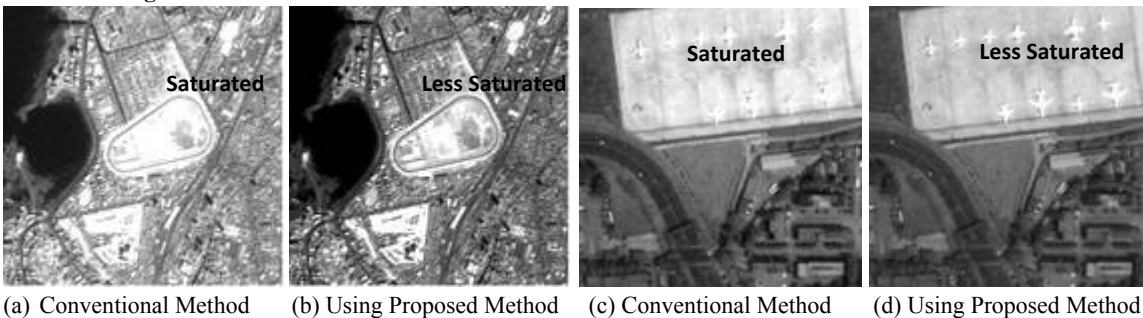


Figure 9. Enhanced Image- Set -2

In Figure 9 (a, c) the ground areas and aircraft objects get saturated whereas same is enhanced without any information loss in Fig 9 (b, d) by new proposed method.

4. ANALYSIS

The proposed method results are analyzed and compared visually with conventional method. The impact of saturation and contrast in resultant image is compared for the three data sets. Saturation and contrast are examined visually. Saturation Presence is compared as Yes/No and contrast is described as Normal/Good

Input Image Data Set	Conventional Linear 2%		Proposed Method	
	Data saturation	Contrast	Data saturation	Contrast
Data with Urban Area	Yes (<i>Saturates</i> data in higher brightness areas)	Good	No	Good
Data with Cloud	No	Normal	No	Good
Data with Water	Yes (<i>Saturates</i> data in higher brightness areas)	Good	No	Good

5. CONCLUSIONS

We have proposed a smart min-max detection method which is found suitable for satellite imageries. The images enhanced by our method has resulted in better contrast while avoiding saturation at both ends of histograms. Comparison with conventional Linear 2% method is done and results have been tabulated. Our method succeeds in handling images affected by cloud regions and large water bodies. The images enhanced by the proposed method are more suitable for printing large scenes and making interpretable photomaps. It finds all major peaks and minor peaks in the imagery. This automatic method is useful while viewing and interpreting the images visually without missing any important features in the scene. This technique is limited to panchromatic images. Our method gives best results on single mode and bi-modal histogram. While it can also handle multimodal histograms and yields better enhancements as compared to conventional Linear 2% method. We would like to extend it to different themes in multispectral images in our future works. Where based on the image content/themes a suitable method can be applied automatically on the imagery from a set of enhancement algorithms, for better contrast and sharpness in features.

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FAHP - GIS BASED DRASTIC MODEL FOR GROUNDWATER VULNERABILITY ASSESSMENT OF A COASTAL URBAN AQUIFER

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ABSTRACT

An increasing worldwide pressure under conditions of global anthropogenic and climatic change often triggers an integrated multidisciplinary approach to address the scientific issues involving water resources. The study involves the assessment of the factors manipulating on groundwater vulnerability of Urban aquifers system of Kozhikode city, Kerala through the modified DRASTIC method with the backing of geospatial techniques. The study area predominantly occupied with shallow aquifers which are easily prone to contamination from surface water sources, seepage from septic systems, the effluent of untreated sewage systems, etc. Rating for the modified DRASTIC factors (Depth to water level, Recharge, Aquifer media, Soil type, Topography, Impact of the vadose zone, Hydraulic Conductivity and land use pattern) were determined with the aid of Fuzzy based Analytical hierarchical process (FAHP). Spatial and non-spatial information integrated into GIS environment and the resultant spatial data thus generated depicted that about 51% of the total study area which is characterized by the low depth to water level, porous and permeable vadose media has a high vulnerability index value. Majority of highly vulnerable urban area extends 0-10 km from the coastal line and have a dense population. Groundwater zone with low indexes represents (13% of the total area) the area is highly protected from contaminant leaching by the natural environment. Low porous vadose media and presence of steep slope terrain favors this low vulnerability. The remaining 11% area shows moderate vulnerability to contamination. The degree of influence each parameter on vulnerability assessment determined using single - parameter sensitivity analysis and depth to water level and impact of the vadose zone have the highest weightages compared to others. Groundwater vulnerability index map of the urban zone derived through the reasonable weight evaluation using the FAHP method and significant integration with ArcGIS software endowed an efficient tool of water-sensitive urban development.

KEYWORDS: Urban, Fuzzy, AHP, GIS, Groundwater, Vulnerability.

1. INTRODUCTION

Groundwater is one of the most important natural resources worldwide serving as a significant source of water to communities, industries and agricultural purposes (Tiwari et al., 2016; Manap et al., 2014; Neshat et al., 2014). It can act as natural storage that can buffer against shortages of surface water, as in times of drought (Berbe et al., 2018). The drinking water quality in Indian cities has been deteriorating in recent years mainly due to the high growth of population, unplanned growth of cities, mixed land use patterns, no proper sewage system, and inadequate disposal of the wastewater both from household as well as industrial activities, polluted surface water bodies, etc (Rahman, 2008). The situations had led to the pollution of shallow aquifers in and around Indian cities in general. So, in order to protect the resources from future contamination, scientists and the resource managers have been trying to develop some techniques which allowed to predict the areas which are more prone to get contaminated than the others as a result of activities at or near the land surface. The three basic methods for vulnerability analysis are a statistical method, process-based simulation models, and overlay/index methods as DRASTIC (Aller et al., 1987) and Susceptibility Index (SI) (National Research Council, 1993, 2000; Neh et al., 2015; Ferreira and Oliveira, 2004). The DRASTIC, the most widely used vulnerability assessment method where DRASTIC index does not mean the absolute value of groundwater pollution; it only means the relative vulnerability of groundwater in different regions (You-Hailin et al., 2011). Some of the researches modified the DRASTIC method and added different parameters such as land use index, lineament, aquifer thickness, and impact of contaminant. Thirumalaivasan et al. (2003) developed a software package AHP-DRASTIC to derive ratings and weights of modified DRASTIC model parameters.

The predefined factor weights as per traditional index/ overlay method do not reflect the changing particularities the physical characteristics of urban area, and the revised indices provides doubtful results depend on the data availability, scale of mapping, and required accuracy and may introduce a substantial bias into the final map (Shrestha et al., 2016). The fuzzy - AHP (Van Laarhoven and Pedrycz, 1983) based methodology enables to address the linguistic uncertainty of the groundwater vulnerability assessments. The advantages of satellite remote sensing and Geographical Information System (GIS) endowed an efficient platform for the integration of these controlling factors along with appropriate weightages for site-specific vulnerability assessments. Hence the study approached a GIS-based fuzzy-AHP analysis of the groundwater zone of Kozhikode Corporation, Northern Kerala, India which is vulnerable to contamination from various anthropogenic activities in the context of climate change and urbanization.

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2. STUDY AREA

Kozhikode Corporation is one of the urbanized cities in Kerala, located between 11° 12'24.96" and 11° 18' 52.5" North latitude, 75° 45' 0.2" and 75° 52' 6.37" East longitude with an area extension of 84.29 square Kilometres. Kozhikode corporation is located in the humid tropical region of Kerala, where the predominant climatic factor is rainfall. The study area has an undulating topography characterized by plains, valleys, and hills. Generally, the ground elevations show a rising trend towards the east from 0 to 94 m (Figure 1). The physiographic zone is divided into low lands and Midlands. The low land covers an area of 7.43 Km² (8.8 percent of the total). The zone exhibits more or less flat and narrow terrain with the presence of landforms such as beach ridges, sandbars, and backwater marshes. Almost the entire zone is covered with coastal Alluvial soil. The midland occupied the balance area of 76.86 Km² (91.2 percent of the total). The maximum width of the zone is about 11.7 Kilometre. This zone is characterized by rugged topography comprising of small flat-topped low mounds and broad valleys. The population density of Calicut city, as per the 1981 census was 4770 and that in 1991 and 2001 are 5077 and 5279 respectively (Census, 2011).

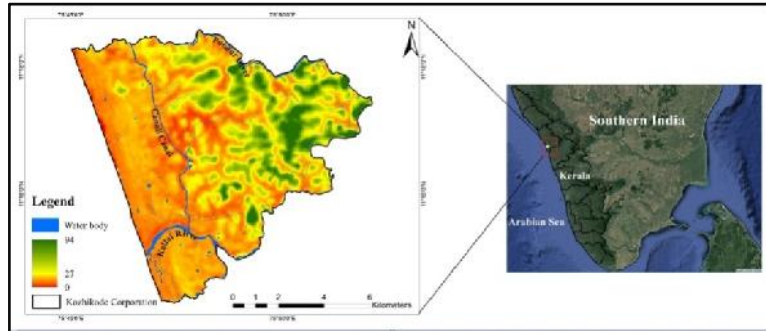


Figure 1. Study area with drainage pattern

3. METHODOLOGY

A GIS-based FAHP (Fuzzy-Analytical Hierarchical Process) based DRASTIC vulnerability Index method was used in the study to compute groundwater vulnerability scores for the urban and peri-urban environment. The method involves three steps, viz designation of DRASTIC layers, the relative ranking of these features through numerical ranking method-Fuzzy Analytical Hierarchical method (FAHP) and spatial and non-spatial integration through ArcGIS 10.5.1 (Figure 2).

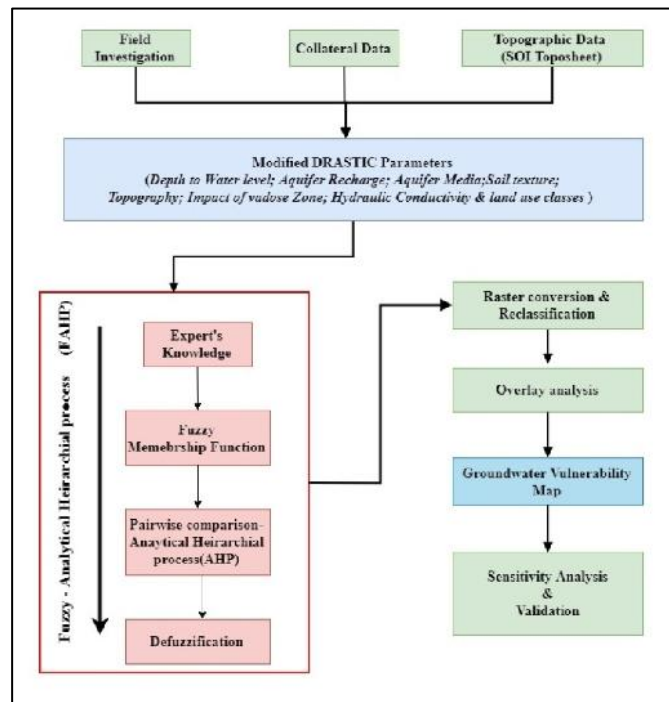


Figure 2. Flowchart showing Fuzzy-Analytical Hierarchical process based DRASTIC modeling for groundwater vulnerability assessment.

Data sources of DRASIC parameters namely depth to water (D), net recharge (R), aquifer media (A), soil media (S), topography (T), impact of vadose zone (I) and conductivity of aquifer (C) were used for groundwater vulnerability assessment in Kozhikode corporation are given in Table 1. A series of geoprocessing functions such as digitization and geostatistical analysis performed in ArcGIS.10.5. for converting spatial and non -spatial data sets in various formats from a various source into a geo-referenced digital format. Land use/land cover classes derived through the supervised classification process in ERDAS Imagine.2014 and verified through ground truth data. The hierarchy Model network of eight hydrogeological parameters was constructed to evaluate groundwater vulnerability, and each DRASTIC parameter assigned a subjective ranking of 1-10 based on experts' opinion and from relevant scientific outcomes. Ranking 1 assigned for components with least contaminant potential and 10 assigned for highest contaminant potential and rescaled with a saaty's 1-9 analytical scale. The Linguistic scale of importance chosen for pairwise comparisons shown in Table 2.

Table 1. The data source for the preparation of DRASIC model parameters

Data Type	Source	Data format	Scale
Groundwater level	Field Investigation	Table	
Water level fluctuation level	Field Investigation	Table	
Slope	SRTM DEM (30m)	Raster	
Soil Permeability	Department of soil survey and soil conservation, Kerala	Table	
Rainfall	Indian Meteorological Department (IMD)	Table	
Geology & Hydrogeology	Geological Survey of India, Hyderabad	Map	1:250,000
Litholog data	Central Groundwater Board, Thiruvananthapuram	Table	
Soil map	Nation bureau of Soil Science (NBSS), India	Map	1: 50,000
Hydraulic conductivity data	Central Groundwater Board, Thiruvananthapuram INDIA-WRIS- http://www.india-wris.nrsc.gov.in/	Table	
Land use / land cover	Satellite Data (IRS P6, LISS III (National Remote Sensing Centre (NRSC))		23.5

These judgments/scores further undergone Fuzzy-AHP (Analytical Hierarchical Process) to determine a composite normalized index value. Apart from AHP, in FAHP method pairwise comparison of criteria and sub-criteria elements were expressed with Triangular Fuzzy Numbers (TFNs).

Table 2. Linguistic scale of importance for pairwise comparisons

Scale of importance	Triangular Fuzzy scale	Triangular fuzzy reciprocal scale
Just equal	(1,1,1)	(1,1,1)
Equally Important	(1/2, 1, 3/2)	(2/3, 1, 2)
Weakly more important	(1, 3/2, 2)	(1/2, 2/3, 1)
Moderately more important	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
Strongly more important	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Very strongly more important	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

The criteria and sub-criteria with varying rate of potential to vulnerability (different scale of importance) assigned with abovesaid TFNs and transformed to a pairwise comparison matrix. The defuzzification processes carried out in order obtain normalized criteria weights from fuzzy membership values. Using this composite weightage value obtained from fuzzy-AHP redirected to calculate groundwater vulnerability index using the equation 1;

$$GWVI = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw \dots \dots \dots (1)$$

Where r and w are the rating and weight assigned to each criterion involved in the analysis respectively. The pairwise comparison matrices were prepared for seven DRASTIC parameters and each parameter along with its composite weightage. Seven data layers prepared in ArcGIS converted to raster format with uniform grid size with 25 X 25 resolution. Integrated the normalized weights into corresponding raster layers using reclassification analysis and carried out a fuzzy overlay analysis in ArcGIS. To reduce the subjectivity arises as a result of composite weightage derivation and to confirm the reliability (Ramos and Rodríguez, 2003) of the analysis sensitivity analysis were carried out. The analysis includes single parameter sensitivity analysis (Napolitano and Fabbri, 1996) and map removal sensitivity analysis (Lodwick et al., 1994). Validation of the resultant DRASTIC map was carried using the hydrogeochemical data for the study area.

4. RESULT AND DISCUSSION

4.1 Description of modified DRASTIC Parameters

Depth to water level (DWL) determines the thickness of the medium through which the infiltrating water must travel before reaching the aquifer- saturated zone. Therefore, it has a direct influence on the degree, extent, physical and chemical attenuation and degradation process of diffusing contaminant and sub-surface materials such as air, mineral, and water (A Rahman (2008). The Depth to water level (DWL) in the study area varies from 0.7-13.7 m (Figure 3a). Shallow wells -0-2 m

covers 3.8% of the study area. A significant part of the study with '*shallow to moderately deep well and moderate*' well covers 37.6% and 31 % of the study area respectively. From '*shallow to moderate*' well the chance of contamination decreases because it needs more distance to travel before contacting with groundwater. Corresponding weightage for various depth of groundwater given in Table 3.

Table 3. Ratings and weightings of modified DRASTIC parameters in groundwater vulnerability assessment					
Criteria	Sub-criteria	Area		Weight	Rating
		Km ²	%		
Depth to water level (D)	0-2m	3.2	3.8	0.224	0.243
	2-4 m	31.7	37.6		0.201
	4-6 m	26.1	31.0		0.168
	6-8m	16.9	20.0		0.122
	8-10m	4.8	5.6		0.11
	10-12m	1.2	1.4		0.089
	> 12m	0.5	0.6		0.063
Recharge (R)	<15	3.9	4.6	0.165	0.371
	15-20	54.5	64.7		0.332
	>20	25.8	30.6		0.292
Aquifer media (A)	Pebble bed	1.7	1.9	0.118	0.301
	Charnockite	59.8	66.4		0.118
	Alluvium	28.4	31.6		0.347
	Laterite	0.0	0.0		0.103
Soil media (S)	Sandy clay loam	8.1	9.6	0.087	0.354
	Loam to clay	24.9	29.4		0.243
	Sandy loam to clay loam	3.9	4.6		0.206
	Gavelly clay loam to gravelly clay	47.7	56.4		0.201
Topography (T) %	0-5	56.2	66.6	0.066	0.396
	5-15	26.6	31.5		0.274
	15-25	1.5	1.8		0.195
	> 25	0.0	0.0		0.134
Landuse classes	Waterbody	1.4	1.7		0.134
	Vegetation	28.4	33.5		0.274
	Built-up area	51.5	60.8		0.396
	Others	3.4	4.0		0.195
Hydraulic Conductivity (C)	> 9	13.5	15.9	0.119	0.495
	8-9	65.8	77.7		0.25
	< 6	5.4	6.4		0.25
Impact of Vadose zone (I)	Coastal Sandy	5	5.9	0.224	0.397
	Coastal Alluvium	18	21.2		0.372
	Laterite	62	72.9		0.225

Aquifer recharge index for the study area calculated using weighted overlay analysis of indicators such as slope factor, soil permeability and rainfall of the study area. Based on the recharge properties the study area divided into three zones. The area with high recharge index covering 30.6% of the study area, whereas 64 % of the study area comes under moderate recharge zone (Figure 3b). Therefore, Recharge index had a high rate of influence in determining the contaminant transport through subsurface of the study area. Aquifer media have a moderate control in contaminant attenuation of a geological area. Coastal sandy and coastal sandy Laterite aquifer is the dominant aquifer media occupied in the study area. The areas with Coastal alluvial aquifers such as Guruvayur and Kadappuram Formations with the composition of medium to fine sand with an admixture of shells constitutes highest vulnerable to contamination (Figure 3c). The areal extent of the aquifer type is 32 % of the study area. Lateritic zone composed of Charnockite formations covered 66 % of the study area assigned with moderate to least vulnerability index to contamination.

'Sandy loam to sandy clay loam' type soil texture characterized with excessive- drained type and moderately rapid to the rapid permeable soil. This medium to coarse-textured soil covered an area of 4.6% (Figure 3d) and assigned highest impact during vulnerability index assessment according to its higher potential to contaminant transfer (Table 3). Majority of the study area occupied with '*gravelly clay loam to gravelly clay*' textured soil(56%) under well-drained type with moderate to moderately slow permeability. Therefore, the soil texture assigned with the moderate DRASTIC rating. The influence of soil texture to contaminate attenuation in the study area summarized as moderate rate.

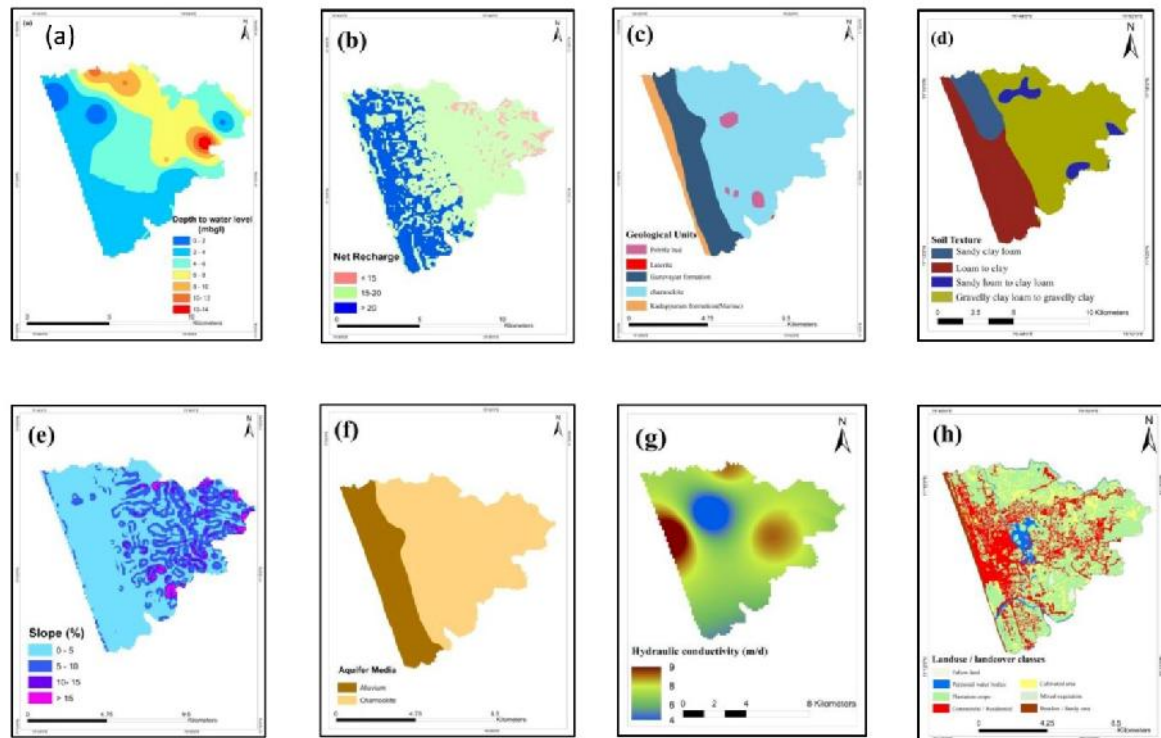


Figure 3. Modified DRASTIC Parameters: (a) Depth to water level, (b) Aquifer Recharge(R), (c) Aquifer media, (d) Soil Texture, (e) Topography, (f) Impact of Vadose zone, (g) Hydraulic Conductivity and (h) Land use classes

More or less flat surface results in less runoff and more infiltration with a possibility of higher risk of groundwater pollution (Aller et al., 1987). For the study area, the slope value ranged from 0- 55% with a mean value of 6% (Figure 3e) and Based on the slope range, groundwater vulnerability potential ranging from highest to moderate value in the study area. The impact of the vadose zone in coastal alluvium attained high rating towards vulnerability where the soil permeability is high (Figure 3f). The very porous laterite covered the remaining part of the terrain with 62 % of the study area, and it forms potential phreatic aquifers along topographic lows and valleys. The permeability of the vadose zone is varying from moderate to low permeability therefore assigned as moderate to low vulnerability index. The hydraulic conductivity of the region is comparatively high in the study area. Hydraulic conductivity of 8-9 m/d covered in the 77% of the area, therefore contributes high chances of contaminant attenuation (Figure 3g).

The type of land use pattern, different population density, and thereby induced anthropogenic activities have a remarkable influence on the groundwater vulnerability of most of the area. Land use types of the Kozhikode corporation composed of six classes, i.e., built-up land, agriculture, forest, fallow land, and water body (Figure 3h). The intensity of pollution varying with changing. The land use pattern such as urban, commercial, agricultural types. Majority of the study area occupied with residential/ commercial built-up areas caused changes on hydrological properties of the area through the addition of urban and domestic wastes, leakages from septic tanks and waste dumping sites. The impervious area increases with the urbanization and subsequently rainfall recharge to ground reduces. At the meantime, recharge may increase due to leakage from leach pits, waste water drainage system, etc. Both the situation adversely affects hydrogeology through quality and quantity respectively. Integrating Groundwater vulnerability index map of the study area divided the study area (Figure 4) into four zones such as low, moderate, high and very high vulnerable zones. 50% of the urban cluster occupied with a very high vulnerable category. Following the very high vulnerable zone 11.6 % the region with the highly vulnerable zone.

Gentle slope, shallow water table, rapidly permeable soil, high rainfall alluvial formations with a high recharge rate resulted in high rate of contaminant attenuation, therefore Very high vulnerable zone (VHVZ). The shallow aquifers are prone to contamination possibly by domestic wastes and other urban-induced pollutants. Due to the inadequate and intermittent piped water supply, people mostly rely on groundwater sources like dug wells, shallow tube wells, stone spouts, etc., to meet daily water need and rapid population growth and urbanization exacerbate the situation. Low vulnerable zone (LVZ) with steep slope terrain with >10m DWI which facilitates the high surface runoff along with silt and clay textures inhibits infiltration, therefore contaminant transport. The high density of residential, commercial built-up zone in the study area involved in the disposal of seepage from seepage from septic systems, effluent untreated sewage systems. In addition to the poor performance of the wastewater disposal system and presence of polluted surface water bodies like Canoli canal, Kallai river, etc, the favourable geographical conditions in VHVZ increases the chances of contamination to groundwater.

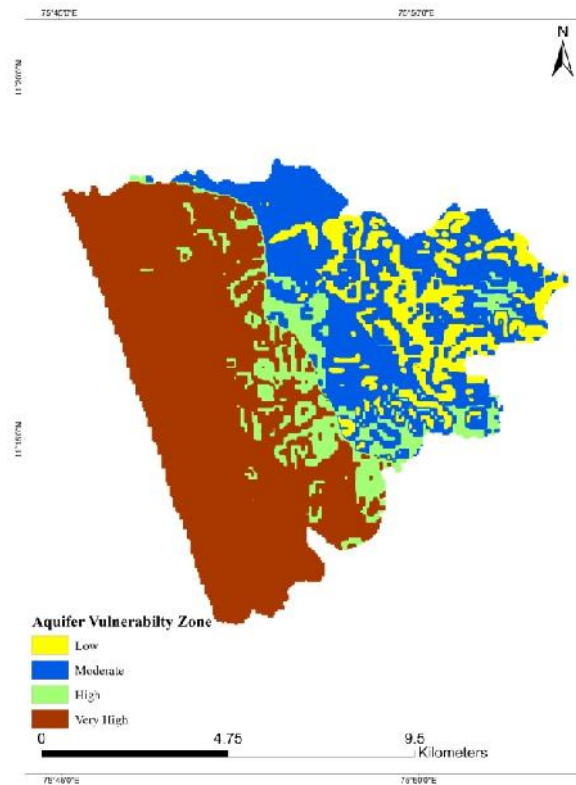


Figure 4. Groundwater vulnerability map of the study area

Table 4. Area distribution of groundwater vulnerability classes and statistics of validation analysis

Groundwater vulnerability classes	Area (km ²)	Area (%)	Total Dissolved Solids (mg/L)		
			Minimum	Maximum	Average
Low	10.69	12.53	35.9	35.9	35.9
Moderate	21.53	25.23	50.3	219.0	124.4
High	9.90	11.61	45.1	207.0	120.3
Very High	43.19	50.63	140.6	1890.0	649.2

Single parameter Sensitivity analysis showed that vadose zone classes with 7.4% effective weight are the most influencing parameter in determining the vulnerability to groundwater contamination in the area. Contaminant attenuation through the highly indexed class of vadose zone i.e. coastal alluvium in the study area leads to groundwater contamination. As a coastal urban zone, most of the urbanization activities of the Kozhikode Corporation concentrated in this zone. Validation analysis performed by the Extraction of hydrochemical data (Total dissolved solids (mg/L)) to Groundwater vulnerability indices through the spatial analyst tool of ArcGIS. The analysis pointed out that the corresponding average TDS value for the very high vulnerability indices is higher than the acceptable limit of drinking water standard. Thus indicated that the water quality deterioration in the area (Figure 5). The table 4, illustrated the statistical values of the concentration of TDS for each vulnerability classes. Validation of the resultant map using hydrochemical data of the study area underpinned the fitness of the groundwater vulnerability map as a decision-making tool for urban sensitive water management.

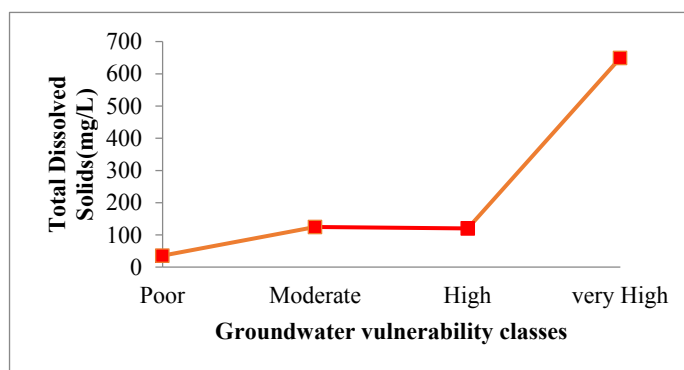


Figure 5. Validation analysis of groundwater vulnerability indices vs TDS (mg/L) value of the study area

5. CONCLUSION

The GIS-based FUZZY AHP DRASTIC analysis carried out in one of the fast-growing urban zones, Kozhikode Corporation, Southern Kerala, India. Thus, it is crucial to identify which aquifer systems and settings are most vulnerable to degradation because as much as subsurface pollution is difficult to detect, it is even more difficult to control. Both Fuzzy-AHP and geospatial analyses enabled to connect a link between inherent hydrogeological properties and over the changing urban spatial structures. As per the analysis, the growing coastal urban zone classified into four differently rated groundwater vulnerability zones. The very high vulnerable zones occurred in the alluvium formation with a shallow groundwater table constrained with intense urban activities. The methodology provided an efficient platform for the vulnerability analysis to the groundwater system by considering the local policies, site-specific urban planning and diverse hydrogeological settings of the study area.

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IMPLEMENTATION OF COLOR BALANCING ALGORITHM ON CARTOSAT AND RESOURCESAT DATASETS

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ABSTRACT

This paper describes implementation of color balancing algorithm on ResourceSat and CartoSat datasets and its results. Color bias is one of the reasons of poor color composite images. In RGB composition if brightness of one band is significantly more than that of others, composite image will show color bias. To balance color bias among three bands a method namely Balance Contrast Enhancement Techniques (BCET) is sought. BCET can stretch image to a given value range and mean without changing the basic shape of the image histogram. Thus three image bands for color composition can be adjusted to the same value range and mean to achieve a balanced color composite. BCET is based on a parabolic function. In this paper, we are presenting results in form of enhanced images, analysis plots of BCET algorithm on CartoSat and ResourceSat data along with implementation techniques.

KEYWORDS: CartoSat, ResourceSat, BCET, color- balancing

1. INTRODUCTION

Contrast enhancement, sometimes called radiometric enhancement or histogram modification, is the most basic but also the most effective technique to optimise the image contrast and brightness for visualisation. ResourceSat & CartoSat contain multispectral payloads. Due to unavailability of Blue channel in ResourceSat, False color composition (FCC) image is generated. Whereas, in CartoSat, natural color composition images can be generated. Sometimes, color bias is observed in datasets acquired with these payloads. To balance color bias among three bands, a method namely Balance contrast enhancement techniques (BCET) is very useful. BCET can stretch image to a given value range and mean without changing the basic shape of the image histogram. Thus, three image bands for colour composition can be adjusted to the same value range and mean to achieve a balanced colour composite. In this paper, we are describing BCET algorithm, its application on ResourceSat and CartoSat datasets.

2. METHODOLOGY

There are various techniques using which we are doing contrast enhancements like linear contrast enhancement (linear stretching, piecewise linear stretching, linear scale and mean/ standard deviation adjustments), logarithmic, exponential contrast enhancement, histogram equalization and Histogram matching and Gaussian stretch. Color bias is one of main reason of poor color composite images. In RGB composition if brightness of one band is significantly more than that of others, composite image will show color bias. To balance color bias among three bands a method namely Balance contrast enhancement techniques (BCET) is sought. BCET can stretch image to a given value range and mean without changing the basic shape of the image histogram. The BCET based on a parabolic function is as below:

$$Y = a(x - b)^2 + c \quad (1)$$

This general form of parabolic function is defined by three coefficients, a, b and c in equation 1. It is therefore capable of adjusting three image parameters: minimum, maximum and mean. The coefficients a, b and c as per equation 2 can be derived based on the minimum, maximum and mean (l, h and e) of the input image X and the given minimum maximum and mean (L, H and E) for the output image Y as below as per ref[1]:

$$b = \frac{h^2(E - L) - s(H - L) + l^2(H - E)}{2[h(E - L) - e(H - L) + l(H - E)]}$$

$$a = \frac{H - L}{(h - l)(h + l - 2b)}$$

$$c = L - a(l - b)^2 \quad (2)$$

where S is mean square sum of input image X

$$S = \frac{1}{N} \sum_{i=1}^N X_i^2 \quad (3)$$

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Derivation of coefficients a, b & c for a BCET parabolic function :

Let X_i represent any pixel of an input image X , with N pixels, then the minimum, maximum and mean of X are:

$$l = \min(X_i), h = \max(X_i), e = \frac{1}{N} \sum_{i=1}^N X_i, i = 1, 2, \dots, N \quad (4)$$

Suppose L, H and E are the desired minimum, maximum and mean for the output image Y , then we can establish the following equations as per ref [1]:

$$L = a(l - b)^2 + c \quad (5)$$

$$H = a(h - b)^2 + c \quad (6)$$

$$E = \frac{1}{N} \sum_{i=1}^N [a(X_i - b)^2 + c] \quad (7)$$

$$b = \frac{h^2(E-L) - s(H-L) + l^2(H-E)}{2[h(E-L) - e(H-L) + l(H-E)]} \quad (8)$$

$$\text{where } s = \frac{1}{N} \sum_{i=1}^N X_i^2$$

With b known, a and c can be resolved from equations 9 and 10:

$$a = \frac{H-L}{(h-l)(h+l-2b)} \quad (9)$$

$$c = L - a(l - b)^2 \quad (10)$$

From the solutions of a, b and c in eqns. We have the following observations:

1. If $b < l$ then $a > 0$, the parabola is open upward and a section of the right (monotonically increasing) branch of the parabola is used in BCET.
2. If $b > h$ then $a < 0$, the parabola is open downward and a section of left (monotonically increasing) branch of the parabola is used in BCET.
3. If $l < b < h$, then BCET fails to avoid the turning point of the parabola and becomes malfunctioned.

3. DATASET AND IMPLEMENTATION

We have used python language to implement algorithm and used many datasets from ResourceSat and CartoSat series to showcase our results. Results of selected datasets are listed below:

Image visualization results on ResourceSat and CartoSat datasets

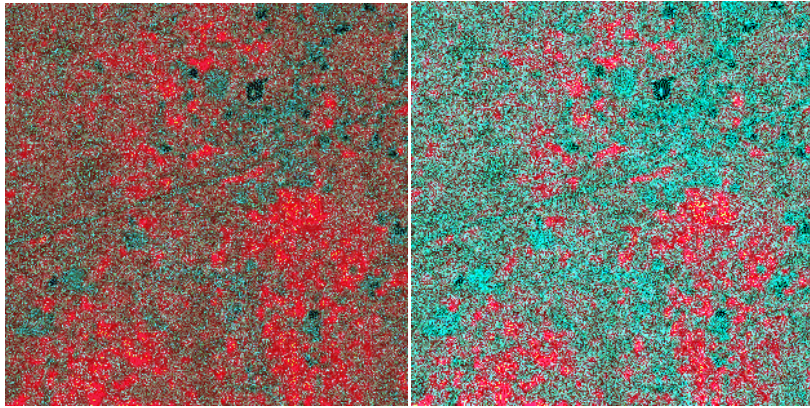


Figure 1. ResourceSat dataset

Figure 2. Color Balanced output

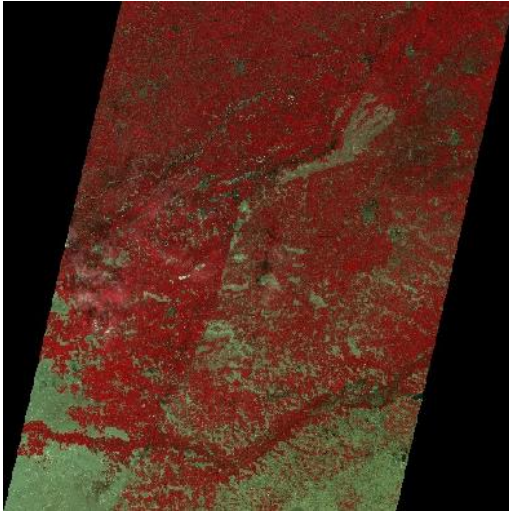


Figure 3. ResourceSat dataset

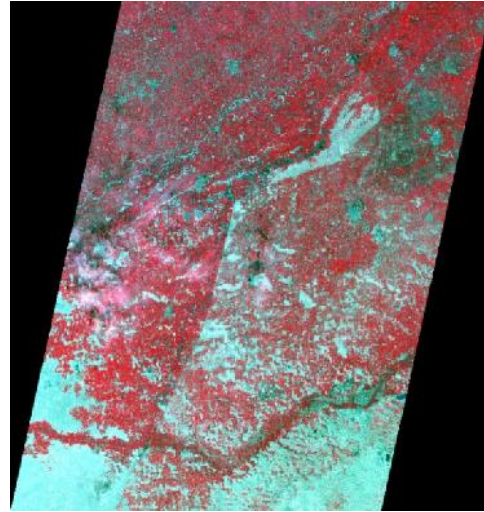


Figure 4. Color balanced output

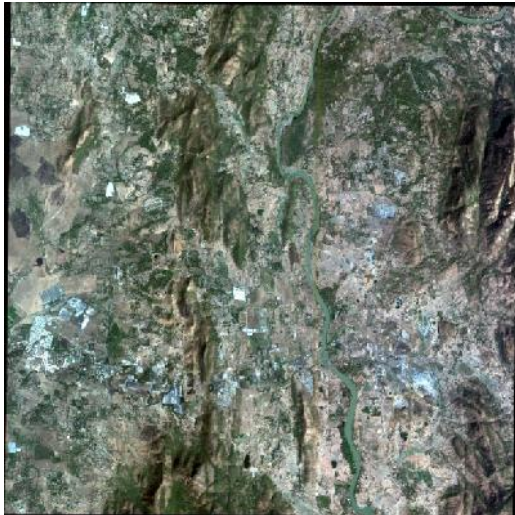


Figure 5. Cartosat dataset



Figure 6. Colored balanced output

4. RESULTS AND DISCUSSION

We have processed more than 100 scenes of Cartosat and more than 50 different scenes of Resourcesat using implemented software. Analysis results are shown in table-1 and table-2 for selected scenes of Resourcesat and Cartosat respectively.

Table-1 Derivation of BCET parabolic functions for the 3 band images of a Resource Sat scene to stretch each band to $L = 1$, $H = 512$ and $E = 256$.

Image bands	Input Image			BCET Coefficients			BCET output image		
Resource Sat	l	h	e	a	b	c	L	H	E
Band2	62	7201.44	137	0.03448	0.52736	-130.32	0	512	256
Band3	35	7190	145	0.02598	0.4448	-31.02	0	512	256
Band4	92	7253	215	0.01358	0.3222	-114.20	0	512	256

4.1 RESULTS ON RESOURCESAT DATA

In Table 1, dataset from ResourceSat is used as an input. l , h and e are minimum, maximum and mean values computed from corresponding bands of input image. Further, values of BCET coefficients were calculated using equations given in section 2. In the last column, L , H and E are new stretched minimum, maximum and mean values. Here in all three bands $b < 1$ and $a > 0$ are obtained. So parabola in open upwards and a section of the right (monotonically increasing) branch of the parabola is used in BCET. We can see the input and output images as figure 1, 3 and 2, 4 respectively. Histogram plots as per figure 7 shows range occupied in original image (80-200) and in output image (0-512). Plot of parabolic functions of three bands of RS2 scene is shown in Figure 8

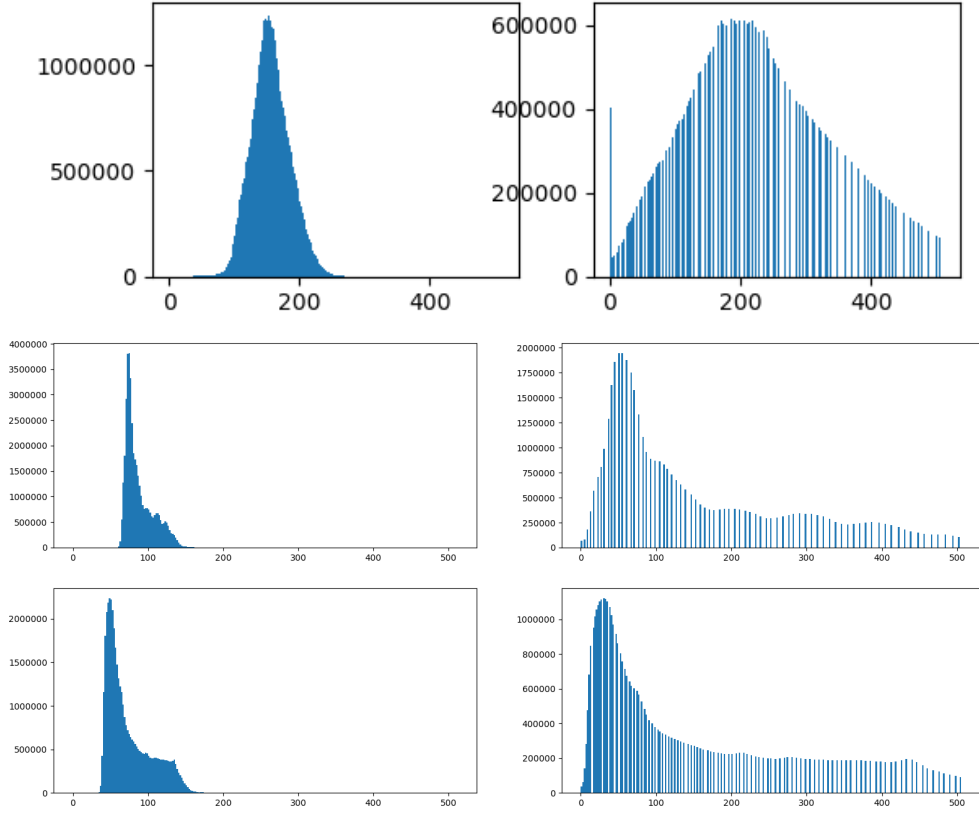


Figure 7. Histogram plots of three bands in original image and corresponding plots after stretched values.

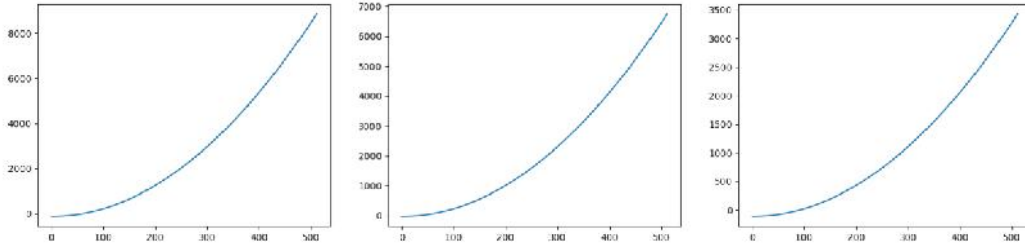


Figure 8. BCET parabolic functions of three Bands of a RS2 Sub-scene

4.2 RESULTS ON CARTOSAT DATA

Further, we have taken dataset from Cartosat series and processed through mentioned algorithm to obtain better images for visualization. We got encouraging results on individual scenes as well on mosaicked scenes too. We can see the input and output images as figure 5 and 6 respectively. Histogram plots as per figure 10 shows range occupied in original image and in output image.

In Table 2, we have mentioned results on Cartosat datasets. l , h and e are minimum, maximum and mean values computed from corresponding bands of input image. Further values of BCET coefficients were calculated using equations given in section 2. In the last column, L , H and E are the new stretched minimum, maximum and mean values. Plots are listed below for all three bands of BCET parabolic functions. Here in all three bands $b > h$ and $a < 0$ are obtained. So parabola in open downwards and a section of left monotonically increasing) branch of the parabola is used in BCET. As observed from fig 9, in original image, dynamic range was not occupying full range of 0-1024 whereas in output, full range is being occupied. Plot of parabolic functions of three bands of Cartosat scene is shown in Figure 10. In Figure 11, processed results of five scenes of Cartosat data are stitched together to form a uniform image.

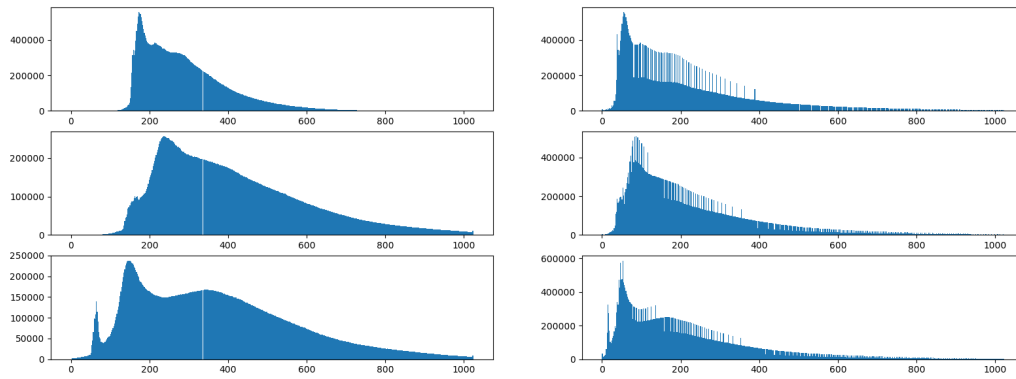


Figure 9. Histogram plots of three bands in original image and corresponding plots after stretched values

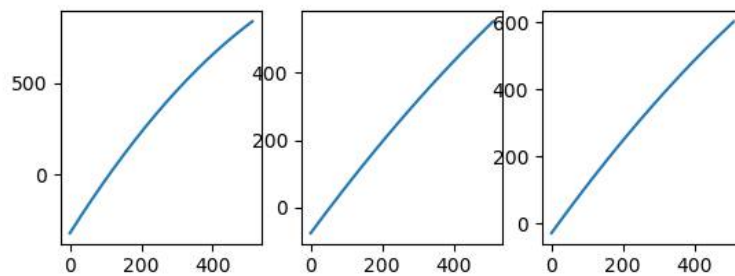


Figure 10. BCET parabolic functions of three Bands of a Cartosat scene



Figure 11. Mosaic of five scenes and color balanced output of Cartosat data.

5. CONCLUSIONS

Balance Contrast Enhancement Techniques (BCET) proved to be very handy in color balancing of identified Resourcesat and CartorSat datasets. It worked well on individual dataset tiles as well as on mosaicked datasets. We could achieve better color composite by improving dynamic range of image and got appealing results for image visualizations.

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3D SURFACE VISUALIZATION OF HIGH RESOLUTION DATASETS ON MULTIPROJECTOR SYSTEM

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ABSTRACT

This paper describes implementation carried out in order to visualize high resolution datasets on a three dimensional (3D) sphere on specialized visualization system available at SAC. Development consists of 3D surface rendering and dynamic terrain generation using available fine/ coarser resolution data from various available CARTOSAT satellites, digital elevation model (DEM) and global data view as per the projection systems. With availability of high resolution imagery and DEM, high resolution 3D surface models are generated which are used for many applications in strategy, urban planning, infrastructural planning and disaster recovery etc.

For the exercise reported in this paper, datasets (imagery and DEM) are taken from Cartosat series of 0.6 m panchromatic and 1.6 m multispectral and CARTODEM ~1-10m for 3D surface visualizations. An in-house software package is developed to drape imagery over DEM and GIS vector layers by using data interpolation, image-mosaicking techniques. The data visualization is implemented based on Level of details (LOD) technique for better performance and accordingly required amount of details (coarser or finer) will be shown to viewer as per viewer's position.

Software (SW) developed can handle large volume of data in terms of very high resolution and large area coverage. It is designed and developed using C++, open scene graphs and it works in both the environment (Windows and Linux) on single screen, and on specialized system such as immersive visualization system at SAC. This paper covers software implementation carried out to generate 3D surface of given place over Earth using available high resolution datasets from CARTO series on specialized multi projector system.

KEYWORDS: Cartosat, High resolution, DEM, Multi projector, immersive system

1. INTRODUCTION

With the increase in availability of high resolution data globally, many new analysis techniques and tools have been developed to visualize 3D surface of any given area for applications in disaster management, urban planning and infrastructure management. In this paper, an approach to generate 3D surface of Srinagar, Muscat, Mumbai using high resolution (0.6 m – 1.6m) datasets is described. Also 3D surface of Laser Interferometer Gravitation wave Observatory (LIGO) project site are generated and visualized.

2. METHODOLOGY

2.1. Input Data for 3D Visualization

The input data used for 3D visualization in the software developed are imagery, digital elevation model generated from CARTO Series (~0.6-1.6m imagery and ~1m DEM) and open street map data. The Level of details (LOD) based data visualization is implemented in Software for better performance. Using LOD based approach specific amount of details (coarser or finer) will be shown to viewer as per viewer's position. For example, if one is viewing from an altitude of 10,000 km, a coarser view of place will be seen; whereas viewing from an altitude of few meters caters to detailed and finer view of the place. With these inputs in place, following tasks were performed to accomplish generation of 3D surface models:

2.1.1. Data mosaicking and interpolation

With varied resolution (0.6-1m) imagery and (1m-10m) DEM, we need to do resampling of data and further mosaicking of overlapped regions to have seamless scene visualization. For difference in pixel resolution and sampling, the set of resampling algorithms available to match the datasets are a. Nearest Neighbor b. Bilinear c. Cubic d. Cubic spline e. Lanczos windowed sinc f. Average g. Mode. However Cubic resampling algorithm was used for resampling most of the data in our study.

2.1.2. Triangulated resampling for DEM

For generation of mesh, Delaunay triangulation algorithm was used as it has various advantages over other algorithms like triangles are as equi-angular as possible, thus reducing potential numerical precision problems created by long skinny triangles, Ensures that any point on the surface is as close as possible to a node, The triangulation is independent of the order the points are processed.

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2.1.3. Texture mapping to 3D surface

Texture mapping is used to improve the visual realism of images synthesized by rendering. The basic idea is to add image-based information to the rendered primitives. The texture is defined by a 2D image array in digital world. The digital image data could be obtained from photographs or videos or generated by mathematical functions. As the data are in a discrete raster format, before texture mapping, a continuous texture function $f(X, Y)$ in the texture space (X, Y) has to be established by using these discrete data. To map from the texture space to the 3D terrain, we have used interpolated data and established one to one relationship between 2D image and generated 3D meshes.

2.1.4. Vector Data

For nomenclature of 3D surface GIS information and place specific shape files available from Open street maps (OSM) were downloaded and overlaid as a layer over surface model. 3D scene was overlaid with number of OSM layers to cater to information such as road network, rail network, water bodies, building etc., for areas of interest.

2.2. Software and System Architecture

The software developed is a desktop application which works well both on Windows and Linux operating systems and also on single screen display, multiple projections systems and specialized system Immersive Visualization system available at SAC. The Basic diagram of software processing is described in figure 1. The software design and development involves Open scene graphs (OSG) libraries, GDAL libraries, C and C++ language. Mainly, the following OSG packages and classes were used to achieve the results.

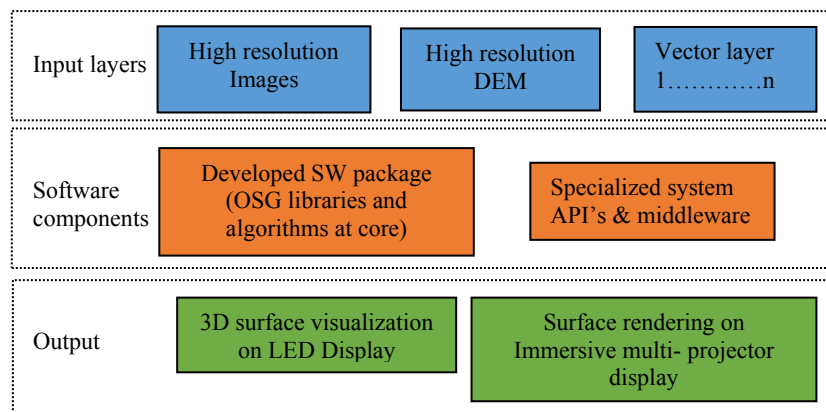


Figure 1. Architecture of 3D Visualization System

2.2.1. OSG Package and classes

The **osg** library contains all classes related to the scene graph node. It also contains class for mathematical operations and rendering state specification and management. The **osgDB** library contains classes and methods to create and render 3D databases. It provides plug-ins to read and write file formats supported by OSG. The **osgViewer** library—contains classes that manage views into the scene. **osgViewer** integrates OSG with a wide variety of windowing systems. The **osgUtil** library—contains classes and functions for operating on a scene graph and its contents, gathering statistics and optimizing a scene graph, and creating the render graph. The software is developed in such a way that it can handle large volume of data in terms of very high resolution and large area coverage.

2.2.2. Immersive multi projector visualization system architecture at SAC

Immersive multi projector system with a display size of 12000-pixel x 3000 pixel (36 Mega pixels); LED based active stereo projection is state of the art system installed at Space Applications Centre and it is mainly used for visualization of stereo data, its analysis, rendering of 3D models and 3D surface visualization of planetary data (Figure 2). The main components of system are

- Remote sensing software, visualization software package, data management software and graphics interface software at layer 1.
- Set of Image Generation (IG) System - High end engineering work- stations to drive the entire display system, storage system, high speed network and display management system.
- Projector Array of 24 to 26 no's Active stereo (3D) solid state projectors with solid state LED illumination.
- High resolution display with 12000X 3000 pixels.
- Control system: Multi-touch table, Table top 12" color touch panel.
- Integrated Audio System, Fly Box and Active Stereo 3D Glasses.
- Calibration system for adjustment of projector array.

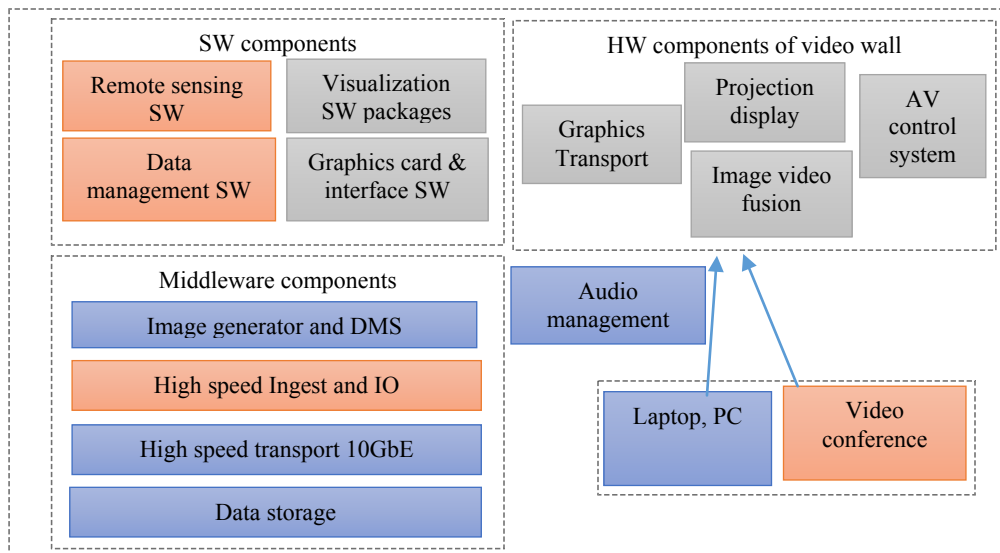


Figure 2. Components of immersive System

2.2.3. Representation of Terrain in Memory

There are various techniques to represent terrain data in memory as discussed below.

- a. Polygon Mesh: As the terrain surface consists only of a number of vertices and faces, we can store it in the form of an ordinary polygon mesh. There are two basic ways to simplify the usage of general polygon mesh - triangulated irregular network (TIN) and regular height field.
 1. Triangulated Irregular Network (TIN): it is a set of contiguous non-overlapping triangles whose vertices are placed adaptively over the DEM Algorithm.
 2. Regular height field: It is a two-dimensional rectangular array of height values which maps its grid point indices (values on X and Y axes) to height values (values on Z axis).
- b. Streaming mesh: It is a "logically interleaved sequence of indexed vertices and triangles with information about when vertices are introduced and when they are finalized. In other words, it is a polygon mesh with neighboring vertices and faces logically reorganized and regrouped close to each other, which makes it possible not to store the whole mesh in a main memory.
- c. Combination: Combining various approaches is also one of the options though a little bit harder to design and implement.

2.2.4. Performance, rendering techniques

We have used streaming meshes algorithm which utilizes advanced features of graphics hardware, such as programmability, displacement mapping, and geometry caching. This involves a light preprocessing stage, in which it generates hierarchies of elevation maps and color textures and stores them in main memory. In this scheme, the coexistence of different discrete geometric resolutions within the same patch enables seamless stitching (without cracks) of adjacent patches. In each frame the algorithm uses an implicit patch hierarchy to select a set of appropriate patches (for rendering) and determine the resolution on their boundaries based on view parameters. The resolution of each patch is determined based on its four boundary edges and without the need to query its adjacent patches. Here, coarser resolution patches are fetched as viewer is farther and finer resolution patches are fetched as and when viewer position is changed from farther position to nearer positions. Further, these patches are stitched together to provide seamless view.

We have data volume in terabytes of size and this may grow to petabytes. So, by keeping system memory and graphics card memory constraints in mind and in order to achieve near real time rendering performance we have generated smaller tiles of data. In this process, we use to fetch and load required tiles in to main memory as per field of view and level of details of the scene. In OSG's paged LOD (level-of-details) mechanism, the tile will only be replaced by its four sub-tiles when the viewer is near enough, and will render data of its range with a higher resolution. The basic structure of a quad-tree LOD in terrain rendering is shown in the following figure 3:

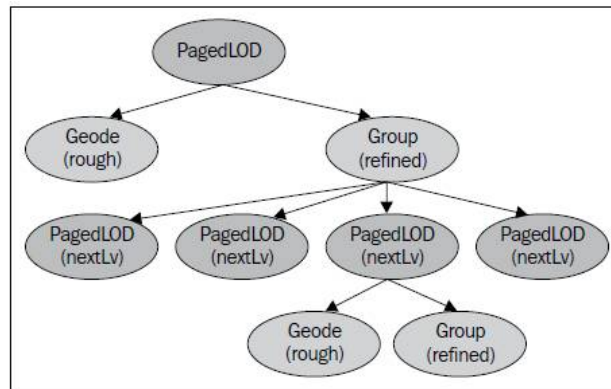


Figure 3. OSG Rendering Mechanism

2.2.5. Coordinate system

In this exercise, datasets were taken from Indian remote sensing satellite series of Cartosat which provides imagery of 0.6 m – 1.6 m resolution. DEM is generated from CartoSat-1 satellite. However the software can handle data with volume of more than 800 GB in WGS84, NAD27, NAD83, coordinate system from other sources also.

3. RESULTS

3.1. 3D Surface Visualization

The 3D surfaces generated using the in-house developed software system for different sites are shown in figure 4,5,6,7 and 8.

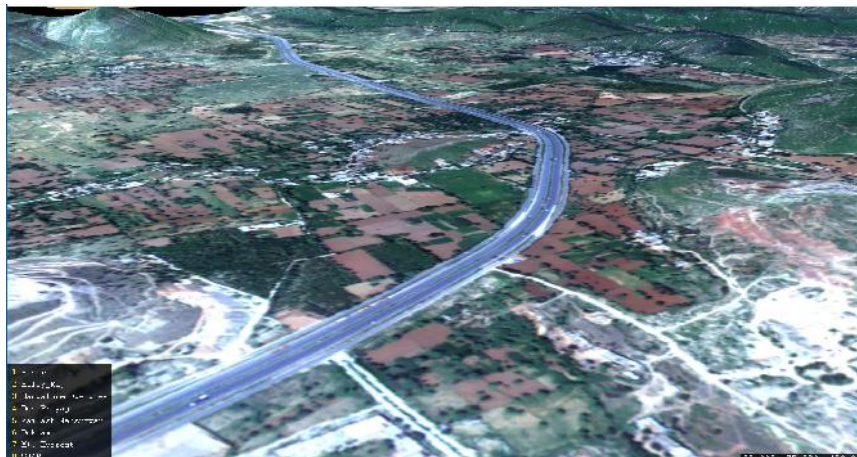


Figure 4. 3D Surface visualization – Part of Alwar at 1.6 m resolution

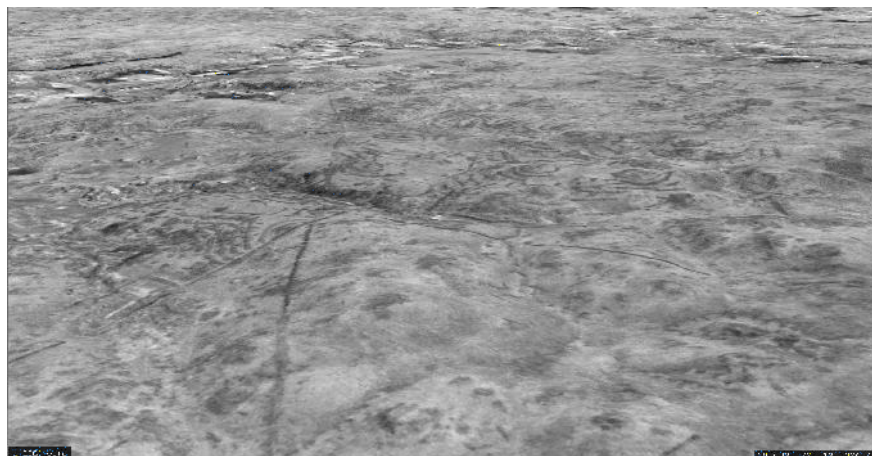


Figure 5. 3D Surface visualization of LIGO site at <1 m resolution

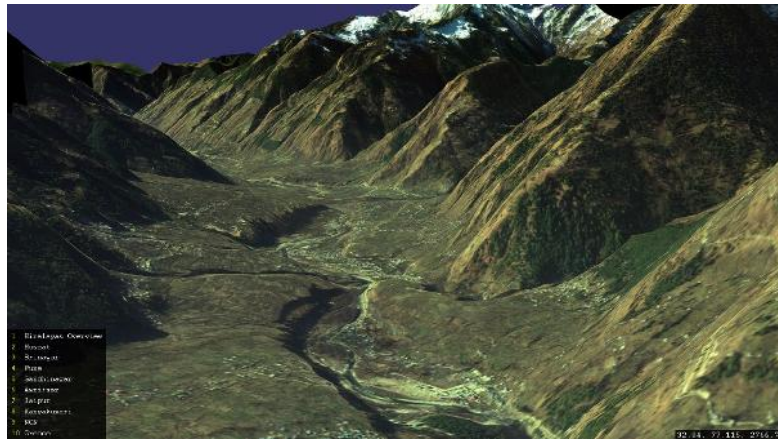


Figure 6. 3D Surface visualization of Kulu Manali at 1.6 m resolution

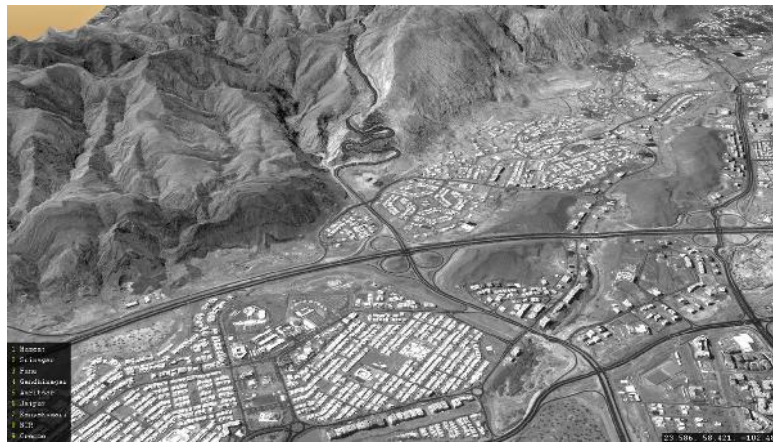


Figure 7. 3D Surface visualization of Muscat at 0.6 m resolution

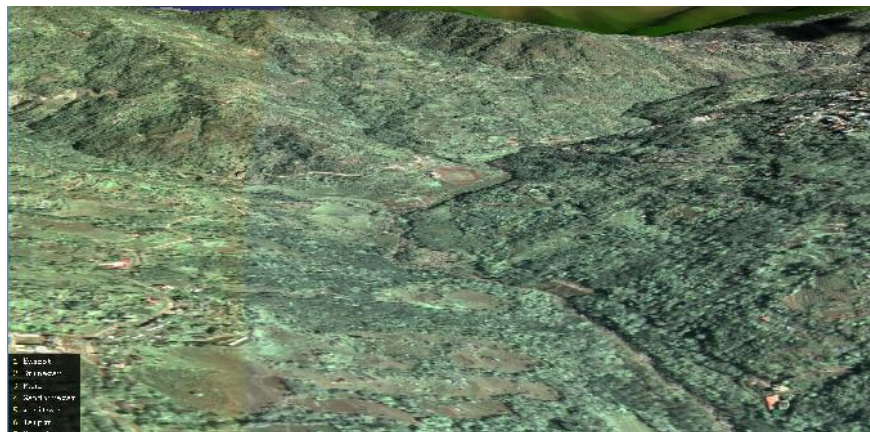


Figure 8. 3D Surface visualization of Gangtok at 0.6 m resolution

3.2. CHALLENGES EXPERIENCED

SAC has immersive visualization system with 26 active stereo projectors and these projectors display a seamless graphics using specialized hardware, middleware and interfaces. We have overcome technical hurdles like specialized interfaces, system dependent API's, aspect ratio of screen, far culling and near culling effects, incorporation of 2D texts, minimal support available for handling of voluminous datasets, limitation of rendering tiles to render the graphics; using in house developed solution based on open scene graphs on immersive visualization system available at SAC. By gaining insight about system architecture, middleware and drivers we have customized our entire solution accordingly. With software customization, we could visualize scenes like 3D surface models, city models, imagery on specialized system comparable to solutions offered by commercial tools in terms of efficiency and performance.

4. CONCLUSIONS

We have developed in-house software for 3D surface visualization. The software is capable to ingest any resolution of data ranging from kilometers to less than a meter and digital elevation model with different DEM posting. It has built-in capabilities to generate 3D surface of any given area, allows overlaying of vector layers for additional information and better interpretation of data. It is capable to render 3D surfaces of a very large datasets on a single screen, multiple projectors as well as on immersive visualization system using developed techniques. This software can be effectively utilized for different applications in the area of strategy planning, disaster management, urban planning, change detection and infrastructure management.

ACKNOWLEDGEMENTS

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DECISION SUPPORT SYSTEM FOR GEOSPATIAL APPLICATION USING OPEN SOURCE TOOLS

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ABSTRACT

Traditionally Decision making in operations planning including site suitability and route planning are done manually using topographic maps. In this paper, authors are presenting decision support solution for site suitability and route planning using open source GIS and digital maps updated from high resolution satellite images. Decision support system for spatial data adopts Modelling. Multi-criteria decision-making techniques like Analytical Hierarchy Process (AHP), Ideal Point Analysis are used to solve problems like site suitability analysis involving conflicting and compromising criteria. In this solution multiple criteria/parameters in terms of spatial data layers are analysed to support in decision making. Relative importance of the criteria can be derived from AHP or by assigning manual weights. A Unique framework has been developed to dynamically select subset parameters from given superset of parameters before performing the analysis. Total solution is built around open source packages. QGIS is used for vector, raster data management and visualization. GRASS GIS, having rich set of vector and raster analysis functions, is used for implementing site suitability and route models. With the combination of these open source software, spatial models were successfully developed. Open source OSG Earth is integrated to visualize data layers and outputs in 3D geospatial environment. While implementing spatial models a unique framework was realized using which spatial model can be created and modified with minimal programming knowledge. Intermediate scripting language is used for define the spatial models. Using the generic framework, models can be mapped to either commercial implementation or open source implementation. Each single spatial model is optimised by experimenting with vector processing and raster processing. Models are further optimised by separating independent steps in to separate processes based on number of CPU cores available. A site suitability model with 18 parameters for 15x15 sq. km area can be executed with in 1 minute to help quickly in decision making.

KEYWORDS: SDSS, MCDA, Spatial Models, GIS, Site Suitability.

1. INTRODUCTION

Recent advances in remote sensing enabled rich data for the users. Data derived from satellite images can be used for effective resource planning like site suitability. Suitability is the characteristic of possessing the preferred attributes or requirements for a specific purpose. Suitability analysis is a GIS-based process used to determine the appropriateness of a given area (land resource) for a specific use, i.e. agriculture, forestry, business, urban development, livelihood projects, etc.

Traditionally GIS are considered to perform basic functions on spatial data: input, storage, analysis and output. A variety of map description and manipulation functions are defined by commercial vendors as being 'Spatial analysis'. If these basic GIS functionalities are used along with modeling techniques efficient Spatial Decision Support systems can be developed. Modeling has three broad aspects: (a) To explain a phenomenon, (b) To predict a trend or future, (c) to act as a tool of discovery. In the present context Spatial Modeling is done to identify suitable sites for planning.

Spatial data modelling adopts multi-criteria decision-making techniques like Analytical Hierarchy Process (AHP), Ideal Point Analysis for solving multi-criteria decision-making problems like site suitability analysis involving conflicting and compromising criteria. Spatial data modelling involves selecting appropriate spatial data as parameters and their weights. GIS analysis functions are applied on these parameters before combining them for multi criteria decision. These GIS functionalities include from basic buffer function to advanced visibility, line density etc...

In traditional processing the processing logic is implemented in the code and parameters are fixed at logic building time. So, there will not be a provision to choose parameters at runtime. Also, as the logic is implemented inside the code to make small changes in the logic, programming knowledge is required. This kind of solutions are tightly bound to underlying GIS packages. If the solution has to be migrated to another GIS package, then entire solution has to be rebuilt.

In this paper, the authors are presenting a framework for representing spatial model and to process them in optimized way. If the model logic is built using a high-level scripting, which is very simple and easy to edit for analyst, small changes in the logic can be handled by analyst himself. As the script will be interpreted at runtime, some parameter can be dropped if user wants. If the solution has to be migrated to another GIS package no need to change the script only mapping from script function to GIS module needs to be changed. The new scripting framework adopted by the authors avoids the problem of being tightly bound to underlying GIS packages.

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2. METHODOLOGY

Spatial decision problems typically involve a large set of feasible alternatives & multiple evaluation criteria. At the most rudimentary level, a multicriteria decision problem involves a set of alternatives that are evaluated on the basis of conflicting and incommensurate criteria according to the decision maker's preferences. Important steps to be followed in spatial decision support system are shown in Figure 1.

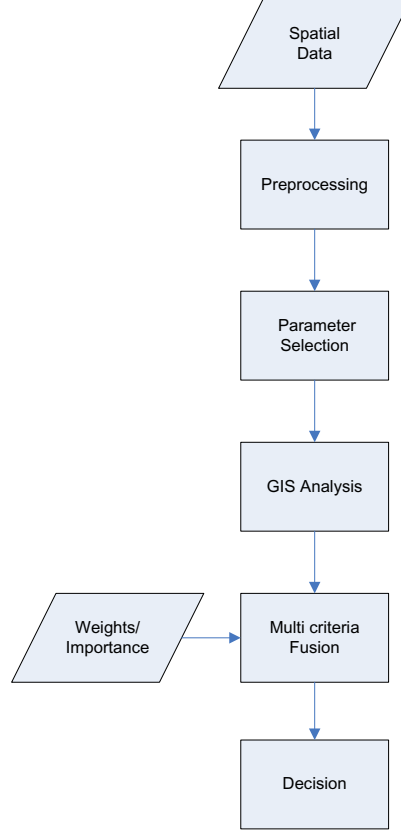


Figure 1: Steps for Spatial Decision Support

Multi-Criteria Evaluation (MCE)

Steps:

1. Set the goal/define the problem
2. Determine the criteria (factors/constraints)
3. Standardize the factors/criterion scores
4. Determine the weight of each factor
5. Aggregate the criteria
6. Validate/verify the result

Here the problem is site suitability. Criteria are Terrain parameters. Terrain related parameters are used for site suitability prediction. These parameters include spatial data like land use, roads, villages, junctions, curves, slope, forest entry exit points, culverts etc. These parameters used for multi criteria optimization. Each parameter is given certain weight/importance in the scale 1 to 100. Buffer is applied for some parameters which are not continuous. After buffer, value 100 is assigned to the polygon if it is preferable and 1 is assigned to the polygon if it is not preferable. Categorical parameters are assigned values 1 to 100 based on category.

All the parameters are combined based on below ideal point analysis formula (1).

$$S_i^p = \left\{ \sum_{k=1}^n \left(w_k \frac{a_k^* - a_{ik}}{a_k^* - a_{k*}} \right)^p \right\}^{\frac{1}{p}} \quad (1)$$

where:

where:

s_i^p is the distance (or separation) between the value associated with i -th alternative and the ideal point based on parameter p ;
 a_k^* denotes the best value of the k -th criteria;
 a_{k*} is the worst value of the k -th criteria;
 a_{ik} is the actual value of i -th alternative for the k -th criteria;
 w_k is the weight of the k -th criteria.

The range of parameter p is $[1, \infty)$. Different p values indicate different contributions of individual separations from ideal point. The greater the parameter p is; the greater emphasis is placed on the larger separations. If the $p = 1$, indicates that the overall score of alternative i is the sum of weighted deviations associated with all criteria. In this case, total compensation between criteria is assumed, which means that a decrease of one unit of one criterion can be totally compensated by equivalent gain on any other criterion (Pereira and Duckstein, 1993). As the p value increases, with higher scores has greater influence on the overall score, while the impacts from other terms may become negligible. The best solution should be the one has the smallest overall score. Therefore, the decision criteria in selecting the compromise solution become the 'avoidance of low performance in any criteria' as the increased value of p (Karni and Werczberger, 1995).

3. DESIGN

In the Framework Each Spatial model will be represented by set of text files. One text file contains parameter names. Another text file contains script to list the operations needs to be performed on parameters. One more text file to list parameter mapping to data (vector files and raster files).

For example, take a spatial model with 8 parameters. In this model all parameters are listed in text file as shown in figure 2. As shown in figure 3 each parameter will take data from particular shape file or raster file. Finally, a script file as shown in figure 4. will list out all the operations to be performed on each parameter including weighted summation. For route model script includes steps to calculate cost by combining necessary layers then cost path function to find the best and alternate routes. Framework has also provision for defining thresholds, weights(importance) and other parameters required.

```
Proximity_to_Water;Not Compulsery;Not Continues;site_WATER;waterpt_cat;Proximity_to_Water
Proximity_to_DrainagePoly;Not Compulsery;Not Continues;comb
Proximity_to_CanalLine;Not Compulsery;Not Continues;comb
Proximity_to_DrainageLine;Not Compulsery;Not Continues;comb
Proximity_to_Village;Not Compulsery;Not Continues;site_VILL;dist2vill_cat;Proximity_to_Village
LandUse;Not Compulsery;Not Continues;site_Lulc;lulccat_n;LandUse
Slope;Not Compulsery;Not Continues;site_Slope;slopecat;Slope
Proximity_to_Tracks;Not Compulsery;Not Continues;site_Tracks;prox2track_cat;Proximity_to_Tracks
```

Figure 2. Parameters for example suitability model

```
Proximity_to_Water;Hydrography;WellPoint.shp;0
Proximity_to_DrainagePoly;Hydrography;DrainagePoly.shp;1
Proximity_to_CanalLine;Hydrography;CanalLine.shp;2
Proximity_to_DrainageLine;Hydrography;DrainageLine.shp;3
Proximity_to_Village;AdminBoundaries;SettlementPoint.shp;4
LandUse;TerrainDetails;LandusePoly.shp;5
Slope;;slope;6
Proximity_to_Tracks;Transport;RoadLine.shp;7
```

Figure 3. Parameters data binding

```

Select;Proximity_to_DrainageLine;DRNL_CODE='01';drn_sel.shp
Buffer;Proximity_to_Water;Proximity_to_Water_BufDistance;Wlaterpt_buf.shp
Buffer;Proximity_to_DrainagePoly;Proximity_to_Water_BufDistance;W2aterdp_buf.shp
Buffer;Proximity_to_CanallLine;Proximity_to_Water_BufDistance;W3atercl_buf.shp
Buffer;drn_sel.shp;Proximity_to_Water_BufDistance;W4aterdl_buf.shp
Buffer;Proximity_to_Village;Proximity_to_Village_BufDistance;Village_buf.shp
Select;Proximity_to_Tracks;ROAD_TYPE='Tracks';Tracks_sel.shp
Buffer;Tracks_sel.shp;Proximity_to_Tracks_BufDistance;Tracks_buf.shp
Unionweightpart;Wlaterpt_buf.shp;W2aterdp_buf.shp;W3atercl_buf.shp;W4aterdl_buf.shp;-;waterpt_cat.dbf;-;CODE;-;Proximity_to_Water_Weight;Vi
llage_buf.shp;-;dist2vill_cat.dbf;-;CODE;-;Proximity_to_Village_Weight;Tracks_buf.shp;-;prox2track_cat.dbf;-;CODE;-;Proximity_to_Tracks_Wei
ght;bound_m;allsite1.shp
CopyFromModel;lulcc_n.dbf;lulcc_n.dbf
UpdateShapeFile;LandUse;LU_CODE;LNU_WIGHT;lulcc_n;dummy
PolygontoRaster2;dummy;LNU_WIGHT;LandUse1
RastertoPolygon;LandUse1;LandUsef.shp
Unionweightpart;LandUsef.shp;-;LandUsef.shp;-;GRIDCODE;-;LandUse_Weight;bound_m;allsite2.shp
CopyFromModel;slopecat.dbf;slopecat.dbf
ReclassByTable;Slope;slopecat.dbf;cVALUE;cVALUE;site_Slope
RastertoPolygon;site_Slope;slope.shp
Unionweightpart;Slope.shp;-;Slope.shp;-;GRIDCODE;-;Slope_Weight;bound_m;allsite3.shp
Unionweightcombine;allsite1.shp;-;allsite1.shp;-;allsite1_WEIGHT;allsite2.shp;-;allsite2.shp;-;allsite2_WEIGHT;allsite3.shp;-;allsite3.shp;
-;allsite3_WEIGHT;fallsite.shp
Dissolve;fallsite.shp;WEIGHT;SiteSuitability.shp
CopytoModel;SiteSuitability.shp;SiteSuitability.shp

```

Figure 4. Script file which lists steps to be performed

Script file includes steps to combine parameters using formula (1) shown in methodology, for example Union weight step combines all the parameter in to single raster or vector according to given weightages. All the data including roads, villages, waterbodies etc. are digitized from high resolution satellite images.

3.1. Framework Execution Sequence:

When a user wants to execute a spatial model, as shown in figure 5 framework first reads parameter file and show the parameters and their importance to user. User can drop some parameters and can add new parameter. User can change the importance of the parameter. When user clicks execute button framework will read the script file and execute the commands one by one. While executing the command framework will check whether the parameter involved in the command is dropped or not if parameter is dropped that command will not be executed.

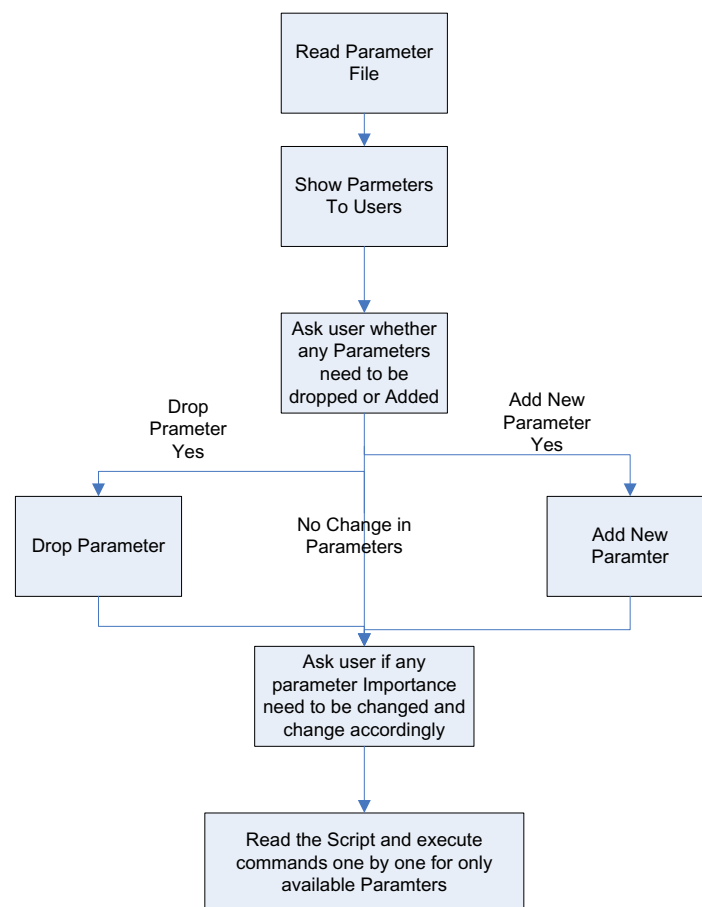


Figure 5. Typical Work flow of the Framework

3.2. Implementation using ARCGIS

Total framework is built using VB.net. First implementation was done using commercial GIS package ARCGIS. Basic GIS functionalities are mapped from script to arc objects. whenever framework needs to be executed underlying arc objects function will be called.

```
mf1 = Newmodelfunctions()
mf1.index = 0
mf1.name = "Buffer"
mf1.operation = AddressOfMe.Buffer
mf1.continuewithoutparam = False
mf1.notavailaleval = 0
mf.Add(mf1)
```

Figure 6: Analysis Function Lookup Creation

As shown in figure 6 Each function is mapped to a script command or operation via model functions. For example, buffer command/operation of script is given the address of function Buffer. Inside the buffer function call to arc objects buffer is made. Same way all the GIS functions list is maintained and mapped to corresponding script command/operation. Initially data is stored in File Geodatabase.

Parameter weights can be given manually from 1 to 100. User can give importance to the parameters through ranking. Ranks given by user will be converted to weights by framework. Users also have option to use AHP to give weights to parameters. Using AHP user can compare two parameters and give importance to parameters and finally weights will be derived using pair wise comparisons

3.3. Optimization

First implementation is based on raster processing i.e. input vectors are converted to raster and then combined using raster arithmetic. With ARCGIS and file geodatabase as input, for 225 Sq.km area, model with 18 parameters was taking 20 minutes' time to execute. Analysis showed that layers accessing from geodatabase itself is taking more time. To reduce the data access time experimented with shape files as input. At the same time instead of converting each input from vector to raster then combining, total model is implemented with vector processing. In raster processing, combining is done through raster arithmetic where as in vector way of processing combining operation implemented with union. Weighting and arithmetic are implemented using ODBC queries on polygon attributes.

For optimizing the execution time, framework allows to split the script in to multiple independent scripts. Whenever framework finds multiple script files under same model name it launches multiple processes to execute the scripts. In the scripting language wait command/operation is provided to wait for particular process.

```
Model1_Script_Process_0
    Buffer;Village;Vill_buff
wait;1
Combine;Road_buff;Vill_buff
```

```
Model1_Script_Process_1
Buffer;Road;Road_buff
```

Table 1: Dividing steps in to two processes

As shown in the above table 1, each model can be divided into multiple scripts with same model name but with different process ids. With vector processing, shape file as input and two processes for one model, execution time of model with 18 parameters is reduced to 2minutes on a system with specifications shown in Table 2.

```
Dell Precision T7600
Windows 7 64 bit
Intel Xeon 2 Ghz E5-2650
16GB RAM
500 GB Harddisk
```

Table 2: specification of the system used for testing execution time

Spatial Model with 18 Parameters	Area 225 Sq. Km
Method	Time in minutes
Raster based	20
Vector based, Arithmetic operations as SQL ODBC queries	2

Table 3: Execution Time using ARCGIS

3.4. Open Source Implementation

The same framework is implemented using open source GIS software. For data editing and visualization QGIS is used. QGIS is customized using python to support Spatial modeling. GIS analysis functions are implemented using GRASS. Through .net necessary GRASS GIS executables are called to implement GIS analysis functions.

First change in the framework is to implement GIS functions for script commands/operations. This is done by just replacing earlier arc objects call to GRASS calls. As the framework reads script for each command in script file GRASS executables will be called.

3.5. Optimization for Opensource Implementation

Vector based implementation with ARCGIS reduced the processing time, interestingly vector based processing with open source GIS increased the processing time from 2 minutes to 6 minutes.

After analysis for open source, raster-based processing was adopted. Raster based processing and MIMD kind of parallel processing (3 process for each model) reduced execution time to 50 seconds. Timelines are shown in Table 4.

Spatial Model with 18 Parameters	Area 225 Sq. Km Open source GIS
Method	Time in Seconds
Raster based	50
Vector based	360

Table 4: Execution Time using open source GIS

4. RESULTS

Following Figure shows site suitability model GUI form developed. Using this form user can drop some parameters. User can add a new parameter. User can change weight, buffer distance and category weights.

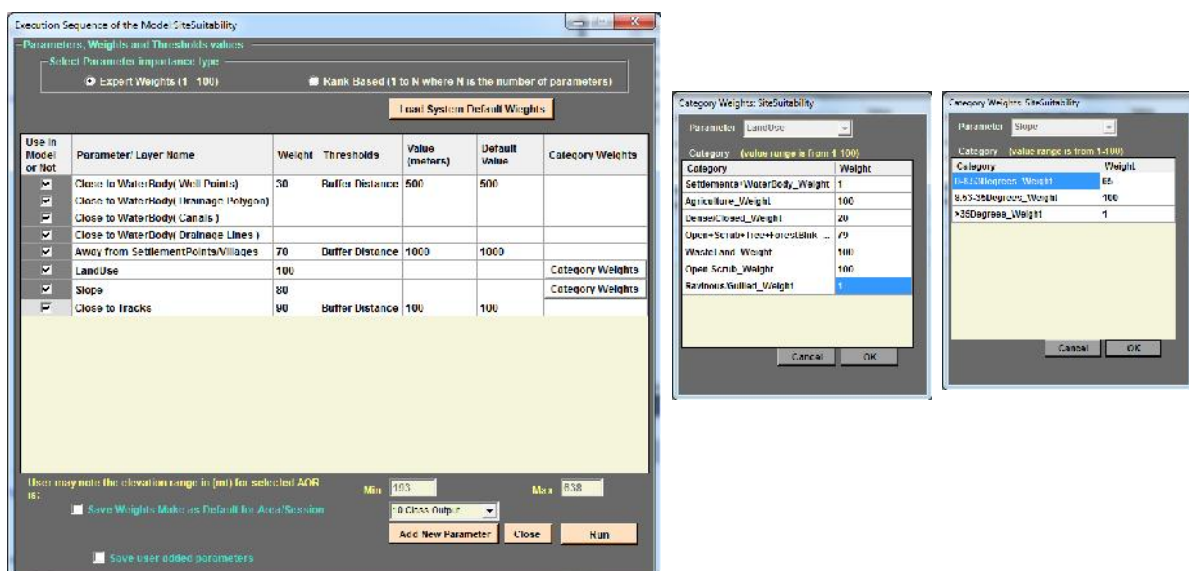


Figure 7: Parameter and weightage selection from for Site Suitability Model.

Based on the given parameters and weights following site suitability output shown by the system (input data layers are waterbodies, settlements, land use, slope, roads).

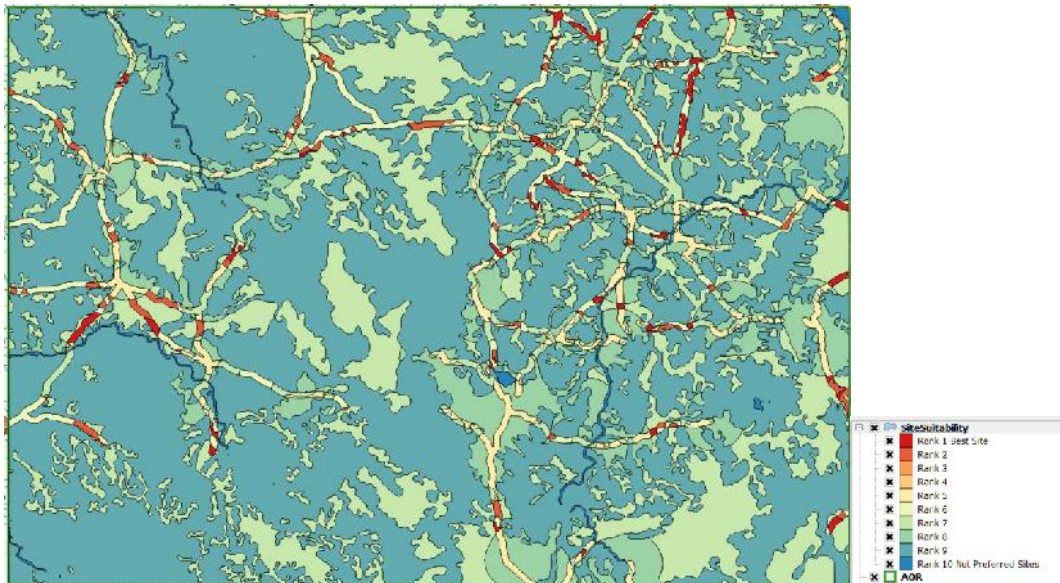


Figure 8: Site Suitability Model Output

After executing the model total area is categorized in to 10 classes from rank 1 to 10. Rank 1 is best suitable site according to given parameters and weights. Rank 10 is least suitable site. Open source OSG Earth is integrated in to the framework and model outputs can be visualized in 3D environment. Following figure9 shows cross country route model output.

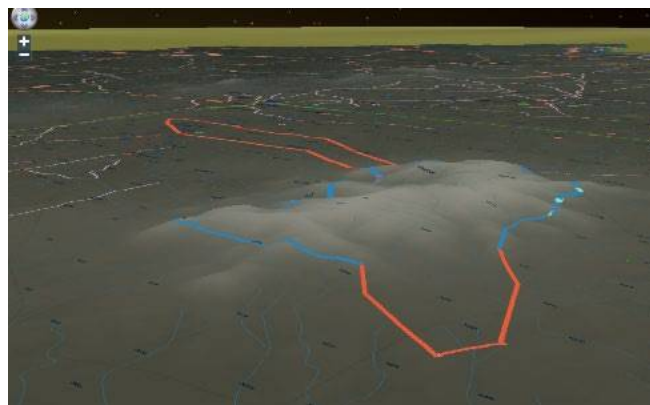


Figure 9: Cross Country Route Model output visualized in 3D

5. CONCLUSION

For spatial problems like site suitability and route finding, to support in decision making a framework is realized using multi criteria decision analysis method and open source GIS tools. This framework allowed the authors to experiment with commercial and open source packages. It allowed to migrate from commercial package to open source with minimal effort. It separated modeling logic from coding so that analyst without or with minimal coding knowledge can change the logic. The framework enables to maintain modeling logic and code separately so that change in model logic will not affect software in terms of bugs. The framework enabled authors to introduce parallel processing, by which processing time reduced considerably. This Spatial Decision Support System incorporated provisions to allow users to dynamically select parameter and add new parameter before executing the model. In the future Framework will be extended to provide a GUI based model creation feature with which analyst will be able to create spatial models with ease.

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IDENTIFICATION OF THERMAL FRONTS IN THE INDIAN OCEAN USING MODIS SEA SURFACE TEMPERATURE (SST) DATA

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ABSTRACT

Oceanic fronts play an important role in the marine ecosystem. Satellite observations of sea surface temperature (SST) fronts has been considered as the best remote sensing tool available today for global mapping and monitoring of the oceanic fronts. The Indian Ocean plays an important role in the climatic changes and variability of the Asian monsoon. MODIS SST data is used for the present study for analysing the seasonal changes in SST for 3 years from 2015 to 2017 and detecting the thermal fronts in the Indian Ocean. The single image edge detection method is considered to be the best and advanced method to locate thermal fronts and hence SIED has been used for the thermal front detection. Oceanic fronts are formed at the boundary between water masses of different temperature or density in the Indian Ocean according to the seasonal changes in the temperature. Thus the monthly variability of the thermal fronts for the Indian Ocean has been studied here during the summer, winter, pre-monsoon and post-monsoon period. The seasonal variation analysis reveals that the maximum number of thermal fronts is observed in the month of February while the minimum is observed in the month of June.

KEYWORDS: MODIS, Sea Surface Temperature SST-Data, Indian Ocean.

1. INTRODUCTION

Sea surface temperature (SST) is the water temperature close to the ocean's surface. SST is dynamic in nature and varies with many factors like wind, water upwelling in seas, surface current intensity, cyclones, dissolved oxygen level and etc. It is a key climate indicator and an essential parameter in weather prediction and atmospheric model simulations. Ocean fronts are sharp boundaries between different water masses and different types of vertical structure (stratification) that are usually accompanied by enhanced horizontal gradients of temperature, salinity, density, nutrients and other properties (Belkin, 2003). Fronts and the associated currents have an important role to play in heat and salt transport, ocean atmosphere interaction and ecosystem functioning. Fronts can be classified according to the characteristic properties: thermal front, salinity front, and density front. A thermal front is a zone with a pronounced horizontal temperature gradient, while a haline front is a zone with a pronounced salinity gradient. Similarly, chlorophyll fronts also exist and can be detected from satellite observations. Distinct shapes of the fronts vary according to their type and are commonly found as elongated stripes or comma-like curve regions covering a wide range of scale: from 100 m to 10,000 km along-front; from 10 m to 100 km across-front; from 1 m to 1 km down-front (Belkin, 2002). Fronts vary temporally and can be permanent large-scale features, or transient mesoscale features occurring seasonally with more diffuse boundaries (Valavanis, et al, 2005). They are accompanied by current jets, convergences, eddies, subsurface intrusions and lenses, and are associated with strong mixing and stirring, elevated biological productivity, acoustical wave guides, marginal ice zones and atmospheric boundary layer fronts (Belkin, 2002). Fronts act to increase production by channeling nutrients through multiple trophic levels. Identification of thermal fronts is essential in determining the potential fishing zone areas and the carbon transport due to increase in biological activity in the upper ocean.

SST fronts were derived from the cloud-masked SST fields with the multi-image edge detection algorithm (Cayula and Cornillion, 1996; Ullman and Cornillion, 1999, 2000, 2001). The single image edge detection (SIED) algorithm is applied to each SST field in the time series. The SIED algorithm operates at three levels: image, window, and pixel. The image level portion of the process is associated with the cloud screening algorithm and is not discussed here. At the window level, a histogram analysis is performed on overlapping square windows of pixels in the image. This study is based on a global survey of SST fronts (Belkin et al., 1998, 2001; Belkin, 2005; Belkin and Cornillion, 2007) for identification of thermal fronts in Indian Ocean using MODIS SST.

2. DATA AND METHODOLOGY

2.1 Data

The NASA Jet Propulsion Laboratory (JPL) Physical Oceanography Distributed Active Archive Center (PO.DAAC) publishes collections of sea surface temperature (SST) images gathered by the Moderate Resolution Imaging Spectroradiometer (MODIS) carried by the Terra and Aqua satellites. Level 3 monthly SST data available format thermal infra-red region is obtained from <ftp://podaac-ftp.jpl.nasa.gov/allData/modis/L3/aqua/11um/v2014.0/4km/monthly>.

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2.2 Study Area

Thermal front detection analysis is done for the northern Indian Ocean. Northern Indian Ocean comprises of Bay of Bengal on the east and Arabian Sea on the west of coastal India (60°E to 96°E and 6°N to 24°N). Despite of similarities between Bay of Bengal and Arabian Sea like same latitudinal extent and exposure to same amount of solar radiation there are striking dissimilarities observed between them like wind speed over the basin, precipitation and riverine run-off. Studies have shown that Bay of Bengal waters are less saline and stratified with turbid sediments in comparison to Arabian Sea.

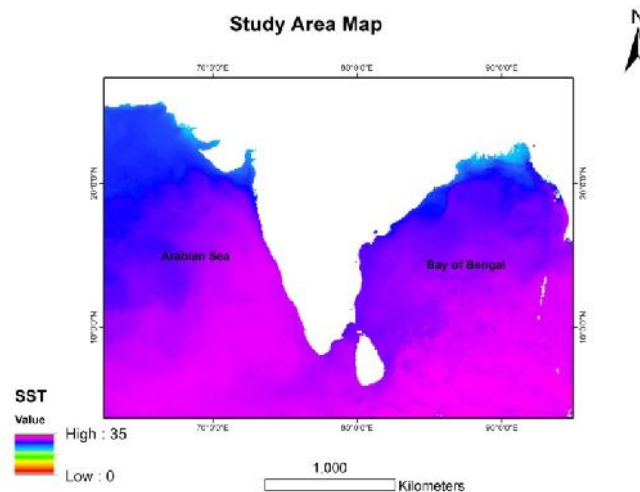


Figure 1: Study area map

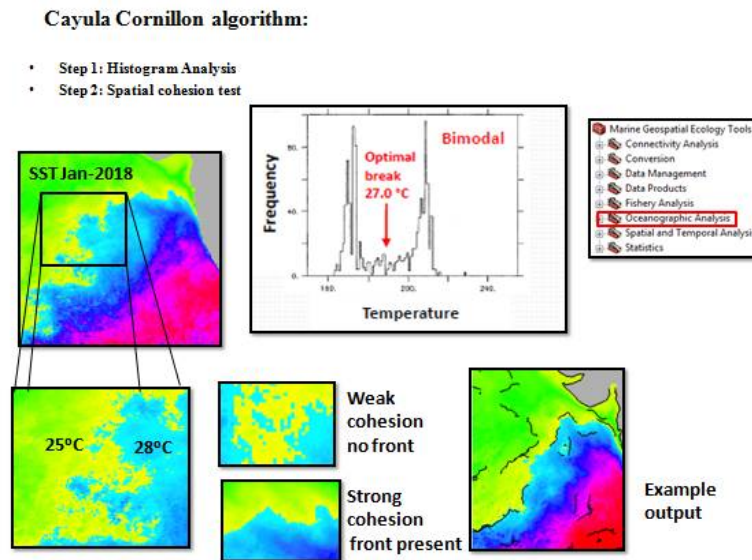
2.3 Methodology

MODIS level 3 SST data used for thermal front detection is processed in ArcGIS software using Marine Geospatial Ecology Tools (MGET) using Cayula and Cornillon algorithm. It is an open source geoprocessing toolbox designed for coastal and marine researchers and GIS analysts who work with spatially-explicit ecological and oceanographic data in scientific or management workflows. MGET includes over 300 tools useful for a variety of tasks, such as downloading popular oceanographic datasets in GIS-compatible formats, identifying fronts and eddies in satellite images, building statistical habitat models from species observations and creating habitat maps, modeling biological connectivity by simulating hydrodynamic larval dispersal, and building grids that summarize fishing effort and other statistics. Prior to the detection of fronts, a pre-processing of the data based on smoothing filters is needed in order to remove the noise introduced by the sensor and the uncorrected atmospheric effects. The smoothing procedure helps to preserve valid information from the original noise (the high frequency signal in the spatial domain) by improving the quality of the subsequent frontal detection. At the same time, the selection of an adequate window size is critical for the performance of the detection. Analysis of thermal fronts detected from the different combinations of median filters: 3x3; 5x5; 7x7 and 9x9 showed that 3x3 median filter size shows the best results for analyzing a large area of interest like Indian Ocean. Similar analysis with different window sizes (16x16, 24x24 and 32x32) showed that 32x32 window size to be the best for analyzing over Indian Ocean. The SST threshold for the frontal detection is kept constant as 0.3 degrees.

A histogram algorithm is run to identify the windows that exhibit a bimodal distribution of values that categorize the pixels into the two populations according to the optimal separation value and apply a spatial cohesion algorithm to determine if two populations are sufficiently spatially separated. On windows that have sufficiently separate populations, mark any pixels in either population that are adjacent to pixels in the other population. These are the pixels that are along the front that separates the populations. After all along-front pixels have been identified, execute a contour-following algorithm that extends fronts on either end so long as a sufficient temperature gradient continues in the direction the front was pointing.

2.4 Cayula and Cornillon Algorithm

The single-image edge detection (SIED) algorithm devised by Cayula and Cornillon (1992) indicates fronts where there is a significant difference between the mean temperature of neighboring water masses: this is a robust and completely automated method for distinguishing genuine oceanic fronts from numerous other thermal gradients on SST images. SIED is available



within the Marine Geospatial Ecology Tools (MGET), an open source toolbox for marine researchers, so it can be downloaded and called from ArcGIS or programming languages including Python. There are two aspects to this algorithm which may need to be adjusted according to your application. The first is a pre-preprocessing step to smooth the SST data, to improve the appearance of the detected fronts. Cayula and Cornillon (1992) recommended a median filter to reduce noise while preserving edges, and a width of 9x9 pixels has been found to be effective in most applications. Secondly, the algorithm applies a lower limit on the mean difference in SST across a potential front. The original paper suggested a lower limit of 0.5 °C difference, though this can be reduced if weaker fronts are of interest and the SST data have low noise characteristics. The SIED edge maps are then overlaid as black lines onto the SST maps to demonstrate good locational accuracy of the fronts compared to the obvious SST color gradients.

3. RESULTS AND DISCUSSION

3.1 Monthly Spatial variability of thermal fronts during Spring/Pre-monsoon season (March, April and May)

Figure 3 shows the year wise distribution of thermal fronts for each month of the spring season (2015-2017) from MODIS SST. The characteristics of thermal fronts in both Arabian Sea and Bay of Bengal are very different during this season. Large number of thermal fronts is observed in the Arabian Sea whereas lesser number of fronts is observed in the Bay of Bengal. It can be observed that in the month of March, thermal fronts are observed in the northern Arabian Sea and in the northern Bay of Bengal.

The maximum number of thermal fronts is observed in the month of March. Long thermal fronts are formed in almost all regions of the Arabian Sea and fewer regions of Bay of Bengal. South east region has the highest SST during this period. In all the three years under study no thermal front was formed in this region in March and almost similar patterns are followed in Arabian Sea region. After the peak period in March, the amount of thermal fronts slowly starts to decrease in the months of April. In 2015 and 2017 almost all the thermal fronts are clustered in Arabian Sea and Bay of Bengal it is fragmented with limited existence of fronts. In May the amount of thermal fronts randomly decreases and the area of thermal fronts gets concentrated on north and North West part of Arabian Sea (Figure 3c, 3f and 3i). And in Bay of Bengal the fragmented very less number of thermal fronts forms. Long areas of thermal fronts are found in 2016 and 2017 in Arabian Sea. Irrespective of the month, the northern Arabian Sea exhibits long and clear fronts. Hence northern Arabian Sea is a region of consistent frontal occurrence. Month of May characterizes the least number of thermal fronts. Inter-annual variability can be observed for the thermal front occurrence for spring with the year 2017 showing large number of fronts.

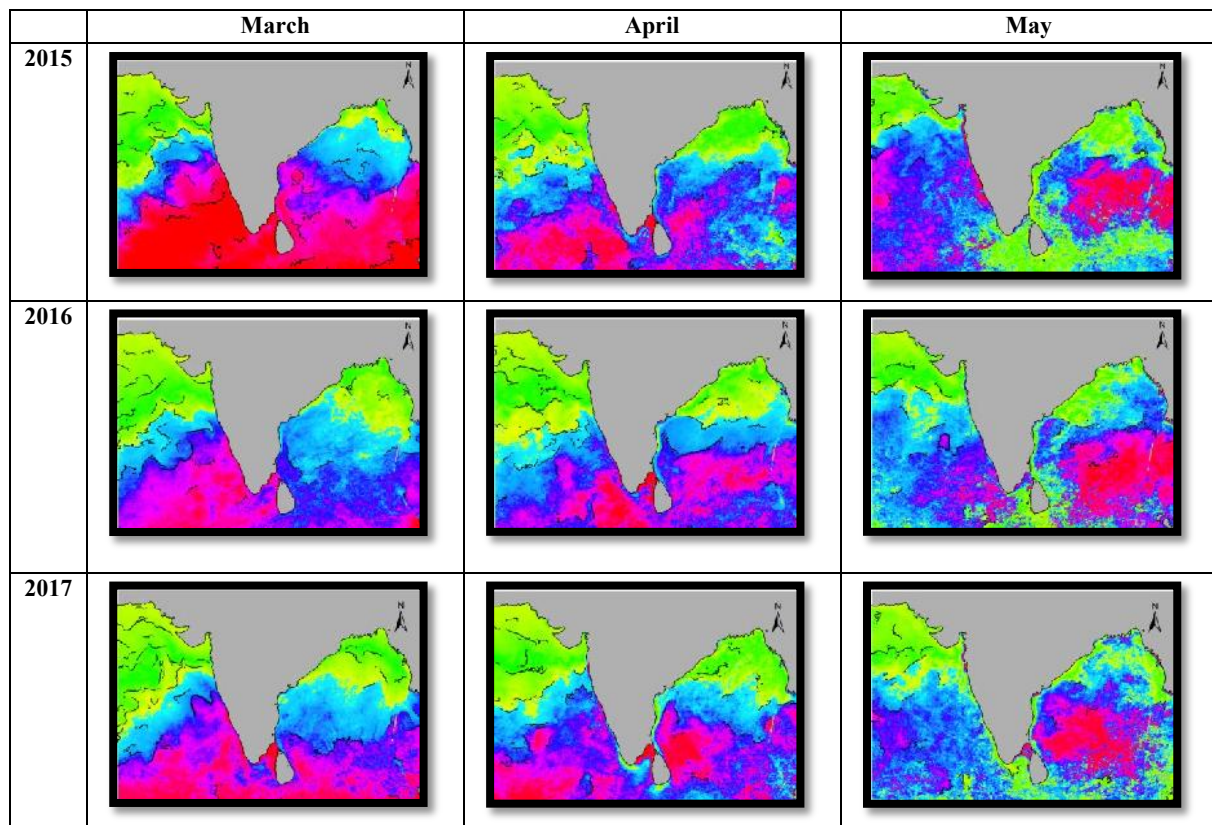


Figure 3. Thermal fronts overlaid on SST for the months March, April and May for the years 2015-2017

3.2 Monthly spatial variability of thermal fronts during Summer Monsoon period (June, July, August, September)

Summer monsoon in the Indian Ocean occurs during June-September. The month of June marks the arrival of summer monsoon. Often the onset of summer monsoon occurs during the end of May to first week of June. The stronger winds associated with the summer monsoon results in larger scales of mixing in the ocean and results in cooling of the SST. Figure 4 and 5 shows the thermal fronts for the months June-September during the years 2015-2017. It can be seen that when compared to the spring season, relatively very less number of thermal fronts are formed in both the basins. In the month of July also the presence of thermal front is rare but slightly more than that formed during June but fragmented and distinct fronts are found in different years during this month.

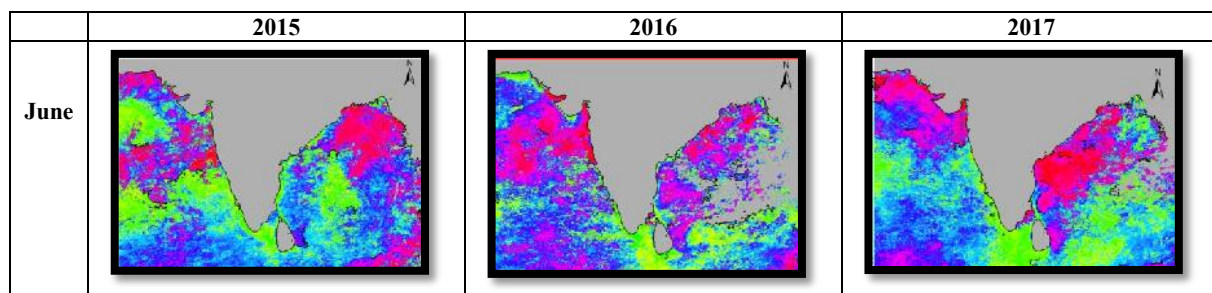


Figure 4. Thermal fronts overlaid on SST for the spring season/pre-monsoon month June for the years 2015-2017

In August and September also the presence of fronts are very low and distinct, small and scattered fronts are found, mostly on the central Arabian sea Figure 5. Presence of thermal fronts increase in a slow rate from June to September and the pattern found in all the years for the month of August and September is almost identical except 2016 September month we see thermal fronts in Arabian Sea. Unlike spring season, the pattern of variability of thermal fronts in the summer monsoon is almost identical in both Arabian Sea and Bay of Bengal. However, the number and length of the thermal fronts are very less in the summer season.

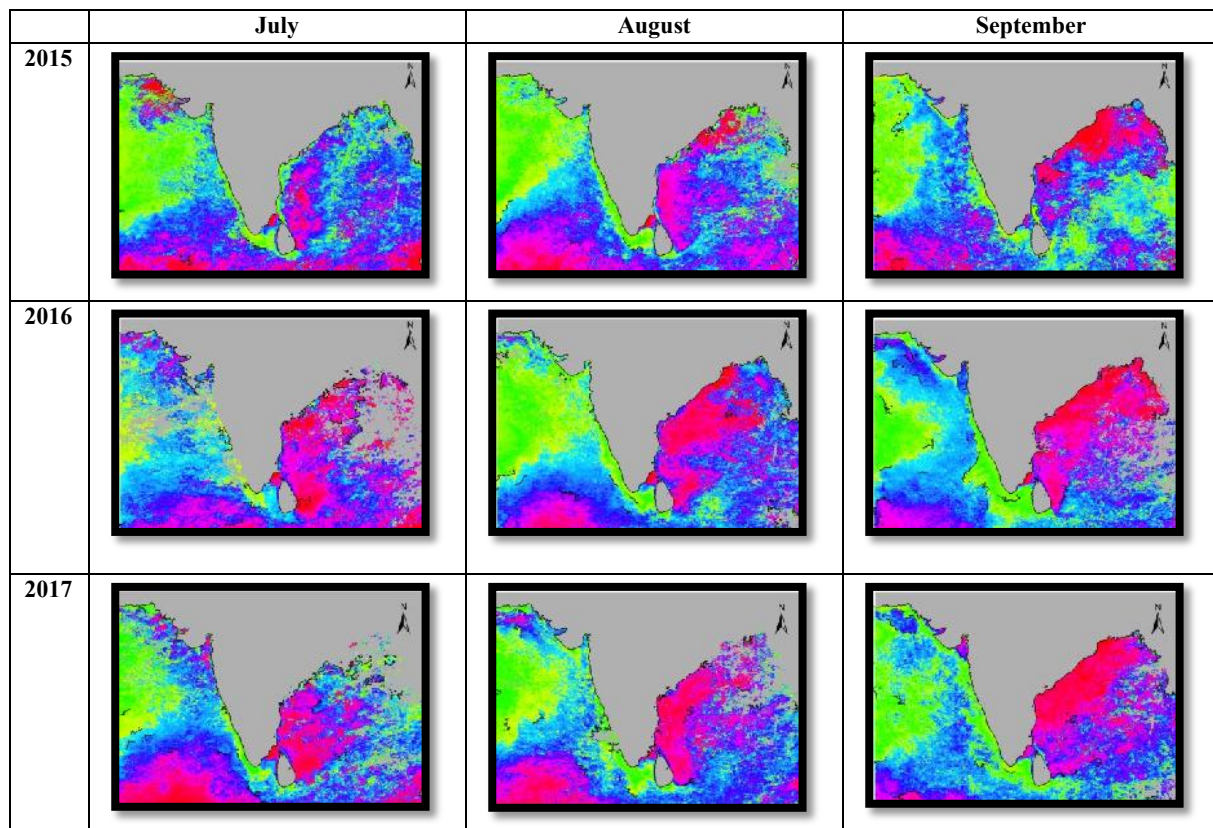


Figure 5. Thermal fronts overlaid on SST for the months July, August and September for the years 2015-2017

3.3 Monthly Spatial variability of thermal fronts during Autumn/Post- monsoon season (October and November)

From October onwards the monsoon weakens this is fairly reflected in the thermal front images (Figure 6). The rate of increase in the number of thermal fronts accelerates from October. In 2015 and 2017 the number of thermal fronts increases during October to November. In all year's long fronts with clustered structure is formed. The amount of thermal fronts rapidly increases from October to November. Thermal fronts found in November are very small in length but they are clustered having distinctive patterns fronts found in different years for November. In Arabian Sea and Bay of Bengal in month November increased number of thermal fronts seen. Strong inter-annual (year to year) variability is seen in the number and length of the fronts with large number of fronts formed in the year 2016.

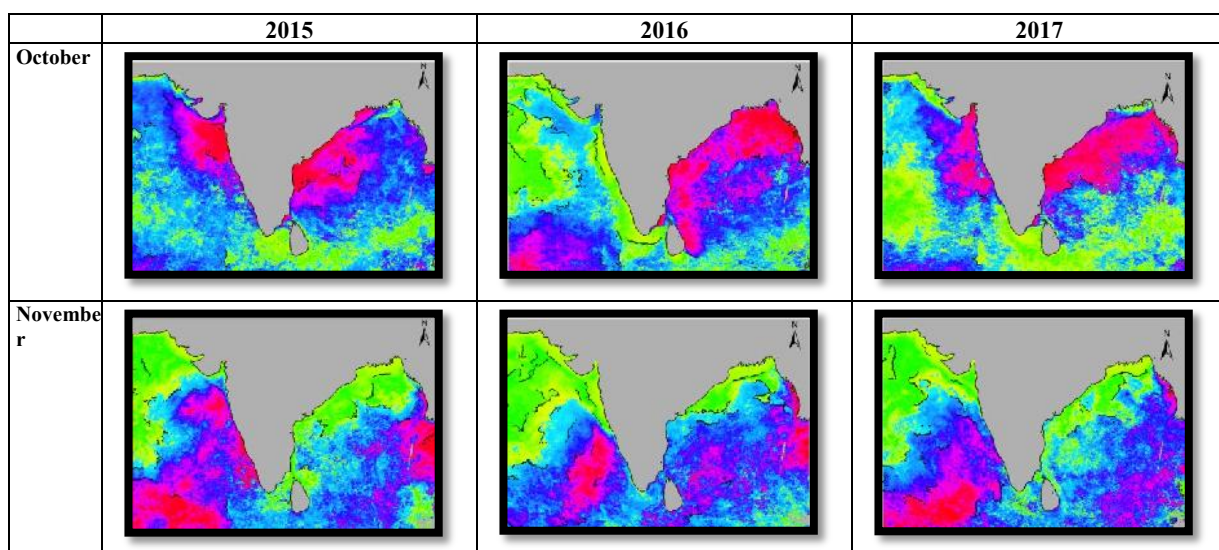


Figure 6. Thermal fronts overlaid on SST for the months October and November for the years 2015-2017

3.4 Monthly Spatial variability of thermal fronts during winter monsoon season (December, January and February)

The variability of thermal fronts during the winter monsoon is shown in the Figure 7. It is evident from the figures that from December, the amount of thermal fronts continues to increase. Long and clustered thermal fronts are found more in the Arabian Sea than Bay of Bengal during the years 2015-2017. In December the northern regions of Arabian Sea and Bay of Bengal exhibits longer and larger number of thermal fronts than compared to the southern region. Year 2016 shows larger number of fronts for the month of December. The number of thermal fronts is observed to be increasing in number and their spatial extent increases in the following months January and February. The maximum number of thermal fronts during the months December to January is mainly due to the effect of winter cooling in the northern Arabian Sea which resulted in the formation of fronts at the boundary between water masses of different temperature or density, and are often associated with mixing and enhanced biological production as reported by (Prasannakumar et al., 2009). In February the amount of thermal fronts continue to increase and it is one of the months with maximum amount of thermal fronts. Long and clustered thermal fronts are found in the Arabian Sea and in Bay of Bengal during the years 2015-2017. Well-developed clusters of thermal front regions are found in Indian Ocean also in this month. In 2017 a maximum number of thermal fronts found in Indian Ocean.

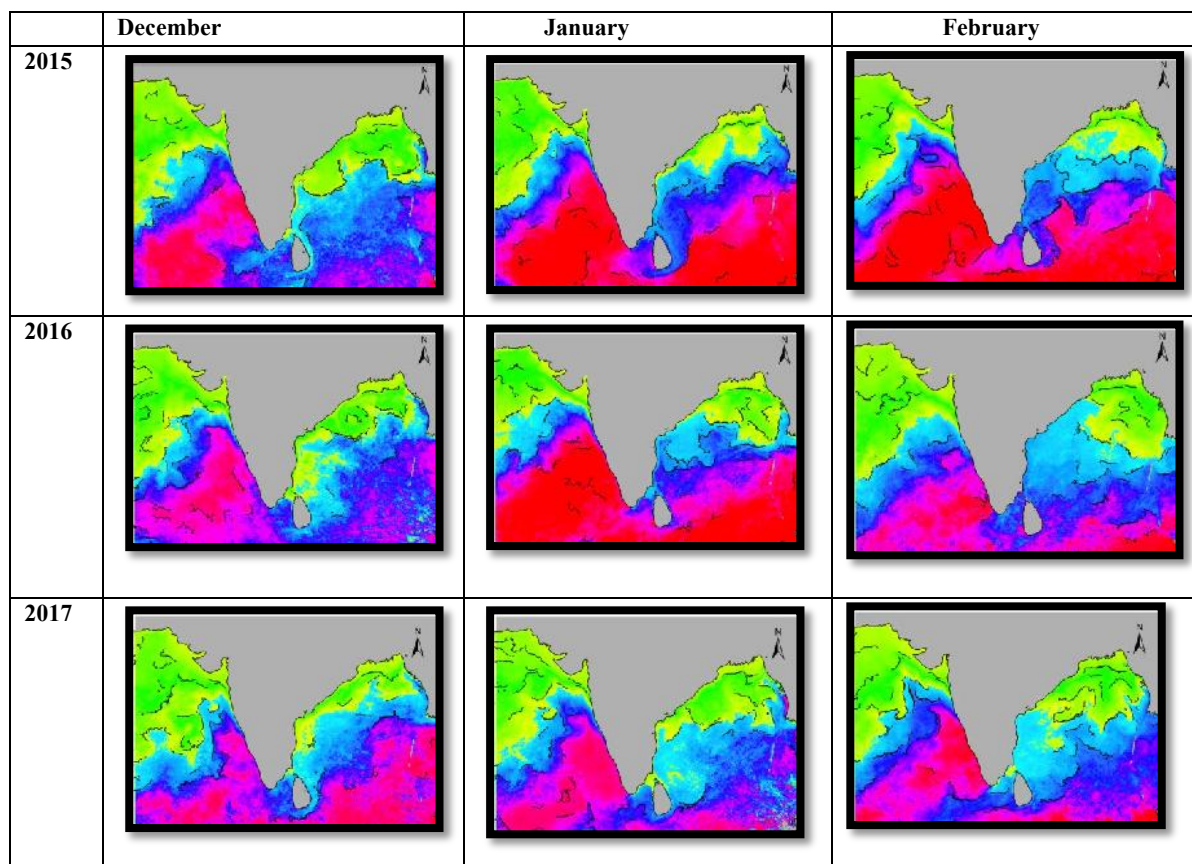


Figure 7. Thermal fronts overlaid on SST for months December, January and February for the years 2015-2017

4. CONCLUSION

Thermal fronts are one of the important oceanographic phenomena and earlier studies show that the presence of the thermal fronts has an influence on the biological production of the sea. Seasonal variability is assessed based on the seasonal categorization: Summer Monsoon (June, July, August, September), Winter Monsoon (December, January, and February) and Spring season/Pre-Monsoon (March, April, May) and Autumn monsoon/Post-monsoon (October, November). It is observed that thermal fronts exhibit seasonal variability and inter-annual variability. Minimum amount of thermal fronts are found in the summer monsoon months: June to August. With post-monsoon season, the number and length of the fronts increases in both the basins. During the winter monsoon period the rate of formation of thermal fronts increases. Very well developed, long and clustered fronts can be seen in winter monsoon period. February marks the month with highest number of thermal fronts. During spring season/pre-monsoon season also relatively large number of fronts can be seen. South western Arabian Sea also is observed as devoid of thermal fronts in the pre-monsoon period. However, the thermal fronts are concentrated

more in the Arabian Sea than Bay of Bengal during March to May. This indicates that the formation and sustenance of thermal fronts in the Indian Ocean is controlled by the monsoon wind condition which drives the mixing processes in the ocean. During the 3 year period, 2015 has been year with lowest number of thermal fronts and 2016 the year with highest number of thermal fronts.

This study reveals that the biological production in the Indian Ocean is cumulative effects of oceanographic mesoscale phenomenon like thermal fronts in the Indian Ocean. However, the mechanism of high productivity in the Arabian Sea is due to the formation of thermal fronts during winter monsoon enhanced by the effects of winter cooling in the northern Arabian Sea as compared to that of the Bay of Bengal. Another observation about fronts is that they are abundantly found in Arabian Sea compared to the Bay of Bengal.

ACKNOWLEDGEMENTS

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ESTIMATION OF CHLOROPHYLL-A BASED ON SENTINEL-2 MSI AND LANDSAT-8 OLI IN THE NORTHERN COASTAL BAY OF BENGAL

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ABSTRACT

Ocean color remote sensing has facilitated the estimation of surface chlorophyll-*a* concentration (Chl-*a*). Accuracy of the estimated Chl-*a* mainly depends on the appropriate algorithm selection for its retrieval. In the present study, we assess and intercompare the Chl-*a* product in the northern coastal Bay of Bengal generated using the bands of two relatively new sensors: Operational Land Imager (OLI) onboard Landsat-8 and Multi Spectral Instrument (MSI) onboard Sentinel-2. OLI and MSI level 1 data for one year (2017) is atmospherically corrected and then suitable band algorithms are applied using ArcGIS. We have used two ocean color algorithms OC-2 and OC-3 for Chl-*a* mapping and inter comparison between the sensors. OC-2 and OC-3 are standard algorithms well validated for case 2 waters. The variability of Chl-*a* in winter, pre-monsoon and post-monsoon seasons over the study region are inter-compared. Preliminary results reveal that the retrieved Chl-*a* varies significantly for the two algorithms, even though overall features identified using both the sensors are similar. It is observed that during winter monsoon, OLI on Landsat-8 is overestimating the Chl-*a* and during pre-monsoon and post-monsoon season, MSI on Sentinel-2 is over estimating Chl-*a*. This work is a preliminary step towards estimation of Chl-*a* in the coastal ocean in high resolution.

KEYWORDS: Chlorophyll-*a*, MSI, OLI, OC-2, OC-3, Northern coastal Bay of Bengal.

1. INTRODUCTION

Ocean color is determined by the incident light interactions with substances or Chlorophyll-*a* (Chl-*a*) present in the water. Phytoplankton forms one of the most important factor determining the ocean color. Chl-*a* pigment is indicative of the presence of phytoplankton. Satellite ocean color data has aided in estimating the near surface phytoplankton indirectly using Chl-*a* for studying the spatial and seasonal variability for decades. This has helped in understanding the primary ocean productivity and also in the study of several biological cycles and fisheries research. Tracing of Chl-*a* has been a major concern since 1970's that started with Coastal Zone Color Scanner (CZCS) sensor onboard Nimbus-7 satellite (sensing period from 1978-1986) (Evans and Gordan, 1994; Acer, 1994). Ocean color remote sensing has progressed with the advent of various new sensors to which Operational Land Imager (OLI) and Multi Spectral Instrument (MSI) are added in recent years. OLI onboard of Landsat-8 has a spatial resolution of 30 m and MSI onboard of Sentinel-2 has a spatial resolution of 10 m. Landsat-8 and Sentinel-2 have a near coast revisit period of 16 days and 5 days respectively near coast. These new sensors have improved the mapping of ocean constituents. It is required to assess the bio-optical algorithms for an efficient retrieval of Chl-*a* to enhance the accuracy of ocean phytoplankton biomass content (Chauhan et al., 2002). Several bio-optical algorithms have been developed in past years for detection of Chl-*a* globally and for different kinds of water.

Analysis of Chl-*a* has been carried out using both the sensors with the standard global Chl-*a* algorithms: OC-2 and OC-3. The study has been limited to the usage of these two algorithms that has been found suitable for the dynamic waters of northern coastal Bay of Bengal amongst a number of retrieval algorithms. Northern coastal Bay of Bengal comprises of the Hooghly estuary. The Hooghly estuarine water has a dynamic nature due to the intermixing of the fresh water and marine water accommodating diverse phytoplankton communities (Rakshit et al., 2014). Table 1 presents the list of bands and spatial resolution of the various bands used in different algorithms.

The main objective of this paper is to inter-compare the sensor performance of OLI and MSI in estimating the Chl-*a* in the dynamic waters of the northern coastal Bay of Bengal. Sentinel-2 MSI is a very high-resolution sensor that can be used to estimate Chl-*a* in waters with high suspended sediments and dissolved organic water. Earlier studies have shown higher values of Chl-*a* for northern coastal Bay of Bengal but accuracy has been susceptible to low sensor resolution and environmental conditions like cloud cover. Scarce field observations have restricted the validation of remotely sensed Chl-*a* in this region. Landsat-8 OLI is a well validated sensor that has been taken as a standard for the study. The study is based on estimating the correlation between OLI and MSI and assessing the bias in their performance in estimating Chl-*a* using OC-2 and OC-3 algorithms.

Table 1: Band resolution and wavelengths of OLI and MSI.

OLI		MSI	
Central Wavelength (nm)	Spatial Resolution (m)	Central Wavelength (nm)	Spatial Resolution (m)
443	30	443	60
482	30	490	10
562	30	560	10

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2. DATA AND METHODOLOGY

2.1 Data

Sentinel 2 is a European wide-swath, high-resolution, multi-spectral imaging mission having a revisit period of 5 days. Cloud free Sentinel-2 MSI (level 1C) data of very high spatial resolution of 10 m is collected from <https://scihub.copernicus.eu/> for the entire year of 2017 covering different seasons. Landsat 8 is an American Earth observation satellite having a revisit period of 16 days. Cloud free images for Landsat-8 OLI pertaining to corresponding months as that of MSI is selected to analyse the seasonal variability of Chl-a as well as the inter comparison of the same algorithms for the two sensors. OLI (Level 1) data is collected from <https://earthexplorer.usgs.gov/>.

Inter-seasonal variations in Chl-*a* is studied from the data products representing each season. Due to cloud cover there was an unavailability of data during the monsoon season for the study period and hence it is not included in the analysis. For intercomparison of sensors, data of the corresponding months and nearby dates were chosen. OLI data for December 2013 and March 2014 has been used for validation with Coastal Ocean Monitoring and Prediction System (COMAPS).

2.2 Study Area

Data is obtained for the study area lying in the region 20°47'44.062'' N-21°40'59.754'' N and 87°28'36.323'' E-89°1'13.385'' E (Figure 1). Mouth of river Hooghly is very dynamic in nature having a lot of sediment content due river runoff that essentially brings nutrients like nitrates and phosphates with it which favours the growth of phytoplankton.

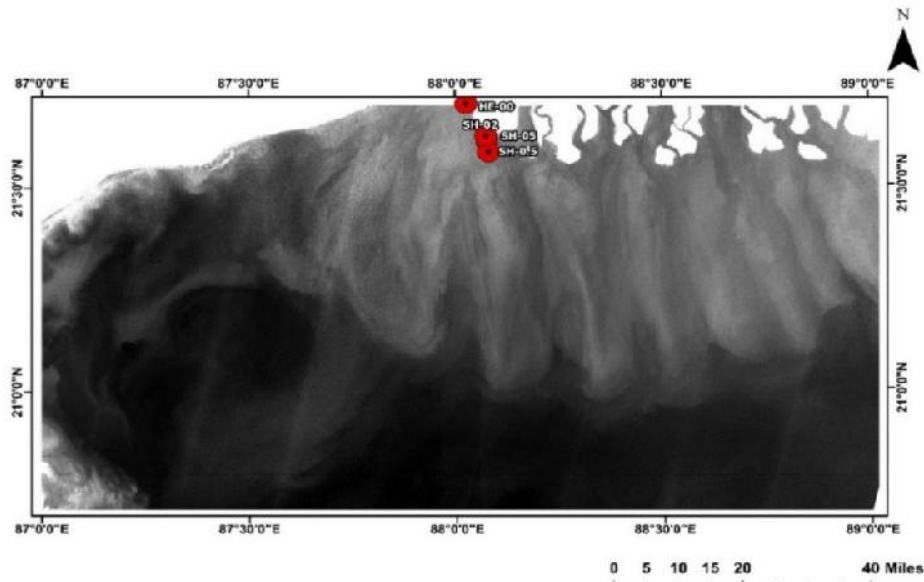


Figure 1: Study area map showing northern coastal Bay of Bengal. The locations of the COMAPS data stations used for the validation are also shown in the map.

2.3 METHODOLOGY

Landsat-8 Level-1 data product consists of quantized and calibrated scaled Digital Numbers (DN) representing the multispectral image while Level 1 images obtained from MSI is in the top of the atmosphere (TOA) reflectance. Data products are converted to remote sensing reflectance (R_{rs}) applying atmospheric correction and dark object subtraction (DOS). DOS is an image based atmospheric correction method which assumes that within the image there are some pixels in complete shadow and whose radiances received by the satellite are due to the atmospheric scattering. This assumption is combined with the fact that very few substances in this Earth are absolute black. So, an assumed 1% minimum reflectance is better than 0% as explained by Chavez (1996). The data products of both the sensors are initially processed in QGIS software using the semi-automatic classification plugin that converts the products into bottom of the atmosphere reflectance or surface reflectance. Semi-automatic classification plugin is an open source free plugin that can be readily downloaded and installed in QGIS. It provides several tools for the download of free images (Landsat, Sentinel-2, Sentinel-3, ASTER, and MODIS), the pre-processing of images, the post processing of classifications, and the raster calculation. It first converts the DN values to TOA radiances and then the TOA radiance to TOA reflectance which is then converted to surface reflectance.

Landsat-8 level 1 products are converted to TOA radiance and TOA reflectance using the radiance and reflectance rescaling factors in the MTL file (<https://landsat.usgs.gov/using-usgs-landsat-8-product>). TOA reflectance is converted to surface reflectance using the equation (Moran et al, 1992):

$$\rho = [\pi * (L_{\lambda} - L_p) * d^2] / [T_v * ((E S U N_{\lambda} * \cos \theta_s * T_z) + E_{down})] \quad (1)$$

where ρ is surface reflectance
 L_p is the path radiance
 T_V is the atmospheric transmittance in viewing direction
 T_Z is the atmospheric transmittance in the illumination direction
 E_{down} is the downwelling diffuse irradiance

Rrs can be obtained from surface reflectance using the following equation (Moses et al, 2015):

$$Rrs(\lambda) = \rho/\pi \quad (2)$$

The Rrs obtained for the bands is then used in the bio optical algorithms for retrieval of Chl-a.

2.4 Empirical Algorithms

Several bio-optical algorithms have been developed in the past few decades but the main challenge lies in identification of the most suitable algorithm for the accurate retrieval of Chl-*a*. Identification of the proper coefficients for the algorithm in dynamic waters like the estuary has been difficult as the rivers bring in a lot of sediments which interact with light affecting the quality and accuracy of parameters retrieved. Out of the many algorithms available, two popular and widely used bio-optical ocean chlorophyll (OC) algorithms are selected for the present study, namely OC-2 and OC-3. The OC-2 is a modified cubic polynomial algorithm which was developed for the SeaWiFS data and tuned to the SeaBAM data has been used for the present study (Reilly et al, 1998). OC-3 algorithm, proposed by Morel and Maritorena (2001), has been used to retrieve low as well as high Chl-*a* hence making it useful for case 2 waters like estuarine regions. In this work, OC-2 and OC-3 algorithms are used with the suitable nearest band ratio combination of the two sensors. Table-2 shows the two algorithms used in the present study and their band ratios and coefficients.

Table 2: Details of the empirical algorithms used for the study.

Algorithm	Equation	Band Ratio and Coefficients
OC-2	$C=10^{(a0+a1*R+a2*R^2+a3*R^3)+a4}$	$R=\log(Rrs\ 490/Rrs\ 555)$ $a=[0.341,-3.0010,2.811,-2.041,0.040]$
OC-3	$C=10^{(a0+a1*R+a2*R^2+a3*R^3+a4*R^4)}$	$R=\log((Rrs\ 443 > Rrs\ 488)/Rrs\ 555)$ $a=[0.283,-2.753,1.457,-0.659,-1.403]$

3. RESULTS AND DISCUSSION

3.1 In-situ validation of Chl-*a* from LANDSAT OLI

In-situ data from Coastal Ocean Monitoring and Prediction System (COMAPS) programme under Ministry of Earth Sciences, Government of India is used to validate Chl-*a* estimated from OLI. Due to the unavailability of COMAPS data after 2014, validation of Chl-*a* estimated from MSI is not done. COMAPS Water Quality Management Protocol (2012) describes the data collection techniques and norms followed during the data collection programme. In-situ locations shown in the study area map (Figure 1) are used for OLI validation for December 2013 and March 2014. Results shows that the Chl-*a* retrieved using OC-2 algorithm has a correlation of 0.7954 and Chl-*a* retrieved using OC-3 algorithm has a correlation of 0.7856. Chl-*a* retrieved using OC-2 has a very low bias of 0.3596 mg/m³ while bias obtained using OC-3 is 1.0629 mg/m³. RMSE for OC-2 and OC-3 is 0.7375 and 1.2374 mg/m³ respectively. This validation shows that OC-2 algorithm estimates Chl-*a* precisely than OC-3 for OLI.

3.2 Estimation of Chl-*a* using OC-2 algorithm

Chl-*a* estimated using OC-2 algorithm from OLI and MSI for three different seasons: pre-monsoon, post-monsoon and winter monsoon seasons (Figure 2). The months April, November and January are considered as the representative months for pre-monsoon, post-monsoon and winter monsoon respectively. During pre-monsoon, OLI Chl-*a* is low (<3 mg/m³) along the study region. In post-monsoon season the Chl-*a* in the northern Bay increases to 4.5 mg/m³. Further increase can be noted in the Chl-*a* (>5 mg/m³) in the winter monsoon season. However, maps of MSI derived Chl-*a* shows higher values in the northern Bay of Bengal for the pre-monsoon and post-monsoon seasons (~10 mg/m³). During post-monsoon the distribution pattern of the Chl-*a* is similar to that of the OLI derived Chl-*a*, but MSI overestimates the Chl-*a*. During winter monsoon season, it is observed that a strong algal plume near the mouth of Hooghly is detected by OLI with Chl-*a* >5 mg/m³ while the values traced by MSI for the same plumes varies up to 4.5 mg/m³ showing a less intense plume. Thus, MSI underestimates Chl-*a* during winter monsoon. MSI maps high Chl-*a* >5 mg/m³ uniformly throughout the study period near the coast while OLI records up to 4 - 4.2 mg/m³.

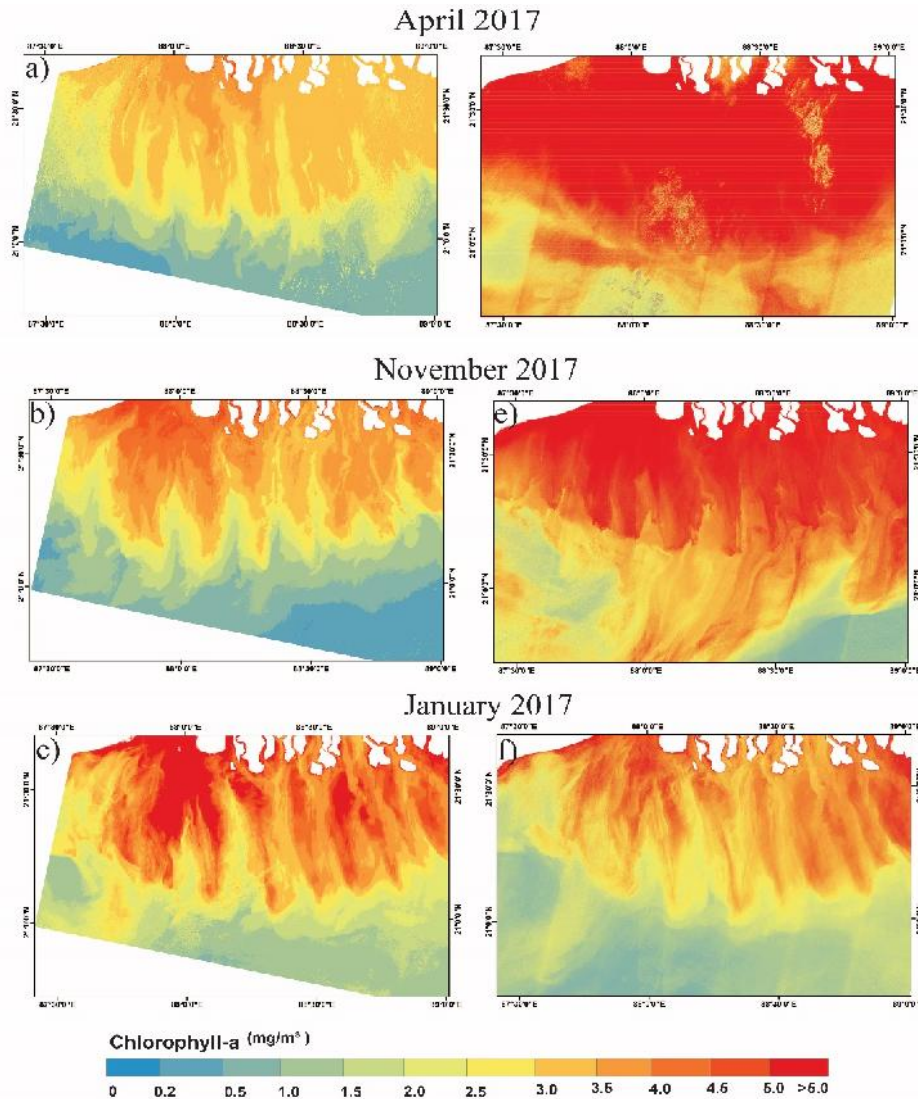


Figure 2: Intercomparison of Chl-*a* derived using OC-2 algorithm. Figures 3a, 3b and 3c represent the maps for OLI, and 3d, 3e and 3f for MSI sensor, representing 3 seasons.

The metrics of the statistical analysis performed using OC-2 and OC-3 algorithms for retrieving Chl-*a* is shown in Table 3. Correlation coefficient (*r*), bias and root mean square error (RMSE) has been computed for OC-2 and OC-3 algorithms.

Table 3. Descriptive statistics of the Chl-*a* measured for OC-2 and OC-3 algorithms.

MONTH	OC-2			OC-3		
	<i>r</i>	bias	RMSE	<i>r</i>	bias	RMSE
April	0.4381	3.0946	3.3677	0.4563	2.1450	2.3213
November	0.8338	1.6008	1.7380	0.8340	1.1666	1.2770
January	0.8739	-0.4553	0.7717	0.8864	-0.3277	0.5449

Scatter plots of MSI and OLI plotted for OC-2 algorithm showing the linear regression line and the equation for it (**Figure 3**). Statistical analysis showed that highest correlation (0.8739) between MSI and OLI is observed during the winter monsoon with a negative bias of -0.4553 mg/m³. RMSE is the lowest during the winter monsoon. It is observed that the least correlation of 0.4381 exists during the pre-monsoon with the highest bias of 3.0946 mg/m³ and highest RMSE of 3.3677 mg/m³. MSI has a good correlation of 0.8338 with OLI for the post-monsoon season with a moderate bias of 1.6008 mg/m³ and RMSE of 1.7380 mg/m³. Thus a strong seasonal variability can be observed in the OLI Chl-*a* maps using OC-2 algorithm.

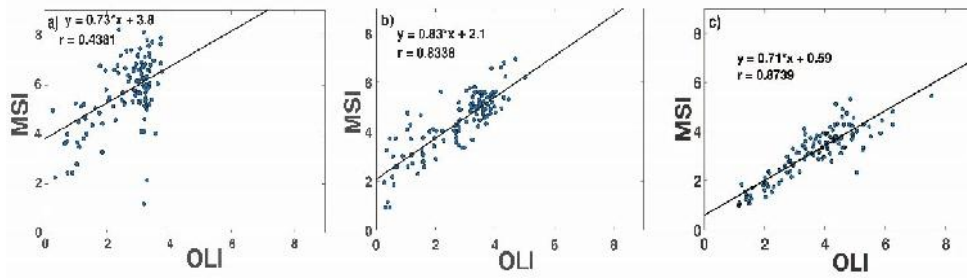


Figure 3. Scatter plots of the MSI versus OLI for OC-2 algorithm for a) pre-monsoon, b) post monsoon and c) winter monsoon respectively during 2017.

3.3 Estimation of Chl-*a* using OC-3 algorithm

The Chl-*a* estimation using OC-3 algorithm for OLI and MSI is shown in Figure 4. In general, it can be observed that the values of Chl-*a* in any season is underestimated when compared to Chl-*a* derived from OC-2 algorithm for both OLI and MSI. The chlorophyll plume observed during the winter monsoon is less intense for MSI than OLI. Pre-monsoon Chl-*a* for OLI ranges from moderate to low values (up to 3 mg/m³) while on a contrary extremely high values (>5 mg/m³) are observed for MSI. The spatial distribution of Chl-*a* is different for both the sensors. Moderate values of Chl-*a* (<4 mg/m³) is observed near the Hooghly river mouth and towards the extreme eastern part of the study area while a continuous distribution (with value up to 4.5 mg/m³) is observed for MSI. It can be observed that MSI Chl-*a* overestimates OLI Chl-*a* during pre and post monsoon seasons and underestimates OLI Chl-*a* during winter monsoon.

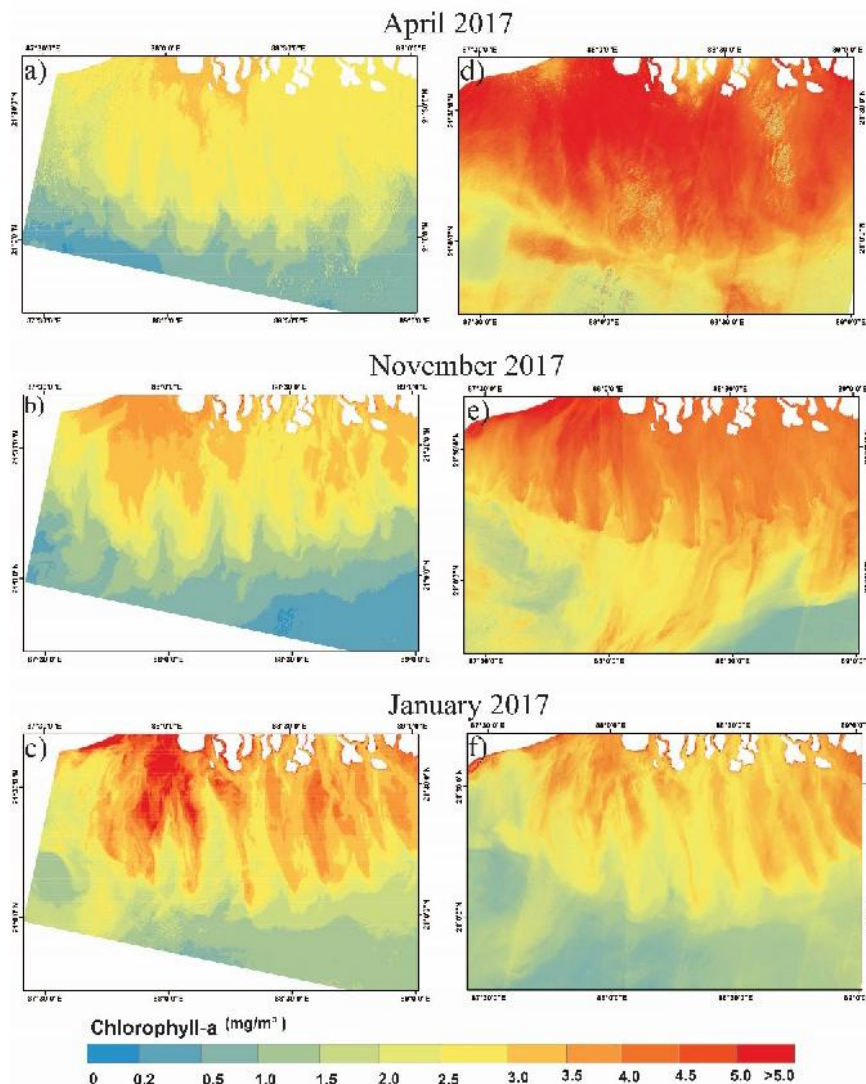


Figure 4. Intercomparison of Chl-*a* derived using OC-3 algorithm. Figures 4a, 4b and 4c represent the maps for OLI, and 4d, 4e and 4f for MSI sensor, representing 3 seasons.

Scatter plots of MSI and OLI obtained for OC-3 algorithm is shown in Figure 5 along with the linear regression line and equation for each scatter plot. Largest correlation obtained between the sensors is for the winter monsoon (0.8864) with a negative bias (-0.3277 mg/m³) and the least RMSE. It is observed that the least correlation of 0.4563 is found during the pre-monsoon with a highest bias and RMSE of 2.1450 mg/m³ and 2.3213 mg/m³ respectively. A moderate bias and RMSE of 1.1666 and 1.2770 mg/m³ respectively with a good correlation of 0.8340 is obtained for post-monsoon.

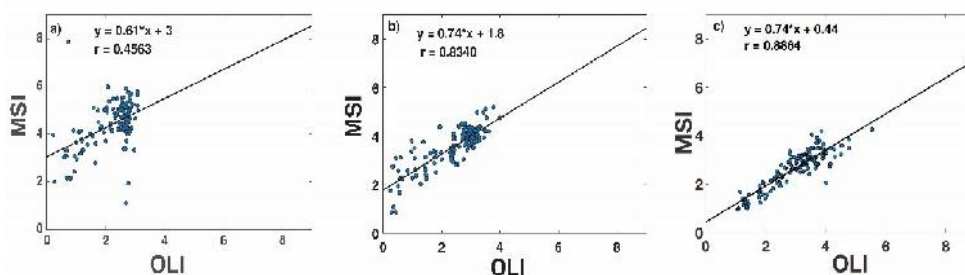


Figure 5. Scatter plots of the MSI versus OLI for OC-3 algorithm for a) pre-monsoon, b) post monsoon and c) winter monsoon respectively during 2017.

The analysis also shows that the mouth maps high values of Chl-*a* throughout the year and the Chl-*a* values decrease on moving off-shore. Chl-*a* values as high as 5 mg/m³ is observed near the estuarine mouth with some variability with the seasons. Very low Chl-*a* (< 1.5 mg/m³) is noticed off-shore almost throughout the year in case of both the sensors. Spatial variability of Chl-*a* for both the sensors is similar despite the sensor resolutions.

4. CONCLUSION

The above work is a preliminary approach towards the intercomparison of the performance of the two new high-resolution sensors OLI on board Landsat-8 and MSI on board Sentinel-2 for Chl-*a* retrieval using two different band ratio algorithms. The preliminary results show a strong co-relation between MSI and OLI for all the seasons except for pre-monsoon for both the algorithms. Extensive study with the use of in-situ data for the estuarine waters is needed to conclude the best performance of the sensors. Initial validation shows that OC-2 algorithm is best suitable for the northern coastal Bay of Bengal with a relatively lower bias (0.3596 mg/m³) for OLI. Intercomparison of sensors showed that best correlation exists during the winter monsoon for both the algorithms while the least exists for pre-monsoon. Spatial variability of Chl-*a* is well observed when MSI is compared to OLI. Chl-*a* values differ in case of both the sensors owing to difference in the sensor resolution and difference in data acquisition dates. Satellite pass over the area is affected by cloud cover which might result in the difference in amount of Chl-*a*. Hence, it can be concluded from the study that MSI has a strong correlation with OLI for all the seasons except for the pre-monsoon for OC-2 and OC-3 algorithms. Chl-*a* traced using OC-3 algorithm shows lower values for the same sensor and date as done using OC-2.

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GEOMETRIC QUALITY ASSURANCE FOR PRECISE RISAT-1 C-BAND SAR IMAGES ACQUIRED IN DUAL POLARIZATION

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ABSTRACT

RISAT-1 launched by ISRO in April 2012 operated in three fundamental modes i.e. Fine Resolution Stripmap (FRS1 and FRS2), Medium and Coarse Resolution ScanSAR (MRS and CRS) and High-Resolution Spotlight (HRS) modes. These modes differ in terms of imaging resolution (1–50 m) and swath coverage from 10-225 km. MRS is a 6-beam ScanSAR mode data, providing a resolution of 18 m with qualified swath of 115 km. RISAT-1 has the capability to acquire data in $12^0 - 55^0$ incidence angle range resulting in varying imaging geometry. Digital elevation Model accuracy and ephemeris errors manifest themselves in different magnitudes and affects the final geometric accuracy of the products. During SAR processing these errors are corrected by different algorithms, registered with LANDSAT-7 ETM PAN data (optical sensor data) and these residual geometric errors are corrected to achieve the accuracy of the order of one pixel. With this process, such precise product, referred as reference images, are generated using RISAT-1 MRS data covering Indian landmass and subjected for independent evaluation & qualification. During geometric quality assurance & qualification procedure, these reference images are evaluated using well-established Data Quality Evaluation Software (DQES) system consisting of pre-processing, reference selection, control point identification on optical & SAR images in semi-automatic mode resulting into error statistics & qualification report. The geometric parameters, which are computed by evaluation software system are geo-location accuracy, scale variation and internal distortion. The statistics generated for these parameters is in terms of, mean, root mean square, standard deviation and Circular Error - 90. The control points are taken from LANDSAT-8 Optical Land Imager (OLI) BAND-8 images with a resolution of 15m. The qualification criteria for a given reference image area is that the mean geo-Location error is better than one pixel and variation in geo-Location (internal distortion) should be within 1.5 pixel. Total 346 reference images are processed and geometric quality parameters are computed. Geo-location accuracy for all images is well within ± 10 meters, which is within a pixel in both directions (azimuth and range). All 346 MRS reference images are qualified and can be effectively used as ground reference in SAR data ground processing.

KEYWORDS: Synthetic aperture RADAR, Medium Resolution ScanSAR, Geo location, internal distortion, reference image, data processing

1. INTRODUCTION

Quality Evaluation and assurance of a final user product is a very important part of mission management for remote sensing satellites. Data Quality Evaluation (DQE) is an established element of ground processing for all earth observations satellite of ISRO (Palsule et al., 2008). DQE system has matured over the years in terms of tools, techniques and procedures it follows over the last three decades and has become an essential sub-system of the whole Indian Remote Sensing (IRS) mission operations. One of the major feedbacks it provides to the mission is the geometric quality of the acquired imagery, which is produced by the Data Products Generation Software (DPGS). The DQE system has to utilize the accurate ground references for evaluating data products for determination of absolute accuracy achieved. Hence, the major requirement for the computation and quantification of DQE geometric parameters is the availability of ground reference, which gives accurate information about location, in terms of latitude, longitude and height, on the Earth surface. To meet the requirement of accurate ground reference, concept of reference image was introduced by DQE from IRS-P6 operations at NRSC, ISRO. Reference image is defined as a product / image whose geo-location accuracy is within a pixel of output resolution.

Radar Imaging Satellite-1 (RISAT-1) launched in April 2012 operated in three fundamental modes i.e. Fine Resolution Strip Map (FRS1 and FRS2), Medium and Coarse Resolution ScanSAR (MRS and CRS) and High-Resolution Spot Light (HRS) modes (Mishra et al., 2013). During the DQE operations of this SAR mission, reference images generated from optical data were used as ground reference. The ground control identification interactively in SAR data with reference to optical data is very difficult due to different type of radiometry. Hence, a need is felt to generate reference images using RISAT-1 data, which can be effectively used for future SAR missions. SAR Data Products team generated reference images (terrain corrected, geo referenced) using RISAT-1 MRS data, covering Indian landmass, and subjected to DQE for assessing the geometric accuracy (qualification). The key objective of this work is to independently evaluate the quality and assure the reference images generated from the RISAT-1, C-band MRS Level-2 ortho-rectified data over Indian region. This paper presents methodology followed for computing and assuring the Geometric Accuracy, in terms of Location Accuracy and Internal Distortion, of said reference images.

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2. DATA PRODUCTS FOR REFERENCE IMAGE

The SAR processor generates terrain corrected geo-referenced products using RISAT-1 data acquired in MRS mode, covering Indian Landmass (Figure 1). The products used in this work are Level-2 Ortho-rectified, projected in UTM map projection and WGS-84 datum with 18m output resolution in GEOTIFF format. Two auxiliary files for layover mask and local incidence angle are also provided with the products. The information in the two auxiliary files are described below (Mehra et al., ?).

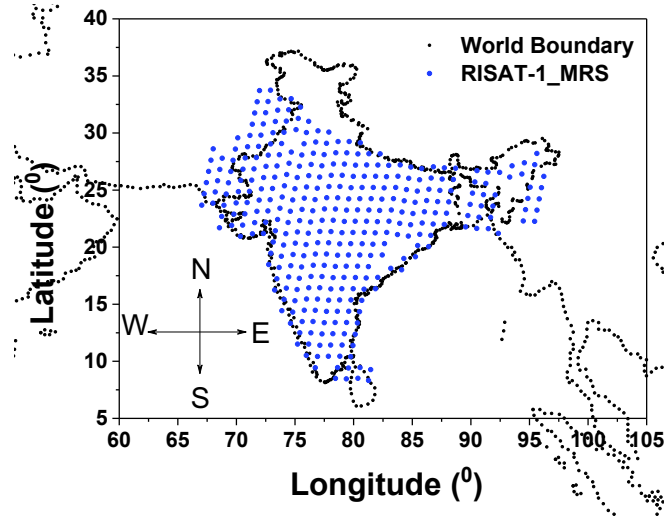


Figure 1: Coverage of MRS Reference Image

2.1 Local Incidence Angle Map file

The angle of Incidence is defined as the angle between the radar line of sight and the local vertical at the point where radar beam intersects the earth's surface. For its determination, it is necessary to know the slant range vector and the local surface normal vector. Topography has an impact in changing the nominal incidence angle i_0 (without topography) to i_t (with topography). Local incidence angle for each pixel of the geo-referenced SAR scene is provided with the L2A product as a GeoTiff in degrees. The definition of Local incidence map is given in Table 1, where the value between 0 to 90 suggests valid incidence angle and in SAR image these are known as Region 'A'; value equals to -1 suggest invalid value and is the masked region in the SAR image as 'B' and the value equals to -2 is the region which is outside the Geo-Referenced image and is given the name Region 'C'.

Table 1: Definition of Local Incidence Angle Map

Value	Significance	Region
0 to 90	Valid Incidence angle Range	(A)
-1	Invalid Value (Masked region from Layover mask file)	(B)
-2	Region Outside Geo-Referenced Image	(C)

2.2 Layover Mask file

Areas of SAR layover are determined via the slant range distance, which in general increases for a scan line from near to far range. Layover occurs as soon as the slant range reaches a turning point and decreases when tracking a scan-line from near to far range. Layover information for each pixel of the geo-referenced SAR scene is provided with the L2A product as a GeoTiff file. Definition of layover mask file is tabulated in Table 2. Similar to local incidence angle map, here also regions are identified. Value 128 indicates the undistorted region of image and is termed as 'A', distorted non-usable region is termed as 'B' and is given value 16 whereas, value equals to '0' is the region outside the georeferenced image and is region 'C'.

Table 2: Definition of Layover Mask

Value	Significance	Correspondence with Local Incidence angle map
128	Undistorted usable region in Image	(A)
16	Distorted Layover Region in Image (Not to be used for further analysis)	(B)
0	Region Outside Geo-Referenced Image	(C)

The brief description of the MRS data used for reference qualification is given in Table 3 and the ground coverage information is shown in figure 1 in a grid of $1^0 \times 1^0$.

Table 3: RISAT-1 MRS data product information for Reference Image Qualification

Sr. No.	Parameters	Description/Value		
1.	Satellite/Mode	RISAT-1/MRS		
2.	Number of Orbits	30		
3.	No of Scenes	400		
4.	Swath	115 Km		
5.	Generation Date	June 2017		
6.	Beam Numbers	87 to 97		
7.	Node	Descending		
8.	Look Direction	Left (West Looking)		
9.	Range Look	2	Azimuth Look	1
10.	Product Type	L2A-Enhanced-Georeferenced in GeoTIFF Format		
11.	Polarization	HH and HV		
12.	Time Period of Data acquisition	27 Days (3 days-Sep 2013; 8 days-Oct 2013;15 days-Nov 2013) and 9 scenes of 29-May 2014		
13.	Resolution Along	24 m	Resolution across	18.71 m
14.	Output Line and Pixel spacing	18 m		
15.	Map Projection	UTM		
16.	Incidence Angle Center	~36.7 to 36.9		
17.	Look Angle	~29 ⁰ to 30 ⁰		
18.	DEM Source	CARTO-1 and CUSTM		
19.	Terrain height applied	True Height		

3. QUALIFICATION METHODOLOGY FOR SAR-MRS PRODUCTS

SAR-MRS products, referred here as reference Images, are qualified by using Landsat-8 OLI (15m) images as ground reference. For qualification of each product following major steps are performed:

3.1 Pre-processing

Data product is extracted from given format (Geo-Tiff) into DQE specific required structure having meta-file and binary image files. Meta-file contains ancillary information about the product (Kartrikeyan and Vaghela, 1999).

3.2 Reference selection

For given product, based on corner coordinates/geometry, the reference images (L-8 OLI) are fetched from DQE reference database. The number of scenes of L8-OLI over Indian region used for qualification is shown in Figure 2, and defined in Table 4.

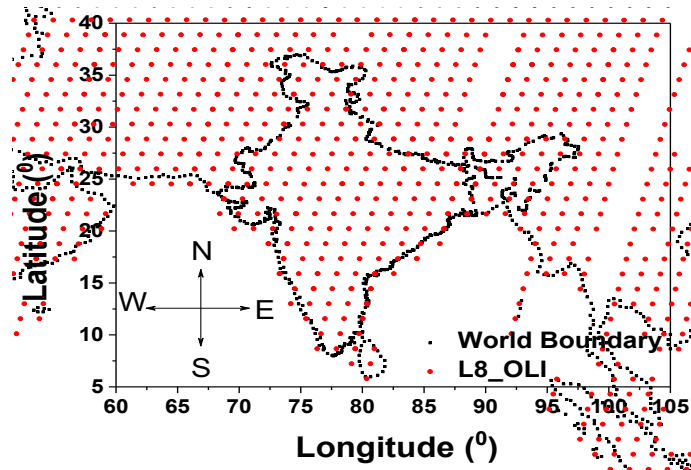


Figure 2: Landsat-8 OLI (15m) Reference Coverage in DQE Database

Table 4: DQE Ground Reference for SAR-MRS Qualification

Satellite	Sensor	Resolution	Projection	No of scenes used
Landsat-8	OLI (Band-8)	15m	UTM	400

3.1. Control point identification on Optical & SAR images

Control points (CPs) required for error estimation are identified semi-automatically as shown in flow diagram Figure 3.

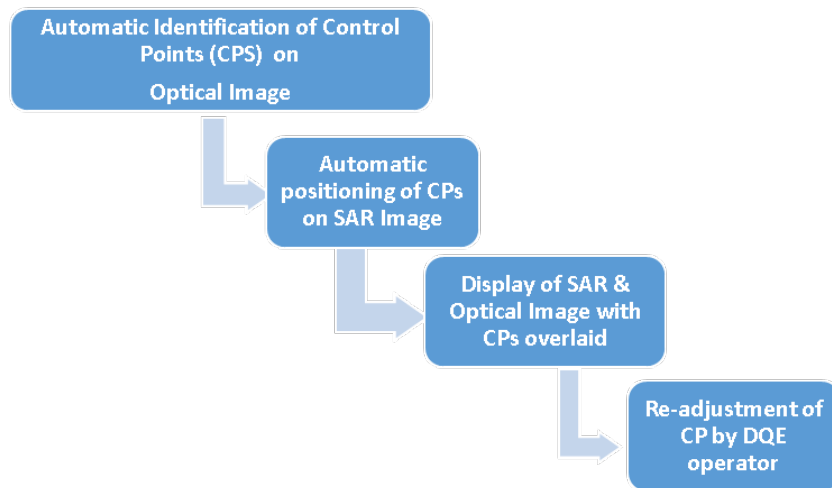


Figure 3: Feature Identification on Optical & Matching on SAR-MRS image for reference qualification

Feature points (ground control points) are identified automatically on the optical image (reference-L-8 OLI) by Triangulated Control Point (TCP) detection approach [5]. High contrast features (corners) in optical image are identified by correlation score with Corner mask library. Some of the identified features are shown in Figure 4.

Ground Control Points (or GCPs), whose geographic coordinates are precisely known in terms of its latitude, longitude and height are conventionally used during image correction process and also for evaluating the corrected image for its geometric accuracy. However, since number of GCPs are limited and also due to possibility of some GCPs being occluded by clouds, additional control points or TCPs are acquired on an image once it is processed, so that other images over the same area can use these additional control points for processing and/or evaluation. TCP, here is defined as a feature on image whose geometric coordinates are known, which may or may not be features marked on a topographic map. TCP concept was first introduced in Cartosat-1 data processing.

TCPs are detected on L-8 optical image based on multi-resolution analysis of image. Detection process starts at the reduced resolution image (by factor of 8), where significant features (having high variance score) are detected. Chips around detected locations are extracted and correlated with a corner mask library. Corner mask library contains masks for corners of different orientations and angles. Location of pixel having maximum response to corner mask is considered as rough location of TCP in chip. This rough location is refined by applying mask library to neighborhood in the next higher resolution iteratively till precise location of TCP is located. The detailed technique is described in [5]. Some of the identified TCPs are shown in Figure 4.

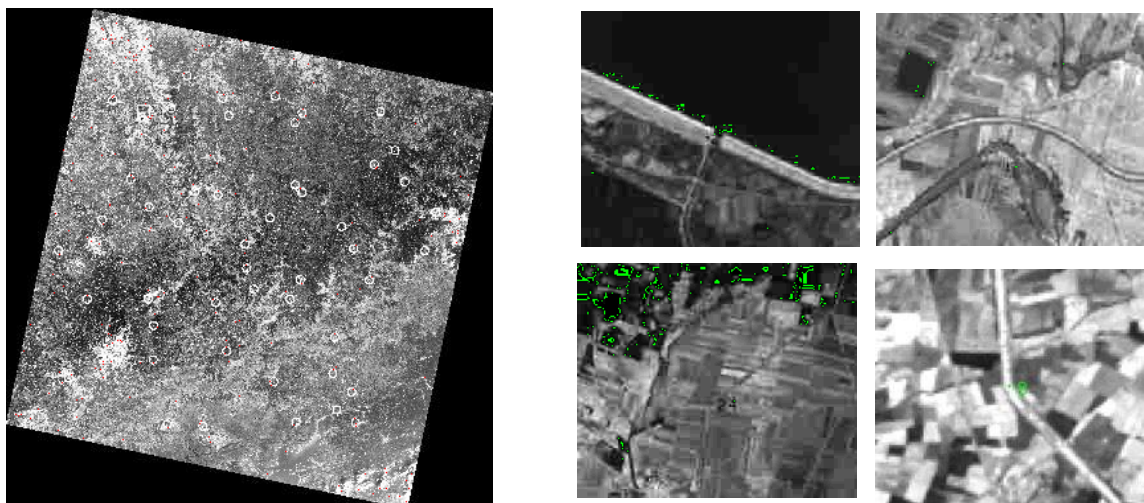


Figure 4: (a) Features identified on L-8 scene (b) Types of features automatically identified in optical (L-8 Reference) image

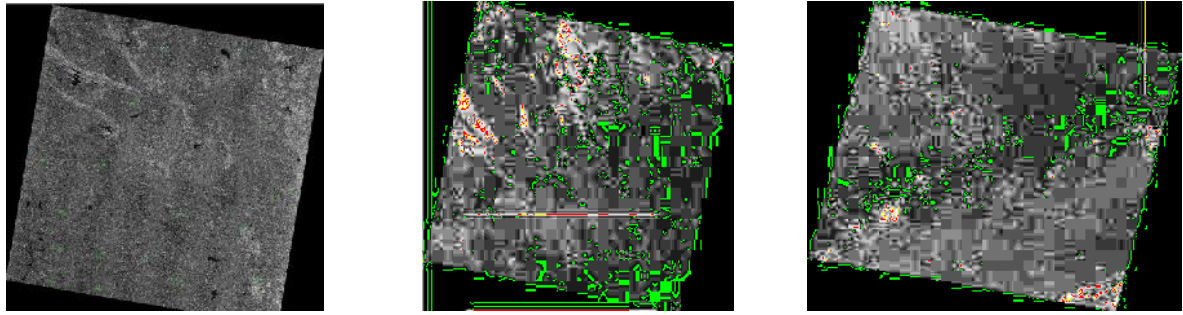


Figure 5: (a) Mapped points on SAR-MRS Image (b) L-8 (Top) Scene (c) L-8 (Bottom) Scene

All identified features are automatically positioned on SAR-MRS image using the geometry information. Figure 5(a) shows the SAR-MRS image having ~ 20 points and Figure 5(b) and 5(c) show two L-8 images from adjacent rows covering the SAR-MRS scene. SAR & Optical images are shown in an Image Display window (Figure 6) with corresponding feature points overlaid and also shown in a table. DQE operator selects each feature point from the table and re-adjusts point in SAR image if required to match correctly with feature shown in optical image. Controls for re-adjusting, deleting or adding control points are also provided in image display software. Figure 7 shows the Matched feature points in MRS, L-8 Reference Image.

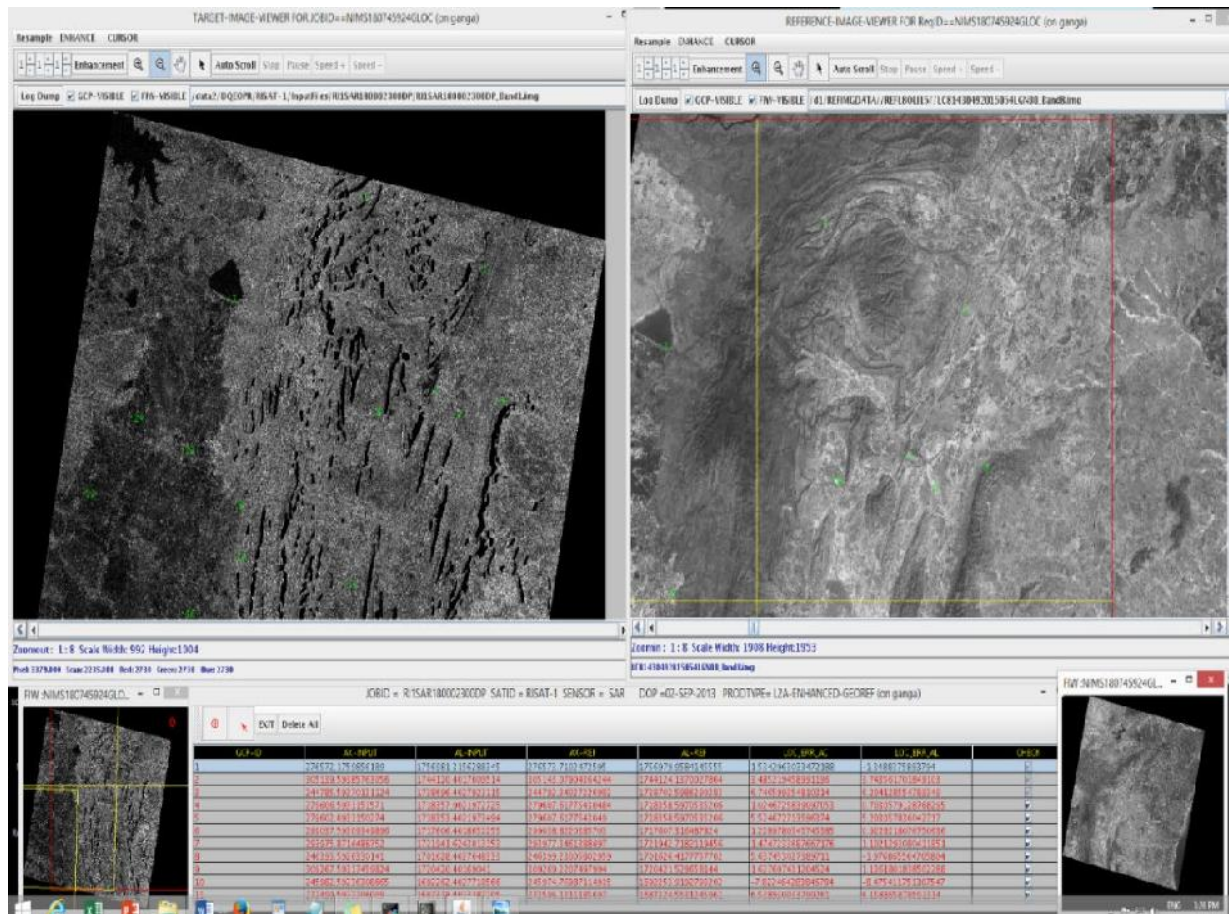


Figure 6: Image Display showing SAR-MRS (Left) & L-8 Reference Image with feature points overlaid

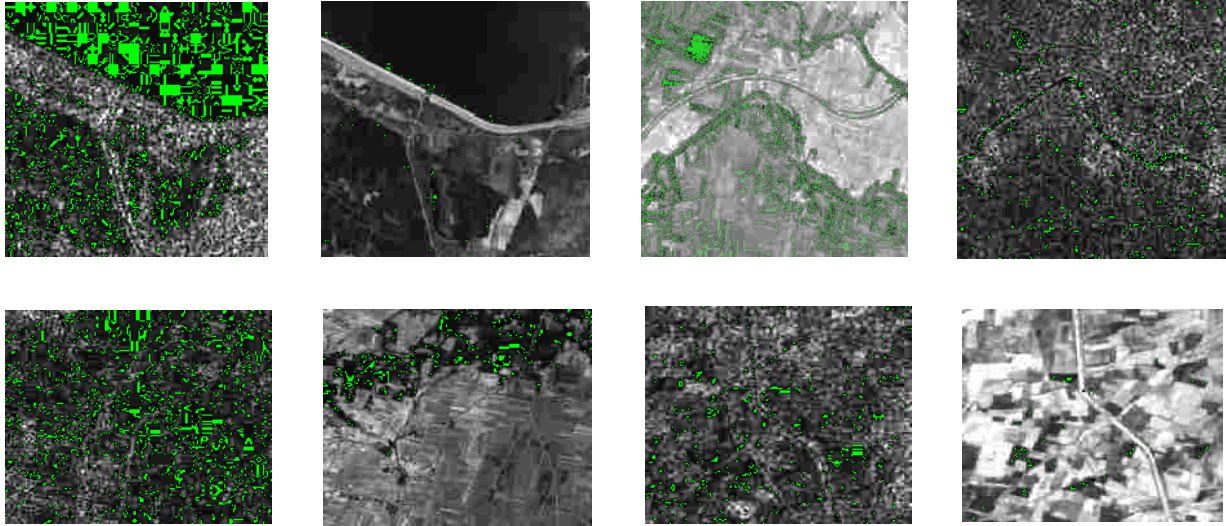


Figure 7: Matched feature points in MRS, L-8 Reference Image

- 3.2. Error statistics:** For a given scene, typically 20-25 well-distributed points are identified. Based on the map-projected feature coordinates (UTM), location accuracy (along/across), internal distortion (along/across) & scale is computed. The summary of statistics carried out in this work is presented in Table 5.
- 3.3. Reference Qualification Criteria:** The RISAT MRS reference images are generated for the proposed work and thereby using it as an authentic ground reference for the geometric accuracy assessment of SAR data products of future missions. It is mandatory that such reference images truly represent the ground. Hence, our qualification criteria is that the mean geo-location error is better than 1 pixel and variation in Geo-Location (internal distortion) should be within 1.5 pixel in a product covering 115 x 115 km area. These are the worst acceptable numbers.

4. RESULTS OF SAR-MRS REFERENCE EVALUATION ANALYSIS

The summary of number of products, qualified products and the error cases is given in Table 6. Total Number of points marked are shown in figure 8 as histogram. Distributed points were marked over the scene. Maximum scenes were marked with 20 to 25 points. This section discusses the DQE observations over these scenes.

Table 6: Qualified Products Summary

Total MRS Products for Qualification	Qualified Products	High Mean Error Cases	Any Other Error
400	346	54	0

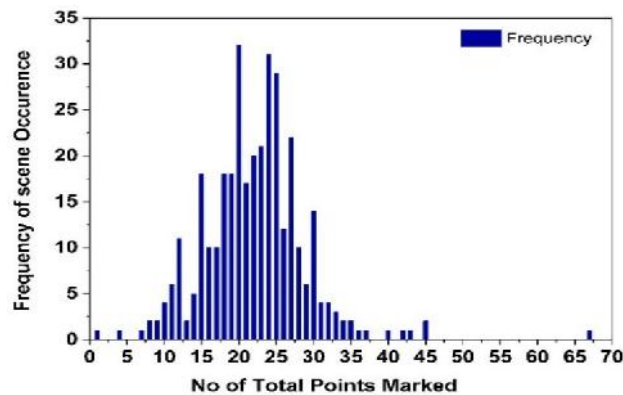


Figure 8: Frequency of Total Number of Points marked in the scenes

- 1. Mean location Accuracy (meters):** The results of the reference qualification is shown in Figure 9. Location accuracy from fig 9(left) suggests that it is well within ± 10 meters which is within a pixel in both directions (Azimuth and Range). DQE criteria is marked with Blue line (± 18 m). The Root Mean Square error in both directions is tabulated in Table 5.

2. **RMS Internal Distortion (pixels):** In both azimuth and range directions, the RMS internal distortion is within 1 pixel except two cases in azimuth which are greater than 1 but less than 1.5 pixels meeting the qualification criteria (Figure 9 right)
3. **Circular Error 90:** The circular error is empirical estimation as 90th percentile of radial error. It is same as radial error of first occurrence of percentile rank > 90. It is observed to be around 5 to 15 meters (Figure 10)

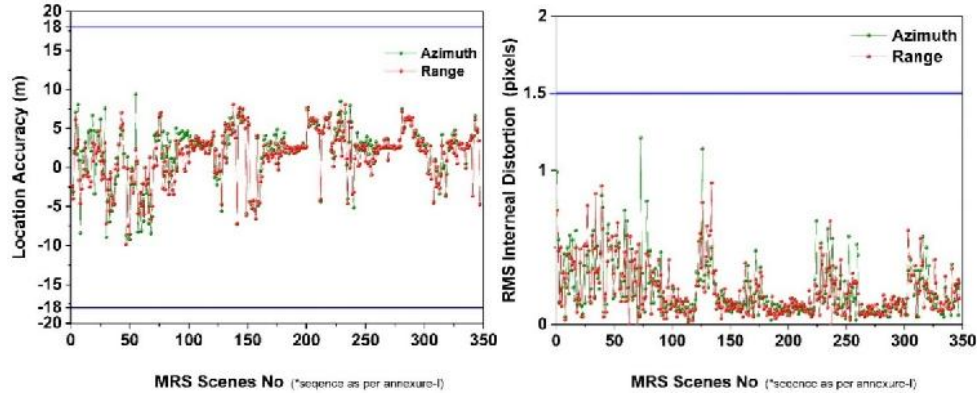


Figure 9: L2-orthorectified MRS products (Left) Mean Location accuracy in meters (Right) RMS Internal Distortions (pixels)

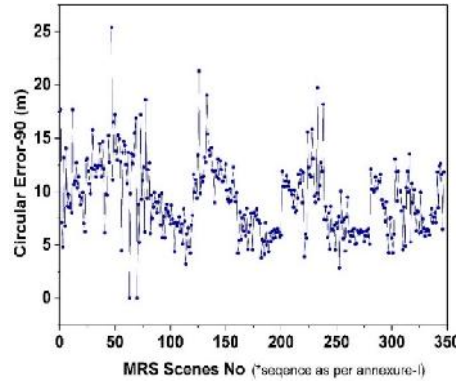


Figure 10: L2-orthorectified MRS products Circular Error (m)

Table 5: Error Statistics for all the reference scenes

Parameter	Minimum	Maximum	Mean	SE of mean
Location Accuracy (m)				
RMS (Azimuth)	0	12.44	4.97449	0.10414
RMS (Range)	0	12.58	4.53797	0.10078
MEAN (Azimuth)	-9.23	9.4	2.01305	0.19392
MEAN (Range)	-9.82	8.09	1.58252	0.17925
STDDEV (Azimuth)	0	10.28	2.78513	0.1066
STDDEV (Range)	0	10.43	2.64725	0.10055
Internal Distortion (pixels)				
RMS (Azimuth)	0	1.21	0.21875	0.0097
RMS (Range)	0	0.92	0.21965	0.0092
MEAN (Azimuth)	1.03	1.09	0.01728	0.01138
MEAN (Range)	0.83	0.55	0.0367	0.01136
STDDEV (Azimuth)	0	0.52	0.15333	0.00585
STDDEV (Range)	0	0.59	0.14591	0.00557
Circular Error (m)				
CE90	0	25.39	9.23394	0.18614

5. CONCLUSION

RISAT-1 MRS scenes over Indian region have been evaluated and qualified independently using L8-OLI optical data for the utilization of SAR products geometric data quality evaluation of future SAR sensors. Geo-location accuracy for 346 reference images is well within ± 10 meters, which is within a pixel in both directions (azimuth and range). These reference images are qualified and can be effectively used as ground reference in SAR data ground processing.

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DETECTION OF ATMOSPHERIC LIGHTNING ACTIVITY WITH GROUND BASED RF RECEIVERS- ESTABLISHMENT AND ITS GEOSPATIAL REPRESENTATION

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ABSTRACT

Understanding the atmospheric lightning flashes and their occurrences is one of the most important questions of the Earth's climate science. Real-time, lightning data have profound importance in climate science, air quality research, and atmospheric nitrogen budget, apart from this being one of the major natural disasters. Keeping these in view Lightning Detection Sensor (LDS) network has been established at 6 locations viz., Kolkata, Ranchi, Raipur, Bhubaneswar, Nagpur and Visakhapatnam. The lightning data have been regularly collected on daily basis since June 2017.

Preliminary analysis suggests that it is possible to detect the phenomena and identify the vulnerable zones of the lightning activity with LDS data. Using the GIS techniques the gathered information on lightning flashes can be visualized for suitable zoning of the vulnerable area for further societal benefits. Analysis on the LDS data collected based on the Nagpur sensor was subjected to layer and proximity analysis. We note that Nagpur, Wardha and Bhandara districts were more vulnerable during June-July 2017, while during August-September 2017, Nagpur, Gadchiroli and Chandrapur were vulnerable districts. In terms of remote sensing capability, the proposed network will provide lightning field intelligence over a large area for any future satellite missions. The collected LDS data had good agreement with field data, thus validating the sensor capability.

KEYWORDS: Atmosphere, Lightning, remote sensing

1. INTRODUCTION

Understanding the lightning physics and future scenarios of lightning strokes and flashes is one of the most important open questions of the Earth's climate science (e.g., Pinto, 2009). Lightning data and its usage in operational weather forecasting has shown phenomenal improvements in extreme events (Stolz et al, 2014). Further, early detection of lightning strikes is required to mitigate the loss of life (Illiyas et al., 2014). The lightning strokes produce NO_x which is immediately transferred to the ground and has important consequences in surface O₃ chemistry (e.g., Kayank et al., 2008). In recent times, it is well understood that lightning activity are indicator of weather and climate changes (e.g., Price, 2000). Further, Romps et al. (2014) have shown that with the surface temperature rise, the occurrences of lightning activity are going to be enhanced. Of the importance to this is that lightning and cumulus activity is the source of atmospheric perturbations, known as gravity waves which are one of the most important coupling agents across the different atmospheric regions (e.g., Kamalakar et al., 2013, Sivakandan et al., 2016). In short, characterization of lightning activity is important not only for lower atmosphere and disaster management, but also to resolve some of the least understood features in the upper atmosphere.

In terms of the space borne exploration, Lightning Imaging Sensor (LIS) on board the Tropical Rainfall Measuring Mission (TRMM), provided snap-shot information and did help in characterizing the occurrences of lightning. However, for the exact monitoring with temporal characteristics and societal applications such as identification of potential danger zones and now-casting, only ground based VHF/UHF receivers have been found very useful since more than a decade. Using this method, few countries, such as USA, Brazil, Poland, Finland, Japan, etc. have established a very dense network of long range lightning detection sensors.

Purpose of the present study is to showcase the installation, characterizing the cloud to ground lightning occurrences and identifying vulnerable zones using single sensor data.

2. METHOD OF OBSERVATION

The Lightning Detection Sensor (LDS) used in this study is Boltek-LD-350. The receiver antenna is omni-directional which detects the frequency ranging from 50 kHz to 500 kHz. This corresponds to wavelengths of 6000 m to 600 m, i.e., the electromagnetic processes occurring at scale size of 0.3 km to 3 km scales are captured by LDS which is highly suitable to detect the cumulus processes including the lightning which arise due to thunder cloud. This antenna has interface with a global positioning system (GPS) antenna for accurate time stamping of the signal received. This LDS also uses gated magnetic direction finder to estimate the direction of lightning occurrences.

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The exact location of lightning occurrences can be obtained using the multi LDS data. Note that individual sensors used in the present work have magnetic direction finders. The LDS antenna uses the characteristics of lightning waveforms which also estimates the distance of cloud-to-ground flashes from the sensor (Note that flashes occur in cloud levels while it is the strikes which impact on the ground). We feed accurate locations of the sensor installation which enables the geolocation of lightning flash occurrences with precision better than 0.02° . A typical installation of the LDS is shown in figure 1 together with initial 6 locations of LDS network.

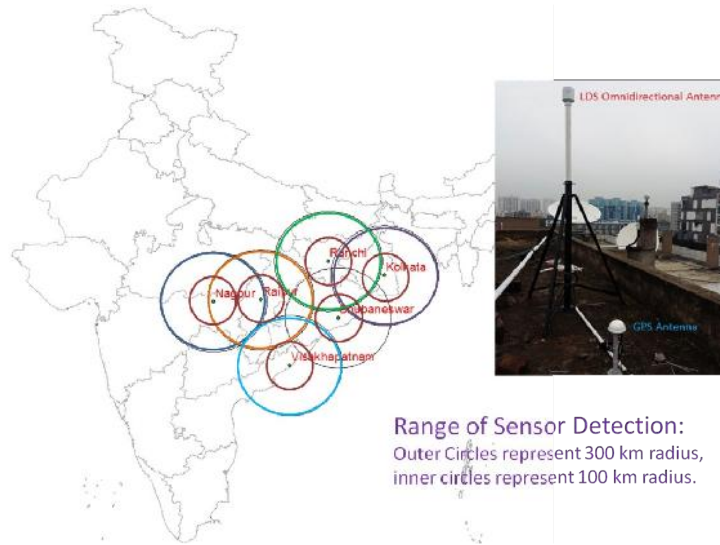


Figure 1. Existing Lightning Detection Sensors (LDS) together with their radius of detection.
A typical set up is shown in right side of the image.

3. DATA COLLECTION

The LDS antenna is operated using the nextstorm software and data is being transferred to the connected PC. The raw data transferred by this, show the time, range, bearing angle, strike rate per minute and type of lightning with polarity and number of flashes. Though, data are collected every second, a text file is created every 5 minutes summarizing the occurrences. However, in doing this, for identified lightning cluster, it provides an average position. This introduces a position inaccuracy ranging from 20 meters to 5 km depending on the velocity of the cluster. In one summary file, there can be as high as 20 clusters. Thus obtained data have been plotted over the geographical information system (GIS). A sample data based on the sensor located at Nagpur, overlaid on the GIS is shown in figure 2. The clouds to ground lightning flashes are shown as filled circles with more number representing the phenomena to be more severe. Note that the number of flashes are not calibrated hence, at present it is considered to be in relative units instead of an absolute number. We also note higher sensitivity near the receiver which can only be eliminated by multi-sensor detection approach (to be implemented upon having denser network of LDS in near future). The cloud to ground flash occurrences and spatial accuracy are elaborated elsewhere (Taori et al., 2018).

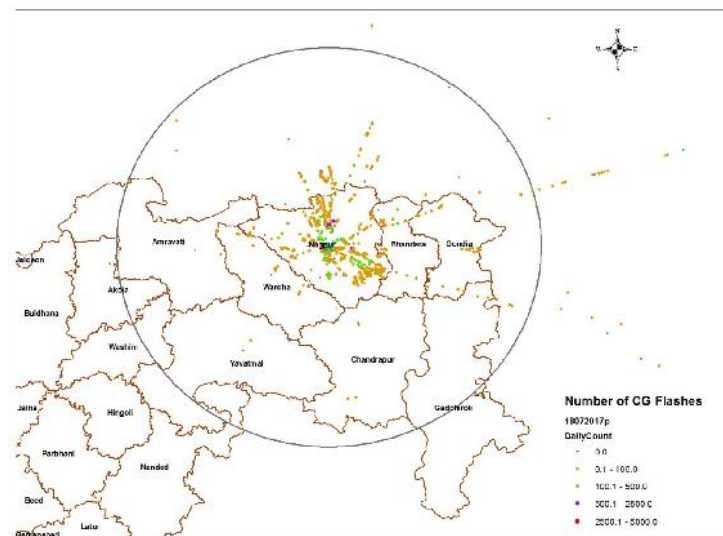


Figure 2. Number of cloud-to-ground lightning flashes as recorded by the LDS located at Nagpur on 18 July 2017.
Circles represent 200 km radius around the sensor.

4. IDENTIFICATION OF VULNERABLE ZONES

We analyze the uninterrupted LDS data collected during June - December 2017 for the districts which are covered by the sensor located at Nagpur in Maharashtra state. These districts are Gondia, Bhandara, Wardha, Amravati, Yavatmal, Chandrapur and Gadchiroli.

Figure 3 plots the number of cloud to ground flashes in these districts. Note that ordinates in figures 3f and 3g are different from others to show variability. During July and September 2017, all districts show occurrence of CG lighting, however, large spatial differences are noteworthy. During November-December there is no occurrence of flashes which is understandable as convective activity during these months remain negligible. Data suggest that Nagpur district witnessed the major number of flashes hence was the most vulnerable. During July 2017, Wardha followed by Bhandara districts noted major number of CG flashes; while, during September 2017, Chandrapur and Gadchiroli were most affected. It is evident that Amravati and Yavatmal were the least impacted districts as far as the occurrence of CG lightning flashes are concerned. We also note that there were occasions when CG lightning activity was confined to a particular district only, for example on 18-19 July 2017, Nagpur district witnessed maximum number of flashes, while other locations shown insignificant activity. We investigated the Nagpur districts at Taluka level (Figure 4). It is noted that during June-July 2017, Nagpur urban received the most number of CG lightning flashes followed by Kamthi and Kuhl Talukas. However, during August-September 2017, Kamthi Taluka was most vulnerable followed by Kuhl and Nagpur Rural Talukas. The above statements on the vulnerable zones are based on single season of data. Upon sufficient multiple seasonal data, we can identify statistically significant vulnerable zones.

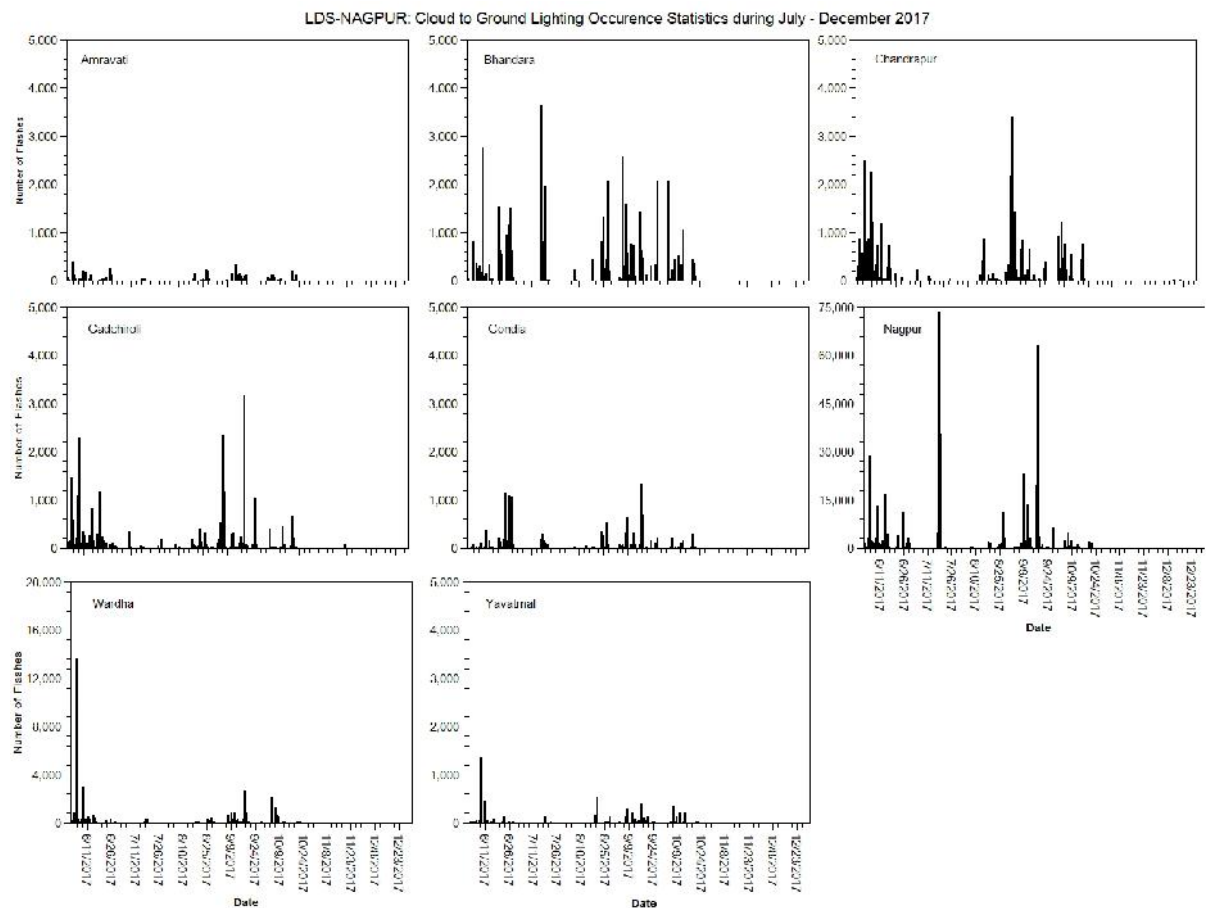


Figure 3. District wise statistics on the number of cloud-to-ground lightning flashes as noted by the LDS located at Nagpur.

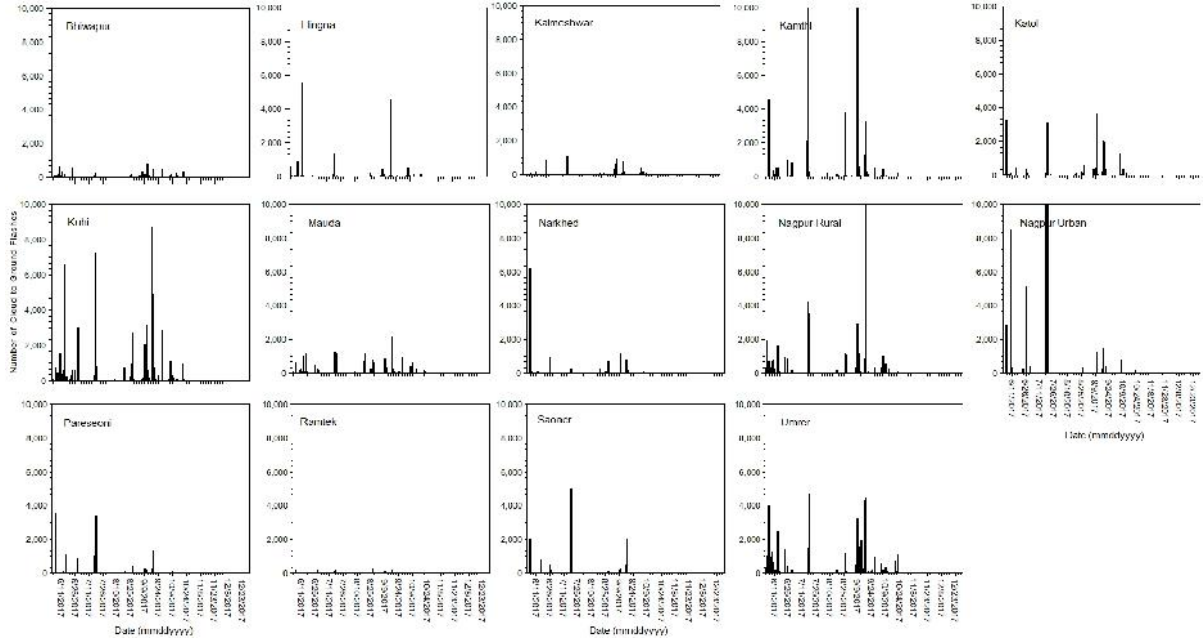


Figure 4. Taluka wise statistics in Nagpur district on the number of cloud-to-ground lightning flashes as noted by the LDS located at Nagpur.

4.1 Potential Warning Method

There are two ways to address the issue of identifying the vulnerable area. One is to club all sensor data and perform time of arrival method on super data set, while, in other case, on single sensor data apply the time of arrival method. While, the first method provides more accurate information, the dependency on the availability from other data and its continuous flow; second method is independent of other data sets. For this reason we showcase here second method for identifying and warning of potential vulnerable area using data mining techniques by process of unsupervised learning. Important to note is that very flash need not result in strike, however, more number of flashes do indicate the occurrence of a strike. The methodology adopts cluster analysis to predict the future scenario. The cluster selection is based on the maximum number of CG occurrences and based on last 1 hour of data, only those points are selected which have more than 80% of CG occurrences. The available lightning flash locations are geo-located which makes it easier to visualize these clusters on a map. The lightning flash locations serve as data points to partition them into small number of clusters. As an example let us consider that there are x number of data points. These are divided into k number of clusters. The algorithm starts with initial estimates of k centroids. Each centroid defines one of the clusters. Then each data point is assigned to k centroids based on the Euclidean distance between the two. If c_i is a collection of centroids in set C , then each data point x is assigned to a cluster based on –

$$\operatorname{argmin}_{c_i \in C} \operatorname{dist}(c_i, x)^2 \quad \text{--- (1)}$$

Where, $\operatorname{dist}(c_i, x)$ function is the standard Euclidean distance. Let us assign the S_i to the data points of the i^{th} cluster. Now the centroids are recalculated using the mean of all data assigned to that cluster's centroid.

$$c_i = \frac{1}{|S_i|} \sum_{x_i \in S_i} x_i \quad \text{--- (2)}$$

The algorithm reiterates between the above mentioned steps until the data points do not change clusters or the sum of distances is minimized. These cluster centroids can give us an understanding of the general direction of movement of the cluster. The velocity of these clusters is calculated by taking into account the lightning flash data from past one hour and seeing the movement in this given time using cluster centroids available at every 5 minute intervals. This is required to get the stabilized velocity vector of the cluster movement. The velocity vector is thus obtained using cluster centroid movements by cross correlating them. Using this speed and direction, the future positions of these centroids is computed.

For the above computation, number of flashes on a particular location in given 5 minutes is used. Every 5 minute incoming data is included in the velocity estimate and velocity vector is changed with time of reference continuously. As this algorithm may overestimate possible CG strike locations, a cut-off has been computed based on regression from multiple outputs. Any data point where the numbers of strikes are less than 10 percent of the mean strikes of a cluster in a given hour, using which the velocity is computed, has been removed. Also, based on whether the number of flashes in a given hour is increasing or decreasing an alert is created which notifies the observer if the strikes are getting severe or not. This information is based on the slope of CG flash occurrences. Figure 5 shows a sample performance of this methodology

applied on the Kolkata LDS data. With the real time trend of occurrences, it is possible to predict whether severity of lightning occurrences are increasing or decreasing as shown in the right bottom corner of this figure.

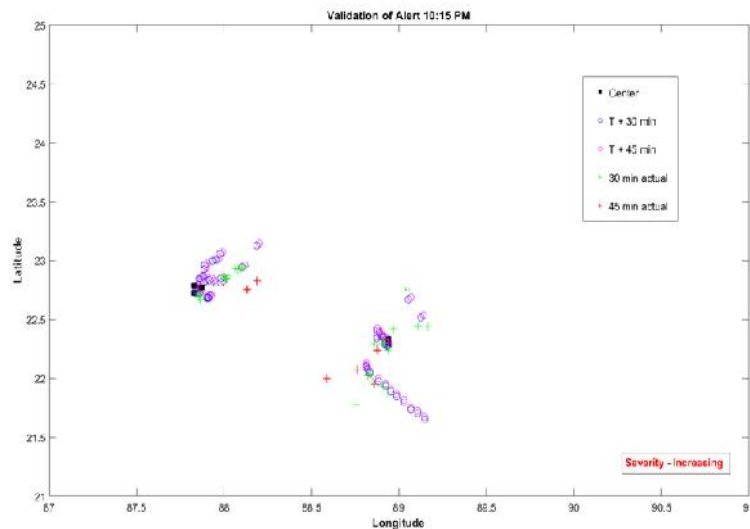


Figure 5. The black squares show the number of clusters and their movement. The identification of clusters at 30 min and 45 min in advance is shown in blue and purple colour open circles. The actual occurrences as noted by the real data are shown as green squares.

5. SUMMARY

The atmospheric lightning activity is being regularly recorded with the help of RF sensors installed by NRSC at 6 locations, of which Nagpur data is showcased here. The vulnerable zones can also be classified depending on the number of CG lightning flashes. It is also possible to provide a warning of lighting occurrences in 30 min to 45 min advance. However, the cross validation of data and a sufficient statistics is required for providing classification of vulnerable areas and warning about the lightning occurrences.

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AN AUTOMATED APPROACH FOR REFERENCE IMAGE GENERATION USING MULTI-TIER RESOURCESAT-2A DATA OVER INDIAN LAND TERRAIN

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ABSTRACT

Sub pixel geometric accuracy and multi temporal registration of remote sensing data is a pre-requisite for mapping changes at the earth surface features including crop pattern studies over Indian terrain at different scales, wetland management, urban sprawl monitoring and large area time series data analysis. To accomplish these objectives, the initial requirement is to generate high quality reference images using on-orbit Resourcesat-2A (RS-2A) LISS-3/LISS-4 data. Resourcesat-2A is a multi-spectral optical imaging mission providing continuity of moderate resolution data for operational monitoring of land cover areas by imaging systematically over terrestrial surfaces at different spatial resolutions using multi-tier imaging scheme with reduced revisit time. Reference images of RS-2A is a collection of orthorectified datasets which should have minimum cloud cover, sub-pixel level co-registration accuracy relative to any standard ortho image database and better absolute geometric accuracy. The paper describes an automatic processing workflow for the generation of reference images using RS-2A LISS-3 and LISS-4 datasets at a spatial resolution of 24 meters and 5 meters respectively over Indian land terrain. The processing workflow is triggered by the ingest of RS-2A raw scene data as input to the chain and generates final ortho-rectified output that is further scrutinized for reference selection depending on the spatial coverage, geodetic accuracy, feature continuity across the scenes and the extent of cloud contamination in an automatic way. Reference images generated establish the geometric base and ground control for current Resourcesat data as well as next generation Resourcesat data sets to ensure multi-temporal registration of the product at sub-pixel level, which will become standard level-1 products for all Resourcesat images in its archive.

KEYWORDS: Geometric Accuracy, Multi Temporal Registration, Sub-Pixel, Reference Images, Resourcesat-2A

1. INTRODUCTION

Resourcesat-2A (RS-2A) launched on 07th December 2016 provides data for long term inventory of land cover change at medium resolution scale. The Resourcesat Data Product Generation Software (DPGS) raised its standard from systematic correction geolocation error of hundreds of meters to terrain correction sub-pixel geolocation accuracies and started to provide with such data as standard products for all Resourcesat images. The absolute geometric accuracy of less than a pixel is possible by co-registration of data with standard reference image database. This gives motivation to generate new set of reference images over Indian land terrain using RS-2A LISS-3 and LISS-4 datasets using an automatic processing workflow that becomes the geometric base for generation of ortho-rectified Resourcesat products. Multi temporal co-registered datasets is a mandatory requirement for any kind of feature change detection and analysis [4]. The use of high-quality reference images ensures both absolute geometric accuracy as well as relative location error between the dates at sub-pixel level. This paper in the subsequent sections elaborates the critical data processing steps adopted for generation of reference images in automatic mode using RS-2A LISS-3/LISS-4 datasets. LISS-3 data have a spatial resolution of 24 meters, swath of 140 kilometers with repetivity of 24 days. LISS-4 data on the other side have spatial resolution of 5 meters that is better than LISS-3, full multispectral swath of 70 kilometers with repetivity of 48 days. Acquisitions of LISS-3 and LISS-4 on-board Resourcesat-2A for more than a year gives an opportunity to generate cloud free reference images over Indian land mass at spatial resolution of 24 meters and 5 meters respectively.

2. DATA PROCESSING STEPS

The data processing steps for reference image generation is triggered by the ingest of RS-2A raw scene data as input. The reference generation in automatic mode requires sequential execution of different steps for generating quality ortho rectified data product. Digital Image Processing techniques are involved at various stages for the processing of the data. The major steps involved in reference generation are:

2.1. Radiometric Correction

Radiometric Processing of Resourcesat data initiates with detector normalization based on the laboratory measured radiometric calibration data. This process of calibration requires response of the various detectors for a wide range of input radiance at different temperatures. The next level of radiometric correction includes dark signal and detector sensitivity correction, defective pixels interpolation and image restoration. The final aim of radiometric processing is to improve the overall radiometry of the images using lab measured external data and by implementation of advanced optical image processing techniques.

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2.2. Geometric Correction

The next step is to perform geometric processing to know the location of each pixel of the image over the earth surface. Geometric correction step establishes a line of sight direction for each pixel relative to spacecraft reference frame on ground to support system level image geo-location. In geometric correction, satellite images are corrected for geometric degradations introduced by mission, platform, and scene related behaviors to orient the image data w.r.t the earth geometry and chosen map projection. In this correction, orbit, attitude and scene information are used to bring the input data to the system level geometric accuracy. Geometric Correction step suppress the systemic error and generates geographic grid that provides both forward and inverse transformation from pixel to ground and ground to pixel [8].

2.3. Global Transformation Estimation

The geometry grid generated further improved by establishing a transformation model using distinguishable feature points and collected simultaneously in input image and standard ortho rectified image. The estimation step employs an automatic Harris corner detection [1] and building a transformation model using Random Sample Consensus (RANSAC) algorithm [5]. So finally, in this step the parameters of the mapping function are absorbed in the geometry grid to align the sensed image with the ortho image to a pixel level geometric accuracy.

2.4. Local Distortion Estimation

The sensed image geometry after global transformation still suffers from local distortion. This forces us to develop a better approach to remove the local distortion and to achieve sub-pixel level geometric accuracy w.r.t. the reference. The local distortion estimates employ Scale Invariant Feature Transform (SIFT) technique [3] along with applying segmented affine based transformation model at image segments to correct the data at geographic coordinate space to achieve sub-pixel level geometric accuracy.

3. TWO PASS GEOMETRIC ACCURACY IMPROVEMENT

The system corrected RS2A data is improved through two pass geometric correction process as described briefly in the above section to correct global and local errors. In the first pass, geolocation accuracy is improved using residual attitude estimation. The steps followed in the residual attitude estimation are:

3.1 Feature Detection

The method computes the abstractions of image information. In other words, to detect features from input and ortho corrected images which are salient and distinctive objects (ex: corners). The Harris corner detector being used for feature detection that has strong invariance to rotation, scale, illumination variation and image noise. The Harris corner detector is based on the local auto-correlation function of a signal; where the local auto-correlation function measures the local changes of the signal with patches shifted by a small amount in different directions [2].

The basic idea of Harris corner detector is to give a mathematical approach for determining whether a point shows significant change in all the directions to designate as a corner point.

It can be easily recognized, the point by looking at intensity values within a small window and shifting the window in any direction should yield a large change in appearance.

Change of intensity for the shift $[u, v]$ is given as:

$$E(u, v) = \sum_{x,y} w(x, y) [I(x + u, y + v) - I(x, y)]^2 \quad (1)$$

In the above equation,

$E(u, v)$, Change of intensity

$I(x + u, y + v)$, Shifted Intensity

$I(x, y)$, Intensity

Using Taylor series for 2D function, taking a first order approximation

$$I(x + u, y + v) \approx I(x, y) + uI_x(x, y) + vI_y(x, y) \quad (2)$$

By substituting and deriving further, the Harris corner detection by change detection for a small shift $[u, v]$ can be expressed in matrix form as

$$E(u, v) \cong [u \ v] M \begin{bmatrix} u \\ v \end{bmatrix} \quad (3)$$

Where M is a 2X2 matrix computed from image derivatives.

$$M = \sum_{x,y} w(x,y) \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \quad (4)$$

Where $w(x,y)$ is a window function, I_x and I_y are components of image gradient.

Subsequently, corner response measure is computed according to

$$R = \det M - k (\text{trace } M)^2 \quad (5)$$

Where $\det M = \lambda_1 \lambda_2$ is the determinant value of matrix M, $\text{trace } M = \lambda_1 + \lambda_2$ is the trace of the matrix M, and λ_1 and λ_2 are eigen values of matrix M and k is an empirically determined constant.

A point is considered to be a “corner” if λ_1 and λ_2 are very large and $\lambda_1 \approx \lambda_2$. It shows that change in intensity of the point is increasing in all direction [1].

3.2 Feature Matching

The step maps and establishes the correspondences between features detected in the input image and those detected in the ortho image. Many feature descriptors and similarity measures techniques are available for this purpose. Normalized Cross Correlation (NCC) based feature matching is being used for feature matching.

3.3 Model Estimate

This step estimates the transform using master and slave coordinates by employing models. In this step the parameters of the mapping functions, aligning the sensed image with the ortho corrected image, are estimated. Iterative methods are employed to estimate the parameters of the geometrical model for robust modeling. Non-linear optimization models are preferred over other to model the distortion between input image and reference image. Model Parameters are finally absorbed directly in the attitude values as residues to improve the geolocation accuracy of the system corrected RS2A images.

The geolocation accuracy of the images after first pass reaches to a pixel level geo-location error. But it is not good enough for RS2A images to be eligible for reference image consideration which should be registered to sub-pixel level with the standard master images. In the second pass, an improved version of SIFT based feature detection with segmented affine transformation model is chosen to suppress the local distortion in the image to reach at sub-pixel level geometric accuracy.

The advantage of SIFT over other feature detector is that it is not only detect the feature points but it also provides the description of the feature point which is not provided in the other feature detectors like Harris Corner. SIFT is also capable to detect feature points at sub-pixel level which is needed for accurate transformation parameter estimation [9].

The SIFT algorithm starts with construction of scale space extrema using Gaussian Kernel (G). The equation-6 shows the relation between Smooth Image (L) and Input Image (I) at point (x, y)

$$L(x, y, \sigma) = G(x, y, \sigma) * I(x, y) \quad (6)$$

$$\text{where } G(x, y, \sigma) = 1/2\pi\sigma^2 (e^{-(x^2+y^2)/2\sigma^2}) \quad (7)$$

It has been found that Laplacian of Gaussian (LOG) found to provide stable features and give excellent notion of scales but it is computationally costly. So, the Difference of Gaussian (DOG) pyramid is created which is considered to be the approximation of Laplacian of Gaussian (LOG). The next task is to scan each DOG image to locate the minimum and maximum around all the neighboring points including the scale.

In the second pass approach, the matched featured points detected and matched by SIFT are divided into multiple segments and affine transformation model is computed for each segment. The affine transform for a segment is shown as:

$$aff(k) = \{a_{0k}, a_{1k}, a_{2k}, a_{3k}, a_{4k}, a_{5k}\} \quad (8)$$

Where k = segment number and a_{ik} = affine transform parameters

The tagged input (lat, lon) of image point (x, y) transformed to corrected geo-point (lat_{cor}, lon_{cor}) depending upon the segment number k of the point (x, y) .

$$\begin{bmatrix} lat_{cor} \\ lon_{cor} \end{bmatrix} = \begin{bmatrix} a_{0k} & a_{1k} \\ a_{2k} & a_{3k} \end{bmatrix} \begin{bmatrix} lat \\ lon \end{bmatrix} + \begin{bmatrix} a_{4k} \\ a_{5k} \end{bmatrix} \quad (9)$$

Each segment contains matched feature points, which is used for affine model estimation for that segment. The segmented affine models estimated for the input image and perform the geometric transform for each segment using its corresponding affine transformation model shown in equation-9 to generate geometrically corrected data. The segmented affine model approach reduces internal distortion in the geo-corrected data and provide sub-pixel level registration accuracy with respect to the standard ortho image [6].

4. PROCESSING WORKFLOW FOR REFERENCE GENERATION

The data processing steps listed in above sections put in an automatic mode of execution to generate reference images of Resourcesat-2A LISS-3/LISS-4. Before processing, it is needed to check the cloud cover of the data. If the cloud cover is less than 10% in whole image, it becomes eligible for further processing of data to generate reference. The next two processing module “Radiometric Correction and Geometric Correction” is part of DPGS chain that is integrated in ortho image generation processing flow. The additional processing workflow is the heart of reference generation that includes global transformation estimate using Harris Corner Detection, NCC and non-linear optimization. The local distortion is tackled using SIFT based feature detection with affine transformation model that brings the RS2A image to sub-pixel level accuracy w.r.t to the standard reference image database. The image is resampled and geometric accuracy [7] is checked based on the Root Mean Square Error (RMSE) threshold of less than one pixel. The sub-pixel geo-accurate RS2A image is finally stored as reference image. The Figure-1 shows the processing workflow of reference image generation.

5. REFERENCE GENERATED USING RS2A LISS-3/LISS-4

The reference images are generated using RS2A LISS-3/LISS-4 datasets at spatial resolution of 24 meters and 5 meters respectively covering Indian land terrain using the workflow shown in Figure-1. The details of reference images generated using RS2A listed in Table-1 and Table-2.

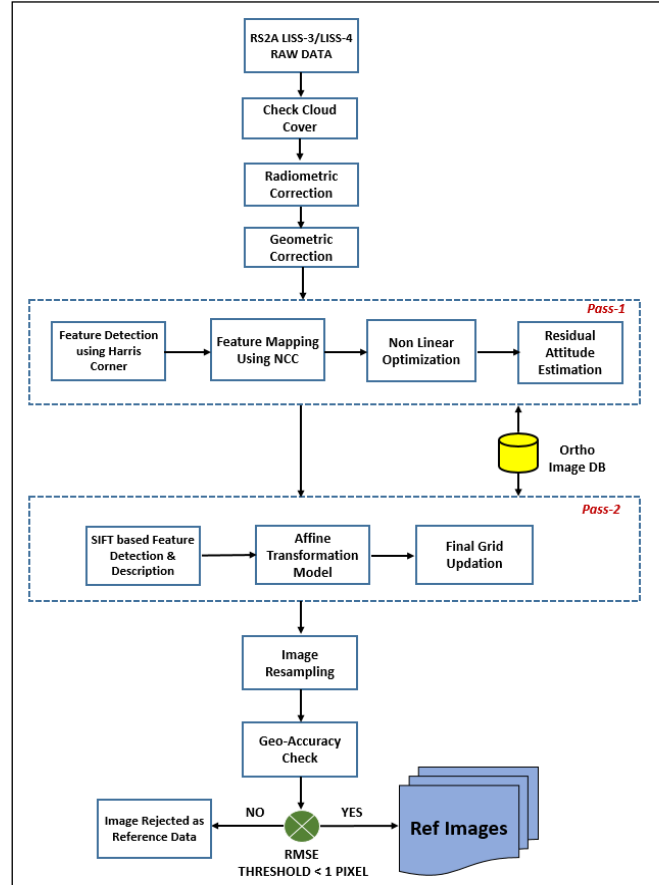


Figure 1. Processing Workflow for Reference Generation

Table-1: Ref Details of RS2A LISS-3

Satellite/Sensor	RS2A/LISS-3
No. of Reference Scenes	390
Spatial Resolution (in m)	24 m
Map Projection/Ellipsoid	UTM/WGS84
RMSE (in pixels)	< 1 pixel

Table-2: Ref Details of RS2A LISS-4

Satellite/Sensor	RS2A/LISS-4
No. of Reference Scenes	1200
Spatial Resolution (in m)	5 m
Map Projection/Ellipsoid	UTM/WGS84
RMSE (in pixels)	< 1 pixel

The selected reference images of LISS-3 are mosaicked together to see the coverage over Indian land-mass and it is shown in Figure-2.

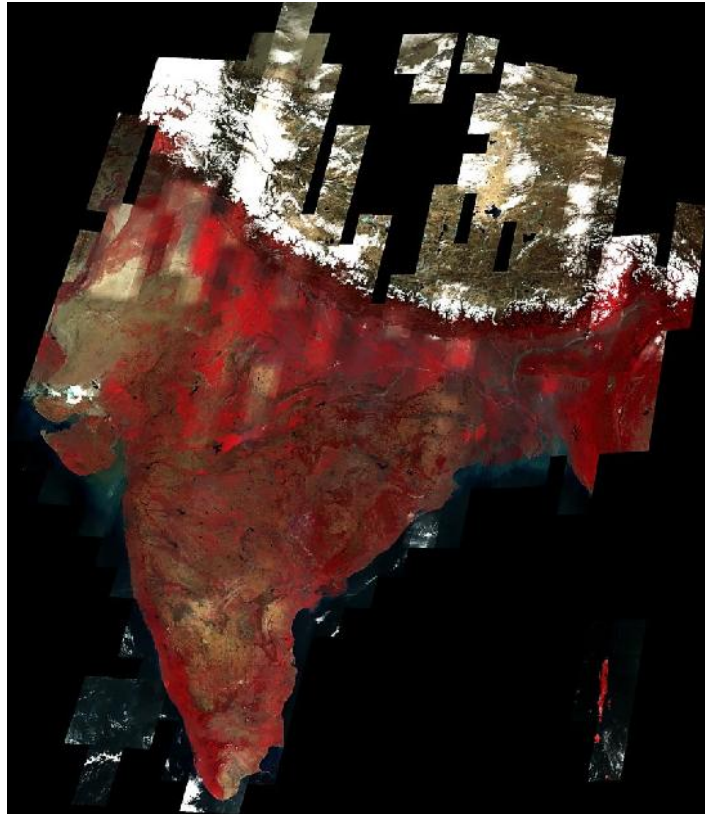


Figure 2. RS2A LISS-3 Reference Image Mosaic over Indian Terrain

In similar way, RS2A LISS-4 datasets generated over Indian terrain. The datasets are checked for feature continuity at mosaic area over different date of acquisitions. The Figure-3 shows mosaic of three different date of acquisitions of RS-2A LISS-4 and the mosaic area shown in full resolution to show the feature continuity across paths at different date of pass.

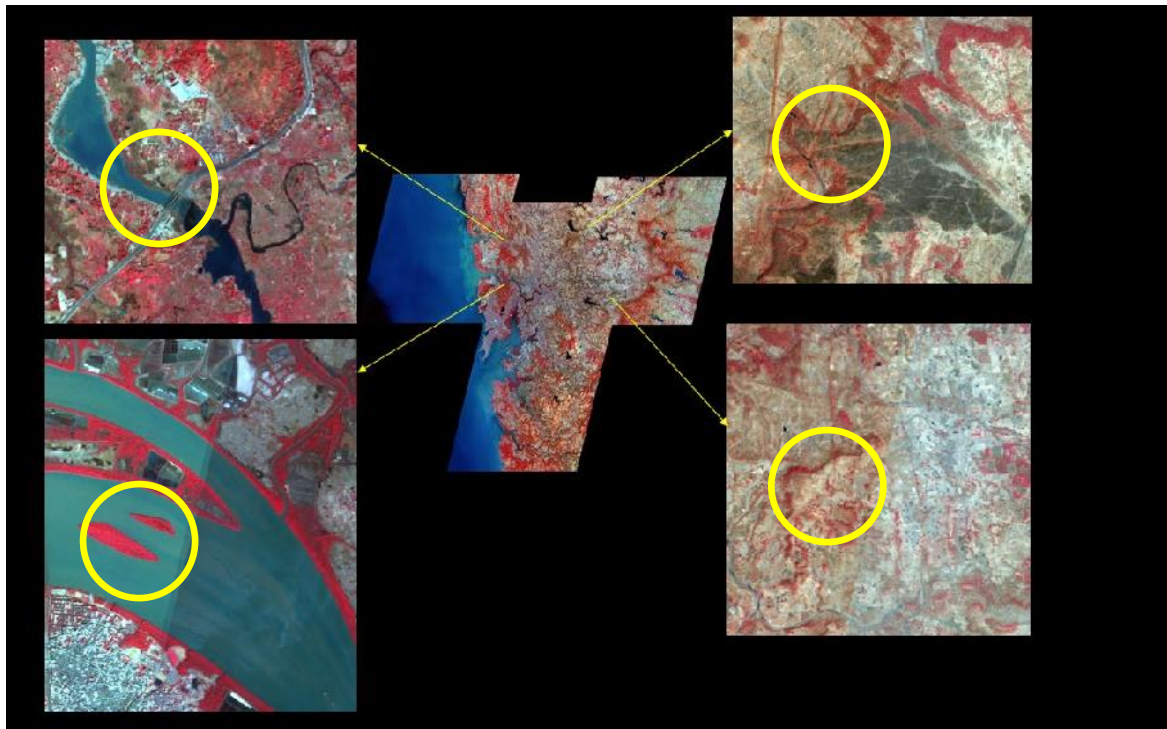


Figure 3. Feature Continuity of RS2A L4FMX Reference across different date of pass

6. CONCLUSION

The automatic processing workflow developed can run for any Resourcesat series data for reference image generation. At present the workflow tested rigorously for RS-2A LISS-3 and LISS-4 datasets. The future work includes automatic checking of reference images with ground control points having geo location accuracy of better than a meter to achieve better absolute location accuracy. The reference datasets generated used in DPGS processing chain to achieve multi temporal registration of data products. Multi temporal registration is a primary requirement for analysis ready data products. The procedure developed further fine-tuned with advanced transformation models and it can be added as plugin in the workflow on the need basis.

ACKNOWLEDGEMENTS

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FEATURE EXTRACTION FOR CHANGE DETECTION IN COASTAL ECOSYSTEM ACROSS KOCHI REGION

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ABSTRACT

Change detection of coastal ecosystem plays a vital role in monitoring and managing natural resources along the coastal regions. The present study mainly focuses on decadal change in Kochi islands connecting the urban flatland areas and the coastal regions where sand deposits have taken place. With this in view the change detection has been monitored in the Kochi area to analyze the urban growth and industrialization leading to decrease in wetland ecosystem. The IRS LISS-IV satellite image has been processed using rule based algorithm to classify and to interpret the changes between 2005 and 2015. The approach takes two steps i.e. extracting features as a single geographic information system (GIS) vector layer using different parametric values and to dissolve them. The different classes were extracted using threshold values of various parameters. The objects obtained in the segmentation process were visualized to be overlaying the satellite image at an object scale of 15. This layer was further segmented using the spectral difference segmentation rule between the objects. Result shows a rapid increase in industrial area of 40% based on industrial area statistics of 2005. There is decrease in wetlands area which has been converted into built-up. New roads have been constructed which are connecting the islands to urban areas as well as highways. The change in coastal region has been visualized due to sand depositions. The outcome is well supported by quantitative assessments which will empower rich understanding of land use land cover change for appropriate policy intervention and further monitoring.

KEYWORDS: IRS, LISS-IV, Land Use Land Cover, Segmentation, vector layers, wetlands

1. INTRODUCTION

Kochi is one of the green cities of India and is well known for its wetlands. Wetlands are the areas that lie between aquatic and terrestrial ecosystems, dominated by the influence of water and play significant role in maintaining the ecological balance of both biotic / abiotic life in coastal and inland environment. By virtue of its geographical extent and varied terrain and climate, India supports a rich diversity of inland and coastal wetlands. Coastal zones in India are constantly undergoing wide-ranging changes in shape and environment due to natural as well as human development activities. Natural processes such as waves, erosion, changes in river courses etc., cause long time effect at slower rate; but manmade activities, such as settlement, industrial activities, recreational activities, waste disposal etc., affect the coastal environment at comparatively much faster rate. Continued loss of these wetlands may lead to the collapse of coastal ecosystems. It is, therefore, necessary to monitor coastal zone changes with time.

Earlier, in accordance to monitor these changes various digital onscreen interpretation methods had been used (Elaalem and Ezlit, 2013). Many analysis of remotely sensed imagery was done using pixel-by-pixel basis. While this analysis was satisfactory in some applications, it was not completely effective to extract the feature information content. As compare to Object based Image analysis (OBIA) approach, pixel-by-pixel based classification method was found to be less accurate for mapping using remote sensed imagery especially from higher resolution imagery. In past few years, there has been a growing interest to develop an automatic land use land cover (LULC) mapping technique to analyse the multi temporal changes in remote sensing images (Bruzzone and Serpico, 1997).

Object based image Analysis (OBIA) refers to image segmentation to create objects and attribution followed by Object classification. It has the ability to query and link the individual objects with information based on texture, shape and context relations with respect to other objects to make it easy for human conceptualization. Image segmentation is the partitioning of image into related sections or regions. It involves grouping of pixels into objects based on either spectral similarity or external variables such as geometric, textural and neighbourhood properties. The idea was to develop a rule set algorithm to extract features using these object information with threshold values and dissolve these objects to obtain a vector layer which contain feature attributes. Meaningful objects always exist over a certain range of scales during segmentation of remote-sensing images (Yuan, Wang, and Li 2014).

The present paper is intended to identify ecologically sensitive locations through advanced methods like digital Image processing, meaningful image-object extraction and GIS for decadal change in Kochi city and islands area, mudflat and development of sand deposits along the coast. A vast amount of world's population is located in coastal belts which lead to urban expansion and industrialization across the region. This rapid industrialisation exerts a lot of pressure particularly on wetlands which has been major concern for many ecological researchers. To analyse this effects, extraction of various features are required which can be obtained implementing OBIA on remotely sensed imagery. The objective of the study is to identify decadal changes by automatically extracting individual features using rule set algorithm and to use optimum combinations of object based and visual LULC classification to achieve higher accuracy.

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2. MATERIALS & METHODS

2.1 Study area

The south-western coast of India, which is a part of Kochi district of Kerala, has been selected as the study area for present study. The study area covers an area of 644.60 km² and located between 76°11'19.134"E to 76°25'42.193"E and 9°52'35.719"N to 10°5'51.575"N (Figure 1). The area consists of Vembanad Lake which was declared as a Ramsar site, a wetland of national importance in Nov, 2002. The area is a complex system of wetlands - Pokkali fields, paddy fields, estuary, mangroves, rivers and beaches. Even though, the paddy fields are located in the eastern fringes of the study area, for this study, they are considered as a part of the wetlands according to Ramsar classification System for wetland as they are seasonally flooded. Also, unlike the Pokkali fields in the study area, these paddy fields are not subjected to mangrove intrusions.

2.2 Data processing

Initially the pre-processing to correct top of atmosphere (TOA) reflectance was carried out to improve the radiometry of images which was followed by image to image co-registration. This helped to ensure that corresponding pixels on both images represented the same geographic location, and misclassifications caused by shifts of unchanged boundaries were reduced.

Two cloud-free IRS RESOURCESAT-2 LISS-IV satellite imageries were used (Table 1). The satellite imageries were segmented using rule based algorithm. Further, sixteen level-II LULC classes (NRSC, 2011) were selected for classification process and accuracy assessment was carried out between 2005 and 2015.

Satellite	Sensor	Date of pass	Spatial resolution	Spectral Resolution	Radiometric Resolution
IRS Resourcesat-2	LISS-4	18 February, 2005	5.8 m	3 bands (2,3,4)	8 bit
		16 February, 2015			16 bit

Table 1. Satellite image specifications

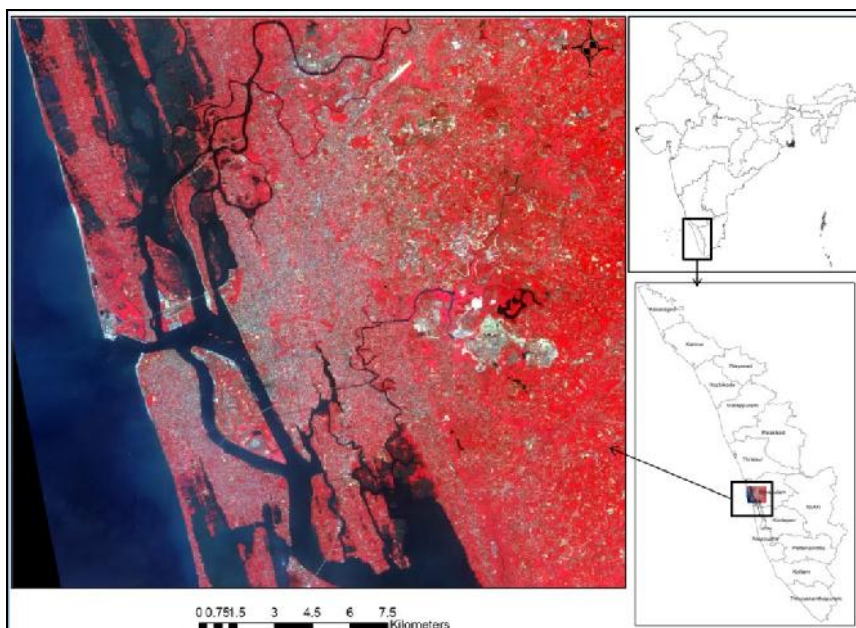


Figure 1. Location map of the study area

3. METHODOLOGY

3.1 Image Segmentation and Feature Extraction

It is a bottom-up region-merging technique which starts at a single-pixel level assembling them into objects based on homogeneity criterion. The homogeneity criteria are based on spectral and shape properties. The scale parameter can be varied depending upon the size of object required corresponding to feature which is being extracted. Here the scale was varied from 10-30 as the output was analysed with the satellite imagery. The objects which were further used were visualized to be overlaying the satellite image at a scale of 15. The initial segmentation (using scale-15, Shape-0.7, color-0.3, compactness-0.5, smoothness-0.5) which was utilised to create homogenous segments was known as multiresolution segmentation. As the multiresolution segment independently becomes an immense challenge due to user defined parameters were set. So, the created objects were further segmented using spectral difference segmentation which merges neighbouring image objects depending upon the difference between their layer mean intensities. The thresholding method to extract features is primarily required to automatically classify land use land cover data sets.

This rule set is based upon the objects and their properties that involves various segmentation using texture properties (GLCM and GLDV, homogeneity, contrast, dissimilarity, mean and standard deviation), geometric properties (shape, compactness, border index), relation to neighbouring objects, customised arithmetic properties (NDVI, NDWI, red ratio, brightness). Figure 2 represents the output of the extracted features.

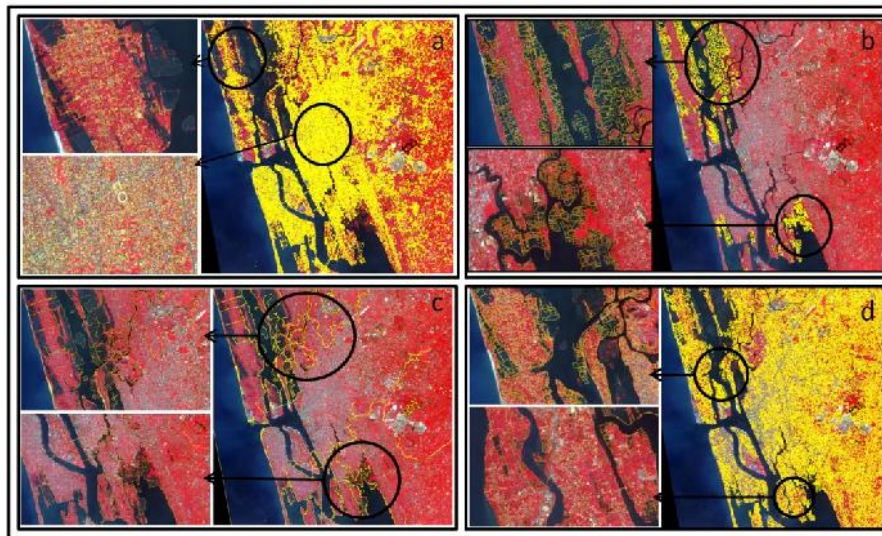


Figure 2. Extraction of (a) built up (b) aquaculture (c) water body (d) cropland layer

3.2 Onscreen Knowledge based detection and Image Classification

Detection for sub-classes requires recognition and classification. Extraction of major LULC classes and many sub-classes cannot be depicted either by object based or pixel based method (K. Ganguly et al, 2016). In addition to this, an onscreen modification was required for extracting sub-classes. This onscreen reconnaissance helps to achieve higher accuracy. The knowledge based value added layers and the extracted layers were dissolved into a single layer by using GIS techniques. On the basis of LULC classification (NRSC, 2011), the classification schema has been used. Thus, the dataset of 2005 was classified using the same approach and was overlaid on 2015 classified vector layer to analyse the change. The preparation chart and the segments obtained for individual classes in 2005 & 2015 vector layers along with LU code and the extraction procedure used has been shown in Figure 3 (a) & (b) respectively.



Figure 3. Ground Truth Points

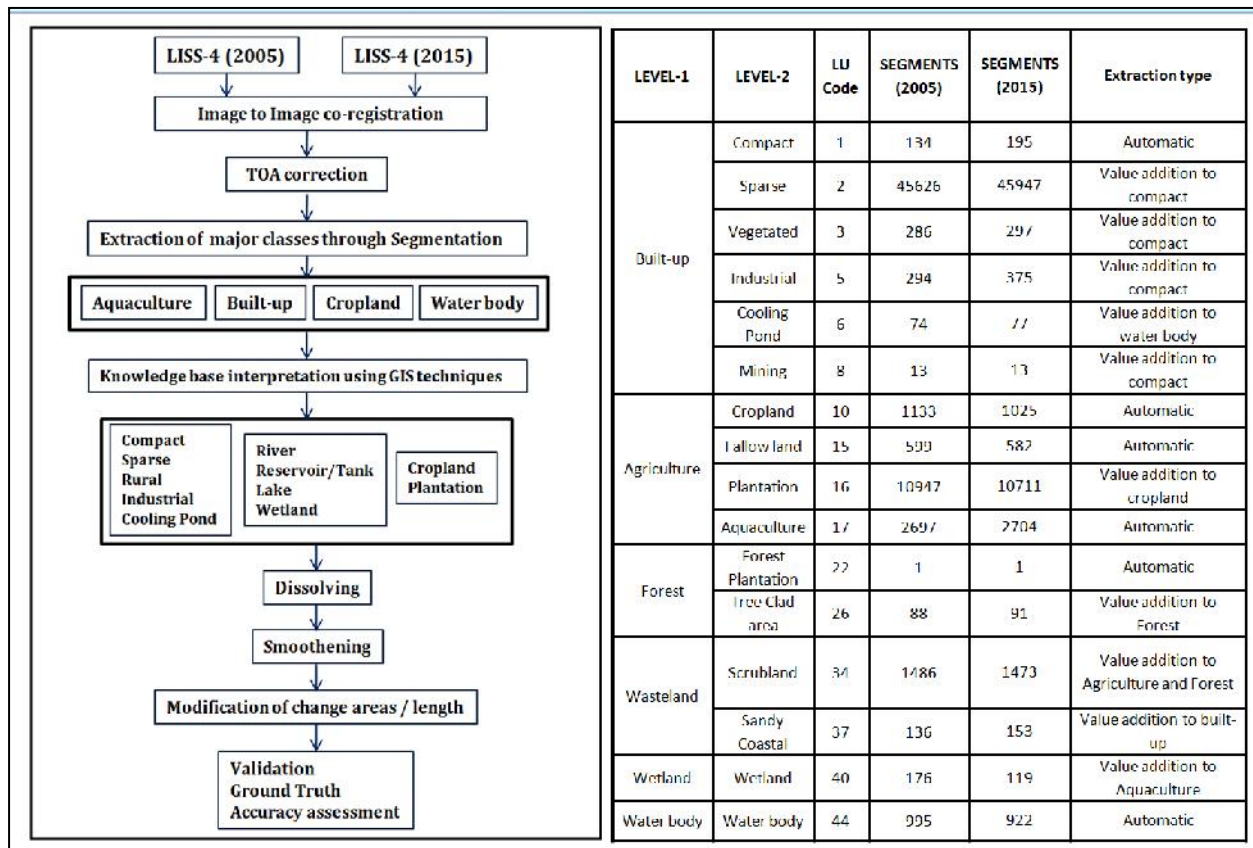


Figure 4. (a) Preparation Chart (b) LU class code and extraction method

3.3 Ground validation

Ground truth verification was done to obtain and verify the training samples (Figure 4). These training samples were created by capturing the location of sites using a GPS enabled geotagged camera and using Bhuvan geo-portal high resolution imagery. These training samples were used while onscreen knowledge based classification correction and accuracy assessment.

4. RESULTS AND DISCUSSION

To assess and monitor the changes, feature based extraction can be seen as more information based classification with higher accuracy and time-effective.

4.1 Land Use /land Cover Change

The statistical analysis with a combination of rule set feature extraction and onscreen interpretation has resulted in a LULC change map between 2005 and 2015 (Figure 5). The output has shown rapid industrialization with an increase of 40% area in 2015 with respect to 2005. The number of segments obtained for 2015 in Built up is greater in number as compared to 2005. Wetland area has shown a decrease in extent. The difference between number of objects obtained for aquaculture in 2005 and 2015 are approximately same which results in higher accuracy. The coastal areas have increased by 46.51% over 2005 (Table 2). The study represents a change in area from agriculture to built up. The changes in paddy cultivated areas which is a base for livelihood is a major concern in the area. There is a decrease in shrub land, fallow land and vegetated areas with major changes for coastal areas, wetlands, Industrial area and built up compact.

4.2 Change Detection

Change categories were carried by post-classification analysis and area of major changes was depicted in Table 2. The major changes are of expansion in industrial area, construction of new road connecting islands to flatland areas, new builtup areas including Kochi metro yard, new coastal areas due to sandy deposits, (Figure 6).

4.3 Accuracy Assessment

Statistics has shown that the extraction of dominant LULC classes through automatic extraction has resulted in a higher accuracy (Figure 2). For carrying out accuracy sample point location were generated using stratified random sampling approaches. A total of 281 ground truth point locations were used and further 80 ground points were generated using Bhuvan geo-portal high resolution

imagery. The accuracy assessment with respect to post classified layer of 2005 shows an overall accuracy of built up, water body, and aquaculture as 78.46%, 97.32% and 99.3% respectively. The overall accuracy for cropland was low as there was ambiguity between agricultural plantation and cropland in level-II classes. The built up and fallow land has same spectral and textural identity which reduces the efficiency to automatically extract them separately which resulted in lower accuracy. The overall accuracy achieved for LULC map was 92.8% which shows the capability of combined feature extraction and onscreen knowledge based classification approach. The result represents that the merging and interpretation of classes with combined approach is better than individual object based or pixel based approach.

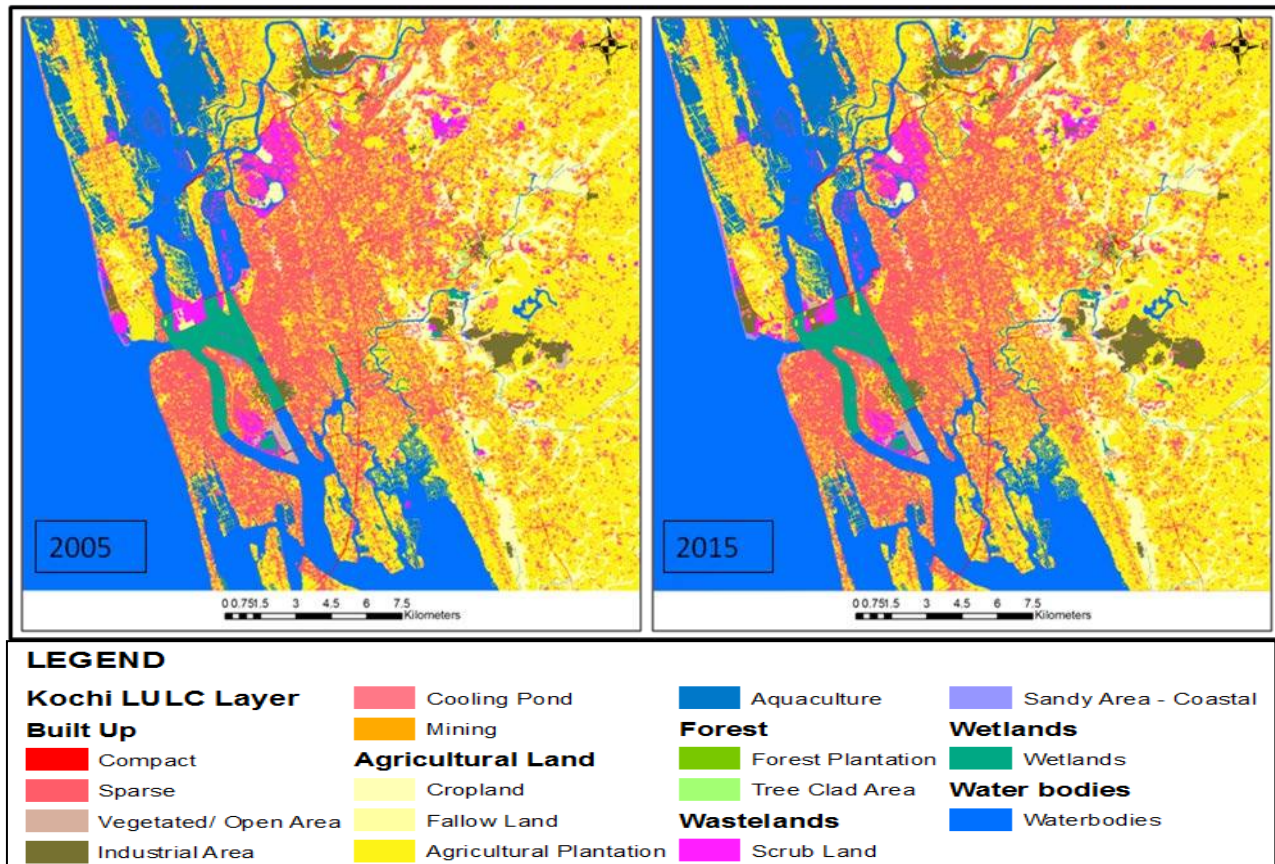


Figure 5. Land Use/Land Cover Map of 2005 & 2015

Level - I Class	Class name	Class Code	2005	2015	Change (sq.km)	% Change w.r.t 2005
Built up	Compact	1	1.70	2.17	0.47	27.89
	Sparse	2	134.51	135.23	0.72	0.53
	Vegetated	3	2.79	2.66	-0.14	-4.96
	Industrial	5	8.48	11.82	3.35	39.45
	Cooling pond	6	0.53	0.66	0.13	25.43
	Mining	8	0.27	0.27	0.00	0.00
Agricultural Land	Cropland	10	40.21	39.63	-0.58	-1.45
	Fallow land	15	3.68	3.29	-0.39	-10.49
	Plantation	16	228.91	226.34	-2.57	-1.12
	Aquaculture	17	30.25	30.42	0.18	0.58
Forest	Forest Plantation	22	0.01	0.01	0.00	0.00
	Tree Clad area	26	0.88	0.89	0.00	0.28
Wasteland	Scrubland	34	13.98	12.82	-1.16	-8.31
	Sandy area	37	0.77	1.14	0.36	46.51
Wetlands	Wetland	40	11.53	10.59	-0.94	-8.14
Water body	Water body	44	166.11	166.68	0.57	0.34

Table 2. Change area statistics

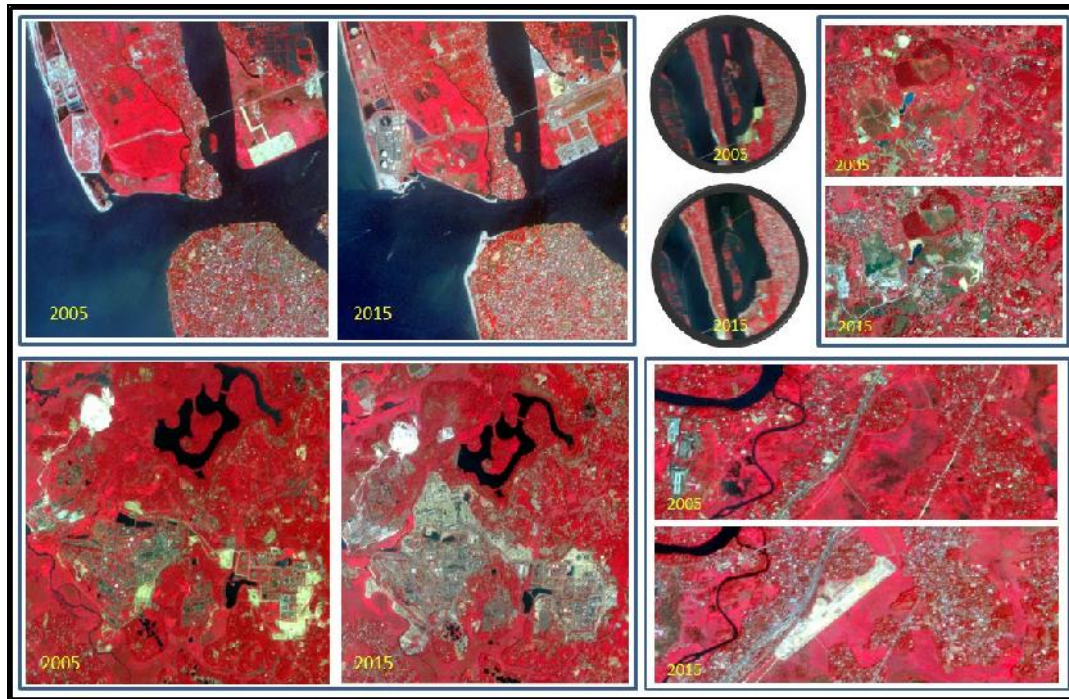


Figure 6. Change areas between 2005 and 2015

5. CONCLUSIONS

The existing methods of LULC classification based on satellite images are not sufficiently effective (Compton et al., 1985). Based on the satellite images on decadal basis and assuming the importance of single feature layer, an automatic feature extraction method has been proposed. The features can be automatically extracted using the threshold values of certain class specific parameters with less human interaction and interpretation. Later, the onscreen knowledge based interpretation is used to achieve higher accuracy in classification. However the method still needs to be updated and improved for different regions such that various other parameters can be used to extract more features and reduce human intervention.

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LAND USE/ LAND COVER CHANGE PREDICTION USING LAND CHANGE MODELER

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ABSTRACT

Land Use / Land Cover change (LULCC) is an important factor to understand human interactions and its impact on environment, climate in temporal scales. Analysis of the series of temporal datasets helps in predicting the future scenario, which in turn aids in proper management of land resources. The objective of the study was to analyze the Land Use Land Cover change around the metropolitan city of Hyderabad and predict the future use of land. Landsat satellite images of 1988, 2000, 2011 and 2017 were used for the LULC classification. The generated LULC maps along with the DEM, slope and road network were used in prediction of future Land Use for the years 2011, 2030 and 2035. Multi-Layer Perceptron (MLP), Markov chain built-in algorithms in Land change modeler (LCM) module were used for the study. Land change maps, including gains and losses, net change, and persistence of specific transitions has been noticed and analyzed. The results of the study revealed that numerous changes occurred in the study area during 1988 and 2017. The major change noticed was rapid urban expansion and this was due to the increased population pressure over the time period. A comparison was made between classified land cover and model predicted land cover for the year 2011 and the results indicate good consistency between predicted results and actual Landuse situations.

KEYWORDS: Land Use Land Cover Change (LULCC), Land Change Modeler (LCM), Future LULC, Multi-Layer Perceptron (MLP).

1. INTRODUCTION

The study of Land Use / Land Cover (LULC) changes is very important and growing rapidly because of importance in identifying the effects of human on the environment, and to have proper planning and utilization of natural resources and their management (N. E. M. Asselman, 1995). With appropriate spatial, temporal and spectral resolution, most of the earth surface can be monitored with remote sensing and satellite imagery. With the advancement of technology, reduction in data cost, availability of historic spatio-temporal data and high resolution satellite images, Remote Sensing (RS) and Geographic Information System (GIS) techniques are now very useful for conducting researches like land cover change detection analysis and predicting the future scenario (Lambin, E.F. 2001). There are many traditional methods for analyzing Land Use / Land Cover changes, now a days many models have come up. Models of Land Use change are tools to support the analysis of the causes and consequences of Land Use changes in order to better understand the functioning of the Land use system and to support Land Use planning and policy (Peter H. Verburg, 2004). At present, models of LULC change have been developed to explore where, when and why it occurs based on the goals of a particular study (Schaldach, R. 2011).

This paper mainly focused on Land Change Modeler (LCM) software extension in Arc GIS developed by CLARK LABS, which was used for rapid assessment of Land Cover change and change prediction. The change modeling process in Land Change Modeler consists of a series of steps, sequentially organized within the Projects and Change Analysis, Transition Potential modeling, Change prediction and Validation tabs (Terr set Tutorial). By analyzing past Land Cover changes, future scenario of Land Cover was predicted for Hyderabad and its surroundings. Multi Layer Preceptron (MLP) Neural Network and Markov Chain (MC) built in algorithms in LCM were used for creating transition potential maps and future Land Cover prediction maps respectively. Model variables have been selected and each transition is modeled using extensively enhanced multi-layer perceptron (MLP) neural network. The Markov model can most importantly depict the direction of LULC shifts, providing a frame work for analyzing future Landuse demand. The model has been widely used to predict LULC change (Huiran Han, 2015). The objectives of the study are to analyze land cover changes from 1988 to 2000 and 1988 to 2017 using LCM for Hyderabad and its surroundings, generate prediction maps for 2011, 2030 and 2035, tabulate statistics and validate model results.

2. STUDY AREA

The study area, a part of Rangareddy district, the metropolitan city of Hyderabad and its surroundings in Telangana state, India, is lies between 17°1'45.17"N and 17°44'55.763"N latitudes and 78°4'52.462"E and 78°50'51.271"E longitudes. The total area under this study is 6503.6 sq. km (Figure 1). This area has increased potential to face massive built-up growth in near future based on current trend of rapid urbanization.

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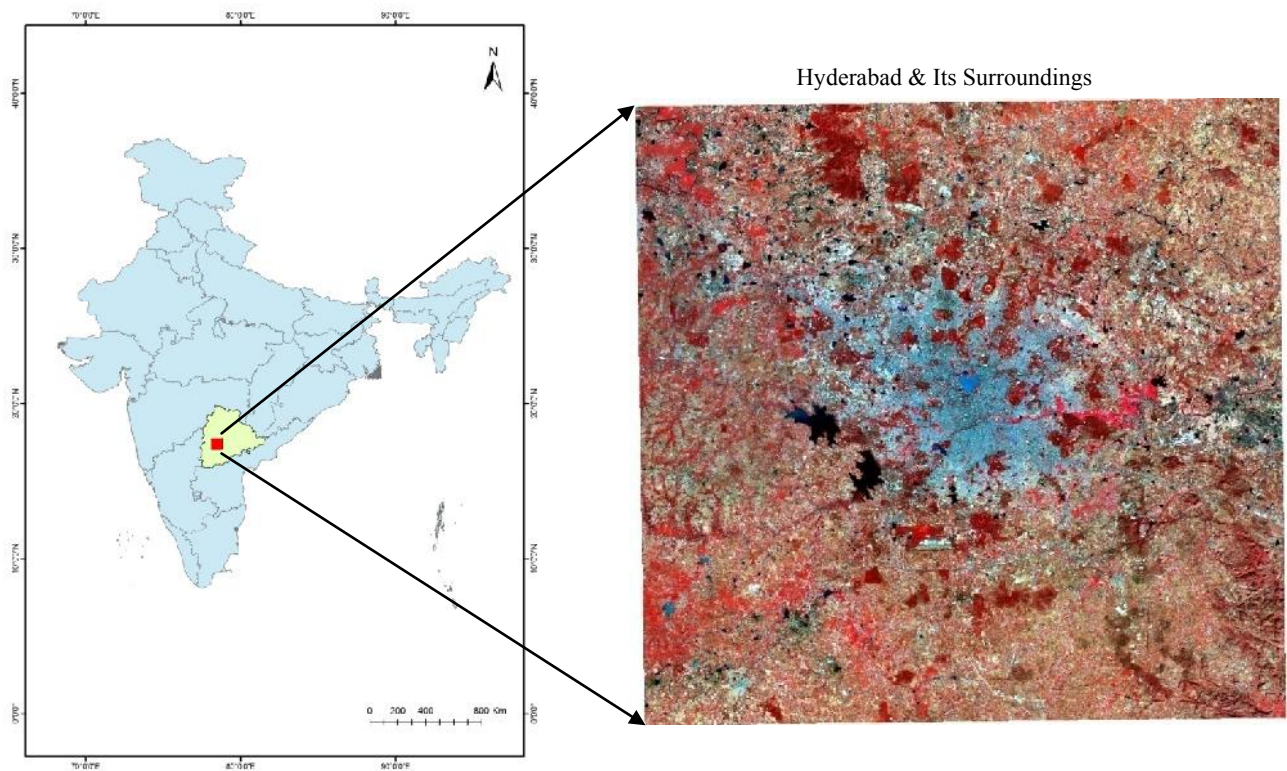


Figure 1. Study area of Hyderabad and its surroundings Viewed by Landsat-8

2.1 Data Used

To prepare Land Use /Land Cover maps for analysis and applying the different methods to achieve the research objectives, the Landsat satellite images for the years 1988, 2000, and 2017 have been collected from the website of US Geological Survey (USGS). Landsat Path 144, Row 48 covers the entire study area. The collected satellite images having Universal Transverse Mercator (UTM) projection within zone 44 North, Datum-World Geodetic system (WGS) 84 and the resolution is 30m. Resourcesat, LISS III data from ISRO's Bhuvan portal, was used for the year 2011 due to unavailability of Landsat data and this was resampled to 30 meters. The detailed specifications of data are represented in below Table 1.

Satellite	Sensor	Path	Row	Resolution
Landsat-5	TM	144	48	30 m
Landsat-7	ETM+	144	48	30 m
Landsat-8	OLI	144	48	30 m
Resourcesat-1	LISSIII	100	61	23.5 m
		100	60	
		99	60	

Table 1. Specifications of Landsat Satellite Data

3. METHODOLOGY

Land Use / Land Cover thematic maps were generated using collected satellite data in Arc GIS software. Remote Sensing based techniques have been used to predict the future Land Cover of study area. Total six Land Use/Cover categories have been identified for this study. The following are the six classes used for classification.

1. Built-up
2. Agriculture Land
3. Forest
4. Scrub Land
5. Barren areas
6. Water body

Classified maps are fed into Land Change Modeler (LCM) software as inputs and change analysis has been carried out. The results in LCM are quantitatively assess the land cover changes. Different transitions were modeled for prediction of future land cover for the study area. The whole methodology is explained briefly with the help of flowchart given in Figure 2.

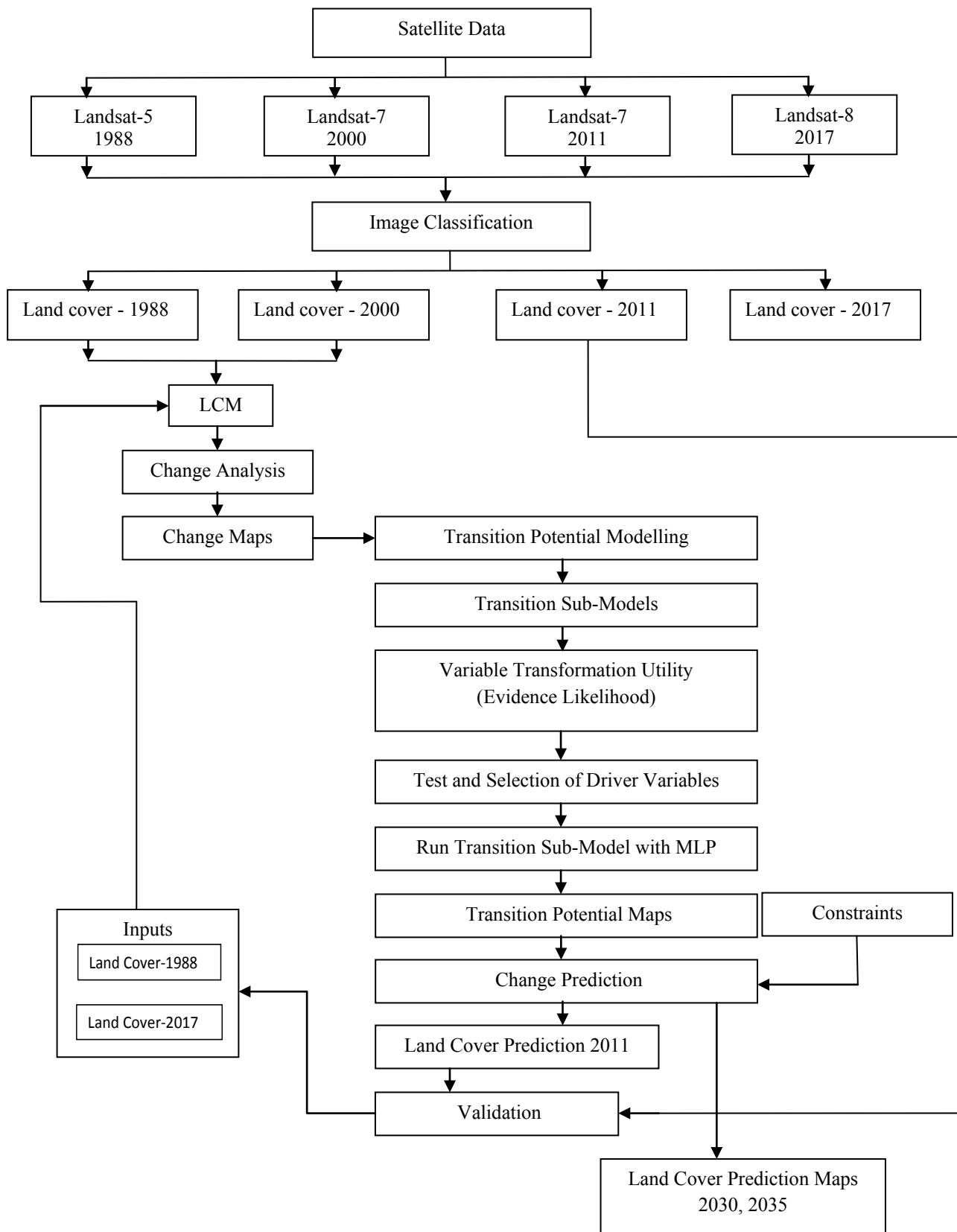


Figure 2. Overview of the methodology

4. RESULTS AND DISCUSSION

Geometrically, atmospherically corrected Landsat series satellite images for different years 1988, 2000, 2011 and 2017 were collected from USGS for the study. Land Use / Land Cover thematic maps (Figure 3) were derived from satellite images through visual interpretation technique.

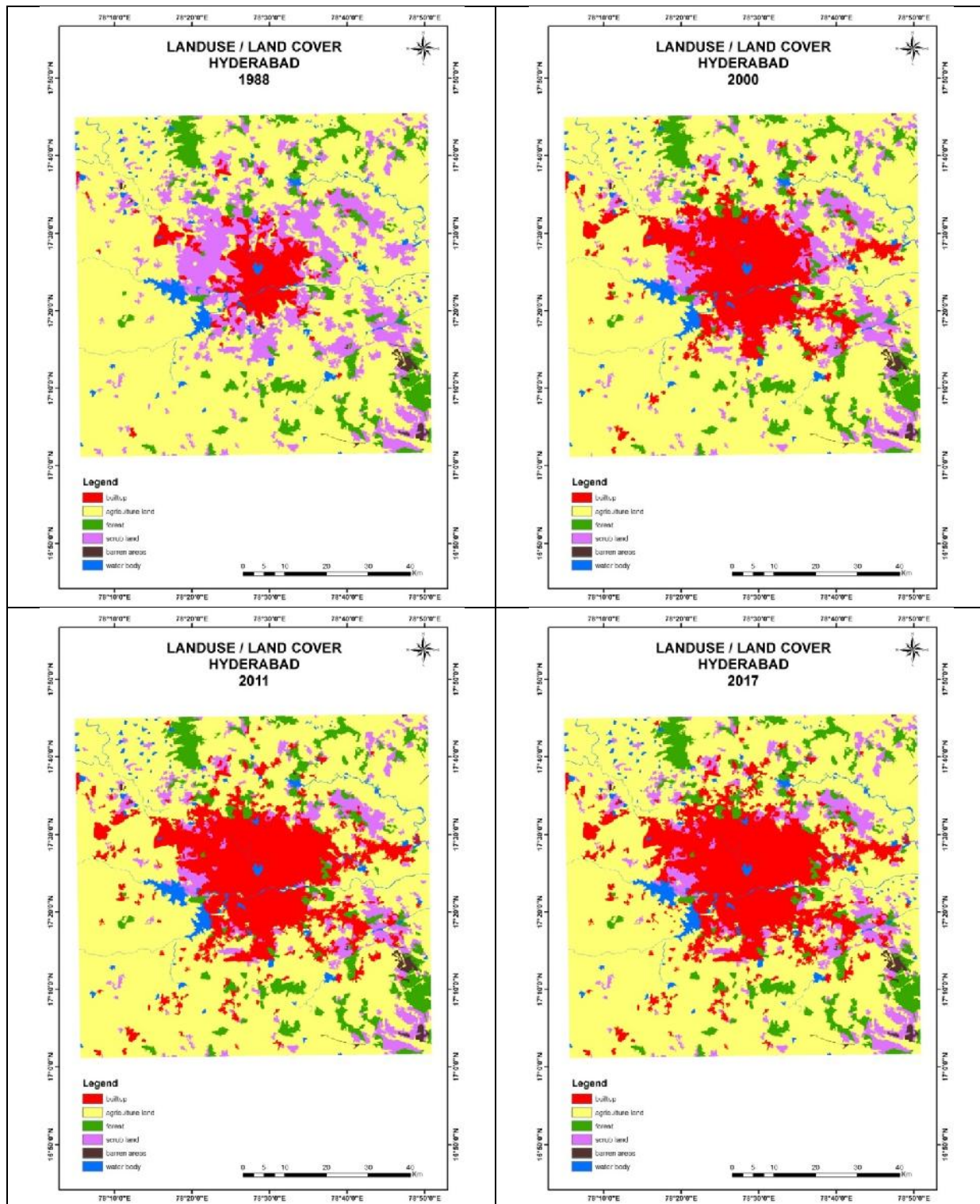


Figure 3. Classified Land Cover Maps of Study Area for 1988, 2000, 2011 and 2017

Land Cover maps are given as input parameters in Land Change modeler (LCM) and changes were analysed from 1988-2000 and 1988-2017. Graphs of gains and losses and net change in each category were derived (Figure 4) in change analysis panel. This

graphs helped in understanding change in categories from earlier land cover to later land cover. The biggest gain observed here is in the Builtup class. Using change analysis panel what are the classes contributing for change in particular class was also analysed (Figure 5). Changes from 1988 to 2000 and 1988 to 2017 were generated as maps by applying the area filter 250 ha. in change maps panel are shown in the Figure 6.

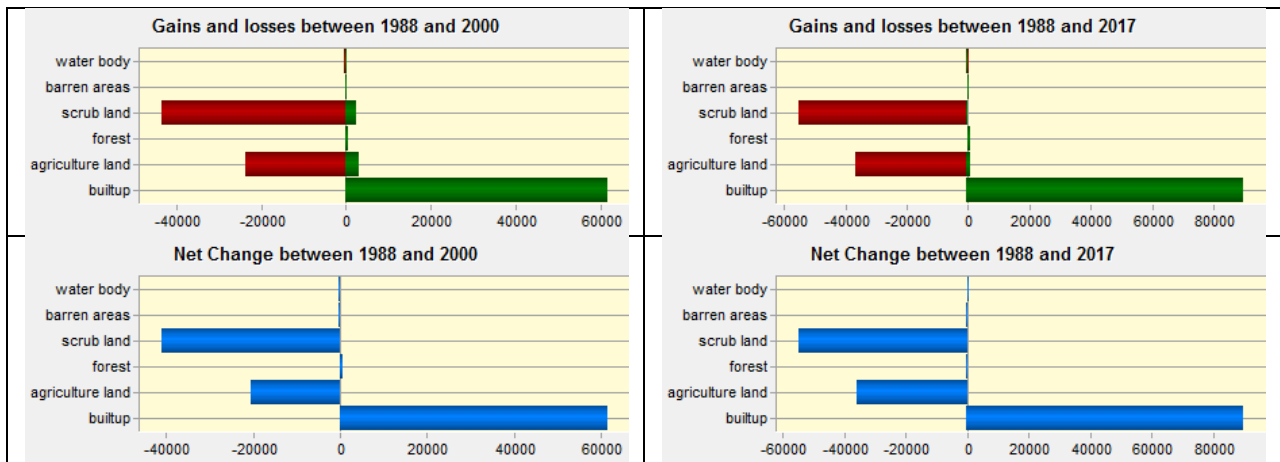


Figure 4. Gain and Losses, Net Change between 1988-2000 and 1988-2017

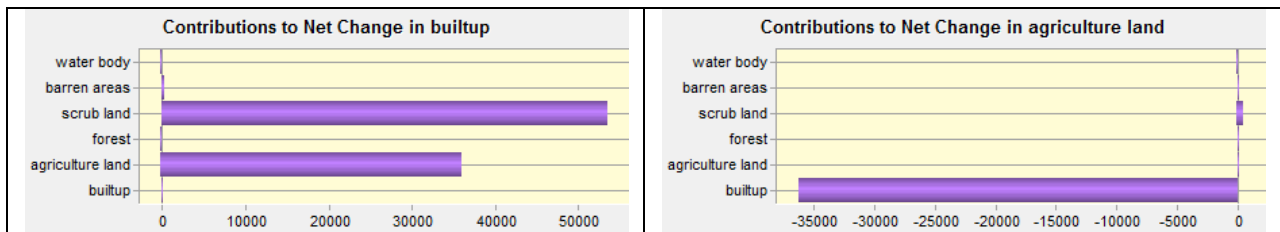


Figure 5. Contributions to Net Change in Category (Builtup, Agriculture) from 1988-2017

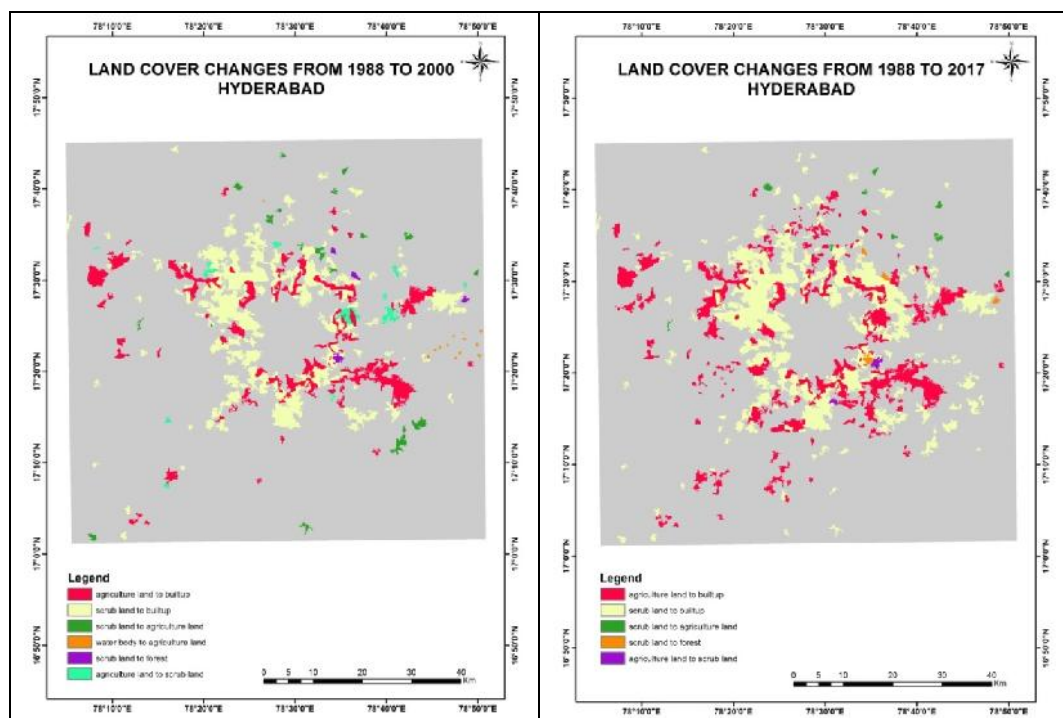


Figure 6. Land Cover Change Maps from 1988 - 2000 and 1988 - 2017

Changes from one category to another category was identified and quantitatively represented in Tables 2 and Table 3 for 1988-2000 and 1988-2017 respectively.

S. No	Category Changes From	% Area Change
1	Agriculture Land To Built-up	3.29
2	Scrub Land To Built-up	6.12
3	Scrub Land To Agriculture Land	0.44
4	Waterbody To Agriculture Land	0.04
5	Scrub Land To Forest	0.10
6	Agriculture Land To Scrub Land	0.35

Table 2. Area Statistics for Changes from 1988 to 2000

S. No	Category Changes From	% Area Change
1	Agriculture Land To Built-up	5.56
2	Scrub Land To Built-up	8.22
3	Scrub Land To Agriculture Land	0.14
4	Scrub Land To Forest	0.10
5	Agriculture Land To Scrub Land	0.07

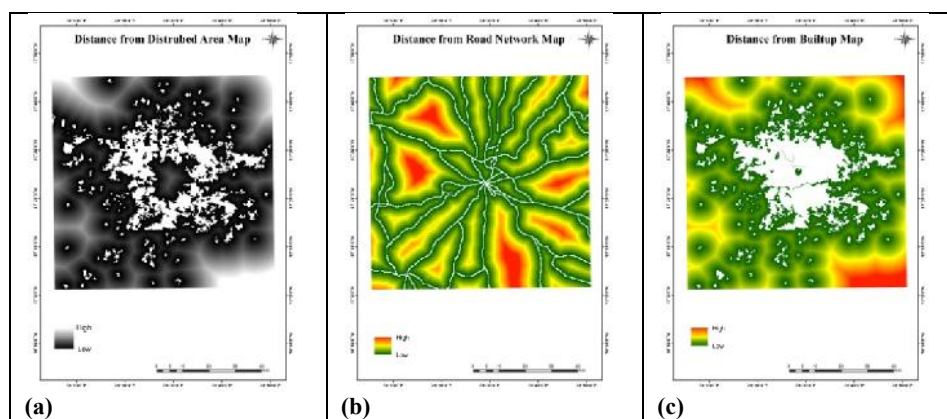
Table 3. Area Statistics for Changes from 1988 to 2017

The results indicating that conversion from Agriculture land and Scrub Land to Built-Up is gradually increasing from the years 1988 to 2000 and 2017. Analysing these changes is very much important to perform transition potential modeling which will be further used for change prediction. In order to predict change, each of the above listed transitions was modeled.

LCM has different tools to create transitions out of which, Multi-Layer Perceptron (MLP) neural network tool was used. MLP is a feed-forward Neural Network with one or more layers between input and output layers. MLP has the capability of modeling several or even all transitions at once. MLP needs to reach higher accuracy and this depends on influencing variables. Different variables were used for modelling transitions. Variables used in this study are:

1. Distance from Road Network
2. Distance from Built-up
3. Elevation
4. Slope
5. Distance from Disturbed areas
6. Evidence likelihood transformation variables for particular category which is to be modeled.

Distance from Disturbed areas map (Figure 7(a)) was created by isolating the disturbed areas from the earlier land cover image filtered it with 3x3 mode filter to remove extraneous pixels and then running a distance analysis on the result. Proximity to road network, Built-up, (Figure 7(b)) was calculated from spatial analyst tool in Arc GIS software. Carto-DEM was used for preparation of elevation map (Figure 7(d)) and slope (Figure 7(e)) was calculated from DEM. Before adding these variables in the model it is required to test the potential explanatory power of each variable. The quantitative measures of the variables have been tested through Cramer's V. It is suggested that the variables that have a Cramer's V of about 0.15 or higher are useful while those with values of 0.4 or higher are good (Cramér, H. 1999). Out of six variables, distance from road and distance from disturbance variables were specified as dynamic as they are time dependent. All the above mentioned variables were tested through Cramer's V and added to the model.



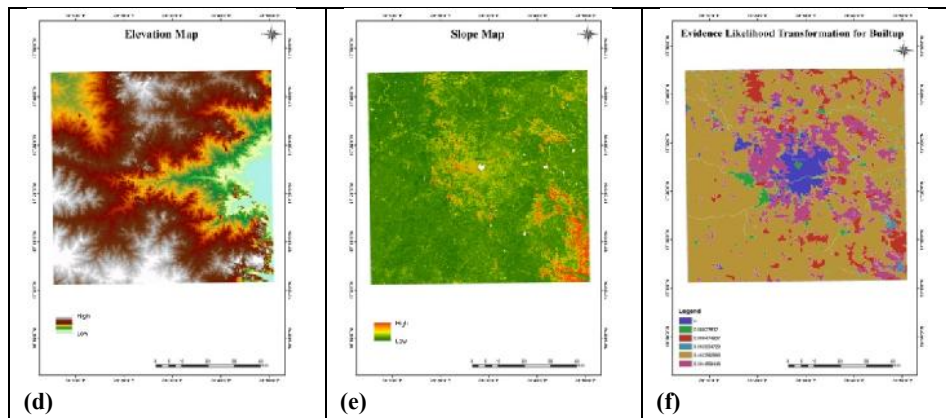


Figure 7. Variables used to create Transition Potential Maps (a) Distance from Disturbance, (b) Distance from Road Network, (c) Distance from Urban, (d) Elevation, (e) Slope, (f) Evidence likelihood transformation for Built-up.

In order to create transition potential maps, MLP should achieve an accuracy rate of 80%. In this study all the transition maps were created with more than 85% of accuracy (Figure 8). A HTML file was generated for each transition after the MLP procedure, which reported the nature of the model.

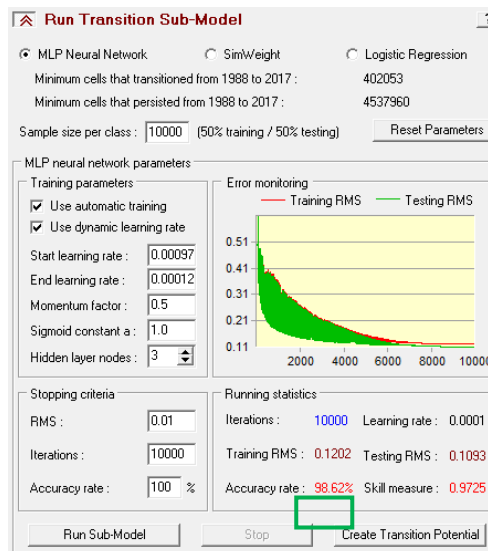


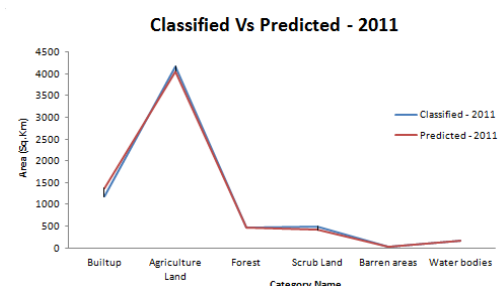
Figure 8. MLP Classifier Process

4.1 Change Prediction and Validation

Different constraints were used in this model before generating prediction map. Constraints are used to limit the alternative under consideration. Basically it identifies the areas in a class that can be used for change from other class to this class, and areas that cannot be changed. The constraints are represented as Boolean maps, considered areas have value 1 and areas not included or not considered have value 0. For each class constraints were used one of the constraint for Built-up areas as they can not built in the area with more than 12 degrees slope. Using Land Cover maps of 1988 and 2000 as inputs, land cover for 2011 was predicted (Figure 9) from Markov-Chain model. Predicted land cover map of 2011 was validated with classified Land cover using model and a validation map (Figure 10) was generated. Results indicated that, model predicted Land Cover image for 2011 was well matched with classified one and maximum 3% area difference was found among all the categories (Table 4).

S. No	Class Name	Classified Area (Sq. Km)	Classified % Area	Predicted Area (Sq. Km)	Predicted % Area
1	Built-up	1178.42	18.12	1369.96	21.06
2	Agriculture Land	4170.81	64.13	4060.89	62.44
3	Forest	473.98	7.29	473.89	7.29
4	Scrub Land	492.68	7.58	411.43	6.33
5	Barren Areas	32.12	0.49	32.20	0.50
6	Water Body	155.58	2.39	155.23	2.39

Table 4. Area Statistics for Classified and Predicted Land Cover - 2011



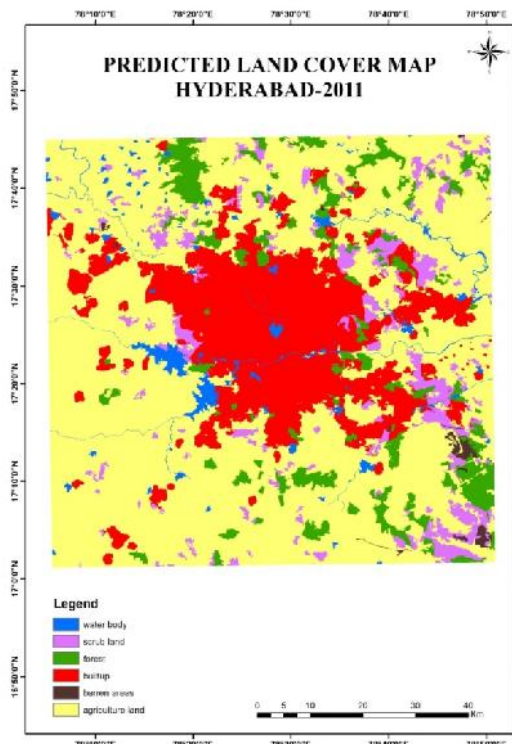


Figure 9. Land Cover Prediction Map - 2011

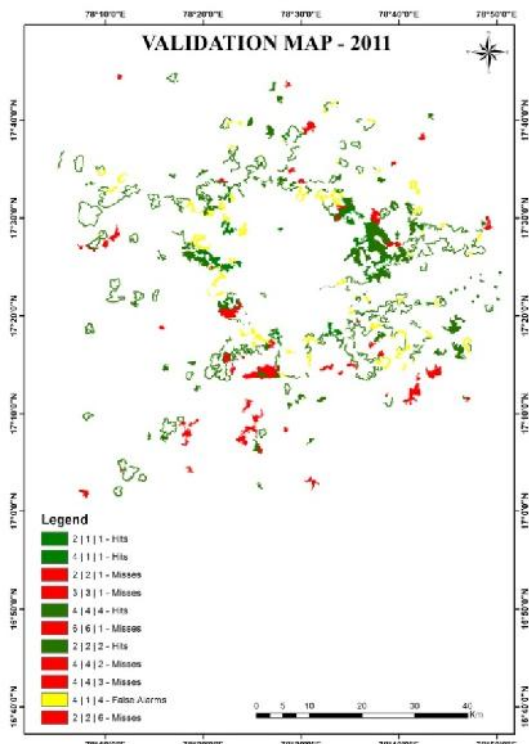


Figure 10. Validation Output map - 2011

A good accuracy was observed from model, future prediction maps for the years 2030, 2035 (Figures 11, 12) were created using land cover maps of 1988 and 2017.

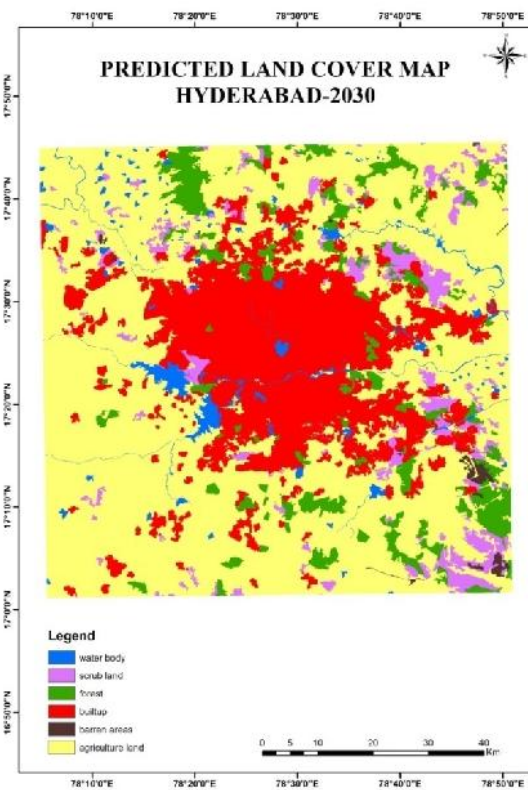


Figure 11. Land Cover Prediction Map - 2030

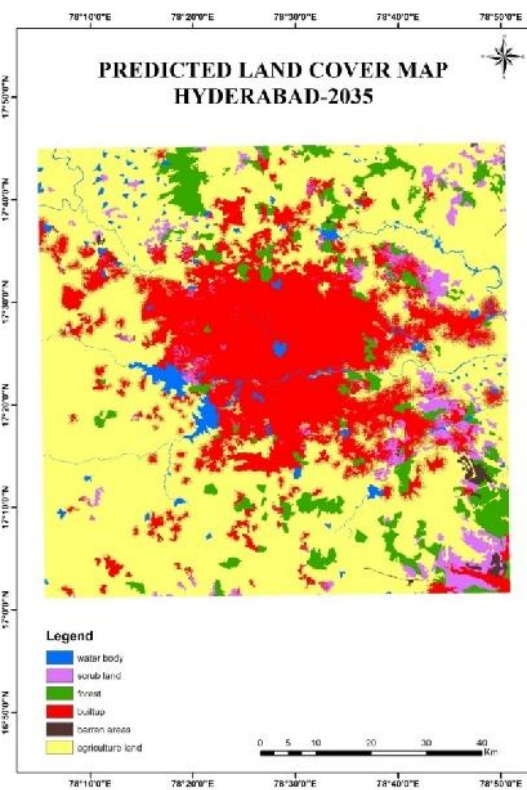


Figure 12. Land Cover Prediction Map - 2035

Results indicating that 4.83% Built-up area will be increasing from 2017 to 2030 and this continue to 2035. Area wise statistics for all categories were represented in below Table 6.

Class Name	Classified Area (Sq. Km) 2017	Classified % Area 2017	Predicted Area (Sq. Km) 2030	Predicted % Area 2030	Predicted Area (Sq. Km) 2035	Predicted % Area 2035
Built-up	1239.54	19.06	1553.46	23.89	1642.30	25.25
Agriculture Land	4096.34	62.99	3944.19	60.65	3889.84	59.81
Forest	474.07	7.29	476.00	7.32	474.07	7.29
Scrub Land	502.44	7.73	338.70	5.21	306.18	4.71
Barren Areas	32.21	0.50	32.20	0.50	32.21	0.50
Water Body	159.02	2.45	159.01	2.45	159.02	2.45

Table 6. Land Cover statistics of the study area for 2017, 2030 and 2035

5. CONCLUSION

This study was to understand the working of the Land Change Modeler and it has been found most accurate module for prediction of Land Cover. Future Land Cover maps for the years 2030, 2035 were predicted using necessary inputs. Current study indicating that, massive urban expansion has happened in the study area and it's going to be happening in future years also, which needs to be done in a planned way. These kinds of studies are more useful for proper urban planning and decision making in current study area Hyderabad city. The present study also demonstrated the usefulness of Remote Sensing data for Land Use / Land Cover Change analysis.

6. APPENDIX

1. All files used in Land Change Modeler (LCM) for ArcGIS must have the same spatial parameters and reference system. This includes the same projection, cell size, spatial extent, spatial resolution and rows and columns.
2. All land cover maps must contain the same categories and sequential order. Labels must be specified in the attribute table for the category names to be displayed in the LCM interface. Background or flag values must be the same for each image, both the values and the spatial extent.
3. Land Change Modeler for ArcGIS uses data only in IDRISI format. However, any raster file format supported by ArcGIS, including grid files can be loaded into the LCM interface. These files will be converted automatically to the IDRISI raster or vector formats having the extensions .rst/.rdc or .vct/.vdc, respectively. (Virginia Smith, 2007 LCM Software from Clark Labs)

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IDENTIFICATION AND QUANTIFICATION OF GROUNDWATER POTENTIAL ZONES FOR SUSTAINABLE DEVELOPMENT IN PALAKKAD DISTRICT: A GEOSPATIAL APPROACH

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ABSTRACT

Groundwater is envisaged as a valuable common resource. In the present day, groundwater is declining very rapidly due to human intervention. Stress on groundwater in the Kerala State, especially in Palakkad district, is very high due to immense demand and overexploitation. The fundamental goal of the study is to identify potential groundwater zones for the appraisal of groundwater availability in Palakkad district using the geospatial tools. Palakkad is a major Paddy growing area of the Kerala State and is often called as the “Gateway of Kerala”. There is considerable change in the land use and cropping pattern in the district for the last five years. Due to low income from paddy and coconut, farmers have changed the cropping pattern to cash crops like sugarcane, vegetables and flower cultivation. Over dependence on groundwater for domestic, irrigation and industrial purposes in the district has led to the lowering of water table and water scarcity especially along the eastern parts. In most of the areas especially in eastern part of the district, decline of water levels necessitates deepening of existing dug wells and putting deep bore wells thereby increasing cost of pumping and quality deterioration.

In this scenario it is right time to have a study on groundwater potential zones in the district. The identification of groundwater prospecting zones can be identified with the help of overlying different thematic layers like Geomorphology, Geology, Soil, LULC, Drainage density, etc., with help of Remote Sensing and GIS. The normalized weights of the individual themes and their different features were obtained through the Saaty’s Analytical Hierarchy Process (Saaty, 1980). Each layers of the theme were given different ranking depending on their significance in groundwater prospect. Based on all these parameters and weightages the potential zones are identified. The identification of Potential Zones in the district will help the planners for having a proper management in the area where ground water is at high risk.

KEYWORDS: Groundwater Potential Zones, Analytical Hierarchy Process, Sustainable Development, Ground water exploitation

1. INTRODUCTION

Ground water is one of the important natural resource which is essential for the sustenance of life on the Earth. The adequate supply of water is important for the drinking, irrigation, domestic and other industrial needs. Groundwater occurs in the pore spaces of sediments and rocks. The occurrence and distribution of groundwater is confined to certain geological structures and formations. Thus, proper exploration technique must be employed to solve the problems of exploitation and management of groundwater.

Remote Sensing is defined as the science of obtaining information about objects or areas from a distance, typically from aircraft or satellites. Remote sensing and Geographic Information Systems (GIS) techniques well established and the most important method for groundwater investigation. The remote sensing technique is widely used because of its theoretical, operational and interpretational ease. The subsurface properties of the earth can be derived based on its surface features and expressions (Lilles and et al., 2004). A detailed picture of subsurface can be obtained by combining different thematic layers of earth surface.

The application of remote sensing techniques in ground water study mainly uses visual interpretation of satellite data. It is rapid and cost- effective tool for assessing, monitoring and conserving groundwater resources. Multi-temporal and multi-sensor data cover large and inaccessible area within short span. The concept of integrating remote sensing and GIS has emerged in the last decade as an essential tool for resource planning and management. GIS is an effective tool for collecting, storing, transforming, retrieving, displaying and analyzing spatial data from the real world for particular use. These days, GIS is being used for various purposes such as evaluation of ground and surface water resources, feasibility of recharge sites, identifying contaminated sites, land use pattern, land cover etc.

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1.2 Study Area

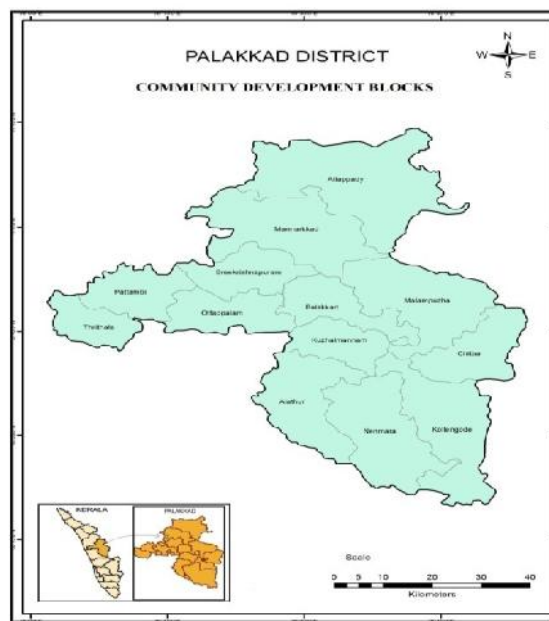


Figure 1. Study area map- Palakkad District

The present study considers Palakkad district of Kerala state as the study area. Palakkad (Palghat) is the land of Paddy fields and Palmyrahs. Palakkad is a major Paddy growing area of the State. It is often called as the “Gateway of Kerala”. Palakkad is the part of erstwhile Malabar district of Madras presidency. The district accounts for about 11.5% of the total land area of the state of Kerala while the share of population is 8.22%. The district has got two types of climate. Ottappalam, Alathur and Mannarkkad are having a climate similar to that of other districts of Kerala whereas Palakkad and Chittur are having rather a dry climate similar to Tamilnadu. There are five Taluks and 163 Villages in the District and four Municipal Towns and ninety one Panchayats. The district is divided into 13 community development blocks for the effective implementation of various developmental activities.

Palakkad district is situated in the South west coast of India. The district is bounded on North by Malappuram district, south by Trichur (Thrissur) district, East by Coimbatore district of Tamil Nadu and west by Trichur and Malappuram districts. The district is between $10^{\circ} 21'$ and $11^{\circ} 14'$ North latitudes and $76^{\circ} 02'$ and $76^{\circ} 54'$ East longitudes. It is located in the east central portion of Kerala district. It covers an area of 4480 sq.km. (438980 hectares) representing 11.53 % of the states geographical area. The district is bounded by high hills of Nilgiris in that north and north east; subdued hills and spurs of the Western Ghats in the east and south east separate the district from Coimbatore. The south and south west portion is partly bounded by high hills and partly by Karappara River separating from the Thrissur district of Kerala state. The west and North West is bounded by low ridges separating it from Malappuram district.

2. MATERIALS AND METHODS

For the identification of Groundwater Potential Zones (GPZ) several thematic layers have been prepared. Various thematic maps like geomorphology, Geology, slope, Lineament Density, Drainage Density, Landuse/landcover, Geo-hydrology, Soils and rocks & minerals were prepared. Suitable weights were assigned to the seven themes and their individual features after understanding their hydrogeological importance in causing groundwater occurrence in the study area. The normalized weights of the individual themes and their different features were obtained through the Saaty's Analytical Hierarchy Process (Saaty, 1980). Each layers of the theme were given different ranking depending on their significance in groundwater prospect. The weights assigned to different features of the individual themes and the ranks of each units of particular theme are presented in Table 1.

Suitable ranking on a scale of 'six' are assigned to each class (factors) of a particular thematic layer on the basis of their significance with reference to their ground water potential. The first rank classes are considered as least favorable zones for ground water exploration and sixth rank is for most potential. So themes are classified based on their ground water potential as Excellent, Very Good, Good, Moderate, Poor and Very Poor. The final scores of each unit of the theme are equal to the product of the rank and weightage. This is calculated using 'raster calculator' and the entire study area was quantitatively divided in to six ground water potential zones and a map showing these zones in ARC-GIS

Table 1. Ranks and weightages of attributes of various themes

Theme	Weight	Identified Factors	Source	Rank	Groundwater potential
Geomorphology	32	Denudational Structural Hills	Kerala state landuse Board	3	Moderate
		Piedmont Zone		3	Moderate
		Waterbody		6	Excellent
		Pediplain		4	Good
		Rock Exposure		1	Very Poor
		Floodplain		5	Very Good
		Plateau		1	Very Poor
		Denudational Hills		2	Poor
		Residual Hills		1	Very Poor
		Structural Hills		2	Poor
Geology	26	Peninsular Gneissic Complex	Kerala State landuse Board	3	Moderate
		Charnockite Group of Rocks		2	Poor
		Basic Rocks		1	Very Poor
		Metabasic and Ultra Basic Rocks		2	Poor
		Pegmatite		2	Poor
		High Grade metasedimentary rocks		3	Moderate
		Migmatite Complex		1	Very Poor
		Laterite		4	Good
		Sand and Silt		6	Excellent
		Kondalite		3	Moderate
		Sandstone		5	Very Good
		Tank/WB		4	Good
Lineament	8	High	Kerala State landuse Board	5	Very Good
		Medium		4	Good
		Low		3	Moderate
Drainage Density	13	High	Kerala state landuse Board	6	Excellent
		Medium		4	Good
		Low		3	Moderate
Slope	5	Nearly Level	ASTER DEM	6	Excellent
		Very gentle		5	Very Good
		Gentle		4	Good
		Moderate		3	Moderate
		Steep		2	Poor
		Very steep		1	Very Poor
Landuse/Landcover	7	Forest	Kerala State landuse Board	5	Very Good
		Grass land		5	Very Good
		Agriculture		4	Good
		Water bodies		6	Excellent
		Built Up		2	Poor
		Wasteland		1	Very Poor
Soil	9	Wetland	Kerala State landuse Board	3	Moderate
		Clay		1	Very poor
		Gravelly clay		3	Moderate
		Gravelly Loam		4	Good
		Loam		4	Good
		Sandy		6	Excellent

3. RESULT AND DISCUSSION

The details of Geomorphology, Geology, Slope, Drainage Density, Soil, Lineament Density, Landuse/landcover with their spatial distribution in the study area are presented below

3.1 Geomorphology

The Geomorphological characteristics of the district affect its response to a considerable extent. The geomorphic units delineated in the present study are Lateritic Plateau, Piedmont zone, Coastal plain, Pediplain, Denudation hills, Flood plain and Residual hills. The relief of the basin varies between -6 to 2331 m. The Ground Water Potential of Flood plain is considered as excellent because of their good porosity and permeability with good recharge potential. Piedmont zone are rock floured plains in the uplands and areas adjacent to hills into which the rainwater from the hills drains. Ground water potential of Pediments has been considered as moderate. Pediplain is the flat surface with good weathered profile covering thick vegetation. This unit occupies the topographically low lying area. The ground water potential of the Pediplain is good. The Lateritic plateau and Denudation hills have poor ground water potential, whereas Residual hills have very poor potential in view of their elevation. The geomorphology of the study area is given in Figure 2.

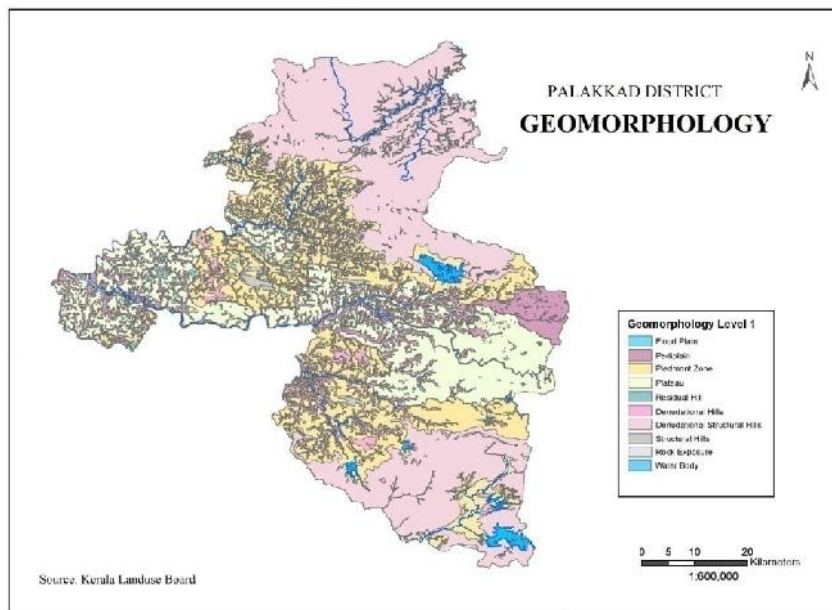


Figure 2. Geomorphology map of study area.

3.2 Geology

Geologically Crystalline rocks belonging to the Archean Metamorphic complex underlie major part of the district. The Charnockite suits of rocks occupy a major part of the district and these are generally massive, devoid of foliations except on weathered surfaces. The Kondalite consists of Granite Silliminate, Gneiss, Granulites and associated with crystalline Limestones. Extensive cover of Laterite occurs all over the midland regions of the district, the thickness of which is often controlled by topography and these laterites are found to increase from east to west favored by topography. They also exhibit a considerable amount of thickness at places of flat topped plateaus. A thin strip of alluvium, consisting of river sand of sandy clay material occurs along major river courses.

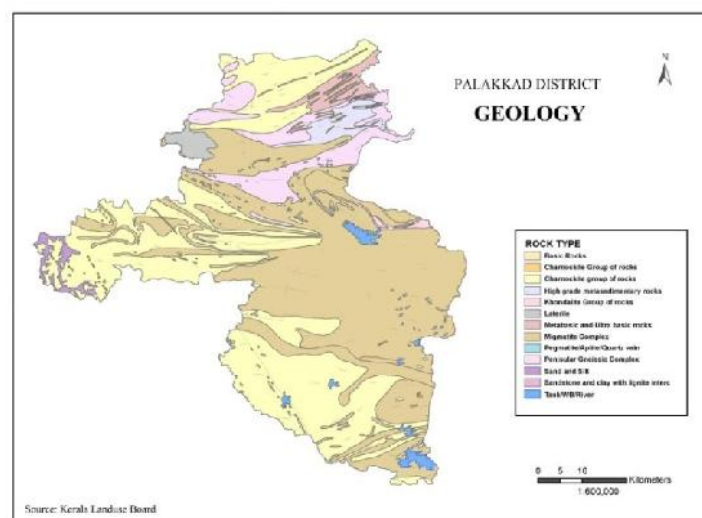


Figure 3. Geology map of study area.

3.3 Lineament Density

In hard rock terrains, lineaments represent areas and zones of faulting and fracturing results in increased secondary porosity and permeability. Lineaments provide the pathways for groundwater movement and are hydrogeologically very important. The Palakkad gap which is considered to be a major east west trending break across the north north-west and south- south east

running Western Ghats is a major geological feature of the district. The major trends of lineaments in the district is WNW-SSE, NNW-SSE and NW-SE. Mostly there are three sets of joints observed trending E-W, NW-SE and NE-SW. The lineament density has been found out with the help of ARC GIS. The whole district is classified into five zones ranging from very low to very high. Very high lineament density is identified in the northern and central part of the district.

3.4 Slope

Slope may be defined as the loss or gain in altitude per unit horizontal distance in a direction. Slope may be dependent on Lithology, Climate, Meteorological parameter, Runoff, Vegetation, Geological structure and the process of denudation. Low degree of slope in the terrain is indicative of nearly level to gently sloping. The slopes have been classified into six categories: Nearly Level Very gentle, Gentle, Moderate, Steep and Very Steep

3.5 Drainage Density

The values have been assigned depending on the density of the drainage pattern. The drainage density of the district is classified into 3 zones, with high, medium and low drainage density. In general, the areas with high drainage density have very good ground water potential and *vice versa*. In the present study, since the drainage density can indirectly indicate the groundwater potential of an area due to its relation to surface run-off and permeability, it was considered as one of the indicators of groundwater occurrence.

3.6 Landuse

Land use refers to man's activities and the various use which are carried on land. Land cover refers to, "natural vegetation, water bodies, rock/soil, artificial cover and others resulting due to land transformations". The landuse/land cover classes like Built-up land, Agricultural land, Waste lands and Water bodies, Forest cover and Wetlands are delineated in the study area. Major share of the district covers under agricultural land where northern and southern part of the district covers with tick forest. The ground water potential of each of these units is given in Table-1.

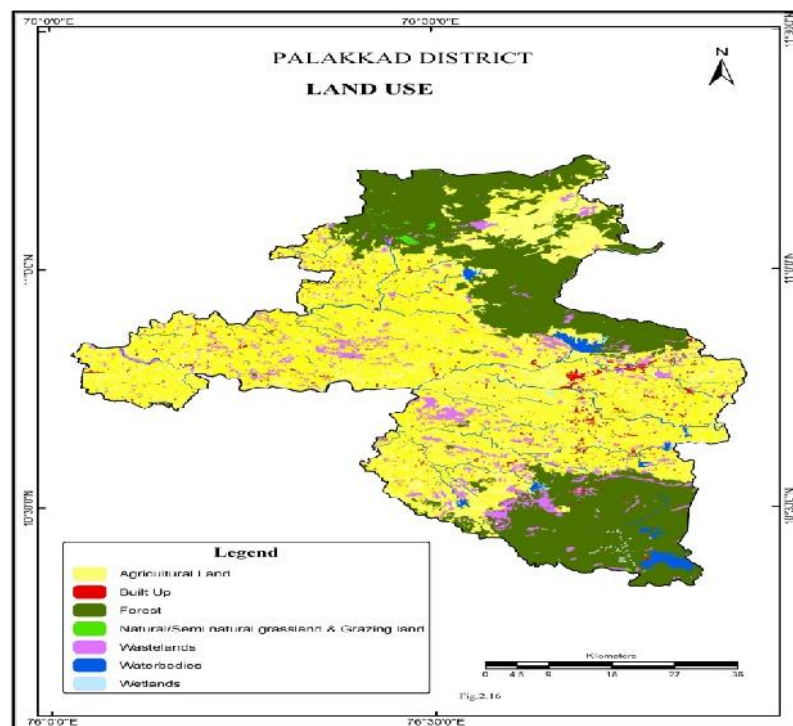


Figure 4. Landuse map of study area.

3.7 Soil

The district have four major types of soil; they are loam, gravelly loam, sandy, loam and clay type of soils. Where as loam and clay soils accounts major share, loam type of soil is concentrated in Central part of the district. The Groundwater Potential for each type has been discussed in table-1.

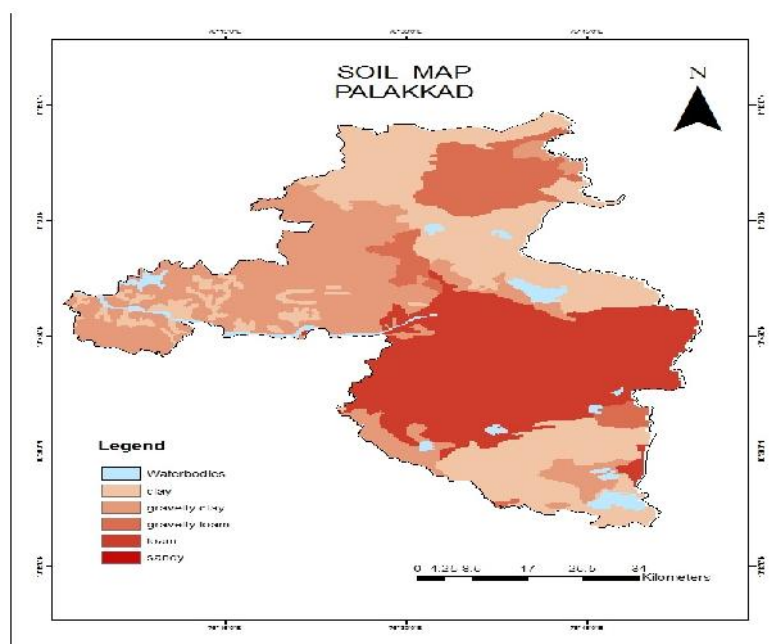


Figure 5. Soil map of study area.

3.8 Groundwater Potential Zones

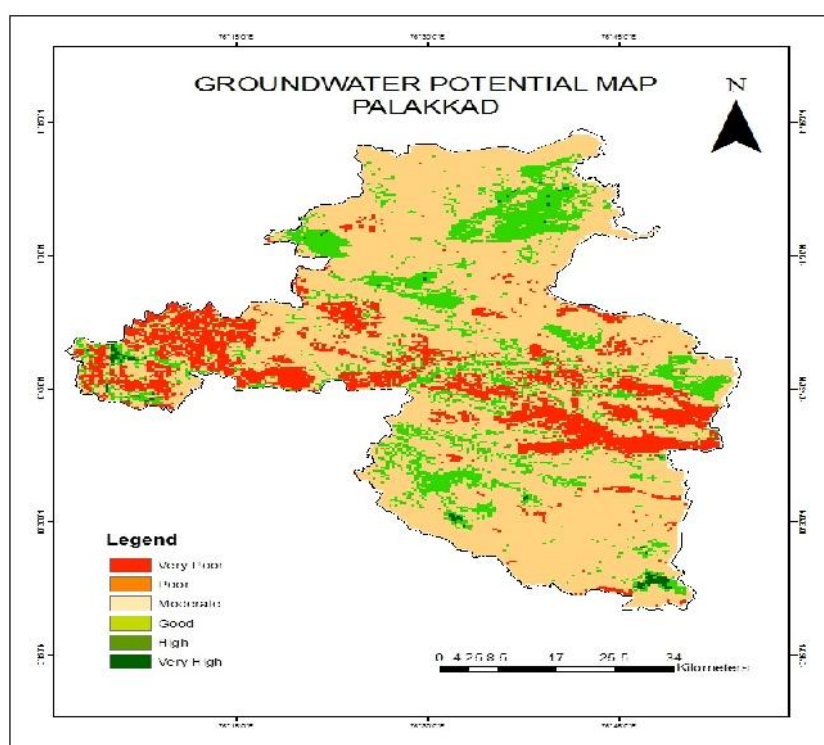


Figure 6 . Groundwater Potential map

Groundwater potential map of Palakkad district shows six distinct classes: Very poor, poor, moderate, good, very good and excellent (Fig.4). Major parts of the district come under Moderate class, where groundwater potential is moderate. Central and eastern part of the district is having very Poor to Poor Groundwater Potential Zones. Thrithala, Pattambi, Palakkad and Chittur comes under this category. These are the areas where over exploitation of groundwater is taking place. Very high to high Groundwater Potential Zone is identified around places like Mannarkkad, parts of Nenmara and Alathur and in some parts of

Ottapalam. The Geology, Geomorphology, Landusetype, Soil have Influenced a lot in identification of Groundwater Potential Zones

The ground water potential maps are providing a basis for the detailed hydrogeological and geophysical investigations. The integrated groundwater potential map thus could be useful for identifying future well locations and development of sustainable scheme for groundwater development in the area.

4. CONCLUSION

Groundwater Potential has been evaluated in Palakkad district, Kerala, India using remote sensing and geographical information system techniques. The various thematic maps like geomorphology, geology, slope, land use/land cover map, drainage density, and lineament density of the study area have been prepared and integrated using overlay analysis in the Arc-GIS platform. The results show that there are Six categories of Ground Water Potential Zones ranging from Excellent, Very Good, Good, Moderate, Poor and Very Poor. Result shows more than half of the district comes under moderate groundwater potential zones and only few areas are identified for having High Groundwater Potential Zones. Area of Very Poor Groundwater potential zone is stretched along central part of the district, proper management of ground water is required in these areas. The study shows the usefulness of remote sensing and GIS techniques for assessment and management of ground water.

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WATER BODIES MAPPING FROM SAR IMAGERY -AN IMPROVED ALGORITHM

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ABSTRACT

Maps are powerful tools for planning and decision making for human development. Water is the key element in sustaining life. Water should be properly preserved to be used in scarcity and safely disposed of in abundance. If water bodies are not properly managed it leads to accumulation of various life forms which may become breeding ground for epidemics. Small water bodies often overflow in case of heavy rainfalls blocking transport lines making life uncomfortable. This makes the water resources most precious to be mapped and monitored at the best possible spatial and temporal scales in abundance and scarcity. Synthetic Aperture Radar (SAR) is an excellent tool for remote sensing in all weather conditions. Feature extraction from SAR data is associated with Noise and low feature dimension due to the lack of spectral information. Deep Neural Networks (DNN) are mathematical structures that have the capability to learn complex function mappings from data which is heavily contaminated by Noise. Features like a water body which is characterized by low backscatter (signal well below the noise level) due to its specular reflection. Delineating water body with features like shadows which results in low backscatter due to the absence of scatterer is challenging. In this paper, we present a new method in which a neural network is trained to predict false water like features occurring in SAR data from a Digital Elevation Model (DEM) of the terrain under consideration. In this paper, we present the design, performance and results of the modified approach using DNN in delineating water bodies.

KEYWORDS: Deep Neural Networks, Water body extraction, Synthetic Aperture Radar, Feature extraction

1. INTRODUCTION

Remote sensing satellites provide an economical means of monitoring and mapping of water bodies due to its systematic and periodic coverage. Optical sensors capture images of earth in different spectral bands. Maps are prepared by identifying features from the image. This is usually accomplished by computing a representative index or using suitable image classification algorithms. Optical sensors cannot effectively penetrate through and acquire images beneath the clouds during the rainy season. For the monitoring of small and dynamic water-bodies, observation during monsoon season is indispensable. Active microwave remote sensing using Synthetic Aperture Radar (SAR) is a robust mode of remote sensing as the microwave can penetrate through clouds and other atmospheric conditions. Microwave sensors are the only mode of observation from satellites that can be reliably used for this purpose.

Due to highly coherent and low bandwidth signal used to illuminate the target in SAR sensors, microwave data suffers from speckle noise. This makes feature extraction from microwave images challenging compared to optical sensor data. Topographical features like hills cast shadows which have similar properties of water in the microwave region. Artificial Neural networks are computational models whose response can be modified by training over a known data to give the required response to specific inputs.

F. Baselice and G. Ferraioli describe a fully unsupervised coastline extraction method from high-resolution SAR images. The method described uses Bayesian stochastic estimation and Markov random field (MRF) frameworks to estimate the spatial correlation among neighboring pixels and this correlation based detector to find the coastline. The system demonstrates a high level of correlation with coastline derived from optical data. M. Silveira and S. Heleno describes Region-Based Level Sets to delineate water and land. The method is a contour evolution based method on a manually defined initial contour. Water extraction from SAR data using Gray-Level Co-occurrence Matrix (GLCM) and Support Vector Machine (SVM) demonstrated by T. Ojala et al. It was shown that this method gives the lowest error compared to otsu based thresholding and entropy based methods. S. Hong et al. describes a water extraction algorithm from SAR imagery based on the thresholding method using SAR amplitude, terrain information, and object-based classification techniques to give best accuracy in all terrains.

Neural networks were widely used in remote sensing applications for different applications. M. Castelluccio *et al.* describes the use of Convolutional neural networks in the semantic classification of remote sensing scenes from aerial images. They have used pre-trained ANN structures of CaffeNet and GoogLeNet with shallow training to the datasets to attain accuracy above 90%. Feature extraction from SAR for ocean pollution monitoring using DNN is explained by C. Bentes *et al.*

DNNs are highly scalable mathematical structure for developing classification algorithms, decision making where function mappings of arbitrary complexity are to be estimated from a set of training dataset. DNNs have been proved to be the best solution for many challenging problems. Being a supervised learning system, the accuracy of the classifier heavily depends on the number and quality of datasets used for training and the structure of the network that is being used. Overfitting is a state where the model gets trained deeply to the training dataset instead of a general model. The goal of designing the neural network lies in creating a model that is complex just enough to accomplish the required task.

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2. SAR CHARACTERISTICS OVER WATER BODIES

Radar uses narrow-band electromagnetic radiation to illuminate a target and record the received echoes from image of the target. The backscattered power is analyzed to estimate and characterize the target. The backscattered power is a function of dielectric constant and surface roughness of the target.

Sentinel-1 A carries C band SAR sensor working at a center frequency of 5.405 GHz with all four polarization (VV+VH+HH+HV). Level 1 products from the satellite are made available systematically and free of charge by ESA in different polarizations and modes. The Ground Range Detected (GRD) products have systematic coverage over India. GRD products are resampled to have pixel spacing of 10x10m on the ground. Among the different modes available, GRD products with VV and VH polarization in Interferometric Wide swath (IW) mode is used for the study in this paper.

Microwave at C-Band exhibits specular reflection on water bodies giving minimum backscatter. As a result water bodies appear as dark patches in the SAR image. There are many other features having a radiometric signature similar to water bodies in C-Band SAR Data. Shadows are ambiguous to water bodies, making water extraction difficult in hilly or uneven terrain. The methodology involves training a deep neural network to detect water bodies from SAR Data along with local incidence angle derived from DEM to avoid possible shadows being misclassified as water bodies.

3. METHODOLOGY

The input dataset (both VV and VH polarised data) is preprocessed for terrain correction as discussed in section 3.1. Data preparation for the Neural Network is described in section 3.2. The design and components of the neural network are described in section 3.3. The proposed new structure of with independent detection of shadows from DEM with a split training approach discussed in section 3.4.

3.1 Terrain correction

Prior to processing the data needs to be corrected for topological errors in the data. The side-looking imaging configuration of the SAR sensor makes radiometric and geometric distortions in the image on an undulating terrain. These distortions are rectified using Range doppler terrain correction] (Small and Schubert) with the aid of ASTER DEM data using SNAP Toolbox provided by ESA. The local incidence angle (derived from DEM and sensor position from metadata of the product) which is an intermediate product for Terrain correction is used as auxiliary data for training the DNN.

3.2 Generation of training datasets

The SAR data in two polarisations VV and VH after terrain correction along with DEM and local incidence angle derived from DEM is stacked as a single image to form a four channel dataset to the DNN. For training the DNN a most accurate estimate of water pixels from the dataset is required. Water layer from OpenStreetMap (OSM)[8] is taken as a reference. For each water body in the reference layer, a rectangular area of interest (AOI) is estimated with the extent of the water body so as to contain the entire water body. Using this AOI co-polarized data (VV) is thresholded using the Otsu threshold[9] to get a fair estimate of water pixels in the region. This thresholded data is used as OSM derived reference layer for training the DNN.

3.3 Deep Neural Networks(DNN)

DNNs are highly scalable hierarchical mathematical structures for developing classification algorithms and decision making. They have been proved to be the best solution for many challenging problems. Being a supervised classification algorithm, Neural networks iteratively get trained in a set of the large training dataset. The accuracy of the trained model highly depends on the volume and quality of the dataset being used to train the structure. Capacity to form highly complex decision space is a function of the size of the neural network (Number of hidden layers). Convolutional neural networks are used for shift invariant feature extraction from images with minimal preprocessing. The minimal preprocessing is achieved using a convolution kernel which convolves the entire image producing a feature vector from a window sliding over the entire image. The convolution kernel converts the image into multiple feature vectors of the size determined by the kernel size and number of bands in the image.

Due to the massive parallel computation capability of recent Graphics Processing Units (GPU), DNN structures can be evaluated at a greater speed with the help of Accelerated libraries like CUDA. GPU based accelerated platforms make training fast and viable from large DNN structures and huge training datasets. Tensorflow from Google is an off the shelf platform for DNNs with support for GPU based accelerated platform. Design and training of the Neural Networks are carried out in Nvidia Quadro FX 5200 GPU with Keras over Tensorflow libraries.

3.3.1 Activation Functions

The activation function imparts nonlinear mapping capability to the neural network. The nonlinear function should be continuous and differentiable to perform back propagation optimization strategy while propagating backward in the network. ReLU (Rectified Linear Unit) Activation Function gives outputs all positive inputs and gives zero for negative inputs. ReLU is widely used in Deep Neural Networks due to its sharp decision boundary and fast convergence rates[10]. The transfer function of ReLU can be represented as in equation (1)

$$f(x) = x^+ = \max(0, x) \quad (1)$$

The sigmoid function is used at the output neurons to give a boolean classification as a sigmoid function follows a logistic transfer function saturating the output at two levels. The transfer function for sigmoid is given in equation (2)

$$S(x) = \frac{1}{1+e^{-x}} \quad (2)$$

3.3.2 Fully connected layers

Fully connected layers are used for learning non-linear combinations of the input features and map to the required output response. More the number of hidden layers in the fully connected network, input can be mapped to more abstract representations from which mapping of a complex output function is feasible. The number of neurons in the fully connected layers determines the order of complexity the transfer function can hold. Increased neurons in fully connected layers come with penalties in terms of time of evaluation and overfitting. After a considerable training cycles, fully connected layers often undergo optimization by pruning of insignificant and duplicate nodes and insertion of additional nodes if required [11].

3.3.3 Optimization algorithms

The optimal weights at which the neural networks give the best results are calculated using the optimization technique. Among the many available techniques, Stochastic Gradient Descent (SGD) [12] is a classical method in which a random node is selected and optimized based on the gradient of the error function calculated with respect to the selected node. SGD is a slow algorithm with respect to the speed of convergence which prevents it from being used in many applications. Many optimized derivatives of SGD is being extensively used in training DNN.

Adam (adaptive moment estimation) is an improvisation on SGD and an efficient algorithm due to its fast convergence. It is being widely used in the deep neural network and machine learning problems. It is a stochastic optimization that requires first-order gradients. The method computes individual adaptive learning rates for different parameters from estimates of first and second moments of the gradients [13].

Adam has the following hyperparameters to control the performance of the algorithm.

- Alpha: referred to as the learning rate. The proportion at which weights are updated. Larger values result in faster initial learning before the rate is updated. Smaller values slow learning right down during training
- Beta1: The exponential decay rate for the first moment estimates. The value should be close to 1 (e.g. 0.9)
- Beta2: The exponential decay rate for the second-moment estimates. The value should be close to 1 (e.g. 0.99)
- Epsilon: Is a very small number to prevent any division by zero in the implementation

Keras is a python neural networks library which is capable of running on top of various fast math libraries like TensorFlow or Theano. It is highly modular and extensible which makes development easy in python programming language.

3.3.4 DNN architecture

The first layer in the neural network is a convolution layer which convolves in an arbitrarily sized input image to form a finite set of input vectors. The convolution layer is initialized with a 3x3 convolution window with 32 feature vectors that act as input to the fully connected hidden layer. The number of neurons in a hidden layer is made an integral multiple of 32 in order to exploit the parallelism available in the CUDA stream processors. Each stream processor in the GPU has tightly coupled 32 parallel execution threads which the CUDA compilers can optimize in a single or adjacent processor for better execution speed.

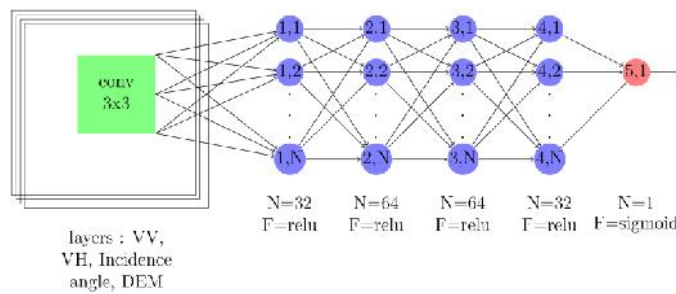


Figure 1: Structure Of CNN used for classification

Input layers consist of VV & VH polarised SAR image along with Local incidence angle and DEM bundled as different bands.

Water layer from OSM is used as the reference layer for training the data set. The vector layer from OSM is rasterised (section 3.2) and given as training for the neural network. The results are shown in figure 3 b&d.

3.4 A modified training strategy for hilly terrain

For a hilly terrain, the normal mode of training is inadequate to bring about the required level of convergence to learn shadows from DEM and eliminate at the output. Though the DNN structure is capable of estimating complex transfer function, the misclassification observed at the output may be attributed to the presence of two entirely different type of data fed into the input of

the neural network (SAR data and Local incidence angle from DEM). The error function in such a scenario tend to have multiple saddle points where the network converges to a local minima instead of the global minimum. For a fast convergence, the structure is simplified by splitting the fully connected layer into two and separately training each branch. In this approach, each branch is expected to have a single minima where the network converges directly. Each of these branch is combined to a single output neuron to produce the desired output. The modified structure is shown in figure 2. The first fully connected network is trained to detect water bodies from SAR data trained with the reference from OSM derived dataset. This layer will extract all water like features including shadows. The second fully connected layer is trained to map shadows in hilly regions from the local incidence angle. It is trained with selected regions(hilly region without water bodies) from the output of the first fully connected network as a reference layer. The final output layer is trained with OSM derived reference layer and hill shadow regions to detect only valid water bodies from the output of both fully connected layers. The results of the modified approach is discussed in figure 4.

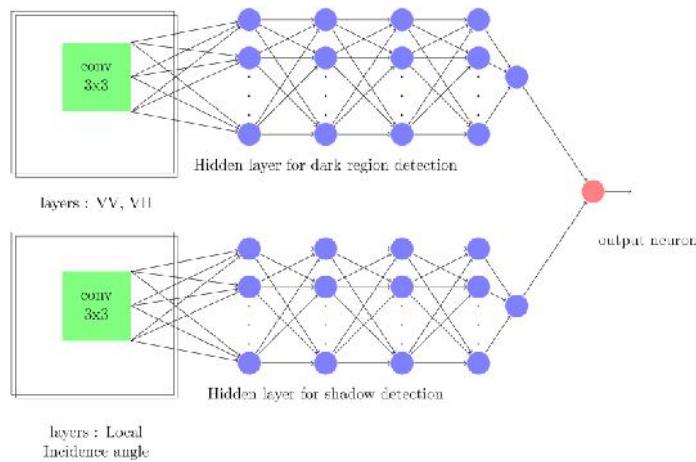


Figure 2 : The modified DNN structure to resolve shadows at the output

4. RESULTS AND OBSERVATIONS

The algorithm was tested on Sentinel 1A GRD IW data on June 3rd 2018 from a site near Karnataka, India. The neural network was trained using Sentinel 1A GRD IW (Date of pass Nov 18 2017). The Reference layer for training was derived from OSM (downloaded on august 12th 2018). From the direct model proposed, the results are presented in Figure 3. Two different terrains were selected for the validation. Besides a normal plain area, a hilly terrain is selected for the performance evaluation of hill shadow elimination. From the results, it was observed that the DNN is able to delineate water bodies at in a plain terrain whereas, misclassification is observed in hilly terrains due to shadows. With the proposed split training approach (section 3.4), the problem encountered in hilly terrains was eliminated. Figure 4 gives the results using the modified network, water bodies are correctly delineated in hilly terrain with all shadows being removed. The accuracy of the algorithm was calculated by using OSM water layer as reference layer. Omissions were not observed in the output with respect to OSM layer for the two different selected terrain. The accuracy in terms of true positive rate (recall) for different terrain is summarized in Table 1.

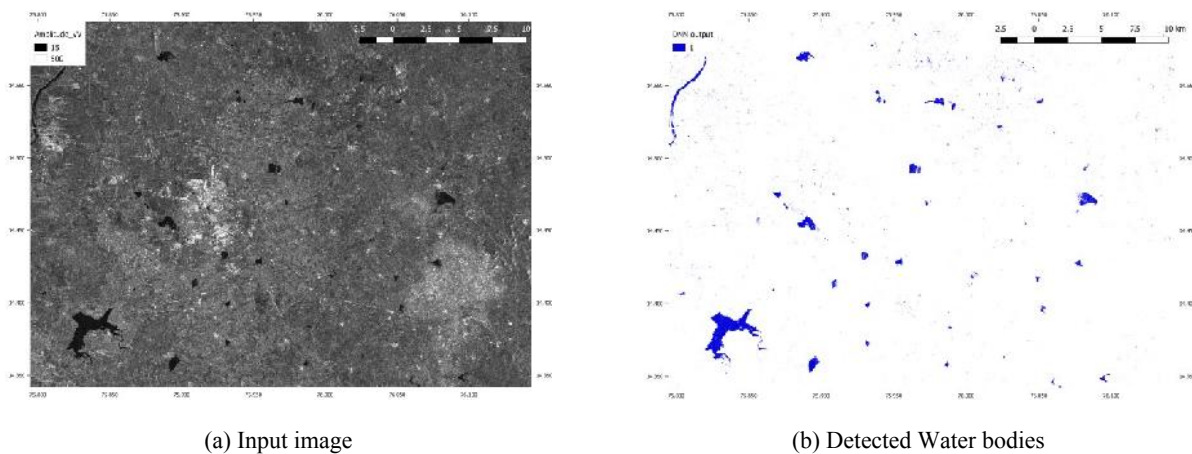


Table 1 :Results

	Accuracy		
Training mode	Hilly terrain	Plain terrain	Total
Direct training	65.34%	70.24%	65.99%
Split training	97.15%	91.5%	96.27%

5. CONCLUSION

This paper demonstrates a new approach to delineate water bodies from microwave SAR data using neural networks and further it discuss a strategy for training the network at places where normal training is difficult to converge. With the modified approach a total performance improvement of 30% was achieved. The method is capable of observing dynamic water bodies which include irrigating of agricultural fields, water logging during rain etc. The system have misclassification at certain soil types, arid regions and establishments like solar fields.

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SPATIO-TEMPORAL EFFECTS ON STREAMFLOW PREDICTION IN VAIGAI BASIN USING SWAT MODEL

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ABSTRACT

Water is the core for the sustainable development of the country, hence proper management of its resources helps in the socio-economic development. The objective was set for evaluating spatial-temporal change analysis and usage of hydrological model (Soil & Water Assessment Tool) to study the hydrological parameters in the Vaigai basin, Tamil Nadu. To evaluate Spatio-temporal changes, Land Use Land Cover (LULC) maps were prepared for the period 1976, 1996 and 2016 utilizing the Landsat series data. The statistics showed decreasing trend of 1.4% every year in surface water bodies and built up increasing by 19% annually. The SWAT model was used to evaluate streamflow of the Vaigai River near Vaigai dam for the three different periods (1979-2009, 1979-2000 and 1989-2009). Statistical measures for the model performance during calibration and validation were calculated using parameters like coefficient of determination (R^2), the Nash–Sutcliffe simulation efficiency (NS). The Mean R^2 and NS values during calibration were 0.64 and 0.16 respectively, similarly for validation 0.29 and -0.19. The results indicated poor performance of the model with very low value of NS suggesting many uncertainties present in Vaigai basin due to various anthropogenic factors including diversion of flow in the upstream through check dams. Such uncertainties can be accounted by appropriately modifying the inflow properties which is currently absent in the SWAT Model.

KEYWORDS: Water management, LULC, SWAT Model, Streamflow, Vaigai basin

1. INTRODUCTION

In recent years, water resources are depleting due to high demand for water, poor storage facility, bad water management etc. The water resources management practices should be based on increasing the water supply and managing the water demand under the stressed water availability conditions. Assessment of watersheds and advancement in management strategy requires accurate estimation of the past and present land cover/land use (LULC) parameters as changes observed in these parameters determine the hydrological and ecological procedures occurring in a watershed. The study (Uwimana, 2017) evaluates the effects of river discharge and LULC on water quality dynamics in Migina catchment, Rwanda. And in another research (Gerlach Jr, 2004) talk about future water demands depending on the land use changes in California. We need to thoroughly study the spatial distribution, geographical conditions (such as topography, soil properties, LULC etc.) and weather conditions for any further improvement we need to apply on water management practices.

With increasing competition for water across sectors and regions, the river basin has been recognized as the appropriate unit of analysis for addressing the challenges of water resources management. Recently, physically based distributed models are being widely used to study the impacts of LULC practices on water, sediment and agricultural chemical yields in large complex watersheds. One such hydrological model called Soil & Water Assessment Tool (SWAT) is being widely tested on different regions across the world. It is a semi-distributed river basin model which works in a daily time step and requires a large number of input parameters for model simulation. SWAT was used to assess the stream flow in the Black Volta basin, Africa (Akpoti, 2016). The results showed that in a span of 13 years from 2000 to 2013, surface flow and lateral flow increased respectively by 27% and 19% while groundwater had decreased by 6% during which Urban, Bare and Agricultural land increased and grassland decreased by 44% in the basin. Another work (Kumar, 2017) done on the Tons river basin, India, applied the SWAT model and observed the differences between the simulated and observed flow in the basin. There are other hydrological models like Hydrological Simulation Program - FORTRAN (HSPF) model, Dynamic Watershed Simulation Model (DWSM) etc., HSPF model was used by (Ribarova, 2008) to model nutrient pollution during a first flood event in Iskar river case study, Bulgaria. DWSM evaluates the alternative land use and best management practice scenarios in reducing flood magnitudes, erosion of stream beds and banks, the filling of stream beds and impoundments (reservoirs, lakes, detention ponds, etc.), and polluting water bodies (Borah, 1998).

This motivated to set the objective to evaluate the streamflow discharge in the Vaigai basin using Soil & Water Assessment Tool (SWAT) and also to assess the impacts of spatio-temporal changes in the basin using LULC Maps prepared using supervised classification.

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2. MATERIALS AND METHODS

2.1 Study Area

The Vaigai basin shown in Figure 1, lies between Latitude 9° 14' 57" N and 10° 19' 33" N and Longitude 77° 9' 55" E and 79° 11' 28" E covering an area of about 7100 km². Next, to Cauvery basin, Vaigai river basin is considered to be the second largest basin whose boundaries are within the administrative boundaries of the state of Tamil Nadu. The basin is surrounded by Cauvery and Kottakaraiyar basins in the North, Gundar basin in the South, the *Western Ghats* in the West and *Bay of Bengal* in the East. The Vaigai river which is 258 Km long, originates in *Varusanadu Hills* which is present in the Periyar Plateau of the Western Ghats range and flows through the districts *Theni, Andipatti, Madurai, Sivaganga, and Ramanathapuram* and joins the *Bay of Bengal*.

In Vaigai basin, the main land use is Agriculture and the dominant SWAT soil type is Lc76-2b-3782. The highest rainfall is usually received in the month of August, September, and October. The average annual rainfall was found to be around 900 to 1000mm. Variety of crops are grown in the basin like rice, cotton, black gram, sorghum and cowpea.

2.2 Materials Used

Data is significant for scientific analysis which shapes the reason for substantial inferences and decision making. The confidence level of the inferences made from the analysis of data depends upon the quality of data collected for the study. The Tables 1 and 2 give details of primary and secondary datasets used for this study.

Primary Dataset			
Satellite Sensor	Period	Resolution (m)	Source
Landsat 1-4 MSS	1976	60	https://earthexplorer.usgs.gov/
Landsat 5 TM	1996	30	https://earthexplorer.usgs.gov/
Landsat 8 OLI	2016	30	https://earthexplorer.usgs.gov/

Table 1: Primary Datasets used

Secondary Dataset		
Data	Description	Source
Survey of India (SOI) Topography maps (1:50000)	These maps were used for spatial precision of the data. Features present in study area were better understood using these maps.	http://www.soinakshre.uk.gov.in/
Google earth (Timescale images)	For Validation of the classified output.	https://earth.google.com/web
DEM (ASTER DEM – 30m)	The DEM data was used for watershed delineation along with stream pattern, outlets and inlet definitions.	https://earthexplorer.usgs.gov/
Slope Map	Derived from the DEM (Figure 2(a))	DEM
Soil Map	Resolution – 250m. It allows to determine soil texture, hydraulic conductivity, available water content and other parameters for different layers depending on its soil type. (Figure 2(b))	http://swat.tamu.edu/software/links/indiadataset/
Weather data (6 stations)	Daily data available from CFSR world database was collected for SWAT Model for the period 1976-2009.	https://globalweather.tamu.edu/
Monthly discharge data – Vaigai dam	Monthly Streamflow measured from 1976-2009.	Public Works Department, Tamil Nadu

Table 2: Secondary datasets

2.3 Methods

SWAT Model was applied on the Vaigai basin by giving a number of input spatial parameters like DEM, Soil Map, LULC Map and Weather data for predicting the streamflow of the river Vaigai at the outlet of the Vaigai dam.

2.3.1 Soil & Water Assessment Tool (SWAT) Model

SWAT is a semi-distributed physical based model. It was jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research. The spatial distribution of the basin is taken into consideration for the model by combining Digital Elevation Model (DEM), soil and land use. Water balance acts as a driving force behind everything that happens in the watershed. The SWAT's simulation of the hydrological cycle is based on water balance equation (Neitsch, 2011):

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{wg}) \quad (1)$$

Where SW_t - Final soil water content (mm H_2O), t – time(days), SW_0 - Initial soil water content on day i (mm H_2O), R_{day} - Amount of precipitation(mm H_2O), Q_{surf} - Amount of surface runoff(mm H_2O), E_a - Amount of evaporation(mm H_2O), W_{seep} - Amount of water entering the zone(mm H_2O) and Q_{wg} - Amount of return flow(mm H_2O). The SWAT model divides the basin into sub-basins. And the sub-basins will be further divided into Hydrological Response Units (HRU) depending upon the land use/land cover, soil, and slope distribution.

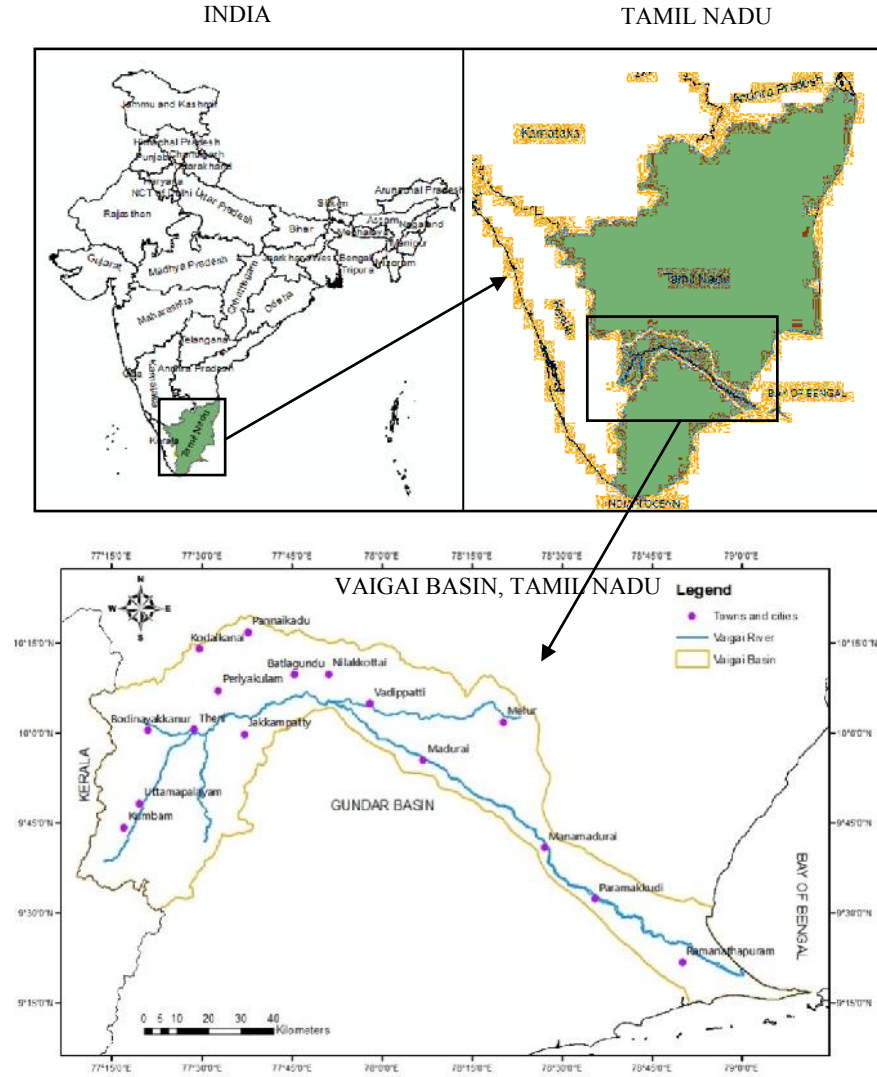


Figure 1: Study Area Representation

2.3.2 Sensitivity Analysis, Calibration and Uncertainty Analysis

SWAT-Calibration and Uncertainty Programs (SWAT-CUP) enables sensitivity analysis, calibration, validation and uncertainty analysis (Arnold, 2012). It links SUFI2, PSO, GLUE, ParaSol, and MCMC algorithms to SWAT. The Sequential Uncertainty Fitting (SUFI-2) algorithm is one such algorithm used for optimization and uncertainty analysis. In SUFI-2, a parameter uncertainty is propagated through a Latin Hypercube (a statistical method for generating a sample of plausible collections of parameter values from a multidimensional distribution) sampling. The degree to which uncertainties are accounted for is quantified by a P -factor. It is referred to as the 95% depicting prediction uncertainty or 95PPU calculated at 2.5% and 97.5% levels for each parameter. The 95PPU is the degree to which all uncertainties are accounted for in model. The average thickness of the 95PPU band divided by the standard deviation of the measured data quantify the strength of the calibration and uncertainty analysis of the model is known as R-factor. The perfect situation would be 100% of the observed

data bracketed in the 95PPU while at the same time R-factor is close to zero. ArcSWAT and SWAT-CUP software were used for streamflow prediction in the Vaigai basin. The model simulations were run for 3 different time period scenarios to check streamflow prediction in different periods at outlet of Vaigai dam present in Vaigai basin. The three different periods considered are: (i) 1979-2009, (ii) 1979-2000 and (iii) 1989-2009. For manual calibration, the model was run in monthly time step basis. Model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions. During the validation step, we make the model to use the calibrated parameter ranges without any changes and run the iteration (with the same number of simulations as used in calibration step). The warm-up period was given which allows the model to get the hydrological cycle fully operational.

2.3.3 Model Evaluation

For evaluating the SWAT Model accuracy (Arnold, 2012), below mentioned parameters were used:

- i. *Goodness of fit or coefficient of determination (R^2)* – This determines the relation between observation and best simulation in the model simulation.

$$R^2 = \frac{\sum_{i=1}^n (Q_{obs} - \bar{Q}_{obs})(Q_{sim,i} - \bar{Q}_{sim})}{\left[\sum_{i=1}^n (Q_{obs,i} - \bar{Q}_{obs})^2 \right]^{0.5} \left[\sum_{i=1}^n (Q_{sim,i} - \bar{Q}_{sim})^2 \right]^{0.5}} \quad (2)$$

- ii. *Nash-Sutcliffe (NS) Coefficient* - NSE is a normalized dimensionless statistic that determines the relative magnitude of the residual variance compared to the measured data variance and its value varies from $-\infty$ to 1, with a high value indicating an accurate model.

$$NS = 1 - \frac{\sum_{i=1}^n (Q_{sim} - Q_{obs,i})^2}{\sum_{i=1}^n (Q_{obs,i} - \bar{Q}_{obs})^2} \quad (3)$$

Where $Q_{obs,i}$ – Observed flow at a time i (m^3/s), $\bar{Q}_{obs}$ – Mean observed flow (m^3/s), $Q_{sim,i}$ – Simulated flow at time i (m^3/s), $\bar{Q}_{sim}$ – Mean of simulated flow (m^3/s). For a model, to accept the calibration phase, it should obtain R^2 greater than 0.6 and the value of NS greater than 0.5 (Moriassi, 2007).

2.4 Data Preparation

The data needed for the SWAT Model are prepared as explained below.

2.4.1 LULC Preparation

For assessing the LULC change in the Vaigai basin, three land cover maps were prepared using the satellite data. The satellite images during period 1976, 1996 and 2016 were collected corresponding to 40 years. The Landsat MSS was collected and processed for the year 1976, Landsat 5 TM for 1996 and Landsat 8 OLI was used for the year 2016. In order to capture the maximum surface area of water body, the images were collected in the post-monsoon season during September to November with minimal cloud cover in the area. These satellite data were collected from the United States Geological Survey (USGS) and are freely available in the USGS EarthExplorer platform.

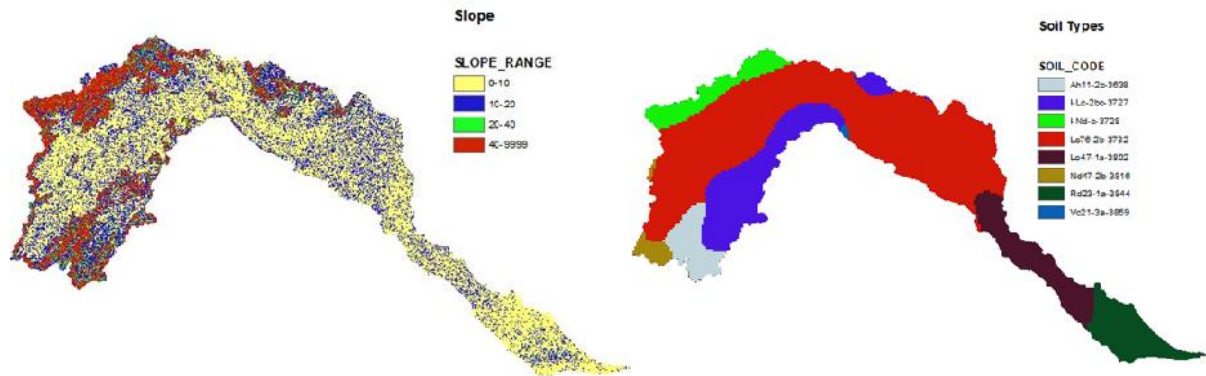
Support Vector Machine (SVM) and Maximum likelihood classifier algorithms of ENVI image processing software were used for the study region and the results were compared. The SVM classifier produced a better accuracy of classified maps than maximum likelihood, hence, here SVM classifier was mainly used for classification of the remotely sensed data. The LULC classes are considered depending on the NNRMS standards (NNRMS, 2005). The classes selected here are: - Built Up, Agricultural Land (Crop Land and Fallow Land), Forest, Wasteland (Scrub Land, Sandy Area, and Barren Rock) and Waterbodies. Change detection matrix was constructed which shows a change in the area of each class over other classes in time. These results helped in assessing change in LULC by human intervention in the ecological system of the basin. This helps us in proper water management strategies and also in the decision making of future programs for watershed development.

2.4.2 Weather Data

Monthly rainfall data for the region from period 1976-2009 was collected through DHAN Foundation, Madurai. Monthly weather data of the study region was estimated using daily data available for the region from the Climate Forecast System Reanalysis (CFSR) world database. The observed rain gauge station values and the CFSR values were varying a lot. So, CFSR data couldn't directly be used. We had to modify it based on the monthly observed data. Equation used for correcting CFSR data:

$$R_{cor,daily} = R_{sim,daily} * \frac{R_{obs,monthly}}{R_{sim,monthly}} \quad (4)$$

Where $R_{cor,daily}$ - Daily Rainfall data corrected (mm), $R_{sim,daily}$ - Simulated daily rainfall data provided by CFSR (mm), $R_{obs,monthly}$ - Monthly observed data at Rain gauge stations (mm) and $R_{sim,monthly}$ - Monthly rainfall data provided by CFSR (mm). This calculated value for the period 1976 to 2009 was used in SWAT modelling. Similarly, the CFSR temperature data was validated with observed data and the results were found to be satisfactory with R^2 value of 0.8 for the station Parthibanur in the Vaigai basin. Other parameters like wind velocity, solar radiation and relative humidity were also validated, the results showed satisfactory correlation, so they were used in SWAT model.



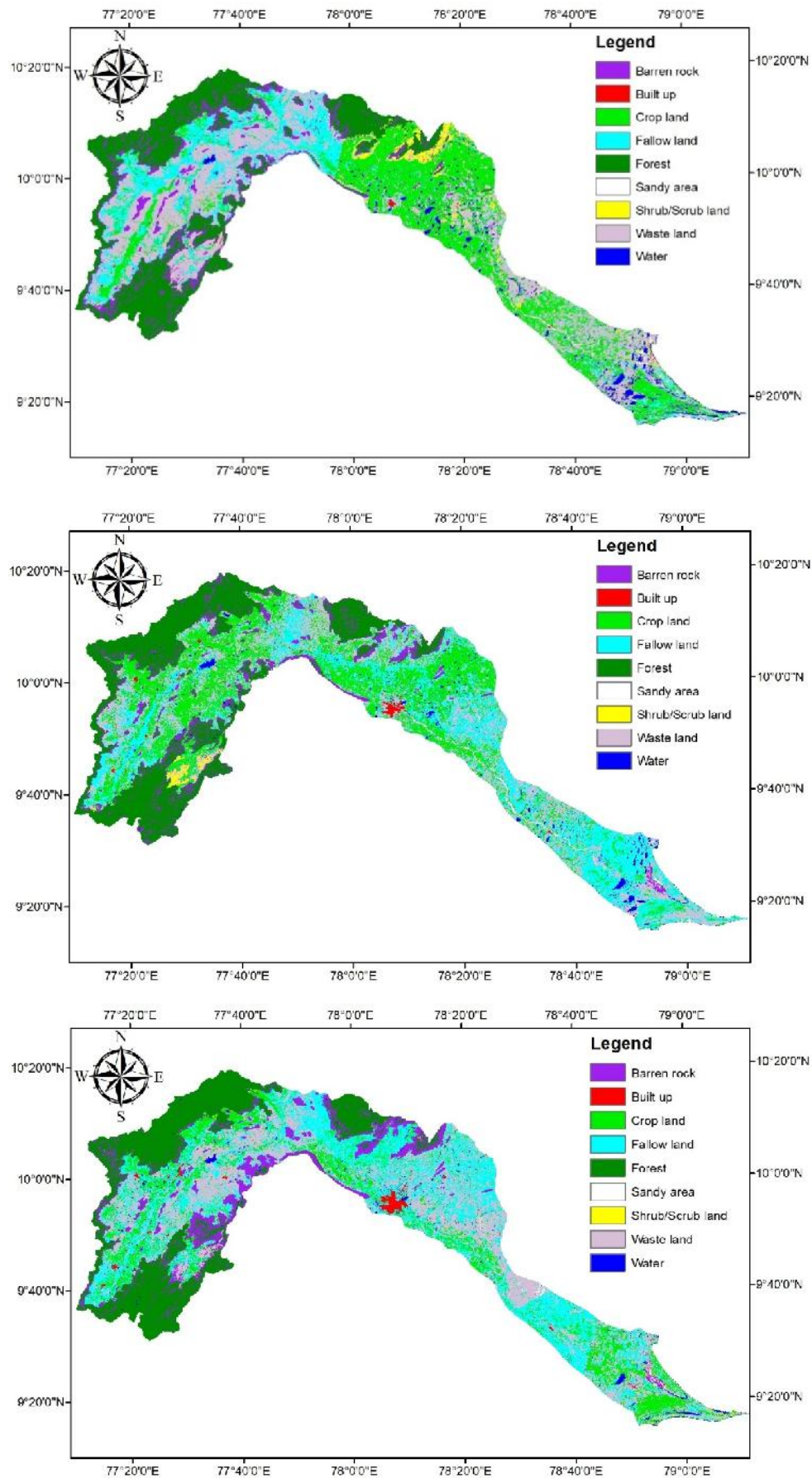


Figure 3: LULC Map of Vaigai basin for the period (a) 1976 (b) 1996 and (c) 2016

LULC classes	Change (%) (Area)		
	1976 v/s 1996	1996 v/s 2016	1976 v/s 2016
Built Up	319.05	107.31	768.77
Agriculture	25.92	-10.13	13.16
Forest	4.78	-3.51	1.1
Wasteland	-26.47	19.57	-12.08
Water	-37.6	-35.42	-59.71

Table 3: Percent Land Use/Land cover changes from 1976 to 2016

3.2 SWAT Model Analysis

3.2.1 Sensitivity Analysis

Sensitivity analysis was performed to find the significant hydrological parameters for the streamflow prediction in the SWAT Model. Several parameters were tested by running the model 500 times examining the t-stat and p-value which gives the measure of sensitivity and relative significance of each parameter respectively. The parameters which have a larger value of t-stat and a smaller value of p are most sensitive parameters. Among the ten final sensitive parameters (Table 4), the six most sensitive includes Soil Conservation Service (SCS) runoff curve number (CN2), Baseflow alpha factor (days) (ALPHA_BF), Groundwater delay (days) (GW_DELAY), Soil evaporation conservation factor (ESCO), Baseflow alpha factor for bank storage (ALPHA_BNK) and Available water capacity of soil layer (SOL_AWC). Most of these parameters are soil and land use land cover related, hence it calls for paying particular attention to soil and land use management practices in the basin.

Rank	Parameters	Range	Description
1	CN	80-90	SCS runoff curve number
2	ALPHA_BF	0-1	Baseflow alpha factor (days)
3	GW_DELAY	30-150	Groundwater delay (days)
4	ESCO	0-1	Soil Evaporation compensation factor
5	ALPHA_BNK	0-1	Baseflow alpha factor for bank storage
6	SOL_AWC	0-1	Available water capacity of the soil layer
7	SOL_K	0.1-0.8	Saturated hydraulic conductivity
8	HRU_SLP	0-1	Average slope steepness
9	SLSUBSN	10-100	Average slope length
10	REVAPMN	0-500	Threshold depth of water in the shallow aquifer for revap to occur (mm)

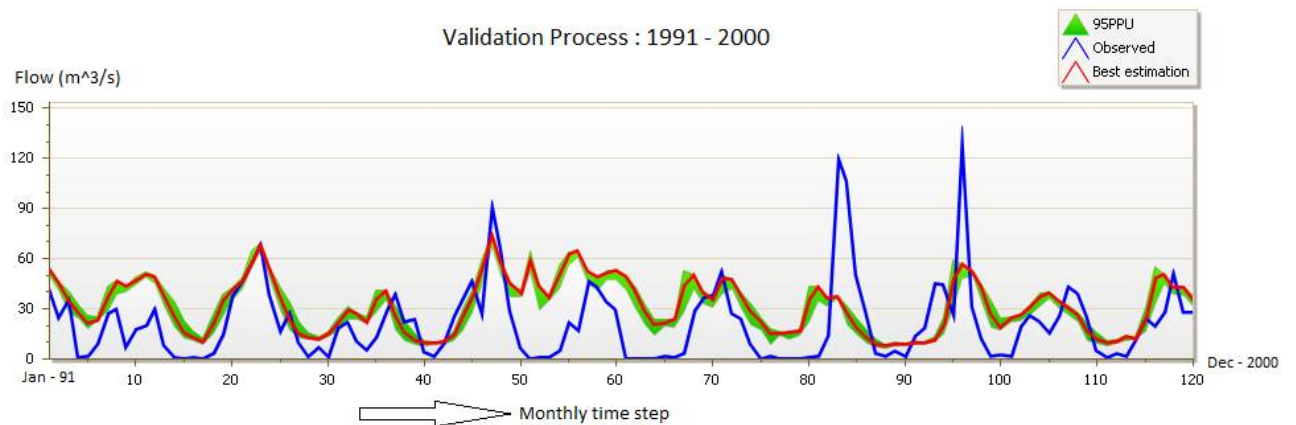
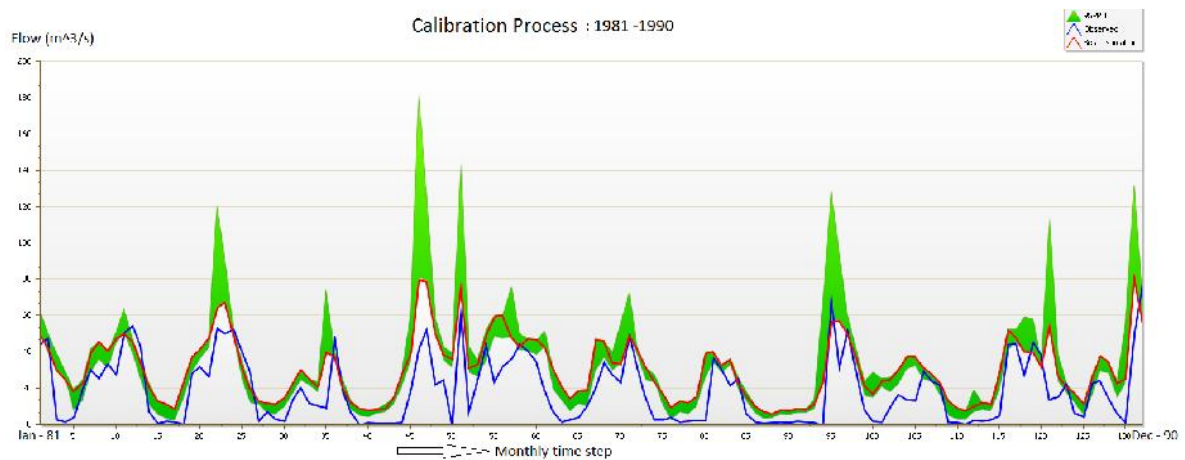
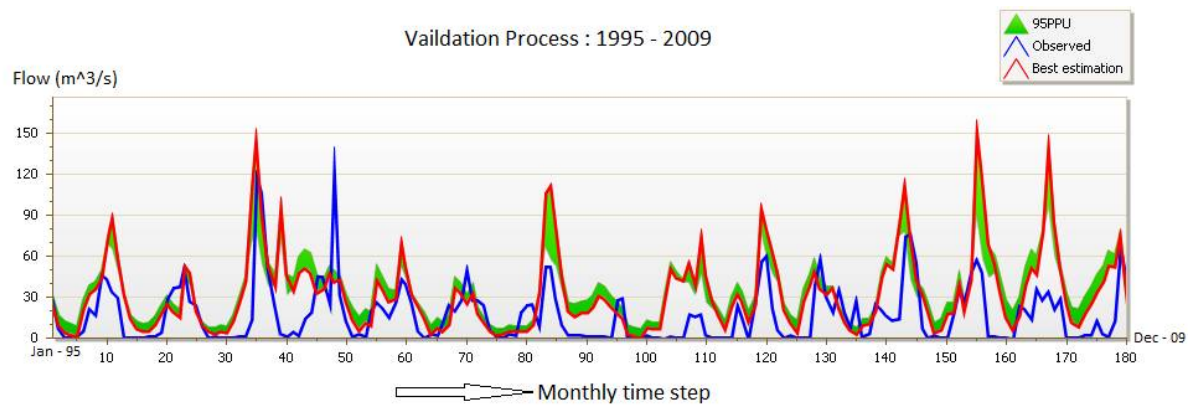
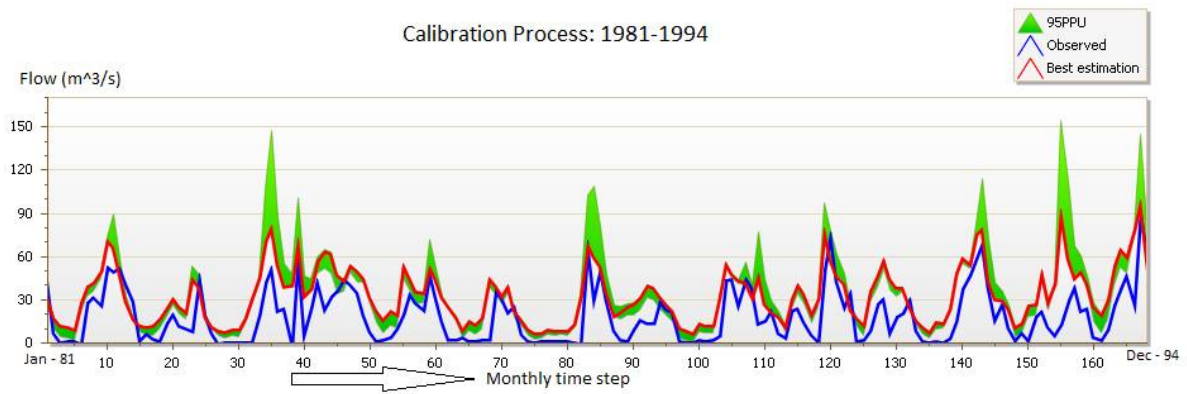
Table 4: Most Sensitive parameters of Vaigai basin for streamflow prediction

3.2.2 Model calibration and validation using SUFI-2 Algorithm

The comparison of observed and simulated streamflow data showed significant difference depicting high uncertainty in the simulated data. In Scenario 1 (Table 5), the p-factor brackets only 21% of the observations and r-factor equals 0.53 for Vaigai outflow at Vaigai dam. The R^2 value was found to be 0.62 and the NSE value was found to be 0.28 which is very less. This shows that SUFI-2 did not capture the observations well during the calibration period. This problem coupled with lower values for NS co-efficient (0.12) indicates that there is the high uncertainty of simulated flow due to spatial and data errors which include diversion of streams for irrigation, upstream dam construction for town water supply, and other activities in the sub-basins. During validation the R^2 was found to be 0.33. The uncertainties may not depend on only rainfall and temperature but also due to input uncertainty because of the construction of infrastructures in the upstream of the watershed. Similarly the values obtained for Scenario 2 and Scenario 3 are all mentioned in Table 5 along with warmup, calibration and validation periods considered. The results show that the model was able to predict the trend in fluctuations but there exists the consistent bias in the predicted streamflow compared to the observed. Peak flows during August, September and October months where not captured in the model mainly during 1995 to 2009. Figure 4 shows the observed and simulated discharge during 3 scenarios.

Variable	Scenario 1		Scenario 2		Scenario 3	
	Warmup: 1979-1981		Warmup: 1979-1981		Warmup: 1989-1991	
	Calibration (1981-1994)	Validation (1995-2009)	Calibration (1981-1990)	Validation (1991-2000)	Calibration (1991-2000)	Validation (2001-2009)
P-factor	0.21	0.16	0.25	0.17	0.18	0.07
R-factor	0.53	0.45	0.66	0.32	0.43	0.56
R^2	0.62	0.33	0.67	0.21	0.65	0.33
NS	0.12	0.07	0.28	0.1	0.1	-0.75

Table 5: Complete statistics of three different Scenarios for Modelling Vaigai basin



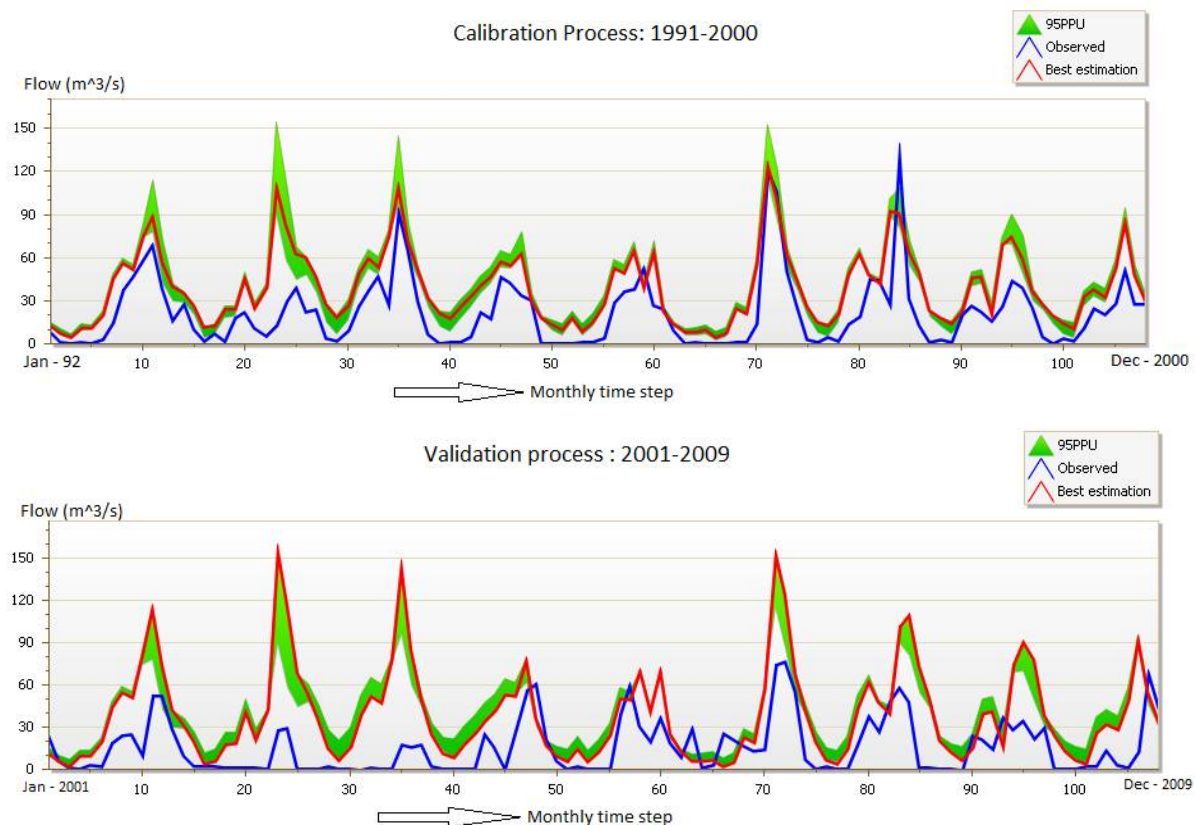


Figure 4: Observed and Simulated discharge during: (a) Calibration process in Scenario 1, (b) Validation process in Scenario 1, (c) Calibration process in Scenario 2, (d) Validation process in Scenario 2, (e) Calibration process in Scenario 3, (f) Validation process in Scenario 3.

3.2.3 Reasons for Model Uncertainties

Results of the model computed show clear difference between observed and measured flow. The following would be probable reasons for the uncertainty :

- i. The inter-basin flow of water from Periyar dam, Kerala to Vaigai basin, Tamil Nadu.
- ii. Check dams which were present along the river course, used by humans for agricultural and other needs, could not be accounted for in the model, which leads to different values for the flow in the model. (Ramasamy, S., 2014)
- iii. Input data uncertainty.
- iv. Vaigai basin extends from the Western Ghats to the Bay of Bengal a region having a lot of spatial and climate heterogeneity to account for in the model.
- v. SWAT model is a semi-distributed model, where it combines metrological variables (rainfall, temperature etc.) and physical parameters (land use, soil, elevation etc.) in to sub-basins in contrast to a fully distributed model where it is capable of capturing spatial distribution of metrological variables and physical parameters at each point rather than HRU level.
- vi. We need more measurements of the flow in the basin at varied locations of the Vaigai River.

4. CONCLUSIONS

LULC change analysis of the Vaigai basin region showed a decrease of surface water bodies when remotely sensed satellite data for the period 1976, 1996 and 2016 with an interval of 20 years used to map the Land use land cover classes. The major factors that were seen affecting water resources were urbanization, increase in agricultural practices from 1976 to 1996 where conversion of land from wasteland to cropland occurred. Then the streamflow of the Vaigai River at the outlet of Vaigai dam was modelled using SWAT model. Because of heterogeneous spatial distribution, varied climatic conditions and anthropogenic factors in Vaigai river basin, the model couldn't account the uncertainties in the region. Moreover, there was inter-basin water transfer from Periyar dam to Vaigai dam, which added more uncertainties near the upstream region of the basin for calibration and validation processes. The Model can be modified and improved to accept varied input parameters to account for anthropogenic factors which reduce failure of capturing uncertainties present in the streamflow discharge in the basin.

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TEMPORAL CHANGES IN THE HIERARCHICAL ORGANIZATION OF A DRAINAGE NETWORK USING GEOGRAPHICAL INFORMATION SYSTEM (GIS) – A CASE STUDY FROM THE WESTERN GHATS

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ABSTRACT

Chalakydy river, the seventh order tropical river originating from the Western Ghats, is the fourth largest drainage network (144 km) of Kerala. The sub-basins of this river are heavily exploited for hydroelectric power generation and irrigation purposes by constructing six major dams and one diversion weir in the tributaries of the river. The Government recently proposed a 163 MW Athirappilly hydroelectric power project to meet the electrical power demand of Kerala. In this context, the present study is an attempt to investigate the temporal changes of the hierarchical organization of drainage network occurred in the sub-basins of Chalakydy river in which reservoirs are constructed and hence evaluating the environmental safety. The land survey data derived from the Survey of India (SOI) topo maps (surveyed on 1909-10, scale 1:63,360 and published in 1912) and open series map published by SOI (details updated on 2004-05, scale 1:50,000 and published in 2010) are used for the study. The first order drainage networks are updated with Shuttle Radar Topographic Mission (SRTM) data. The hierarchical anomalies in the drainage network of sub-basins of Chalakydy River, pre and post-dam construction are observed from the multi-temporal data sets and are evaluated using ARC GIS 10.4 software. Recent flood disaster at Kerala instigated the need of geospatial processing of older SOI topo-maps to infer the temporal variation in the earth surface features to ensure environmental safety.

KEYWORDS: Morphometry, Hierarchical anomaly, Temporal drainage network analysis, Tectonic imprints, Geospatial analysis, and Environmental surveillance.

1. INTRODUCTION

Topographic maps are data repositories that describe the physiography, drainage network and land use patterns of the terrain. It is the unique data product from which we can interpret the past conditions of the terrain, as the satellite data are only available since the 1980's. GIS-enabled temporal analysis of vectorized topo-maps serves as a data product of utmost importance in environmental monitoring, policy decision making, and project implementation. Recent flood disaster in Kerala State had instigated Government the need for terrain mapping, flood mapping, disaster zonation mapping and stringent steps for environmental conservation.

The river is one of the earth's dynamicsystems, developed in a geomorphic setting and characterized by spatial heterogeneity and connectivity. The form and structure of drainage basin and their associated drainage networks can be described by morphometric parameters. Morphometric analysis of drainage network can be used to study about bedrock characteristics, structural influence on drainage development and its progression. The fluvial geological agents play an important role in creating temporal changes on the earth's surface. Many river courses of South India show ponding, deflections, and changes in drainage texture in response to various degrees of crustal movements (Valdiya and Narayana., 2007).

Streams respond to vertical displacement along faults by aggradation or degradation which results in the formation of fluvial geomorphic markers (Anderson and Burbank., 2001). The presence of unpaired terraces, strath terraces, channel migration and river incision, paleo-channels and paleo-alluvial fans reveals the involvement of variable geologic factors in the drainage basin evolution (Anderson and Burbank, 2001). The present study is an attempt to appraise the drainage hierarchical organizations of the sub-basins of the Chalakydyriver in which reservoirs are constructed.

2. STUDY AREA

Chalakydy river (length=144 km; basin area=1448 km²) originates from the Anamalai hills of Western Ghats is the fourth biggest river of Kerala flowing through the Southern Granulite terrain (SGT). The Chalakydy drainage system traverses the high land, midland and lowland physiographic divisions of Kerala. The Chalakydyriver is formed by the confluence of six major tributaries (Sholaiar, ParambikolamAr, Kuriyarkutti, Karappara, Kannankuzhi, and AnakkayamAr and the basin is divided into seven subbasins for the present study (Fig. 1.1). The river flows through the high altitude lush green grasslands, reserve forests to reach the plains at Kanjirapally and finally joins the Periyar at Elanthikara and ultimately debouches into Lakshadweep Sea. Study area (N. Latitude. 10°0' and 10° 15'; E. Longitude. 76° 15' and 76° 50') is represented in the Survey of India toposheets 58B/7, 58B/8, 58B/11, 58B/13/58F/3. The drainage basin extends over Thrissur and Palakkad districts and Coimbatore district of Tamil Nadu.

Chalakydy basin lies in the northwestern part of Southern Granulite Terrain (SGT). The regions are dominated by ancient crystalline rocks of Precambrian age and its metamorphic equivalents (Soman, K., 2002). Hornblende gneiss, hornblende-biotite gneiss, and intrusives of granites, dolerite, gabbro, syenites are the major rock types of the study area. Most of the rocks near the river bed follows a general east-west trend and dips towards the south. Laterites and recent sediments cover the plains of low altitude region. The drainage pattern of ChalakydyRiver Basin (CRB) is influenced by WNW-ESE, N-S, and NNW-SSE oriented lineaments.

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The Poringalkuthu hydroelectric power project (PLB HEP) commissioned in 1957 and ParambikulamAliyar Project (PAP) implemented five dams commissioned between 1965 and 1971, together constituted the construction of six major dams on the tributaries of the river. The proposed 163 MW Athirappilly hydroelectric power project recently by the Government instigated the alternative to contemplate for exploring new energy sources to meet the electrical power demand of Kerala and protection of the riverine ecosystem. Illegal mining, quarrying, and other anthropogenic activities at or near the drainage basins, lead to landscape deterioration and hydrologic pathway migrations (Rajendran and Rajendran, 1996; Padmalal D, 2014). The sub-basins Sholaiar SB, Parambikulam SB, Kuriyarkutty SB are selected for the present study and the general temporal drainage changes are evaluated in the context of the recent flood disaster.

3. MATERIALS AND METHODS

Geographical Information System (GIS) serves as a precise tool for evaluating the extent of drainage network changes occurred due to geologic processes and anthropogenic interventions in the drainage basin using multi-temporal land survey datasets and remote sensing data products. The land survey data are derived from the Survey of India (SOI) toposheets (surveyed on 1909-10, scale 1:63,360 and published in 1912) and open series map published by SOI (details updated on 2004-05, scale 1:50,000 and published in 2010) are vectorized to derive the drainage net configuration with the processing of ArcGIS 10.4 software. The first order drainage networks are updated with Shuttle Radar Topographic Mission (SRTM) remote sensing data (2014). The base data of drainage network composition is obtained from the vectorized data, following the Strahler's scheme of stream ordering. Appraisal of temporal hierarchical anomalies in the drainage network is carried out with the scheme proposed by Bahrami (2013). The stream is said to have a hierarchical progressive organization of drainage network when 'n' stream of lower order joins the next higher stream order $n+1$ ($n+1 \rightarrow n+2$, $n+2 \rightarrow n+3$). Drainage networks imprint hierarchical anomalies when lower order stream 'n' joins the highest stream orders ($n+2, n+3, n+4$), other than its next higher order. Hierarchical number (Ha) refers to the minimum number of first-order streams required to make the drainage basin to be perfectly hierarchical (Avena, C.G.,1967). Hierarchical anomaly index (Δa) is defined as the ratio of hierarchical anomaly number of the whole basin (H_a) and (N_1), the number of actual first-order streams in the sub-basin (Avena C G.,1967; Bahrami, S.,2013).

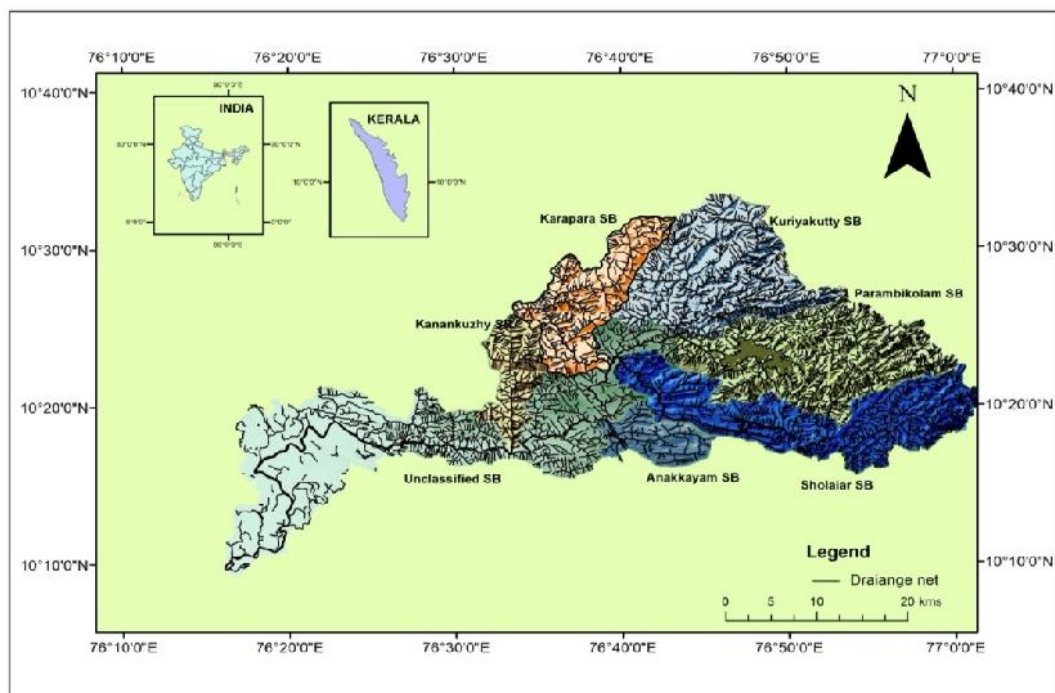


Figure 1.1. Location map of the Chalakudy river basin(CRB).

4. RESULTS AND DISCUSSION

The drainage network of the sub-basins of CRB – Sholaiar, Parambikulam and Kuriyarkutty digitized from 1910 and 2005 SOI topo-maps are depicted in Fig.2.1, 2.2, 2.3 respectively. Hierarchical anomalies primarily reflect the effects of tectonics; and also may result from lithological variation factors, climate and human interferences in the drainage basin by the construction of mega-engineering structures. The scheme for determining hierarchical anomaly index of sub-basins and the data is represented in Table 1.

Stream	Multiplication factor	Sholaiar SB I*		Sholaiar SB I**		Parambikolam SB II*		Parambikolam SB II**		Kuriyarkutty SB III*		Kuriyarkutty SB III**	
Junctions	A	B	A*B	B	A*B	B	A*B	B	A*B	B	A*B	B	A*B
(i-j)	(Ha i-j) 2(r-2)-2(i-1) r-recipient i-tributary	(NSi-j)											
1→2	0	1110	0	490	0	1255	0	588	0	953	0	379	0
1→3	1	196	196	86	86	261	261	148	148	162	162	81	81
1→4	3	96	288	45	135	143	429	107	321	26	78	73	219
1→5	7	117	819	98	686	98	686	69	483	53	371	37	259
1→6	15	29	435		0	80	1200	10	150	14	210	3	45
Total I order streams		1548		719		1837		922		1208		573	
2→3	0	249	0	112	0	235	0	149	0	198	0	98	0
2→4	2	25	50	12	24	38	76	38	76	39	78	22	44
2→5	6	43	258	30	180	45	270	16	96	25	150	11	66
2→6	14	13	182		0	20	280	5	70	4	56	2	28
3→4	0	64	0	0	0	57	0	31	0	2	0	17	0
3→5	4	4	16	28	28	8	32	7	28	7	28	2	8
3→6	12	2	23	0	0	12	144	4	48	2	24	2	24
4→5	0	17	0	5	0	10	0	7	0	3	0	5	0
4→6	8	2	16			9	72	1	8	1	8	1	8
5→6	0	2	0		0	1	0	2	0	1	0	1	0
Ha _i		2284		1139		3450		1428		1165		782	
Total I order streams		1548		719		1837		922		1208		573	
Δa		1.48		1.58		1.87		1.55		0.96		1.36	

Table 1. Determination of Hierarchical anomaly index (Δa) (after Bahrami, S. 2013). * represents vectorized data derived from SOI topo-maps (1910) and ** represents vectorized data derived from SOI topo-maps (2005-06).

The temporal analysis of stream network shows the change in drainage composition. The wide variation in stream numbers is observed from temporal data. Table 1.2 represents the details of stream numbers in each stream order derived from vectorised SOI top sheets surveyed on 1910 and 2005-06 respectively.

Sub basins	I *	I **	II *	II **	III *	III **	IV *	IV **	V *	V **	VI *	VI **
Sholaiar	1548	719	330	154	70	31	19	5	3	1	1	0
Parambikolam	1837	922	338	208	77	42	19	8	3	2	1	1
Kuriyarkutty	1208	573	266	133	51	21	11	6	4	2	1	1

Table 2. Stream numbers of each stream order. * represents vectorized data derived from SOI topo-maps (1910) and ** represents vectorized data derived from SOI topo-maps (2005-06).

The first order and second order streams are reduced to half of its numbers in the recent vectorized topo-map data. Maximum stream order of Sholaiar sub-basin is changed from sixth to fifth order. This data shows that the sequential drainage network progressions had been altered. The construction of dams altered the drainage system, resulted from head ward and lateral erosion due to impounded water. This in-turn inundated part of the forest cover of the drainage basin.

Temporal analysis of hierarchical anomaly index (Δa) shows that the hierarchical anomaly of the sub-basins Sholaiar and Kuriyarkutty is increased during the past 100 years. The temporal variation of (Δa) value of Parambikolam sub-basin is due to the

higher number of first order streams joining the sixth order stream (as inferred from 1910 data). These first order streams joining the sixth order stream are destroyed due to the reservoir construction (as inferred from 2005 data). The temporal change in the number of streams in each stream orders affected the hierarchical organization which in turn reflected in the hierarchical anomaly index value (Table 1).

The recent flood (16-24 August 2018) occurred in the drainage basin had devastated the man made constructions in the flood plains. Many of the house basements had been demolished. Many paleo first order streams has rejuvenated and the terrain had witnessed slope failures at several locations. Torrential rainfall accelerated the fluvial erosion and slumping, soil piping occurred in the drainage basin increased the intensity of the disaster. The manmade constructions in the first order and second order paleo-stream networks are demolished during the recent flood.

GIS enabled geospatial processing of temporal maps serves as a guide to delineate disaster risk zones. Studies of paleo-channels and its distribution have to be considered by the civil engineers, town planners before the implementation of projects in a terrain. Vectorized temporal maps help the professionals in different disciplines to consider the factor of environmental changes before the implementation of projects. For instance, many civil engineers recommend the sites for house construction even in the second order paleo-channels as they are unaware of the geologic factors. Heavy rains may initiate the flow in these paleo-channels which may affect the basement of these constructions. Awareness has to be created to consider the geologic and environment factors to ensure safety as the first priority, before the implementation of a project. Detailed flood mapping, risk zone delineation is recommended to ensure the safety of men and materials in the drainage basin.

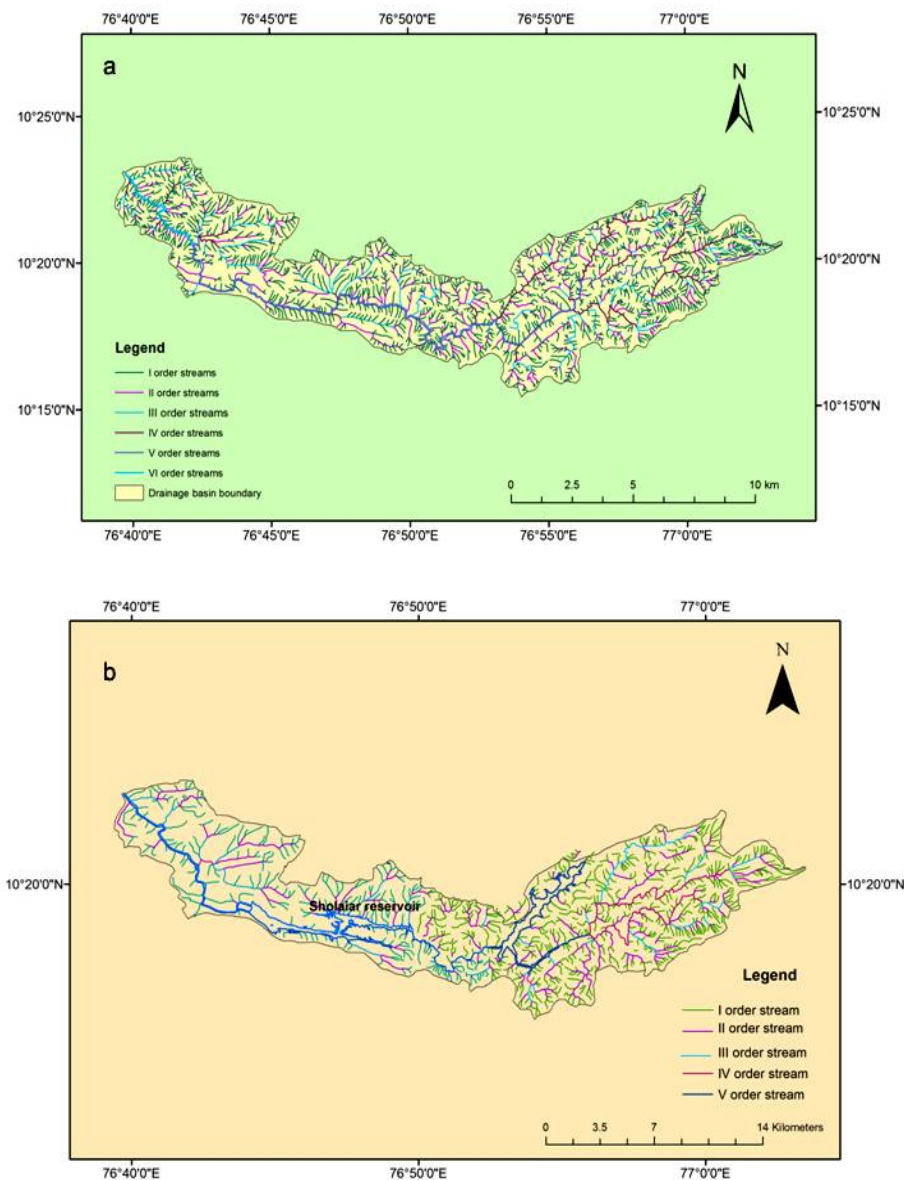


Figure 2.1 a,b. Drainage network of Sholaia sub-basin. Figure 2.1.a. Vectorized drainage data derived from SOI top sheets (1910). Figure 2.1.b. Vectorized drainage data derived from SOI top sheets (2005-06).

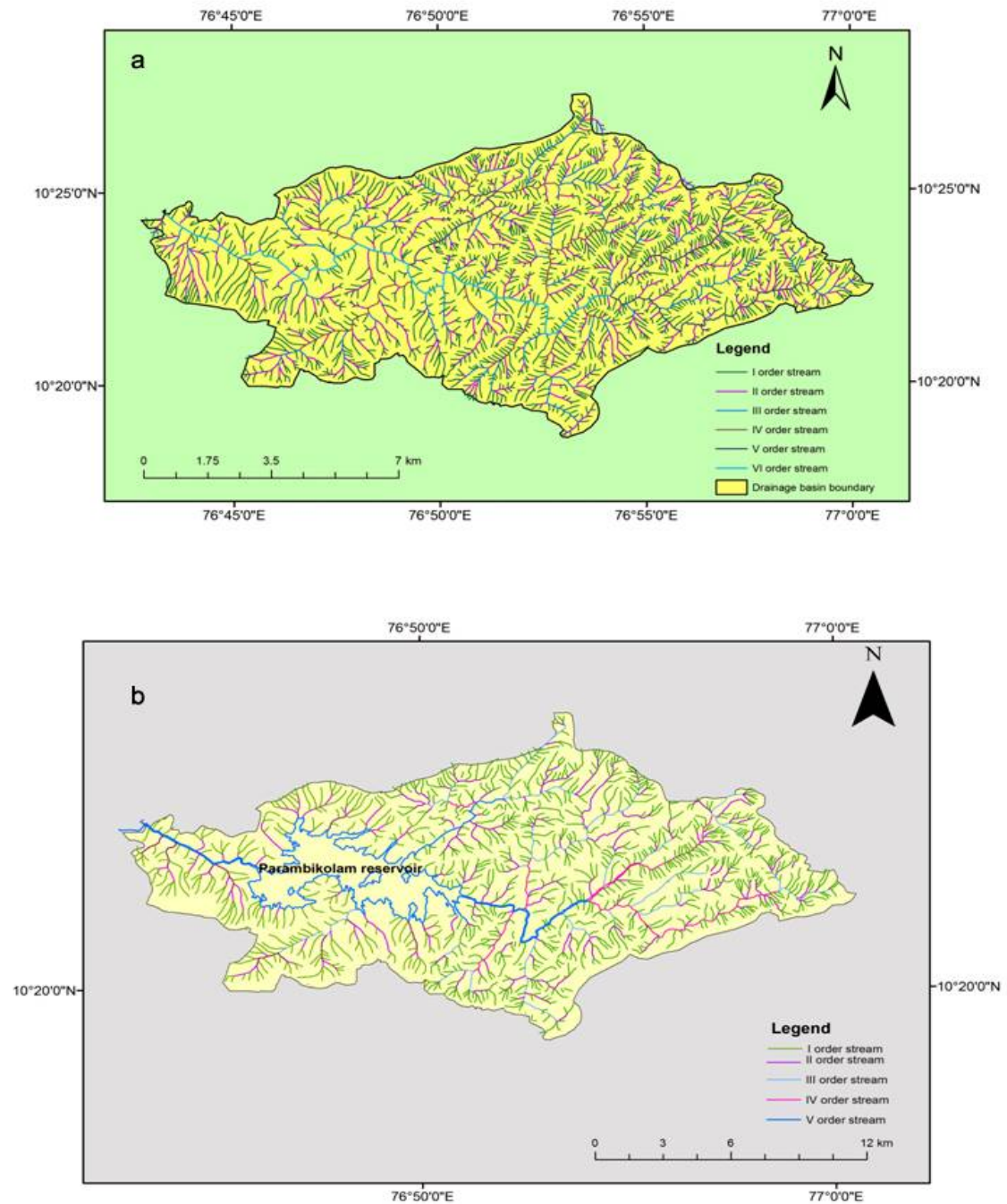


Figure 2.2 a,b. Drainage network of Parambikolam sub-basin. Figure 2.2.a. Vectorized drainage data derived from SOI top sheets (1910). Figure 2.2.b. Vectorized drainage data derived from SOI top sheets (2005-06).

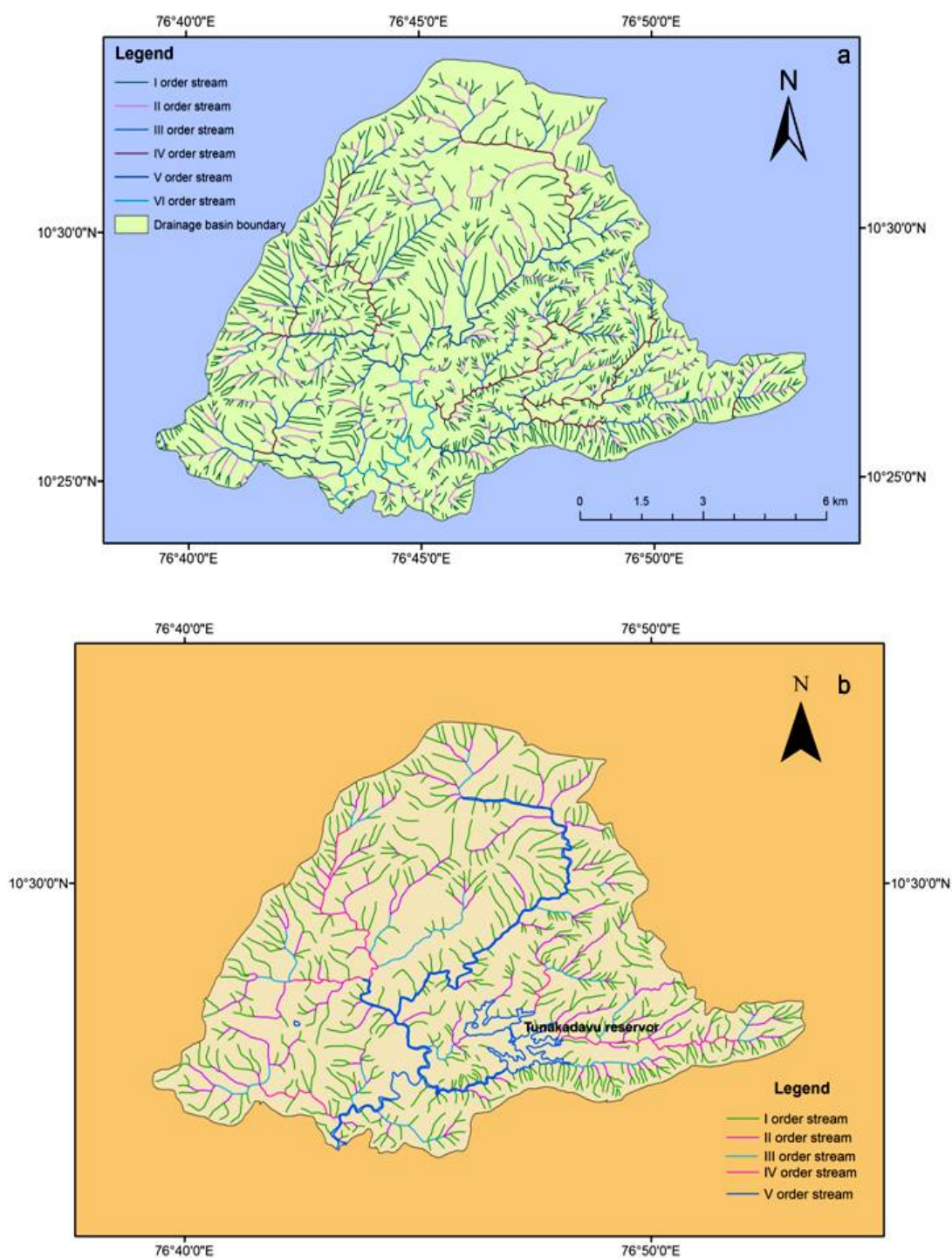


Figure 2.3 a,b. Drainage network of Kuriyarkutty sub-basin. Figure 2.3.a. Vectorized drainage data derived from SOI top sheets (1910). Figure 2.3.b. Vectorized drainage data derived from SOI top sheets (2005-06).

5. CONCLUSION

GIS-enabled analysis of temporal topographic maps depicting three-dimensional data is a good tool for delineating the prospective disaster zones. Ancient topo-maps are data product of utmost importance in the mapping for security, safety, and surveillance of the environment. The study of paleo-channels and hierarchical progressions of drainage networks helps to monitor the extent of environmental deterioration and influence of tectonics in creating anomalies in the drainage network. Landslide zone delineation studies should consider the hierarchical anomalous streams bearing watersheds as a prospective zone for slope failures. The decline trend line of stream numbers of each stream order and spatial variation in hierarchical organization of drainage network over the past years are interpreted from the temporal analysis. Human intervention by the construction of dams had altered the drainage network and the maximum stream order of Sholaiar sub-basin shows variation. Declassification of temporal digitized topo-maps and its geospatial analysis is essential for effective land use planning and environmental conservation.

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PERFORMANCE ASSESSMENT OF TANK IRRIGATION SYSTEM USING REMOTE SENSING

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ABSTRACT

Remote Sensing and GIS provide objective solution for monitoring and assessment of irrigation systems. Satellite data is useful to assess the performance of irrigation systems using performance indicators pertaining to cropping pattern, cropped area, and crop health. Government funded development programmes are implemented to restore the healthy state of tank irrigation systems. Most of the tanks in the country are non-system tanks, used for agriculture purpose and depend on the monsoon rainfall. The present study aims to assess performance of tank irrigation system using satellite data over two different time period of similar rainfall. In this, cropping pattern, cropped area, and crop health were analyzed for 2009-10 and 2017-18 crop season. Results show increase in cropped area in 78% of tank ayacuts, with cropping pattern shifted towards more paddy cultivation in 2017-18 compared to 2009-10. Cumulative Water Spread Area remains unchanged in magnitude after Monsoon period from October to January in 2017-18.

KEYWORDS: Minor Irrigation System, Unsupervised Crop Classification, Crop Health, Water Spread Area, Remote Sensing & GIS.

1. INTRODUCTION

Tank irrigation is one of the oldest irrigation methods being practiced in various parts of Indian region. Tanks are water storage structures that support agriculture, satisfy local drinking water needs, and sustain local ecological balance. Owing to their importance, tanks were made, maintained, and preserved by locals especially in geographical regions lacking in perennial water resources, such as Telangana state (India). Minor Irrigation Census conducted by state government reveals number of tanks to be 46,531 [1]. 'Tank restoration' programme of Telangana state government aims to restore all 46,531 tanks during 2015-2020 by taking 20% of total tanks each year. The objective is to restore tanks to their original storage capacity by de-silting the tank beds and by improving and strengthening infrastructure such as bunds, sluices, weirs etc.

Remote Sensing and GIS technology provide space-based solution to monitor and assess the performance of irrigation system [2]. Satellite data is useful in assessing the performance of irrigation schemes using performance indicators pertaining to cropping pattern, cropped area, crop health, and water availability [3]. Supervised and Unsupervised Classification techniques can be adopted to demarcate cropped area from other land cover classes in order to estimate total cropped area. Further, Crop Classes can be classified in Paddy and Non-Paddy crop classes. Changing cropping pattern, i.e. shift from paddy to non-paddy or vice-versa, is a proxy indicator of change in water availability for irrigation. Crop Health can be assessed on the basis of Normalized Difference Vegetation Index (NDVI) [4]. Normalized Difference Water Index (NDWI) can be used to estimate surface water spread area [5].

Overall, this study involves proxy indicators related to area under crops, its health, and water availability to assess the impact of minor irrigation system, pre and post implementation. In India, agriculture is heavily dependent on intensity and distribution of South-West Monsoon. Rainfall remains the most crucial factor in deciding the fate of agricultural production. Hence, year 2009-10 is selected as pre-implementation year to compare with year 2017-18 based on similar rainfall in Mahabubnagar district. Mahabubnagar district in Telangana state is selected as study area as it is one of the most adversely affected region of the state in terms of water availability [1].

2. STUDY AREA

Mahabubnagar, being the largest district of Telangana state is chosen as study area. The total geographical area of the district is 5,285.1 sq. km. It is located between 15°55' and 17°29' N Latitude and between 77°15' and 79°15' E Longitude. River Krishna and Tungabhadra flows through the district. Agriculture is the main occupation of people in Mahabubnagar and Drought is ever persistent problem in the district which makes it suitable for the present study. Spatial distribution of selected tanks (926 nos) in the study area is shown in Figure 1.

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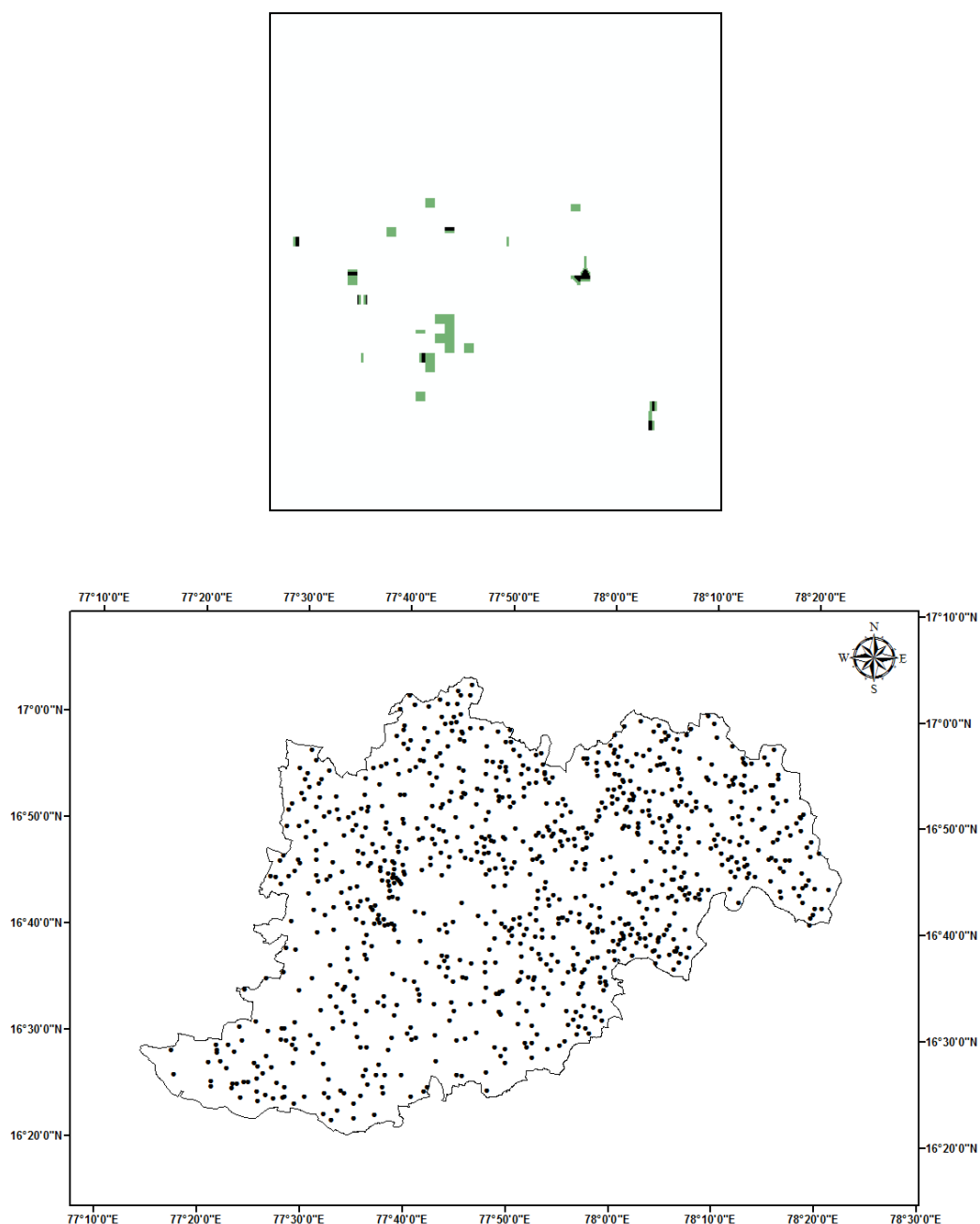


Figure 1. Spatial distribution of selected tanks in Mahabubnagar district

3. METHODOLOGY

3.1. Selection of Study Years

In order to assess the performance of tank irrigation system on its response for similar rainfall over different time periods, historic rainfall data for past ten years were analyzed. For this, CPC (Climate Prediction Centre) precipitation daily rainfall data was used.

Daily data was aggregated to monthly to derive total rainfall during South-West and North-East Monsoon over Mahabubnagar district (Figure 2 and 3). It is found that the year 2009-10 is the most similar to 2017-18 in terms of mean Rainfall during South-West (S-W) Monsoon. Rainfall during S-W Monsoon is what determines largely the volume of surface water storage.

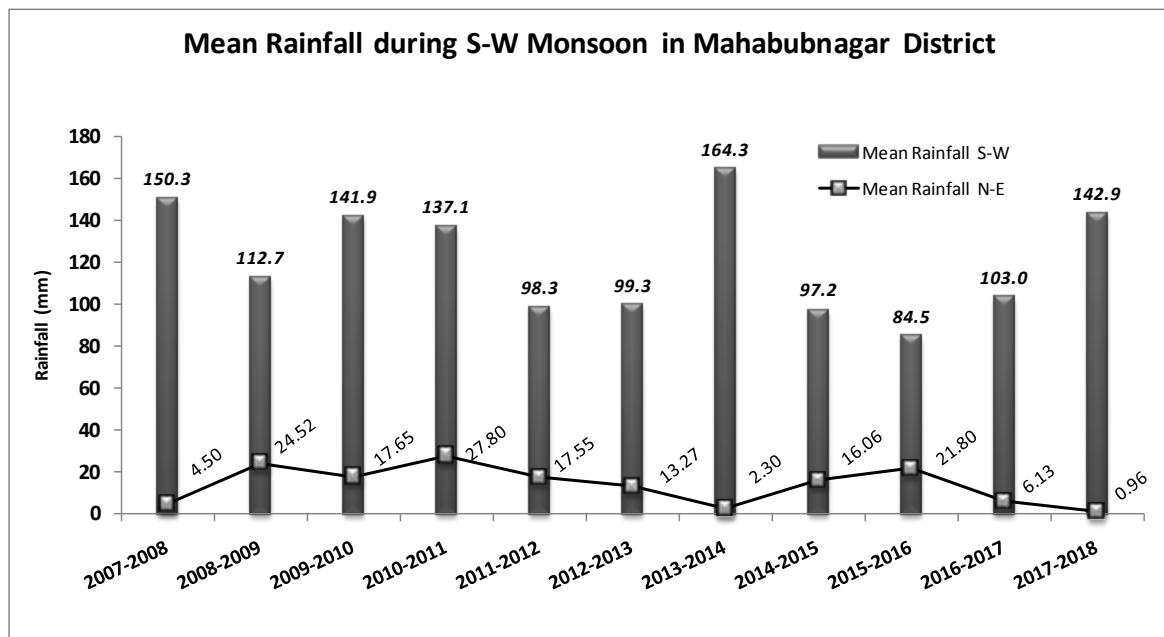


Figure 2. Mean Rainfall during South-West and North-East Monsoon period over Mahabubnagar district

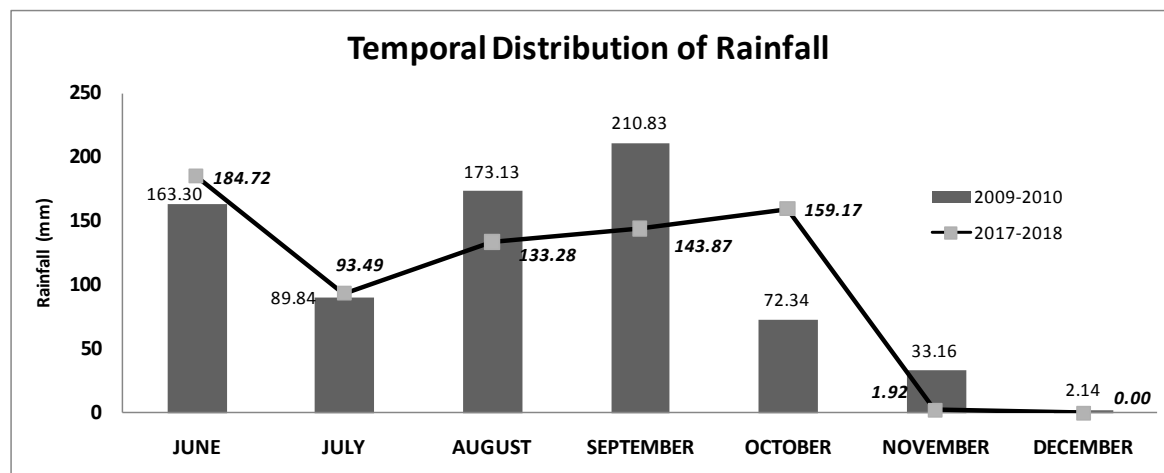


Figure 3. Mean Rainfall in Mahabubnagar district during months of June to December.

It is observed in Figure 2 that mean Rainfall during S-W Monsoon in 2009-10 is 141.9 mm which is closest to 2017-18's mean Rainfall of 142.9 mm. In terms of temporal distribution of rainfall in both the years (Figure 3), rainfall in first two months (June and July) shows similar pattern but 2009-10 had more rainfall in August and September as compared to 2017-18 which is compensated by heavy rainfall in October 2017. There is a little difference in N-E Monsoon Rainfall in both the years.

3.2. Analysis of Satellite Data

Remote Sensing is used to estimate and compare area under the crop, crop health, and water availability in both the years. Satellite data used belongs to Landsat 8, Landsat 5, and IRS-P6 (LISS III). Scenes used from different satellite platforms are tabulated in Table 1 for Reference. Atmospherically corrected Landsat products were used and LISS 3 scenes were atmospherically corrected using FLAASH package. After atmospheric correction, Normalized Difference Vegetation Index (NDVI) was computed for each scene and layer stacked for Kharif and Rabi seasons.

2009-10		2017-18	
Date of Pass	Satellite - Sensor	Date of Pass	Satellite - Sensor
September 25, 2009	Landsat 5 - TM	November 02, 2017	Landsat 8 -OLI
October 27, 2009	Landsat 5 - TM	December 04, 2017	Landsat 8 -OLI
November 28, 2009	Landsat 5 - TM	December 24, 2017	Landsat 8 -OLI
December 14, 2009	Landsat 5 - TM	January 21, 2018	Landsat 8 -OLI
January 31, 2010	Landsat 5 - TM	February 06, 2018	Landsat 8 -OLI
February 06, 2010	IRS P6 – LISS 3	March 10, 2018	Landsat 8 -OLI

Table 1. Satellite data used in study

3.3. Estimation of Total Cropped Area

The multi-date NDVI stacked images for Kharif and Rabi season of selected years were classified using ISODATA Unsupervised Classification technique in to 40 Classes. Unsupervised classification technique is adopted due to lack of Ground Reference data. Crop and Non-crop classes were identified based on temporal NDVI Responses of each class. Further, Crop Classes were classified into Paddy and Non-Paddy crop classes based on NDVI as well as Spectral responses. Paddy has a unique spectral response among crops as it shows strong absorption in NIR and SWIR Band. In False Colors (NIR) Paddy is easily distinguishable because of its darker tone.

At first, Crop Classification is done for entire Mahabubnagar district then same is clipped for corresponding tank ayacuts. A sample of Classification for Rabi Season 2017-18 is shown in the tank areas around Mahabubnagar town in Figure 4.

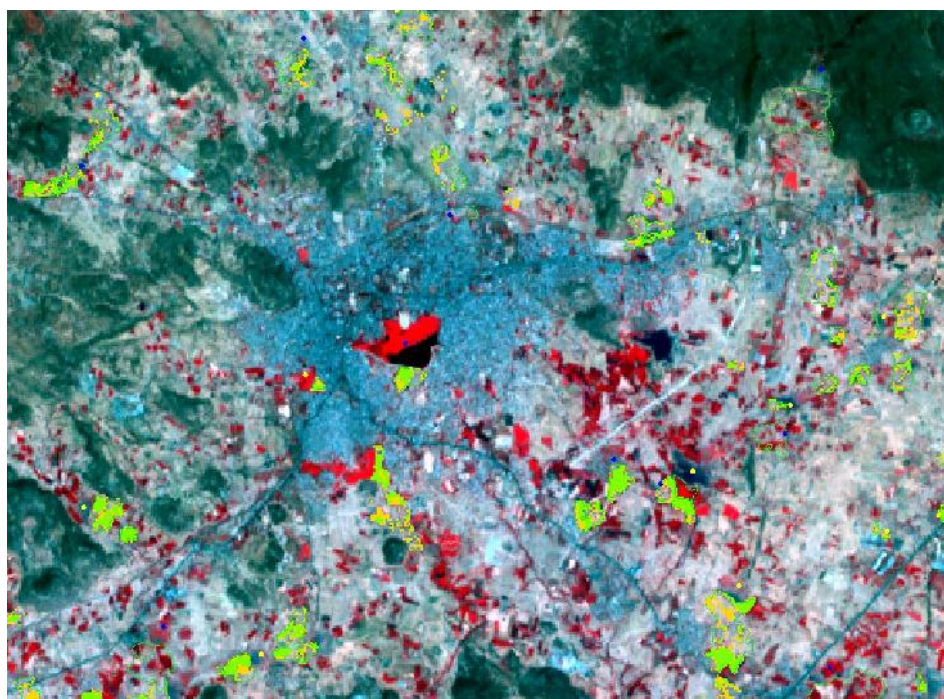


Figure 4. Paddy (Yellow) and Non-Paddy (Green) classes in Tank Ayacuts around Mahabubnagar town over 10 March 2018 (Rabi) Landsat 8 OLI data.

3.4. Assessment of Crop Health based on NDVI

NDVI based approach was used to assess crop health within tank ayacuts. In both, Kharif and Rabi seasons, NDVI images are layer stacked and for each pixel maximum NDVI value is calculated. As NDVI correlates positively with crop health, this method takes care of best of crop health from its plantation to harvest. However, if crop health gets adversely affected after its maturity, such changes remain uncovered in this method. So, this method compares the crops in their stage of maturity.

Maximum NDVI Raster for each scene is clipped for Tank Ayacuts to assess the condition of the crop within tank ayacuts. Peak NDVI distribution provides information related to general behaviour of crop health. Histogram of NDVI values are plotted for both the season for Paddy and Non-Paddy crops for the year 2009-10 and 2017-18 to assess the change in crop health. Figure 5 shows the change in crop health between 2009-10 and 2017-18 for Kharif crop.

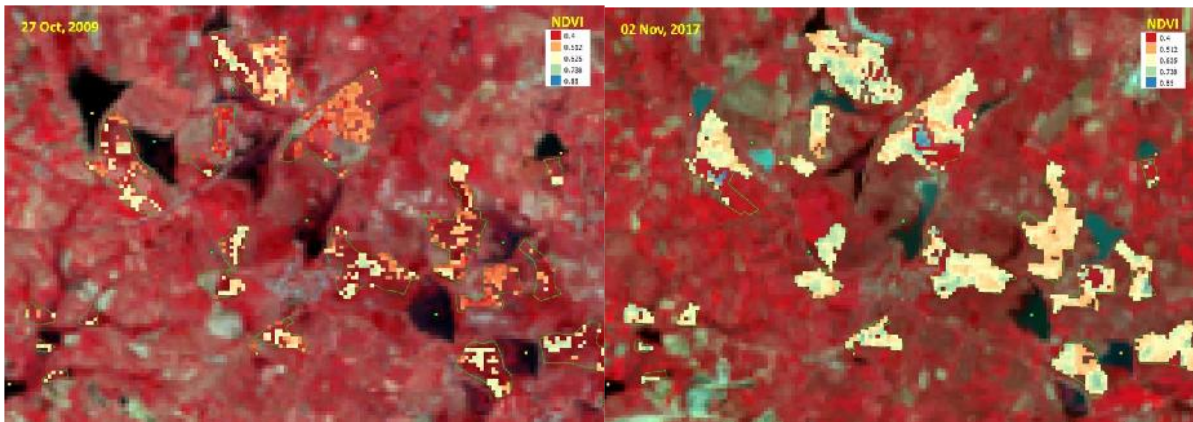


Figure 5. Crop Health in Kharif season for years 2009-10 (left) and 2017-18 (right).

3.5. Water Spread Area based on NDWI

Normalized Difference Water Index (NDWI) is used to detect water pixels in the satellite images which in turn is used to estimate Surface Water Spread area in the tanks earmarked for tank restoration programme implementation in Mahabubnagar district. NDWI takes the ratio of difference and sum of Green and NIR reflectances. NIR radiation is strongly absorbed by waterbodies whereas Green region is identified to be local maxima of reflected radiation by waterbodies. Hence, higher the NDWI better are the chances of pixel belonging to water class. NDWI raster are calculated for each scene and a thresholding technique is applied to separate water pixel from other classes.

4. RESULTS AND DISCUSSION

Total cropped area within tank ayacut boundaries in both the seasons is presented by Figures 6 and 7. It is observed that total cropped area in 2017-18 is roughly 1.64 times of 2009-10 in Kharif season. There is 1.65 times increase in Paddy cultivation and 1.6 times increase in cultivation of non-paddy crops.

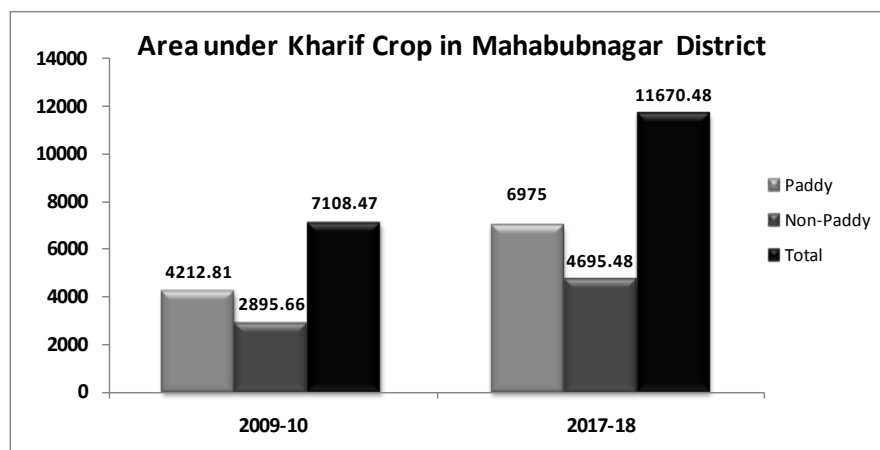


Figure 6. Cropped area under Kharif crop within Tank ayacuts in 2009-10 and 2017-18.

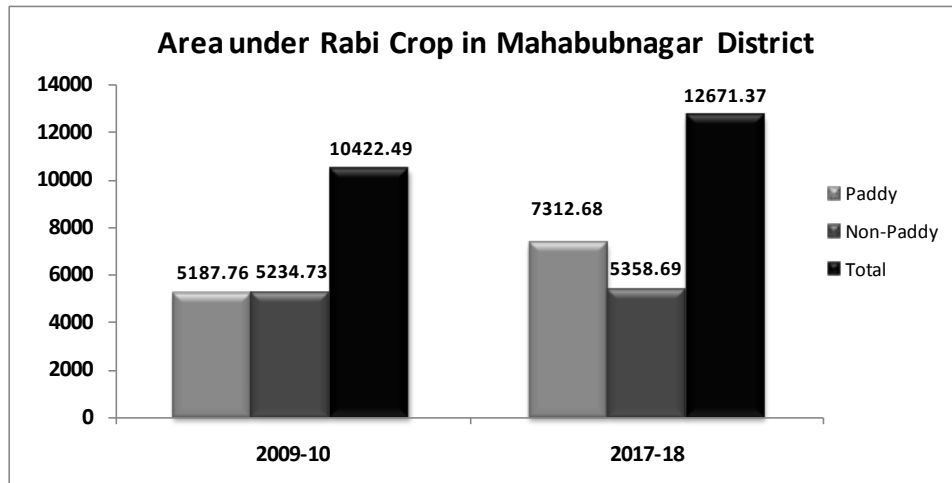


Figure 7. Cropped Area under Rabi crop in 2009-10 and 2017-18 within Tank ayacuts.

2017-18 Rabi season experienced 1.41 times increase in Paddy cultivation whereas non-paddy cultivation is almost unchanged. Increase in total cropped area is 1.22 times that of 2009-10.

On Tank-Ayacut wise comparison in both the seasons (Figure 8), it is seen that in Kharif season most of the ayacuts experience increase in total cropped area. However, in Rabi season trend is not as promising as of Kharif season.

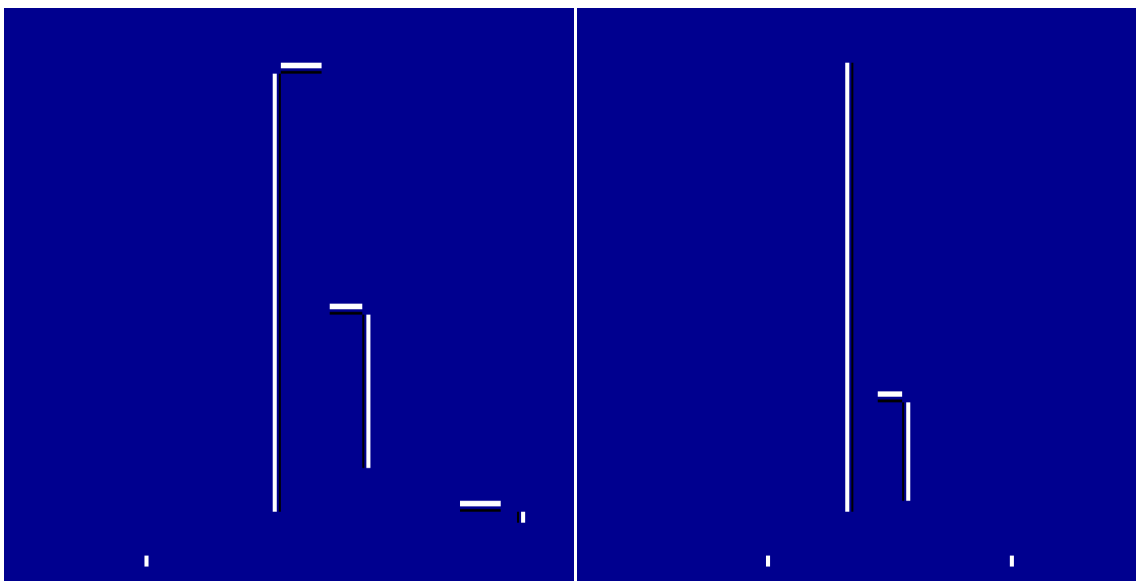


Figure 8. Tank Ayacut wise comparison of fractional increase in Total Cropped Area in Kharif(left) and Rabi (right) seasons.

Crop Health assessed is also based on peak value of NDVI during Kharif and Rabi Seasons. Histogram plots in Figure 9 and 10 reflect the distribution of peak NDVI in Kharif and Rabi seasons respectively in both the years. In Kharif season, there is shift in case of both Paddy and Non-Paddy crops towards higher NDVI value in 2017-18 as compared to 2009-10. Also, the most probable value in 2017-18 is close to 0.8 in case of Paddy and Non-paddy whereas in 2009-10 it is close to 0.6 for both the crops. It shows, crop health in tank ayacuts has improved significantly.

Rabi Paddy and Non-Paddy crop in 2017-18 has also improved significantly as compared to 2009-10 which is observed through right shifting of NDVI peak value distribution. Also, the most probable value in 2017-18 is 0.7 which is much higher compared to most probable values for both crops, 0.5 (Paddy) and 0.35 (Non-Paddy), in 2009-10.

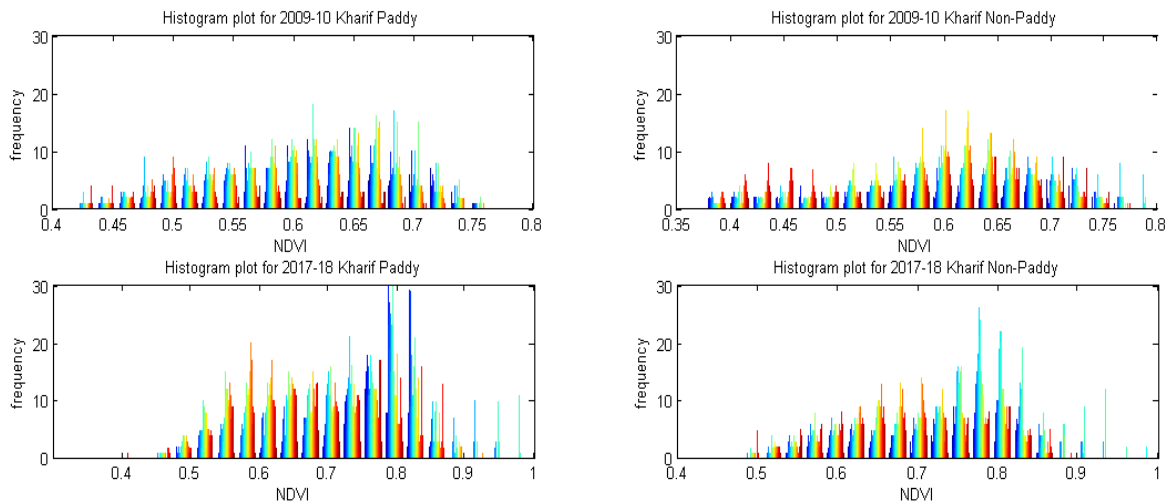


Figure 9. Peak NDVI distribution for Paddy (Left) and Non-Paddy (Right) crop in Kharif season of 2009-10 (Top) and 2017-18 (Bottom).

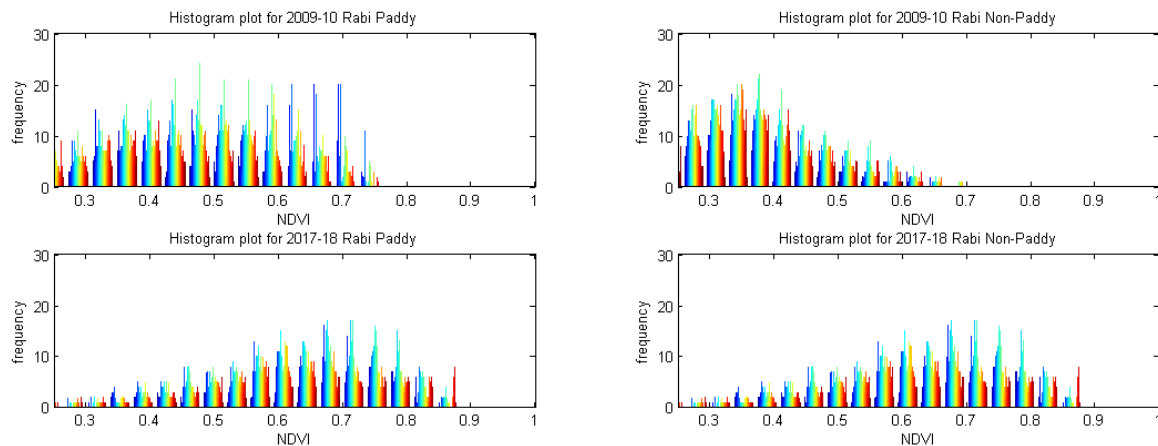


Figure 10. Peak NDVI distribution for Paddy (Left) and Non-Paddy (Right) crop in Rabi season of 2009-10 (Top) and 2017-18 (Bottom).

Tank restoration programme's first objective is to de-silt the tanks to increase their water storage capacity. Remote Sensing is useful in estimating the water spread area of surface water bodies. Time series water spread area information gives an idea of sustainable water availability. NDWI based cumulative water spread area of the tanks under tank restoration is given by the Figure 11.

Magnitude wise trend in cumulative water spread area reflects a huge drop in 2017-18 as compared to 2009-10. Drop in water spread area is also not unexpected due to de-silting of tanks post implementation of programme. It must also be noted that the year 2017-18 follows three consecutive deficit rainfall years as shown in Figure 2. If trend of water spread area is considered, 2017-18 maintains almost unchanging cumulative water spread from October starting to January end whereas 2009-10 experiences downfall throughout the same duration. Slight increasing trend of water spread area in 2017-18 during October to December can be attributed to heavy rainfall in October month (Figure 3).

It is seen that there is increase in Total cropped area, improvement in crop health, and improvement in performance of ayacut with respect to crop area. The magnitude of Water spread area in year 2017-18 shows unchanging pattern after Monsoon which shows the capacity of water storage structure to deliver water during Rabi season.

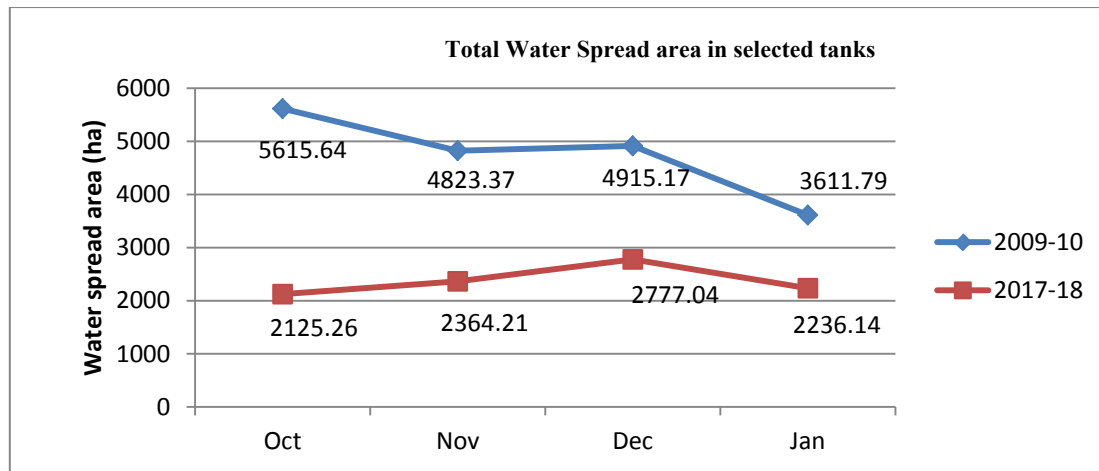


Figure 11. Cumulative Water Spread Area (ha) of the Tanks in Mahabubnagar district.

This study uses Unsupervised classification based crop and non-crop classification of temporal NDVI scenes to assess total cropped area in the year 2009-10 and 2017-18. Further, Crop classes are classified to Paddy and Non-Paddy crop classes based on spectral response. Unsupervised studies are generally supported through ground reference data which provides better accuracy to classification. This study does not take support of ground truth which probably will induce a little error in classification. However, this study focuses only on trends of increase and decrease in crop related parameters.

5. CONCLUSION

Tank Ayacut areas in Mahabubnagar district in 2017-18, two years after the Tank restoration programme's inception, experience increase in Total Cropped area especially in Kharif season, improvement in Crop Health, and water availability for longer period. Total Cropped area in Kharif season increases by 1.64 times as that of 2009-10 and in Rabi season same goes up by 1.41 times. In Kharif season, 78% of tank ayacuts show a positive increasing cropped area. In Rabi season, only 22% tank ayacuts show positive increasing cropped area trend with 46% showing no change at all. In 2017-18 Rabi season, Area under Paddy crop increases significantly while Non-Paddy cropped area remains stagnant as compared to 2009-10 Rabi season which is a positive sign towards sustainable water availability for irrigation.

Cumulative Water Spread Area in tanks remains constant in magnitude after Monsoon period from October to January end.

Crop Health improves significantly in 2017-18 as compared to 2009-10 which is shown by the clear shift in NDVI towards higher range and increase in most probable value of 0.8 in 2017-18 as compared to 0.6 in 2009-10.

All the parameters discussed above show a positive trend and indicate growth in healthy agriculture production within tank ayacut areas. Though other factors such as technological improvements, availability of quality seeds, subsidy on fertilizers and electricity may have influence on indicators (crop area and crop health), water availability remains a critical factor in governing the overall performance of minor irrigation systems.

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BATHYMETRY ESTIMATION IN TURBID WATER USING SENTINEL 2 IMAGE

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ABSTRACT

The Hydrographic surveying techniques provides bathymetric data with precision and accuracy to fulfill demand of 'Zones of Confidence' as per IHO (International Hydrographic Office) standards. The cost of operation for Hydrographic surveying is very high, which restricts repetitive and frequent survey in any area of interest. Recently, various modern techniques are adopted to determine the bathymetry of the ocean. This includes LIDAR, use of ROV's & AUV's for effective determination the depth in coastal waters, which are also very expensive for its high purchasing and maintenance costs. Remote sensing and GIS techniques have been extensively used in monitoring and management of natural resources in the coastal areas for its advantage of repetitive, multispectral and synoptic nature.

Since last three decades, satellite images are being evaluated as one of the most potential alternative to depth estimation by researchers. But three decades of research is just in stage of infancy in terms of application. Recently, various researchers have used Landsat 8, Spot 5, Worldview 2 & IRS data to depth retrieval using various algorithms. This study uses SENTINEL 2 multispectral satellite image for depth derivation. To achieve the objectives of this research, out of available 15 bands only Blue (band 2), Green (band 3), & Red (band 4) are applied with empirical algorithm and comparative analysis has been done between the few applied algorithm. The resultant image was overlaid by bathymetric chart of the area to derive the conclusion of the study.

KEYWORDS: Satellite Derived Bathymetry, Hydrography, Bathymetry, IHO

1. INTRODUCTION

Historically, conventional bathymetry practices included depth measurements using sounding leadline, pole log, etc. to retrieve the depth at a single location. The next stage in modernization of bathymetry techniques was acoustic echo-sounding technique. The technique used two different methodologies viz Single-Beam Echo Sounder (SBES) and Multi-Beam Echo Sounder (MBES) for depth as well as seabed topography determination. These techniques provide data with precision and accuracy to fulfill demand of 'Zones of Confidence' which are indicative of quality of bathymetric data, as per IHO (International Hydrographic Office) standards. However, SBES/MBES surveys are very costly for repetitive and frequent surveys. Recently, various modern techniques are adopted to determine the bathymetry of the ocean. This includes LIDAR, use of ROV's & AUV's for effective determination the depth in coastal waters. But these techniques are also very expensive for its high purchasing and maintenance costs. Recently, there is a surge of research from academia and industries on Satellite Derived Bathymetry (SDB) and its applications in maritime industries. Though, SDB was developed in the late 1970s, its application was in infancy stage till last decade. Recent advances in satellite technology in terms of higher resolution, multi-spectral bands, open-source availability, etc. have enhanced its potential to be used as source hydrographic data. The use of satellite data is increasing throughout the hydrographic industry as a low cost source of data. This has been further supplemented by proposal placed forward by United Kingdom Hydrographic Office (UKHO) to 11th CSPWG (now NCWG-Nautical Chart Working Group), 2015 meeting of IHO to consider standardization and guidance for the representation of SDB data on paper charts and ENC's. Also, in October 2015, the UKHO published its first nautical chart – BA 2066 (Southern Antigua) incorporating data derived from satellite images. Further, SDB is gaining importance in all the Regional Hydrographic Commission (RHC) meetings of IHO. Briefly, it can be concluded that SDB is gaining acceptance not only as an operational exploration tool, but also as an advanced technique that is capable of providing calibrated and validated depths to the mariners with very less resource utilization.

Remote sensing and GIS techniques have been extensively used in monitoring and management of natural resources in the coastal areas due to its repetitive, multispectral and broad nature (Jawak, Vadlamani, & Luis, 2015). Remote sensing data has been previously used to evaluate the coastal processes like littoral drift, erosion/ accretion and shoreline changes and to study water geomorphology, landforms, coastal wetlands, suspended sediment concentration, water quality, tidal boundaries (high/low), brackish water areas coastal currents, vital coastal habitats etc (Mishra & Gould, 2016; Pacheco, Horta, Loureiro, & Ferreira, 2015; Sánchez-Carnero et al., 2014). The major advantages of RS and GIS are that it allows identifying the spatial relationships between features and temporal changes within an area over time. Since last three decades, Remote sensing images are being evaluated as one of the most potential alternative to depth estimation for its wide coverage of the area, repeatability and low cost. Recently, various researchers have used LANDSET 8, SPOT 5, WORLDVIEW 2 & IRS data to depth retrieval using various algorithms (Halls & Costin, 2016; Jagalingam, Akshaya, & Hegde, 2015; Kabiri, 2017; Maheswari, 2013).

The theory building of empirical approach in SDB is mostly accredited to Lyzenga, (1978) who introduced the log-linear empirical approach on single band image for detecting SDB by focusing mainly on removing all other reflected parameters attenuating water bottom signals. Lyzenga's research continued for three decades in improving his model for multiband images by proposing log-linear correlation between multiband and water depth values (Lyzenga et al. 2006). Another empirical approach which conceptualized

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(difference in attenuation of different bands in water can be used for SDB) on band ratios, was developed by Stumpf, Holderied, & Sinclair, (2003). On the other hand analytical methods utilize spectral libraries (for bottom reflectance, suspended and dissolved matters) in interpretation of SDB using Multispectral (MS) or Hyperspectral images (HS). However, analytical approach have several limitations over empirical models for dependency on different parameters collected from field data (Bramante, Raju, & Sin, 2013). Jawak & Luis, (2015) in their review on SDB using RS compared few models & methods; mainly classified as imaging methods and non-imaging methods (Table 1). The non-imaging method (like use of LIDAR) and imaging methods (in which satellite images pixel values or digital numbers (DN) represent reflectance using Visible/Near infrared (NIR) and Microwave radiation) are applied with analytical or empirical (or by a mixed method) algorithms to SDB.

Table:1 Types of remote sensing techniques for Bathymetry -Advantage & Drawbacks
(Source: Jawak & Luis, 2015, p.149)

Method	Sensor	Type	Accuracy	Controlling Factors	Advantages	Drawbacks	Scope of Application
Imaging	Microwave or SAR sensor	Active	Relatively low	Image resolution, slicks, waves, fronts, weather condition	- Applicable over large areas - Unaffected by cloud cover	- Relative low accuracy	Bathymetry derivation from open oceanic waters
Non-imaging	Radar Altimetry	Active	Very low accuracy	Elastic thickness of the lithosphere and/or crustal thickness, sediments	Global coverage, needs only simple altimetry with no iono/tropo sphere measurement	Possible over a limited wavelength band	Coarse bathymetry derivation for oceans
Non-imaging	LIDAR	Active	≈15 cm	Water clarity or turbidity, bed material, surface state	Wide depth range; concurrent measurement not essential	- Expensive - Limited swath width	Varied aquatic environments of narrow range
Imaging	Optical (analytical)	Passive	Relatively high	Water quality (clarity or turbidity), cloud cover, atmospheric conditions	- Based on physical process - Relatively higher accuracy	- Complex execution as input parameters are required - Real-time <i>m-situ</i> data essential	Turbid and shallow inland waters, estuaries, river channels
Imaging	Optical (empirical)	Passive	Varying accuracy	Atmospheric calibration, water turbidity, bottom reflectance	- Simple to execute - Accurate at definite depth	- Limited depth - Accuracy lower at a larger depth - Real-time ground truth essential	Near shore and coastal waters, open waters
Imaging	Video	Passive	Relatively high	Image resolution	- Capable to produce minor bathymetric change	Restricted area Bathymetry along profiles	Intertidal zone and estuaries

The chronological order of development of few SDB algorithms commonly used is as; Linear Band Model – Lyzenga 1978; 1985; 2006; Benny and Dawson (1983); Flow Radiative Transfer Model- Spitzer & Dirks, 1986; Depth of Penetration Zone (DOP) Model – Jupp, 1988; Philpot (1989); & Linear Ratio Model - Stumpf et al. 2003. These models are based on conceptualization that there exists a mathematical relationship between the remotely sensed radiance/reflectance of a water body and in-situ depth (ground truthing at few control points). A strong correlation exists between depth and single band radiance if optical properties and bottom reflectance remains uniform throughout the area. The complexity in SDB increases with changes in water column properties and nature of bottom which often leads to erroneous predication of SDB. Generally, the errors in SDB are attributed to water turbidity and sub-bottom vegetation which impacts signal attenuation.

This study focuses on Optical RS for SDB and uses SENTINEL 2 multispectral satellite image to depth derivation using ratio transform algorithm developed by Stumpf et al., 2003. The regression coefficient R^2 is calculated between the pixel DN value and the bathymetric data for corresponding pixel value. The regression analysis has been done for band ratios of Band 2 & Band 3, whereas NIR Band 4 has been used to mask land over sea surface. The statistical indicators, RMSE and R^2 were used for the retrieved depth values obtained by applying all above methods. The estimated results were subsequently compared to the field measured data.

2. STUDY AREA

2.1 Location and Extent

Coastal waters offshore to island city Mumbai in geographical extent 18° 53' N-72°39' E (LL) and 19°11' N -72°50' E (UR) as shown in figure below has been selected for study. This area has several creeks and discharges from the city, which makes it very turbid in nature.

The sediments are mainly carried by Vaitarana River, Mithi River, Malad Creek, Thane Creek and several other outlets carrying discharge. The satellite image of the area has been acquired for the month of October, so that resultant image will have minimum effect of high amount of sediments resulting from flooded rivers due to heavy rainfall during monsoon. The weather is generally calm in October along the western coast of India.

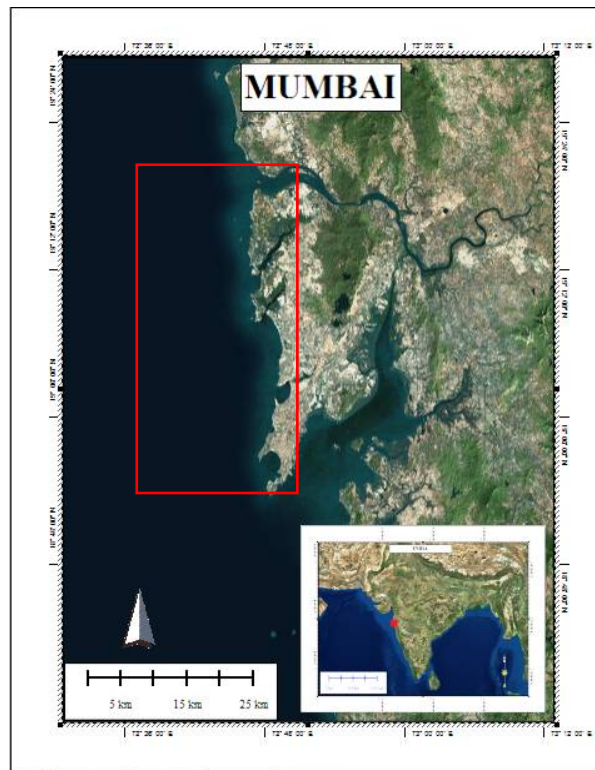


Figure 1: Location of the study

3. MATERIALS & METHODS

3.1 Satellite Image

The SENTINEL_2 MSI satellite image of study area (10 meter spatial resolution) has been downloaded from Sentinels Scientific Data hub for 30 Oct 2017 (which was filtered for less than 5 % cloud cover). The image was preprocessed to LEVEL-1C i.e. orthorectified, TOA reflectance with sub-pixel MS registration. Out of available 15 bands only Blue (band 2), Green (band 3), Red (band 4) and Near Infrared band (band 7) are used for this study. The selection of bands was based on literature review in which various researchers(Jawak et al., 2015; Pushparaj & Hegde, 2017; Stumpf et al., 2003)emphasized use of blue and green band in the coastal environment SDB. The Near Infrared band is used for masking land. Satellite images and bathymetric data were referenced to WGS84. The images of different bands are shown below:

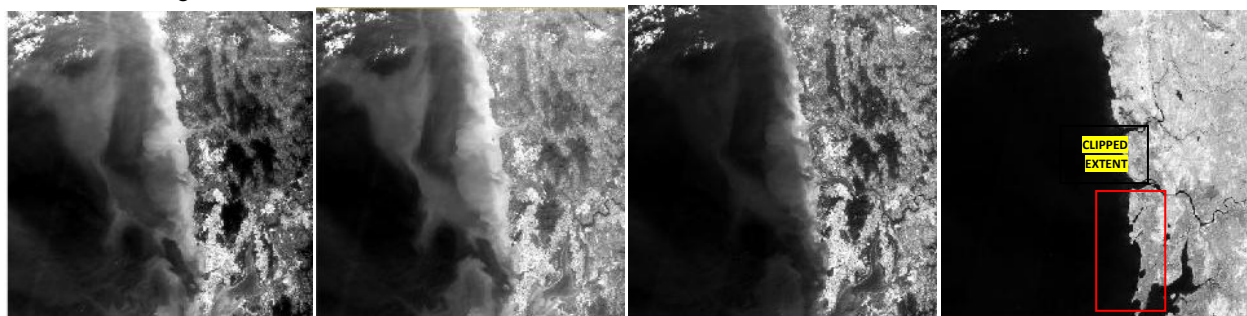


Fig.1 (a): Band 2 (Blue) Fig.2(b): Band 3 (Green) Fig. 2(c): Band 4 (Red) Fig. 2(d): Band 7 (NIR)
(Source: <https://earthexplorer.usgs.gov/>)

3.2 Hydrographic data

The bathymetric data has been derived from the recent nautical chart of the area published by National Hydrographic Office. The soundings represented on nautical chart are reduced to chart datum (usually LAT- Lowest astronomical tide), while post-processing of SB/MB echo sounder bathymetric data. Thus, the depths at control points for corresponding pixel values need not be rectified for tidal variations. Further, the difference in period of satellite image and bathymetric data collection is irrelevant for any empirical algorithm;because depth corresponds to image pixel values of that particular image. The ratio transform algorithm is based on derivation of gain (m_0) and offset (m_1) values by regression of soundings values (depth) verses DN values of satellite image. Total

215 control points has been utilized for deriving gain and offset parameters, while another 80 control points has been used for validation of the applied algorithm.

4.3 Data Processing

Pe'eri et al., (2016) has provided detailed procedure to be followed for depth derivation using satellite image (using LANDSAT 8). The steps involved in the process of depth derivation are mainly consisting of pre-processing, spatial filtering, land masking, establish the extinction depth and application of Stumpf et al., (2003) bathymetry algorithm as shown in flowchart below.

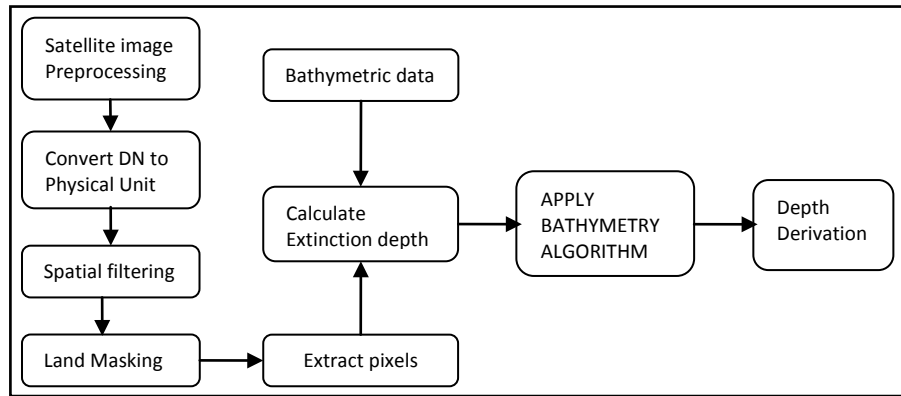


Figure 3: Methodology for SDB

The Sentinel-2 Level 1C satellite image data provided by Sentinels Scientific Data Hub have pixel in Top-of-Atmosphere reflectance with all other radiometric parameters in metadata file. The conversion formula for TOA reflectance to surface reflectance is as follows:

$$\text{Reflectance} = \text{DC} / \text{Quantification value}$$

Where DC represents *DN values of pixel* and *Quantification value* is provided in metadata file. This has been carried out using Semi-automatic classification plugin (SCP) in QGIS which automatically converts radiance to reflectance values. Spatial filtering of low-pass filter (3×3) is applied to remove the speckle noise from the image. NIR band has been used to mask land area from the image, as the water appears dark and has sharp edge discriminating water from land which looks relatively much bright. A threshold value that separate land from water has been determined by using a line profile crossing from land into the water. The result of profile plot represents smooth trend-line representing water and irregular curves representing land region. The resultant images were clipped to extent of study area, rescaled (float) to min-max (reflectance values were converted to 0-255) and also band 2, 3, & 4 were layer-stacked to composite image. The next stage was determination of extinction depth and deriving gain & offset as per Stumpf et al. (2003) algorithm. The SNAP software of Sentinels Scientific Data Hub provides a tool for automatic extraction of pixels by using text/*.csv file. The bathymetric data of 215 control points was converted to *.csv and pixel values were extracted from composite image. This provided pixel values in all three bands from geographical coordinates of all the location of bathymetric data collection points. The resulted data was opened in MS Excel to carry out regression analysis. The regression equations are generated for each band and the statistical index (R^2) is calculated as shown below in figure 4. This step was done to analyze simple linear relationship between depth and bands; so that comparison can be made between ratio transform algorithm and simple regression parameters.

Stumpf et al. (2003) developed ratio transform algorithm to estimate the bathymetry in coastal waters. This algorithm is based on assumption that radiation entering water in one band attenuate more quickly than other band; as band of higher absorption decrease relatively quicker than band of lower absorption with increase in depth. Thus, the ratio between these two bands differs significantly with respect to the bathymetry and on transformation gives linear relationship independent of nature of bottom. This relationship has been expressed with following formula:

$$Z = m_1 \frac{\ln(nR_w(\lambda_i))}{\ln(nR_w(\lambda_j))} - m_0$$

Depth

Where, m_1 is a 'gain' to scale the ratio to depth,

m_0 is the 'offset'

R_w is reflectance of water for band λ_i or λ_j

λ is the spectral band

n is a constant for all areas to assure that the logarithm will be positive in all cases and the ratio will derive a linear response to depth

5. RESULTS AND DISCUSSION

The result of correlation analysis of all the three bands with ground data is presented below in figure4. The result of correlation showed the coefficients decreasing order from green, blue and red band respectively. Comparatively, the difference between the indicators was marginal. However, in consistency to the contemporary researches on SDB, Green band has been found more significant for depth derivation.

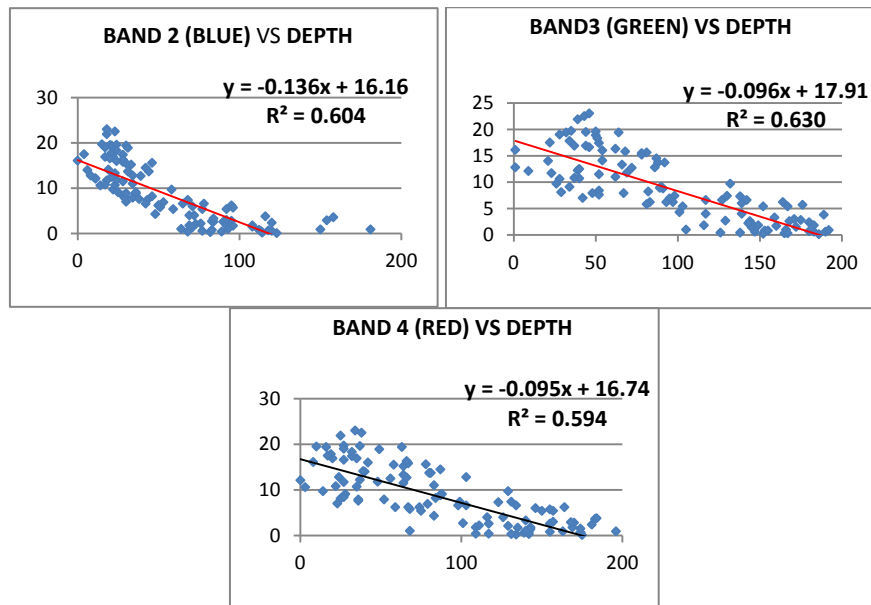


Figure 4: Result of Correlation (Blue vs Depth, Green vs Depth and Red vs Depth)

The methodology proposed by Stumpf et al. (2003) for the ratio transform algorithm using green and blue band has been used for SDB. The ratio transform has been carried out in SNAP software and pixels from image have been extracted for spatial position of corresponding depth values. The obtained value for pixel and depths was imported in MS Excel to carry out regression analysis. The regression equation of ratio transform of green and blue band has given values of m_0 and m_1 as shown in Fig. 5 (b). The model summary of regression analysis is presented in Fig. 5 (a), which indicates significant correlation value $R^2 = 0.642$ for the depth upto 30 meter and standard error of estimate as 5.287. This implies marginal increase in accuracy for deriving depths by using ratio transform algorithm compared to above models. The few other band combinations (G/R, R/G, B/R) was assessed for suitability for SDB, but was found weak relationship with ground data ($R^2 < 0.40$).

Model Summary ^b				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.801 ^a	.642	.641	5.2878593
a. Predictors: (Constant), GREEN/BLUE				
b. Dependent Variable: depth				

Figure 5(a): Model Summary

Coefficients ^a					
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	30.470	1.187		25.676	.000
GREEN/BLUE	-577.999	29.549	-.801	-19.561	.000
a. Dependent Variable: depth					

Figure 5 (b): Coefficients of Regression Analysis

It is very difficult to apply any algorithm of SDB in turbid waters (especially, in coastal areas or Case II water than in open seas & oceans Case I water for the presence of higher concentration of dissolved sediments. Besides, SDB may be predicted for shallower depths (upto 30 m) beyond which substantial attenuation of light in all bands occurs while passes through the water column. The validation plot for actual depth verses predicted depth by SDB has been plotted and shown below in fig. 6 (a) and (b). The analysis of the plot indicates that

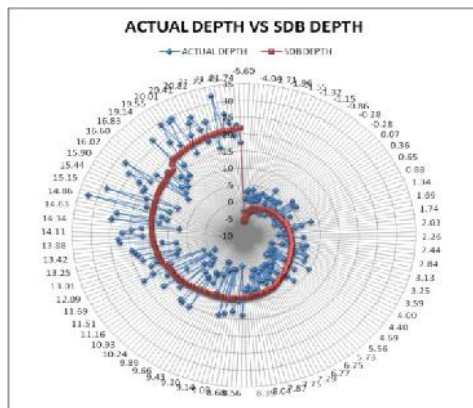


Figure 6(a): Actual depth Vs SDB

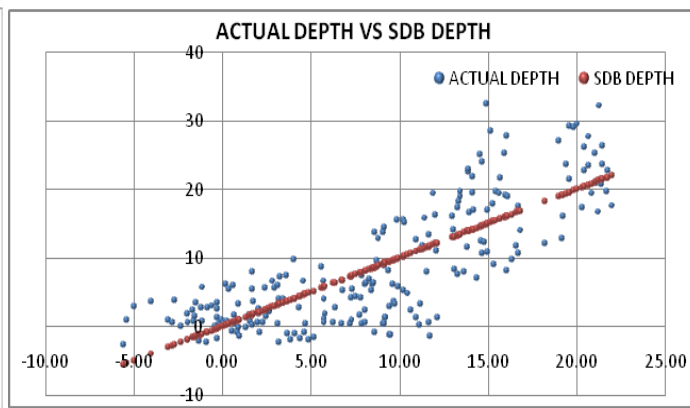


Figure 6 (b): Actual depth Vs SDB

derivation of the bathymetry in the shallow waters of coastal region, especially in intertidal areas below drying heights of 04 meter was erroneous and underestimated by the ratio transform. However, depths from -01 meter to 10 meter were well within the RMSE limits of estimation. Beyond 12 meter there was apparent increase in inaccuracy of SDB estimation in terms of RMSE. In the coastal region nature of bottom is very dynamic and water is mostly turbid which degrade accuracy of SDB assessment. The degradation may be result of any or few of the reason such as, errors in bathymetric data itself; time lag between image acquisition and hydrographic data acquisition; varied nature of sub-bottom and uneven distribution of turbidity across the extent of study area. The resultant map shown below has been created by applying ratio transform algorithm to green band.

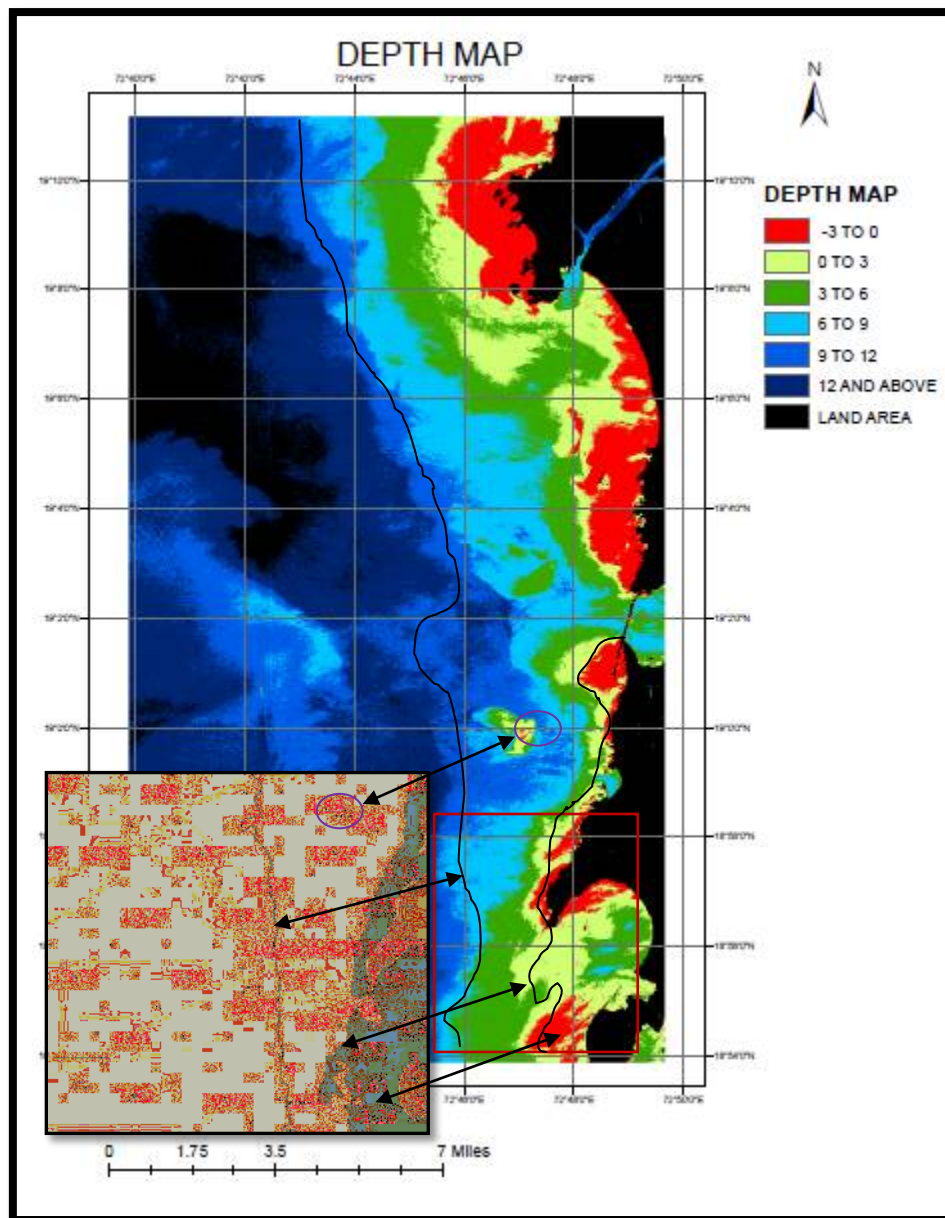


Figure 7 SDB Chart vs Hydrographic Chart of the area

The resultant image was overlaid by bathymetric chart of the area and it was found that approximately 70 % soundings are falling in the same depth area region. However, other soundings are distributed unevenly throughout the chart and not concentrated in any specific area or depth region. The general trends of contours are almost following the trends of bathymetry in the area as depicted on hydrographic chart of the area. The fig. 7 shows the comparison of SDB chart and portion of the navigational chart of the area. It is visual from the comparison that 5 meter and 10 meter contour follow the same trend as per paper chart. The few navigational aids in the area (shown in circle) have been accurately determined by applied algorithm. Moreover, some of the error in some derived sounding is attributable to misinterpretation of ground data, where shallow depth on wreck has been used in algorithm for deeper depths.

6. CONCLUSION

Traditionally, nautical charts are published from Hydrographic data collected by survey vessels using Multi-beam or Single-beam echo sounders, which is further routed through stringent QA/QC stages as per standards promulgated by International Hydrographic Organization (IHO). The data qualifying through all QA/QC checks is only used for depicting on nautical charts. The derived bathymetry from the satellite image is far from use by Navigators or Hydrographic Offices. The vessel navigation needs accuracy of more than 95 % bottom insonification using tested means and methods. The bathymetry estimation in coastal waters especially turbid waters depends on other variables like water clarity, cloud cover, sunglint, sediments, etc. which necessitates different algorithms are to be considered that would enhance the precision of estimated depth. Practically, the SDB is researched for last three decades but it is still in infancy stage in terms of application. However, the SDB data has a potential to be cost-effective alternative to re-validate near shore coastal bathymetry or on-ground Hydrographic Surveys.

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FLOOD MODELING FOR ADYAR RIVER BASIN USING GIS

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ABSTRACT

Water is essential for all living organisms for survival and it is the main constituent of Earth. A country's economy depends on its wealth of water resources. Nowadays there are many pressures on water resources which include those arising from human activities. Many parts of our country are affected by severe flood and drought conditions. They are the extreme events in the hydrological cycle that helps in describing the movement of water throughout the earth in different ways and at different rates. Human activities like urbanization and industrialization are the major driving force in altering the land use pattern and significantly affect the hydrologic processes. The effect of this land transformation increased the flood flows. Hydrological modeling is one among the tools which is used to estimate the basin's Hydrological response due to precipitation. This study aims to develop the rainfall runoff relationship using hydrological model and GIS in Adyar watershed. The HEC-HMS model was chosen for hydrological modeling in which the SCS Unit hydrograph is used for the Transform method, SCS-CN as the Loss method and Muskingum as the Flood routing method. Flood hydrograph is derived for specific rainfall event by giving the meteorological data and control specification data. Calibration and validation were carried out using observed field data. The results obtained from this research will be beneficial for future modeling efforts by providing tool for hydrological forecasts of flood in a catchment and also to assess the impact of land use changes.

KEYWORDS: HEC-HMS, SCS-CN, Hydrological modeling, Land use changes.

1. INTRODUCTION

Water on Earth is in constant motion with respect to hydrological cycle. A proportion of the rainfall seeps into the ground, infiltrating down to the local water table or is eventually lost through evapo-transpiration. The remaining finds its way to streams and river channels as over land flow or through groundwater and the portion of water available after meeting the losses is termed as runoff.

Flood is a high extreme of water, which occurs when the flow in channel exceeds the channel capacity. It results in disastrous effects on life and property. Damage of hydraulic structures lead to loss of water for the current situation and future needs. Recurrence of flood is more pronounced in many parts of Tamil Nadu during the last century, which demands the importance for flood estimation, prediction and control.

The development of HBV model and a DUFLOW model for flood wave behavior is analyzed in Pasig marikiana river basin located east of metropolitan Manila (Badilla, 2008). Flood prevention works includes Flood forecasting, Flood warning, Flood hazard zone marking, Flood inundation works etc. Bouabid, (2010) described long term past trends of stream flow in relation to climatic data in four sub-basins of the Sebou basin in northern Morocco. All the above studies are carried out using Flood modeling. Flood prediction and modeling refers to the process of transformation of infiltration excess rainfall into a flood hydrograph. Bruce, (2010) proposed this report for continuous simulation of stream flow in Johnson County with HEC-HMS Hydrologic modeling System of the U.S. Army Corps of Engineers.

Floods are extreme part of the hydrological cycle and it occurs when a river or stream overflow unexpectedly and inundate the surrounding area. Among all kinds of natural hazards in the world, flood is probably most devastating, wide spread and frequent. Kishore et al, (2014) evaluated on SCS curve number, SCS unit hydrograph, Exponential recession and Muskingum routing methods are chosen, respectively. Durgaet et al, (2011) describes a flood forecast model is developed for the Godavari Basin, India through a distributed modeling approach using space inputs; divided into 128 sub basins to improve the model accuracy. James et al, (2010) described a holistic application of HEC-HMS. Its applicability, capability and suitability for flood forecasting in catchments were examined. Tamil Nadu receives less rainfall than the other states of South India and is also more prone to flood. This is mainly due to the periodical high intense rainfall, topography, land and soil properties and improper structural measures. Any measure taken for flood mitigation, flood warning etc., requires flood estimation. With the advancements in Hydrologic knowledge and technology flood estimation is done using flood modeling. Jeongwoo, (2010) described the stream flow estimation and comparison of peak discharge and discharge volume as results of different transform methods in HMS.

2. ADYAR RIVER BASIN

Adyar basin situated between Latitudes 12°47'6"N and 13°3'22"N and Longitudes 80°17'1"E and 79°52'36"E originating near the Chembarambakkam lake flows through Chennai and joins the Bay of Bengal at the Adyar estuary. Araniyar, Kosasthalayar, Cooum and Adyar are the four rivers of the Chennai basin group. The Adyar is a short river of about 42 km in length and enters the city limit near Nandambakkam Bridge (10 km upstream from the river mouth). The river consists of three arms. The northern branch comes from Chembarambakkam minor basin, the second branch comes from Guduvancheri and the third branch comes

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from Malaipattu tank near Manimangalam village. The river is almost stagnant round the year except during the rainy season rapid industrialization and urbanization directly contribute to waste generation.



Figure 1. Study area

3. METHODOLOGY

The following flow chart represents the overall methodology of the flood modeling project.

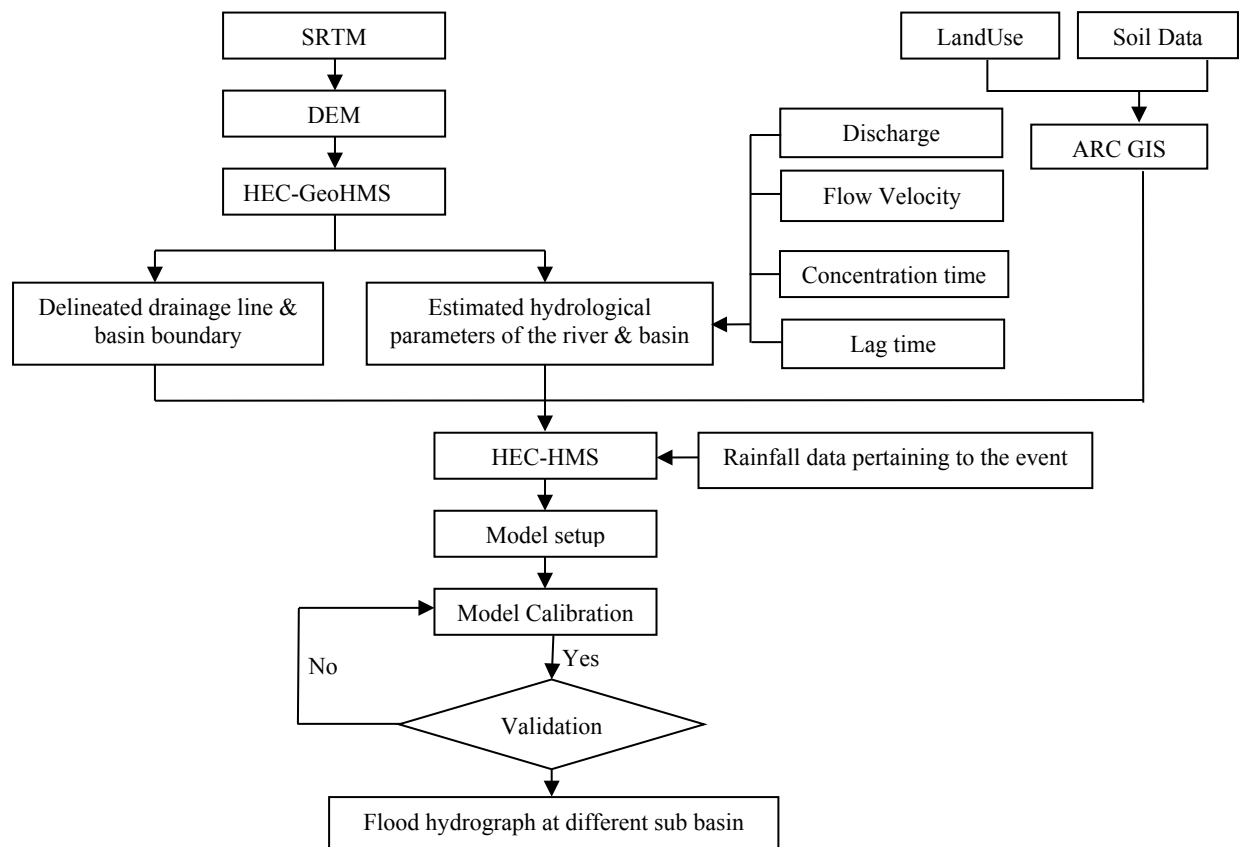


Figure 2. Methodology of Adyar flood modeling.

HEC-HMS consists of three modules that is basin, meteorological, control specifications. HEC-geoHMS is the pre-processor of HEC-HMS and it is an extension of Arc GIS which aids for the basin module. In HEC-geoHMS, the basin will be disaggregated into sub basins. The Physical characteristics of the river basin such as river length slope and longest flow path for each basin will be extracted. The weighted curve number for each basin will be created by considering land use information, soil type, rainfall data and curve number. After creating the basin module, the meteorological data like rainfall data and the control specification data will be given. Then the HEC-HMS model is executed and will get the output as peak discharge.

4. MODELING METHODOLOGIES

4.1 Terrain Processing

Terrain processing marks the first step in developing an HEC-Geo HMS project. In this step, a terrain model is used as an input to derive eight additional dataset that collectively describe the drainage pattern of the watershed and allows for stream and sub basin delineation. The first five datasets are grid layers; they represent the flow direction, flow accumulation, stream network, stream segmentation, and water shed delineation. The next two layers are vector layers of watersheds and streams. The last datasets, the aggregated watersheds, is used primarily to improve the performance in watershed delineation. The terrain data is processed and analyzed using the eight-pour point approach to determine flow paths. This approach uses the steepest slope to define the direction that water flows from one grid cell to one of its eight neighbors. Terrain analysis has some steps that may require several hours, depending on the amount of data and computer resources.

4.2 Flow Direction

The direction of the steepest descent for each terrain cell gives the flow direction. Similar to a compass, the eight-pour algorithm specifies the following eight possible directions.

4.3 Flow Accumulation

Flow accumulation is the number of upstream cells draining to a given cell. Upstream drainage area at a given cell can be calculated by multiplying the flow accumulation value by the grid area.

4.4 Stream Definition

This step classifies all cells with accumulation greater than the user-defined threshold as cells belonging to the stream network. The user specified threshold may be specified as an area in distance units squared, e.g., square kilometers, or as a number of cells. The flow accumulation for every particular cell must exceed the user-defined threshold for a stream to be initiated. The default is one percent of the largest drainage area in the entire DEM.

4.5 Stream Segmentation

This step divides stream grid into segments. Stream segments, or links, are the sections of a stream that connect two successive junctions, a junction and an outlet, or a junction and the drainage divide.

4.6 Watershed Delineation

After the terrain pre-processing is completed and a new project has been created, the Basin processing menu can be used to revise the sub basin delineations. Customized sub basin and routing reach delineations should include points where information is needed, i.e., stream flow gauge locations, flood damage centers, environmental concerns, and hydrologic and hydraulic controls. The tools described will allow the user to interactively combine or subdivide sub basins as well as to delineate sub basins to a set of points. This step delineates a sub basin for every stream segment. Watershed delineation and catchment area are shown in figure 3.

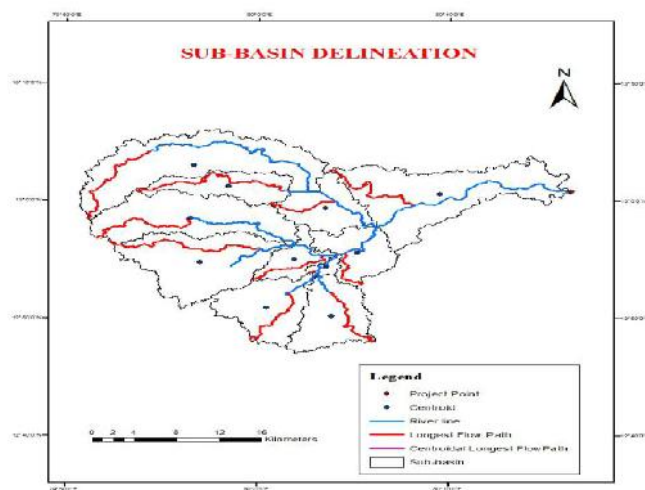


Figure 3. The Watershed Delineation and Catchment Area

4.7 Hydrological Parameter Extraction

After the physical characteristics of streams and sub basins have been extracted, users have the option to estimate a number of hydrologic parameters. Parameters can be estimated as sub basin average and grid-based values using soil and land use databases. Other hydrologic parameters, such as time of concentration and Muskingum routing parameters can be obtained from the terrain,

precipitation data. The program can consist in estimating a number of parameters for the loss method, Muskingum routing parameters, sub basin time of concentration and basin lag time. Tools on the Hydrologic parameter's menu will populate the attribute tables for the sub basin and river layers. This information will be contained in the HEC-HMS model file generated by HEC-GeoHMS, thus saving the user time when parameterizing the model.

4.7.1 Lag Time

The most important parameter required for any hydrologic analysis using a synthetic unit hydrograph is time of concentration or lag time. A method is given that uses GIS vector objects with equations assigned for the calculation of time of concentration or lag time for use in hydrologic analysis and design.

Parameter: Lag time = $0.6 * T_c$

T_c = Time of concentration

$T_c = 0.01947 * L^{0.77} * S^{-0.383}$

L = Longest flow path

S = Basin slope

4.7.2 Curve Number

Runoff curve number maps for captive catchment of Adyar by helping GIS and also remote sensing which based on factors such as vegetation, lands using group of soil hydrology and hydrological conditions were obtained. Runoff curve number map was obtained by combining these maps in ARC GIS and SCS table. To evaluate the accuracy of the results, the maximum flow rate of flood which was obtained from curve numbers, was computed with the measured maximum flood rate at the watershed outlet and correctness of curve numbers were approved and figure 4 represent in CN value map.

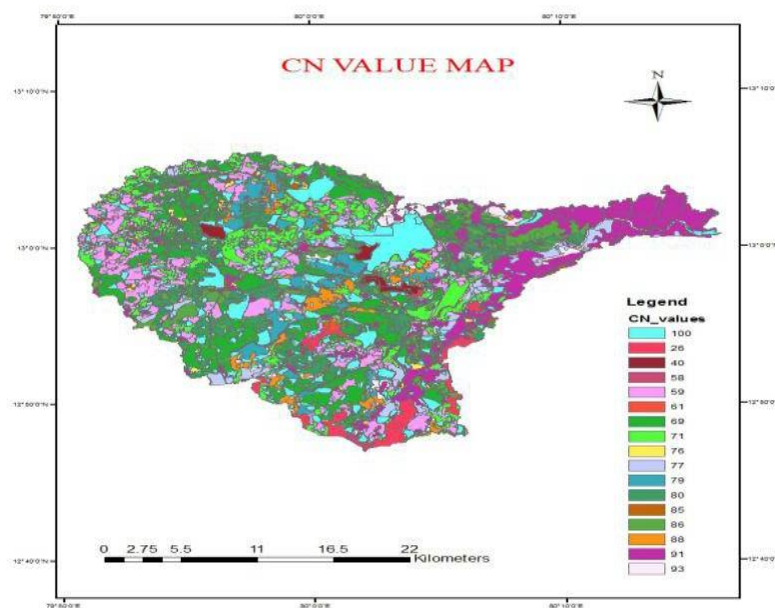


Figure 4. CN value Map of Adyar River Basin.

5. HYDROLOGIC MODELING WITH HEC-HMS

In this study the distributed modeling approach is used in flood hydrograph computation. The methodology involved in computing the flood hydrograph of the basin at the outlet can be broadly divided into five stages, including computing runoff volume, modeling direct runoff, flood routing, calibration of the model, and model validation. Various best possible modeling algorithms were used in each stage of computation based on the available and sub basins characteristics. The surface runoff in each pixel will drain towards the outlet of the sub basin SCS-Unit Hydrograph techniques are used for direct runoff estimation.

In the hydrological cycle, infiltration is to be considered as a major component after the Evapotranspiration. Infiltration at a given time depends upon the soil texture and the existing soil moisture at the point of time in the study area. Soil texture in conjunction with the land use can derive various parameters such as runoff curve numbers, coefficients and channel roughness parameters for hydrological modeling. Soil texture is one of the important input parameters in this topographic parameter extraction. Model relevant parameters are derived from theoretical relationships between soil texture and soil hydraulic properties and figure 5(right) represents the soil texture map for Adyar Basin.

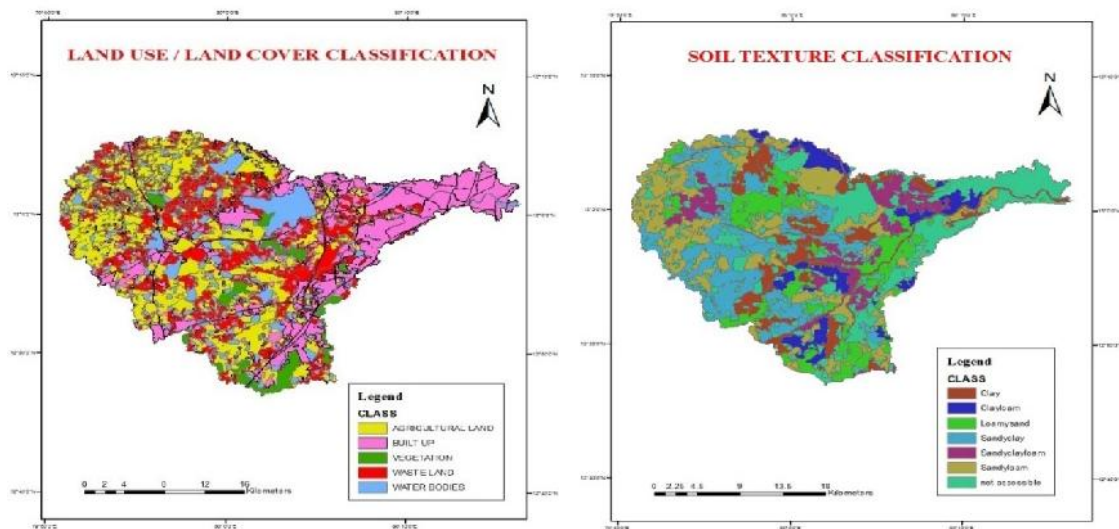


Figure 5. The land use and land cover classification (left); soil texture classification (right)

5.1 Meteorological and Basin Model Setup

The meteorological model calculates the precipitation input required by a sub basin element. The meteorological model can utilize both point and gridded precipitation and has the capability to model frozen and liquid precipitation along with evapotranspiration.

5.2 Control Specification

Control specifications are one of the main components in the project, even though they do not contain much parameter data. Their major objective is to control when simulations start and stop, and what time interval is used in the simulation. Here simulation is done from 01dec2015 to 02dec2015.

5.3 Specified Hyetograph

The specified hyetograph method specifies the exact time-series to use for the hyetograph at sub basins. This method is useful when precipitation data will be processed externally to the program and essentially imported without alteration. This method is also useful when a single precipitation gauge can be used to represent what happens over a sub basin. Each sub basin is shown on a separate row of the table. A hyetograph must be stored as a precipitation gauge before it can be used in the meteorological model. Total depth can be specified for no sub-basins, one sub basin, many sub basins, or all sub basins.

5.4 Time Series Data Results of Sub Basin

A variety of graphical and tabular results are available after a simulation run is computed. The same results are also available for the current run, so long as no data used in the simulation has changed. The program tracks all of the data in the simulation run, the selected basin model, the selected meteorological model, and the selected control specifications. Results for a simulation run can only be accessed when none of this data has changed since the last time the run was computed.

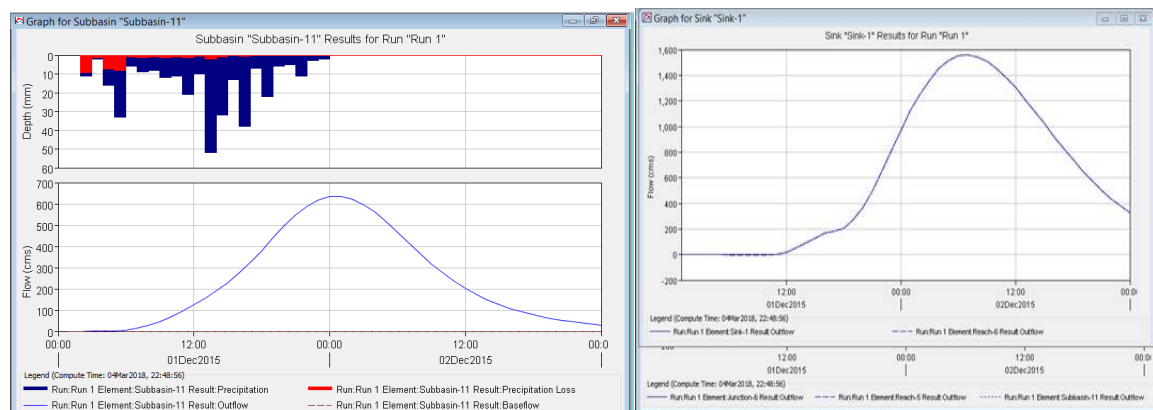


Fig 6 The Sub Basin Element Results Graph (left); Graph for Sink (right)

6. RESULTS AND DISCUSSION

The basin boundary and drainage line layers prepared as background files for HEC HMS are imported into the model from ArcGIS10.3. Once the input data is given, the simulation run is executed and the final report is generated. This resultant file shows the peak discharge with respect to time of peak for the corresponding sub-basin. It clearly depicts the maximum discharge for all the sub-basins. The simulation run was done for the time period between 1 Dec, 2015 (19:00) and 2 Dec, 2015 (07:00). The maximum discharge occurred is $1571.8 \text{ m}^3/\text{s}$ at junction-6 with which flow vs time graph is plotted for various sub-basins and it is shown in fig.7 runoff graph (right).

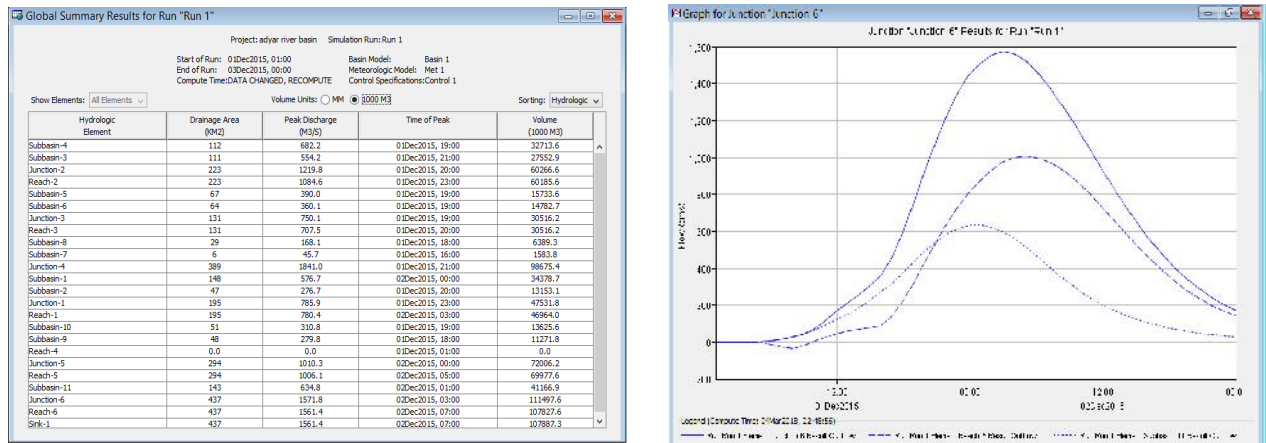


Figure 7 Global Summary (left); Runoff Graph for Final Outlet (right)

Landuse changes in a basin are the most important factors affecting its hydrology and water quality. Landuse classification is done for the year of 1990, 1995, 2015.

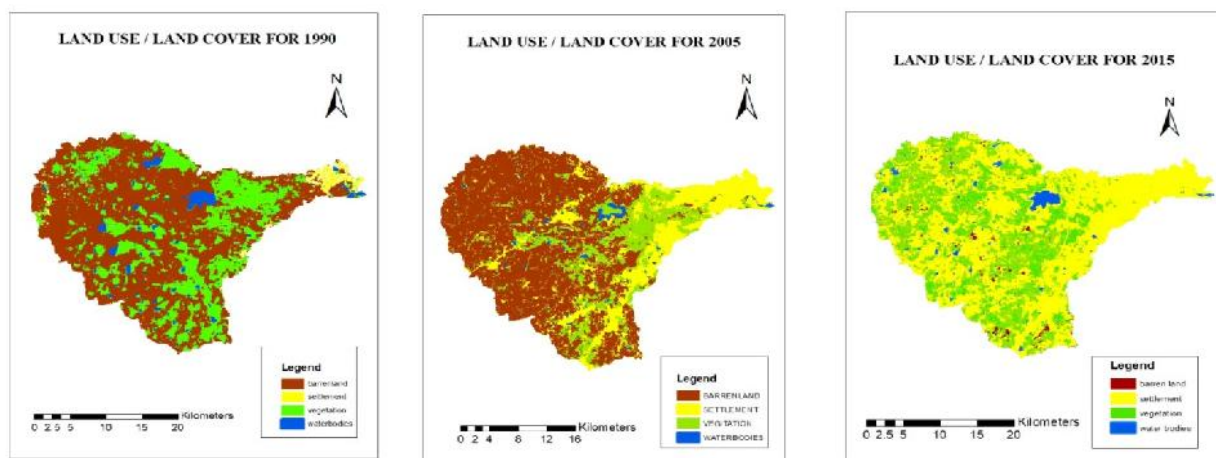


Figure 8 The land use classification for the year 1990, 2005 and 2015 respectively

The figure 9 represents the variation in the flood hydrograph for the years 1990, 1995, 2015 between discharge in cubic metre per second and time in hours. We can clearly infer that the maximum discharge occurred in 2015 when compared with the others. This is due to predominant amount of rainfall which occurred within the time period and the poor maintenance of drainage system over the basin area.

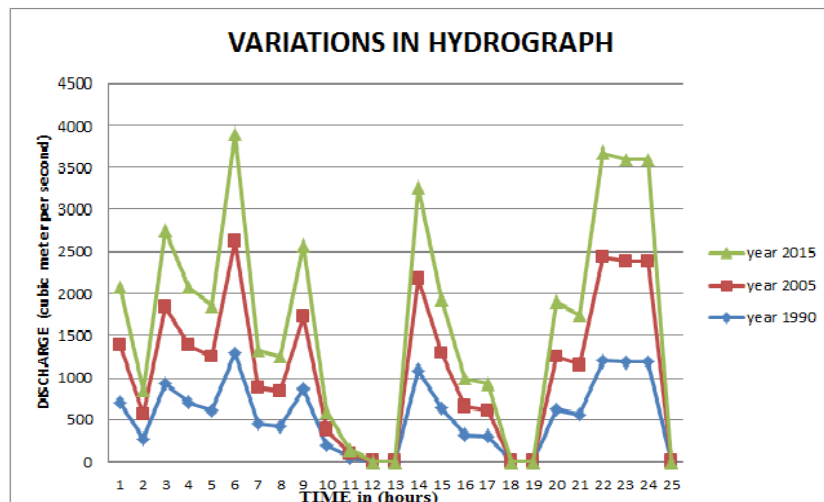


Figure 9 Variation in hydrograph

7. CONCLUSION

Remote sensing data can provide new neat time field scenario on land use / land cover which is a main input for distributed modeling approach. The simulated runoff computed by HEC-HMS for the year 2015. From this, it may be inferred that the estimation of runoff by HEC-HMS model integrated with GIS can be used in watershed management effectively. This approach could be applied in other Indian watersheds by planning of various conservation measures. HEC-HMS model may be used to simulate rainfall-runoff process in the Adyar watershed. The model cansave time and money in obtaining the runoff data rather than measurement of runoff in the watershed by conventional method.

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E-GOVERNANCE FOR LUDHIANA MUNICIPAL CORPORATION

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ABSTRACT

One of the major sources of revenue for any municipal corporation is its property tax collection. For higher revenue realization, transparency and ease of carrying out operations using GIS based technologies can be efficiently utilized. World View-II High Resolution Satellite data of 2010 was the basis of demarcation for all the individual properties aided by field visit for the city of Ludhiana. In all, approximately four lakh properties were demarcated within the Municipal Corporation limits of Ludhiana. Each property has been given a unique 18 digit identification number (UID). These numbers are sequential so as to afford a proper address system for the city. The spatial data of each property were linked with attribute data that was collected by door to door survey by vendors appointed for the purpose which includes landuse, ownership details, contact address/details, year of construction. In addition, the photograph of each property is being linked. A number plate based on UID is being erected at each of the properties. The digital database thus created has also been uploaded on Bhuvan Portal of National Remote Sensing centre, Govt. of India, Hyderabad (<http://bhuvan.nrsc.gov.in/urban/municipalgis/municipal.php>¹). The GIS database has been cited as one of the key reasons for including Ludhiana in the list of first 20 Smart Cities.

KEYWORDS: Municipal Corporation, Property Tax, GIS, WORLDVIEW-II, UID, BHUVAN, Smart Cities

1. INTRODUCTION

In municipal corporation, GIS system which manages various tasks of a municipality such as property tax, birth and death registration, socio economic data management and holding registration amongst other tasks. The municipal GIS service also assists in generation of a geospatial view of the current municipal area linked with the corresponding up-to-date database. The databases ideally possess attributes of every individual property with information such as land owner, mailing address, house style, built year, individual room measurements, and compliance with the regulations of the building authorities, public/private utilities, street characteristics and amenities (Sandeepan Saha). There can also be a provision of linking individual plots with their digital photographs. Urban Infrastructure planning, development and analysis for future infrastructure requires a robust municipal GIS system in place. The generation of thematic map / zoning map creates a high visual impact and is used for assessment of several sectors such as for water network planning, property mapping, maintenance of cities civic amenities services etc. The updated spatial and non-spatial database on the Municipal GIS system helps the concerned municipality to export and print the generated maps for any specific usage by the concerned field officer, thereby saving cost and time. A citizen centric service center is also organized wherein a daily updation of the spatial and non-spatial database is being taken care of, thereby keeping the Municipal GIS System up to date. City planning needs diverse data such as number of buildings, persons living in a locality, quality of living conditions, traffic pattern, electricity and water usage, road conditions etc. Information about spatial distribution of buildings is one of the vital indicators which can provide clue about many of the above said parameters, in conjunction with door to door data, and also help in property tax assessment, identifying planned/unplanned developments, illegal constructions and growth of slum areas. In this regard, remote sensing image provides first hand information about buildings location, shape, size, distribution and temporal changing pattern. Property tax is calculated differently in different countries/cities, and the factors generally considered are: number of rooms, rental value, area, age and property usage. In India, Unit Area Method (UAM) is emerging as a new taxation method which is currently being used in Delhi, Chennai, Bangalore, Hyderabad and many more cities. In the UAM approach the tax is calculated based on easily measurable quantities such as area, age and use of building (Jeganathan et. al.). The attributes can be collected by door to door data and integrated with relevant building polygon. The information system thus developed can be used not only for property taxation but for planning purpose also.

2. STUDY AREA

Ludhiana Municipal Corporation with an area of 142 km² is located with a latitudinal and longitudinal extent of 75°51'13.48" E 30°53'20.85" N to 75°51'31.921" E 30°52'30.17"N (Figure 1). The present study focuses on one of 37 blocks i.e., Block no.27.

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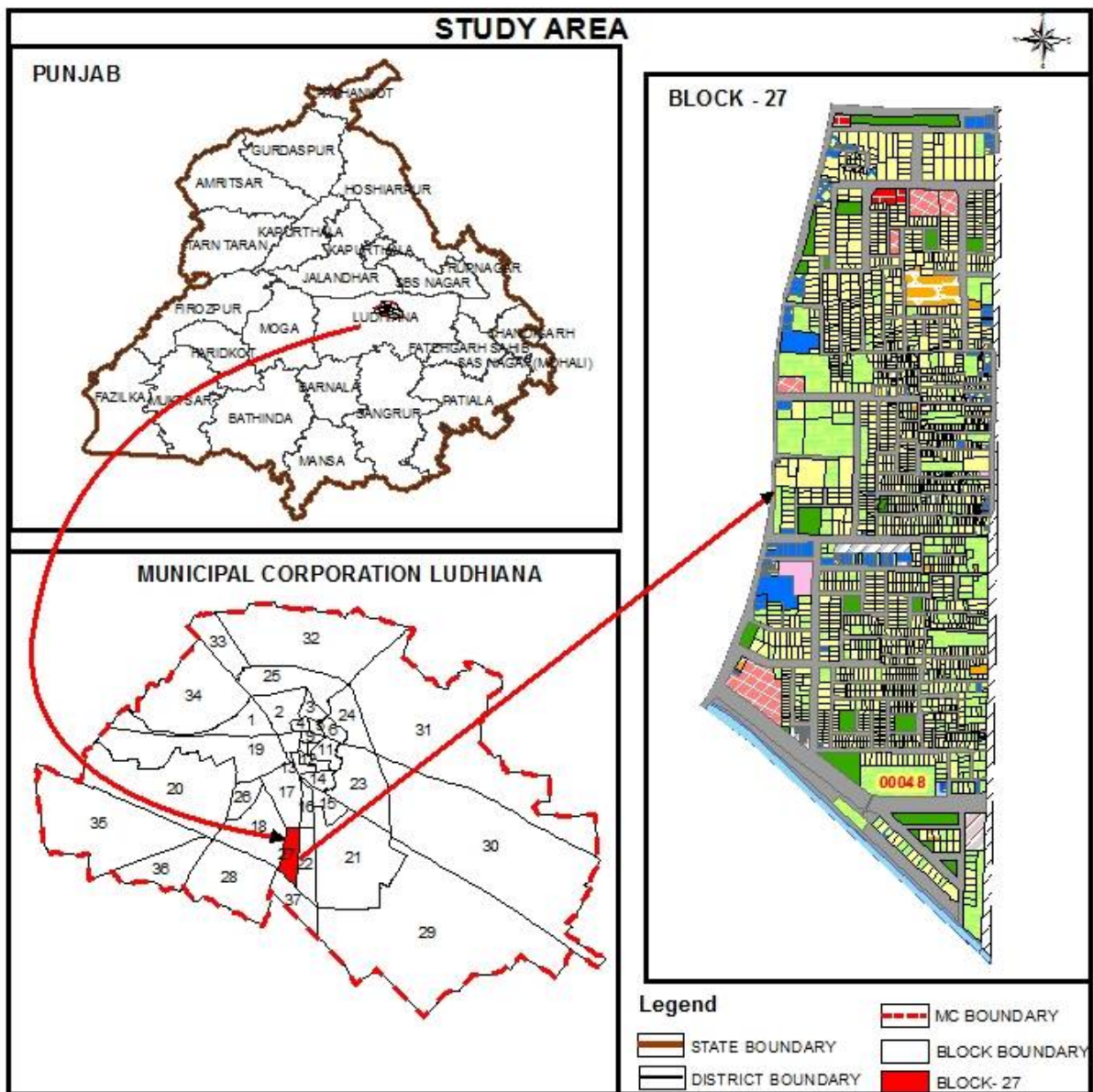


Figure 1. Study Area

3. METHODOLOGY

The methodology comprises first of demarcating all administrative boundaries such as Corporation boundary, Zones, Block and Ward boundary on World View-II high resolution satellite data with the help of maps and Corporation officials. The area comprises of a mix of planned and unplanned area and therefore, demarcation of properties was undertaken with the aid of field visit where satellite data was interpreted for properties in the field itself. In addition, existing maps provided by MCL were employed and direct interpretation of satellite data was used for planned areas. The properties were given ID sequentially block wise as the block boundaries do not change with time. Maps depicting properties with ids on were used by vendors appointed to collect door to door data. The door to door data were integrated with the intended property polygon in GIS. The database has been hosted on BHUVAN portal (<https://bhuvan-app1.nrsc.gov.in/state/PB>). World View-II High Resolution Satellite data of 2010 -was the basis of demarcation of all the individual properties aided by field visit for the city of Ludhiana.

After demarcation of each property, a Property Identification number (PID) is given to the property. Each property has been given a unique 18 digit unique identification number (UID). These numbers are sequential so as to afford a proper address system for the city. The spatial data of each property were linked with attribute data that was collected by door to door survey by vendors appointed for the purpose which includes landuse, ownership details, contact address/details, year of construction (Figure 2). In addition, the photograph of each property is being linked (Figure 3). A number plate based on Block no and PID is being erected at each of the properties (Figure 4).

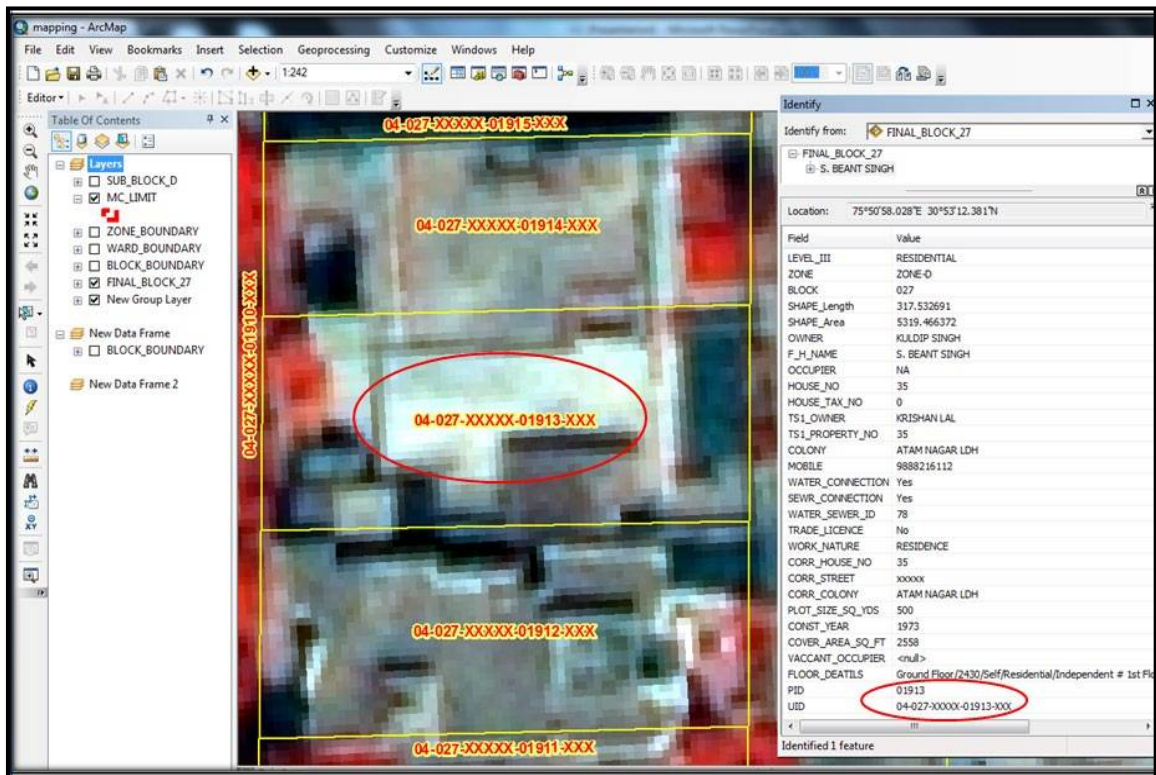


Figure 2. Linking of Spatial and spatial data with the help of PID

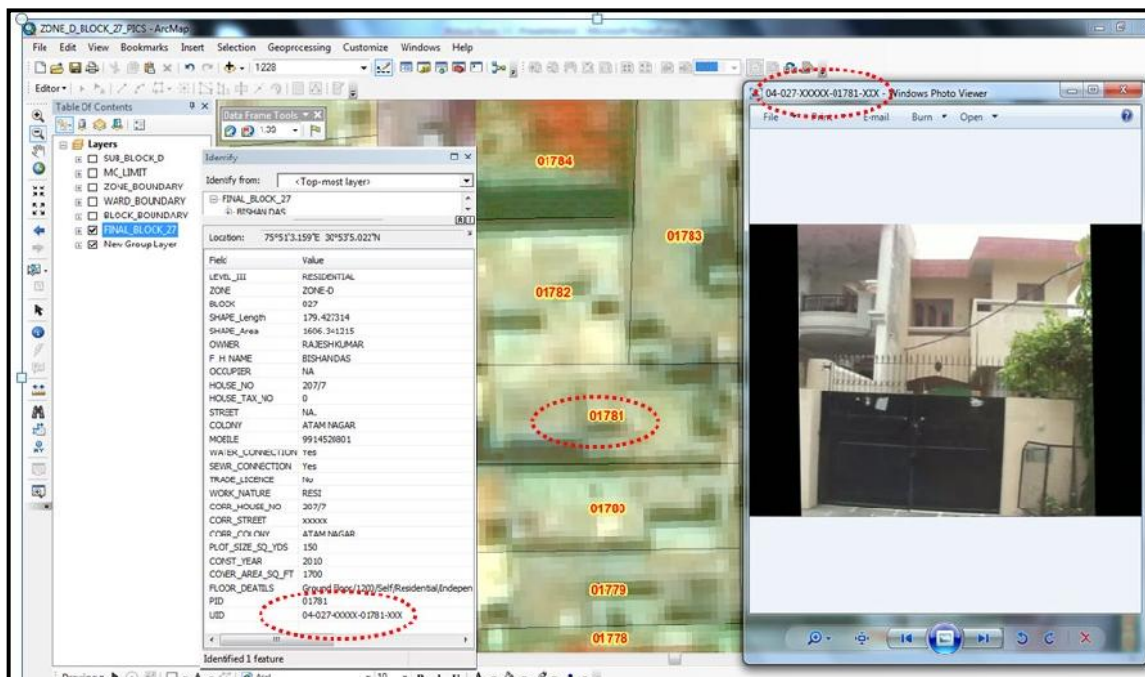


Figure 3. Field Photo of the Property



Figure 4. UID based Plate outside a Property in Municipal Corporation Ludhiana

4. RESULTS AND CONCLUSION

WORLDVIEW-II data aided with field work and other related maps can be utilized for property mapping. In all 37 blocks were demarcated on very High Resolution satellite data. A particular case of Block-27 is the focus of the present work. In all 2233 properties were demarcated and based on door to door data further classified as 1629 as residential, 143 as commercial, 3 as industry, 1 hospital, 4 schools and 20 as parks. Zone D commissioner said that "It was found that only 1606 properties had authorized water supply connections, 1426 houses were paying bill. One of the immediate benefits of the GIS system was to identify properties defaulted on paying utility bills".

Civic body goes innovative to recover dues

HI-TECH MC uses geographic information system to identify houses defaulting on utility bills, a survey was conducted in Block 27 recently and it was found that of total 2,233 houses in the area, only 1,426 had authorised connections

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LUDHIANA: In a bid to recover water and sewerage bills from tax defaulters, the Ludhiana municipal corporation (MC) has started conducting surveys through geographic information system (GIS) and scrutinising unauthorised connections.

PS Ghuman, commissioner, Zone D, said: "Recently a GIS survey was conducted in Block 27, which includes Atam Nagar, Kartar Nagar, New Kartar Nagar, Adarsh Nagar and Model Town extension. It was found that of total 2,233 houses in these areas, only 1,606 properties had authorised water supply connections." Ghuman said of 1,606 houses, which had authorised connections, 1,426 houses were paying bills.

Hartej Singh, superintendent, MC, said: "The MC teams had visited different areas of the city where people had given pending dues so that they could not face any disconnection of water supply." "Earlier, it was difficult to

PS Ghuman, commissioner, Zone D

identify the properties which have illegal water supply connections. With help of GIS, it has become easy to find out illegal connections," he said.

He said five to six illegal connections were disconnected on Thursday, while some defaulters had paid dues as they did not want disconnection of water supply.

Sources said the civic body was yet to recover around ₹150 to ₹200 crore from defaulters as there were several people who had failed to submit sewerage and water supply bills while many were enjoying facilities by getting illegal connections.

"They said a city-based private firm had prepared data through satellite pictures of the properties and the MC officials were cross checking the properties which did not have valid sewerage and water connections. "It will take four more months to prepare the data of the entire city with GIS," Ghuman said. He appealed to the people concerned to regularise their unauthorised connection by paying the required fee, otherwise connections will be disconnected.

SHINGAR CINEMA TO PAY ₹1.5 LAKH FOR FAILING TO PAY BILLS

LUDHIANA: Taking a strict note on those failing to pay water and sewerage bills, the municipal corporation issued a notice to Shingar Cinema, one of the old cinemas of the city, and directed it to pay around ₹1.5 lakh for not paying the charges.

Sources said the cinema authorities had failed to pay the charges for water and sewerage for long time.

Executive engineer Rajinder Singh said: "We have given seven days time to Shingar Cinema to pay the pending dues of ₹1.5 lakh."

On the other hand, Gurcharan Singh, an official of the cinema, claimed that they were paying water and sewerage charges to the MC regularly.

It was learnt that MC Commissioner Pradeep Kumar Agarwal has given directions to all zonal commissioners to recover pending dues from all the defaulters.

Figure 5. Applications of Municipal GIS

The study was one of the key reasons for including Ludhiana in the first twenty SMARTCITIES. The mapping of Ludhiana corporation limit suggests that at present, property tax, water supply and sewerage dues are not connected. But under the UID project, these will be linked. After a resident pays property tax, he will receive a message to pay water and sewerage dues as well. It will also help MC to identify those who default in payment of dues. Earlier, it was difficult to identify the properties which have illegal water supply connections. With the help of GIS, it has become easy to find out illegal connections. The study clearly shows that property mapping can be undertaken with WORLDVIEW-II data and aided with door to door survey can help to increase the revenue of the Corporation.

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PAN SUBTRACTIVE RESOLUTION ENHANCEMENT USING BLOCK REGRESSION FOR IRS-SENSORS

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ABSTRACT

Space borne high resolution multispectral data is required for various applications like monitoring vegetation change and urban planning etc. Traditional pan-sharpening methods fuse features from a high spatial resolution panchromatic (PAN) image into a low spatial resolution multispectral (MS) image to combine spectral signatures from MS image and improve spatial resolution to that of the PAN Image. However, the challenge of the fusion method is to provide Pan-sharpened image that would be observed by a sensor with identical spectral response as the MS sensors and the spatial resolution of the panchromatic sensor.

To generate pan-sharpened products using contemporary satellite sensors, it may be observed that, the combined individual bandwidths of MS sensors will not fill the entire spectrum of PAN. Hence, information not covered by MS sensors is also used in pan-sharpening, resulting in distortion in spectral quality. Block regression based synthetic-variable-ratio (SVR) method and Wavelet transform based pan-sharpening methods retain better spectral characteristics but represent poor spatial details in fused images across non-linear features. To solve the potential color distortion problem of SVR method and Block regression based SVR method for multi-temporal PAN and MS data fusion, an improved pan-sharpening method which uses local spatial & spectral correlation for Block based regression along with PAN subtractive resolution merge is presented.

The proposed method uses local optimization strategy using block based regression to simulate a highly correlated panchromatic image with MS and can effectively reduce the spectral distortion of the fused image. The fidelity of spatial details is ensured by PAN subtractive resolution. Experimental study of the method on Cartosat-1 and Resourcesat-2 LISS-4 MS images was carried out and is found to preserve the spectral and spatial details better than conventional methods and is verified by using the fusion metrics like ERGAS spatial and spectral.

KEYWORDS: PAN-Sharpener, PAN subtractive Resolution Merge, Block regression

1. INTRODUCTION

Majority of Earth observation satellites, provide both panchromatic (PAN) images with high spatial resolution but low spectral resolution and multispectral (MS) images with high spectral resolution but low spatial resolution. To make full use of the spatial and spectral information, image fusion techniques have been applied in various remote sensing applications, such as image visualization, Watershed monitoring, cadastral mapping applications etc.

Over the years, many image fusion methods have been proposed, which can be classified into two categories by their method of generating fused product, i.e., component substitution (CS) methods and methods belonging to multi-resolution analysis (MRA). The widely used CS methods are Generalized intensity–hue–saturation adaptive (GIHSA), Brovey transform, Synthetic Variable Ratio (SVR), Principal Component Analysis, and Gram–Schmidt spectral fusion (GS) and wavelet based, Laplacian pyramid based methods are well-known MRA methods.

In CS methods, the spatial details will be injected into the fused products with best spatial details, but spectral distortion may happen. The methods based on the MRA framework become well known for their reduced color distortions, such as wavelets, Laplacian pyramids etc., but the spatial enhancement that is attainable is not satisfactory with respect to CS methods, particularly in the case of dissimilarities and also requires high accuracy co-registration between the PAN and MS data sets. Several recent methods take advantages of the two fusion categories and bring in new theories and optimized approaches into a single method.

1.1 Subtractive Resolution Merge using Block regression

Subtractive Resolution Merge uses a subtractive algorithm which is available in COTS packages to pan sharpen multispectral (MS) images. The input consists of overlapping panchromatic (PAN) and MS images. The output is an MS image that retains the colors of the MS image while maintaining the spatial detail of the pan image.

This algorithm is designed to provide a solution that is fast, yet produces quality results for the most common types of images. Specifically, it is designed for Quick Bird, IKONOS and Formosat images that have simultaneous acquisition of the PAN and MS, with all 4 MS bands present, and a ratio between the MS and PAN image pixels sizes of approximately 4:1. Other sensors that have similar capabilities should also work well with this algorithm. The algorithm uses a weighted sum of the MS bands to emulate the pan image.

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These are fixed for the above sensors, which are used during the synthetic PAN generation and subsequently for the fused product generation. The PAN images for IKONOS, QuickBird and Formosat all contain a significant near IR contribution. Therefore using an MS image that only contains RGB bands results in a poor match, this results in significant color shifts in the final merged image.

As can be seen, the subtractive resolution merge is not suitable for IRS sensor images and with resolution ratio less than or greater than 1:4. It emulates the weights for generating a synthesized PAN, which varies from image to image in case of Cartosat-1 PAN and Resourcesat-2 LISS-4MSas they are not acquired simultaneously. Block regression based SVR method produces better spectral results as it accounts for the local spectral correlation, but spatial enhancement is not satisfactory.

To account for spatial enhancement with spectral fidelity, the Block regression method has been modified to incorporate local spatial and spectral correlation of MS with PAN image to generate a synthesized PAN image in place of weighted MS image as in the case of subtractive resolution merge. This synthesized PAN and 3-Band MS data are used to generate the output product using the PAN subtractive resolution algorithm.

2. FUSION METHODS BASED ON SYNTHESISED PAN BAND AND THEIR LIMITATIONS

2.1 SVR and Improved SVR Methods

Munichika et al., 1993 developed the SVR method to merge MS images and a high-resolution PAN image. They assumed that the low-resolution synthetic PAN image can be created from low-resolution MS bands whose spectral response overlap the one of the input high-resolution PAN band. The principle is as follows:

$$\text{Pan}_{\text{syn}} = \sum \phi_i \text{MS}_i \quad (1)$$

Where Pan_{syn} is the low-resolution synthetic PAN band, MS_i is the i^{th} band of the MS image to be fused, and ϕ_i is the weight of the i^{th} band of the MS image. The SVR method supposes that the gray value ratio between the high-resolution PAN band and the low-resolution Pan_{syn} band reflects the spatial detail difference between the PAN and MS images. If these differences are distributed to every MS band by proportion, a high-resolution MS image can be reproduced, whose spatial resolution is the same as the PAN image, i.e.,

$$\text{Fused}_i = \text{MS}_i \times \frac{\text{Pan}_{\text{ori}}}{\text{Pan}_{\text{syn}}} \quad (2)$$

Where Pan_{ori} is the high-resolution PAN image to be fused, and fused where i is the i^{th} band of fused MS image. The SVR method assumes that ϕ_i weight can be obtained from the multiple linear regressions between the high resolution PAN and low-resolution MS images, i.e.,

$$\text{Pan}_{\text{ori}} = \sum \phi_i \text{MS}_i \quad (3)$$

Various methods have been suggested to determine the ideal weight ϕ_i . In the technique developed by Munichika et al., 1993 weights ϕ_i were calculated by using the five land cover types, i.e., urban, soil, water, grass, and trees. Zhang took a further research on the SVR method and clearly explained that the MS bands used to calculate ϕ_i should be from the MS bands whose spectral ranges were overlapped by the spectral range of the PAN image but not from all MS bands. At the same time, Zhang suggested that ϕ_i should not be calculated only with the five land cover classes but with the global information of image. In his Modified SVR Pansharpening method, Zhang first performs histogram standardization on the MS and PAN images to improve the solution stability, and then, the whole image is used to calculate ϕ_i by least-square fitting. Although Modified SVR Pansharpening has been popular, it may occasionally produce fused image with much spatial and spectral distortion when used for multi temporal images due to the following factors.

1. If the spectral wavelength of the MS image cannot overlap that of the PAN image completely, the spatial enhancement or the spectral preservation of the fused image may not be satisfied.
2. Even if the wavelength satisfies the overlapping condition, there may still be spectral distortion due to the uneven distribution of the land cover type in the image. According to the property of the least-square fitting, dominating the land cover type may hide the contribution of the minority type, resulting in low accuracy of weights ϕ_i .
3. As established by C. Thomas et. al., 2008, the PAN and MS images may present some local instability or dissimilarity, such as object occultation and contrast inversion. Thus, using the whole information of the image to calculate ϕ_i will make local Pan_{syn} not close to the original PAN image.
4. The multiple linear regression of Equation-3 simply considers the spectral relationship between the PAN image and the corresponding MS image, in which high-resolution PAN is directly used for the regression of the coefficients, while neglecting the spatial correlation between the pixels in the PAN image. In this case, a correct calculation of the coefficients could be undermined by the decoupling between the high spatial frequencies present in the PAN images and absent in the MS images.

2.2 Robust SVR method

Histogram standardization in the Modified SVR Pansharpening method may cause the loss of spectral information. To overcome this, Robust SVR fusion method (Wang et. al., 2014) is developed, which is based on Modified SVR and is insensitive to band overlapping and land-cover-type distribution and can adapt to the local instability of the image and the detail difference between the PAN and MS images.

In the image fusion, the spectral preserving methods correlates with the inter-band structure of the MS image, and the spatial preserving methods correlates with the injection of the spatial structure from the PAN image. The traditional fusion method such as SVR only uses the spectral correlation between the PAN and MS images to build the multiple-linear-regression model. However, the pixels in an image are spatially correlated, meaning that, for a source image, if one pixel contributes to the fused image, its neighbors are likely to contribute to the fused image as well. Therefore, the decision making during the fusion process should exploit the property of spatial correlation. In addition, the wavelength of the PAN image is relatively wide; thus, the information in the PAN image not only contains the spectral characteristics of the MS bands but also contains more spatial details than the MS bands. Based on these, a more appropriate regression model to calculate weight ϕ_i , including both the spatial and spectral correlation (SSC) fraction is

$$\text{Pan}_{\text{ori}} = \sum \phi_i \text{MS}_i + \beta \quad (4)$$

where β is the weight of the spatial correlation fraction, and G_s is the spatial correlation fraction, i.e., high-frequency information. In order to get the high-frequency G_s , we adopt the Gaussian filter method. $\otimes$ denotes the convolution, and PanL denotes the low frequency of the PAN image. Here, we employ the standard normal distribution $\sigma = 1$. The expression is as follows:

$$\text{PanL} = G(x, y; \sigma) \otimes \text{Pan}_{\text{ori}}; G_s = \text{Pan}_{\text{ori}} - \text{PanL}. \quad (5)$$

The matrix form of the SSC model is expressed as

$$\text{Pan}_{\text{ori}} = [\text{MS}_1 \text{MS}_2 \text{MS}_3 \dots \text{MS}_n \quad s] [\phi_1 \phi_2 \dots \phi_n \quad \beta]^T = \mathbf{B}\mathbf{X} \quad (6)$$

Where $\mathbf{X} = [\phi_1 \phi_2, \dots, \phi_n \beta]^T$ is the weight coefficients vector to be solved. $\mathbf{B} = [\text{MS}_1 \text{MS}_2, \dots, \text{MS}_n G_s]$ is the known spectral and spatial fractions. Equation (4) can be written as

$$\text{Pan}_{\text{ori}} = \sum \phi_i \text{MS}_i + \beta (\text{Pan}_{\text{ori}} - \text{PanL}) \Rightarrow \text{Pan}_{\text{ori}} (1 - \beta) + \beta \text{PanL} = \sum \phi_i \text{MS}_i. \quad (7)$$

The strategy of directly using the high-resolution PAN can keep well spatial details but bad spectral preserving, while the strategy of directly considering the low-resolution PAN is in contrast. The Robust SVR is a tradeoff between the two strategies of considering the high- and low-resolution PAN images in computing the coefficients. β is not a fixed value but an adaptive value that is the same as the other coefficients, which could be obtained by Equation-6. If β is 1, the strategy of considering the low-resolution PAN image is adopted, whereas if β is 0, the strategy of using high-resolution PAN is considered.

2.3 Block Regression Based SVR method

Block-based synthetic variable ratio (Block-SVR), which is a technique based on multiple linear regression of block regions to fuse optical and SAR imagery. With the implementation of the block-regression based technique there are at least two advantages. One is that the block-regression based technique drastically decreases the amount of computation, whereas regression of the whole scene image is almost impossible. The other, most important, advantage is that adjustment of regressed block size can result in different emphasis between preservation of spectral characteristics and enhancement of spatial and textural content. The larger the regression block, the more the spatial and textural details are enhanced. In contrast, the smaller the regression block, the more the spectral features are preserved.

The SVR algorithm can be regarded as a special case of Block-SVR in which the block size of the regression is the size of the whole image to be merged. Block-SVR involves multiple linear regression of block regions between PAN and MS images instead of multiple regression of the whole image with the SVR method. In this method, the PAN and MS images are co-registered and the bands of the multispectral image are re-sampled to have the same size as the panchromatic image. The following steps are used in generating the fused product:

- 1 A block and its neighbours are fetched from the PAN image and the re-sampled multispectral (MS) bands in sequence.
- 2 Linear multiple parameters are calculated according to Equation-8 given below, directly through multiple linear regression between the 3×3 blocks fetched from PAN image and the 3×3 blocks fetched from multispectral bands.

$$\text{PAN} = C_1 (\text{MS})_1 + C_2 (\text{MS})_2 + C_3 (\text{MS})_3 + \delta \quad (8)$$

Where C_1, C_2 and C_3 are block regression coefficients,

- 3 The central block of the 3×3 blocks is selected for the PAN image as well as for the multispectral bands.
- 4 According to the coefficients of multiple linear regression, the synthetic block is produced by Equation-9 given by

$$\text{syn} = C_1 (\text{MS})_1 + C_2 (\text{MS})_2 + C_3 (\text{MS})_3 \quad (9)$$

- 5 The PAN block, three multispectral blocks and the synthetic block are used to do ratio-calculation by using Equation-10 to generate the fused blocks (XS) given by

$$(\text{XS})_{(k,i,j)} = (\text{MS})_{(k,i,j)} + \{(\text{MS})_{(k,i,j)} / \text{syn}\} * \delta \quad (10)$$

- 6 The resultant blocks after step 5 are added to the fused bands.
- 7 Then steps (1)–(7) are repeated until the last block is completed.

It was observed in testing using the IRS satellite images, the SVR and Robust SVR methods are giving good results in case of simultaneous acquisition of PAN and MS images, whereas Block regression SVR for SAR and optical Imagery fusion.

Hence a method which produces best results by combining the principles of block based Robust regression to simulate a PAN band and subsequently PAN subtractive resolution merge to generate spatially and spectrally high quality fused output images has been proposed for IRS satellite images.

3. PROPOSED METHOD

PAN subtractive resolution merge using Robust Block regression to synthesise the PAN image has been implemented for fusing IRS Cartosat-1 and Resourcesat-2 LISS-4 MS multi-temporal images with high spatial and spectral fidelity.

The Algorithm consists of the following steps:

Step 1: Calculation of the synthesized PAN (Synpan) image using Equations-4,8 using Block regression to account for local spatial and spectral characteristics of the input images.

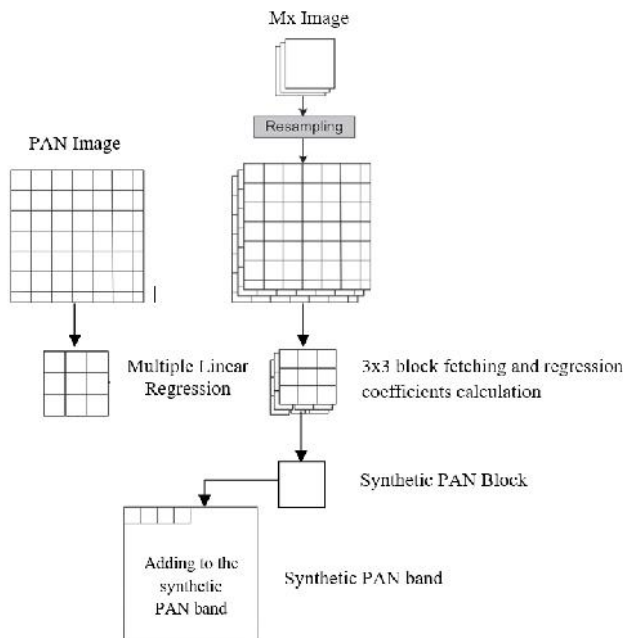


Figure 1. Generation of synthesised PAN band using Block regression

Step 2: Usage of PAN subtractive resolution merge algorithm to derive the merge image using the following procedure:

- Normalisation of Synpan by using the Standard deviation and Mean of the PAN image using $\text{NormSynpan} = ((\text{Synpan} - \text{MeanSynpan}) * (\text{PAN_SD} / \text{Synpan_SD})) + \text{PAN_Mean} + 0.5$
- $\text{Smoothed_NormSynpan} = \text{LPF}(\text{NormSynpan})$ (By using 5x5 LPF Kernel)
- $\text{Sharpened_PAN} = \text{HPF}(\text{Input_PAN})$, By using 3x3 HPF kernel with center value 21
- $\text{Smoothed_MS} = \text{LPF}(\text{Input_MS})$ (By using 5x5 LPF kernel)
- Now, Calculate $\text{HPF_Via_subtraction} = \text{Sharpened_PAN} - \text{Smoothed_NormSynpan}$

Finally, the merged image is computed using the equation

$$\text{Merged_Image} = \text{Smoothed_MS} + (\text{MS_SD} / \text{PAN_SD}) * \text{HPF_Via_subtraction} * \text{PAN_Wt} + 0.5$$

where PAN_Wt varies from 0-1, and accordingly decides the PAN contribution weight in the merged product.

4. DATA SETS USED AND EXPERIMENTAL RESULTS

Experiments were conducted to evaluate the performance of the proposed method using Cartosat-1 PAN and Resourcesat-2LISS-4MS images covering different types of thematic features like urban, forestry, hilly areas etc. The sample results shown were using the Cartosat-1 PAN and Resourcesat-2 LISS-4MS images, which provides the PAN band at 2.5-m resolution and the MS bands at 5-

mresolution, and is located in Machilipatnam, Andhra Pradesh, India and the other sample is from Part of Shimoga District, Karnataka.

Location	Data Product	Path /Row	Date of Acquisition
Machilipatnam	Cartosat-1 PAN	560/321	23 Feb 2015
	Resourcesat-2 LISS-4MS	103/62	19 Jan 2015
Shimoga	Cartosat-1 PAN	533/331	31 Oct 2013
	Resourcesat-2 LISS-4MS	98/63 C	30 Dec 2013

Table 1. Details of Satellite Data Products

Figure s2&3 illustrates the source and the fused images based on the proposed-method using Cartosat-1 and Resourcesat-2 LISS-4MS images for Shimoga in Karnataka and Machilipatnam in Andhra Pradesh.

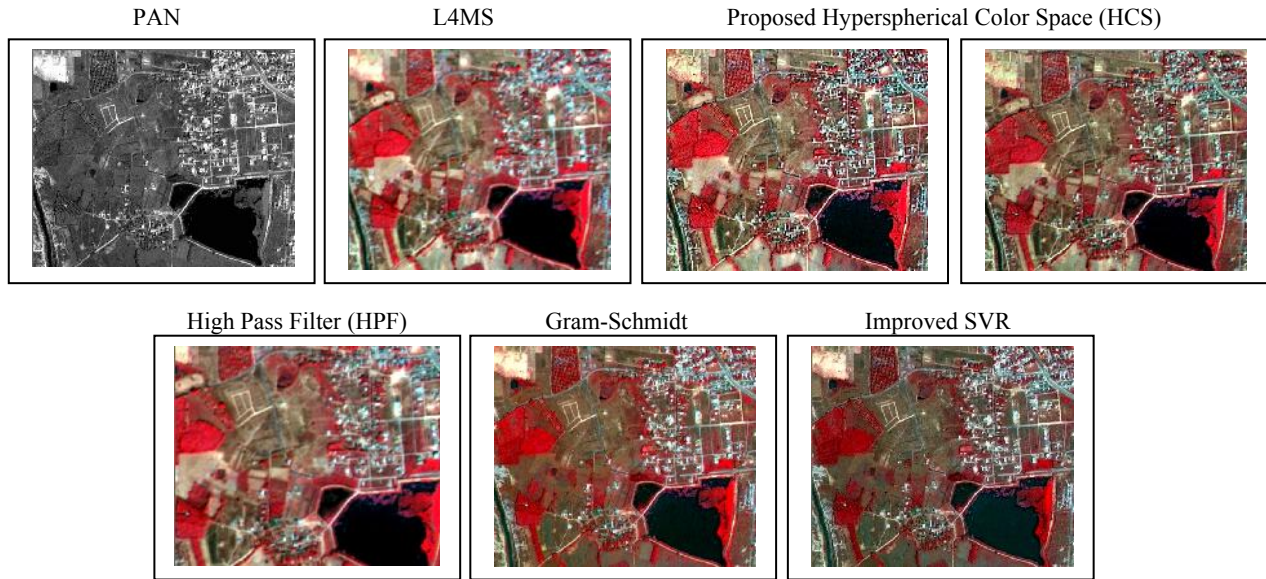


Figure 2. Shimoga, Karnataka, India.

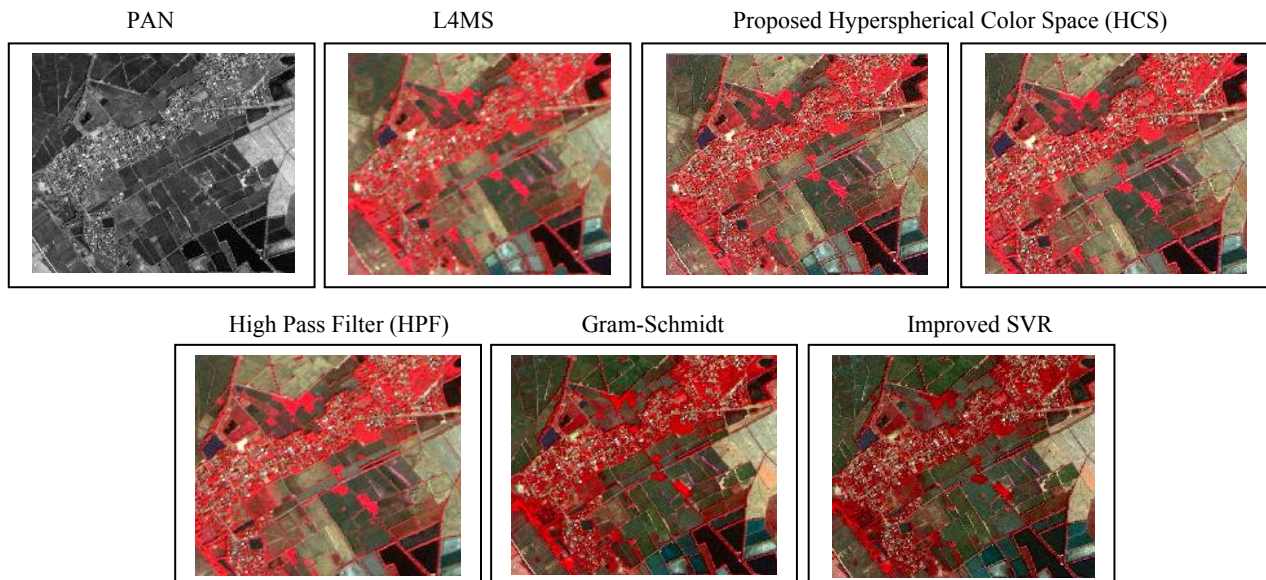


Figure 3. Machilipatnam, Andhra Pradesh, India

To evaluate the fusion quality, fusion is performed on input data sets, and the fused high-resolution MS images are then compared with the original low-resolution MS images, which are seen as the reference images. Results are compared with Gram-schmidt, Hyperspherical color space resolution merge (HCS), High-pass filter (HPF), Improved SVR methods. For visual estimation, the display of all images was made consistent by employing at 2% linear stretch in environment for visualizing images, and for clear visualization, only small chips were provided in results section.

Table 2 lists the quantitative scores for all methods by considering metrics as the Mean, Standard Deviation, Universal Image quality Index Average Q-Factor (Jixian et al., 2006), Relative global-dimensional synthesis error (ERGAS) spatial and spectral.

Quality Parameters	Area of the scene	Original L4MS	Proposed Method	HCS	HPF	Gram Schmidt	Improved SVR
Mean	Machilipatnam(B4,B3,B2)	97.71, 82.773, 105.542	97.740, 82.785, 105.579	97.224, 82.316, 105.126	97.210, 82.273, 105.042	97.432, 82.697, 105.95	97.691, 82.744, 105.475
	Shimoga (B4,B3,B2)	102.369, 99.661, 158.313	102.514, 99.670, 158.322	102.001, 99.357, 158.0	101.669, 99.160, 157.813	102.026, 99.50, 158.117	102.330, 99.603, 158.25
Standard Deviation	Machilipatnam (B4,B3,B2)	10.239, 15.997, 36.453	10.243, 16.017, 36.459	11.573, 16.886, 37.236	10.248, 16.035, 36.553	11.588, 16.620, 34.053	11.913, 18.766, 35.726
	Shimoga (B4,B3,B2)	14.321, 21.086, 26.071	14.324, 21.088, 26.073	17.965, 24.054, 30.166	14.331, 21.098, 26.082	16.233, 22.166, 24.942	18.454, 26.140, 26.939
Qavg	Machilipatnam		0.979	0.937	0.944	0.856	0.916
	Shimoga		0.981	0.943	0.957	0.889	0.921
ERGAS (Spatial)	Machilipatnam		53.21	66.13	65.14	55.23	54.12
	Shimoga		52.68	60.56	59.61	54.19	53.27
ERGAS (Spectral)	Machilipatnam		1.082	1.953	1.566	4.632	4.123
	Shimoga		0.93	1.532	1.156	3.632	3.123

Table 2. Quality Evaluation Parameters

As can be seen from the above results, Q-Factor is highest for proposed method, and the ERGAS scores are the lowest. Hence, both visually and quantitatively, the proposed method has the best spatial and spectral preserving characteristics than the methods under comparison.

5. CONCLUSION

In this paper, PAN subtractive Resolution merge using Block regression algorithm has been implemented for Cartosat-1 and Resourcesat-2 LISS-4MS imagery to keep the spatial details from the PAN image and preserve spectral characteristics from the MS image. The spectral distortions in the traditional PAN synthesis based SVR method and resolving them by improving the regression model and adopting an adaptive local process using Robust SVR was described. The proposed algorithm has been explained with test cases. The proposed method has been compared with the typical Gram-schmidt, HCS, HPF and Improved-SVR Pansharpening methods. The experimental results suggest that the images obtained with the proposed algorithm have higher fusion quality than that produced with other well-known methods in terms of visual analysis and quantitative evaluation indicators.

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GENERATION OF IMPROVED GRAM PANCHAYAT BOUNDARY MAPS USING VILLAGE CADASTRE & HRSI: A CASE STUDY

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ABSTRACT

In India, rural developmental planning is heading towards web-based geospatial enablement. But, data-gap exists in case of clearly defined territorial boundaries outlining the Gram Panchayats (GPs) which are the basic planning units. Currently, the jurisdiction of GPs is restricted to a mere list of revenue villages that are pooled to form any particular GP. It is, therefore, a prime requisite to derive GP boundaries from cadastral village maps (Khasra maps) available with revenue authorities. Under National Land Records Modernization Programme, traditional cadastral and land information systems are already undergoing major digital upgrading countrywide. But, it would take its own time and direction to arrive at a stage of supplying accurate GP boundaries derived from the authenticated village cadastre. Therefore, a study was carried out covering seven GPs from Sojat Block in Pali District of Rajasthan with an objective to test a comparatively faster methodology towards generating GP boundaries directly from Khasra maps using high-resolution satellite imagery (HRSI). Khasra maps were geo-referenced and GP boundaries were abstracted which were later fine-tuned with 2.5 m spatial resolution ortho-rectified satellite imagery as a base-layer. Further, GP boundaries were validated in the field using ground coordinates of village tri-junction pillars and boundary pillars. The results show that the methodology is well suited for the precise demarcation of the territorial extents in a time-effective manner.

KEYWORDS: Administrative Boundaries, Cadastral Maps, HRSI, Georeferencing, Gram Panchayat Developmental Planning

1. INTRODUCTION

Rural developmental planning follows a decentralized bottom-up approach in India, beginning with Gram Panchayat (GP) which is considered as a basic unit for planning. The process of preparing a Gram Panchayat Development Plan (GPDP) involves village-wise data collection for situation analysis. More recently, with the advent of web-enabled services as in Bhuvan Geo-portal developed by Department of Space, Govt. of India (<http://bhuvan.nrsc.gov.in/>), village-wise resource map preparation is being facilitated by the available high resolution satellite imagery (HRSI) and associated spatial and non-spatial information about the region. However, there is a lack of clearly defined territorial boundaries outlining the Gram Panchayats in the geospatial domain. Currently the jurisdiction of GPs is restricted to a mere list of revenue villages that are pooled to form any particular GP. It is therefore a prime task to derive GP boundaries from the cadastral village maps available with the revenue authorities.

The cadastre is a public record of location, extent, value and ownership of land in a district for the purpose of taxation (SISDP, 2010). Under National Land Records Modernization Programme (NLRMP), traditional cadastral and land information systems are undergoing major digital upgradation countrywide. But, cadastral maps have their own limitations like varying mapping scales and accuracy levels across the States, degraded quality and projection related issues that may hamper the process of seamless mosaic of maps. Yet, efforts are being made to overcome these limitations by converting the analog cadastral maps into digital and making them compatible in GIS environment. Hence significant time and direction are required by the system to arrive at a stage of supplying accurate GP boundaries derived from the authenticated village cadastre.

High Resolution Satellite Imagery (HRSI) have previously been proved to be useful for developing land information system in general, and re-survey of cadastral maps in particular (Rao, et al., 2014). In order to link any scanned map to some spatial reference and projection system, Ground Control Points are needed, which may either be acquired from topographic / GPS-based survey or from current digital cartography (Brovelli & Minghini, 2012). Numerous attempts have been made previously to digitize the administrative boundaries from scanned and georeferenced cadastral maps for geospatial purposes (Baiocchi & Lelo, 2005; Bitelli & Gatta, 2011; Brovelli & Minghini, 2012). Although, the vector boundaries have served the purpose of particular applications for which they were intended, yet, more recently, with increasing spatial resolution of the satellite imagery, demand for precision has increased (Shawa, 2017; Ojha et al., 2018) which relies more on time consuming processes (Sengupta et al., 2016). Hence, a trade-off is often necessary which can guarantee high precision levels in time-effective manner (Sengupta et al., 2016).

The geo-referenced cadastral map-sheets can be used to derive village boundaries which may further be dissolved as per notified jurisdiction to get the refined GP boundaries. Towards this, a study was carried out covering seven GPs from Sojat Block in Pali District of Rajasthan with an objective to test a comparatively faster methodology towards generating GP boundaries directly from Khasra maps using HRSI. The subsequent sections provide a brief methodology for generation of HRSI-aided and cadastre-based improved GP boundaries.

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2. MATERIALS AND METHODS

2.1 Study area

Seven contiguous Gram Panchayats in Sojat Tehsil of Pali District of Rajasthan were chosen for mapping of their administrative boundaries as demarcated by the concerned revenue authority and represented through the village cadastral maps. In all, there were 30 villages comprising 7 GPs (Local Government Directory, Ministry of Panchayati Raj, Govt. of India, 2017).

2.2 Data used

Hard copy sheets of village cadastral maps (hence forth interchangeably referred to as “Khasra map-sheets”) as obtained from respective village Patwaris were used as statutory references of administrative boundaries. A 2.5m spatial resolution fused product of orthorectified imageries from Cartosat-1 (panchromatic, 2.5m spatial resolution) and LISS-IV (multispectral, 5.8m) sensors were used as base-layer. The seamless mosaic of such satellite data was prepared under ‘Space-based Information Support for Decentralized Planning (SIS-DP)’ project of NRSC/ISRO (SISDP, 2010). Since the above mentioned fused product was in Geographic Coordinate System (GCS WGS 1984) with WGS 1984 as datum, it was reprojected to Projected Coordinate System (UTM with appropriate selection of zone) so as to make it in concurrence with measurement unit of Khasra map-sheets (chain units / metres). A Survey of India sourced village boundary was used for preliminarily locating the map-sheets before georeferencing.

2.3 Methodology

The methodology adopted in the present study consisted of the steps as described in the flowchart below (Figure 1):

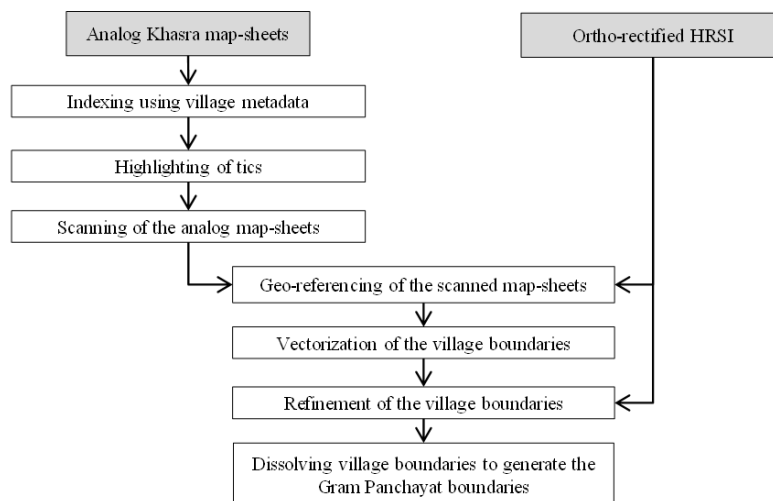


Figure 1. Flowchart of the methodology adopted

2.3.1 Collection of analog cadastral map-sheets: The hard-copy Khasra map-sheets were collected from the Village Patwaris through the District administration. The condition of the sheets was fairly good; therefore, a contact (roller) scanner was used for scanning, although a flat-bed scanner may be preferred. The gridlines were available and clearly visible on the sheets. 164 such sheets were collected covering all the 30 villages of seven GPs forming the study area.

2.3.2 Appropriate indexing of the map-sheets: All the sheets were indexed with appropriate index number. Unique index numbers were generated using the village metadata with respect to the various administrative codes (State, District, Tehsil and Village codes).

2.3.3 Highlighting of the tics: Intersection points of gridlines on the Khasra map-sheets were utilized for highlighting the tics. The distances between uniformly distributed tics was ascertained and measured as per the scale. These measurements were later utilized for validating the geo-referencing of the scanned map-sheets.

2.3.4 Scanning the analog map-sheets: The hardcopy Khasra map-sheets were scanned using A0 size raster scanner in 24-bit colour at 400 dpi. While scanning, the sheet was fed in straight upright position and smoothened so as to avoid any fold. The raster image of scanned sheet was stored in TIFF format. The scanned copy was checked for any errors related to noise (unnecessary dark pixels in the image), skewedness, warping or line-dropouts/stretched pixels. Rescan was performed wherever such errors were encountered. The scanned file was ascribed with the same name as assigned while the map indexing.

2.3.5 Geo-referencing of the scanned map-sheets: Spatial reference and coordinate system are assigned to the scanned Khasra map-sheets for making the data amenable to Geographic Information System (GIS). This is performed by using ortho-rectified high resolution satellite imagery as a base layer. This layer acts as the source of geodetic control as well as a media for better identification of features (SISDP, 2010). For all the GIS-based operations in the methodology, ArcGIS 10.4.1 (ESRI) was used. The geo-

referencing procedure consisted of the following sub-steps:

- a. *Preliminary identification:* The location as represented by the map-sheet was identified over the satellite imagery by overlaying a Survey of India sourced village boundary. This step was helpful in easy identification of control points.
- b. *Establishing the controlling-links:* The scanned Khasra map-sheets contained information of features that were correspondingly identified on the fused product of satellite imagery (Figure 2). Sufficient numbers of such controlling links were established by carefully marking the control points in both scanned Khasra map-sheets and satellite imagery. These controlling links were used to generate a suitable transformation model for image-to-image tying. The spatial and radiometric resolutions of the satellite data plays a major role in identifying the control points that would lead to a good geometric definition. The characteristics of such control points are corners of water tanks, intersection of parcel boundaries and intersection of roads with parcel boundaries (SISDP, 2010).
- c. *Transformation model assessment:* The coordinate transformation algorithm is employed to utilize the ground controlling links established between any scanned map and reference/projection system of the HRSI (Brovelli & Minghini, 2012). Boutoura & Livieratos (2006) provided an overview of common transformations for georeferencing of scanned historic maps that included similarity/conformal, affine, projective, polynomial and finite element transformation. Out of these, only the finite element method is an exact transformation, remaining being non-exact transformations, meaning that the transformed points are not fully coincident with the reference points after applying the non-exact transformation. Density and spatial distribution of the control points also affect the results of transformation (Boutoura & Livieratos, 2006). The coordinate transformation algorithm that induces lesser distortions (angular, linear, and area distortions) is adopted for the task of geo-referencing (Krishna Murthy, 2010). In the present study, second order polynomial model was applied for geo-referencing the Khasra map-sheets. The area of the village, number of map-sheets that cover a single village, condition of the cadastral map-sheets, number and characteristics of control points collected and terrain conditions influence the order of the polynomial model. The transformation model was assessed by the values arrived for residual error at each controlling link and root mean square (RMS) error for the entire model. The RMS error should be less than the size of a pixel in the base-layer satellite imagery, i.e. 2.5 m (SISDP, 2010). The transformation model was accepted when the actual RMS and residual errors were within the acceptable limits.
- d. *Registration:* Once the transformation model was accepted, the scanned Khasra map-sheet was rectified as per the model-generated spatial reference. A new raster file was generated that had the same coordinate system as that of the satellite imagery.
- e. *Validation of the registered Khasra map-sheets:* Output product validation is an essential element in geo-referencing of scanned Khasra map-sheets. The geo-referenced Khasra map-sheet of each village was validated with reference to the merged product. The rectified raster file was overlaid on the reference image and initial validation was carried out through visual checking. The distances measured between the highlighted tics were also utilized. If the parcel boundaries coincided with the image features and deviations/displacements were minimal, the geo-referencing was considered successful. The displacement, wherever observed, was measured as the distance between the image point and corresponding point in the Khasra map-sheet. The feature match error tolerance in controlled region was taken to be one pixel and in uncontrolled region, it was taken around two pixels (SISDP, 2010). Feature matching was checked in the following order of priority: tanks, water bodies, tank bunds, ponds, road, rail, canal, stream, nala, river, field bunds, forest boundary / vegetation boundary, village settlements, for matching in all eight directions within tolerance. If the shift was more than allowable limits, geo-referencing was carried out for a second time.

In this way each of the map-sheet covering any village is registered as shown in Figure 3. Although care was taken to improve the accuracy levels while geo-referencing of Khasra map-sheets; yet the idea was only to use the registered map-sheets as a guide providing statutory information.

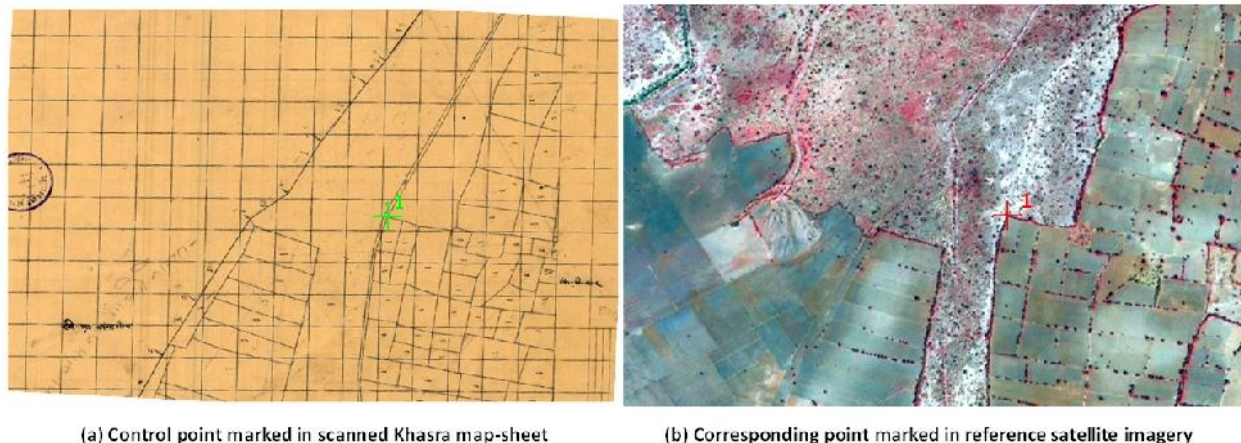


Figure 2. Establishing the controlling links

2.3.6 Village boundary abstraction / vectorization: All the scanned and registered Khasra map-sheets were displayed in the GIS environment. The required environment settings for digitization were set and the village boundaries were captured into a polyline layer. In order to avoid the topological errors while digitization, polygon features were not adopted at this stage. Error should be within permissible limits for digitization viz. weed tolerance, coordinate movement tolerance, coordinate unit, planimetric errors, fuzzy tolerance, etc. (SISDP, 2010). The final output of this process was a digital map village boundary as per the Khasra map-sheets (Figure 3a). The village boundary was digitized in such a manner that the resulting vector line falls in the centre of the raster data element (pixel) being vectorized. The boundaries were digitized such that there are no overshoot or undershooting of arcs or duplicate arcs. The features were digitized with minimal number of vertices while at the same time, maintaining the smoothness and angularity of the lines (arcs, curves) were also considered to be important. The village boundaries were made into closed polylines without any dangles (hanging arcs) or slivers.

2.3.7 Refinement of the polylines: The village boundaries abstracted in the above step is dependent on the accuracy of geo-referencing of the scanned Khasra map-sheets w.r.t. the reference satellite imagery. Even if the above mentioned steps are executed with utmost precautions, the output vector village boundaries may not exactly match with the ground reality as depicted in the satellite imagery. Hence, the vector boundary abstracted needed to be refined over the 2.5m spatial resolution reference satellite imagery at the mapping scale of 1:4000. While refining, care was taken that the delineated boundary becomes properly aligned to the centre line of farm-bunds as seen on the reference satellite imagery. Reshaping of the polylines was done wherever necessary, if not found in perfect alignment with the ground features. An example of refined village boundary thus generated is shown in Figure 3b. The process was repeated to generate a mesh of refined village boundary polylines for all the 30 villages (common boundaries of adjacent villages were mapped only once). The refined polyline features were converted to polygons so as to enable filling of village name attributes for each polygon feature.

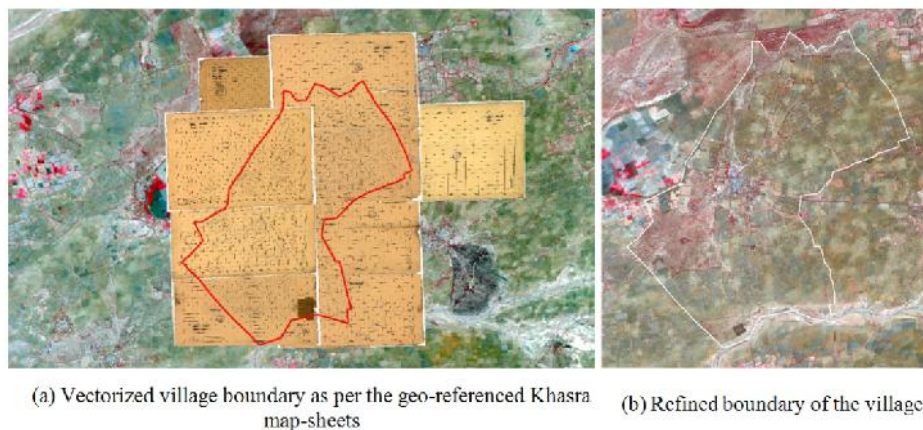


Figure 3. Village boundary abstraction; example of a village in the study area

2.3.8 Dissolving village boundaries to generate Gram Panchayat boundaries: The refined village boundaries prepared in the steps above, were dissolved appropriately so as to generate respective GP boundaries as per Local Government Directory, Ministry of Panchayati Raj, Govt. of India (2017). This product was considered as final refined GP boundary that was prepared using village cadastral map-sheets and HRSI.

2.4 Validation of the work

The final product, i.e., the refined GP boundary was validated with respect to the ground reality in three ways: (i) using the information from a settlement layer, (ii) using the information from assets mapped in the study area, and (iii) by field visit. The same are elaborated as follows.

2.4.1 Validation using the settlement layer prepared on HRSI: Settlements consist of areas covered by human inhabitation like villages, towns, cities, hamlets and dispersed households. The settlement polygons were mapped under the project SISDP at the mapping scale of 1:10000 (SISDP, 2010). For any general case, a Gram Panchayat boundary is not expected to cross the settlement polygons on the map. A close examination revealed that at several locations this was not the case with the previously available generalized GP boundary (Figure 4). A check was performed for the selected seven GPs and it was found that 5 settlement polygons were being crossed by the old GP boundary while no settlement polygons are crossed by the refined GP boundary. One example is shown in Figure 4. It shows that settlement area outlined in red is getting crossed by the older boundary, while refined boundary is completely containing the settlement. Hence, it may be concluded that exactness of administrative boundary has improved in case of refined boundary polygons.

2.4.2 Asset-based validation of the refined village boundary: Every village has community assets that are specific to the local area and may often act as identification for the village. These assets, once mapped in the spatial framework, along with associated attributes and photographs may prove useful for validation of any specific area. Asset mapping task was done as a part of EPRIS (Empowering Panchayati Raj Institutions Spatially) Project of NRSC / ISRO wherein, about 10% of the Gram Panchayats of the

country were selected for outreach activities with a goal to enable the grassroot level planners to utilize space-based inputs (EPRIS, 2016). Also, a pilot study was conducted in Luni Block of Jodhpur District wherein Khasra maps were scanned, geo-referenced and vectorized in a similar manner as shown in the present methodology. An example over a part of Luni Block is shown in Figure 5 which displays few of the assets mapped under EPRIS project. These asset locations were seen once with old village boundary and the second time with refined cadastral-based village boundary. It was observed that the refined village boundary correctly contains the asset locations (Figure 5) while older boundary does not. Hence, the refined boundary prepared as per the presented methodology is found to be fitting as per the ground reality.

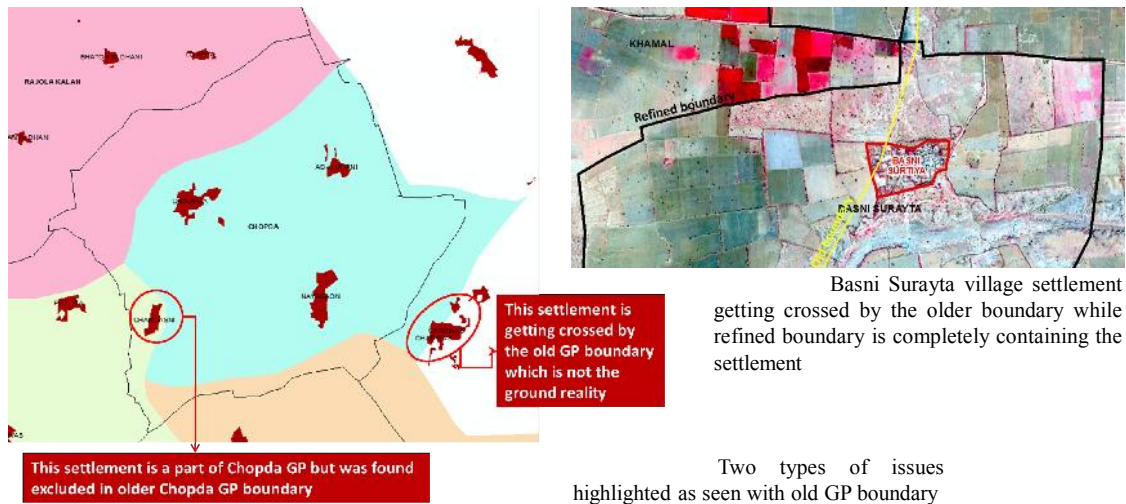


Figure 4. Validation using the settlement layer

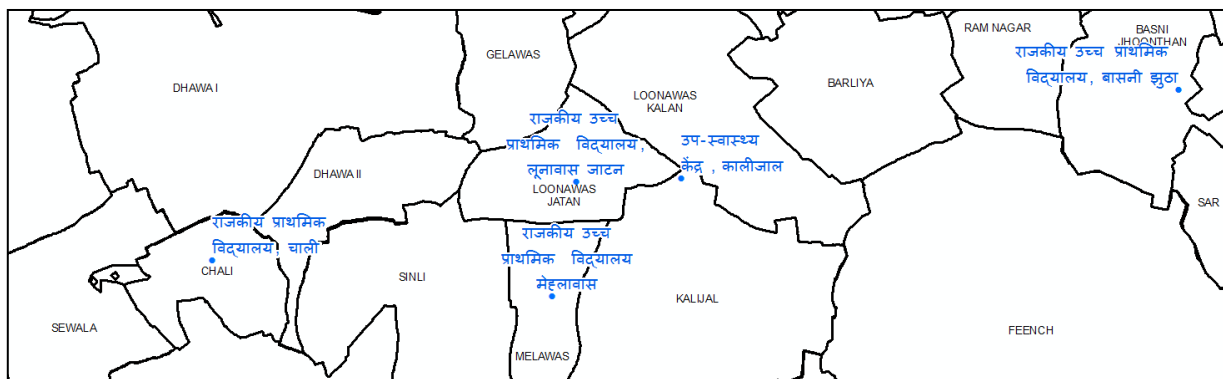


Figure 5. Asset point locations as overlaid on the refined village boundary (black); it may be observed that the village name is matching with the village name as per the refined village boundary

2.4.3 Field validation: For ground-based cross-checking of the GP boundaries generated through the presented methodology, a field visit was conducted in Sardar Samand Gram Panchayat of Sojat Block in Pali District. A hard copy map was prepared depicting the refined GP boundary of Sardar Samand GP as overlaid on 2.5 m spatial resolution HRSI and the same was shared with the concerned Patwari. The map was cross-checked with the corresponding Khasra maps in the Patwari office. The Patwari found the refined GP boundary map to be correct while validating with the available Khasra maps in his office. Further to this, few of the boundary pillars on ground were visited and their point location was recorded using a GPS device (Figure 6). This location information helped in verifying the precision of the refined GP boundary of Sardar Samand Gram Panchayat. Location of the boundary pillars recorded during the field visit was found to be displaced within acceptable limits from the corresponding vertices in the refined boundary (Figure 6). The distance is of the order of few meters and the variation in distance may be attributed to the following factors: natural features (such as growth of shrubs) hindering access to actual pillar location, intentional misplacing of the pillar by the nearby villagers and positional accuracy of the GPS device used. Hence, it was concluded that the refined GP boundary is precisely representing the ground reality. Thus, it may be considered that the methodology adopted here is able to generate acceptable GP boundaries.

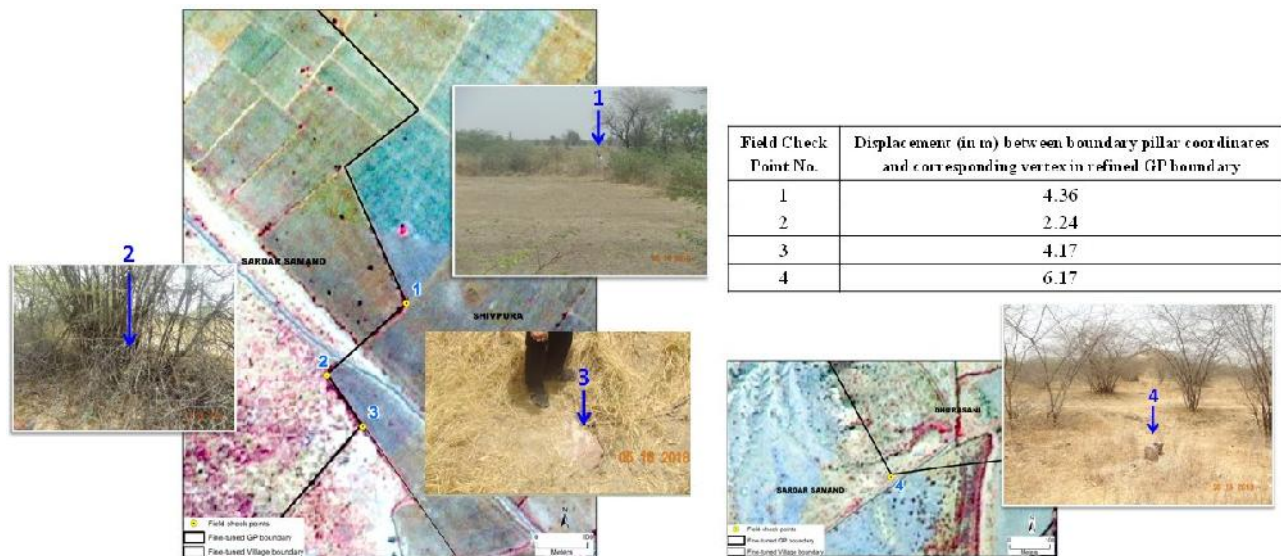


Figure 6. Field photographs at the field check points indicating the boundary pillars as shown by the concerned Patwari

3. RESULTS AND DISCUSSION

The refined GP boundaries generated during the present study were compared with the previously available GP boundaries. Figure 7 shows that there is a significant change in terms of polygon areas and their extents that may be attributed to the differences in mapping scales while preparation of both the products. The boundary as prepared in the present methodology is at a larger scale (1:4000) than that prepared earlier. Calculations were made for corresponding shifts (in km) in x and y directions. Overall shift was -0.699 km in x-direction and -0.502 in y-direction. Shift direction with respect to the older centroid was also calculated (Figure 7a). An evaluation study was performed for each of the GP where areas excluded versus areas included was determined and the same is shown in Figure 7c.

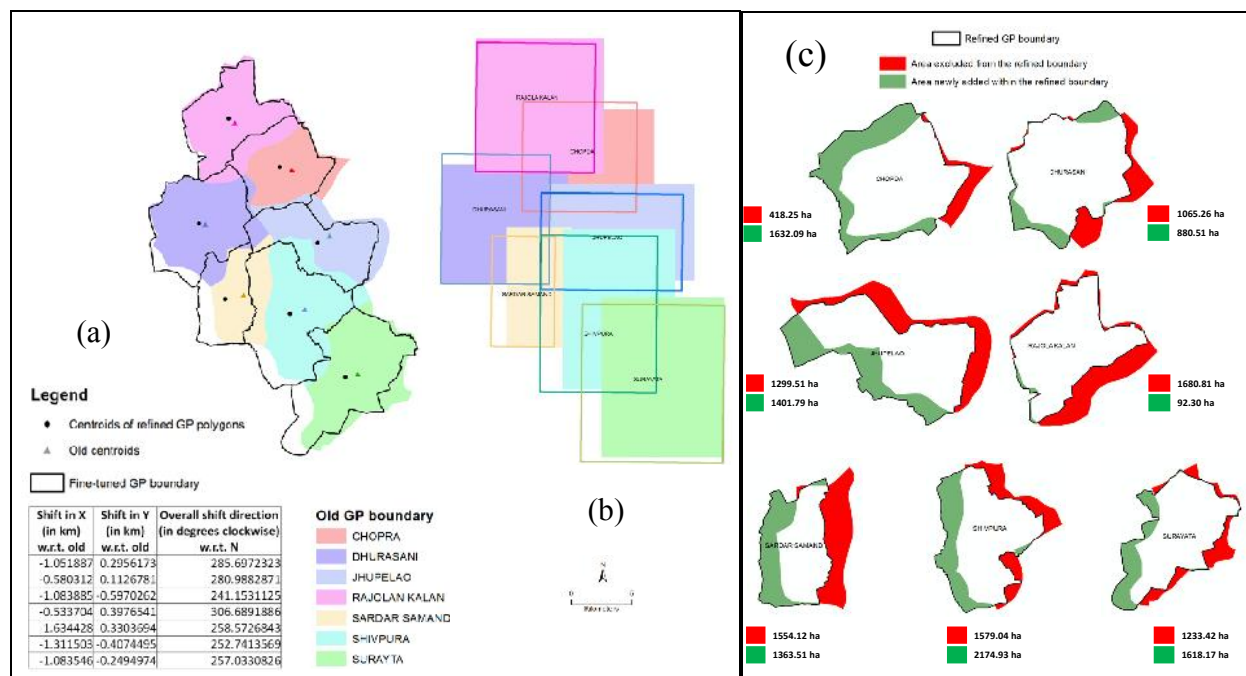


Figure 7. (a) Centroid-shift in old vs. new GP boundary polygons; (b) Change in spatial extent of GP boundaries (filled polygons are bounding boxes of older GP boundary while outline boxes are bounding boxes of the refined GP boundary); (c) GP-wise spatial changes in the area w.r.t. old boundary with areas excluded shown in red and the areas added are shown in green.

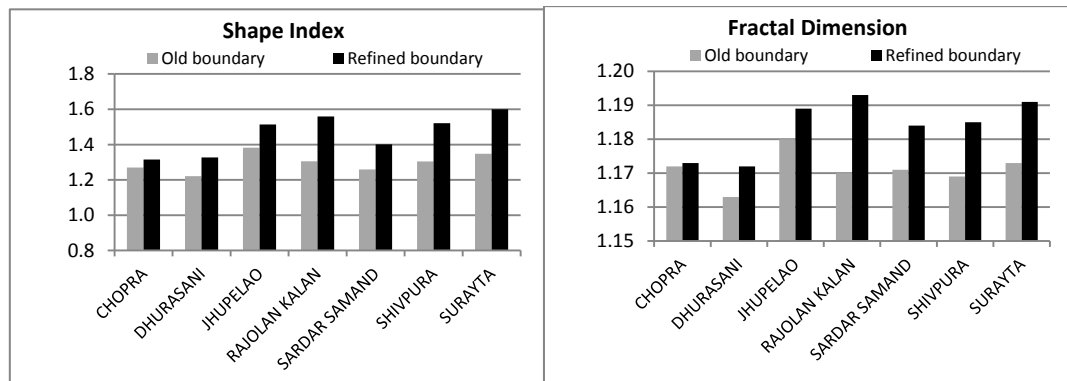


Figure 8. Graphs showing increase in shape index and fractal dimension for the refined GP boundaries

A test was conducted on the polygons in both the boundaries using the quantitative indices like shape index and fractal dimension. The lower the shape index of any GP boundary, the more regular and simpler will be its shape (XueLu, 2000). Hence, this index signifies the difference between the generalized boundaries and the refined boundaries as generated under the present study. The difference is attributed to the change in scale of mapping between the sources. The fractal dimension is an index of the complexity of shapes on the landscape. The fractal dimension will be small (tending towards 1.0) if the landscape is composed of simple geometric shapes like squares and rectangles, whereas, the fractal dimension will be large, if the landscape contains many patches with complex shapes (O'Neill et al., 1988). Fractal dimension index reflects shape complexity across a range of spatial scales. The refined boundary polygons are less generalized than that of the old boundaries. This is attributed to scale variation as well as the task of aligning the boundaries with the features as seen on HRSI at the mapping scale of 1:4000.

4. CONCLUSION

The results show that 2.5 m spatial resolution ortho-rectified satellite imagery is well suited for the precise demarcation of the territorial extents in a time-effective manner. The Khasra map-sheets are used as an indicative background information source to start with. The use of HRSI proved helpful while refining the boundaries. The refined Gram Panchayat boundaries thus produced are capable for applying the spatial statistics such as area calculation. The digital geospatial modernization of the administrative boundaries proves to be of immense help while implementing the Governmental schemes including asset mapping. The methodology may be adapted for development to suite the requirements at an operational scale for the national roll-out towards refining the Gram Panchayat boundaries.

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QUALITY METRICS OF DRAINAGE NETWORK DERIVED FROM CARTODEM USING OPEN SOURCE GIS

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ABSTRACT

Digital elevation models (DEM) are being used in wide variety of applications, one such application is towards drainage network generation for hydrological modeling. The present study deals with the use and applicability of freely available CartoDEM with 1 arc second resolution available on Bhuvan Indian Geo-platform of ISRO, for drainage network generation in comparison with contour elevation data derived from the surveyed topographical sheet. The drainage network extracted from the CartoDEM are compared with the elevation data of a conventionally digitized topographic sheet at 1:25K and the variations are analyzed using open source GIS. The statistical indices for the drainage data like the total number of streams, stream length, drainage density and stream frequency are derived for both the CartoDEM and contour derived DEM from the topographical map at 1:25K. The quality metrics for the drainage network of both the datasets are validated using correctness index to ascertain the level of agreement between the drainage patterns (CartoDEM and contour derived DEM from topographical map). The derivative outputs like the streams and contours derived from CartoDEM suggests its wide-scale regional application for hydrological modeling, terrain characterization and disaster management studies.

KEYWORDS: CartoDEM, topographical maps, drainage network, quality metrics, Open source GIS.

1. INTRODUCTION

The Digital Elevation Models (DEMs) are an important source of information for hydrological modeling and watershed characterization and can be used with ease in many GIS processes and operations. Other interesting application of DEM is for intervisibility analysis of GPS satellites in urban areas. In the study proposed by Sreedhar et al. (2017) Cartosat-1 stereo data was utilized to generate accurate DEM. The study shows building heights are estimated with Root Mean Square Error of only 3.7m and thereby predicting the satellite visibility in dense urban areas. Apart from the above such applications the DEMs are extensively utilized in disaster management studies which requires drainage network as one of the important attribute.

Extraction of drainage networks from raster DEMs is a necessary requirement for hydrological and environmental analysis and determining surface water flow direction is important for analysis. The basis for the derivation of many hydrological parameters is the drainage network, which can be extracted automatically using the DEMs. A digital elevation model (DEM) in raster format, carries elevation information for many applications in hydrologic studies (Freeman, 1991; Arun et al., 2005). Cell-wise elevation information in a DEM can be used to find the drainage structure, which gives the basic information for runoff analysis and sediment transport studies (Jana et al., 2007).

Stream mapping accuracy has improved over the recent years with the availability of both global and regional elevation datasets acquired by modern remote sensing technologies. Before the year 2000, the digital elevation models depicting a global coverage were available with 1 km resolution like GTOPO-30 (Global Topography in 30 arc-sec) and GLOBE (The Global Land 1 km- Base Elevation Project) (Sefercik and Alkan 2009). However, in the last decade, more advanced global DEMs with better resolutions have become available, like the Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010 available in 7.5, 15 and 30 arc seconds resolution), Shuttle Radar Topography Mission (SRTM) (version 4, C-Band DEM of 3 arc-second, 90 m resolution), the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) (version 2, 30 m resolution), ALOS world 3D (30m resolution) captured by the Japan Aerospace Exploration Agency's (JAXA) all these DEMs have addressed the problem of spatial resolution to a great extent thereby improving the accuracy of stream mapping.

For users within India, or those seeking to examine Indian landscapes, the available DEM dataset library received another member through the release of the CartoDEM data (version 3.1, for Indian territories) at 30 m. Apart from these, WorldDEM captured from Terrasar X and Tandem X RADAR satellites are available as paid DEMs. In addition to these freely available readymade DEM datasets, purchased stereo-images from a number of satellites (e.g. Cartosat-1, Landsat 7 ETM+, QuickBird, IKONOS, SPOT, ASTER sensors, among others) have also been used to create DEMs using various software applications for examining landscapes and deriving stream networks (Toutin, 2004). Delineation of stream network is dependent on the resolution of DEM as well as on the choice of the ideal threshold flow accumulation. In the study proposed by Sreedhar et al. (2015) densified mass points are derived using multi-date Cartosat-1 stereo data and were utilized to derive the DEM. The study shows 20% improvement in the drainage delineation using multi-date DEM derived using Cartosat-1 stereo data.

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In the recent years free open source software (FOSS) GIS tools have gained huge popularity as they are able to provide similar solutions as compared to the commercial software's. These free open source software (FOSS) GIS tools provide solutions without any restriction of cost, licensing and access to full source code. On the contrary, free and open source (FOS) software is commonly considered to be more secure, reliable, and adaptable to their commercial counterparts (Fisher et al, 2017).

In the present study an attempt has been made to extract the drainage network and evaluate the quality metrics of drainage derived using CartoDEM. The derived drainage network from CartoDEM is then evaluated with the surveyed topographical sheet at 1:25,000 scale which is referred as TopoDEM (1:25K). The workflow for deriving and carrying out the quantitative analysis of stream network has been developed using the FOSS GIS software's – SAGA GIS 2.1, QGIS 2.1 and GRASS GIS 7.0.

2. STUDY AREA AND DATA SOURCES

The study area covers part of Alwar district of Rajasthan in India. It is located between latitudes of 27° 37' 30" N–27° 45' 0" N and longitudes of 76° 30' 0" E–76° 37' 30" E, with elevation ranging from 2m to 625m with respect to the mean sea level. The DEMs and the details of the datasets used in the study are shown in Figure 1 and Table 1.

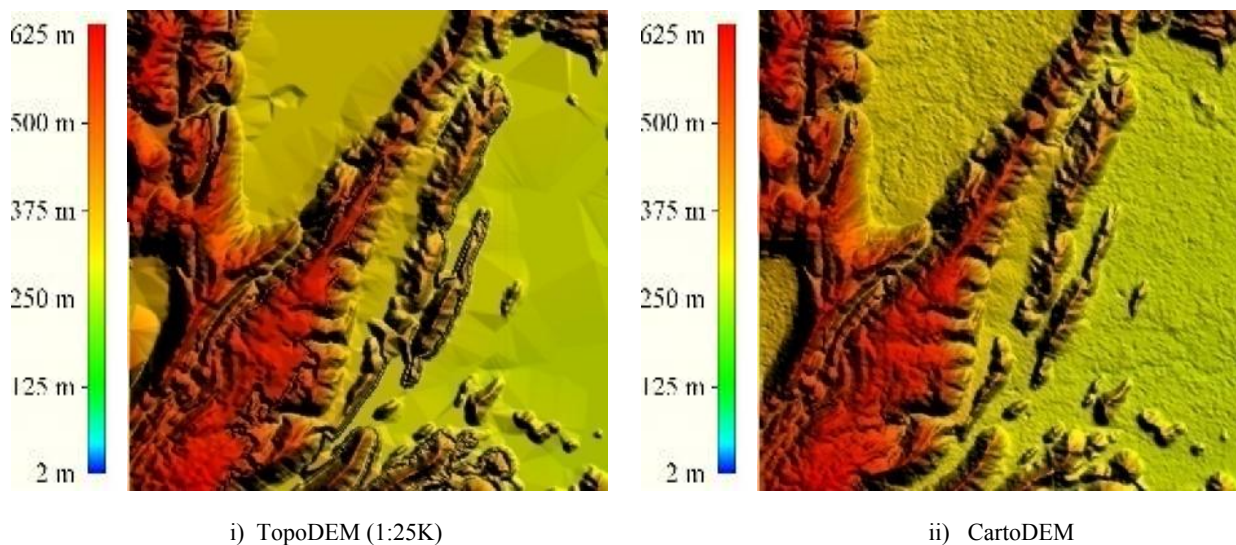


Figure 1. DEM data sources for the study area - TopoDEM (1:25K) and CartoDEM (30m).

S.No	Type of Data	Details of data	Sources
1	Survey of India, toposheet	Toposheet No. 54A/10/NW Scale: 1:25000	Survey of India (SOI), Dehradun, India
2	CartoDEM	CartoDEM Version-3 Resolution: 1 arc second	Bhuvan, Indian Geo- platform of ISRO

Table 1. Data used in the present work.

3. METHODOLOGY

The study has six distinct stages:

- 1) Scanning and georeferencing of SOI toposheet.
- 2) Contour digitization of 1:25k toposheet and subsequent conversion to raster DEM.
- 3) Datum conversion of CartoDEM and comparison with TopoDEM (1:25K).
- 4) Co-registration of TopoDEM (1:25k) and CartoDEM
- 5) Drainage network generation using open source GIS for TopoDEM and CartoDEM.
- 6) Quality metrics and validation of drainage network derived from TopoDEM and CartoDEM.

The flow chart for the methodology is given in Figure 2 which shows the sequence of steps carried out for drainage network extraction using TopoDEM (1:25K) and CartoDEM.

3.1 Scanning and Georeferencing of SOI Toposheet

The SOI topographical map with sheet number 54A/10/NW at 1:25,000 scale was scanned and geometrically rectified and geo-referenced using the geo-referencer tool in raster utility of QGIS 2.1.

3.2 Contour Digitization of 1:25K Toposheet and DEM Generation

The 10m contours from the SOI topographical map were digitized manually using QGIS software. Then the digitally captured contour data were compiled to generate a raster DEM of the area using QGIS software for subsequent extraction and analysis of drainage network.

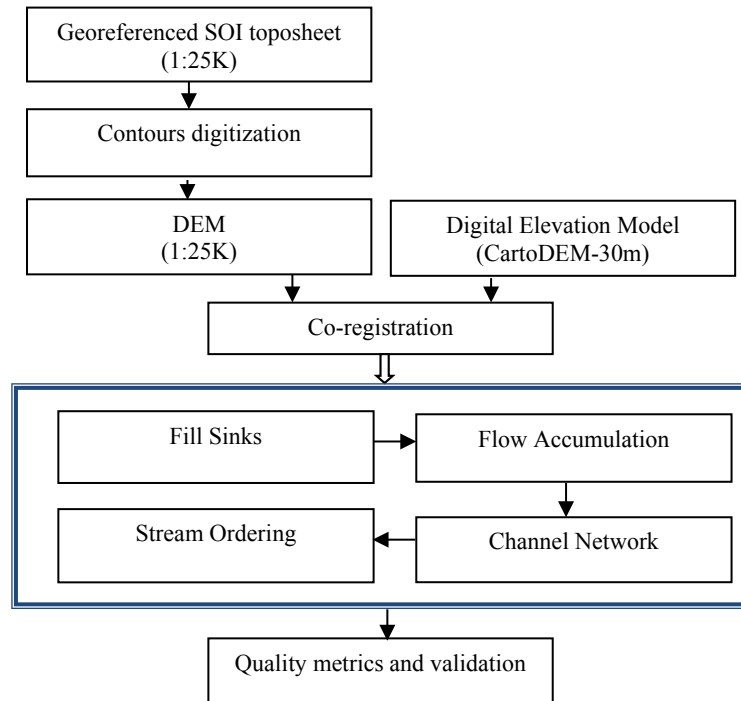


Figure 2. Flowchart showing the process extraction of drainage network using a DEM, deriving quality metrics and validation of derived drainage network.

3.3 Vertical Datum conversion for CartoDEM - WGS84 to MSL using EGM2008 geoid

The vertical datum of SOI toposheet and the CartoDEM downloaded from the Bhuvan Indian geo-platform of ISRO (<https://bhuvan.nrsc.gov.in>) are different. The details of vertical and horizontal datum of the data sets are given in Table 2. The elevation of a point on Earth surface measured from Mean Sea Level (MSL) can vary from GPS derived elevation because of the variation between WGS84 ellipsoid and Geoid (local MSL). The Geoid surface is an equipotential or constant geopotential surface which corresponds to MSL. The geoid height/geoid undulation (N) is the difference in height between geoid and ellipsoid at a point. Figure 3 represents ellipsoid height (h) and height above geoid surface (H) which is orthometric height. However, it can be derived using the equation 2:

$$h = H + N \quad (2)$$

The magnitude of geoid height/undulation ranges from a low of about -105 m at southern tip of India to a height above +85 m at New Guinea (Kaplan and Hegarty, 2006).

S.No	Data	Horizontal datum	Vertical datum
1	Survey of India, toposheet	Everest	MSL
2	CartoDEM	WGS84	WGS84

Table 2. Horizontal and vertical datum of elevation data sets used in the study

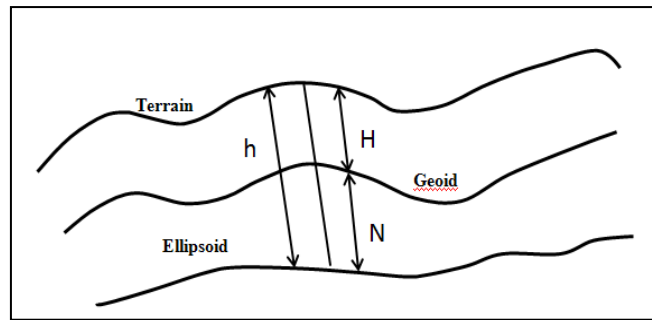


Figure 3. Relation between ellipsoid height, orthometric height and geoid undulation

Hence, for the comparison of drainage network, from two different data sources CartoDEM (WGS84) and TopoDEM (MSL), vertical datum and co-ordinate system are firstly checked and matched. Indeed, different datum for DEMs to be compared will lead to a small shift of the position, and therefore the height of a single point from one DEM to another. Similarly, different coordinate systems will result in mis-interpretation of point positions in DEMs and the validation of drainage network. The CartoDEM elevation data available in WGS84 datum is converted to EGM2008 geoid using the recalculate elevation utility available under terrain preparation tool of ERDAS Imagine 2018.

3.4 Co-registration of SOI 1:25K DEM and CartoDEM

The input DEMs (TopoDEM and CartoDEM) must be aligned in order to compensate for major discrepancies between them. This process is usually referred to as co-registration. The co-registration removes global systematic errors like translations, rotations, scale differences, while it also permits calculation of differences after co-registration. After co-registration the pixels in the two elevation data products represent the same location and area on the earth surface. The two DEMs are co-registered using the LS3D surface matching software. The method performs 3D least squares matching between a “slave” and a “master” surface (Gruen and Akca, 2005). The pair-wise LS3D matching is run on the overlapping dataset, setting the slave DEM – CartoDEM and master DEM – 1:25K topoDEM. After the co-registration, the Euclidean distances (E) between the two DEMs are calculated pair-wise, together with the X, Y, Z components. The results are summarized in Table 3.

Co-registration of TopoDEM (1:25K) and CartoDEM	No of match points	No of iterations	σ_o (m)	t_x σ_{tx} (m)	t_y σ_{ty} (m)	t_z σ_{tz} (m)	ω σ_ω (grad)	$\emptyset$ $\sigma_\emptyset$ (grad)	K σ_K (grad)
	114252	12	7.47	110.76	-22.87	-0.0028	-0.011	-0.025	-0.079

Table 3. Numerical results of Co-registration – TopoDEM and CartoDEM

where σ_{tx} : Standard deviation of the X component of the estimated translation vector tx. Similar symbolization is used for other components ty, tz, ω , $\emptyset$ and K.

3.5 Drainage Network Generation using Open Source GIS for TopoDEM and CartoDEM

A fully standardized stream network extraction was performed using a work-flow of hydrological modules within GRASS (GRASS Development Team, 2017). GRASS GIS offers a reasonably exhaustive analytical GIS environment with a vast number of auxiliary tools, access to different data types via GDAL/OGR, and advanced map algebra (Shapiro and Vestervelt, 1991). GRASS GIS integrates raster and vector data processing techniques with access to numerous database systems and with full SQL language support. GRASS GIS as a programming environment has a very stable and mature application programming interface (API) and provides a spectrum of functions for handling input/output sub-routines and file management. The presence of segment library within GRASS environment, allows users to make calculations on finer resolution DEMs derived from HR satellite imagery, LiDAR and radar interferometry (IFSAR) that could not be performed all in memory.

Stream network extraction from raster grids can be categorized into channel initiation (CI) methods, valley recognition (VR) methods, and a mixture of both. Mostly D8 based approach was adopted in CI methods assuming that flow dispersal is limited from each cell to only one cell of eight principal directions separated by $\pi/4$ (45°). The D8 method gives erroneous results in the slope subsystem (Tarboton, 1997), whereas the VR methods do not create topologically correct drainage systems. Hence, a combination of CI-VR method (Tarboton, 1997) with a multiple-flow-direction approach was introduced, however this method has a limitation as it uses accumulation maps to determine the stream threshold but uses elevation to trace the stream. All the above limitations are addressed in the GRASS module r.stream extract tool which gives topologically correct, dendritic stream networks and therefore this software was chosen for the study to extract the stream network. This tool uses a DEM, matching flow accumulation, threshold for flow accumulation as input. The accumulation map is derived using the watershed tool and the threshold is defined based on the resolution of DEM. In this study the resolution of DEM is 30m and the minimum drainage area chosen was 0.3 sq.km and therefore

the threshold value of 300 was given as the input. The results of the drainage network derived for the TopoDEM and CartoDEM are shown in Figure 4.

3.6 Quality metrics and validation of drainage network derived from TopoDEM and CartoDEM

The morphometric parameters of stream network are derived for TopoDEM (1:25K) and CartoDEM. These parameters are calculated according to formulas given by R. Horton (Horton, 1945). The composition of the stream system of a drainage basin can be expressed quantitatively in terms of stream order, drainage density, bifurcation ratio, and stream-length ratio. Table 4 shows the catchment and stream statistics derived for TopoDEM (1:25K) and CartoDEM. Table 5, 6 and 7 shows the stream statistics derived for each order. Figure 5 and 6 shows the comparison of stream counts and total stream lengths derived for each order of stream network for both TopoDEM and CartoDEM.

Evaluation of stream networks was done based on raster based approach suggested by Pontius et al. (2008) and Li and Wong (2010). The reference used was the stream networks generated from SOI topomaps at 1:25,000 scale. The Correctness Index (CI) was calculated as

$$CI = N(A \cap B) / N_B \quad (3)$$

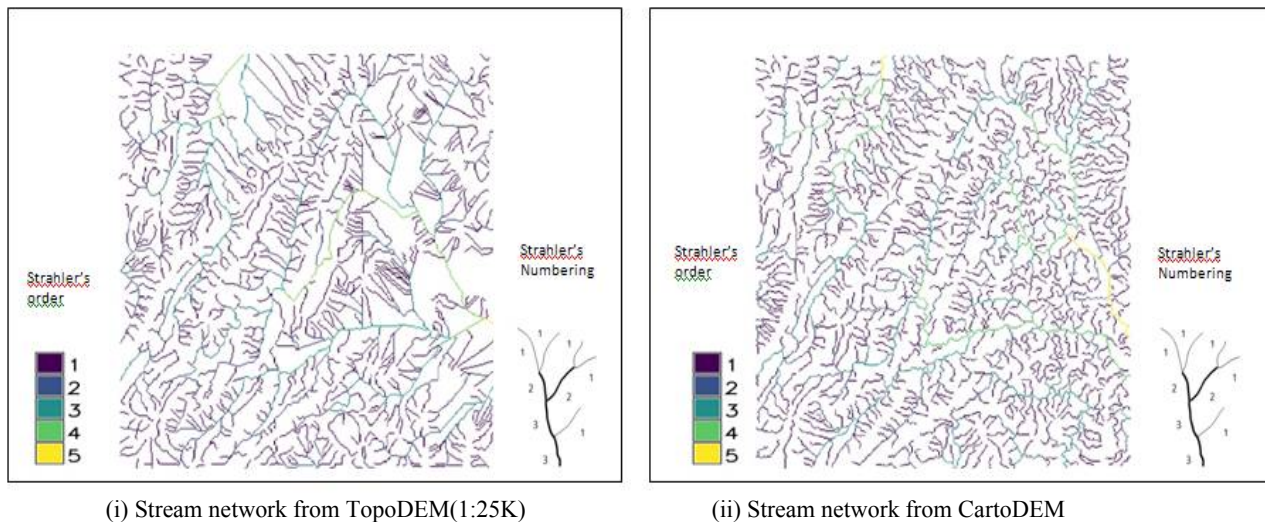


Figure 4. A comparison of results of stream network modeling for strahler's order 5.

Where, $N(A \cap B)$ is the number of cells found in both the extracted network and the drainage digitized from SOI topomap. N_B represents the number of cells in the drainage digitized from the SOI Topomap. The CI estimated was 58% for the drainage pattern between TopoDEM and CartoDEM.

S.No	Stream attributes	TopoDEM (1:25K)	CartoDEM
1	Area (sq. km)	107.89	107.61
2	Maximum stream order	5	5
3	Total no. of streams	831	922
4	Total stream length (km)	510.92	574.74
5	Drainage Density (km/km ²)	4.74	5.29
6	Stream frequency (num/km ²)	7.72	8.5
7	Bifurcation ratio	3.62	4.59
8	Stream length ratio	1.12	1.70

Table 4. Stream attributes extracted for the study area.

Stream order	TopoDEM (1:25K)	Average length (Kms)	CartoDEM	Average length (Kms)	Absolute difference	% Absolute difference (w.r.t Topo DEM)
1	643	0.525	721	0.537	0.012	2.33
2	142	0.610	163	0.622	0.016	2.66
3	32	1.60	31	1.64	0.043	2.69
4	10	5.64	5	5.94	0.297	5.27
5	4	2.15	2	2.37	0.217	10.13

Table 5. Average length of stream for each stream order from different datasets.

Stream order	Topo DEM average area	CartoDEM Average area	Absolute difference	% Absolute difference (w.r.t. Topo DEM)
1	0.097	0.098	0.001	1.163
2	0.429	0.438	0.008	1.990
3	2.190	2.166	0.024	1.091
4	14.325	15.130	0.805	5.620
5	26.970	25.513	1.457	5.402

Table 6. Average area for each stream order from different datasets

Stream order	TopoDEM average slope (m/m)	CartoDEM average slope (m/m)	Absolute difference	% Absolute difference (w.r.t Topo DEM)
1	0.149	0.132	0.017	11.620
2	0.062	0.052	0.009	14.800
3	0.024	0.020	0.004	15.910
4	0.018	0.018	0.001	6.980
5	0.006	0.011	0.004	9.330

Table 7. Average slope for each stream order from different datasets

Figures 4 and 5 depict the comparisons for DEMs derived from the different datasets with respect to stream counts and total stream lengths respectively.

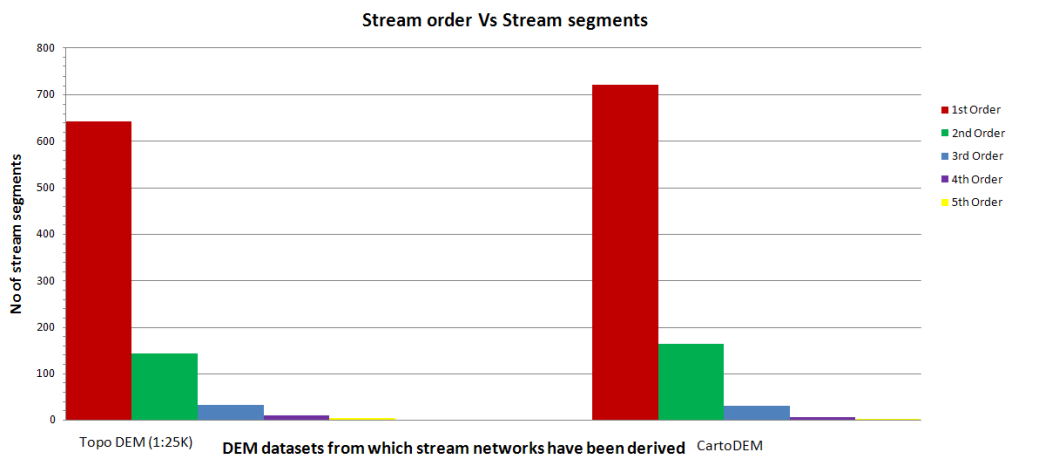


Figure 5. Comparison of stream counts after Strahler (1954). Order-wise stream networks derived from TopoDEM and CartoDEM

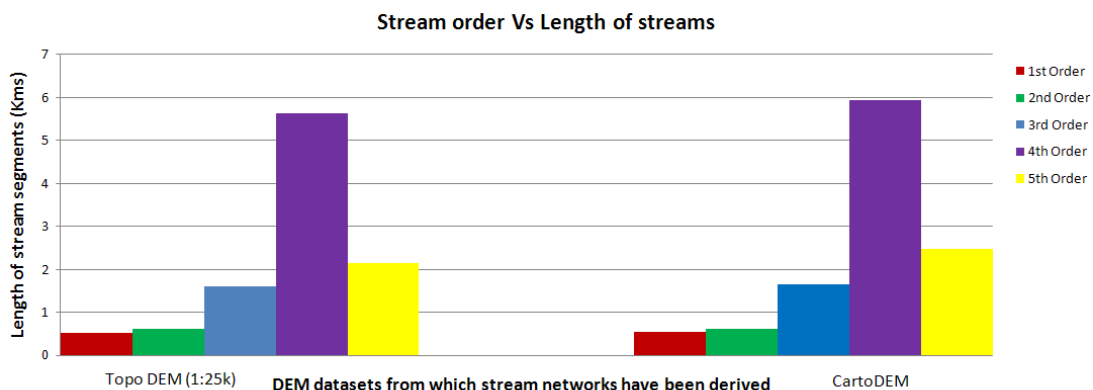


Figure 6. Comparison of stream counts after Strahler (1954). Order-wise stream networks derived from TopoDEM and CartoDEM

4. RESULTS AND DISCUSSION

The numerical results of co-registration of TopoDEM (1:25K) and CartoDEM using the least square surface matching method are shown in the Table 3. After the co-registration, the euclidean distances between the two datasets are computed as the X, Y, Z components along with the rotations (ω , ϕ , κ). Using the outputs of the co-registration drainage networks from both the datasets are generated for further evaluation.

The evaluation of the morphometric parameters of the drainage networks derived from the topographic map and the CartoDEM are given in Tables 4, 5, 6 and 7 respectively. As expected, DEM resolution and map scale are significant factors in determining the various morphometric attributes. For the comparison sake the resolutions of both the DEMs are resampled to 30m. There is a slight variation in the extent of basin areas extracted from different DEMs, but no significant changes in basin shape parameters arise. The basins derived are all of similar shape and preserve their aspect ratio regardless of DEM resolution or map scale. In case of drainage density, stream frequency and stream length ratio it is observed that the results obtained are highest for the CartoDEM with 5.29 km/km², 8.5 num/ km² and 1.7 as compared to the TopoDEM with 4.74 km/km², 7.72num/ km² and 1.12. The absolute difference in average length for order wise stream network is varying between 2-10% for CartoDEM when compared with TopoDEM (Table 5). In case of area and slope for each order of stream network the absolute difference is varying between 1-5% and 9-11% for CartoDEM when compared with the reference TopoDEM (Table 6 and 7).

Figure 5 and 6 shows the comparison of stream counts and stream lengths for order-wise stream networks derived from TopoDEM and CartoDEM. From the statistical analysis it is inferred that the total stream count extracted from the CartoDEM is 10% higher when compared with the reference TopoDEM. In case of total stream lengths the stream network extracted from the CartoDEM is 12% higher than the TopoDEM.

Bifurcation ratios characteristically range between 3.0 and 5.0 for watersheds when the influence of geological structures on the drainage network is negligible (Verstappen 1983). The mean bifurcation ratios in both drainage networks of the basin are 3.8 and 4.1. This result suggests that the geological structures have little influence on the drainage networks. The difference or deviation of each of the attributes like the length, area and the slope of the drainage network for each stream order have been computed for the datasets (TopoDEM, CartoDEM) for comparison of the degree of change. The percentage change of this is presented (Table 5, 6 and 7), which shows that the absolute percentage difference is the least for the CartoDEM when compared with the TopoDEM, thus substantiating its correctness for obtaining morphometric values closest to those of a surveyed map (topographical map, 1:25K). To further corroborate, the extracted stream networks (TopoDEM, CartoDEM) were assessed based on correctness index (CI). The CI estimated was 58% for the drainage pattern between TopoDEM and CartoDEM.

5. CONCLUSIONS

In this study, open source tools are used to derive and evaluate the quality metrics of drainage network from the freely available CartoDEM with 1 arc second resolution available on Bhuvan Indian Geo-platform of ISRO. The drainage metrics derived from the CartoDEM are validated with the reference TopoDEM (1:25K). The statistical analysis for the stream network for the maximum order of five shows 10%, 11% and 12% higher number of total stream count, drainage density and stream frequency when compared with the TopoDEM. The percentage absolute difference for stream length, area and slope for order wise stream network shows a variation between 2-10% (stream order 1-5), 1-5% (stream order 1-5) and stream slope between 9-15% for CartoDEM when compared with the reference TopoDEM.

To substantiate further correctness index based on raster approach was calculated which shows 58% of streams extracted from CartoDEM are matching with the TopoDEM. The major variation is found in the first and second order streams. This variation in the stream network was noticed in flat areas possibly due to change in vegetation and in very high relief areas. This study also ascertains the fact that a close degree of proximity of stream network generated from CartoDEM when compared with the surveyed topographical map at 1:25,000 scale. As demonstrated here, the CartoDEM will provide a timely and cost-effective way to assess the drainage and contour information for any study area with varied topography. Moreover, the derivative outputs like the streams and contours derived from CartoDEM suggests its wide-scale regional application for hydrological modeling, terrain characterization and disaster management studies.

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3D MODELLING OF IIST CAMPUS USING TERRESTRIAL LASER SCANNING DATA

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ABSTRACT

Virtual 3D models of urban infrastructures offer new possibilities for strategic planning, development assessment and visualization. With the potential of directly capturing the third dimension, Light Detection and Ranging (LiDAR) is revolutionizing the way earth surface features can be mapped and thus enabling generation of measurable 3D models. The objective of this study is to demonstrate and implement a methodology to create virtual 3D campus model of IIST (Indian Institute of Space Science and Technology) using terrestrial laser scanning data. Initially, 3D data points acquired from multiple scans using the terrestrial laser scanner were registered and geo-referenced. Ground points were separated from non-ground points using filtering algorithm. Digital terrain model and contours were generated using the ground points. Non-ground points were classified into various classes such as buildings, shrubs, trees, lamppost, and cars. Building points isolated from the LiDAR point cloud were used to create 3D building models. Finally, 3D campus model with various objects including buildings, road, trees, cars, and lamp post was generated. The model thus developed is true to geometry and can be directly used by decision makers for making informed decision. Thus, the methodological approach developed as part of this research can be used for creating 3D models from point cloud.

KEYWORDS: 3D building models, LiDAR, TLS, virtual 3D models.

1. INTRODUCTION

3D maps are gaining popularity amongst the map readers for navigating and exploring area of interest owing to the ease of visualization and realistic views it offers. This is evident with the availability of 3D walkthroughs and street views of selected earth surface features in popular platforms such as Google Earth, Apple Maps and Bing maps. Images from very high resolution images captured in stereo has been a source of data for creating high quality 3D maps/models (Jin et al., 2005; Suveg et al., 2004). The elevation information retrieved through photogrammetric techniques from the high resolution stereo images are used to create 3D models of various earth surface features. However, an unparalleled remote sensing technology, Light Detection and Ranging (LiDAR) has changed the way elevation measurements can be made (Baltsavias, 1999). Employing monochromatic and coherent electromagnetic waves for ranging, integrating three important components, laser ranger, IMU (Inertial Mapping Unit) and GPS (Global Positioning System), LiDAR is capable of measuring the elevation changes of objects at unprecedented accuracy (Golovinskiy et al., 2009; Sun et al., 2013; Ramiya et al., 2016b). The ranging measurement by the laser ranger is through two methods: time pulse method (Wehr et al., 1999) or phase-shift measurement (Mallet et al., 2009). While time pulse method is employed for sensors operating at longer ranges, the latter is popular in short range terrestrial laser scanners. The ranging measurement when combined with the orientation information from IMU and positional information from GPS results in integrated geocoded 3D coordinates (X, Y, Z) of objects commonly referred to as LiDAR point cloud. Thus the dense point cloud inherently captures the geometric details of the object which can be used for discriminating various earth surface objects. The unprecedented accuracy and the ability to directly record elevation of terrain makes LiDAR an unique geospatial technology for creating 3D maps/models.

3D maps/models thus created has endless applications ranging from mere visualization to simulations and virtual reality useful for navigation, disaster management etc., (Dash et al., 2004; Fritz et al., 2012; Ramiya, et al., 2016a). 3D campus models/ maps of educational institutions are important asset to prospective students as well as visitors to get around the campus. There have been studies on using terrestrial/airborne LiDAR data for creating 3D campus maps. However, to our knowledge, there has not been any study for campus modelling using TLS reported in Kerala.

The overall objective of this study is to employ terrestrial laser scanner to create 3D model of the academic sections of IIST campus. Specific objective is to create a methodological framework to convert the 3D point cloud obtained from TLS to 3D models. Another objective is to use the geometrical information present in the LiDAR to create 2D maps of the campus along with Digital Terrain Models (DTM) and contour lines.

2. STUDY AREA AND INSTRUMENT USED

Indian Institute of Space Science and Technology (IIST) is located at Valiamala, about 25km from Thiruvananthapuram city, Kerala. IIST is situated between 77° 01' 54" to 77° 02' 06" East longitude and 08° 37' 45" to 08° 37' 28" North latitude. With a total area of about 100 acres (0.4 km²) housing academic and residential blocks, IIST is surrounded by lush greenery. For this study, the part of IIST campus which houses the academic block occupying roughly 30 acres of the total area is considered.

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FARO FOCUS 360 S, terrestrial laser scanner was employed for range measurements. Based on phase shift method, the instrument operates in NIR region at 1550 nm wavelength with a ranging error of ± 1 mm.

A total of 26 scans were taken to cover the academic blocks of IIST. With a field of view of 300° in vertical direction and 360° in horizontal direction, the scanner is able to completely cover the whole scene. With the point cloud acquisition setting at capturing a point every 20 mm, each scan was completed within 15 minutes. The whole area was scanned in approximately five hours containing approximately 31 million points. LiDAR point cloud contains only the range measurement apart from the backscattered intensity in the the operating wavelength. This dense point cloud captures the minute geometrical details of the object but lacks spectral details. Hence, the instrument has a built-in 165 megapixel, HDR-camera so as to provide a natural color overlay to the scan data thus creating colored point cloud. For each scan, approximately 65 color photos were captured. The scan positions around the campus are shown in the Figure 1.

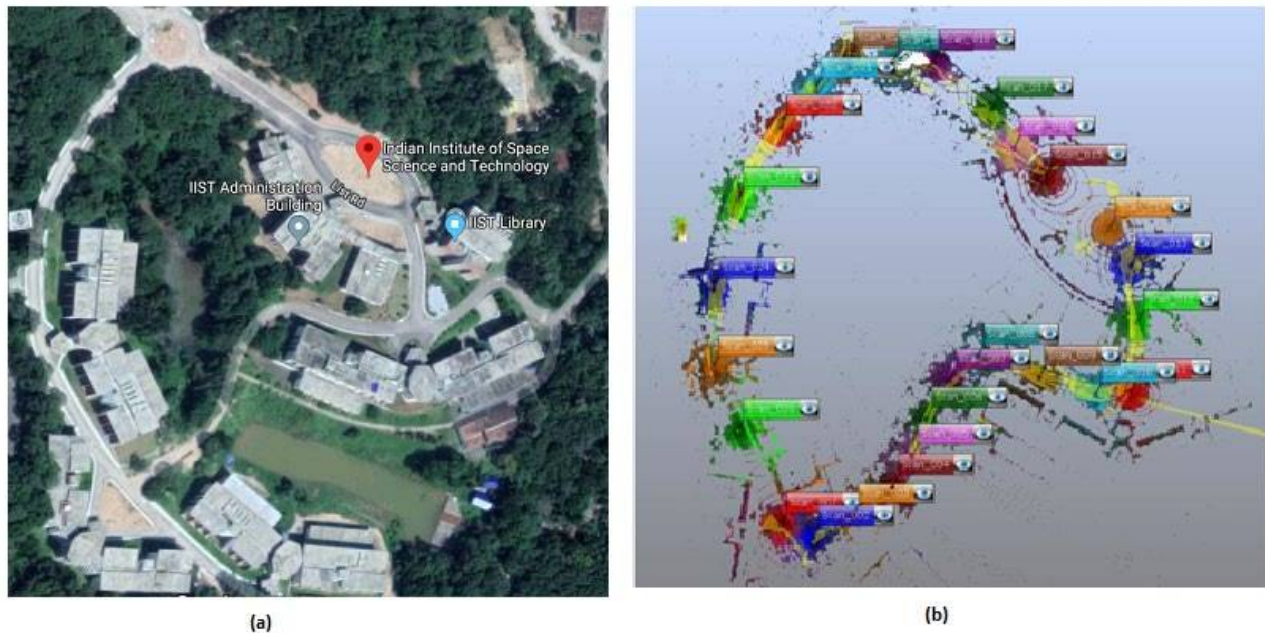


Figure 1. (a) Google Earth image showing the academic blocks of IIST campus (b) Scan position of TLS around the campus to cover the academic blocks (26 scans)

3. METHODOLOGY AND RESULTS

The overall methodological framework adopted to meet the objectives of the study is illustrated in Figure 2. Each of the processing steps are elaborated in the following sections.

3.1. Point Cloud Preprocessing

In order to cover the academic blocks of IIST, around 26 scans were captured around the campus as shown in Figure 1 b. The scanned points are registered, geo-referenced and colorized using proprietary software of FARO, i.e., SCENE. Initially each of the scans were taken with respect to the internal coordinate system. The location of the points in each scan are with respect to the location of the scanner which is fixed as (0,0,0). The scans are thus with respect to local coordinate system of the sensor. The scans need to be registered together to form a complete scene. Geometrical primitives such as planes are used for registering the adjacent scans (Bienert et al., 2009). The registered scans have a local coordinate system. These were converted to world coordinate system using ground control points in the scenes for which the accurate GPS locations are used. Minimum three GCP points are needed in the first scan to geo-reference the scene. This can be used to register subsequent scenes. The scans were registered with point error of around 10mm.

Further, the spectral information from the images taken was used to colorise the point cloud. Thus based on the position of the camera and laser ranger position, each point in the point cloud is assigned R,G,B value. Thus each point in the point cloud has X,Y,Z,R,G,B values. Registration is a time consuming process and it took nearly ten hours for registration, geo-referencing and colorizing 26 scans. The registered scans with colorised point cloud are shown in Figure 3.

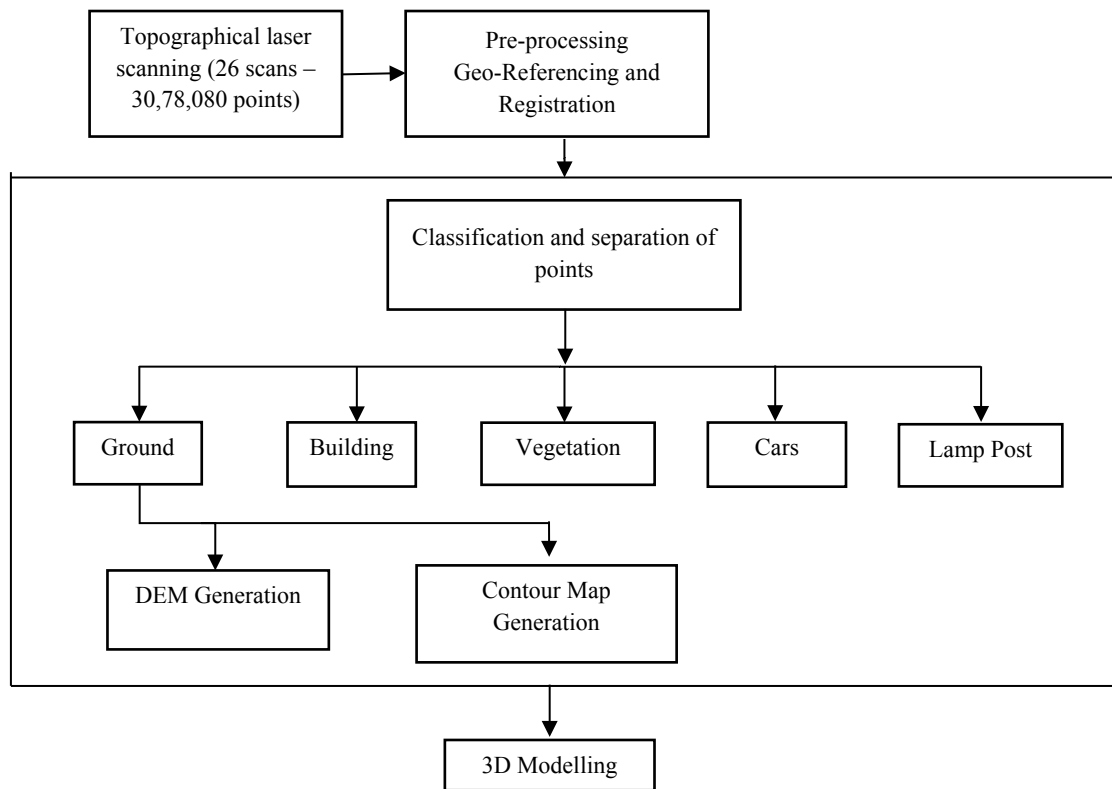


Figure 2. Methodology for 3D building model generation



Figure 3. Top view of the registered, geo-referenced and colored scans

3.2. Point Cloud Classification

In order to better utilize the LiDAR points (X,Y,Z, R,G,B) for specific application, it is important to assign classes to each and every point in the point cloud. Point cloud labelling similar to image classification assigns particular class to each and every point in the point cloud (X,Y,Z,R,G,B,C). Point cloud classification can be broadly categorized into point based labelling (Lalondeetal., 2006) or object- based labelling (Zhang, et.al 2013, Ramiya, et.al 2016b). In point-based labelling methods, local geometric features such as elevation, distance from ground etc., are used for classification. However, in object-based methods, the points are grouped to form segments based on homogeneity criteria and complex features extracted from these segments are used for classification. The unclassified points are shown in Figure s 4(a) & 4(b). In this study, we have used point based labeling technique to classify each and every point in the point cloud. Terrasolid software (Soininen, 2004) was used to classify the point in the point cloud for this study. Initially the points are classified as ground points based on filtering algorithm (Axelsson, 2000). TIN based filtering is used to classify the ground points from the non-ground points. In this method, a triangulated network is generated with the initial set of seed points. The triangulated network is progressively densified based on the slope and distance threshold set to the new point from the underlying TIN. 107933 points were classified as ground points which were used for further processing. Based on the distance from the ground points and a set of other criteria, the points in the point cloud are classified into seven classes namely ground, low vegetation, medium vegetation, high vegetation, buildings, cars and lamppost. The point cloud after classification is shown in Figure 5.

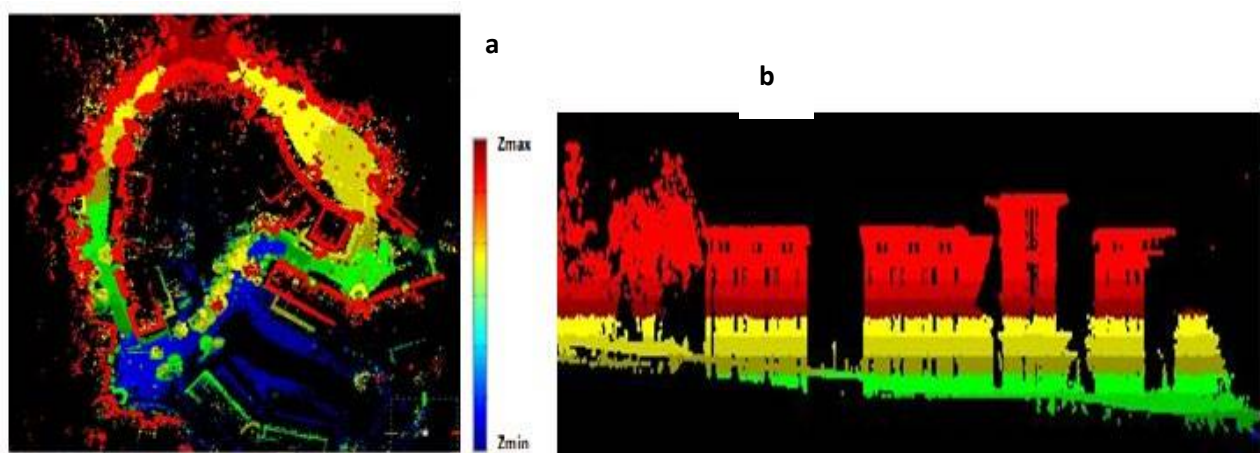
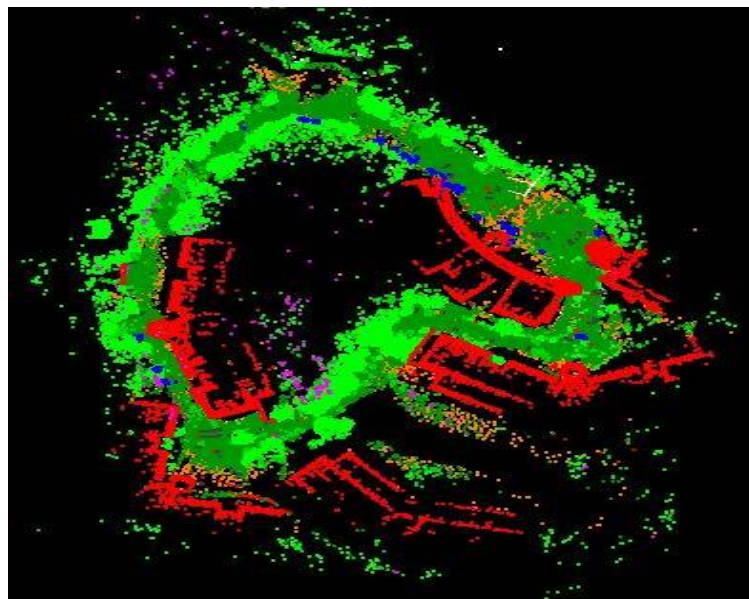


Figure 4 (a) & 4(b). Top view of the unclassified point cloud coloured based on elevation and 3D view of a section of unclassified point clouds coloured based on elevation

a. Top view



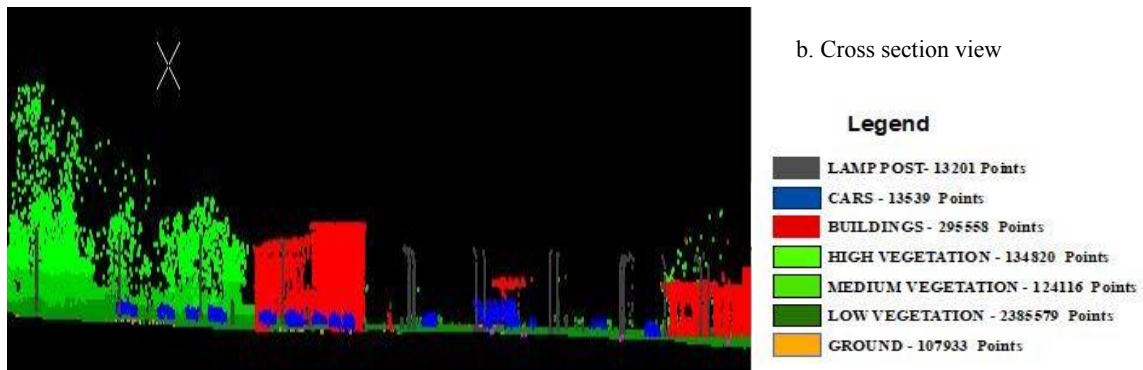


Figure 5. Classified LiDAR point cloud

3.3. 2D Footprint Extraction

The classified building points are extracted from the point cloud and are used to generate 2D footprints of buildings. This 2D footprint is fixed with the ground surface created using the ground points. Similarly, footprint of other classified objects in the point cloud such as road, trees, cars, and lamp-post was created. Figure 6 shows the 2D footprints of roads and buildings in study area. The 2D footprints were further used for 3D reconstruction.

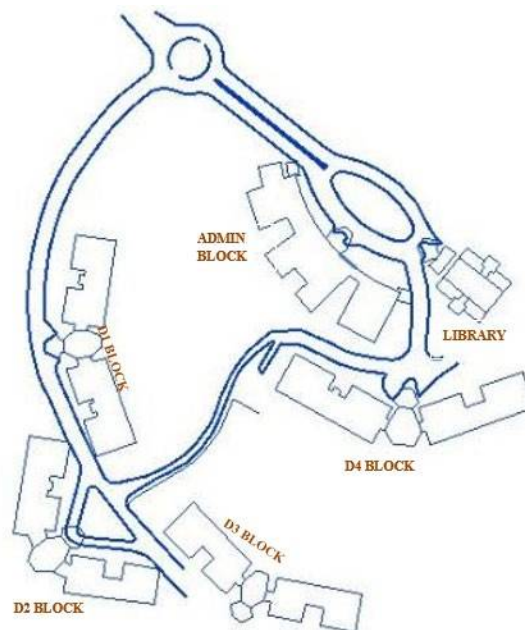


Figure 6. Footprints of Buildings and Roads

3.4. DTM and Contour Lines

The ground point classified using filtering algorithm was used to generate two important products: digital terrain model and contour lines. Digital Terrain Model (DTM), also known as the bare earth model is a digital representation of the ground elevation surface (Hodgson, et. al., 2003; Gil, et. al., 2013). Mostly represented by regular grids, DTM surface holds the surface elevation at regular intervals. The accurate elevation information from the point cloud aids in generating detailed digital terrain model. The isolated ground points were converted to DTM surface using LAS Tools (Isenburg 2012). Contour lines are lines joining points of equal elevations and are usually used to represent the steepness or gentleness of the slopes (Kuldeep K. Sareen, et. al., 2010). The ground points can be used to generate contour maps with 5 m contour interval. Figure 7 shows the variation in the elevation of the surface using DTM and contour lines.

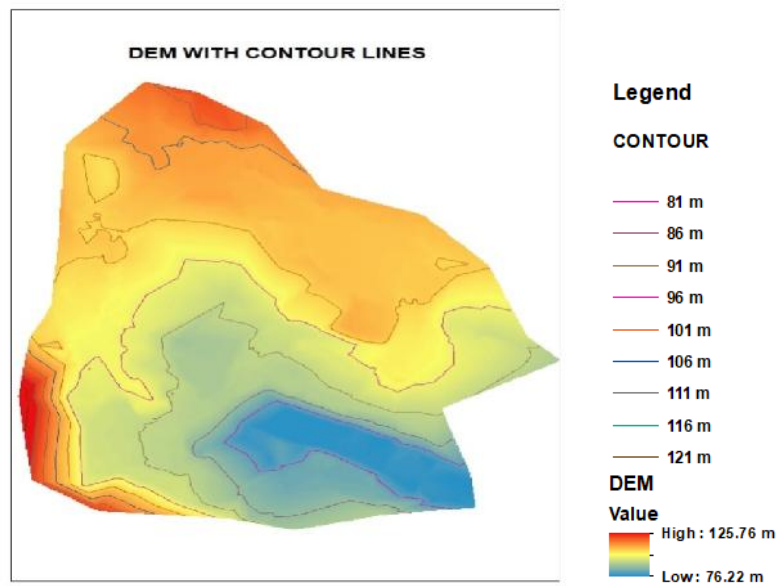


Figure 7. DEM and Contour lines

3.5. 3D Modeling

The classified point clouds were used to create 3D models of the campus. 3D models are basically a computerized or digital models with graphic representation of buildings and other objects in 3D (Yahya Alshawabkeh, et.al 2006). The elevation values from the LiDAR point cloud were used to create 3D models. Open source SketchUp software was used to render 3D from the point cloud. Initially the ground points were used to create the base ground surface. Objects such as building, roads vegetation were added to the terrain so as to create a realistic 3D model. The dimensions of the 3D reconstructed buildings were validated with the dimensions measured using Laser Distometer.

The resultant 3D models are shown in Figure s 8(a), 8(b).

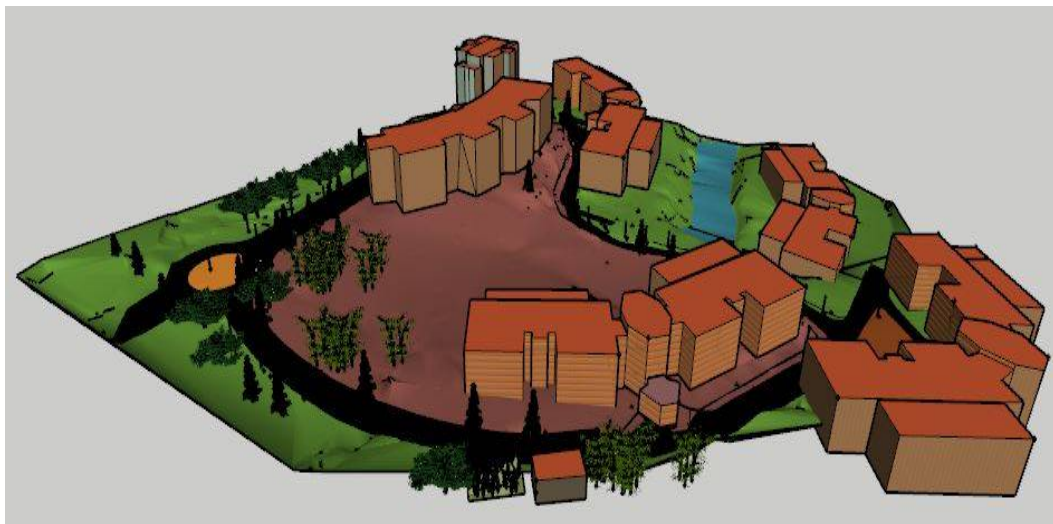


Figure 8(a). Perspective view of the study area



Figure 8 (b). Top view of the 3D model of the study area

4. DISCUSSION

With the increasing demand for digital 3D documentation of buildings and natural resources for sustainable planning and developmental activities, terrestrial laser scanning has proven to be unique and valuable technological solution for the same. With its rapidness and ease in collecting elevation information at unprecedented accuracy, LiDAR is slowly replacing traditional remote sensing technologies for creating digital documentation. However, the unstructured data which is stored as point cloud compared to raster images makes processing complex and challenging. The uniqueness in capturing the elevation directly with geometrical details at very high precision outweighs the processing challenges in LiDAR. In this study, a methodological framework was developed to create 3D models from LiDAR point cloud using terrestrial laser scanner. Further, elevation models and contour lines were generated using the point cloud. Some of the important results that emerge from this part of the study are summarized below.

- i. Terrestrial laser scanning has proved to be a reliable technology for producing 3D models and maps in a fast and efficient way. The technology has the potential to replace the existing survey methods for map creation. In this study, a total of 26 scans were taken to cover around 10.75 hectares. With each scan requiring around 15 minutes, the entire area was covered in five hours. The scans were able to generate roughly 307 million elevation points (X,Y,Z) of the study area within this period. This is close to impossible with traditional surveying and remote sensing technologies within the similar time.
- ii. The unstructured nature of the data makes processing of LiDAR data complex when compared to uniformly gridded raster images. Initial registration and geo-referencing is a time consuming process owing to identifying matching geometrical primitives such as planes, cylinders in neighboring scans. The effort gets reduced when planar structures such as buildings are present in the scene. However, when the scene is dominated with natural objects such as trees with complex geometrical structures, the task becomes complex. In this study, the entire area could be registered with 10.1 mm mean point error owing to the presence of building objects in the scene.
- iii. Point cloud labeling is an important stage in utilizing the point cloud for specified application. In this study, point-based labeling approach which utilizes the elevation from ground as local feature was used for classifying the points. The classified point cloud can be separated and used for creating other products such as DTM, 3D models, DSM etc. The accuracy of classification will affect the accuracy of products created using the classified LiDAR points.
- iv. The resultant DTM from the ground points are very precise. In this study, a very high resolution DTM was generated for the study area. Similarly, contour map with 5m interval was created which shows valleys, hills, and the steepness or gentleness of slopes in the IIST campus.
- v. 3D models offer realistic visualization and can act as a digital documentation of the study area. 3D campus models can assist prospective students to visualize and get a more realistic view of the campus. The models can be brought into GIS environment and can assist decision makers in making informed decisions.

5. CONCLUSION

In this study, terrestrial laser scanner was employed to create 3D model of the academic sections of IIST. A methodological framework has been developed to convert LiDAR point cloud to 3D models. The point clouds thus generated were classified into various land cover categories. In addition, elevation measurements made from TLS was used to generate 2D footprints and thus a 2D map of the campus in addition to digital elevation models and contour maps. Finally 3-D model for the IIST campus (buildings, road, trees, cars and lamp-post) has been developed using SketchUp software with accurate elevation details. The dimensions of the

3D reconstructed buildings have been validated with the dimension measurements using Laser Distometer. The 3D models created using 3D point cloud data are more precise when compare to the models created using traditional methods.

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MAPPING URBAN INDIA: COMPARING THE CARTOGRAPHIC GAZE OF PORTUGUESE, DUTCH, DANISH, FRENCH AND BRITISH COLONIZERS

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ABSTRACT

Cartographic representations of urban spaces in India varied among the five prominent European Colonizers, namely, Portuguese, Dutch, Danish, French and British. For them, mapping Indian urban spaces became a tool for claiming, organizing and appropriating the new colony. The colonizers' basic cartographic approach was focused on familiarization of the newly conquered region through navigative and accessibility maps; territorialization of place through mapping of enclosed urban spaces such as forts, town plan maps and promoting supremacy of their culture through language, pictographs and symbols. As India witnessed successive incursions of colonizers who were initially involved in trading activities like the Portuguese, Dutch, Danish and French colonizers and later Empire building activities by the British Colonizers, their Cartographic depiction of India also bore similar imprints on their maps. While basic mapping exercises pioneered by the Portuguese in the sixteenth century focused on depiction of detailed coastlines and relevant ports, detailing of colonized establishments such as forts, walls and churches, was superseded by the British cartographers' scientific approach through the Great Trigonometrical Survey and Cadastral mapping of local administrative areas. The paper aims to compare and critically analyze the varying cartographic gaze of depicting urban India by the successive streams of colonial powers.

KEYWORDS: Cartographic gaze, Colonial cartography, Colonial towns, Portuguese maps, Dutch maps, Danish maps, French maps, British maps

1. INTRODUCTION

Every map is someone's way of getting you to look at the world his or her way

(Lucy Fellowes, Smithsonian curator, quoted in Henrikson 1994 - taken from 'Thinking about Maps', Martin Dodge, Rob Kitchin, Khris Perkins and, 2011)

India has been mapped incessantly with the advent of European colonizers initially by the Portuguese, followed by the Dutch, Danish, French and English colonizers since the fifteenth century. The European Colonization process projected maps as a pre requisite tool to have possession before venturing into a foreign land. As a consequence, the project of mapping their colonies in India and using those maps for the many roles it played to serve the interests of the colonizers gained currency. As navigation along sea routes was the chief mode of transport for the European colonizers, they began with the mapping of coasts and ports of call along peninsular India with little or vague representation of the interior of the sub-continent. This was followed by the mapping of their defined, claimed and enterprising fortified territories creating their own urban world within those spaces. The cartographic gaze of their early maps portrayed a picturesque gaze of what the sailors would have seen while arriving towards those fortified town from the sea front. In others, the strategic location of the towns, the ordered features of defensive establishments, residential buildings, roads, churches, administrative and business houses, gardens, rural vistas, and dramatic vistas formed the elements of cartographic gaze. Their symbols of identity with emblems, flags, royalty seals, directional Cross Rose and religious symbols were another dimension of cartographic gaze which were categorized under 'map aesthetics' of those maps. Though the mapping exercises were constantly shaping, modifying and transforming the cartographic gaze from time to time by the colonizers, the 'hegemony of visualization' was often selective and unrealistic.

The initial involvement of the Portuguese, Dutch, Danish, French and English East India Company was trade and later Empire building activities were adopted by the British Colonizers. Their Cartographic depiction of India also bore similar imprints on their maps. The basic mapping exercises pioneered by the Portuguese focused on depiction of detailed coastlines and relevant ports, followed by detailing of colonized establishments such as forts, walls and churches. The British cartographers' scientific approach superseded the rest through the Great Trigonometrical Survey and Cadastral mapping of local administrative areas.

The intrinsic characteristics of maps shaped by the three basic elements - the map maker, the subject of mapping and the objective to be served by mapping, allows scope for enquiry into the distinct cartographic gaze of the five European Colonizers, namely, Portuguese, Dutch, Danish, French and British. Since, the colonial towns established by them were the pinnacles of political and commercial life in Colonial India, mapping Indian urban spaces became a tool for claiming, organizing and appropriating the new colony. The colonizers' basic cartographic approach was focused on familiarization of the newly conquered region through navigation and accessibility maps; territorialization of place through mapping of enclosed urban spaces such as forts, town plan maps and promoting supremacy of their culture through language, pictographs and symbols. The paper aims to compare and critically analyze the varying cartographic gaze of depicting urban India by the successive streams of colonial powers.

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2. THE BACKGROUND OF MAPPING IN INDIA

Mapping is a continuous process and it varies with time and space representing the uniqueness and dynamics of its character. According to Kitchin, Perkins and Dodge (2011), the historical cartographic investigations are not static and moribund exercise as cartographic theory and praxis have varied to a large extent in time and space. They asserted that 'Mapping is epistemological but also deeply ontological'. Anderson (1991) asserts that in new cartographic discourse, historical maps are designed to demonstrate the antiquity of specific, tightly bounded territorial units that had not previously existed. Thereby, mapping legitimized the claim to inherit ancient geo-bodies (Thongchai Winichakul, 1997). The historical cartography of India has evolved with successive colonial invasions and mapping projects with particular priorities, limitations, experiences and cultural biases of the map makers.

Subrahmanyam (2017) opines that though political, military and diplomatic contacts between the spaces denoted as Europe and India date back at least to the times of Alexander the Great (356 – 323 BC); but it was only after 1500 AD an intensification of these dealings were observed. With the rolling in of the second quarter of the century, the Portuguese began collecting and compiling literary knowledge of the natives in India. Joao de Barros (1496 – 1570) wrote 'Decades de Asia, and began the process of representing India to Europe by compiling objects and written materials. Allen (2017) traces out the word Coromondel on Portuguese maps which were later used by the Dutch, the French, Danes and British. The word has its roots in the word Chola mandalam, or the region of Chola Empire. Similar is the story behind the naming of Malabar with its origin in 'malai' or mountains. Portuguese were different from the English and the Dutch as their missionary impulse was more intense; and that also impacted in how India was viewed. The Dutch Company Employee Francisco Pelsaert prepared a Kronick and a Remonstrative (contemporary description) which was the key source for the Leiden based Geographer and Humanist Johannes de Laet for writing *De Imperio Magni Mogolis* in 1631. The Dutch missionary van Linchosten travelled to Goa between 1583 and 1589. It is during this time that he collected information and on his return to Amsterdam, prepared maps of South Asia (India in particular) and which were referred to by sailors for their subsequent voyages. Linchosten's maps stood out for his Compass Rose, rhumb lines and sailing ships on the Arabian Sea. His depiction of crypto zoological creatures like sea monsters routinely found space in his maps.

Apart from representation of motives on maps, certain technique like use of colour was judiciously applied on maps by Europeans cartographers. Monmonier (1996) terms colours are a source of attraction as well as distraction in a map. Colours provide visual appeal as well as offer contrasting categories separating features like the roads, geological formations and the likes¹. Apart from the sensory effect on the viewers, colour also transmits ideas of visual perceptions and the cultural preferences of the map maker. This fact throws light on the colonial mapping exercise as successive streams of colonial cartographic exercise have distinct colour preferences while mapping the new territories colonised by them. The element of exoticism that was innate to the European depiction of the Oriental lands, colours on maps abetted to perpetuate the vibrancy of the region to the armchair travelers in the Europe. Madan (2001) refers to the time period 1600 – 1800 AD, as the 'Age of Romance.' It was during this time period that the interest of the European cartographers shifted from mapping the coastline to focusing their attention to inland features. In the phase that followed, which began in the Nineteenth Century and continued till mid- Twentieth Century, which Madan terms as the 'Modern Era,' the science of map making became more sophisticated and perfect accurate topographical surveys took precedence with triangulation or Trigonometrical surveys².

With the successive entry of Portuguese, Dutch, Danish, French and English in India and the palimpsest of India's topography on paper began to take shape. Changing technologies helped in circulation of images and lithographs became popular. Maps began to be used as a political tool specifically with British maps by James Rennel in Bengal Atlas in 1781 followed by Colin Mackenzie in 1800 and Arrowsmith's mapping exercises in 1822. The British maps in the 1830s and 1840s projected India as an Imperial possession and a significant element of British Identity, at the same time underlying the need for a rational control of territory (Barrow, 2004:677-702). Thus, in 1858, British East India Company's power was transferred to the Parliament and the British crown for Empire Building. The many maps fundamentally reflected a Europeans' view of India obscuring the true picture of India. Edney has categorized British Cartographic gaze into two types – i) Scientific gaze – Topographical Survey, Trigonometrical Survey and Revenue Survey and ii) Picturesque gaze – Idealized representation of landscape and communities.

However, critics on British mapping process have given the view that the over ambitious approach was subjected to criticism as many aspects of India's societies and cultures remained beyond British experience (Edney, 1997) and their depiction of colonized society were subjected to biases and omissions (Kalpagam, 1995).

Indian Cartographic Studies have not paid enough attention to the variety of colonial cartographic initiatives made by different streams of colonizers. NATMO (2007) in its compilation of the Historical Atlas of India, briefly mention the Portuguese settlements and the aspiring British traders to establish contact with the Mughal Court during 1556 to 1605 AD. The maps have no demarcation of the regions occupied by colonial traders. The following period of 1605 to 1707 mentions emergence of British, Dutch and French having established factories in southern part of India. The map depicting the time period has no mention of the colonial trading posts. It is during the period of 1707 to 1766 AD, that the Atlas assigns space for British possessions on the map of India 1857 to 1859 onwards. In the map depicting Territorial and Administrative Changes from 1857 to 1904; clear demarcation of French and Portuguese colonies along with British colonies were shown. It is interesting to note that the Dutch, Danish territories did not find space in the maps as their colonial possessions were already on the decline by the late Nineteenth Century.

¹ Monmonier (1996) *How to Lie with Maps*, The University of Chicago Press, Chicago.

² Madan P L (2001) *Indian Cartography*, Mahohar Publishers and Distributors, Delhi.

3. DATABASE AND METHODOLOGY

The cartographic gaze of the European Colonizers with regard to urban spaces in India have been critically analyzed by studying the maps prepared by them and as case studies, two colonial towns that were mapped by the respective colonizers in India have been selected for this paper. The attempt to analyze the cartographic gaze is an attempt to ponder upon the two questions here, i.e., Where does the cartographer wants the viewer to focus? And what is the purpose or objective of mapping?

The following characteristic features in the colonial map have been selected to analyze the emphasis of the cartographer providing the viewer with the information it wants to portray through the maps – i) Foreground features, ii) Background features, iii) Fortified settlements, iv) Natural Landscape features, v) Territory depiction, vi) Transport Accessibility, vii) Trade related depiction, viii) Rural vistas, ix) Dramatic vistas, x) Emphasis on Colors, xi) Cross Rose, Scale, Legends, emblems, flags, seals and symbols.

The following table shows the colonizers and the list of towns whose maps have been selected for analysis,

No.	Colonizers	Towns	Period of Rule
1	Portuguese	Calicut	1498 – 1663
		Goa	1510 – 1961
2	Dutch	Hugly-Chinsura	1650 – 1759
		Cochin	1663 – 1773
3	Danish	Tranquebar	1620 – 1845
		Serampore	1755 – 1845
4	French	Pondicherry	1674 – 1954
		Mahe	1720 – 1954
5	British	Calcutta	1690 – 1947
		Delhi	1803 – 1947

Table 1. Details of Colonizers

The maps of the selected towns have been critically examined to study the cartographic gaze of the respective colonizers in power during the time period mentioned above. The maps have been obtained from a wide variety of sources ranging from online archival library websites and national museum websites. The advantage of these sources is that many of these provide a close up view of the maps. The others are sourced from a compendium of maps of India termed ‘Mapping India’ authored by M. Lahiri.

4. CARTOGRAPHIC ENDEAVOURS OF SUCCESSIVE STREAMS OF COLONIAL RULERS

In this section of the paper, maps constructed by each European colonizers have been presented. The Colonial rulers as well as the towns they laid control on have been organised chronologically.

4.1 Portuguese : Casa da India (1434 – 1883); Portuguese East India Company (1628 – 1633)

The towns of Calicut and Goa have been selected for analysing the Portuguese mapping endeavours.

4.1.1 Calicut

The 1572 map of Calicut, titled ‘Calechut Celeberrimum Indiae Emporium’ is composed of a coastal settlement of prominence. The spectacular ‘bird’s eye view of Calicut was a treat to the armchair traveler which portrayed the town of Calicut where the Portuguese had first set foot in their quest to arrive at India (Lahiri, 2012) . The map is a depiction of what the sailors would have seen while arriving towards the town from the sea front.

The foreground of the map depicts the advantages of natural harbor facilitating the accessibility of Portuguese ships to Calicut. Portuguese visitors seen approaching the fortified Portuguese settlements in small boat while displays the feasibility and ease of reaching, the presence of other varieties of native boats in picture depicts the genial atmosphere of pursuing trade. The Portuguese settlements appear as red thatched roofed houses, forts and watchtowers. A small watchtower or fortress protects the city from invaders approaching through the sea route. The map portrays a vibrant coastal native community as their everyday lives are depicted in snapshots. The women head loader with her little child carrying out their daily chores, as well as a ruler being transported on a palanquin portrays a glimpse of their social characteristics while the fishermen with nets drawing fish from the ocean, workers constructing and repairing boats, Mahauts (elephant riders cum trainers) riding elephants used in carrying loads of wood from jungle depicts the natural resources and economic characteristics of the coastal communities and the image of soldiers marching on the land creates an image of the prosperity of the land.

The coast and beyond shows swaying palm trees, and hill ranges romanticizes the tropical landscape. The presence of a river and another small stream flowing from the hills add up to the visual treat. These rivers and streams flow from the Western Ghats and drain into the Arabian Sea and the coast line is dotted with sailing ships and boats. Natural colors of green, brown and red have been used in the map. Bold brown lines define the land and sea front. The map is devoid of any Cross Rose, Scale, Legends, emblems, flags, seals and symbols.



Map 1. A panorama of Calicut, 1572

(Source: A panorama of Calicut from the atlas *Civitates orbis terrarum*, 1572)
https://img.theculturetrip.com/840x440/smart/wp-content/uploads/2018/01/0-featured_image_-1.jpg)

4.1.2. Goa

The Sixteenth Century map engraved by J. Hugonius Linschoten in the year 1595 shows the Island and metropolitan city of Goa, which was the capital of the Portuguese East India Company. Jan Huyghen Van Linschoten was a Dutch merchant, trader and historian. He also served as the Portuguese viceroy to Goa from 1583 to 1588. His personal knowledge of Goa was later added on to these base maps and was circulated among the Dutch, French and English too. Later versions of detailed maps of Goa clearly reveal the base map to have been compiled from the original maps.

Goa was attacked by the Portuguese and taken over by Admiral Alfonso de Albuquerque from Adil Shah of Bijapur. Goa was turned into a flourishing entrepot; though in the later stages, repetitive bouts of cholera epidemics and ruthless proselytisation of natives to Christianity wrecked havoc to the port town which led to feeling of the native population from the town (Lahiri, 2012).

The map is a perspective diagram, positions itself on an elevation in terms of an island with reference to the rivers and seas encompassing it. Representations of forts, palaces, gardens, monuments, prisons and harbour found space on the map. The Foreground of the map portrays the navigational advantage showing fleet of ship carrying Portuguese flags endorsed with a red bordered white 'Cross of Christ' in the centre, entering the waters of the city of Goa. They could be reached directly to the grand bazaar or market along the banks of the waterways. The map depicts the defensible island site of Goa with harbor facilities of big ships. Background: surrounded by hilly terrain.

The central theme is focused on the Portuguese city of Goa with details of layout depicting the Viceroy's territory, row of settlement houses encircling spacious gardens and groves, grand bazaars, well defined streets named after Portuguese colonialists, religious establishments named after saints, pillories showing the nature of disciplining acts executed by the Portuguese. The Portuguese territorial security of Goa is emphasized with natural boundaries marked with bold borders. The main Fort is facing the sea at entry points and watch towers erected at the corners. The urban map also depicts the religious fundamentalist nature of the Portuguese as symbols of Cross on top of settlement buildings and at all sides of the territory, asserting cartographically their possession of territory.

The Landscape detailing portrays the potential availability of natural resources showing the diverse nature of crops in agricultural field, availability of palm trees and forests for timber, and lagoons with swans, adding to the dramatic vistas to the map. The image of domesticated elephants, boat construction activities along the shores shows the vibrant nature of the native community and their everyday activities. Shades of green, red, yellow and blue has been used to depict a natural view of the landscape. Landscape is in shades of brown and green and the land is bordered with blue. The bold blue border lines have been used in this map to define the land territory of Portuguese possession.

Typical Portuguese symbology of Portuguese coat of arms, shields and Royal crowns, Cardinal hat on top of the Portuguese arms has been used in the map. The Compass Rose figure with head arrow, with the symbol of 'lily's flower' to represent north that is used for depicting orientation of geographical objects on the map in relation to cardinal and intermediate directions on maps. The sixteen direction Compass Rose illustrates another significant aspect - a coalesce of geographical and religious representation with East marked by the sign of Cross, symbolically the direction towards Jerusalem, the Christian holy city. The other pictographic decoration has added to the map aesthetics of the Portuguese map of Goa.



Map 2. Island and city of Goa, capital of the Portuguese East Indies, 1595

(Source: Cartography, India, 16th century. Island and city of Goa, capital of the Portuguese East Indies. Engraving by J. Hugonius Linschoten, 1595 . Lisbon, Museu De Marinha (Navy Museum), <https://www.agefotostock.com/age/en/Stock-Images/Rights-Managed/DAE-11194876>)

4.2 Dutch India (1605 – 1825)

The towns of Hughli-Chinsurah and Cochin have been selected for analyzing the Dutch mapping endeavours.

4.2.1. Hughli-Chinsurah

The map of Hughli was prepared by the French author and novelist Aantonio Francoise Pervost Historie Generale Voyages Atlas 1721. Hughli was already an established trading centre. The viewer is seeing the European settlement while travelling by ship on the river. The Portuguese arrived in Hughli in 1537 and the town at Hughli – Chinsurah, was founded in 1579. In 1625, Dutch Vereenigde Oosrendische Company Established a ‘loge’ or a small settlement at Chinsurah, south of Portuguese Hugli. They received their trading rights from the Mughals. In 1653, the Dutch founded a factory at Chinsurah, and Van den Broucke became its first governor. The Dutch put their efforts on building up Chinsurah into a pleasant and spacious town with gardens and well constructed roads. In 1774, they made further efforts to fortify the town.

The foreground of the map shows a variety of Dutch ship carrying Dutch Flag with Symbol of Dutch Republic Lion and boats approaching the Dutch trading and factory town of Hughli-Chinsura. The map depicts the bounded nature of settlement, gardens, groves and fields. The map is alphabetically coded with an index which provided the explanations and helps in ordering space representation by eliminating jumbles and simplifying harmonious viewing. The explanations of the index depicts the location guide relating to Dutch industrial, administrative and accommodation units with bounded gardens setting a favorable atmosphere for undertaking and pursuing the trading operation. The features of the landscape portray order and harmony making a Picturesque gaze.

The map is in natural colors and bold red lines in the map define the Dutch territory - the boundary of Dutch settlements, gardens and agricultural fields. The map has a scale showing the introduction of quantification used by the Dutch cartographers. The Cross Rose is similar to those used by the Portuguese cartographers in their maps of Goa, except that it shows eight directions in comparison to their sixteen directions Compass Rose. The decoration of the Legend box adds to the map aesthetics.



Map 3. Plan de la Loge Hollandoise d'Ougly A. 1721

(Source: http://www.columbia.edu/itc/mealac/pritchett/00routesdata/1600_1699/calcutta/chinsura/plan1726.jpg)

4.2.2. Cochin

The Dutch displaced the Portuguese from Cochin in 1663, demolished the old city laid by the Portuguese and built a new one. The new town is depicted in the map of Cochin presented below dates back to 1665 AD.



Map 4. "De stad Couchijn" Plattegrond in opstand van Couchin / Cochin, India 1665

(Source: <http://www.gahetna.nl/collectie/afbeeldingen/kaartencollectie/zoeken/weergave/detail/q/id/af87c38e-d0b4-102d-bcf8-003048976d84>)

The map is composed of a coastal setting with a large neatly arranged fortified settlement and native villages with agricultural fields and forests. Ships stationed along the coast depict the natural harbor facility of the town. The central theme of the map is the tightly bounded Dutch occupied territory of Cochin. The pattern of settlement inside the fort is quite distinct with gardens encircled by row of houses and religious buildings and watch towers. The pattern is quite similar to the Portuguese settlement of Goa, reflecting the Portuguese influence of town planning in the past. An outer boundary wall beyond the fort wall signifies the double layer defensive protection of the Dutch communities.

A closer scrutiny into the map reveals organised levels of planning that went into the spatial organisation of Cochin by the Dutch colonisers. The extreme western parts of the map shows area reserved for Coofers or Dutch men occupying very high ranks. The South Central part was designated for 'Werfs' or shipyards, which were christened with names bearing association with the

metropolis. A few of the names were, Bolwerck Gelderlandt, BolBolwerk Groningen and many mre. These names on the colony, created a home away from the homeland and the map exuded familiarity to the Dutch who migrated to the colony for trade.

The native rural communities residing outside the fort represents the presence of local communities living alongside the acquired Dutch territory. The native settlements with distinct houses different in pattern from the settlements inside the fort are set in a natural setting of palm trees and forests in its vicinity. The details of the island in the northern portion have been depicted in faded tone color. Colonial dominance in terms of religious establishments is shown in the big and small islands.

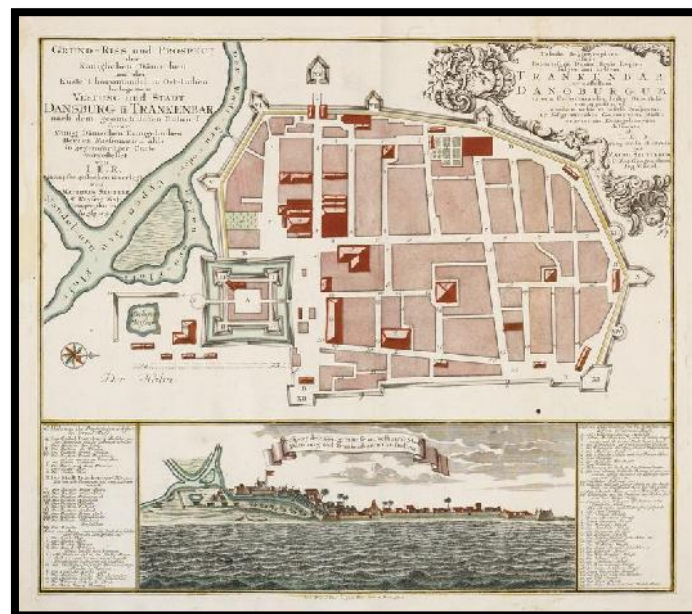
Natural shades used with prominence of green shows the rich flora of the coastal landscape providing a visual treat to the viewer. An eight directional Cross Rose with symbol of 'lily's flower' representing north and Christian Cross symbol representing east direction. The map is devoid of any Scale, Legends, emblems or decoration.

4.3 Danish India (1620 – 1869)

The towns of Tranquebar and Serampore have been selected for analysing the Danish mapping endeavours.

4.3.1. Tanquebar

Tranquebar is a small settlement in the Carnatic coast, north of Karaikkal. The Fort Dansberg was set up at Tranquebar by the Danes in 1620. It was sold to the British in 1845 as the Danes incurred huge losses in their trading company. The Danes took cognizance of the fact that they were unable to maintain safe trading posts in India. The 1730 map of Tranquebar by cartographer Matthias Seutter shows the layout of the Danish township, and garrison prominently marked out through fortification of the town.



Map 5. Map of Tranquebar by Matthias Seutter, 1730

(Source: <https://en.natmus.dk/historical-knowledge/historical-knowledge-the-world/asia/india/tranquebar/collections-in-the-national-museum-of-denmark/maps-and-sketches-from-tranquebar-c-1670-1845/>)

The map is a composite picture of two sections. The bottom section shows the cityscape of the fortified Danish territory of Tranquebar with Danish flag flying high and swaying palm trees along the coast presented as a picture as seen by a sailor from a distance approaching the land. The Beach Masters Office, Flag Staff house and store houses were marked well on the map, denoting the fact that any approaching ship could be seen from the fortified zone of the township. Boats are seen lying idle on the sand banks along the fort. A wide banner on the skyline shows the territory being projected as a property labeled by Danish ownership.

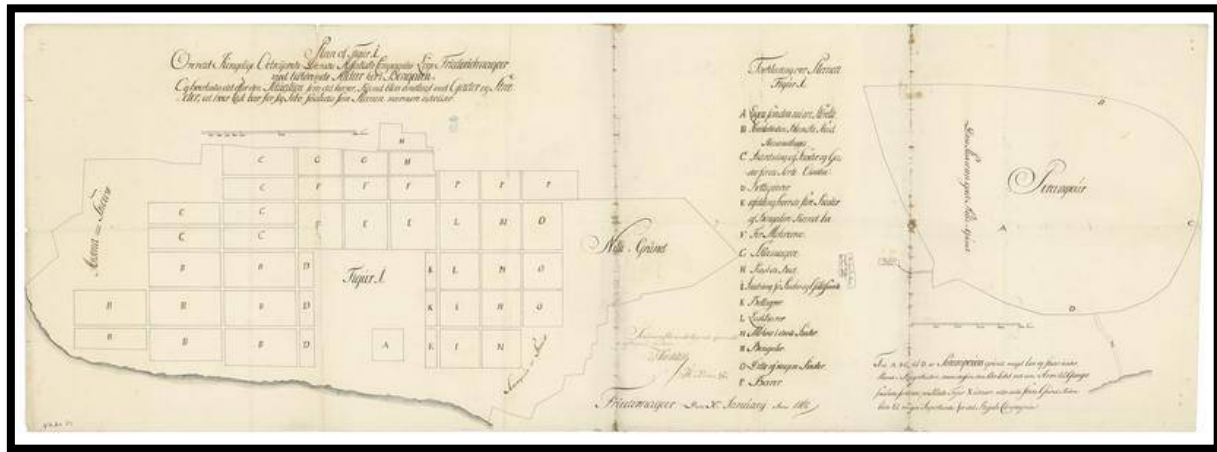
The other half of the map shows a cross sectional detail layout plan of the Dansburg Fort. It shows the Ground Rift and Prospect of the Royal Danish on the coast of Coromandel in East India. The layout depicts a neat urban plan of ordering of houses based on defensive functions, administrative, hierarchical residential living, layout of open spaces and gardens. The river drainage system provides a defensive advantage as a channel is seen connected to a moat circled around the fort. The fifteen watch towers, marked in Roman numbers, could be seen all along the four corners of the Dansburg fort and eleven along the boundary walls of the fortified settlement shows a system of order and discipline in town planning and defense management.

The map is painted in natural colors. An eight directional Cross Rose with symbol of 'lily's flower' representing north direction is shown. The map is devoid of any Scale. The faces of angles used in map decoration signify the evangelic nature of the Danish colonizers.

4.3.2. Serampore

The map dated 1762, is the earliest existing map of the Danish town of Serampore. An ideal plan for the development of Frederiksnagore indicates how the place was planned with streets and different zones. The location of the Danish administrative quarter and future European quarters has been depicted in the layout map.

The history of Serampore dates back to 1755 when in October 1755, Frederiksnagore was established at Serampore to the south of Chandannagore on the Hugli river. This location was opposite to the British settlement of Barrackpore. Fredriksnagore was a well laid out city with impressive structures and manicured gardens.



Map 6. Serampore, 1762

(Source: The earliest existing plan of Serampore from 1762 (© Her Majesty the Queen's Reference Library, Copenhagen), (<https://en.natmus.dk/historical-knowledge/research/research-projects/the-serampore-initiative/historical-background>)

The cartography undertaken for Serampore was conducted with great detail with geometric boxes showing the segregated quarters of residence, business and religious buildings. The road network was meticulously depicted and important landmarks such as the Danish Church, Roman Church, Baptist Church, Mission premises including its college, Printing Office and paper engine was marked on the map. European, Portuguese, Mussalman and Baptist burial grounds too were specified on the map. Sociologically, the map was one of its kind making contribution to spatial segregation on the basis of delineation of residential quarters of different communities of Indians and Europeans. The map has a graphical scale.

4.4 French India (1668 – 1954)

The towns of Pondicherry and Mahe have been selected for analysing the French mapping endeavours.

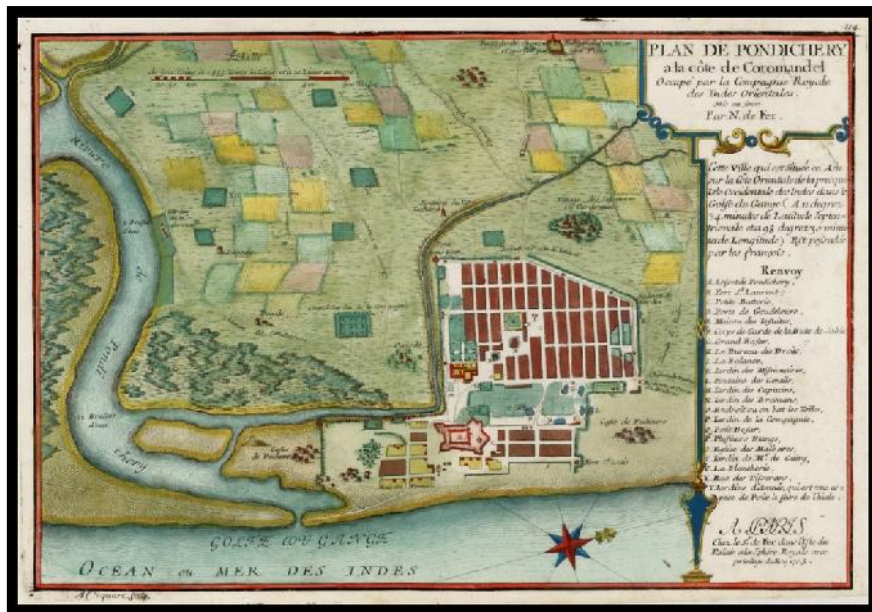
4.4.1. Pondicherry

The 1705 map of 'Plan de Pondicherry' shows the French ruled territory of Pondicherry. It remained the cornerstone of French activities till 1954. Pondicherry was built on the land which was purchased from the Sultan of Bijapur by the French trading company. In 1791, the British razed and destroyed Fort St. Louis, and completely plundered the precincts. The weavers, bleachery, dyers painters and other related to textile industry were shifted out of Pondicherry after the British mayhem took place.

The foreground of the map of 1705 depicts the location of the French territory of Pondicherry. Important landmarks such as the Fort of Pondicherry, the Fort of St Laurent, houses of navy officers and administrative and law offices, churches, bazaars, fountains, Company's office, gardens, homes of well known gentlemen found space in the map. The map depicts the fortified city as well as the rectilinear road network. The plan of the fort also clearly shows five bastions.

The map portrays the adjoining country side vistas of villages with trees, Hindu temples, agricultural fields growing a variety of crops, forest area, and river of Pondicherry meeting the Indian Ocean. Roads that led out of the city showed the destinations like Veldour (Vellore) to the west, Goudeloure (Cuddalore to the east; Madras (Chennai) to the north.

The map is painted in natural colors. An eight directional Cross Rose with symbol of 'lily's flower' representing north direction is shown. The map has a Scale showing the scientific approach of French cartography. The title and legend boxes are ordained with decorative borders which increases the map aesthetics of the map.



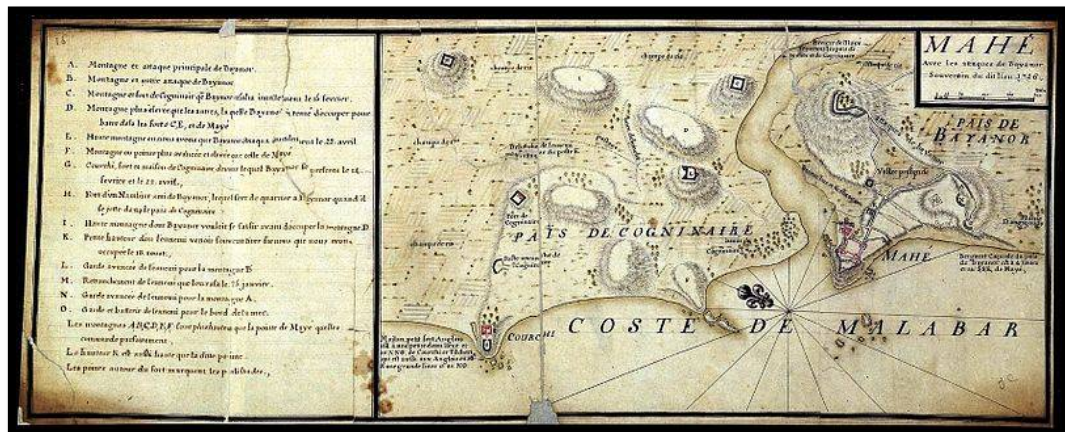
Map 7. Plan de Pondichery, 1705

(Source: <https://www.raremaps.com/gallery/detail/31394/plan-de-pondichery-a-la-cot-de-coromandel-occupe-par-la-comp-de-fer>)

As was observed in maps prepared by the European colonial traders, the French cartography too showed caste groups in their segregated quarters housed in the Black city, of whom the largest community was of the weavers.

4.4.2. Mahe

The 1726 map shows the French territory of Mahe, a small town on Malabar coast on the mouth of River Mahe. The French named River Ramatally to Mahem and was an important spice trading point especially for pepper and cardamom.



Map 8. Plan de Mahe avec les attaques de Bayanor souverain du lieu, 1726

(Source: Archives de l'outre-mer : <http://anom.archivesnationales.culture.gouv.fr/sdx/ulyse/>)

The map is composed of the location of the fort and a larger view of the country side view with flat topped hilly terrain and low lying valleys cultivated with rice fields. The foreground of the map shows the sea front location of a Fort at the entrance of the town which was protected by rocks and boulders. Apart from the primacy of the fort, several military related information too can be gathered from the map. The map also shows the position vis a vis the Arabian Sea, the river coming through the Ghats leading to Fort St George to the north of the river which also was the limit of the French territory. Beyond that point, the British domain may be seen.

Detailing of physical features especially elevation is shown with hachures which is unique when compared to previous colonial techniques of cartography. The physiographic features were best represented by the French. The geometrical description of rice fields in the lowland valleys. All these show the improvement of measuring techniques and height description. The map is painted in natural colors with the predominance of yellow shade. The circular Cross Rose is replaced by only the symbol of 'lily's flower' representing north direction. The map has a Scale showing the scientific approach of French cartography.

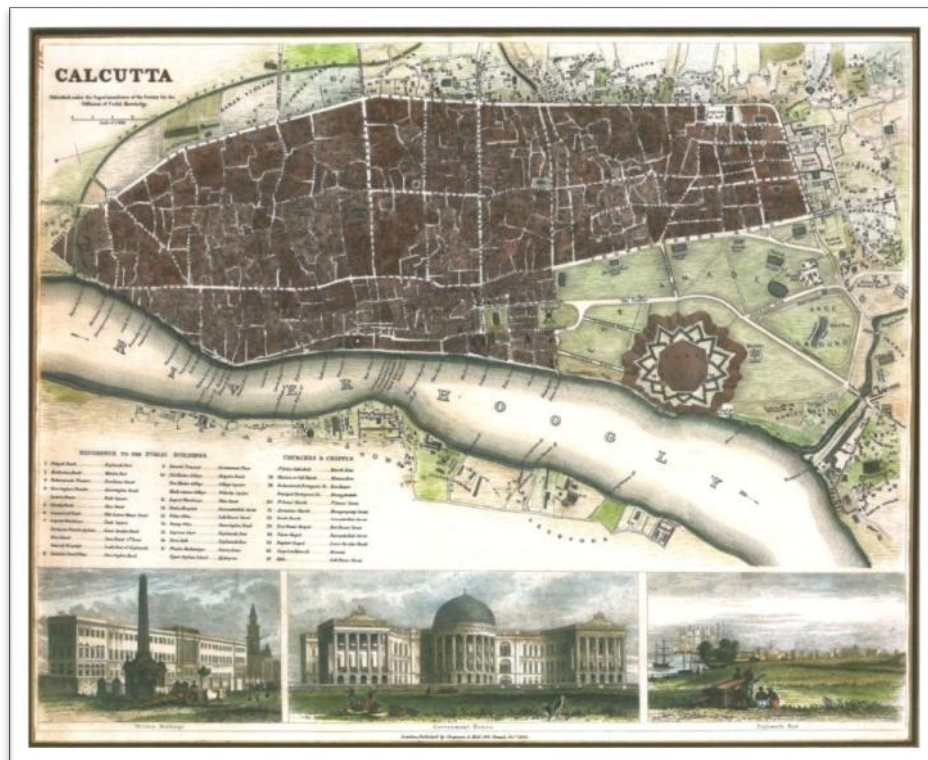
4.5 British East India Company (1612 – 1757); Company Rule (1757 – 1858); British Raj (1858 – 1947)

The towns of Calcutta and Delhi have been selected for analysing the British mapping endeavours.

4.5.1. Calcutta

The 1842 map of Calcutta by British cartographer shows the Colonial town of Calcutta. By now there has been a paradigm shift in European approach of map making and Empire building of India. The shift was towards quantification and universalization of depicting the location of a point in terms of latitudes and longitudes. The cartographic gaze of the British shifted from trade related activities towards governing and controlling India. The urban spaces gained prominence as they became the centers of administration, military activities, trading and residential stations over viewing the adjoining regions of British control. Apart from the coastal towns, inland towns became centers of British power. Calcutta was established as the centre of British Raj in India.

The map of Calcutta in 1842, shows the closely built up city area adjoining the Hughly river. The Fort William is surrounded by open spaces segregating the British and native urban spaces. The details of road network and with British road names, ghats, public buildings and churches shown on the town map depict a British influence of domination and control.



Map 9. Calcutta, 1842

(Source: Calcutta, November 1842, Atlas published under the Sperintendence of Society for the Diffusion of Unified Knowledge, London)

The Circular Road or the main thoroughfare that ran through northern and southern parts of the city has been clearly plotted. Colonial grand structures constructed in Calcutta like the Victoria Memorial, St Paul's Church (which was nearing completion), the Governor's house, the Ochterlony Monument (presently known as the Shahid Minar) and Esplanade Row are also shown prominently in the map. The cartographer included vignettes from the cityscapes to very subtly create mental maps of the newly constructed colonial capital in the minds of the potential viewers from the metropole.

The illustrations that appear on the map are ones depicting the urban life emerging within the milieu of the exotic landscape. The cranes and men relaxing with the backdrop of the Governor house as well as the Writer's Building and the Ochterlony Monument. The palanquins bearers resting by Esplanade row along with views of the banks of the Hughly river also evokes similar emotions.

The Cross Rose used by the Portuguese, Dutch, Danish, and French has been fully replaced by a north line as the depiction of geographical direction shifted from astronomical and religious norms to a more universal grid pattern of latitudes and longitudes with Greenwich as the main reference point. The map has a scale.

4.5.2. Delhi

Stanford's Delhi map of 1857 and its Environment is a thoughtful construction to give the viewer a comprehensive location in terms of physical features that exist around Delhi.



Map 10. Delhi and Its Environs Surveyors of east India Company, 1857
(Source: Stanford's Map of Delhi, 1857, Edward Stanford, London.)

The map depicts the ridge, the river and the positioning of the main roads, city forts and position of the British Troupes in the light of the Revolt of 1857. The historical city of Indraprasth has been marked incorrectly vis-a-vis the location of Delhi. The Plan of the British Position in Delhi 1857 was prepared by the Military Department of the Government of India based on records collected by the military. The scale of the map was Four Inches to One Mile; and it was published by the Survey of India Office, Calcutta in 1904. This map was perhaps the most comprehensive map of the old city produced at the time recording not only the road network but also the canal routes that intersected the city.

The Najafgarh and Jeel Canals can be seen on the map as water channels passing Chandni Chowk. The Western Jumna Canal too was plotted on the map which traversed the regions around Begum Bagh. The other prominent fortified feature of the map was the depiction of the Red Fort. The four direction north line has been used in the map to show the direction. The map has a scale.

5. DISCUSSIONS ON SIMILARITIES AND DIFFERENCES IN URBAN MAPPING TECHNIQUES OF COLONIAL RULERS

Cartographic Gaze of Urban spaces by the Portuguese, Dutch, Danish and French was mainly from sea (outside) to land (inside) view with a focus on navigational accessibility, fortified territory creating their own world set in fascinating Oriental environment settings, conducive atmosphere for trade operations and projection of a missionary approach. The maps portrayed the urban spaces located along the peninsular coasts and the banks along the Hugly river. The cartographic gaze of the British colonizers was centered around the East India Company forts, military cantonments, esplanade as in case of Calcutta, administrative buildings, public buildings, commercial buildings, religious buildings and recreational centres. Their maps of Calcutta (1842) and Delhi (1857) gave equal emphasis in mapping native old settlements and rural spaces adjoining the British establishments. Subsequent mapping exercise of these two towns showed their expansionist and Empire building legacy such as the maps Constable's Hand Atlas of India, 1893 and the Imperial Gazetteer of India Atlas 1931. Similarly, the 1910 map of Delhi showed the old existing city in black color and newly constructed Imperial city in red color.

The Cartographic gaze of the five European colonizers had some similarities as well as some differences. The garden centered settlement pattern, wide roads, churches, watch towers; active ship building works with the use of elephants formed the distinct characteristics of Portuguese cartographic gaze. Symmetrical and ordered settlement patterns with fine architectural details of houses inside the forts and harmonious landscape features in the map were the characteristics of the Dutch cartographic gaze. The depiction of Picturesque gaze or post card picture has gradually shifted towards more schematic forms in Danish cartographic gaze with organized layout plans and laying the foundation of segregated quarters for European and native population. The physiographic depiction of elevation of topography with hachures and depiction of valleys where rice cultivation is most dominant have been distinctly introduced by the French cartographic gaze. The British cartographic gaze was more intrinsic, scientific, objective and was projected as a commodity of possession and imposition of British Identity.

The angle of view of urban mapping has shifted from a low angle view with landscape and horizon detailing to a more vertical view with details of built up and planned zones, giving information related to area, position, association and direction information. The maps also promoted the supremacy of their culture through language, pictographs and symbols. The textual descriptions on the maps were in their own native languages. The maps had their own nationalistic elements such as seals and emblems. The Compass Rose figure with head arrow being depicted with the symbol of 'lily's flower' (Religious meanings and nobility) north have been used for depicting orientation of geographical objects on the map in relation to cardinal and intermediate directions by Portuguese, Dutch,

Danish, French and English colonizers. East was marked by the sign of Cross, symbolically the direction towards Jerusalem, the Christian holy city in the Compass Rose on the town maps by Portuguese and Dutch colonizers. Decoration to increase map aesthetics. Compass Roses were replaced by north line during nineteenth century British maps. There has been a subsequent reduction in decoration relating to map aesthetics

6. SUMMARY OF CONCLUSIONS

While the cartographic gaze of the Portuguese, Dutch, Danish and French were mainly picturesque, imaginative, and qualitative and focused in nature, the British gaze was more scientific, ordered, objective and political. The maps by the Portuguese, Dutch, Danish and French were concerned with the establishment and protection of trade routes (with ships and fortified settlements) as trade was their only motive in India and were little involved with the conquest of territories. The contrary was the British mapping approach which was associated with expansionist ambitions of Empire Building. Their depictions were associated with supremacy, domination and subordination of the Indian communities.

In an attempt to compare the colonial cartographic gaze of the five European colonizers, the paper brings forth a narrative of the change and continuity of historical cartography with India set as a stage of performance.

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MAPPING AND ASSESSMENT OF WASTELAND CHANGES USING MULTI TEMPORAL SATELLITE DATA IN ANDHRA PRADESH

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ABSTRACT

Information on wastelands in the form of maps and statistical data is very vital for spatial planning, management and utilization of land sustainably. The aim of this study is to map and analyze the changes in wastelands on 1:50,000 that occurred between 2008-09 and 2015-16 in Andhra Pradesh. The geometrically corrected Resourcesat-2 LISS III multi-temporal satellite data corresponding to *kharif*, *rabi* and *zaid* cropping seasons were used for deriving information on wastelands. The visual image interpretation techniques have been used for delineation of wasteland categories through on-screen heads-up digitization in GIS environment. Cross-tabulation has been used for summarising the category wise wasteland changes during 2008-09 and 2015-16. The result shows that, an area of 23,946 sq. km corresponding to 14.69 % of the geographical area of the State has been estimated to be under wastelands during 2015-16, compared to 24,790 sq. km (15.21%) in 2008-09. There has been a reduction in the spatial extent of wastelands to the tune of 0.53 % (844 sq. km) with reference to the year 2008-09. This may be due to the implementation of developmental programmes in the State. Mapping and assessment of wasteland changes, would help to plan developmental activities such as major schemes and used for other requirements of the State.

KEYWORDS: Andhra Pradesh, Change Detection, GIS, Mapping, Remote Sensing, Wastelands

1. INTRODUCTION

The ever-growing population has created an excessive demand for food, fodder, fuel, and fiber. This has resulted in the adoption of scientific measures for increasing land productivity and bringing more areas under productive lands. At the same time, land degradation due to desertification, soil salinity, water logging, floods, droughts, excessive soil erosion, and unscientific agricultural practices has resulted in the creation of vast stretches of wastelands. Wasteland means degraded land which can be brought under vegetative cover with reasonable efforts, and which is currently under-utilized or land which is deteriorating due to lack of appropriate water and soil management or on account of natural causes (NRSA, 2007). Information on geographical location, aerial extent and spatial distribution of wastelands is essential for their effective management and sustainable development (Gautam and Narayan, 1988). Information on the rate and kind of changes in the use of land resources is essential for proper planning, management and to standardize the use of such resources (Gautam and Narayanan, 1983). Knowledge about existing wastelands and its trend of change provides a better understanding of land utilization aspects and plays a vital role in development planning. Spatially explicit temporal data helps in the inventorying, mapping and monitoring spatiotemporal processes and changes (Babu et al., 2014). Change detection is an important process in monitoring and managing natural resources. Geographic Information Systems (GIS) and Remote Sensing (RS) techniques provide effective tools for analyzing the wasteland changes of the region as well as for monitoring, mapping, and management of natural resources (Sreenivasulu and Udaya Bhaskar, 2010) and predict the future scenario using models like cellular automata (Ramana et al., 2012).

Rawat et al., (2018) demonstrated the potential of earth observation data and spatial approach to delineate and manage aeolian sand-affected wasteland in highly productive lands of Haryana State and the study illustrates how to classify aeolian sand-affected wasteland from satellite imagery. Manoj Kumar and Sunil Kumar (2017) have mapped wasteland categories systematically and explained wasteland development plan in Jind district of Haryana State using IRS-IC/ID LISS-III digital data along with on-screen visual interpretation techniques. Arya et al., (2015) have studied change detection of wastelands of Jhajjar District, Haryana using three seasons satellite data for the years 2005-06 and 2008-09. A similar study was done by Arya et al., (2014) for the arid zone of Haryana and demonstrated the wasteland change analysis by using multi-temporal satellite data. Change detection in Wastelands using Remote Sensing and GIS Techniques for SPS Nellore District, Andhra Pradesh was studied by Sastry et al., (2011). Nathawat et al., (2010) described the utility of temporal satellite data (IRS-P6 LISS-III) and high resolution satellite data (IRS-P6 LISS-IV) for monitoring & analysis of wastelands and its dynamics for Bhagwanpur mandal in Vaishali district of Bihar State. Keeping the above in view, the present work has been undertaken to prepare the multi-date wasteland maps from Remote Sensing data and to monitor the changes in various wasteland categories using GIS techniques.

2. MATERIALS AND METHODS

2.1 Objectives

The main objective of the present study is to map the spatial extent and distribution of wastelands of two time periods and to assess the wasteland change in the landscape of State of Andhra Pradesh during the period 2008-09 and 2015-16 by using IRS-R2-LISS-III digital data for the three seasons i.e., *Kharif*, *Rabi*, and *Zaid*.

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2.2 Study Area

The study area comprises of State of Andhra Pradesh, situated on the south-eastern coast of the country and lies between 12° 33' - 19° 09' of North latitude and 76° 38' - 84° 42' of East Longitude with a geographical area of 1,62,970 sq. km. It is located east of Karnataka, south of Telangana, south west of Odisha, and north of Tamil Nadu. Andhra Pradesh ranks as the 8th largest State in the country. Situated in a tropical region, the state has the 2nd longest coastline in the country with a length of 974 km. The state comprises two regions i.e., Kosta and Rayalaseema and it is divided into 13 districts. These 13 districts are further divided into 50 revenue divisions. The 50 revenue divisions are in turn divided into 674 mandals. There are 110 urban local bodies and 12,918 gram panchayats in the State.

2.3 Data Used

For monitoring the changes in wastelands, multi date IRS-R2-LISS-III data has been used in conjunction with the Survey of India (SOI) topographical maps on 1:50,000 scale. The utilization of three season's satellite data of 2008-09 has enabled accurate delineation of wasteland categories. This database on wastelands is used as a reference for monitoring changes in the spatial extent of wastelands in 2015-16.

2.4 Methodology

In the present wasteland change analysis mapping, visual interpretation based on image characteristics and knowledge of the study area was carried out to delineate wasteland areas and discern the extent of changes occurred in the study area. Since the State receives rainfall during Southwest and Northeast monsoon seasons, intermixing of different wasteland classes occur for this period due to the growth of hydrophytic grasses and weeds. To overcome this, the three season's images were used for delineation of different wasteland classes, where separation among land use /land cover classes is more. This helped in better identification and mapping of wastelands. The methodology essentially includes geo-rectification of temporal satellite data of *Kharif*, *Rabi* and *Zaid* seasons of the study area. The visual image interpretation techniques have been used for delineation of wasteland categories through on-screen heads-up digitization in GIS environment. Cross-tabulation has been used for summarising the category wise wasteland changes. Ground truth verification has been performed by using the mobile app, which is provided by NRSC to achieve better accuracy. The methodology adopted for the updation and identification of changes during 2008-09 and 2015-16 is presented in the form of a flowchart in Figure -1.

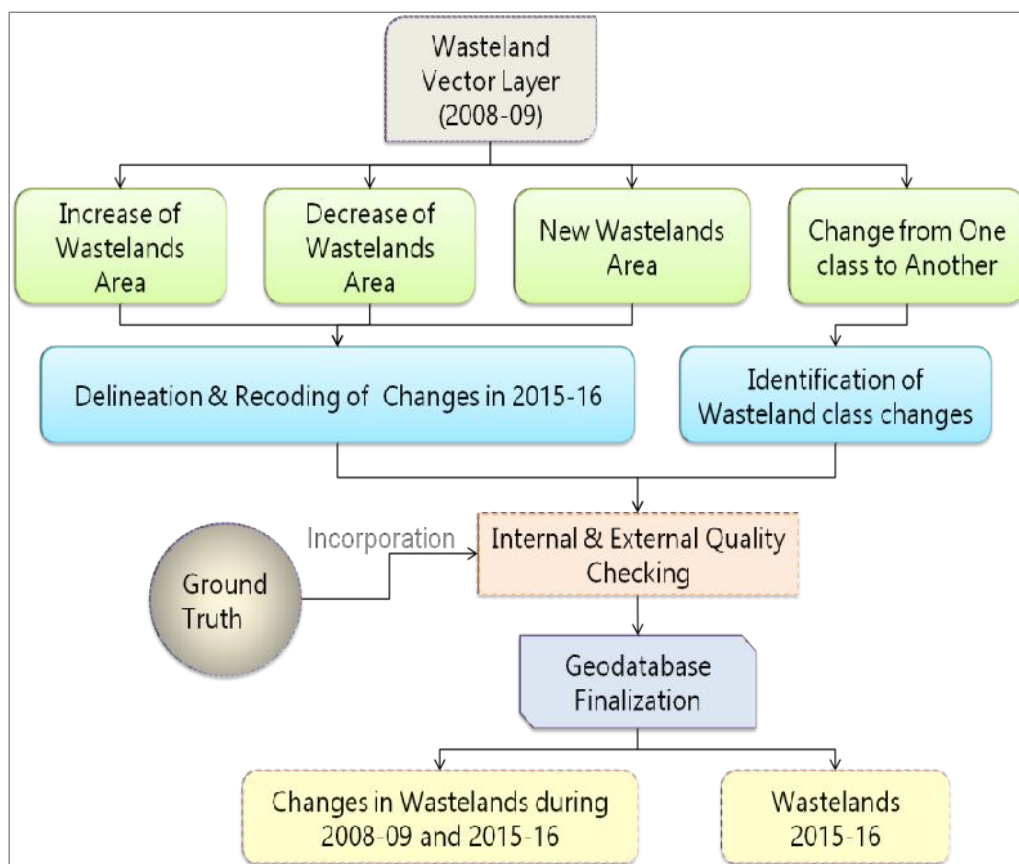


Figure 1. Methodology - Wasteland mapping and change analysis

3. RESULTS AND DISCUSSION

The world is changing at every second and all things are in the endless movement. The world is comprised of ever-changing and eternal developing material elements. Development is the creation of new entities, the disappearance of old entities, which is a process that new entities take the places of old entities. Therefore, a profound knowledge of the changes of geographical entities contributes to a better understanding and modernization of the society (Yang Ping, et al., 2008). Macleod and Congalton (1998) have listed four important aspects of change detection that are crucial for monitoring natural resources. They include detection of changes that have occurred, identifying the nature of change, measuring the areal extent of the change and assessing the spatial pattern of the change. Wasteland maps of the two selected years have been generated using the methodology described above and the spatial distribution & temporal changes have been analyzed. The category-wise distribution of wastelands in the State during the study period is presented in Table-1.

3.1 Wastelands in Andhra Pradesh during 2008-09

Twenty wasteland categories have been delineated with an extent of 24,790.10 sq. km during the year 2008-09 and accounts to 15.21% of the total geographical area of the State. Scrub dominated forest is the predominant category with an extent of 8332.22 sq. km and occupies 33.61% of the total wastelands of the State, mainly concentrated along the hilly tracts. The next dominant wasteland category is land with scrub followed by open scrub, which is mainly concentrated in and around foothill region and upland areas of central part of the State. Land with dense scrub and open scrub occupied 26.90% and 19.56% of total wasteland area of the State respectively. The gullied medium and deep lands contribute 169.93 sq. km and 3 sq. km respectively and found along the running waters at hillsides. Under the waterlogged & marshy category, permanent and seasonal categories contribute 143.08 sq. km (0.58%) and 16.96 sq. km (0.07%) respectively. Shifting cultivation found in the hilly region of Visakhapatnam and East Godavari Districts contributes an area of 15.42 sq. km of Current Jhum and 1.29 sq. km of Abandoned Jhum respectively. Under the sands category, Riverine, Coastal, Desertic contributes 0.09%, 1.22%, and 0.02% respectively. The riverine sands found along the major rivers as well as coastal sands are seen in along the coastline of the state. The desertic soils are found in Prakasam District which is due to accumulation of sand grains from the Bay of Bengal. The mining wasteland contributes an area of 3.03 sq. km and found in Anantapuramu, Chittoor, YSR Kadapa and West Godavari Districts. Barren rocky area constitutes 9.18% of total wasteland area of the State during 2008-09. The spatial distribution of wastelands of the year 2008-09 is shown in Figure -2 (a).

S. No	Category	Year 2015-16	(%)	Year 2008-09	(%)	Change	% diff
1	Gullied and/ or ravenous land (Medium)	115.14	0.48	169.93	0.69	-54.79	-0.20
2	Gullied and/ or ravenous land (Deep)	1.90	0.01	3.00	0.01	-1.10	0.00
3	Land with Dense Scrub	6368.78	26.60	6669.41	26.90	-300.63	-0.31
4	Land with Open Scrub	4604.91	19.23	4848.71	19.56	-243.80	-0.33
5	Waterlogged and Marshy land (Permanent)	115.37	0.48	143.08	0.58	-27.71	-0.10
6	Waterlogged and Marshy land (Seasonal)	16.96	0.07	16.96	0.07	0.00	0.00
7	Land affected by salinity/alkalinity (Moderate)	800.67	3.34	885.64	3.57	-84.97	-0.23
8	Land affected by salinity/alkalinity (Strong)	349.66	1.46	376.86	1.52	-27.19	-0.06
9	Shifting Cultivation - Current Jhum	14.37	0.06	15.42	0.06	-1.05	0.00
10	Shifting Cultivation - Abandoned Jhum	2.34	0.01	1.29	0.01	1.05	0.00
11	Under-utilised /degraded forest (Scrub dominated)	8204.20	34.26	8332.22	33.61	-128.02	0.65
12	Under-utilised /degraded forest (Agriculture)	681.60	2.85	589.28	2.38	92.32	0.47
13	Degraded pastures/ grazing land	99.41	0.42	99.41	0.40	0.00	0.01
14	Degraded land under plantation crop	13.06	0.05	26.82	0.11	-13.76	-0.05
15	Sands – Riverine	15.75	0.07	22.94	0.09	-7.19	-0.03
16	Sands – Coastal	266.23	1.11	303.33	1.22	-37.10	-0.11
17	Sands – Desertic	1.94	0.01	3.80	0.02	-1.85	-0.01
18	Mining Wastelands	2.52	0.01	3.03	0.01	-0.51	0.00
19	Industrial Wastelands	3.22	0.01	3.28	0.01	-0.05	0.00
20	Barren Rocky Area	2267.62	9.47	2275.71	9.18	-8.09	0.29
Total		23945.66	100	24790.10	100	-844.44	0.00

Table 1. Category-wise wastelands distribution and changes during the period 2008-09 and 2015-16 (Area in sq. km)

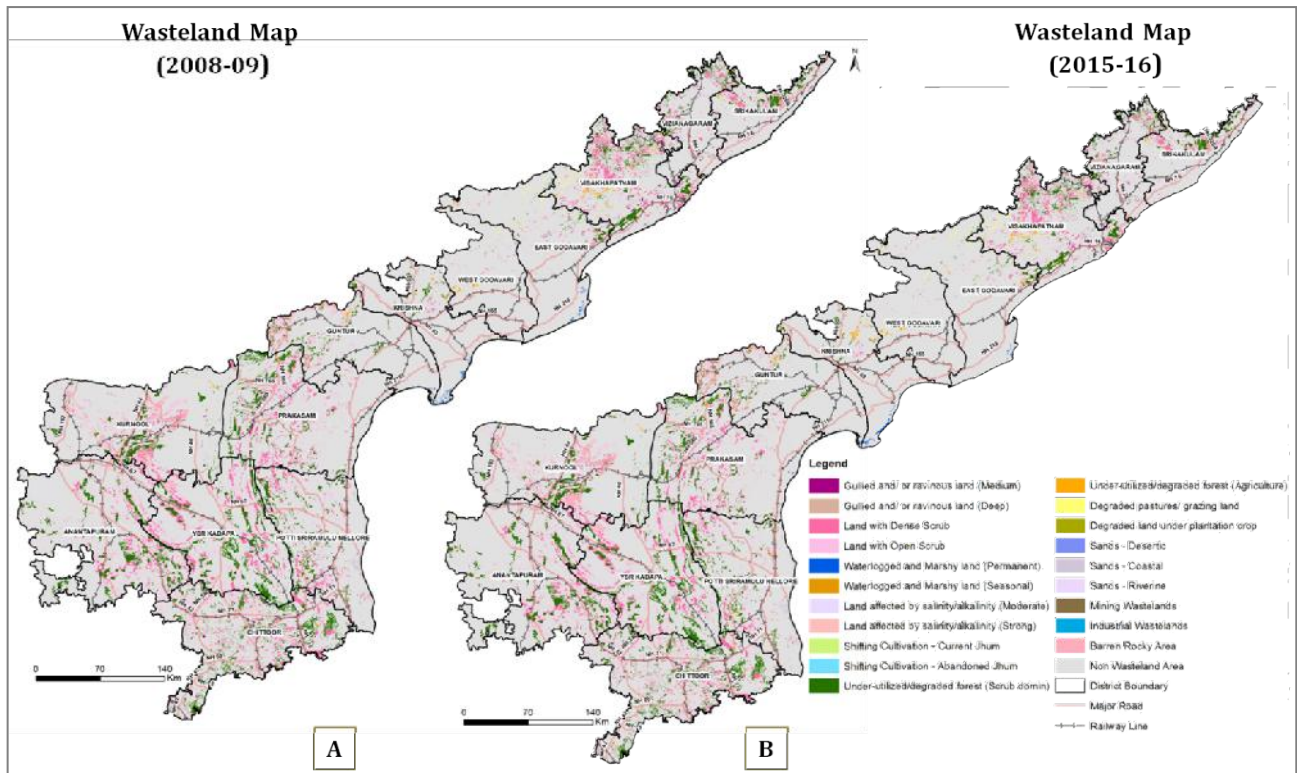


Figure 2. Wasteland Map of Andhra Pradesh during (A) 2008-09 and (B) 2015-16

3.2 Wastelands in Andhra Pradesh during 2015-16

The total area under various wasteland categories in Andhra Pradesh State (2015-16) is about of 23,946 sq. km which contributes about 15% of the total geographical area of the State. The scrub lands occupied 10,974 sq. km, which is about 46% of the total wasteland area of the state. The gullied lands contributed 117 sq. km during the year 2015-16. The scrub dominated forest and underutilized agriculture forest occupied an area of about 8204 sq. km (34.26%) and 681 sq. km (2.85%) of the total wasteland area of the State. The areas occupied by industrial and mining wastelands are 3.22 sq. km and 2.52 sq. km respectively. The grazing lands are found in hilly regions of Visakhapatnam, East Godavari and West Godavari Districts, contributed an area of 99.41 sq. km (0.42%). Degraded land under plantation crop attributed 13.06 sq. km during the year 2015-16. Sands together contribute about 284 sq. km (1.19%) in the year 2015-16. The area under scrub dominated forest is 8204.20 sq. km, which is about 34.26% of the total wastelands of the State. There is a decrease (0.65%) in this category from 2008-09 to 2015-16 due to constant felling of trees for fuel and fodder as well as agriculture activity at forest fringe area. The saline lands totalling 1150.33 sq. km (4.80%) of which moderate saline lands is about 800 sq. km (3.34%) and strong saline lands are 349.66 sq. km (1.46%). These are significant in south coastal and Rayalaseema Districts of the State. Barren rocky area occupies 2267.62 sq. km, which is about 10% of the total wasteland area of the State in the year 2015-16. It is found that there is decrease in barren rocky area of 8.09 sq. km during the study period. The wasteland map for the year 2015-2016 is shown in Figure 2(b).

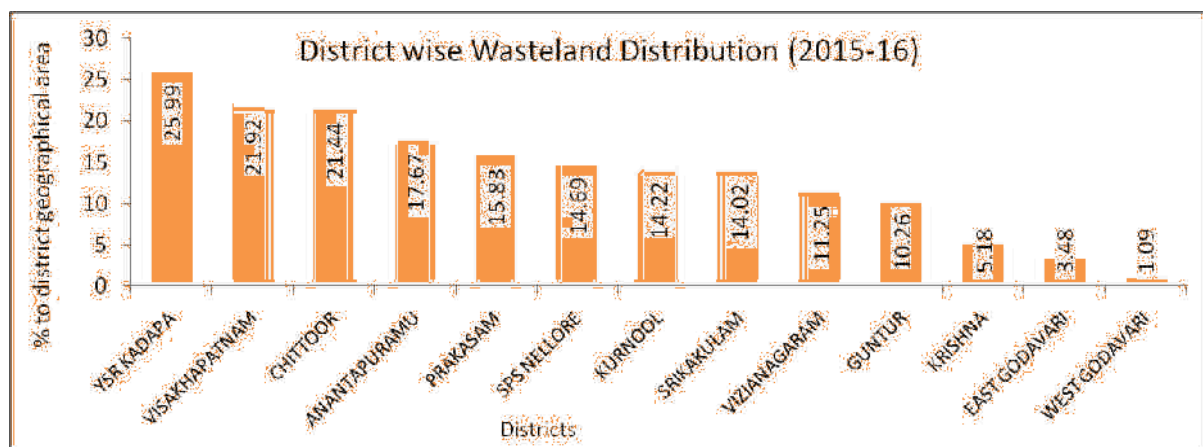


Figure 3. District-wise wastelands distribution in Andhra Pradesh (% to total district geographical area)

3.3 District wise wastelands occupancy in Andhra Pradesh during 2015-16

The distribution of wastelands with respect to the percentage of the total geographical area of each district is given in Figure -3. As evident from the Figure -3, YSR Kadapa District has more than 25% of its area under wastelands. There are two Districts viz., Chittoor and Visakhapatnam that have wastelands ranging between 20% - 25%. Prakasam and Anantapuramu Districts accounted 15% - 20% area under wastelands. Five districts viz., Sri Potti Sriramulu Nellore, Kurnool, Srikakulam, Vizianagaram and Guntur have wastelands ranging between 20% - 40% while in Krishna District wastelands occupy only 5% - 10%. Both East Godavari and West Godavari Districts have less than 5% area under wastelands. YSR Kadapa District ranks first in the area under wastelands with 25.99 % while West Godavari District, located in the East Coast deltaic region has the least (1.09 %).

3.4 Wasteland changes in Andhra Pradesh during 2008-09 and 2015-16

In Andhra Pradesh, an area of 23,946 sq. km corresponding to 14.69 % of the geographical area of the State has been estimated to be under wastelands during 2015-16, whereas 24,790 sq. km (15.21%) in 2008-09. There has been a reduction in the spatial extent of wastelands to the tune of 0.53 % (844 sq. km) with reference to the year 2008-09. In terms of predominance of wastelands category, under-utilized/degraded forest (Scrub dominated) has a maximum areal extent 8204.20 sq. km in the year 2015-16, whereas 8332 sq. km in the year 2008-09. Table-1 reveals that the State has registered a slight decrease in the category of gullied land (medium) from 169.93 sq. km to 115.14 sq. km during the study period. The salinity/alkalinity land of 112.16 sq. km has been converted to non-wasteland from 20108-09 to 2015-16. There is a decrease in scrub lands (land with dense scrub & open scrub) with an area of 544.43 sq. km.

WL_2015-16	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	20	21	22	24	25	26	27	28	29	30	32	999	Area in Sq Km	
WL_2008-09																															
1	115.14			18.55																	3.75	18.45	3.10	10.14			0.79		169.93		
2		1.90		0.79																		0.31								3.00	
3			6364.64	33.18																	21.62	1.29	140.39	66.44	37.15		4.70		6669.41		
4				4506.01																	29.29	1.67	244.35	41.24	23.40		2.75		4848.71		
5					114.70																	0.49	0.60	0.06		27.23				143.08	
6						16.96																								16.96	
7			3.42	28.94			795.07	0.14											0.15		0.93	47.38	7.58	1.41			0.62		885.64		
8			0.26	14.02			5.59	349.52													0.49	6.03	0.22	0.11			0.61		376.86		
9									14.37	1.05																				15.42	
10										1.29																				1.29	
11											8204.20	92.58										4.34					29.00	2.10		8332.22	
12												589.02										0.26								589.28	
13													99.41																	99.41	
14				1.46										13.06							1.87		2.22	0.74	7.47					26.82	
15				0.94											15.75								6.25							22.94	
16			0.45	0.69	0.67											266.23					0.05	0.20	20.41		13.02	1.61			303.33		
17																	1.94						0.11	1.42	0.32					3.80	
20				0.33														2.52				0.18								3.03	
21																			3.07			0.20								3.28	
22																						2267.62	8.09							2275.71	
999																												138176.80	138176.80		
Grand Total	115.14	1.90	6368.78	4604.91	115.37	16.96	800.67	349.66	14.37	2.34	8204.20	681.60	99.41	13.06	15.75	266.23	1.94	2.52	3.22	2267.62	71.09	3.64	486.50	120.79	93.02	28.84	29.00	11.56	138176.80	162966.90	

WL Code	Description	WL Code	Description	Non-WL Code	Description
1	Gullied and/ or ravinous land (Medium)	11	Under-utilized/degraded forest (Scrub dominated)	24	Built - Up
2	Gullied and/ or ravinous land (Deep)	12	Under-utilized/degraded forest (Agriculture)	25	Industrial Area
3	Land with Dense Scrub	13	Degraded pastures/ grazing land	26	Cropland
4	Land with Open Scrub	14	Degraded land under plantation crop	27	Fallow Land
5	Waterlogged and Marshy land (Permanent)	15	Sands - Riverine	28	Plantation
6	Waterlogged and Marshy land (Seasonal)	16	Sands - Coastal	29	Forest (Dense/ Open)
7	Land affected by salinity/alkalinity (Moderate)	17	Sands - Desertic	30	Forest Plantation
8	Land affected by salinity/alkalinity (Strong)	20	Mining Wastelands	32	Water bodies
9	Shifting Cultivation - Current Jhum	21	Industrial Wastelands	999	Non Wasteland Area
10	Shifting Cultivation - Abandoned Jhum	22	Barren Rocky Area		

Table 2. Wastelands change analysis under different categories from 2008-09 to 2015-16. (Area in sq. km)

The important aspects of changes are the detection of changes that have occurred, identifying the nature of change, measuring the areal extent of the change and assessing the spatial pattern of the change. These aspects are crucial for monitoring natural resources. The temporal changes in wastelands were analyzed based on the change matrix (Table-2), which is derived from the wasteland maps of the study period. The diagonal matrix given in blue colour denotes no change, the red colour indicates a class change or category change, change of wastelands to productive lands indicates positive change and is shown in green colour. It is observed that 271.59 sq. km. of the dense scrub category is converted into productive lands from 2008-09 to 2015-16, of which 140.39 sq. km. is in cropland and 66.44 sq. km of fallow land respectively. An area of 342.70 sq. km. has been converted to productive lands from open scrub during the study period, of which 244.35 sq. km. is in cropland. It is also found that about 58 sq. km saline lands are converted into cropland which is due to best agricultural practices and implementation of different developmental programmes. An area of 29 sq. km of scrub dominated forest is converted to forest plantation and about 93 sq. km of area converted to under utilised agriculture forest during the same period. This is due to the implementation of programmes like Neeru-Chettu, Vanam-Manam, Vana Sanjeevani etc. It is found that the population growth and consequent demand for residential needs are responsible for the increase in built-up land in the outer fringes of towns, leading to urban sprawl. About 71 sq. km of wastelands are converted to the built-up area

during the study period. It is also noted that 11.56 sq. km of the area of wastelands is converted to water bodies. This is due to implementation of irrigation projects and laying of new canals during the study period.

4. CONCLUSIONS

This study elucidates the significance of Remote Sensing and GIS for change detection study of wastelands of an area as it offers crucial information about the spatial distribution as well as nature of changes. The integration of satellite remote sensing along with visual interpretation is an effective method for the documentation of changes in wastelands of an area. This study provides the database on wastelands which at district/block/village level can be utilized for various reclamation measures and for development activities such as social forestry, agro-forestry, fuel and fodder, farm forestry, afforestation programmes etc. The reduction in the area of wastelands is attributed to the growth of non wastelands i.e. cropland, plantations, settlements, industries, etc. The detailed analysis has revealed that the area under wastelands is decreased from 15.21% to 14.69% during the period from 2008-09 to 2015-16. The generated information for the wastelands will aid in understanding the spatial distribution and extent which will help in further planning and taking in time appropriate decisions for sustainable development. Also the local people should be made aware of the importance of the wastelands and its change.

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INVENTORY OF GLACIAL LAKES IN GILGIT SUBBASIN OF INDUS BASIN USING HIGH RESOLUTION SATELLITE IMAGERY

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ABSTRACT

Glacial lake monitoring is very important to understand glacier associated terrain dynamics in mountainous region in the context of climate change and Glacial Lake Outburst Flood (GLOF) risk. Remotely sensed data is considered very useful to map and analyse critical glacial lakes for evaluating in disaster risk and preparedness. This study provides a comprehensive inventory of glacial lakes in Gilgit subbasin by using high resolution multispectral satellite data and identifies critical lakes which may be susceptible to GLOF. Lakes of size greater than 0.0025 sq.km. were mapped, that are total 852 (34.626 sq.km.), out of which 827 lakes are associated with glaciers, covering area of 31.332 sq.km. Study area lies within elevation range from 1216 to 6375 m and it has been observed that more than 67.11% of glacial lakes are located between 4000-4500 m elevation range, whereas 0.24%, 1.69%, 4.84%, 25.76%, and 0.36% lies within <3000 m, 3000-3500 m, 3500-4000 m, 4500-5000 m, >5000 m respectively. Glacial lakes were classified into various categories viz., moraine dammed lake, ice dammed lake, glacier erosion lake, and other lakes, which are 134, 59, 605, and 29 respectively. Based on three critical parameters of lakes namely areal extent, type and its association with glacier, 17 glacial lakes out of 827 may be considered as critical lakes, located in the altitude between 2500-5000 m. Prioritisation of these critical lakes could be useful for GLOF risk assessment and need to be carried out with more detailed glacial lake and parent glacier information.

KEYWORDS: Indian Himalayas, Gilgit Subbasin, Glacial Lake Inventory, Critical Lakes, High Resolution Satellite Data

1. INTRODUCTION

Glaciers are large mass of ice which begins to form when perennially accumulated snow transforms into ice and moves down slowly due to its own weight. Surging, retreating and melting of such glaciers in high mountains, expose terminal moraines and create glacial lakes at the end of it (ICIMOD, 2005). But glacial lakes can also be formed newly within, under, beside, or in front of glacier due to changes in parent glacier conditions. These glacial lakes can be classified into several types according to their position relative to the glacier and damming mechanism (Panda et al., 2014). Rapid accumulation of water in these glacial lakes particularly those adjacent to receding valley glaciers can lead to a sudden breaching of the unstable debris dam which may ultimately cause glacial lake outburst floods (GLOF) (ICIMOD, 2005). GLOFs are characterized by extreme peak discharges, with an exceptional erosion/transport potential; therefore, they can turn into flow-type movements (Emmer, 2017). Failure of such lake happens due to many factors which include erosion process, increase in water pressure, merging of an avalanche/rock into lake, nature of the damming materials etc., and this may lead to a GLOF event which could be highly disastrous in nature and create long-term degradation in the valleys, both physically and socio-economically (Hakeem et al., 2018, ICIMOD, 2001).

Few of such lakes which are real threat and can cause damage downstream if burst due to a triggering or non-triggering event are end-moraine dammed and supra glacial lake. Previous studies shows that, end-moraine dammed lakes appear to be the most common type of glacial lakes by which a GLOF event can occur in HKH region (Ashraf et al., 2012). Whereas, ice dammed lakes can also create such event when there is an increase in water level, which could be due to sudden emergence of upstream lake(s) or by intensive precipitation events. Carrivick and Tweed (2016) showed that the majority of recorded GLOFs originated from ice-dammed lakes. In above such cases, failure of these moraine or ice dams leads to flash floods caused by the outburst of glacial lakes are well known in Indian Himalayan region. That is why, glacial lakes are a matter of concern and monitoring of these can be useful to understand the phenomena of potentially dangerous lakes located upstream. Glacial lakes and GLOFs are attracting substantial scientific attention, not only for monitoring and flood modeling, but also for the following reasons: (a) erosion-accumulation interactions and sediment dynamics studies, and its changes spatially and temporally (Maizels, 1997; Morche et al., 2007; O'Connor et al., 2015); (b) planning and implementation of any water resources development projects (Hakeem et al., 2018) and (c) they may represent a threat to society in settled areas (Carey, 2005; Carey et al., 2015; Carrivick and Tweed, 2016; Haeberli and Whiteman, 2015; Hewitt, 2016; Reynolds, 2003). Accordingly, Emmer et al., (2016) showed an annual nonlinear increase in the number of scientific publications focusing on GLOFs recently.

Hence, monitoring of glacier associated lakes is very useful in the Indian Himalayan region to identify potentially dangerous lake, and to identify those, a detailed inventory of glacial lakes and its type is required. However, to systematically identify and make an inventory of different types of glacial lakes, a detail inventory of glaciers at the larger scale can also be useful (ICIMOD, 2005).

As, majority of lakes can be found in high mountainous region under inclement weather conditions, which are unapproachable for detail investigation and continuous monitoring, remote sensing techniques play much greater role in that case. Historic and real time

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remotely sensed space borne and airborne imageries are of high interest since many years for research related studies. Satellite remote sensing technology is found to be one of the best tool for rapid, qualitative hazard assessment and inventorying of glacier and glacial lakes (Raj 2010). Satellite images have been extensively used in studying and mapping of the glaciers and glacial lakes (Østrem, 1975; Dozier, 1984; Hall et al., 1988) not only in Indian Himalayas but also in many parts of the world, such as Canada (Bolch et al., 2010; Schiefer et al., 2008; Ommanney 1980; Ommanney 2002), Norway (Andreassen et al., 2008; Paul and Andreassen 2009), Switzerland (Paul et al., 2002; Paul 2007), China (Shi et al., 2009) and Iran (Moussavi et al., 2009).

There have been a good number of inventories covering glaciated regions in various parts of the Indian Himalayas. Though efforts have been made to map glacial lake for Indus, Ganga and Brahmaputra region, the inventory was prepared using coarser resolution satellite data during 2003-2007. In this study, an effort has been made to map current glacial lakes for a part of Upper Indus basin by using recent high resolution satellite data.

2. STUDY AREA

Three major river basins are draining into India from Himalayas, namely, Indus, Ganga, and Brahmaputra. Gilgit River is one of the Himalayan tributary of Indus, originates from Shandur Lake in southwest and joins Indus at junction of three mountains ranges near town of Juglot (<http://en.wikipedia.org> 2018). The present study is Gilgit subbasin lies within geographical extent of 35.711°N and 36.924° N latitudes and 72.506°E and 74.769°E longitudes, shown in Figure 1. The Gilgit subbasin is covering an area of 1363.57 sq. km. which is 0.39% of Indus basin covering area of 3,42,737.89 sq. km. within Indian Himalayas. The average minimum and maximum temperature is -2.7°C (January) and 36.2°C (July) while average rainfall recorded minimum 2.4 mm (November) and maximum 25.1 mm (May) (<http://weather-pk.com> 2018). The highest elevation of the area of study is 6375 m and lowest 1216 m above mean sea level. The study area is well known for occurrences of natural hazards such as avalanches, landslides, rock falls, debris flows, flash flooding and Glacier Lake outburst flood (GLOF) (Ali et al., 2017).

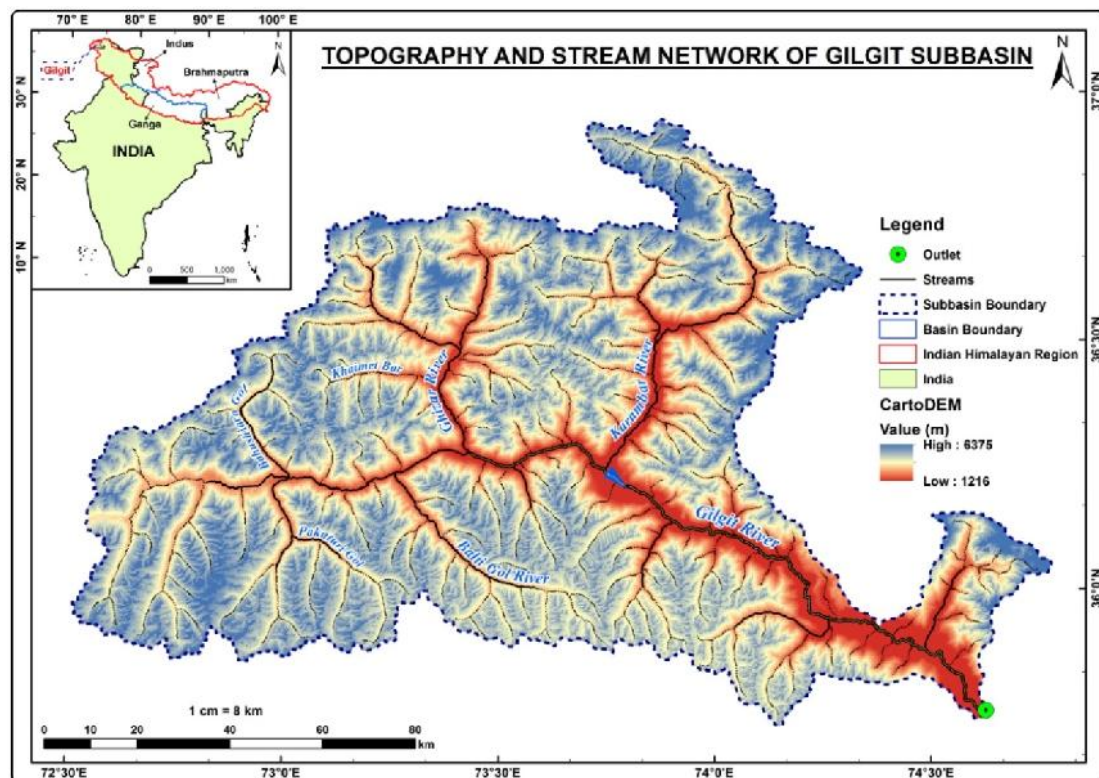


Figure 1. Location map of study area along with topography and stream network

3. MATERIALS AND METHODOLOGY

The mapping and inventory of glacial lakes in Gilgit subbasin was based on Resourcesat-2 LISS-IV images from 2013 to 2016 having spatial resolution of 5.8 m, details mentioned in the Table 1. For glacial lake identification from satellite imagery, the images should be cloud free and with least or no snow cover, which in the Himalayas occurs generally between August and December. Topographic information of the study area was derived from the Cartosat-1 digital elevation model with 10m DEM posting (CartoDEM 10 m). For better visualisation and identification of lakes, especially for lakes under shadow and/or snow-covered areas, DEM and Google Earth were also used. For few glacial lake attributes like river and lake name, Toposheet at 1:250000 was used, is downloaded from University of Texas Topo Library.

S.No.	Satellite / Sensor	Path	Row	Date of acquisition
1	Resourcesat-2 / LISS IV	089	44d	26-Jul-2016
2	Resourcesat-2 / LISS IV	089	45b	23-Sep-2014
3	Resourcesat-2 / LISS IV	090	44c, 45a	03-Oct-2013
4	Resourcesat-2 / LISS IV	090	44d, 45b	17-Sep-2016
5	Resourcesat-2 / LISS IV	091	44c, 45a, 45c	08-Oct-2013
6	Resourcesat-2 / LISS IV	091	45b	28-Jul-2013

Table 1. List of satellite data used in glacial lake inventory

Complementing visual interpretation method with the knowledge and experience of the terrain conditions, glacial lake mapping and monitoring can be done. Visual interpretation of satellite data by using spectral band combinations in false colour composite (FCC) of NIR, Red, Green bands in Red, Green, Blue channels respectively, along with the knowledge of image interpretation keys such as size, tone, texture, pattern, association, shape, shadow, and orientation, can be used to identify glacial lakes. Glacial lakes appear in dark blue to black colour in false colour composite, whereas frozen lakes appear in white colour. To identify glacial lake and demarcate its boundaries clearly, appropriate image enhancement techniques were used, which improves the interpretation by highlighting the lake (Figure 2).

The inventoried glacial lakes were broadly classified based on their type, such as moraine dammed lake, ice dammed lake, erosion glacial lake, other lake fed by glacial melt and water body. Moraine-dammed lake is the lake dammed by moraine following glacial retreat can become trapped in the trough between the glacier terminus and its moraine. Moraine-dammed lake is classified into four type's viz., End-moraine dammed lake, Lateral moraine dammed lake, Lateral moraine dammed lake with ice covered and Other moraine dammed lake. However, End-moraine dammed lake is one of the most potential dangerous moraine dammed lake which is mostly responsible for GLOF (ICIMOD 2011). Ice-dammed lake is the lake dammed by glacier ice only and most common type of ice-dammed is supra-glacial lake, form on the surface of a glacier. Glacier erosion lake form as a result of an earlier glacial erosion process, which accumulate in depressions after the glacier has retreated or melted away. Glacier Erosion Lake is classified into three types' viz., Cirque Erosion Lake, Glacier Trough Valley Erosion Lake, and Other Glacial Erosion Lake. Other glacial lakes formed in a glaciated valley, and fed by glacial melt, but damming material not directly part of the glacial process.

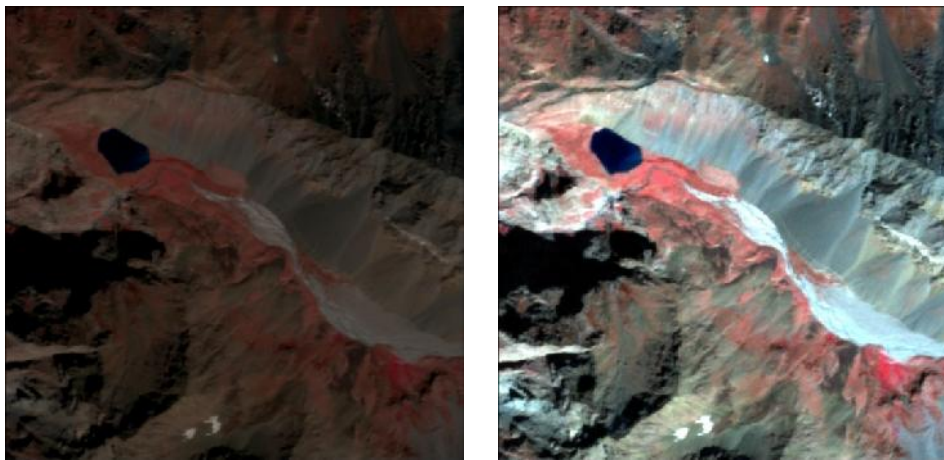


Figure 2. Image enhancement for improved visual interpretation of glacial lakes (Left: Normal Image, Right: Enhanced Image)

Altogether 19 different attributes were considered in the glacial lake inventory, divided into four groups: Hydrological information, which includes basin, subbasin, river, lake; Geometric information, which includes elevation, maximum length, mean width, surface area, aspect; Lake information, includes feature types, glacial lake type, lake ID; Other information, which includes latitude, longitude, Topo grid 250k, Topo grid 50k, source of database, source of elevation, and date of pass. Typically, lake ID is given in 12 digit format like "0142H0300080", where first two digit '01' refers to Basin code which is Indus, next five character '42H03' refers to the 1:50,000 scale Toposheet number, and the last five digit refers to the sequential number for each lake within the study area.

4. RESULTS AND DISCUSSION

The current mapping of glacial lakes in Gilgit subbasin includes all those with an area greater than 0.0025 sq.km (0.25 ha), that are total 852 covering area of 34.626 sq.km., out of which 827 lakes are associated with glaciers, covering area of 31.332 sq.km., (as shown in Fig 3) whereas 25 are water bodies with an area of 3.295 sq.km. Glacial lakes found in our study area were moraine dammed lake, ice dammed lake, glacier erosion lake, and other lakes, which are 134, 59, 605, and 29 respectively. Detailed distribution of glacial lakes based on type is given in Table 2 and Figure 4 shows percentage distribution of various types of lakes.

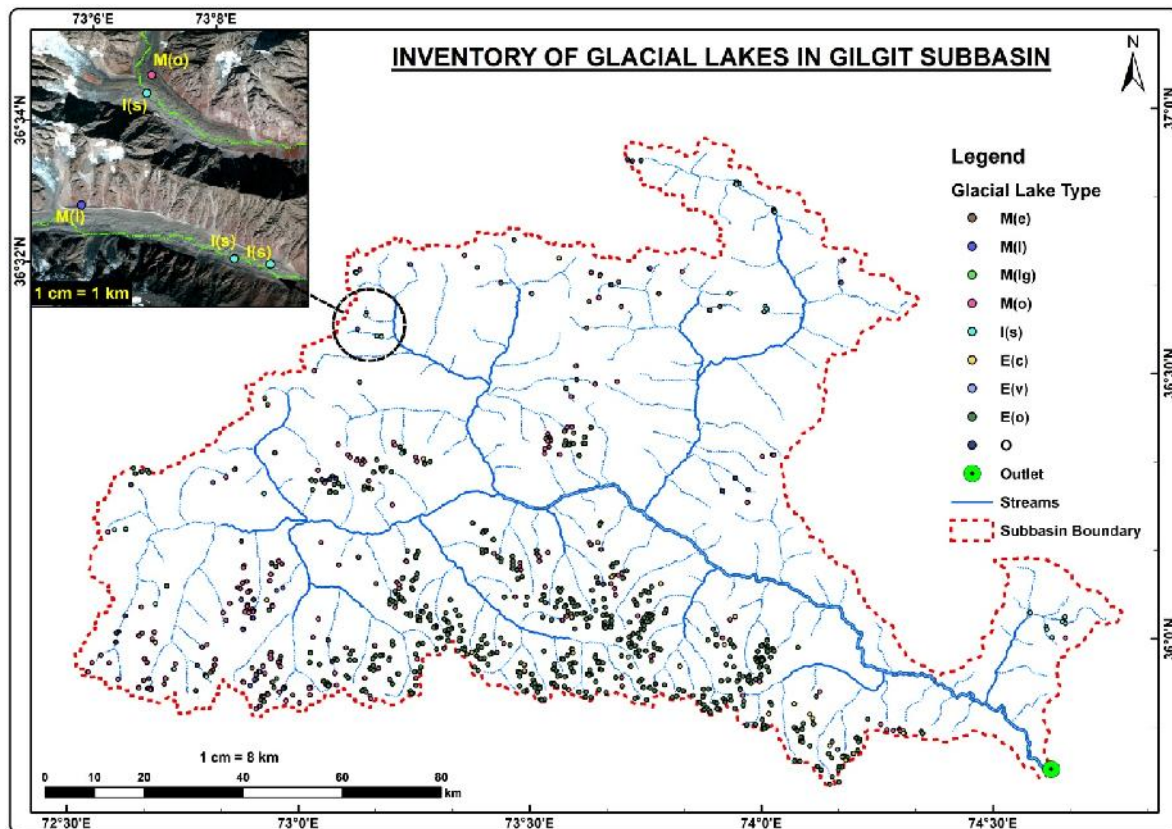


Figure 3. Inventory of Glacial Lakes in Gilgit Subbasin

S.No.	Lake Type	Total No	Area (sq.km.)
1	M(e): End-moraine Dammed Lake	24	0.550
2	M(l): Lateral Moraine Dammed Lake	14	0.105
3	M(lg): Lateral Moraine Dammed Lake with Ice	1	0.003
4	M(o): Other Moraine Dammed Lake	95	0.893
5	I(s): Supra-glacial Lake	59	0.358
6	E(c): Cirque Erosion Lake	42	3.099
7	E(v): Glacier Trough Valley Erosion Lake	2	0.173
8	E(o): Other Glacial Erosion Lake	561	17.978
9	O: Other Glacial Lake	29	8.174
	Total (Glacial Lakes)	827	31.332
10	WB: Water Body	25	3.295
	Total Features	852	34.626

Table 2. Distribution of glacial lakes based on its type

It has been observed that 67.11% of inventoried glacial lakes are located between 4000-4500 m elevation range and only 7.03% of lakes in that range are greater than 0.1 sq.km. However, 0.24%, 1.69%, 4.84%, 25.76%, and 0.36% lies within <3000 m, 3000-3500 m, 3500-4000 m, 4500-5000 m, >5000 m respectively, also mentioned in detail in the Table 3. It has been also observed that, more number of lakes were of size ranges between 0.01 and 0.05 sq.km and less number of lakes are greater than 0.5 sq.km. Table 4 describes areal distribution of glacial lakes.

Analysis of glacial lakes of different sizes with reference to elevation are shown in Table 5, which shows that the lakes in the higher altitudes are small in size, whereas maximum number of glacial lakes lies within the elevation range of 4000-4500 m having an area between 0.01 and 0.05 sq.km.

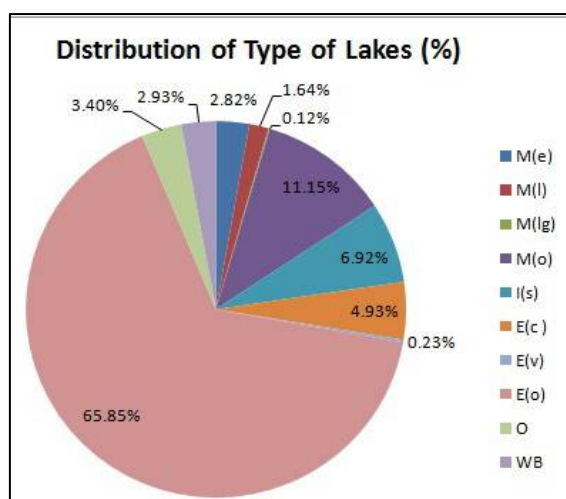


Figure 4. Percentage distribution of types of lakes

S.No.	Elevation Range (m)	Total No	Area (sq.km.)	No. of lakes (%)
1	<3000	2	0.144	0.24
2	3000-3500	14	0.095	1.69
3	3500-4000	40	5.167	4.84
4	4000-4500	555	22.187	67.11
5	4500-5000	213	3.728	25.76
6	>5000	3	0.012	0.36
Total (Glacial Lakes)		827	31.332	100.00

Table 3. Elevation range wise distribution of glacial lakes

S.No.	Area Range (sq.km.)	Total No	Area (sq.km.)	No. of lakes (%)
1	0.0025 - 0.005	188	0.671	22.73
2	0.005 - 0.01	170	1.212	20.56
3	0.01 - 0.05	354	8.303	42.81
4	0.05 - 0.1	61	4.154	7.38
5	0.1 - 0.5	47	8.277	5.68
6	> 0.5	7	8.715	0.85
Total (Glacial Lakes)		827	31.332	100.00

Table 4. Areal distribution of glacial lakes

S.No.	Area Range (sq.km.)	Elevation Range (m)					
		<3000	3000-3500	3500-4000	4000-4500	4500-5000	>5000
1	0.0025 - 0.005	1	8	14	85	77	3
2	0.005 - 0.01	0	2	7	114	47	0
3	0.01 - 0.05	0	4	10	265	75	0
4	0.05 - 0.1	0	0	2	52	7	0
5	0.1 - 0.5	1	0	4	35	7	0
6	> 0.5	0	0	3	4	0	0

Table 5. Distribution of glacial lakes with reference to size and altitude

Glacial lakes with an area above 0.02 sq.km (2 ha) were considered large enough to cause damage downstream if they burst out; this potential would be heightened if they are associated with a glacier. A total of 296 lakes were identified in this manner and out of these 17 lakes may be considered as critical based on its areal extent, type and association with its parent glacier. More information of these lakes are listed in Table 6 and few critical lakes are shown in Fig 5. Out of 17 glacial lakes, 6 lakes are of end-moraine dammed type, 1 is lateral-moraine lake, 7 are other moraine dammed lakes and 3 are ice-dammed supra glacial lake, which are located in the altitude between 2500-5000 m. Whilst, larger lake is an end-moraine lake of area 14.061 ha at 2692 m Above Mean Sea Level (AMSL). All end-moraine, lateral-moraine and supra glacial lakes are associated with valley type glacier, whereas, other moraine dammed lakes are associated with valley, mountain, and outlet glacier type.

S. No	ID No	Glacial Lake	Lat	Long	River	Area (ha)	Elevation (m)	Aspect
1	0142D1500015	M(e)	36.412	72.901	Hurguji Gol	11.226	4,226	N
2	0142D1600046	I(s)	36.046	72.877	Serbato Gol	3.966	4,738	NE
3	0142H0200063	M(e)	36.671	73.208	Kerun Bar	4.578	4,132	SE
4	0142H0300078	I(s)	36.319	73.207	Barsaler Bar	2.118	4,395	NW
5	0142H0600167	M(e)	36.642	73.407	Darkot Bar	14.061	2,692	E
6	0142H1000228	M(e)	36.630	73.751	Mahthantir Gah	2.941	4,089	W
7	0142H1100251	M(o)	36.347	73.524	Kurkuhi Bar	2.479	4,470	NW
8	0142H1300360	M(e)	36.841	73.920	Karambar River	4.440	3,508	SE
9	0142H1400372	M(e)	36.608	73.883	Diran Gah	2.864	3,674	W
10	0142H1400374	M(l)	36.601	73.862	Diran Gah	2.259	3,462	NW
11	0143A0900427	I(s)	35.860	72.647	Shunil Gol	2.970	4,697	SE
12	0143A1300441	M(o)	35.930	72.930	Bakbhuru Gol	7.101	4,440	W
13	0143A1300486	M(o)	35.833	72.910	Anari Gol	4.357	4,268	E
14	0143E0100506	M(o)	35.930	73.247	Ano Gol	7.920	4,293	W
15	0143E0100524	M(o)	35.899	73.070	Rani Gol	6.962	4,360	N
16	0143E0100526	M(o)	35.894	73.246	Ano Gol	2.760	4,326	NW
17	0143E0100550	M(o)	35.853	73.149	Kanu Gol	2.192	4,676	SW

Table 6. Details of critical lakes

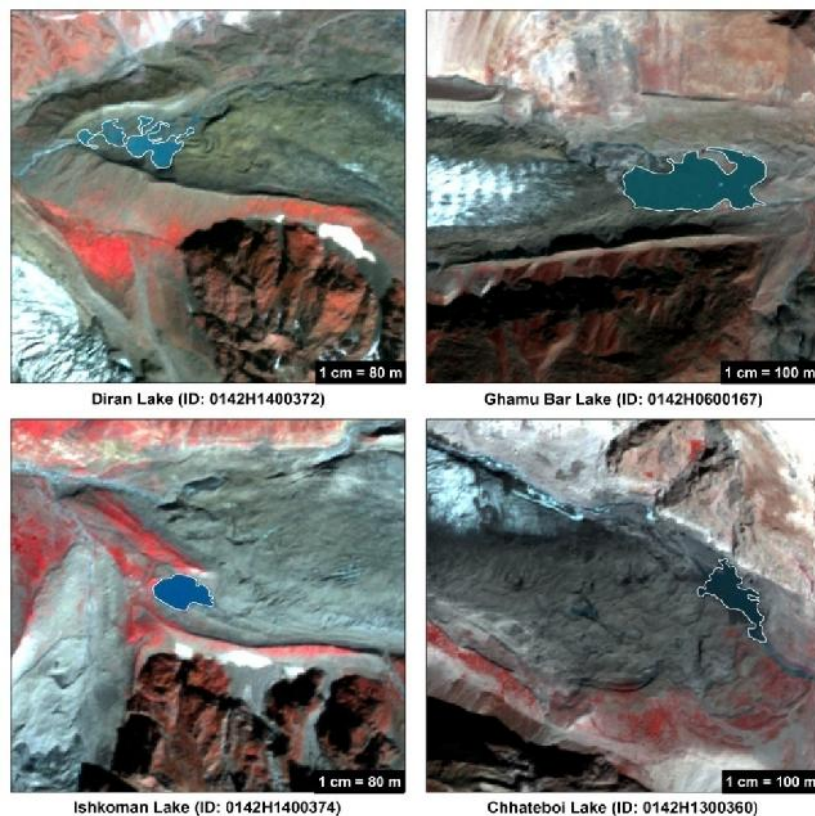


Figure 5. Identified critical lakes associated with glacier

5. CONCLUSIONS

This study demonstrates the effectiveness of remote sensing data for generating information on glacial lakes for inventory in Gilgit subbasin of Indus basin in the Indian Himalayas. Present inventory has mapped a total of 852 lakes (greater than 0.0025 sq.km), out of which 296 lakes were found greater than 0.02 sq.km. Though only 17 glacial lakes were found critical to cause damage based on its size, type and association with glacier. There is scope for considering additional parameters for identifying critical lakes and later for prioritisation and its ranking as per GLOF risk vulnerability. It is recommended that similar studies using high resolution satellite data can also be taken up in other sub-basins/basins in the Indian Himalayas for inventorying and ranking of potentially dangerous lakes, in order to mitigate the effect of GLOF in future.

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WEB-ENABLED GEO-SPATIAL URBAN GOVERNANCE

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ABSTRACT

Under National Urban Information System (NUIS), 152 towns thematic urban geo-spatial database has been created on 1:10,000 scale using high resolution satellite data. For effective utilization of these databases by respective Urban Local Bodies(ULBs), NRSC has developed a Geo-web portal (Bhuvan-NUIS) for updating/modifying and preparation of city level plans like Master Plan, Infrastructure plan etc. for governance. The main features of this Geo-web portal are ULB specific access control for (1) Database creation by Junior Engineer, (2) Review and approval of database created by the Junior Engineer along with the feedback mechanism, and (3) The Visualization and status control at city level, state level and central level. The access control is provided as per the responsibilities and jurisdiction. -Training and capacity building was imparted to around 2700 Town planning officials in all the States and Union Territories (UTs) through National, Regional and State-level workshops. The application has been developed using OGC compliant open-source technologies viz., Geoserver for data publishing, and web services (WMS). Bhuvan-NUIS is integrated with specifically designed software plug-in for QGIS (an Open Source software) to augment the GIS facilities. Bhuvan-NUIS is a national Geo-spatial Governance application with the GIS facilities, first of its kind. It also leads to incorporate the GIS technology as a major component in Urban and Regional Development Plans Formulation and Implementation (URDPFI) guidelines framed by Government of India (MOUD, 2015).

KEYWORDS: NUIS, WMS, Town Planning, Open Source, QGIS, Geoserver

1. INTRODUCTION

In 2011, India accounted for 11 per cent of the world's urban population; the United Nations projects it to be 15 per cent by 2030. The number of cities/towns in India increased from 5161 in 2001 to 7933 in 2011. The details of Census are given in Table 1 which has decadal details of rural, urban and level of urbanization which is growing rapidly. Also, urbanization for various class towns with decadal growth are given in Table 2 (MOUD, 2015).

Year	Population (millions)			Level of urbanization (%)
	Total	Rural	Urban	
1961	439.2	360.3	78.9	17.96
1971	548.2	439.1	109.1	19.90
1981	683.3	523.8	159.5	23.34
1991	846.3	628.7	217.6	25.71
2001	1028.6	742.5	286.1	27.81
2011	1210.2	833.1	377.1	31.16

Table 1. Urbanization of India as per census

Sl. No	Class	Population Range	2001 Census		2011 Census		Decadal Population Growth Rate (%) 2001-2011
			No. of Towns	Population (millions)	No. of Towns	Population (millions)	
1	Class I	1 lakh plus	441	196.3	468	264.9	34.9
2	Class II	50,000-99,999	496	27.8	605	41.3	48.7
3	Class III	20,000-49,999	1388	35.2	1905	58.2	65.5
4	Class IV	10,000-19,999	1563	19.5	2233	31.9	65.5
5	Class V	5000-9,999	1041	6.7	2187	15.9	137.5
6	Class VI	Below 5000	232	0.7	498	2.0	186.0
	Total		5161	286.1	7933	377.1	31.8

Table 2. Urbanisation- Class wise Decadal Growth Rate

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As per Ministry of Urban Development Government of India, out of 7933 towns only 2100 have the notified master plans. Hence, in the present scenario of urban planning, traditional approaches seem to be inadequate. The Integration of Remote sensing and GIS technologies with these traditional approaches provides a way for Geospatial governance. NUIS scheme was initiated by Ministry of Urban Development (MoUD), Survey of India (SOI) and National Remote Sensing Centre (NRSC) in 2006. Geospatial Database for 152 Cities/towns on 1:10,000 scales was created under NUIS Scheme and made available as thematic service through Bhuvan portal in the public domain. Bhuvan-NUIS is an extension of NUIS Scheme to enable the preparation of urban plans in Geo-spatial domain. Geo-spatial data aided by the guidelines enables town planners to formulate various types of plans. Hence, this system acts as catalyst for respective ULBs to use, the datasets of NUIS, Bhuvan and Town/city specific attribute data for the preparation of urban plans like Master plan, Proposed Land use Plan, Transportation plan, Utility plans etc.

2. MATERIALS AND METHODOLOGY

1. Data Used

The primary datasets are geo-spatial layers in nature primarily in vector format, which are generated under National Urban Information System (NUIS) thematic geospatial database at 1:10,000 scale were prepared from high resolution satellite data for 152 towns. These datasets include Bhuvan Satellite image as Web Map Service (WMS) overlaid by NUIS vector data which includes Base data (Road, Rail, Town Boundary etc.) and Landuse/Landcover (LULC) data. Further, there is a provision for uploading various data by ULBs such as Cadastral Map, utilities, Master plan etc. In this system, the data gets value added further, since the data keep getting updated and renewed with the time which will become a great asset for the planners and also can be exploited by other government agencies such as electrical, sewerage, revenue etc.

1.1 System Architecture

The application is conceptualized to facilitate the planners for access and value add the geo-spatial data to be coupled with auxiliary data to formulate town specific plans with in the URDFI guidelines as mentioned in the Figure 1(a). To realize this a system is designed with 3 tier architecture as mentioned in the Figure 1(b) consisting of data tier, application tier including map servers and presentation tier consisting of web browser and QGIS software with customized plug-in. The data is stored in a central server which is accessed by a Geoserver to generate WMS which shall be consumed by both web application and QGIS through internet. This architecture is realized with various open source tools and technologies which are described in the following section.

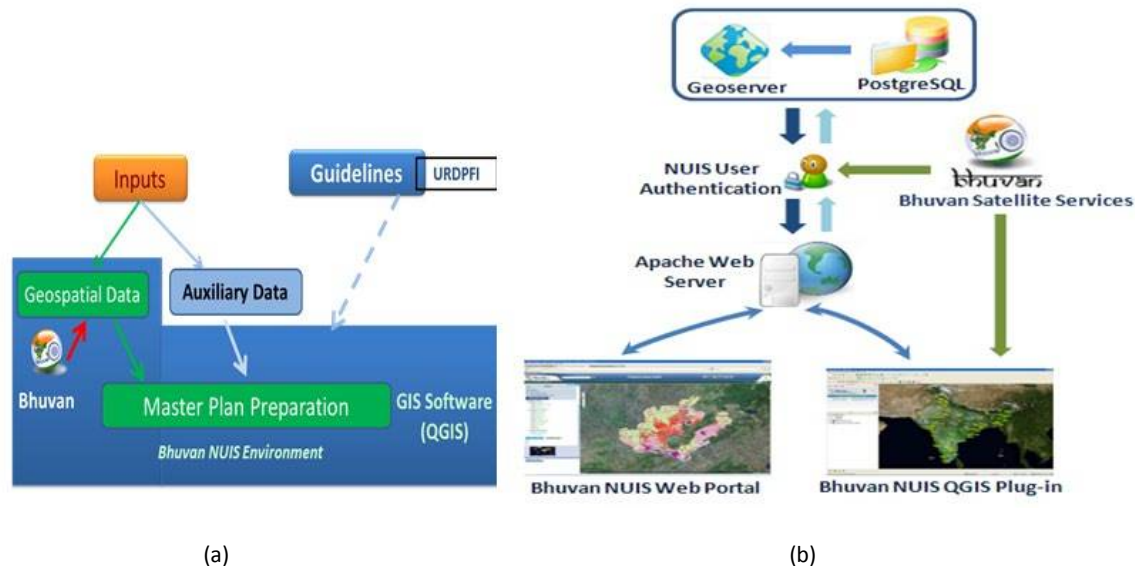


Figure 1. (a) Conceptual Diagram ;(b) Application Architecture

1.2 Tools and Technologies

Various tools and technologies employed in realizing this application are open source in nature and are listed in Table 3. The database used is PostgreSQL which is empowered by PostGIS to store geo-spatial data store, update and retrieve over the network. This geospatial data is published as WMS using Geoserver to be consumed by open layers which is embedded in PHP pages and QGIS at client side. Other technologies such as python, JavaScript etc., are used for programming the functionalities in relevant areas.

Role	Tool/Technology
Web Server	Apache
Spatial Data Server	Geo server
Server Side Programming	PHP
Client Side Programming	HTML, JavaScript, Ajax, JQuery, Open Layer, Python.
Database	PostgreSQL
GIS Gateway	PostGIS
GIS Software	QGIS

Table 3. List of Tools and Technologies used in Bhuvan-NUIS

1.3 Methodology

The Bhuvan-NUIS application is a web-based application developed using PHP, open layers, html and JavaScript which allows geo-spatial data to be viewed in web and QGIS for the preparation of town development plans. The geo-spatial data of 152 towns of NUIS were stored in PostgreSQL database. The geo-spatial data is published in Geoserver and made available as a WMS service for the portal and QGIS plug-in. The web portal makes use of open layers to visualise the WMS data. The QGIS Plug-in act as a gateway between QGIS and Bhuvan-NUIS portal and it exploits features of both QGIS and Bhuvan and aids the town planner for the preparation of development plans of the town. Secured authentication mechanism is provided in web portal.

After valid authentication, the town planner will be able to view the data belonging to the town. The data can be viewed in both portal and QGIS using the plug-in. The Satellite data in the form of WMS service is also made available to user as a background image through internet. The town planner uses the QGIS software along with the plug-in for the preparation of town specific development plan and uploads them to the Bhuvan server.

The verification of the town specific development plan layers can be done online using validation module of the portal. The town specific development plan layers uploaded by the town planner can be viewed by officer of higher grade. He can either approve or reject data with proper comments. In the case of rejection by the higher officer, the town planner will be notified about the same along with comments made. The town planner will correct the plan layers and re-upload them to the server. This cycle of operations will continue and on approval of competent authority in the web portal, the layers can be viewed by the public. The intermediate layers with the corrections will be saved as versions of data layers with the date and time stamps at the server side. This way, this application practically removes all the paper work done at Urban local bodies and helps in making the workflow digital.

3. RESULTS AND DISCUSSION

The main aim of this application is to aid urban planners in the preparation of urban plans using geo-spatial framework. This application comes in two components, web application and QGIS Plugin. In this roles of users and their functionalities are defined and implemented. For example, a junior engineer who is responsible for data level creation he is provided the facility to create or modify. While a town planning officer is to monitor and approve the changes carried out by the junior engineer. Hence, he has the functionalities to approve or reject the data. On the other hand, state and central level officers are facilitated for monitoring. So, the web application is facilitated with user management, data visualization, communication among officials.

This Geo-web application will enable urban planners of respective town to use NUIS data, satellite data and Town/city specific attribute data for the preparation of urban plans such as Proposed Land use Plan, Utility plan etc., based on the Urban and Regional Development Plans Formulation and Implementation (URDPFI) Guidelines. It also has hierarchical user management which enables the online approvals and rejection mechanism. The QGIS plug-in is add-on component for QGIS software developed using python at client-end and PHP, POSTGRESQL at backend. The QGIS plug-in enables the planner to visualise NUIS data layers in QGIS along with the satellite data as a web-service from Bhuvan in the preparation of town specific plans. The planner can upload the prepared plan layers to Bhuvan server from QGIS itself. Around 2700 urban planners across India were trained in using this application.

The potential of this application is to derive various plans by planners using central repository of data, ease of use of geo-spatial datasets in formulating plans and total digital workflow.

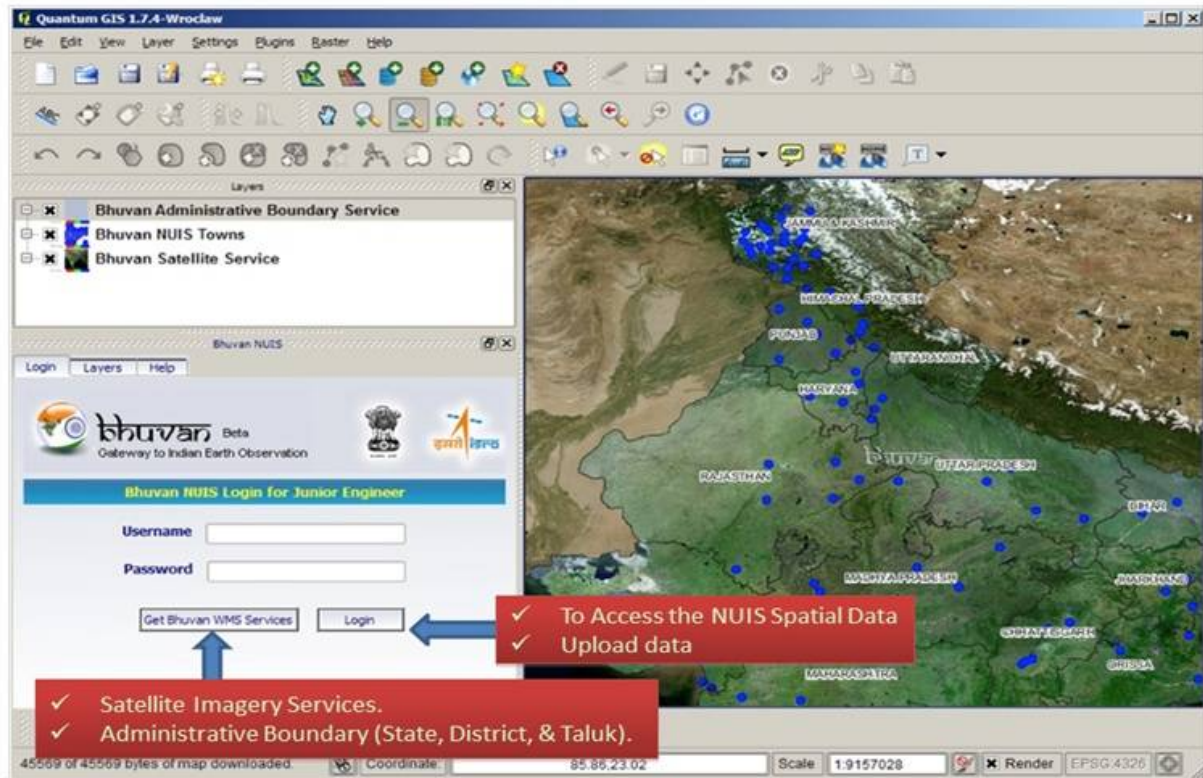


Figure 2. Visualization of Satellite Data in QGIS Environment

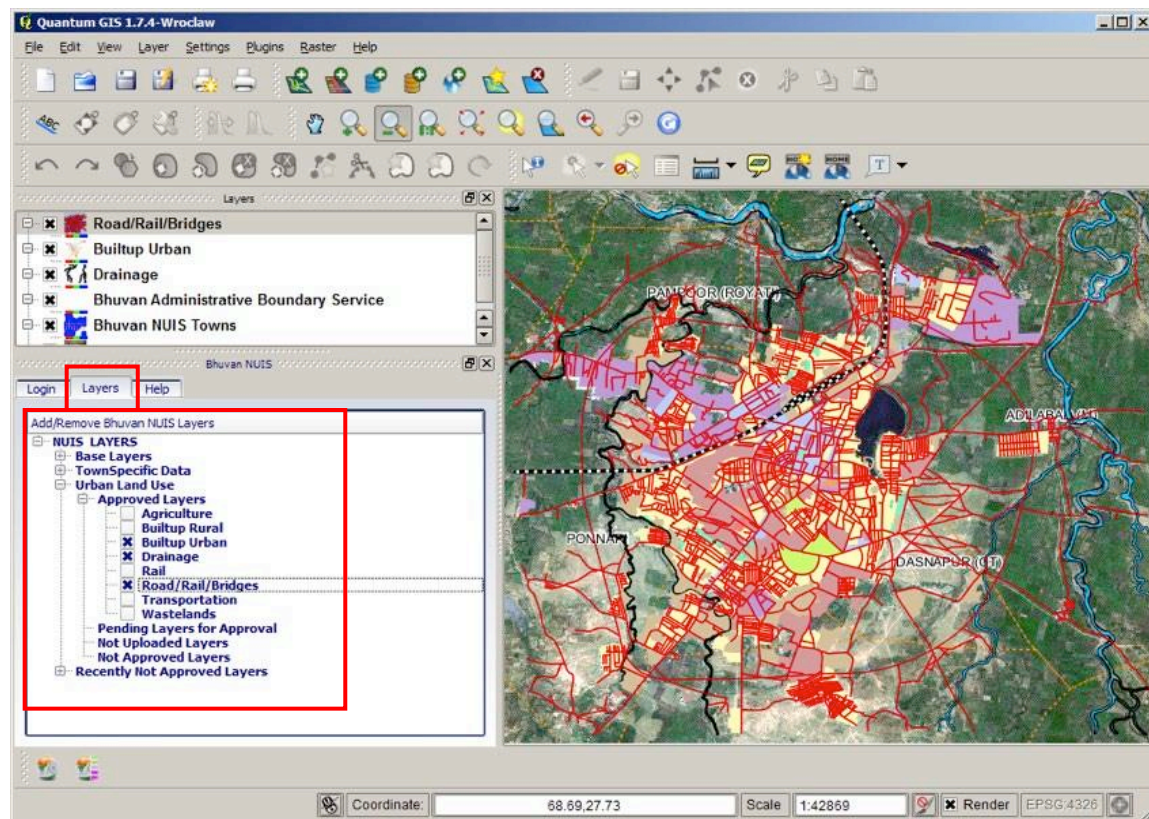


Figure 3. Visualization of NUIS Data Layers in QGIS Environment

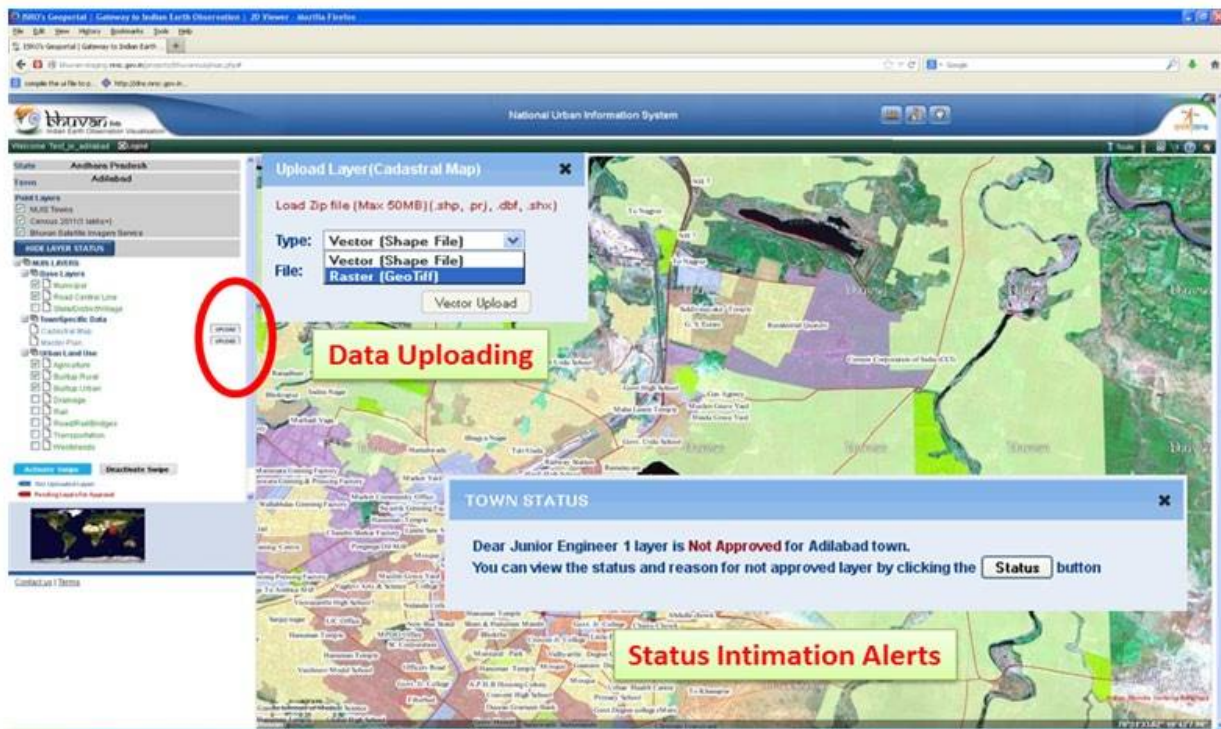


Figure 4. Uploading layers from Web Portal

4. CONCLUSIONS

Bhuvan-NUIS, a Geo-web application, provides a suitable platform for the preparation, modification approving and viewing the town specific developmental plans like Master Plan, Infrastructure plan etc. It provides a single-point data management and workflow management for easy governance. The main features of this Geo-web portal are urban local body specific access controls for database creation, online facilities for reviewing, approving/rejecting of database layers created by town planner along with the feedback mechanism, visualization and status control at town level, state level and national level. It facilitates online vector and raster uploading and maintains the spatial data versioning with proper logging.

Hence, this application can be used by urban planners for making GIS based urban developmental plans using satellite data and vector data in a more easy, timely and transparent manner. This project being first of its kind was well received by the Town planners across the country. It reduces communication among the officials and increases ease of use of geo-spatial datasets in formulating plans. Although this application is currently specific to the town planners, it can be extended to facilitate the public comments on a formulated plan before finalization.

Apart from urban governance, there is a potential for such applications in various government agencies in utilizing geo-spatial data such as water, power, transport, revenue etc., integrated with advanced sensor network to enhance the management and services to the society and country.

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ROAD EXTRACTION USING MORPHOLOGY AND SNAKE MODEL WITH LINE SIMPLIFICATION FROM SATELLITE IMAGERY

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ABSTRACT

Remote Sensing satellite image based road feature extraction reflects dynamic changes in the existing road network to update the maps and is cost effective with more periodicity compared to manual updation methods. The road feature extraction from the satellite images will generally be carried out in two stages, viz., 1) Identification of road feature from the image 2) Extraction and regularization of the extracted roads for their size and shape. Most of the available methods for road feature extraction using conventional methods suffer from omission errors and shape preservation. This paper presents morphological processing based road feature extraction from Cartosat images, where in morphological operators are used in pre and post processing stages while extracting the roads. The extracted roads from High Resolution (HR) images are regularized using snake active contour model along with Douglas & Peucker (DP) algorithm to retain the size and shape. The active contour model or snake model is an energy minimizing spline which is guided and pulled towards the features by external constraint forces and image force, i.e., delineated as a controlled continuity model under the influence of image forces. Snake model is incorporated with morphology during preprocessing stage to extract the (final contour) roads from HR images. Contours are irregular line in vector format. A line simplification algorithm i.e., Douglas & Peucker algorithm is used to regularize (smooth) line. The proposed techniques have the following advantages compared to the similar contemporary techniques: 1) Minimization of omission errors 2) Preservation of size and shape etc. The quantitative results are given in experimental results.

KEYWORDS: Road feature extraction, Mathematical Morphology, Snake Model, line simplification

1. INTRODUCTION

Roads are very important for transportation. Road Extraction is current research topic in feature extraction using Remote Sensing images. Though, most of the researchers have shown attention on the road feature extraction from last two decades, no specific methodology is evolved till date, as a general method to extract the road features from RS images. Several researchers have used the Mathematical Morphology (MM) as preprocessing or post processing technique for road extraction. Few researchers have used MM for Edge detection where roads are extracted using Sobel, Prewitt, etc.

MM has been proven to be a very important and useful tool for applications such as image restoration, segmentation, pattern recognition etc., R.M. Haralick and S.R. Sternberg *et.al* [1] have given broad analysis on the processing of the images using the MM. Maillard and Cavaye *et.al* [2] demonstrated road extraction from RS images using different approaches & methodologies for the extraction of roads from the multispectral images. In [3], the road extraction was carried out by using K-means clustering and MM, where K-means was used to detect the road which is vulnerable in identifying non-road areas also. The non-road areas are removed by MM and connected component algorithm. Zhang and Murai *et. al.* [4], extracted the roads based on the combination of fuzzy and MM which is used at the preprocessing stage as the connected components with certain criteria. All the different approaches that highlight the use of MM include the study of the structural properties of objects from their images [6]. Jalal Aminiet *et.al* [7] identified roads by extracting the statistical features which are converted into specific fuzzy sets using linguistic variables and then employed MM (skeleton) on the identified features followed by deploying a snake model [11] on the skeleton to extract the roads [12]. From these studies, it is understood that, the MM is playing a key role in image enhancement while extracting the object feature in pre or post-processing stage. For Image segmentation one of the widely used technique is Otsu thresholding [8], which is based on the gray level histogram of the image, and takes an advantage in using variance between the clusters as criteria to select the optimal threshold. In this paper, initially the roads are extracted using the MM operations at the pre-processing or post-processing stage and segmented using Otsu threshold. The extracted roads are used as an initial contour to the snake model to find the exact road. The final snake contour is irregular and to regularize (smooth) the road contour, DP algorithm [13] was used, as it can preserve the shape and size of the road. The experimental results show the minimization of the omission errors.

2. MORPHOLOGICAL OPERATORS

Matheron (1975) and Serra (1982) proposed Mathematical Morphology (MM) based on set theory. Similar to logical operators, it involves the AND, OR and NOT [8]. MM deals with the mathematical theory uses sets to narrate the shape of the object. In image processing, MM is used to find the interaction between images and the chosen structuring element using the basic operations of dilation and erosion. Dilation, in general, causes objects to expand in size; erosion causes objects to shrink. The amount and the way that they expand or shrink depends upon the chosen structuring element. The derived operators are opening and closing. Opening is defined as erosion followed by dilation which generally smoothens the boundary of objects and eliminates the thin portions. Closing is dilation followed by erosion which eliminates the small holes and fills gaps in the contour (boundary). Top-hat is a subtraction of

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the opening ($A \circ B$) image from the input image, which highlights the bright objects and suppresses remaining. Bot-Hat is a subtraction of the input image from closing($A \bullet B$) image, which highlights the dark objects and suppresses remaining. The mathematical expressions of the aforementioned are expressed as

$$A \oplus B = \left\{ x : \hat{B}_x \cap A \neq \Phi \right\} \quad (1)$$

$$A \ominus B = \{ x : B_x \subseteq A \} \quad (2)$$

$$Closing = A \bullet B = (A \oplus B) \ominus B \quad (3)$$

$$Opening = A \circ B = (A \ominus B) \oplus B \quad (4)$$

$$Top - Hat = A - (A \circ B) \quad (5)$$

$$Bot - Hat = (A \bullet B) - A \quad (6)$$

Here, A is the original binary image and B is the defined structuring element in shape as well as size. By using the Morphological operators, the initial roads are extracted. The extracted boundaries of the roads are taken as the input for the snake model instead of manual selection.

3. SNAKE MODEL WITH LINE SIMPLIFICATION

The active contour model or snake model (Kass, Witkin and Terzopoulo, 1988) is an energy minimizing spline which is guided and pulled towards the features by external constraint forces and image force, i.e., delineated as a controlled continuity model under the influence of image forces [11]. The internal forces control the bending characteristics of the line while image forces, such as the gradient, serve to push the snake towards image features. The snake's coordinate vector is defined parametrically as $v(s) = (x(s), y(s))$, where s is a parameter of arc lengths $\in [0, 1]$. The total energy function of the snake is defined as

$$E_{snake}^* = \int_0^1 E_{snake}(v(s)) ds$$

$$E_{snake}^* = \int_0^1 E_{int}(v(s)) ds + \int_0^1 E_{image}(v(s)) ds \quad (7)$$

Where, E_{int} and E_{image} are the internal and image energy terms, respectively.

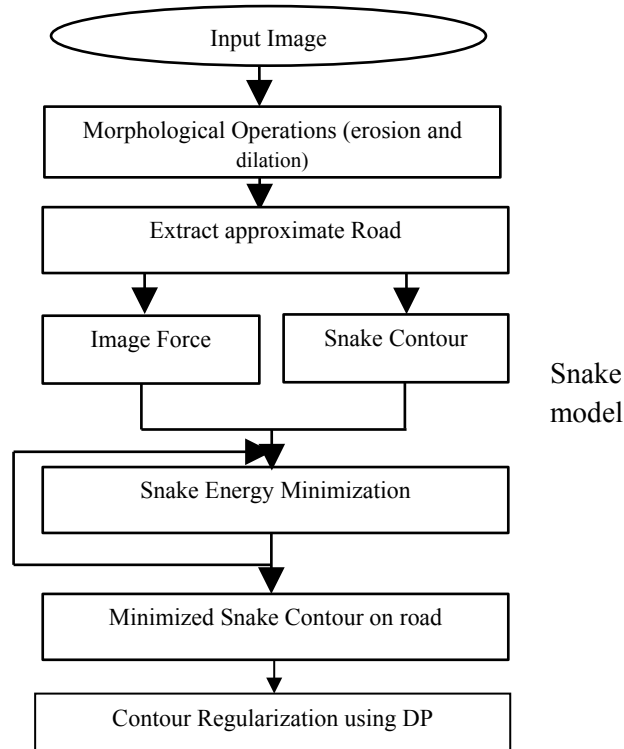


Figure 1. Block diagram of snake model with line simplification using DP Algorithm

3.1 Internal Force (Energy)

The spline's internal bending energy has been defined by this paper as follows

$$E_{\text{int}} = \alpha(s) \left| \mathbf{v}_s(s) \right|^2 + \beta(s) \left| \mathbf{v}_{ss}(s) \right|^2 \quad (8)$$

Here $\mathbf{V}_s$, the first spatial derivative of the snake's vertices (coordinates) term represents elasticity or membrane-like behavior and $\mathbf{V}_{ss}$, the second spatial derivative of the snake's co-ordinates term represents rigidity [11]. The coefficients $\alpha(s)$ and $\beta(s)$, weighting parameters constants, can be used to control the continuity characteristics of the snake by changing its elasticity and rigidity or stiffness.

When E_{snake}^* is minimized, the snake has reached a local minimum related with a contour of the image, and the modeling conclude to progress until the image is changed. Through variation calculus, the minimization of snake energy determined by the Euler equation as

$$\frac{d}{ds} (2\alpha \mathbf{v}_s(s)) + \frac{d^2}{d^2s} (2\beta \mathbf{v}_{ss}(s)) + \frac{\partial E_{\text{external}}}{\partial \mathbf{v}} = 0 \quad (9)$$

Since $\mathbf{V}$ is a vector of x and y , equation represents two independent equations with respect to x and y . Equation (9) is solved by using discrete formulations of differentials. First, the internal energy is discretized by the following equation

$$E_{\text{int}}(i) = \alpha_i(s) \left| \mathbf{v}_i - \mathbf{v}_{i-1} \right|^2 + \beta_i(s) \left| \mathbf{v}_{i+2} - 2\mathbf{v}_i + \mathbf{v}_{i-1} \right|^2 \quad (10)$$

The equation (10) is further differentiating and by grouping snake parameter ($\mathbf{v}$) terms, and solved by use of matrix formulation for efficient calculation of each snake point in a single matrix operation. This can be seen by representing the parameter coefficients as in the equation

$$C_{-2} \mathbf{v}_{i-2} + C_{-1} \mathbf{v}_{i-1} + C_0 \mathbf{v}_i + C_{+1} \mathbf{v}_{i+1} + C_{+2} \mathbf{v}_{i+2} + (f_x(i), f_y(i)) = 0 \quad (11)$$

The above equation (11) can be written as in matrix form given by [9]

$$\begin{aligned} \mathbf{A}\mathbf{x} + \mathbf{f}_x(x, y) &= 0 \\ \mathbf{A}\mathbf{y} + \mathbf{f}_y(x, y) &= 0 \end{aligned} \quad (12)$$

Where, $\mathbf{A}$ is penta-diagonal matrix.

The solution of the equations (12) are obtained by setting the right hand side equal to product of an arbitrary step size and the negative derivative times of the left hand side. Assuming the external force is constant during a time step, the solution to a single iteration is determined by matrix inversion:

$$\begin{aligned} \mathbf{x}_t &= (\mathbf{A} + \lambda \mathbf{I})^{-1} (\lambda \mathbf{x}_{t-1} - \mathbf{f}_x(\mathbf{x}_{t-1}, \mathbf{y}_{t-1})) \\ \mathbf{y}_t &= (\mathbf{A} + \lambda \mathbf{I})^{-1} (\lambda \mathbf{y}_{t-1} - \mathbf{f}_y(\mathbf{x}_{t-1}, \mathbf{y}_{t-1})) \end{aligned} \quad (13)$$

The snake energy minimization is applied iteratively for given internal energy parameters and the specified image information as shown in block diagram Figure-1. Under the smoothness constraints of the internal energy coefficients, the local minimum system is determined through the application of the image information. The elasticity and rigidity parameters are suitably taken for the system being modeled, along with user-placed initial snake parameters and meaningful image information. The final snake contours are shown in Figure-5 for various test cases.

3.2 Image Forces (External):

Image forces (External energy) try to pull (attract) the snake towards the feature due to the relevant features such as intensity of image, gradient of image and texture.

$$E_{\text{image}} = W_{\text{line}} E_{\text{line}} + W_{\text{edge}} E_{\text{edge}} + W_{\text{term}} E_{\text{term}} \quad (14)$$

Line Functional: Line function defines the intensity of the image, which is written as

$$E_{\text{line}} = I(x, y) \quad (15)$$

The sign of parameter W_{line} will decide the snake movement towards light or dark region of contour.

Edge Functional: Attracts the snake contour towards the large intensity gradients. The edge function is written as

$$E_{\text{edge}} = -|\nabla I(x, y)|^2 \quad (16)$$

Termination Functional: Termination function is defined by using curvature of level lines in $C(x, y)$, where $C(x, y)$, a smoothed image given by the equation

$$C(x, y) = G_{\sigma}(x, y) * I(x, y) \quad (17)$$

It attracts the snake contour towards the line termination and corners

$$\begin{aligned} E_{\text{term}} &= \partial\theta / \partial n_{\perp} \\ &= (\partial^2\theta / \partial n_{\perp}^2) / (\partial\theta / \partial n_{\perp}) \\ E_{\text{term}} &= \frac{C_{yy}C_x^2 - 2C_{xy}C_xC_y + C_{xx}C_y^2}{(C_x^2 + C_y^2)^{3/2}} \end{aligned} \quad (18)$$

3.3 Douglas and Peucker (DP) Algorithm

In the “Theory of the Cartographic Line”, Thomas K. Peucker and David H. Douglas explained that the algorithm was meant for line generalization (Peucker 1976: 138). The Douglas & Peucker (DP) algorithm is the most popular method for vector line simplification.

The DP algorithm takes the snake contour as input, a vector line or polyline [13] (a chain of vertices). In the input vector line, the possibilities of triangles of areas are calculated. If the area of the triangle is less than the defined threshold, then the third vertex of the triangle is removed and is replaced by a line connecting the other two as shown in Figure-2. DP algorithm is employed on snake model to smooth (line simplification) the contour line i.e., snake’s irregular contour line is simplified (regularized) by DP algorithm. The experimental results of DP algorithm on snake model are shown in Figure-6.

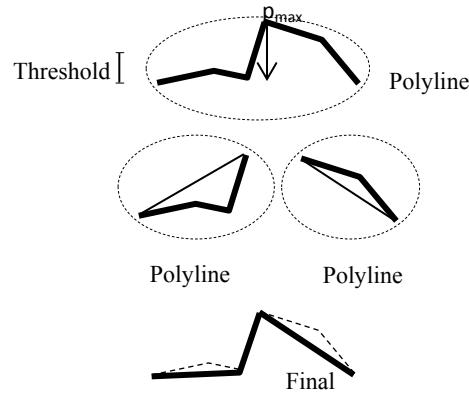


Figure2.Line generalization of DP algorithm

EXPERIMENTAL RESULTS

Accuracy Evaluation

To evaluate the accuracy of the road extraction results in the experiments, we compare them to reference data that is manually digitized.

$$\text{Completeness} = \frac{TP}{TP+FN} ; \text{Correctness} = \frac{TP}{TP+FP} ; \text{Accuracy} = \frac{TP}{TP+FP+FN}$$

where TP is True Positive, denotes the extracted road pixels that matched with the reference data that is manually digitized; FN is False Negative, denotes the road pixels that are in the reference data but not in the extracted result, and FP is False Positive, represents the extracted road pixels that are not in the reference data. The results are shown in Table -1 and 2.

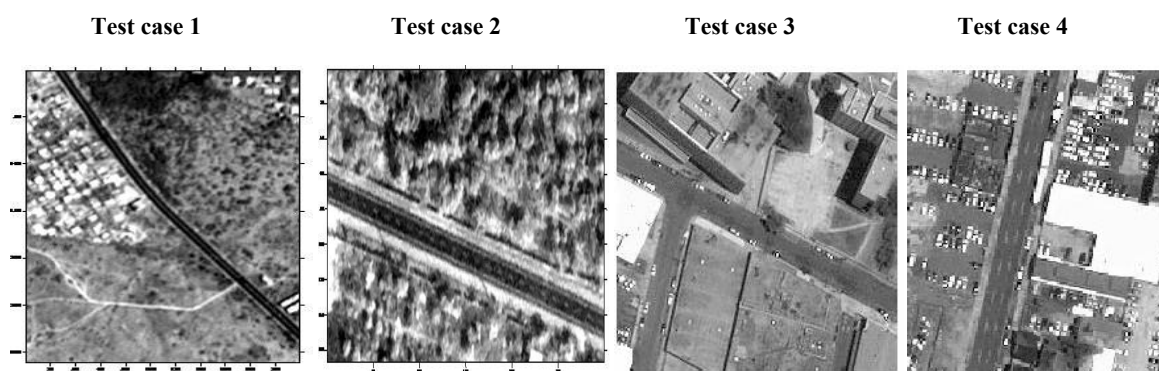


Figure 3. Original images

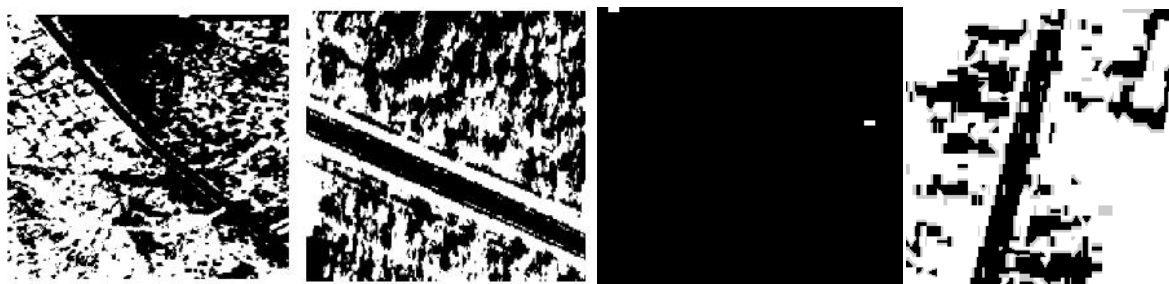


Figure 4. Road extraction by MM

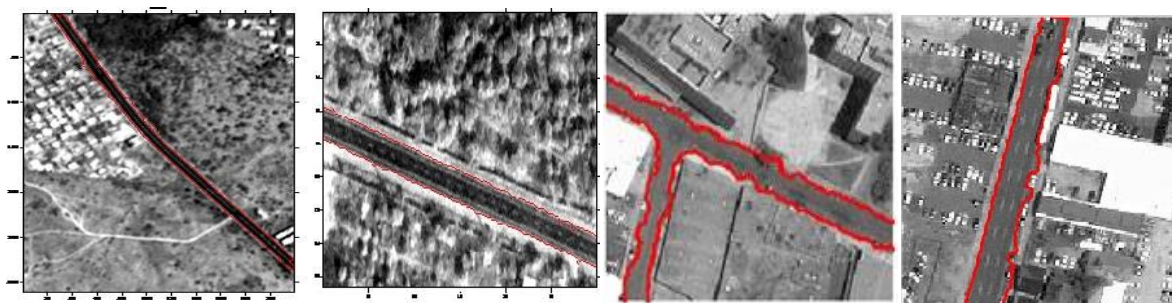


Figure 5. Final Snake contour model

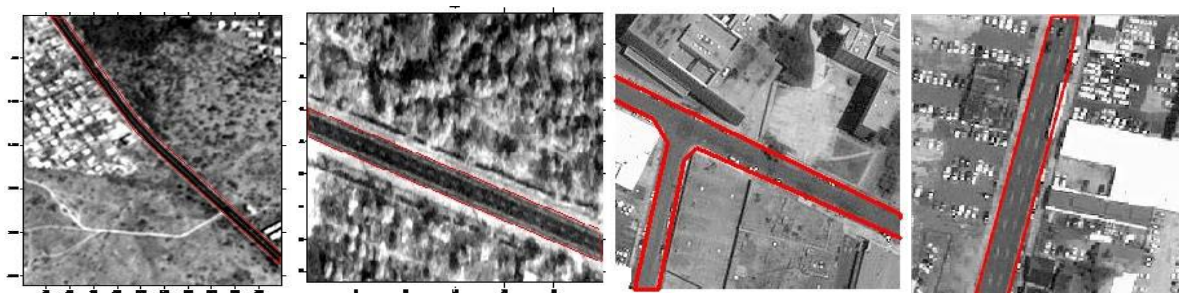


Figure 6. Line Regularization by DP algorithm

Images (Cartosat-2S @ 0.6m)	Snake model Accuracy	Snake with DP Accuracy
Test case 1	84.57	89.55
Test case 2	82.52	82.32
Test case 3	68.86	87.93
Test case 4	85.22	95.25

Table 2. Comparison of Accuracy

	Images	Completeness	Correctness	Accuracy
Snake model	Test case 1	95.68	87.93	84.57
	Test case 2	95.70	85.70	82.52
	Test case 3	72.13	93.84	68.86
	Test case 4	90.02	94.11	85.22
Snake Model with DP	Test case 1	97.93	91.27	89.55
	Test case 2	96.47	84.88	82.32
	Test case 3	94.51	92.67	87.93
	Test case 4	96.59	98.57	95.25

Table 1. Snake model, Snake model with DP Accuracy

4. CONCLUSION

In this paper, the methodology was developed using the Mathematical Morphology to extract the initial roads and combined this with the snake model to get the more precise roads. The snake contour is irregular in shape due to obstacles like vehicles, trees, etc. The irregular contour is regularized by the DP algorithm due to its ability to retain the shape and size of the roads, producing final results. In DP regularization (threshold area), the selection of area triangle is set manually and it varies for different cases of roads. In future study, automation of selection of threshold area will be presented.

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GIS BASED PREPAREDNESS AND EMERGENCY RESPONSE FOR AN EVENT: THRISSUR POORAM MASS GATHERING OF KERALA, INDIA

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ABSTRACT

Over the years, lack of preparedness and emergency response plan in mass gatherings increased the vulnerability towards hazards and fatalities. The mass flow of people into constrained and dense urban spaces creates pressure on infrastructure and poses challenges for the safe management of these gatherings. Thrissur Pooram festival of Kerala is one of the greatest gatherings in Asia and is held annually at Thaikenkadu maidan (Pooram ground) in centre of Thrissur city, resulting in the enforcement of special guidelines for the traffic and crowd management during the festival. The aim of this paper is to propose guidelines for preparedness and emergency response in case of any crowd disasters. Preparedness guidelines will be suggested after a crowd capacity and visibility analysis for better crowd control, using the visualization capabilities of 3D GIS. Response guidelines include the identification of emergency response vehicle routes to reduce the fatality rate. The methodology adopted for deriving these guidelines can be generalised for similar mass gatherings.

KEYWORDS: mass gatherings, preparedness, emergency response, GIS, crowd control and management

1. INTRODUCTION

India is home to some of the biggest mass gatherings in the world. History has shown that large crowd gatherings create annoyance to section of the society and are potentially prone to disasters including but not limited to stampede, crushing, asphyxiation and death (Mohd Arif Shuib, 2013). Mass gatherings in Urban areas such as the Allahabad Kumbh mela, Puri Ratha Yatra, Mumbai Ganesh Visarjan and Thrissur Pooram exerts incredible pressure on the urban living and infrastructure. Influx of large number of people into dense urban areas will challenge services and infrastructure systems which makes the management of these events more problematic. As per World Health Organization (2008) mass gathering is defined as “more than a specified number (may be as few as 1000, although much of the available literature refers to gatherings exceeding 25,000 persons) of persons at a specific location for a specific purpose for a defined period of time”. Gatherings that are planned well in advance, often referred to as ‘planned mass gatherings’, are of two types; one that happens regularly but at different locations and the other which repeats regularly but at the same location, such as the Thrissur Pooram (WHO, 2008). As stated by the International Federation of Red Cross and Red Crescent Societies (IFRC), disaster preparedness refers to “measures taken to prepare for and reduce the effects of disasters” and the primary aim of disaster response is given by IFRC as “rescue from immediate danger and stabilization of the physical and emotional condition of survivors.”

Learning from these definitions, this paper will outline preparedness and emergency response guidelines for potential crowd disasters specific to the Thrissur Pooram mass gathering. Despite constant efforts from authorities, Pooram have seen some unfortunate mis-happenings over the years. While Kerala eyes for growth in tourism, there is a need for research ensuring safe mass gatherings. Preparedness is a significant factor of disaster management and is key for the safe functioning of these gatherings. Also, in case of any mis-happening in a gathering, emergency services need to reach the venue in least possible time, which makes the emergency planning guidelines very important to reduce fatalities.

Limited literature is available on effective planning, preparedness and response to hazards at mass gatherings due to the lack of priority in that perspective (Faisel T. Illiyas, 2013). The National Disaster Management Authority (NDMA) provided a framework for crowd management, which specified general measures in various stages of disaster management cycle, to guide the administrators and organisers of gatherings (NDMA, 2014). Only a few studies investigated the applications of technologies like Geographical Information System (GIS) and remote sensing for avoiding crowd disasters. Mei-Po Kwan (2005) examined the potential of using 3D GIS for quick emergency response on multi-story office buildings. Christian J.E. Castle (2005) focused on utilising spatial decision support systems and GIS for modelling evacuation scenarios and quick emergency response in the aftermath of a disaster. While few studies focused on the utilisation of GIS for the response stage of a disaster, very few studies concentrated on the utilisation of those technologies for the preparedness stage. Highlighting this gap in the literature, this paper attempts to highlight the need of utilising 3D GIS techniques for disaster preparedness.

In the recent years, many researchers have done substantial amount of research on understanding dynamic nature of crowd and modelling crowd behaviours (Oberhagemann, 2012; Khozium, 2012; Gupta R., 2010; Johan Schubert, 2008; Fruin, 1993; Still, 2014). Schubert et al. (2008) derived crowd control strategies using decision support system and control strategies are derived from a set of pre-stored example situations using algorithms. To detect a possible crowd emergency, Deshpande and Gupta (2010) have proposed computer-based system combining fuzzy logic and GIS for pre-disaster planning as well as real time crowd analysis.

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Khozium (2012) contributed for the provision of crowd safety in one of Hajj rituals using a Hybrid Intelligent Information System. Dirk Oberhagemann (2012) gave detailed analyses of pedestrian flows, static and dynamic crowd densities and their potential hazard for risk minimisation at major public events. We employed the static and dynamic crowd densities calculated by Dirk Oberhagemann (2012) which will be further discussed in the following sections.

This study identifies the practices adopted by the event coordinators and gives suggestions for better preparedness and response for potential crowd disasters during Thrissur Pooram mass gathering while exploring the potential use of 3D GIS. The primary objective of this study is to provide disaster preparedness guidelines for better crowd control and management of event and the secondary objective is to provide suggestions for quick emergency response.

2. SITE CONTEXT AND PROBLEMS

Thrissur is the cultural capital of Kerala and the district headquarters with a spatial area of 101.42 km². The most recent data put the population at 315,957 making it the third largest urban agglomeration in Kerala (census2011). The city is built around Thaikenkadu maidan, a hillock of 0.26 km², with Vadakkunadan temple at its focal point. The innermost circular road in city called the Swaraj round surrounds this hillock and is the biggest round-about in south-east Asia. Thaikenkadu maidan (Pooram ground) is an eminent location for many political, educational and religious gatherings with Pooram being the most prominent of all. A National Highway and three State Highways traverses through the length and breadth of the city. The city has two private and one government bus stands, the private bus stand is the biggest in the state. The city is largely dependent on private buses, auto rickshaws and taxis for urban transport.

The highlights of the 36 hours Thrissur Pooram, which is considered as one of the greatest gatherings in Asia are; thirty adorned elephants, Kudamattom- the rhythmic change of decorated colourful parasols, fireworks and traditional orchestra. The major event, Kudamattom happens in southern part of ground and other events like traditional orchestra happen in west. In Kudamattom, two groups of temples with fifteen elephants each compete against each other standing face to face in east-west direction on the south side of the temple. Colourfully decorated Elephants parades across the city to finally reach the Pooram ground, in certain procession routes, see Figure 1.

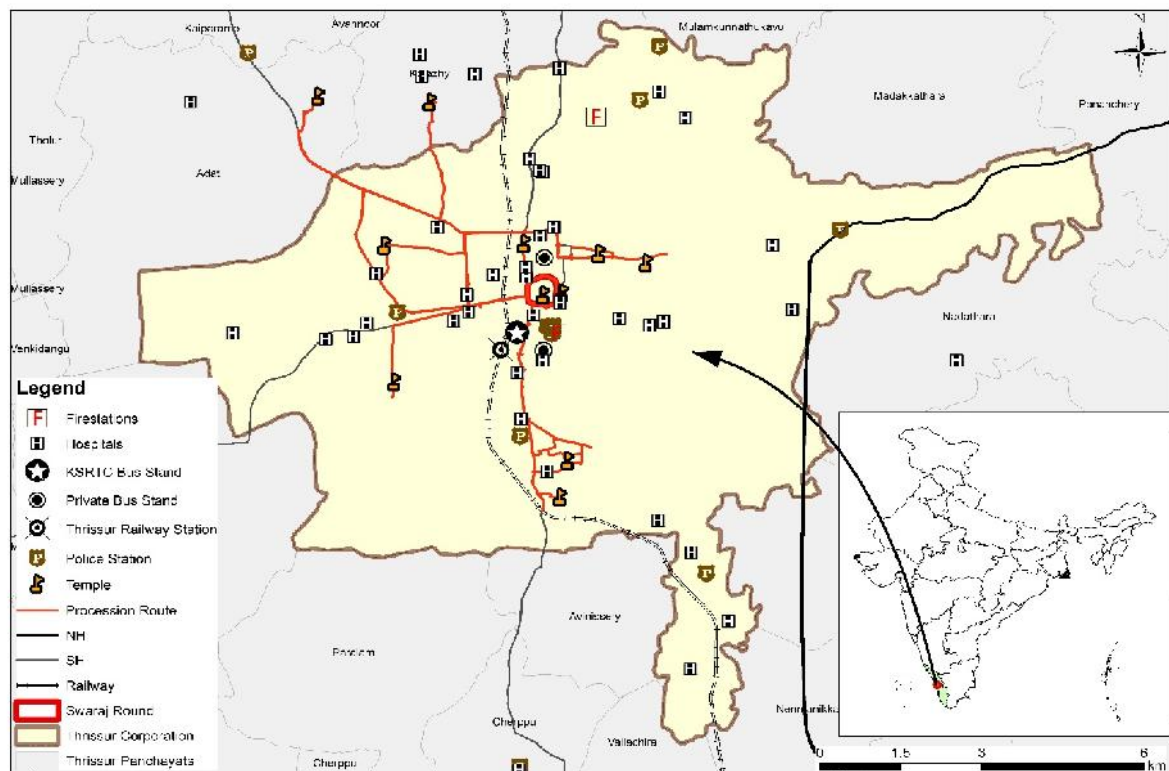


Figure 1. Study location map

Several people gather on roads to see the procession, and inflow of such heavy traffic in a short span creates a tremendous amount of pressure on infrastructure systems. Despite special efforts of event coordinators, women, children and foreign tourists could not get a comfortable or appropriate view of the event. Due to crushing and other safety concerns most of the women and many local people do not attend the event. The lack of information on the number of people gathered in the past Pooram gatherings makes it difficult to project the future scenarios. There is also lack of knowledge on the capacity of the venue making the safe crowd management hard.

3. METHODOLOGY

The study utilizes four primary source of information; satellite images, field studies, web GIS and literature. Thrissur district spatial plan(2011), high resolution satellite imagery and WebGIS platforms were referred for the identification of road and social infrastructure and in the preparation of base layers such as roads, open spaces and other important landmarks. The spatial data generated in WebGIS platforms was verified during field visits and is converted into GIS format. Interaction with Pooram authorities helped us identifying and mapping the temples participating in Pooram as well as the procession routes leading to Swaraj round. Venue and its surrounding areas were mapped in detail to get a better understanding of the facilities as well as the terrain. ArcGIS 10.2 was used for generating, storing and analysing the spatial data. The locational data collected from multiple sources is converted to geodatabase format in ArcGIS. Initial reconnaissance survey was followed by a detailed physical survey and interactions with concerned authorities and on-field staff helped us in attaining better understanding of the overall scenario of Thrissur Pooram-2017.

The various analyses carried out in this study include Emergency route identification, visibility analysis and crowd capacity analysis. Line of sight analysis is a three-dimensional visibility analysis undertaken to categorize zones based on the visibility factor. After spatially demarcating zones, calculations are done based on standards to find out the holding capacity of venue. After reviewing the existing emergency management system, we proposed the feasible emergency response vehicle routes. The maps in this paper including the results of analyses are outputs from ArcGIS. Preparedness and emergency response guidelines for Thrissur Pooram were outlined with the help of reviewed data and various analyses.

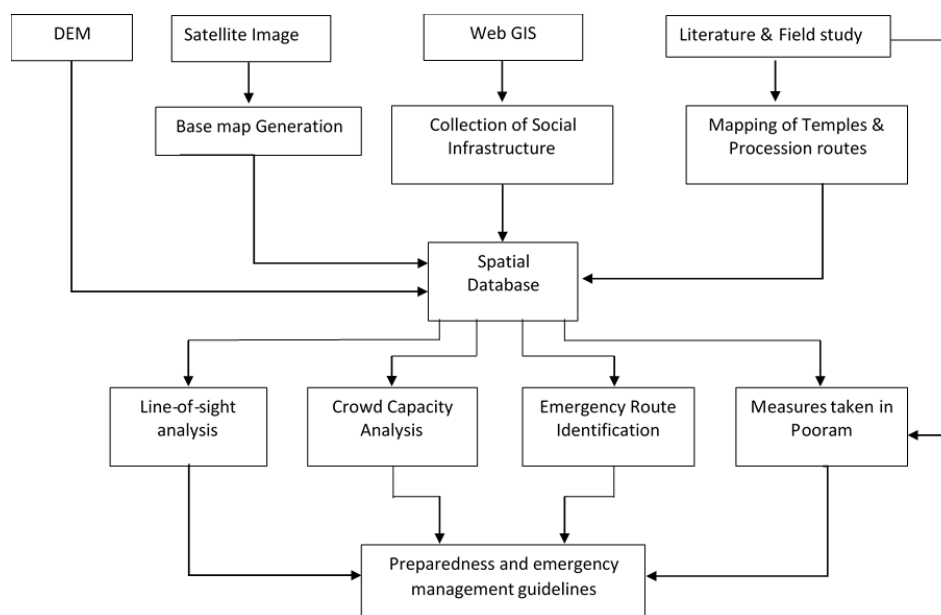


Figure 2. Stages in the evolution of Preparedness and emergency management guidelines

4. RESULTS AND DISCUSSION

The paper discusses the measures taken for the preparedness and emergency management of the event by the authorities. Crowd capacity of the area utilising the visibility analysis is calculated to improve the preparedness of the event. The existing emergency response measures are reviewed, and few guidelines are suggested for conduction of a safe event.

4.1 Measures taken for preparedness of the event

To understand the preparedness of the event, it is important to know the availability and readiness of critical infrastructure facilities and the traffic management plan that are implemented for the safe conduction of the event. This study utilizes the spatial data and the observations survey inputs from the 2017 Pooram.

The adequate number of social infrastructure facilities such as hospitals and police stations will ensure the operational efficiency and safe conduction of the event. As the travel distance increases, the risk to reach the hospitals rises, as the city roads will be hindered with traffic congestion. Seven major hospitals come under the 1Km radius of Swaraj Round and can act as the emergency aid. With as many as nine police stations and one Kerala police academy in Thrissur, there are adequate security personnel for safeguarding the event. For 2017 Pooram as many as 3500 police personal were deployed for the safety and security (source). For security purposes the authorities divided the ground area and swaraj round into different categories. With a fire training institute and one fire station within the city, emergency firefighting staff and vehicles were provided during the event. As part of event preparedness and capacity building the access for emergency resources including ambulances and fire engines was taken care by the authorities.

For safe traffic and parking management, special guidelines are laid by authorities during the days of Pooram. The vehicular traffic in and around Swaraj round will be restricted to avoid any unfortunate events. Two bus stands, within a range of 1.5km from Swaraj round receive the major share of buses while a bus stand which is close to Swaraj round will remain closed. Major share of the

people visiting Pooram do not stay in Thrissur but in the neighbouring places such as Guravayoor and visit only at the time of event, thus those people who reach Thrissur by rail or road, usually walk to Swaraj round. Limited passes are provided for police vans, few Pooram committee vehicles and ambulances to enter the swaraj round. Special parking arrangements are made during Pooram in both government and private vacant spaces spreading across the city and still cannot meet the need of parking. The procession routes which include both major and minor roads, see Figure 1, are cleared of traffic at the time of the procession. The procession routes which witness thousands of pilgrims during the procession are lacking proper infrastructure and face issues such as uneven footpaths, potholes and down-and-out drainage system.

4.2 Crowd size estimation using visibility analysis

The crowd capacity of the Pooram ground is determined based on the visibility analysis. For efficient crowd control and management, one requires the knowledge of crowd capacity of the venue and the major crowd concentration areas. The Pooram committee and other agencies involved in the management proved to be successful in organising the event, where we identified few gaps for efficient crowd control. A field study of Pooram-2017 helped in identifying the functional and crowd control issues. There is no precise method to count the number of tourists that have attended the Pooram, especially the number of people being accumulated in the ground. Every year different surveys and organizations come up with different number of attendees. Attention should be focused on the risks associated in overcrowding of the event space. As stated by Oberhagemann (2012) the major approach of any government should be to know the count of people that can be contained without risk.

For further analysis, we differentiated the crowd on the ground into two categories: Static and Dynamic crowd, based on the observational study during 2017 Pooram. According to Still G. K. (2014) static crowds are the crowds that are relatively stationary and dynamic crowds are the crowds which are typically moving. During the main event the south side of the ground will be densely crowded and is considered static. Figure 3 shows the space distribution of Pooram ground along with various entries and exits. Public park in the north-east is excluded from the analysis as the entry to that area is not from ground. Exhibition space in the east along with north and North-west areas of ground which have basic facilities like toilets and hawkers are considered as dynamic crowd.



Figure 4. Space distribution of Pooram ground and its surroundings

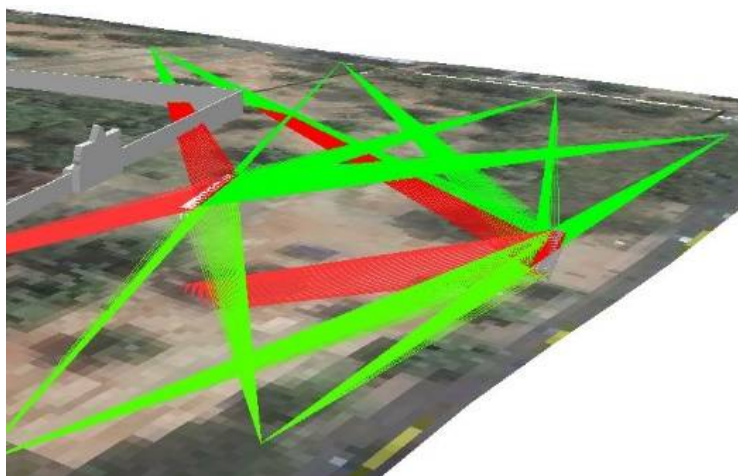


Figure 3. Line of sight analysis using DEM with 3D models of temple gateway and wall, and elephants; green lines-visible, red lines-invisible

Line of sight analysis is chosen to identify the visibility towards major event of the gathering – Kudamattom. Line of Sight analysis calculates the inter-visibility of the observation point and the target, line-feature, in 3D space while taking the consideration of all obstructions provided by a surface or any 3D feature. The current model features the upright elephants (standing at the centre of the event) as target and several observation points are taken plausibly in the ground. GPS coordinates are taken all along the ground leading to the generation of elevation points, which are further interpolated to obtain Digital Elevation Model. Three-dimensional surface was generated using highly accurate DEM in Arc Scene and satellite image was draped for 3D effect. By varying the observation points, visibility from different areas in the ground is calculated and 3D models of the temple wall and gateway are taken as the obstruction layers. The output is represented as three dimensional lines with visibility codes, where

green means visible and red means invisible, see Figure 4. Temple entrance gateway and wall are obscuring the visibility towards north direction. As seen in the Figure 4 the elevation difference in the ground also affects the visibility from certain areas. Based on visibility from several observation-points the area is divided into two zones, see Figure 5. The first zone comprises the area which provide maximum visibility i.e., people in that zone can see both groups of elephants and the second zone belongs to medium or poor visibility as only one group of elephants can be viewed from there, either completely or partially.

The crowd capacity analysis took into consideration the line-of-sight analysis to delineate the static crowds (stationary) and Dynamic crowds (moving) in the venue area. The area demarcated by line-of-sight analysis is considered static crowd and the remaining areas are taken as typically dynamic crowds. The Pooram ground of about 600mts diameter is only 130mts wide on the southern side of temple and thus

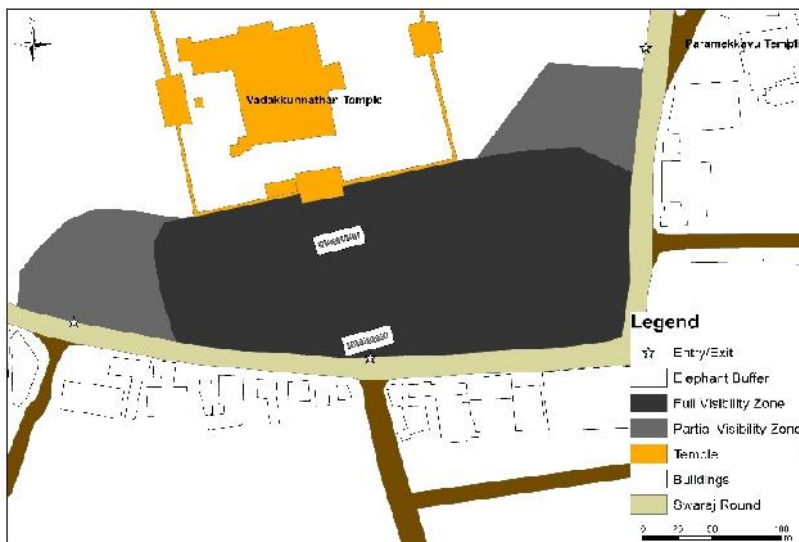


Figure 5. Zones of full visibility and partial visibility

reduces the area for full visibility. Based on line-of-sight analysis the static crowd zones i.e., 'Full visibility' and 'partial visibility' zones, have an area of 41,478 m² and 13605 m² respectively. The remaining portion of the ground excluding the temple, Nehru Park and exhibition areas sums up to 42,700 m² which is dynamic crowd area.

Several studies (Oberhagemann, 2012; Still G. K., 2014; Still G. K., Event Industry Association of Ireland, 2015; RainaldLohner, 2014) are conducted to identify the critical static and critical dynamic crowd densities. Oberhagemann (2012) calculated that densities of 5-6 p/m² must not be exceeded in static crowds to minimise the risk. The threshold for a critical crowd density is given as 6.0 p/m². For pedestrian flows there is no risk of congestion up to 1.5 p/m² and first stage of congestion is reached at a crowd density of approximate 2 p/m².

This paper considers the crowd densities calculated by Oberhagemann (2012) to determine the crowd capacity of the Pooram gathering. Table 1 summarises the results of Crowd Capacity analysis by assuming both 'full and partial visibility zones' are equally dense.

Table 1. Crowd capacity of Pooram ground

	Crowd Densities (persons/m ²)	Crowd count in static crowd zones (persons)		Crowd count in Dynamic crowd zones (persons)		Total crowd limit (persons)
		'Full visibility' zone area- 41,478m ²	'Partial visibility' zone area- 13,605m ²	Dynamic crowd zone area- 42,700m ²		
Acceptable limit	Static- 5 p/m ² Dynamic- 1.5 p/m ²	41,478* 5 = 207,390	13,605*5 = 68,025	42,700 * 1.5=64,050		339,465
Critical limit	Static- 6 p/m ² Dynamic- 2 p/m ²	41,478* 6 = 248,868	13,605*6 = 81,630	42,700 * 2 = 85,400		415,898

The crowd capacity analysis establishes the need of limiting crowd entry into venue to reduce the risk of crowd disasters such as stampedes. Pooram authorities and local sources estimate the crowd during Pooram to be around 6-7 lakh per day and the influx of tourists is increasing every year. During Pooram there is no track of the number of people entering and leaving the ground from various entry and exit points. For effective and safe crowd control it is recommended to limit the crowd inside the venue area to critical limit. The provision of scanners for mass-crowd counting at the entry and exit points will make the crowd size estimation easier.

4.3 Emergency Response

There is immediate need of emergency response plan for Thrissur Pooram in the view of ever increasing numbers of tourists and limited venue area. The development of city around the Pooram ground, facilitated with amenities like police stations, hospitals and fire stations in close proximities, can make the emergency response efficient. This paper talks about an important component of any emergency plan which is the identification of emergency routes. Currently, in case of any emergency during Pooram, the Chembottil lane, see Figure 6, is used as an emergency route. The lane is very narrow with many obstructions and it is not practical to have this lane as the only emergency route.

Emergency response vehicle access routes for the area are identified based on the proximity to fire protection and emergency medical services. Figure 6 shows the identified emergency routes which connects major hospitals and fire station. As shown in the figure 6, as many as 7 hospitals come within the 1Km buffer zone around Swaraj Round and 10 hospitals come in between 1km and 2Km distance. Nearest major hospital is only 200mts away from the Swaraj round making it easier for quick response. The entry/exit gates which are close to the emergency routes can be identified as emergency exits.

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EMPIRICAL MODEL FOR REAL TIME STAGGER COMPUTATION

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ABSTRACT

The staggered array configuration is widely used in satellite imaging systems mainly to improve the resolution, increase the swath and to overcome the technological constraints of onboard electronics and charge leakage between adjacent CCD elements. Though the design and arrangement of CCD arrays is fixed in the focal plane, it is observed that the stagger value when projected on the ground changes according to the view angle. During the product generation this value is computed and applied using rigorous sensor model. Computation of stagger value involves considerable amount of time and poses a challenge for real time implementation as it involves a series of floating point operations and evaluating mathematical functions used to describe the rigorous sensor model. This paper brings out a linear regression model based stagger computation dependent only on attitude of the satellite. This model speeds up the computation of stagger value for near real-time realization of product generation on hardware using FPGAs.

KEYWORDS: sensor model, staggered array, stagger correction, real time implementation, FPGA.

1. INTRODUCTION

The use of staggered arrays for remote sensing systems started with SPOT5 and later by ORBView-3 (George Joseph, 2015) for improving the resolution. In case of high resolution imaging sensors, the size of CCD element is of the order of few microns, which poses challenges in error free image acquisition in terms onboard electronics, accurate localization of optical instruments and charge leakage (pixel-cross talk) between immediate/adjacent CCD elements (Herbert Jahn, 2000). These constraints compel a designer for custom design the sensor configuration and device placement in the focal plane. To overcome the above said issues, the design adopted for cartosat-2A, cartosat-2B focal plane with two arrays is shown in figure (1). Staggered array configuration is obtained by shifting two linear CCDs in along the track/ velocity direction by 5 lines. This configuration has some disadvantages besides the cause for its design. The physical gap between the two arrays implies that the adjacent ground pixels are not acquired at the same time which induces misregistration problems linked to time dependent platform disturbances. The registration accuracy will depend on any disturbance concerning the satellite orbit, the platform attitude (roll, pitch, yaw angles) or the instrument itself. These disturbances are annoying if their frequency is compatible with the time lag but cannot be measured by on board monitoring instruments such as GPS gyros (Singh.A.K., et.al., 2011).

This paper brings out a simple model based stagger computation based only on attitude of the satellite. This model is useful for near real-time realization of product generation on hardware using FPGAs. First we observe that the value of stagger changes as a function of viewing angles namely roll, pitch and yaw. Now we assume stagger as a mathematical model consisting of these variables in the form of sum of individual terms and/or interaction terms. However there is an ambiguity in selection of variables that really contribute a true model to represent stagger (Kutner, 2004). Many variable selection procedures are available in statistical literature to address this ambiguity (George E.I., 2000) using multiple criteria (Kadane., et.al., 2004). Here in this paper we propose to use stepwise regression model for an appropriate model generation. We carry out the said procedure on many data sets of Carto-2A and 2B. The results suggest that a model upto second order terms can explain 97% of the variability of the stagger data.

2. GEOMETRY OF STAGGERED ARRAYS

The payload design of Cartosat-1 and Cartosat-2 is such that the odd and even detectors are staggered by five scan lines (35 μ m) in the focal plane as shown in Figure 1. However, this separation in the focal plane does not translate into a constant stagger in the image data. The impact of line separation in the focal plane during imaging with different viewing configurations results in misregistration. Stagger varies along the track with different scan angles which results in a variable sampling pattern on ground. Therefore, video alignment by simple sliding the images from the two arrays (by five lines) is not feasible. The stagger parameters are computed by the reconstruction of the viewing geometry with a calibrated camera

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geometry model (Radhadevi, et. al., 2010). Reconstruction of the viewing geometry includes the exterior and interior orientations of the sensor. The image data of both staggered lines can be combined using a one-dimensional re-sampling which accounts for all these effects. The model is designed to provide an accurate method of transforming points from image space to object space and vice versa.

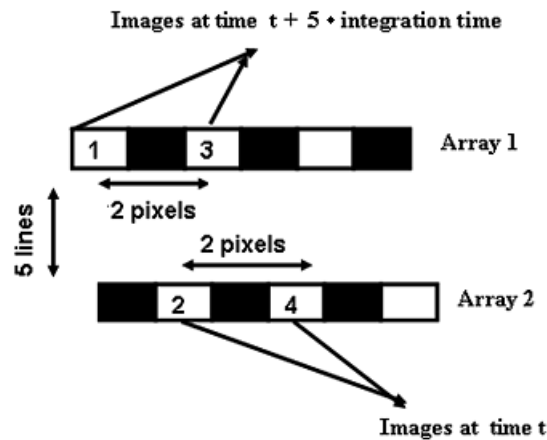


Figure1. Stagger Array configuration

2.1 Calculation of stagger value

Ground coordinates are computed for a particular pixel in an odd array using the initial fitted trajectory. Height at this particular point is interpolated from a public domain DEM such as SRTM. Re-projection of this ground point is done to the even array. The difference between the image co-ordinates computed in the even array and odd array gives the effective stagger parameter. The schema is shown in Figure (2).

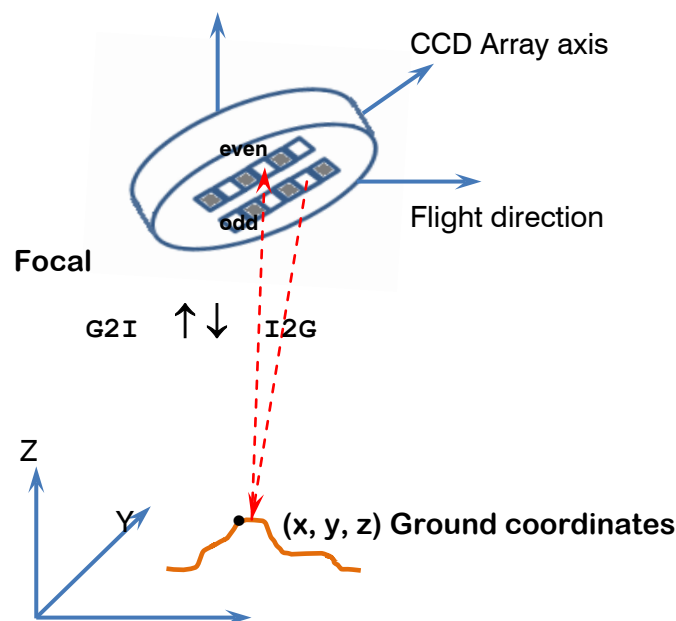


Figure 2. Pictorial depiction of Stagger calculation scheme

2.2. Algorithm for Stagger correction using geometric model

Inputs : satellite ephemeris, starting values of scan, pixel, approximate height, Datum.

Output : stagger value.

1. calculate the approximate values of latitudes and longitudes using Image-to-Ground (I2G) transformation from starting scan and pixel values and given ephemeris.

2. calculate the corresponding scan and pixel values of latitude, longitudes obtained in step (2) using Ground-to-Image (G2I) transformation.
3. The difference in scan lines gives the stagger value.

The important observation that stagger depends up on the orientation of the satellite position and attitude suggests us to model the stagger value(s) as a function of roll (r), pitch (p) and yaw (y) angles.

As an exercise we have collected orbit and attitude data of thousands of scenes acquired on different days from Cartosat-1 and Cartosat-2 image database.

Figure 3 shows the stagger calculated using above algorithm for thousands of data sets. The positive and negative stagger values correspond to main and redundant CCD arrays respectively. For the analysis purpose we consider positive values only, the observations hold good for negative values as well with different model coefficients.

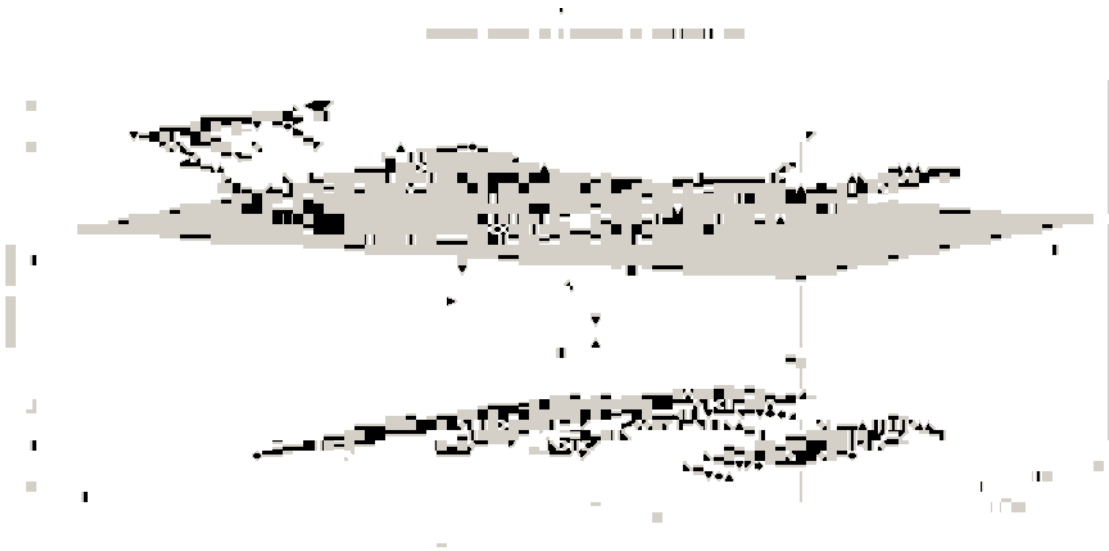


Figure 3a. Scatter plot of stagger against roll and pitch

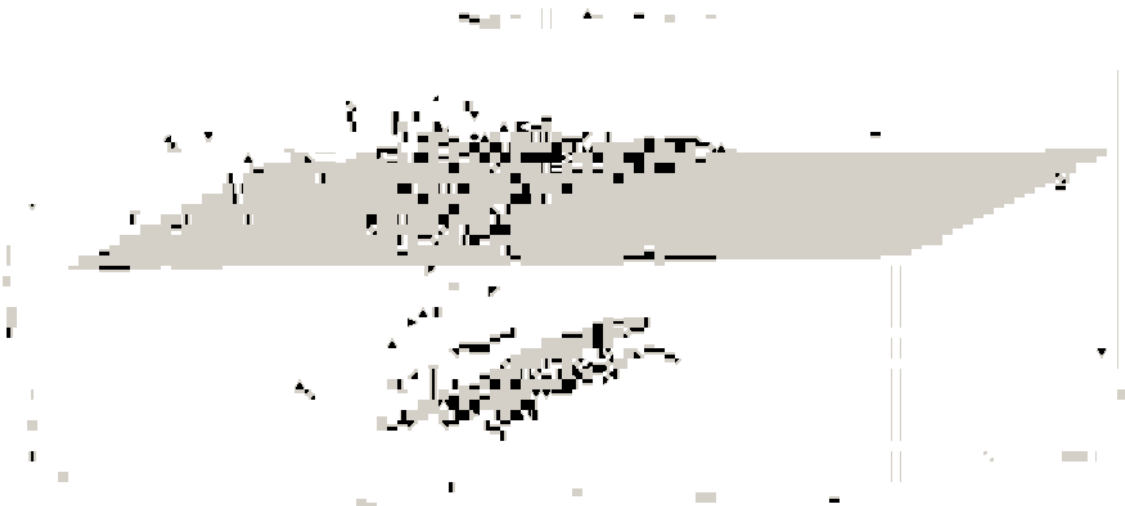


Figure 3b. Scatter plot of stagger against roll and yaw



Figure 3c. Scatter plot of stagger against pitch and yaw from different data sets.

3. EMPIRICAL MODEL FOR STAGGER COMPUTATION

Three empirical models (s_1 , s_2 or s_3) studied for different satellite ephemeris are given as follows

The models $s = f(r, p, y)$ under study are as follows

$$s_1(r, p, y) = b_0 + b_1r + b_2p + b_3y \quad (1)$$

$$s_2(r, p, y) = b_0 + b_1r + b_2p + b_3y + b_4rp + b_5py + b_6yr + b_7r^2 + b_8p^2 + b_9y^2 \quad (2)$$

$$\begin{aligned} s_3(r, p, y) = & b_0 + b_1r + b_2p + b_3y + b_4rp + b_5py + b_6yr + b_7r^2 + b_8p^2 + b_9y^2 \\ & + b_{10}rpy + b_{11}r^2y + b_{12}ry^2 + b_{13}rp^2 + b_{14}r^2p + b_{15}p^2y + b_{16}py^2 \\ & + b_{17}p^3 + b_{18}r^3 + b_{19}y^3 + b_{20}rpy \end{aligned} \quad (3)$$

Model s_1 consists of a terms roll, pitch and yaw terms up to order 1.

Model s_2 consists of roll, pitch, and yaw terms taken up to second order along with all interaction terms (rp, py, yr) to study coupled effects.

Model s_3 consists of roll, pitch, and yaw terms up to an order of 3 which includes all possible interaction terms.

The model parameters are obtained using Least squares fitting to models s_1, s_2, s_3 by minimizing the error term $L(e_i) = \sum_{i=1}^k e_i^2$ where $e_i = s_i - s_1(r, p, y)$ for the given data $(r_i, p_i, y_i, s_i), i = 1, 2, 3 \dots k$.

The normal equations derived for model s_1 is given by

$$\begin{bmatrix} n & \Sigma r & \Sigma p & \Sigma y \\ \Sigma r & \Sigma r^2 & \Sigma rp & \Sigma ry \\ \Sigma p & \Sigma pr & \Sigma p^2 & \Sigma py \\ \Sigma y & \Sigma yr & \Sigma yp & \Sigma y^2 \end{bmatrix} \begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} \Sigma s \\ \Sigma rs \\ \Sigma ps \\ \Sigma ys \end{bmatrix}$$

solving the above normal equations with the available profiles of roll, pitch, yaw and the corresponding computed stagger values we obtain the parameters b_0, b_1, b_2, b_3 .

Similarly, the normal equations for models s_2 and s_3 can be formulated. Three empirical models (s_1, s_2 or s_3) are studied for different satellite ephemeris of many data sets of Cartosat-2A and Cartosat-2B.

4. RESULTS AND DISCUSSION

A common concern in regression with multiple variables is overfitting, stepwise multiple regression is a familiar approach to control overfitting [5]. We carried out stepwise linear regression procedure to find out the significant predictors that really represent the data well. Stepwise linear regression has removed the term $p \cdot y$ in s_2 as its p-value is 0.432 and do not contribute significantly ($\alpha = 5\%$) to improve the model s_2 . From table-1 we note that the R^2 and adjusted R^2 values for s_2 is better than s_1 and only marginally lesser (0.1%) than s_3 . Similar observation can be made for RMS errors, ie., RMS error for model s_2 is lesser than s_1 and slightly more (0.1%) than s_3 . Figure (4) and Figure (5) displays the actual stagger value and the model s_2 . The error between the models s_1, s_2, s_3 and the corresponding profile number of the stagger data are given in figures (6), (7) and (8).

The impact of third order terms such as $r \cdot p \cdot y$, $r^2 \cdot p$, $r \cdot p^2$ etc., in model s_3 have not significantly contributed ($<0.1\%$) in explaining the model variation compared to model s_2 . The loss in representing the computed stagger value with s_2 model is only 0.01 of a pixel which will not hamper the accuracy of stagger value. Almost similar results are observed with many data sets of C2B. Hence with the above observations we consider model s_2 as a representative empirical model for stagger computation since model s_1 is not adequate and s_3 do not offer a significant improvement over model s_2 as seen from figures (7) and (8), furthermore, a good model with fewer terms runs faster and apt for real time implementation.



Figure 4. Model s_2 for Cartosat-2A

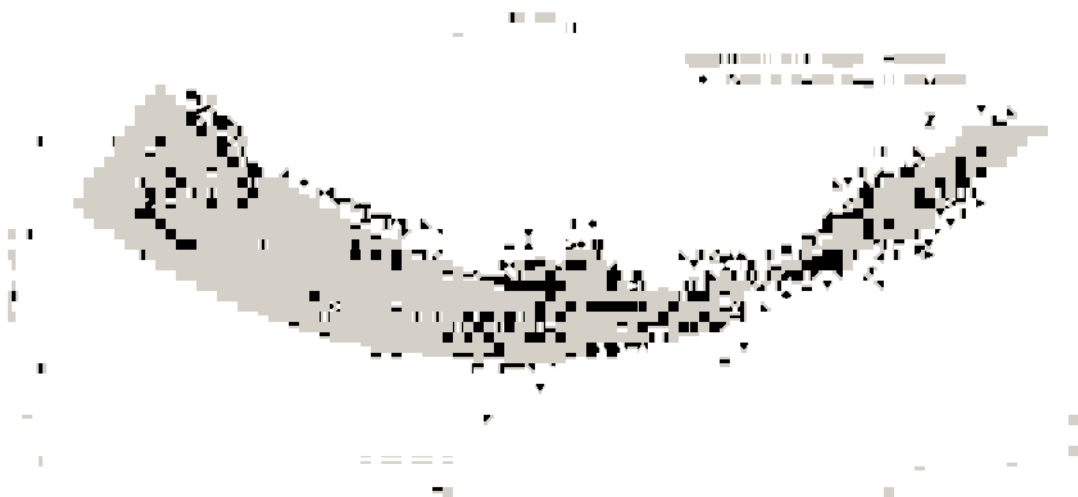


Figure 5. Model s_2 for Cartosat-2B

Table 1. Coefficients and RMSE values for models s_1 , s_2 , s_3 for main array of Cartosat-2A.

Estimated Coefficients for C2A:

Model	Estimated Coefficients		tStat	pValue	RMSE, R^2 , Adj- R^2
	term	Coeff. (b_i)			
s_1	Constant	5.635	623.65	0	0.751
	r	-0.0019409	-4.6979	2.6452e-06	0.0384
	p	0.0084195	26.922	6.0744e-157	0.0383
	y	-0.0074098	-9.4111	5.408e-21	
s_2	Constant	4.9872	2692.6	0	
	r	-0.0016775	-14.875	9.0149e-50	
	p	-0.00099312	-17.256	3.1582e-66	
	y	-0.0011309	-7.0372	2.0275e-12	0.105
	$r:p$	0.00035359	62.81	0	0.971
	$r:y$	-0.00014387	-13.687	1.925e-42	0.971
	r^2	0.00089825	192.03	0	
	p^2	0.0020631	760.87	0	
	y^2	-7.4932e-05	-20.581	4.0457e-93	
s_3	Constant	4.9715	1736.1	0	
	r	-0.0011062	-5.6688	1.4585e-08	
	p	-0.0065959	-28.836	4.5794e-179	
	y	-0.0016651	-6.1378	8.5298e-10	
	$r:p$	6.778e-05	6.2227	4.9863e-10	
	$r:y$	1.1818e-05	0.84959	0.39557	
	$p:y$	-0.00011213	-8.1636	3.45e-16	
	r^2	0.00086596	101.18	0	
	p^2	0.0021888	387.05	0	0.0987
	y^2	1.8372e-05	3.0066	0.0026456	0.974
	$r:p:y$	-2.2867e-05	-32.311	4.1049e-223	0.974
	$r^2:p$	7.6818e-06	15.716	2.5766e-55	
	$r:p^2$	3.4715e-06	9.9544	2.7453e-23	
	$r^2:y$	-7.0307e-06	-8.6469	5.6986e-18	
	$p^2:y$	8.8596e-06	18.537	4.713e-76	
	$r:y^2$	2.1043e-06	5.7553	8.7813e-09	
	$p:y^2$	-1.5621e-06	-6.6361	3.3063e-11	
	r^3	1.6409e-06	4.4126	1.0269e-05	
	p^3	5.7256e-06	18.188	2.626e-73	
	y^3	8.9837e-07	7.3956	1.4653e-13	

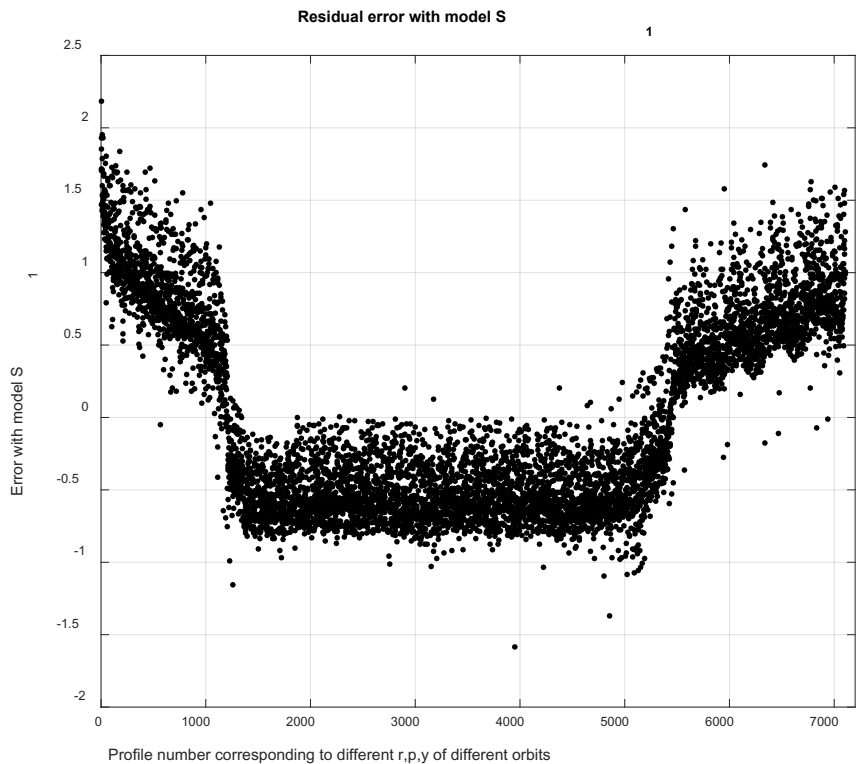


Figure 6. Residual error with model s1

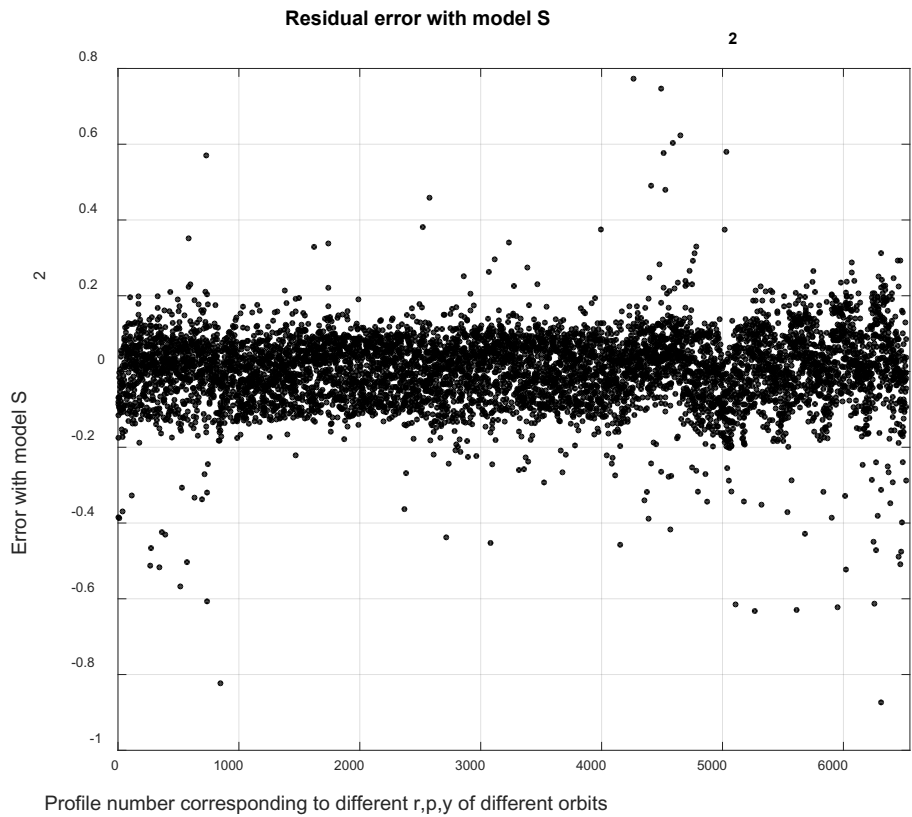


Figure 7. Residual error with model s2

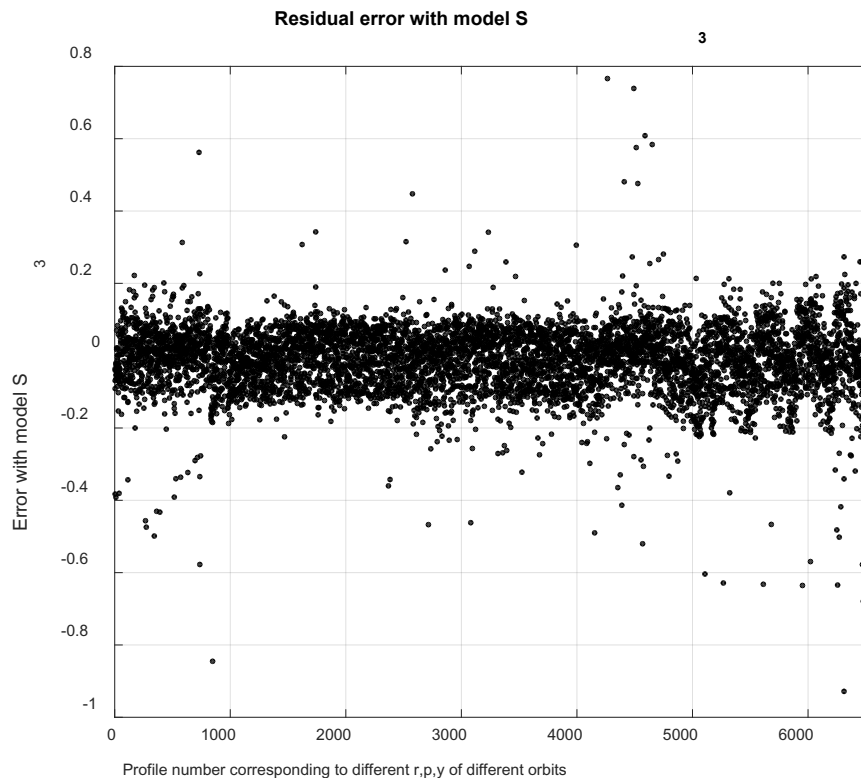


Figure 8. Residual error with model s3

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COMPLEMENTRY MULTI-FREQUENCY InSAR DATA- A SIMULATION

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ABSTRACT

In microwave remote sensing, backscattering information of different features of SAR images is a function of transmitted signal's wavelength, type of terrain, look angle and many other system and ground parameters. This backscatter information in different frequencies for different targets comes from different penetration levels. So, there is a need for multi frequency SAR missions to enhance the information and better utilization of SAR data. ISRO is planning to launch its first multi-frequency SAR mission NISAR (NASA ISRO Synthetic Aperture Radar) which will provide S and L band space borne SAR data with high repeativity, high resolution and large swath with full polarimetric and interferometric modes of operations. Interferometry (InSAR) techniques are applied in microwave remote sensing for generation of digital elevation model (DEM), surface change, displacement and motion maps from the interference of phase of two or more SAR acquisitions over the same area. InSAR products have inherent phase error. This phase error can be due to various reasons like system noise, decorrelation for non-simultaneous imaging acquisitions, image mis-registration, geometric decorrelation and atmospheric phase screen (APS) difference between acquired InSAR pairs. To reduce the phase error and utilizing complementary information of both the bands, S & L band InSAR phase information are exploited. In this paper, we have presented the generation of simulated raw data for InSAR mode for S and L band of NISAR and applied Interferometry process on the above simulated InSAR pair individually and final results are generated by fusion of interferograms of S and L band InSAR pair. Repeat pass across track InSAR pair of L and S-band for same geographic terrain has been simulated using ADRIN's SAR raw data simulator using local terrain model and sensor parameters of NISAR. This interferometric pair raw data was processed using ADRIN's generic Synthetic Aperture Radar Processor (ShARP+). InSAR process is applied on this processed pair under the same environment. Fusion provides better and continuous phase information complementing each other for the accurate and reliable end product generation. The present work shows fusion of S and L –band Interferogram improve InSAR phase quality. The result is promising and better as compared to single frequency InSAR pair.

KEYWORDS: Manuscripts, SAR raw data simulation, InSAR, NISAR, Back-scattering coefficient, Targets, Phase unwrapping, State vectors, Interferogram, ShARP+

1. INTRODUCTION

Synthetic Aperture Radar (SAR) records electromagnetic energy of backscatter and phase delay of the signal. SAR is used for mapping the scattering properties of the Earth's surface in the respective wavelength and many physical and geometric parameters of the imaged scene contribute to the grey value of a SAR image pixel. SAR data taken at different wavelength, polarization, time, incidence angle, etc. SAR backscatter information of different system parameter is different. To enhance the backscatter information and better utilization of SAR data, multi frequency SAR missions are required. In this context ISRO also launching multi-frequency SAR mission NISAR (NASA ISRO Synthetic Aperture Radar) which will provide S and L band space borne SAR data with high repeativity, high resolution and large swath with full polarimetric and interferometric modes of operations.

Synthetic aperture radar is a coherent active microwave radar imaging technology. The coherent property of SAR is used in Interferometric Synthetic Aperture Radar (InSAR). Interferometry is a technique in the field of microwave remote sensing for precise measurement of topography, surface change and surface displacement from the interference of phase of two or more SAR acquisitions over the same area. InSAR is the synthesis of conventional SAR techniques and interferometry techniques.

Simulation of SAR raw data is useful for mission planning, SAR system design, processing algorithm testing, and inversion algorithm design. To investigate the utilization of multi frequency SAR missions we have simulated the SAR raw data for InSAR mode for S and L band of NISAR mission and applied the vegetation and dense/snow backscattering coefficient on the simulated data of S and L band. To observe the backscattering effect on different wavelengths on SAR phase, InSAR process was applied on both the simulated pairs individually. To compare the phase information loss on vegetation and snow coherence maps are compared. Final results are generated by fusion of interferograms of S and L band InSAR pair to reduce the phase information error or coherence loss.

In this paper we have presented ADRIN's SAR raw data simulator that can be used to generate SAR raw data for different imaging modes such as spot, sliding spot and strip along with InSAR pair. The simulator can simulate data for different frequency bands, polarizations, squint angles and also for different surface covers. The raw data is simulated using sensor state vectors, local terrain model (from SRTM DEM) and other sensor parameters. Local incidence angle map is generated using sensor orbit and SRTM DEM. This incidence angle map is used to generate terrain's back scattering coefficients. Simulation algorithm also includes an azimuth and range antenna pattern that provides the variation of signal strength as a function of squint, beam width and pulse width.

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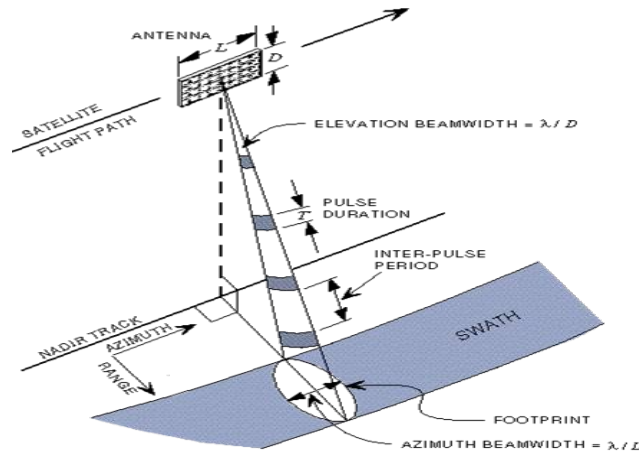


Figure 1. SAR geometry

This paper is organized as follows. Section II explains SAR raw data simulation. Section III explains the techniques of SAR interferometry. Section IV provides the results and comparison between simulated L band and S band InSAR pairs. Section V concludes the paper.

2. SAR RAW DATA SIMULATION

Synthetic aperture radar is an active side-looking microwave sensor. SAR geometry is explained in Fig. 1. Expanded response of all the targets present in antenna footprint is known as SAR raw data. The raw data compression is done by match filtering. Steps involved in simulation of SAR raw data are as follows:

2.1 Sensor State Vector Estimation

Sensor state vectors for every pulse repetition interval can be estimated by interpolating its orbit. The interpolation is needed because satellite state vectors are not available at particular imaging interval. Thus, prior information about start state vectors, end state vectors and pulse repetition interval are needed. In case, orbit prior information is not available, NORAD SGP4 orbit propagation model can be used to simulate sensor's orbit for a given epoch using TLE.

2.2 Local Incidence Map Generation

Local incidence angle is a very important parameter for SAR simulation. It is explained in Figure. 2. SRTM DEM was used for terrain information (latitude, longitude and height). These lat, long and height parameters of terrain are converted into ECEF co-ordinate system. The angle between local normal and the line joining sensor position vector and ground object position vector is known as local incidence angle.



Figure 2. Local incidence angle computation geometry

2.3 Back-Scattering Coefficient Estimation

Back-scattering coefficient of a terrain for a given sensor will depend on its local incidence angle, polarization, imaging band and type of terrain and its dielectric constant. Back-scattering coefficient is being calculated from parametric equations given in [1].

2.4 Raw Data generation

Raw data generation is explained in following flow diagram-

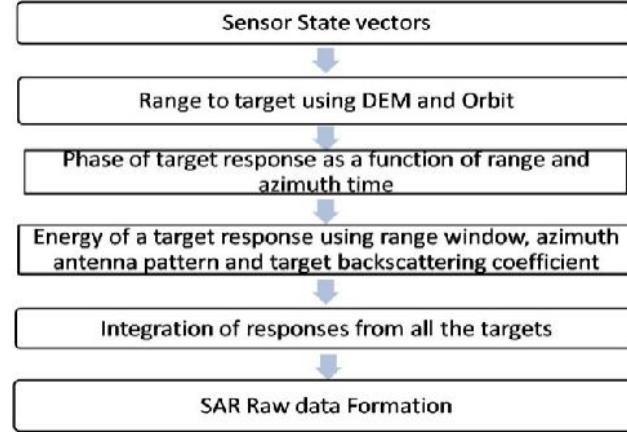


Figure 3. SAR raw data simulation steps

Demodulated baseband signal (Equation (1)) given in [3] was used to generate raw data. It is a function of range and azimuth time. In Equation (3), A_o contains the information about back-scatter and antenna pattern. w_r (Equation (2)) and w_z (Equation (3)) are range and azimuth windows respectively. In Equation (1), τ represents range time of the emitted signal, R is the slant range, f_o is Carrier frequency, η and η_c are azimuth time and azimuth time at zero Doppler. K_r is range FM rate and Θ represents squint angle.

Demodulated Baseband Signal	Range Window	Azimuth Antenna Pattern	Azimuth chirp signal	Range chirp signal
-----------------------------	--------------	-------------------------	----------------------	--------------------

$$s_o(\tau, \eta) = A_o w_r \left(\tau - \frac{2R(\eta)}{c} \right) w_a(\eta - \eta_c) \exp \left\{ -\frac{j4\pi f_o R(\eta)}{c} \right\} \exp(j\pi K_r (\tau - 2R(\eta)/c)^2) \quad (1)$$

$$w_r = \text{rect} \left(\frac{t}{T} \right) \quad (2)$$

$$w_a(\eta - \eta_c) = \text{sinc}^2 \left\{ \frac{0.886(\theta_{sq} - \theta_{sq,c})}{\beta_{bw}} \right\} \quad (3)$$

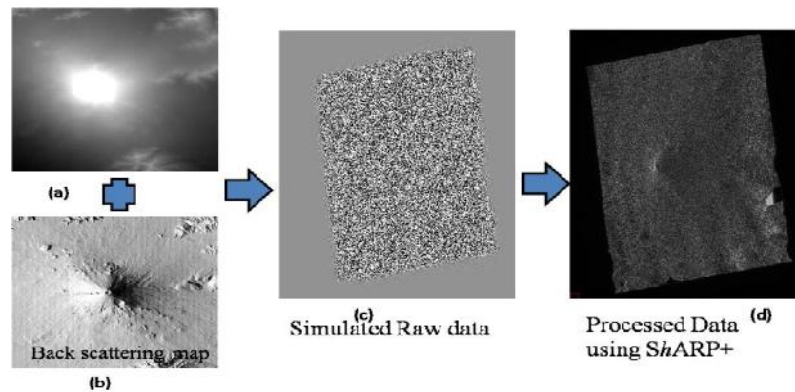


Figure 4. SAR raw data simulation procedure. (a) represents SRTM DEM, (b) represents back scattering map for a given sensor (here ALOS PALSAR) and given terrain using DEM. (c) represents the simulated raw data using sensor parameters, SRTM DEM and back scattering map for the given terrain. (d) represents the final amplitude image i.e., processed image

A simple SAR raw data simulation model has been presented in Figure 4.

3. SAR INTERFEROMETRY TECHNIQUE

SAR Interferometry is a unique technique for mapping the Earth's land, ice, sea surface topography, change detection and mapping of surface displacements over large temporal and spatial scales with precision of cm to mm range. SAR Interferometry is based on the coherence of SAR signal. The recording of two images of the same area from different across track position and the utilization of phase information of the SAR images to form phase difference image results into interferogram. Interferogram phase values are periodic function of 2π . Figure. 5 shows across track InSAR geometry.

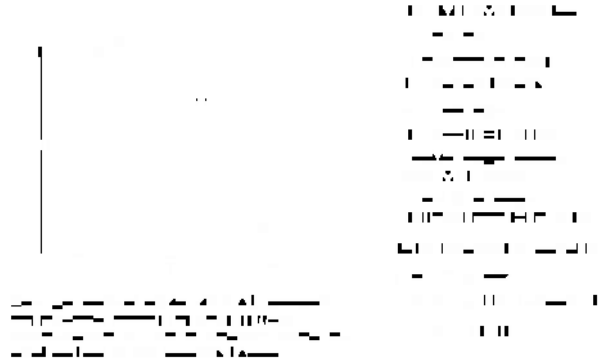


Figure 5. InSAR Geometry

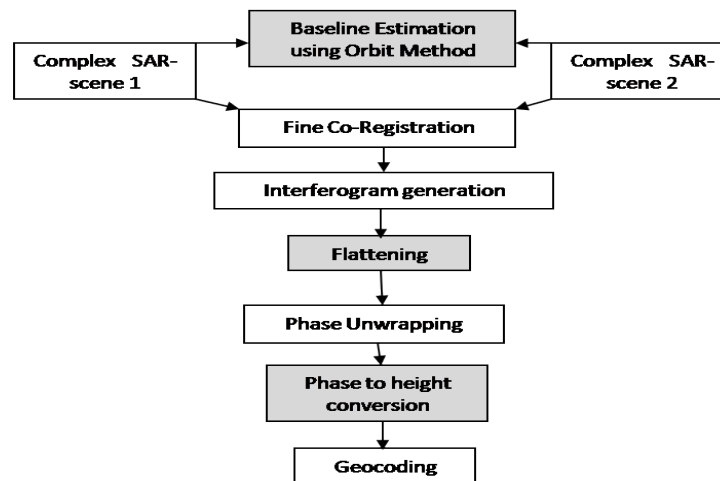


Figure 6. Block diagram of InSAR processing

We have developed an across track Interferometry automated module. Across track Interferometry processing steps are fine co-registration, interferogram generation, coherence map generation, adaptive filtering, baseline estimation using orbit method, flattening, phase unwrapping, phase to height conversion and geocoding. Figure. 6 shows block diagram of InSAR processing steps.

4. RESULTS AND ANALYSIS

Raw data was simulated for both L-band and S-band interferometric pair in strip imaging mode with zero squint. Sensor parameters for raw data simulation are mentioned in Table. 1. Back-scattering model of short vegetation was used for both the InSAR pair datasets to get natural speckle in data. For multi frequency interferometry analysis we used shrubs vegetation backscatter model in small ROI region in 2nd orbit dataset. Data was simulated in HH polarization [1]. SRTM one arc sec DEM near mount Fuzi Japan was considered for terrain input. Along with ephemeris data, ALOS PALSAR's orbits were used instead of NI-SAR as NI-SAR is yet to be launched. Figures 7 and 8 represent simulated and processed raw data for both interferometric orbits for S-band and L-band using the parameters given in Table 1. Raw data is being processed using ADRIN's ShARP+ software. ADRIN has developed a SAR data processing and exploitation chain known as Synthetic Aperture Radar Processor (ShARP+). It is designed in such a way that it supports different SAR sensors irrespective of frequency, operational mode and imaging squint. SAR raw data simulation is also a part of ShARP+.

Parameters	L-band	S-band
Polarization	HH	HH
Carrier frequency	1.267 GHz	3.2 GHz
Wavelength	23.622cm	9.375cm
Pulsewidth	25 μ s	25 μ s
LookAngle	38.683deg	38.683deg

Table 1. Sensor parameters used for simulation of raw data

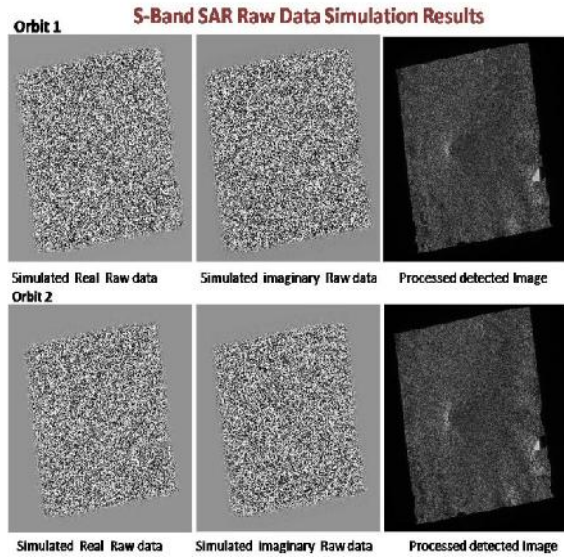


Figure 7. S-band simulated raw data and processed data for interferometric pair

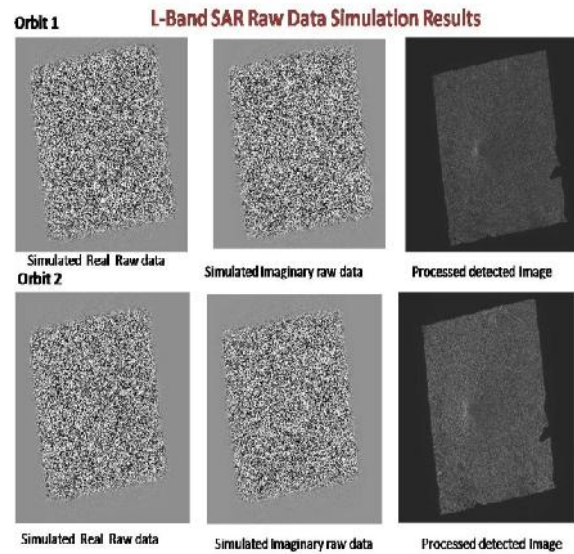


Figure 8. L-band simulated raw data and processed data for interferometric pair

On the simulated pair of S and L band, InSAR process was applied using InSAR module of ShARP+. Results are shown in Figure. 9 to 14. The baseline, height ambiguity and other parameters [7] for L and S band for simulated InSAR pair were computed and shown in Table 2. Interferogram and Coherence maps were analysed and compared for both the bands. In S-band interferogram, fringes are very fine because of short wavelength of S band and phase error was introduced at ROI of shrub vegetation. Similarly, coherence was also lost in shrub region because of short penetration depth of S-band. On the other hand, in L-band interferogram fringes were very sparse because of longer wavelength. Phase error was not observed in shrub backscatter region in L-band interferogram and a high value of coherence was found because of longer wavelength. For both the bands interferogram and coherence maps are shown in Figure.9, 10 and 11 respectively.

A method has been presented to combine the phase information of both bands for utilizing complementary information. Phase error in shrubs vegetation ROI of S band was replaced with L band interferogram. For this L-band interferogram was mapped into S-band as shown in Figure.12. Final improved interferogram was generated by fusion of S and L band interferograms. Fusion was performed on the basis of coherence maps values of L and S band. Comparison of phase standard deviation and coherence values for shrub ROI of original S band and fused L & S bands are shown in table. 3. Figure.14 shows phase profile of shrub ROI where left one is original S band phase profile which is random and right one is fused L and S band interferogram phase profile which has become periodic after fusion. Improved interferogram with reduced phase error and improved coherence map which are better as compared to single frequency InSAR pair has been generated.

Parameters	L-band	S-band
Baseline	276.3m	276.3m
Normal Baseline	272.8m	272.8m
Alpha	0.40565	0.40565
Height Ambiguity	229.124m	90.9341m

Table 2. InSAR Parameters

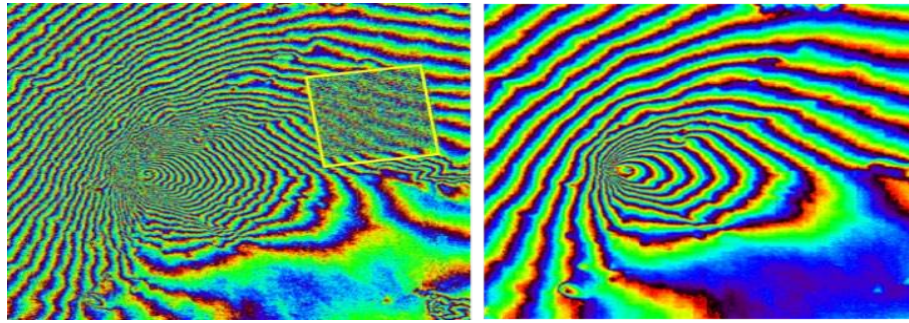


Figure 9. (Left) S-band Interferogram(Shrub vegetation region marked with yellow ROI box), (Right) L-band Interferogram

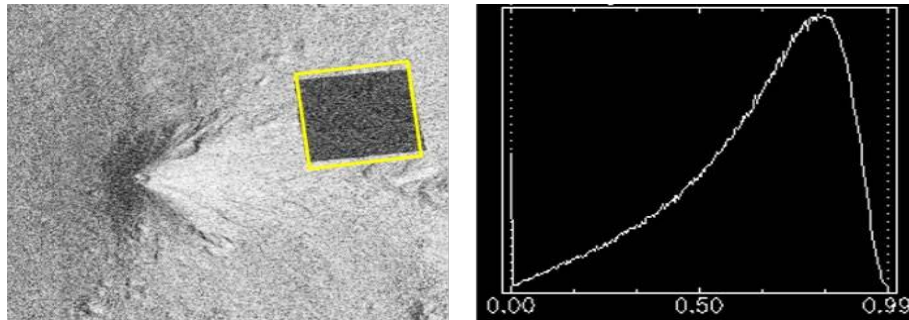


Figure 10. (Left) S-band Coherence Map, (Right) S-band Coherence Map histogram

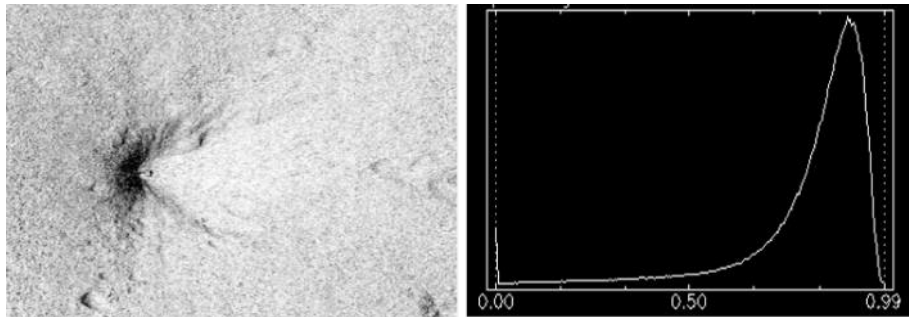


Figure 11. (Left) L-band Coherence Map, (Right) L-band Coherence Map histogram

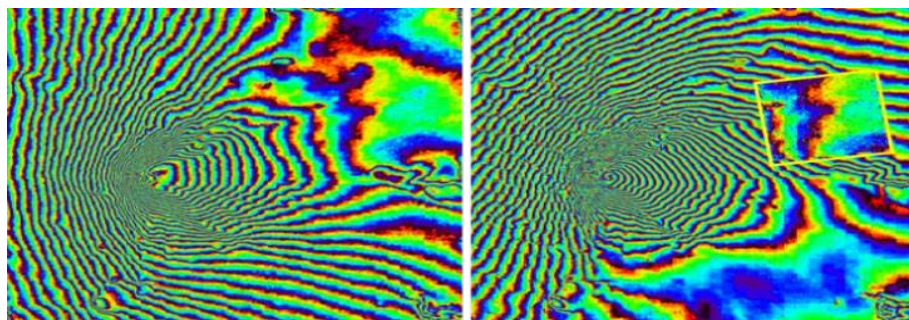


Figure 12. L-band Interferogram mapped to S-band, (Right) Fused (Improved) L & S-band Interferogram.

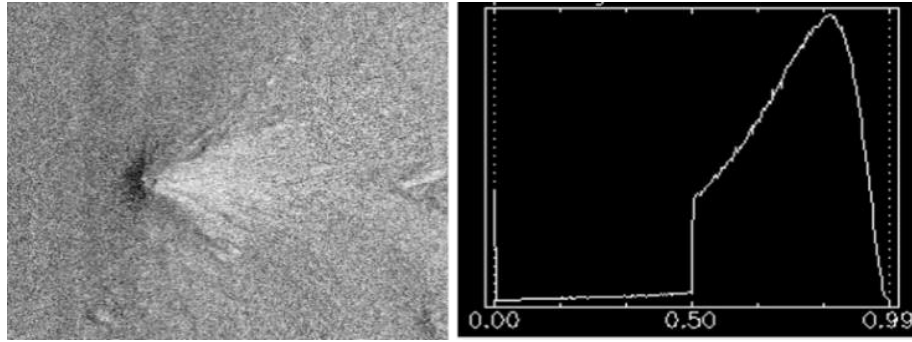


Figure 13. (Left) Fused L & S-band Coherence Map, (Right) Fused L & S-band Coherence Map histogram

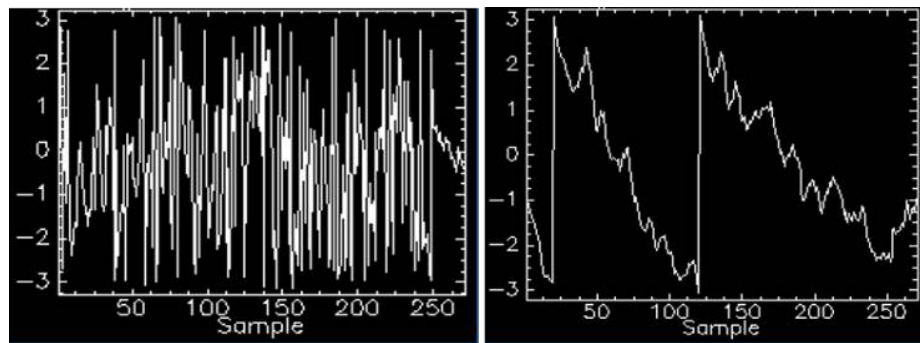


Figure 14. (Left) S-band Interferogram (Shrub vegetation region ROI) phase profile, (Right) Fused Interferogram (Shrub vegetation region ROI) phase profile

Parameters for shrub vegetation ROI region	S-band Interferogram	L & S-band Fused Interferogram
Standard Deviation of phase	1.82	1.12
Coherence mean value	0.274	0.789

Table 3. InSAR Result Parameters

5. CONCLUSION

In this paper we have demonstrated simulation of L and S band InSAR raw data, processing and its application in SAR interferometry for NI-SAR mission. This is the first mission of ISRO's dual frequency SAR in interferometric mode. To exploit the best of L and S band InSAR information, we have used complementary phase information of the datasets. In future, availability of large data sets of multi frequency, multi- temporal and full polarimetric SAR data will be very useful to generate accurate and detailed topography information and surface deformation by combining the dual frequency information.

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AN ALGORITHM FOR FULL STRIP PROCESSING OF CARTO-2S IMAGERY WITH TWO LEVEL ADJUSTMENTS USING RPCS

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ABSTRACT

This paper proposes a new algorithm of processing full strip images of carto-2 Series high resolution images. Carto-2 series images of full strip consist of more than 2000 km. Initially, sub scene definition of images are established and cut accordingly. Rigorous sensor model can be established strip wise or scene wise and rational function model is fitted for each image. It will be easier to handle sub scene images than full strip, both sensor modeling wise and process wise. If ground control points are identified for each sub scene and processed individually we may end with strip discontinuity between scenes. We propose a new method to avoid this problem. Rigorous sensor model is fitted for whole strip. Tie points are introduced for each pair of adjacent scenes and bundle block adjustment is done with tie points. Now all sub scenes are adjusted with tie points and good relative continuity is maintained. We perform a global adjustment using GCPs, identified of all scenes to get good absolute accuracy. Now all of our scenes are adjusted both relatively and absolutely. This algorithm is tested with two strips of C2 Series images. Results obtained showed excellent relative and absolute accuracy.

KEYWORDS: Rigorous sensor model, Rational polynomial coefficients, Bundle block adjustments, Mapping

1. INTRODUCTION

Photogrammetric technologies particularly large scale 3D Mapping is rapidly getting grown towards the High resolution Satellite imagery (HRSI) and very high resolution satellite Imagery. Particularly, Cartosat 2S satellites provide PAN image on 0.6 meter spatial resolution and 1.2 meter MX imaging. This has created a new revolution in Indian remote sensing mapping program. This is in par with aerial imageries which gives a resolution around 10 to 20 cm. In future, Carto series may replace completely the need of aerial imageries. Urban mapping needs 1:2000 scale of ortho maps. Also high spatial and high temporal resolution carto2S is taking advantages over aerial images. Multiview capabilities of Carto-2S images gives a path to 3D mapping. Even though multiview coverage are less and can not be compared to Carto-1 stereo image coverage, upcoming remote sensing satellites may fulfill the needs of remote sensing users community.

A satellite sensor model will connect image and ground. It will establish a relationship between image co-ordinates and ground co-ordinates. It will be divided into two broad category namely rigorous sensor model and generalized sensor model. A rigorous sensor model is otherwise known as physical sensor model which use camera and satellite parameters like positions velocity etc., This becomes more complex and tedious and different satellite imaging system use different types of model which in turn users has to develop sensor model for each satellite imaging system. Alternately generalized sensor model (RFM) can be used as an alternate sensor model or replacement sensor model. Many users agency give their image data along with RPCs. It will also produce same accuracy as RSM from which users can do all photogrammetric related processes. It is currently used for many satellite imaging system like Ikonos, SPOT and Worldview etc., This is used for Indian satellites like cartosat-1, IRSP6, RS2, RS2A and current C2 Series also.

2. RIGOROUS SENSOR MODEL

Rigorous sensor model (RSM) otherwise known as physical sensor model which use position, velocity and attitude parameters of the satellite and uses the concept collinearity equation which sensor position, image co-ordinate and ground co-ordinate lies in the straight line. RSM connects image and ground mathematically which will be for further processing (Radhadevi. et al 2009).

The delivered Carto2S Level1A Data consists of the image data meta data for both PAN and MX sensor from ADIF file. The following information are extracted from file

1. Satellite ephemeris data containing the position and velocity at every regular interval in the ECI reference frame.
2. Integration time for each sensor
3. Data used for time synchronization. For example, line sampling time, sweep start time (of each band), Data used for ephemeris start time and attitude start time.
4. Attitude data in terms of quaternions
5. Sidereal angle (to convert from ECI to ECEF) is given in ADIF for the full pass at every regular interval.

The quaternions are converted into Euler angles. Smoothing of Euler angles is required before the actual adjustment because the discreteness in angles caused by direct interpolation of the attitude data will end up as a co-registration error between the different bands. Expressing the position, velocity and attitude angles as function of time,

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$$q = q_0 + q_1 * t + \dots + q_n * t^n \quad (1)$$

Where t is scan time and q corresponds to ω , ϕ , κ , X_p , Y_p , Z_p , V_x , V_y , and V_z .

The order of the polynomial 'n' can be set. Generally, third order for position and velocity and ninth order for attitude is used. Main source of error is the attitude angles. Therefore, attitude modelling is done with higher order polynomials in the adjustment for the full-pass. The coefficients of the polynomials for position, velocity and attitude are computed. These parameters at a particular time are connected to the corresponding ground coordinate and image coordinate through collinearity equations. Thus, if the initial trajectory is fitted, image to ground and ground to image transformation can be done using the collinearity condition equations.

Collinearity equations express the fundamental relationship that the perspective centre, image point and object point lies on a straight line i.e.

$$\begin{pmatrix} f \\ -x_s \\ -y_s \end{pmatrix} = d.M \begin{pmatrix} X - X_p \\ Y - Y_p \\ Z - Z_p \end{pmatrix} \quad (2)$$

Where $(f, -x_s, -y_s)$ are the image coordinates, (X, Y, Z) are the coordinates of the object point and (X_p, Y_p, Z_p) are the coordinates of the perspective centre, d is the scale factor and M is the orthogonal rotation matrix to transform the geocentric to sensor co-ordinate system i.e.

$$\text{The rotation matrix } M = Q_{GI} * Q_{IO} * Q_{OB} * Q_{BP} * Q_{PC} \quad (3)$$

where

Q_{PC}	=	CCD to payload transformation matrix
Q_{BP}	=	Payload to body transformation matrix
Q_{OB}	=	Body to Orbit matrix
Q_{IO}	=	Orbit to Inertial matrix
Q_{GI}	=	ECI to ECEF matrix

3. IMAGE DATA

The Image data is extracted from the Ancillary data information file which will be cut as per subscene definition and concerned radiometric correction will be applied on the images.

4. RATIONAL POLYNOMIAL COEFFICIENTS (RPC OR RFM)

The rigorous sensor model based on the collinear equation describes the imaging geometric relationship between the image points and homologous ground points, with parameters which have understandable physical meanings. However, it lacks generality because of its complexity and varying with different sensor types. Also, the physical parameters are often made unavailable intentionally or unintentionally. Rational Polynomial Camera (RPC) models transform 3-dimensional object space coordinates into 2-dimensional image coordinates traditional photogrammetric workflows perform sensor model with a physical camera model and then calculate RPC coefficients to speed the photogrammetric processing like DEM extraction, orthorectification and 3D city modeling etc. This is a generalized sensor model which makes the data processing chain more generic. End user need not know the geometry and related parameters of the sensors. RPC models are simple, fast, and accurate from which users cannot derive the physical parameters of the sensor which will keep our sensor information confidential.

Rational Function is the ratio of two, third order Polynomials. It is a three dimensional model. The general form of Rational Function Equation is as follows.

$$S = \frac{p_1(X,Y,Z)}{p_2(X,Y,Z)} \quad (4)$$

$$P = \frac{p_3(X,Y,Z)}{p_4(X,Y,Z)} \quad (5)$$

Where

$$p_i(X, Y, Z) = a_0 + a_1X + a_2Y + a_3Z + a_4XY + a_5XZ + a_6ZY + a_7XYZ + a_8X^2 + a_9Y^2 + a_{10}Z^2 + a_{11}X^3 + a_{12}X^2Y + a_{13}X^2Z + a_{14}XY^2 + a_{15}Y^3 + a_{16}Y^2Z + a_{17}XZ^2 + a_{18}YZ^2 + a_{19}Z^3 \quad (6)$$

Where a_i 's are polynomial coefficients and X, Y, Z are normalized object co-ordinates. This may be in spherical or Cartesian co-ordinate system. S, P are normalized image co-ordinates. Original values of image and ground co-ordinates are Offset and Scaled to fit between -1.0 to $+1.0$. The values are normalized by using following equations.

$$\left. \begin{aligned} X &= (X_{\text{original}} - X_{\text{offset}}) / X_{\text{scale}} \\ Y &= (Y_{\text{original}} - Y_{\text{offset}}) / Y_{\text{scale}} \\ Z &= (Z_{\text{original}} - Z_{\text{offset}}) / Z_{\text{scale}} \\ S &= (S_{\text{original}} - S_{\text{offset}}) / S_{\text{scale}} \\ P &= (P_{\text{original}} - P_{\text{offset}}) / P_{\text{scale}} \end{aligned} \right\} \quad (7)$$

Where values subscripted with "original" is the raw co-ordinates values. X, Y, Z, S and P are corresponding normalized values. Values subscripted with "offset" and "scale" are offset and scale of concerned values which should be computed from the range of the corresponding values.

5. BIAS COMPENSATION

The RPCs which are derived from the RSM can be used for direct geo referencing. But it has the inaccuracy due to various reasons which can be further corrected with ground control points. This process is called bias compensation (Fraser et al. 2003). Normally, ground controls are used to obtain bias compensation transformation which is to be applied further correction after RPCs. In this way, RPCs and bias compensation transformation combinedly used for further processing like ortho rectification.

Normally there are two types transformations are applied.

(1) Bias

$$S = \frac{p_1(X, Y, Z)}{p_2(X, Y, Z)} + \Delta S \quad (8)$$

$$P = \frac{p_3(X, Y, Z)}{p_4(X, Y, Z)} + \Delta P \quad (9)$$

(2) Affine

$$S = \frac{p_1(X, Y, Z)}{p_2(X, Y, Z)} + a_0 + a_1 * S + a_2 * P \quad (10)$$

$$P = \frac{p_3(X, Y, Z)}{p_4(X, Y, Z)} + b_0 + b_1 * S + b_2 * P \quad (11)$$

We use normally affine transformation for further correction.

6. BUNDLE BLOCK ADJUSTMENT

Bundle block adjustment is one of the important concepts in photogrammetry which will compute the bias compensation parameters simultaneously for all images. The standard formulation requires the linearization of the rational polynomial equation and satisfaction of the least squares principle for the equation residuals (Grodecki et al. 2003; Nagasubramanian.V. et al 2014). Block adjustment will improve the absolute as well as relative accuracy. Block adjustment is required for

seamless mosaic and continuity of features between the scenes. Block adjustment uses the tie points which are computed across and along the scenes and ground control points identified for each scene. In our experiment, only along scenes tie points are computed. Tie points which are used in the block adjustment which will ensure the relative accuracy and ground control points will ensure the absolute accuracy. Even identification ground control points failed with some of the sub scenes, block adjustment can be done with existing ground controls and tie points for all possible set. Only tie points also can be used in bundle block adjustment which will ensure only the continuity between the images.

Advantages of Bundle adjustment procedure:

- The number of ground control points are largely reduced
- All geometric correction are computed together
- Homogenous and seamless digital elevation model can be generated if the images are adjusted as a block
- Better relative accuracy between images can be obtained.
- More homogenous and accurate DEM/Ortho mosaic can be generated over large area can be obtained and Homogenous GCPs network can be established for further processing.

7. TWO DIMENSIONAL TRANSFORMATION

The two dimensional transformation which will be used for universal correction for the full strip is as follows.

$$\Delta lat = a_0 + a_1 * lat + a_2 * lon + a_3 * lat^2 + a_4 * lon^2 + a_5 * lat * lon \quad (12)$$

$$\Delta lon = b_0 + b_1 * lat + b_2 * lon + b_3 * lat^2 + b_4 * lon^2 + b_5 * lat * lon \quad (13)$$

Where a_0 to a_5 and b_0 to b_5 are coefficients of universal transformation and (lat,lon) is ground co-ordinates derived from first level bias compensation correction and Δlat and Δlon are correction to updated object co-ordinates.

Here also, normalization should be used as in the RPCs before computing the values.

8. ALGORITHM

The algorithm is as follows. Initially, we take strip of C2S Images contain around 80 sub scenes. For the whole strip Rigorous sensor model parameters like position, velocity and attitude are fitted for whole strip. RSM Grid for RPC generation is extracted for each image. This full strip fitting of RSM helps us to get continuity between adjacent sub scenes. For each sub scene, RPCs are extracted which preserves continuity as RSM. We will establish tie points between adjacent sub scenes. Since we know from which line sub scenes are extracted, we can form (not necessary to identify) tie points. This have advantage of not only reducing the time of computation of tie points but also tie points are extracted for even homogenous surfaces also. With all collected tie points along with RPCs Bundle adjustments is done. We use affine transformation for this bias compensation correction. Now the strips are relatively adjusted and we get the better relative accuracy. Now we introduce ground control points at this stage. Ground control points are identified for all sub-scenes using our procedure Automatic GCP/Tie identification which is already established and running successfully with many satellites like Cartosat-1, IRS-P6, RS2 and RS2A (Akhilan A et al. 2014). In this context, GCPs may not have been extracted due to homogenous areas, clouds coverage, poor illumination etc., But the Correction is universal, we need not bother about this. Correction coefficients will be found even GCPs are not identified at a particular sub scene. A universal correction is applied further on bundle adjusted RPCs. Once this correction is applied, its absolute accuracy also is improved. Now the resultants RPCs are adjusted both relatively and absolutely. Each sub scenes will undergo ortho/DEM generation using the updated RPCs. If our image acquired in multiview mode, we can go for DEM extraction. Otherwise, the regular ortho generation procedure is applied on these images.

9. DISTRIBUTION OF CONTROL POINTS

Since a two dimensional transformation is used for a global correction, distribution of GCPs played a crucial role in the correction procedure. From our experiment, it is come to know that at least every fourth image should have GCPs and overall at least one sub scene of top 3 and bottom 3 each should have control points. Otherwise, a curved effect is seen in the images and accuracy is further reduced. For example if a strip contains 40 images, ground control points should exist any one of scene number 1,2 and 3 and any one of 4 ,5,6 and 7 and any one of 8,9,10,11 etc., and finally scene of 38, 39 and 40.

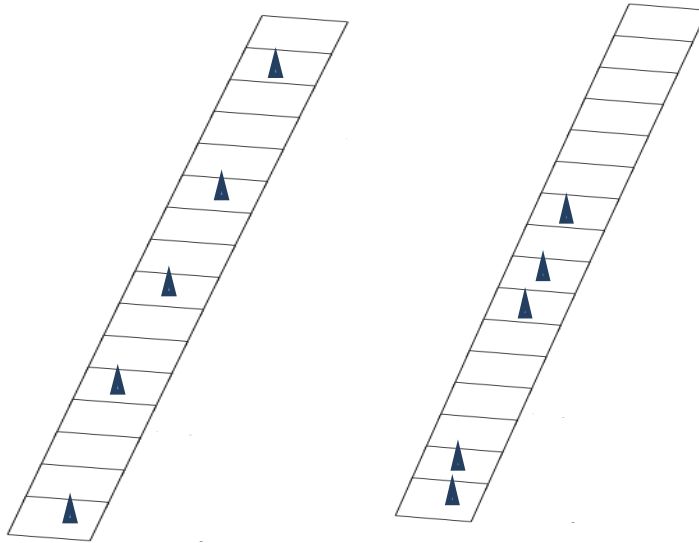


Fig.1 Correct distribution of controls

Wrong distribution of controls

10. FLOWCHART

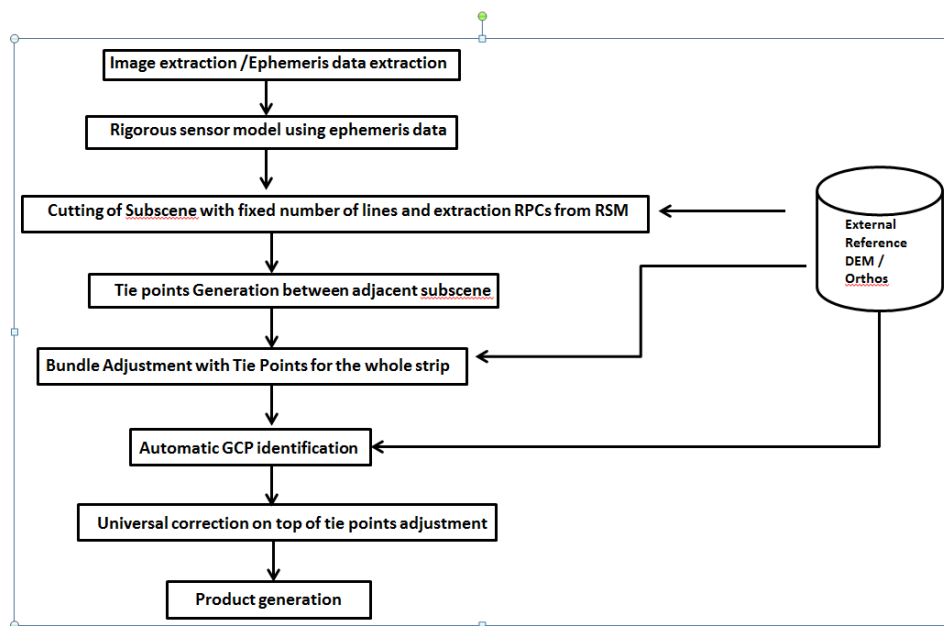


Fig. 2. Work Flow of the proposed method

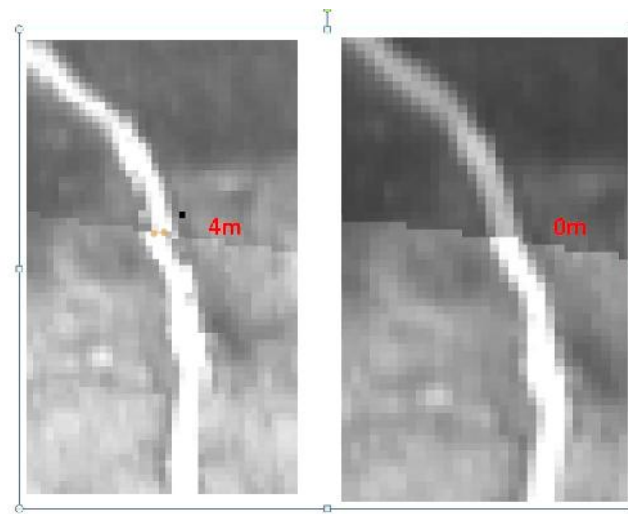
11. TEST DATA

Two data sets C2 Series are chosen for testing. One is C2E dated 12-10-2017 of orbit no: 1645 covering northwest region above the India. This data set contains 44 sub scenes. Another one also a C2D image dated 29-11-2017 with strip no: 4357 covering northeast region above India. This data sets contains 92 sub scenes. Each sub scene covers 31 km x 15 km approximately of both data sets. PAN Images data sets are considered for the experiments. Results are showed that accuracy of product was not reduced with universal correction and gives almost same accuracy as individual scene correction.

12. RESULTS

Image File Name	Direct Ortho RMS Error (m.)		Bundle Adjusted RMS Error (m.)	
	Lat.	Lon.	Lat.	Lon.
Subscene 5	17.2925	19.097	14.6679	18.9761
Subscene 25	18.9736	13.405	22.474	15.7546
Subscene 30	18.475	13.2474	15.9292	11.6791
Subscene 40	19.1368	17.4953	17.5758	13.9619
Subscene 60	18.8028	13.0132	16.4192	15.5521
Subscene 75	13.8848	17.8018	14.7655	19.8707

Table 1. Accuracy of Data Set 1 (Dated 12-10-2017)



Direct Ortho

Bundle Adjusted Ortho

Figure 2. Showing Discontinuity when adjusted individually of data set2

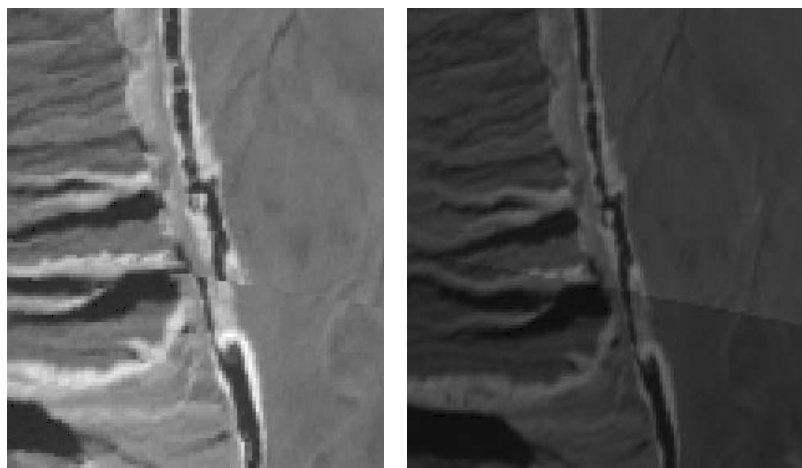


Figure 3. Another region result of Bundle Adjustment (Right Image) of Data Set 2

13. CONCLUSION

The new approach of two level full strip adjustments with RPCs has been presented. Beside the theoretical interest, this algorithm has the advantage of using bundle adjustment procedure which yields theoretically optimal estimators since it minimize the relative and absolute error. The results show that, it produces the same level accuracy as individually adjusted. This method minimize the usage of GCPs, Since GCPs are not required to be present in all the sub scene images except some distribution of control should be preserved. Since RPC bundle adjustment is used instead of RSM adjustment it can be extended to any type of sensor. This experiment shows the algorithm gives promising result and improved accuracy. This is one of the effective algorithms to process full strip images. This can be extended further for any other satellites.

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3D-MAPPING FROM MULTIVIEW GEOMETRY OF CARTOSAT-2S SATELLITE IMAGERY

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ABSTRACT

Cartosat-2S are of state-of-art very high resolution imagery satellite series built with multi viewing capability over given region of interest. This has undoubtedly opened up new application areas especially to digital mapping community. Spatial resolution at sub meter level and Multiview imaging geometry with B/H ratio about 0.7 are significant merits of Cartosat-2S to derive precise height information for 3D-Mapping. Aerial imagery was widely used for the purpose as they are of very high resolution and better geometry fidelity but with smaller swath and acquisition only over unconstrained areas. Today, availability of Cartosat-2S imagery and well established geometric modelling and processing procedures have removed all such constraints. By exploiting all these merits, we have implemented our own methodology to generate 3D maps using photogrammetry technique. 3D Map generation requires pre-processing steps such as orbit modelling, geometry error correction, establishment of epipolar geometry and extraction of height information. All these functionalities were indigenously developed and the entire pre-processing runs in automatic mode without any intervention. The subsequent steps are done in semiautomatic mode to generate 3D models. This paper explains in detail about our methodology to extract precise height information of above ground objects to generate 3D-building models using photogrammetry technique.

KEY WORDS: Epipolar geometry, RPC, SIFT, RANSAC, SGM, DSM, Block Adjustment, Multiview imagery

1. INTRODUCTION

Remote sensing technology is moving rapidly towards acquiring and processing the High Resolution Satellite Imagery (HRSI) and Very High Resolution Satellite Imagery (VHRSI). Cartosat2S satellites provide images in 0.6 meter spatial resolution. This has created new revolution in the field of cartography and mapping applications. It has replaced the need of aerial imagery which is limited in spatial coverage and temporal resolution. Urban mapping need of 1:5000 scale ortho photos are pretty much possible to be generated from the imagery. The High Resolution Satellite Imagery (HRSI) enables the mapping community to better interpret the Earth surface feature compared to coarser resolution especially in urban mapping. High spatial and temporal resolution with better interpretability literally takes advantage over aerial images. Nowadays, multiview capability is built-in with the satellites that acquire high spatial resolution images. This facility adds incredible advantage to derive high quality Digital Surface Models (DSM) over given region of interest. Consequently, generation of city level 3D site modelling and mapping becomes easy and consumes quite less time. In case of Cartosat2S, the multiview images are acquired by tilting satellite to look at the same region at different time interval. This is done from the same orbit or from the different orbits.

2. RATIONAL POLYNOMIAL COEFFICIENTS (RPC)

Cartosat-2S images are obtained with geometry information stored in separate flat file called RPC file. The file consists of 90 coefficients. These coefficients are abstract form of imaging geometry of associated image, interior and exterior orientation parameters. Most of satellite agencies do not reveal internal geometry of the satellite parameters hence provide in the form of coefficients. The coefficients describe the geometrical relationship between normalized object space (ϕ, λ, h) and image space co-ordinates(s, p):

$$s = \frac{F_1(\phi, \lambda, h)}{F_2(\phi, \lambda, h)}, \quad p = \frac{F_3(\phi, \lambda, h)}{F_4(\phi, \lambda, h)} \quad (1)$$

OR

$$\phi = \frac{F_1(s, p, h)}{F_2(s, p, h)}, \quad \lambda = \frac{F_3(s, p, h)}{F_4(s, p, h)} \quad (2)$$

F_m 's are third order 3D polynomials of the type

$$F(X, Y, Z) = \sum_{i=0}^3 \sum_{j=0}^3 \sum_{k=0}^3 a_{i,j,k} X_i Y_j Z_k = a_0 + a_1 X + a_2 Y + a_3 Z + a_4 X Y \dots + a_{19} Z^3 \quad (3)$$

RPCs are used to correct geometry distortion present in the raw image and the coefficients are updated with ground control

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points to better location accuracy of the image in the sense that the image represents true ground. The RPC coefficients are derived from interior and exterior orientation parameters of the respective satellite during the image acquisition. Geometry error correction is the first and foremost step in any 3D mapping process.

3. GEOMETRY CORRECTION

Extraction of height is the main objective from multiview imagery. The number of images is normally two or more. Unlike ortho rectification process that uses external Digital Elevation Model (DEM) sources for height induced error correction, the multiview images need only scale correction. In our procedure, the first level geometry correction is done using coarser DEM as base layer. The residual height errors are corrected iteratively. The coarser DEM is updated at the end of iteration.

3.1. Control Points

RPC coefficients updated with ground control points (GCP) are used to correct scale distortion and location inaccuracy exists in the raw multiview images. Resampling is performed during the correction process to ensure that the squared output pixels takes up appropriate input pixels. The output to input transformation is established with the updated RPC coefficients. Ground control points (GCP) are obtained from well-known ground reference images or ground survey to achieve better location accuracy. In case of city level 3D mapping that involves block or bundle of images covering the city, tie control points (TCP) are identified between bundle images on overlapping region to ensure continuity across them. In general, both GCP and TCP points are obtained using robust image matching procedures.

These points are taken into rigorous photogrammetry procedure, so called Block Adjustment (BA), to generate one unified seamless geometry from multiple and independent image geometries. The accuracy of the final geometry is highly depending upon the control points. Feature points driven matching procedures is more robust and popular in today's scenario. In our procedure, the initial feature points are collected using Forstner operator and subsequently submitted for normalized cross correlation (NCC) to obtain correspondence. The NCC of two multiview images (A, B) is given by,

$$NCC = \frac{\sum (A(x,y) - \bar{A}(x,y)) * (B(x,y) - \bar{B}(x,y))}{\sqrt{(\sum (A(x,y) - \bar{A}(x,y))^2 * \sum (B(x,y) - \bar{B}(x,y))^2)}} \quad (4)$$

the value is in between 0 and 1. Value close to 1 will be correct match.

The entire matching is done automatically by taking guidance from system level error present in the data sets. For that purpose each data set is geocoded. During the process, the target image and its corresponding reference image are brought to the same scale to facilitate auto matching. This module is made as plug-in type in order to accommodate any robust matching procedure such as SIFT, SURF, ORB etc., in future without affecting rest of the system. Ground surveyed control points are more accurate than any reference in public.

3.2. Reference Layers

The Landsat Enhanced Thematic Mapper (ETM), Landsat Data Continuity Mission (Landsat 8), Google maps/ortho photos, Shuttle Radar Topography Mission (SRTM), ASTER Global DEM are such globally available references can be utilized in any planimetry error correction. Other high accuracy references like Cartosat-1 ortho images/DEMs, aerial Orthos/DEMs as well as surveyed controls also can be used as references. The control points acquired from matching function is based on system level knowledge of the data sets. The images to matching function may possibly be captured in multi temporal conditions, seasons. So the control points extracted at the first level need not be as accurate as expected. Inaccurate points without any filtering mechanism lead to error in planimetry and feature continuity between adjacent images as well.

3.3. Error Model

We perform multi-level robust weeding out mechanism to ensure that points chosen are well accurate in sub-pixel level. In the first level, spurious points are eliminated which are having errors above 3-sigma over physical sensor model respect to data. Second level is based on histogram variation around the points of interest using mutual information (MI) procedure. To meet the sub-pixel level accuracy Random Consensus (RANSAC) method is applied with sensor model (RSM). As all these levels of filtering are not mandatory for all sensor data, user is provided with the option to enable/disable secondary and tertiary level filtering.

4. BLOCK ADJUSTMENT TECHNIQUE

Once the ground control and tie points pass through weeding-out process, block adjustment procedure is invoked to establish geometric relationship between the target images and respective ground. Single least square adjustment (LSQ) is applied over the equations generated from ground control and tie points for error minimization well within the threshold.

At ADRIN, rigorous geometric model combining the principles of photogrammetric collinearity equations was originally developed for SPOT-1 [Radhadevi et al., 1994], and further adapted to multi-sensor geometries from IRS-1C/1D to Cartosat-

2 [Radhadevi, 2013]. Due to its simple implementation and standardization, the RFM have been widely used in the remote sensing community. Rational Function Model was also developed for different sensors [Nagasubramanian et.al, 2007]. We have further extended these models and developed a full-fledged system for Bundle block adjustment.

In any photogrammetry, error evaluation, analysis and correction are essential work to adjust the input parameters to meet the error budget. Error plot, error log and error statistics are the addition details as result of the bundle adjustment process. Error plot is a visual display of error trend of each GCP, tie and check points over image coverage. Root Mean Square Error (RMSE) is also part of this plot. Once adjustment is done, user can observe through all these details and if needed, the points can be added/removed (erroneous) from adjustment to well improve the accuracy of final product. The advantages of the block bundle adjustment over the independent adjustment (as explained by Toutin, 2003) are:

- ❑ The number of ground control points (GCPs) is largely reduced
- ❑ All image geometric models are computed together
- ❑ Homogeneous digital elevation model (DEM) can be generated when the block has a full and good stereo coverage
- ❑ Better relative accuracy between the images can be obtained
- ❑ More homogeneous and accurate ortho-mosaic over large area can be obtained and Homogeneous GCP network for future geometric processing can be generated

5. DIGITAL SURFACE MODEL (DSM) GENERATION

Basically, multiview contains three images, one is nadir (vertical) image and remaining two are off-nadir that are of high look angles. As on today, Cartosat2S provide multiview with two images. High look angle causes planimetry shift of ground features on images which is proportional to the height value present in that location. In the other way, the amount of feature shift is directly proportional to the height value present in the location. Feature shift is detected with matching technique. Dense matching is the key in the generation of Digital Surface Models. The spatial resolution of 0.6meter from Cartosat2S enables to extract the heights of man-made structures.

Compute time for generating dense matching points is so high. Therefore, we establish epipolar geometry for the multiview imagery before obtaining dense match or conjugate points that aligns the features over same scan line across multiview images. Therefore search space is reduced from two dimensional to one dimension which saves compute time incredibly. The following equations (1) shows the epipolar geometry constructed using conjugate points between image pair,

$$\left. \begin{aligned} A_{\text{left}} &= \begin{bmatrix} 1 & x_{\text{lskew}} & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \text{rot}_{\text{left}} & \text{and} & \\ A_{\text{right}} &= \begin{bmatrix} x_s & x_{\text{rskew}} & x_0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & y_s & y_0 \\ 0 & 0 & 1 \end{bmatrix} \text{rot}_{\text{right}} \end{aligned} \right\} \quad (5)$$

where $x_{\text{lskew}} = -\frac{x_{\text{left}}}{2}$ and $x_{\text{rskew}} = \frac{x_{\text{skew}}}{2}$.

The DSM procedure takes up first level multiview ortho images rectified with respect to coarser DEM such as SRTM/ASTER. SRTM is of 90meter resolution (interval) and about 30meter locational accuracy and ASTER is of 30m interval and locational accuracy is about 20m.

We have adopted iterative ortho refinement method for DSM generation with little modification to capture depth discontinuity of built-up features. The basic matching technique is NCC over pyramid levels. Shuttle Radar Topography Mission (SRTM) is used as base layer. The objective of iterative ortho refinement (IOR) method is to improve the base DSM in terms of dem interval, location accuracy and features than the original that result in final DEM. Matching and other DEM related parameters i.e., match window size, noise and accept threshold values, reference image and respective path are inputted through configuration file. The procedure is,

- [1]. Geometry error correction using control points obtained from reference layer/surveyed.
- [2]. Initial ortho product generation with updated RPCs and base coarser SRTM height.
- [3]. Construct Gaussian pyramid for the ortho images.
- [4]. Perform the NCC based matching function for every 4 pixels to generate 2.5m resolution DSM. Matching starts from coarser level image pair. Carry the match points from coarser (low) to finer (high) level and perform interpolation followed by matching for the current level.
- [5]. Continue the matching until the level of original image resolution.
- [6]. Run edge detector operator to obtain feature points over edges of the building and other facilities. Perform matching only for edge points with smallest window size to capture depth discontinuity.
- [7]. Find the height of the conjugate point by means of space intersection method using respective RPCs
- [8]. Update the base DSM

- [9]. Generated next level ortho images from the updated new height values (new DSM).
 [10]. Repeat the steps from (2) through (8) until the disparity value of maximum number of match points is zero.
 [11]. Repeat the steps from (1) through (10) for both Nadir-to-AFT and Nadir-to-Fore image pairs.

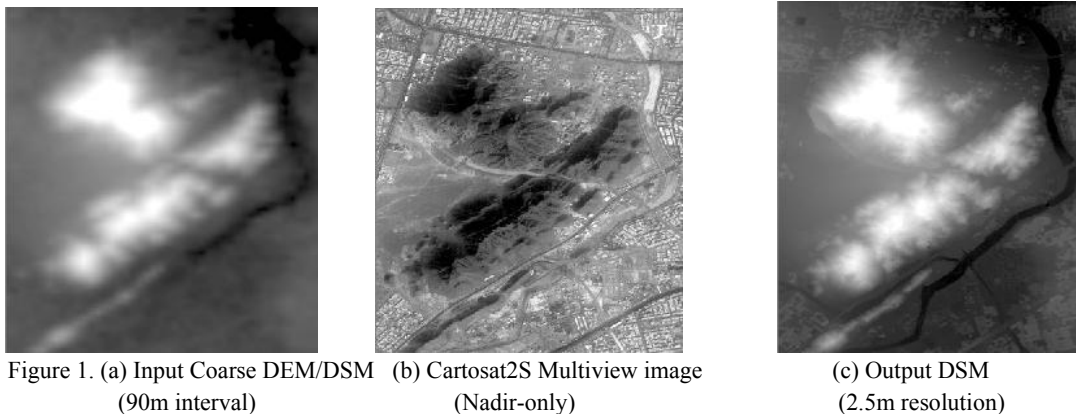


Figure.1 (a) shows the base DSM taken into the process to start with and it shows only prominent features such as river, mountains. Cartosat2S multiview images and the base DSM are taken as input. The above explained iterative procedure is performed and at the completion of each iteration updated DSM is generated. Figure.1. (c) shows the DSM resulted at the end of all iteration. We use NCC function to identify disparity which falls under area based matching technique. Therefore we do matching for every 4 pixels on ortho images to generate about 2.5m resolution DSM. The updated DSM contains many new features which are not present in base DSM. The new features are derived from the disparity map obtained from multiview images. Also, we get new ortho photo at the end of each iteration as by-product. The orthophoto and DSM from final iteration are the inputs to 3Dmapping process. Figure.2. shows the complete workflow and framework of 3D mapping process.

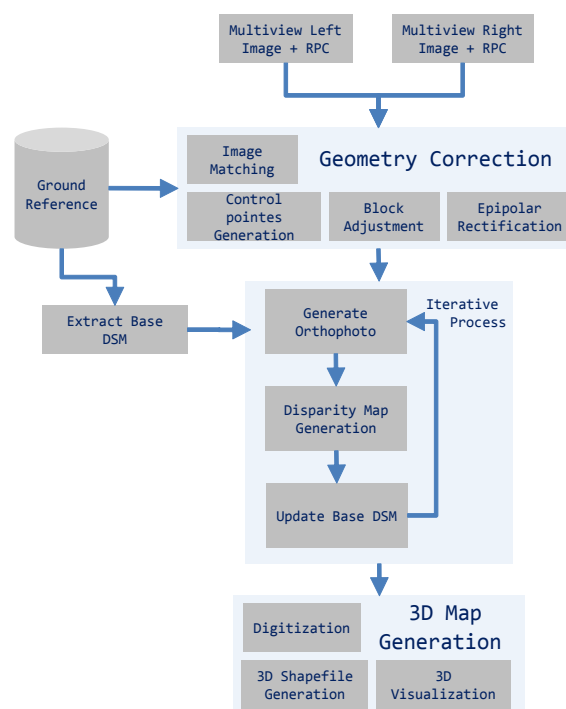


Figure 2. 3D Mapping Workflow

In the whole DSM generation process, we have applied several optimization techniques to the level best in order to highly utilize multi core/Symmetric Multi-Processor (SMP) machines. Open MP, boost thread pool and high performance Eigen C++ library are used in bundle adjustment, matching, input/output grid generation and resampling towards achieving high performance on SMD/high end server architecture.

6. 3D SHAPE FILE GENERATION

ESRI shape file supports third-dimensional coordinate insertion to represent any feature on ground with appropriate depth information. Our 3D shapefile generation is based on this concept. Final level orthophoto is used to digitize the structures. Orthophoto of Cartosat2S multiview images are generated in the same input spatial resolution of 0.6 meter that shows more details on visual to simplify digitization work. We work towards automating the digitization work. At present it runs in semiautomatic mode. In the sense that major structures are identified by automated procedure and subsequently corrections and further additions on the results are carried out manually, shown in Figure.3 (a) and (b).



Figure 3. (a) Orthophoto [Digitized] (b) Final DSM over Digitized region

There are number of open source software tools available to facilitate digitization. Quantum GIS (QGIS) is one of the best open source software that consists of enormous tools and utilities to perform digitization effectively. We have used both automatic software developed indigenously and QGIS as well.

Once digitization is completed on ortho, the shapefile will contains only two-dimensional details and is inputted to subsequent procedure to populate Z-values. This is done using simple automated application which takes shapefile and DSM. Transformation from geospatial coordinates of the shapefile to respective DSM line and sample location picks the height value and assigns to Z-component in the shapefile. The details present in the structures can be brought out in the 3D model if the details are captured in DSM. Therefore, the DSM generation procedure must be robust enough to exploit the high resolution imagery in order to generate quality DSM. Pixel based matching such as semi global matching (SGM) has been more popular in resulting good quality Digital Surface Models (DSM) wherein depth discontinuities are well captured into the disparity map. We are working on fine tuning of our DSM generation procedure to capture very finer roof structures.

7. 3D VISUALIZATION

With the above explained procedure, the entire geospatial points in the shapefile are updated to Z-values that represent height value. We have built our own 3D visualization application to visualize and verify the models in 3D perspective. Either the building wall can be textured synthetically or with original wall photographs. Following Figure.4 shows the visualization of 3D shape created with the above described procedure and displays with synthetic wall.

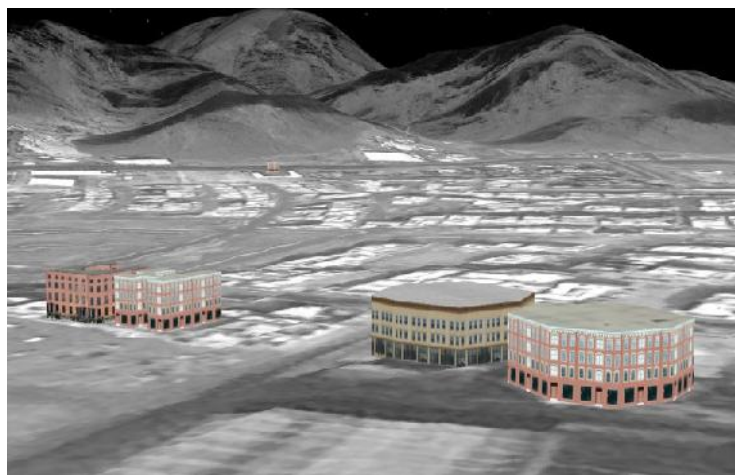


Figure 4. 3D visualization of digitized shapefile

8. RESULTS AND CONCLUSION

We tested the procedure on few multiview datasets received from Cartosat2S satellite. The vertical accuracy of DSM is well within 5meter. We recommend using highly accurate control points to rectify geometry errors at the beginning of the above explained procedure which will produce high quality DSM in terms of planimetry and vertical accuracy. Pixel based

matching on very high resolution imagery is ideal method to generate DSM of better than 2.5m resolution especially for 3D mapping applications. The 3D mapping was highly challenging area in the absence of high resolution multiview satellite images. Aerial imagery was used with more limitations such as low temporal resolution, less coverage and cumbersome in accessing to remote areas. Today, with availability of very high resolution images from Cartosat2S with multiview steering capability has created new opportunity to 3D mapping community to build 3D city models with better quality in terms of accuracy and details and importantly at quick turnaround time.

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IMAGE MOSAIC OF HIGH RESOLUTION REMOTE SENSING DATA WITH IRREGULAR SEAM LINE AND MULTI-RESOLUTION PYRAMIDS

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ABSTRACT

With the availability of high resolution remote sensing data, there is a continuous need to generate reference layers for different resolutions for various cartographic applications like change detection, overlay of road network, water body, man-made features etc. User area of interest may not be covered by single image thus the image mosaicking plays very important role in cartographic mapping applications. Mosaicking helps to seamlessly stitch more than one image to form big canvas which serve the purpose of mapping and generating city/district/country level products. There are many challenges viz. a) High volumes of data b) handling of many images) seamless stitching d) feature continuity across scenes e) radiometric normalizations among multi-date and multi-sensor images. With current available hardware support, the first two challenges become possible to handle. The other three challenges became more intricate with increasing resolutions and agility of the satellites. Like, the appearance of high raised terrain features like buildings will not be similar. With straight seam-line there is possibility in the deformation of the objects. To avoid such feature disturbances, we are proposing new automatic methodology for irregular seam line construction based on minimum gradient flow. To handle radiometric normalization and local seam correction, we are proposing multi resolution pyramids based fusion of the images in the overlap area to avoid blur and double exposure effects that occur with the normal approaches. To handle feature discontinuity in overlap areas, area based matching technique is applied and the images will be transformed based on these match points with local transformations. In order to generate satellite image mosaics with radiometric and geometric corrections under operational conditions a fully automatic generalized mosaic processing software was developed. The results on use of different satellite images of multiple dates will be presented.

KEYWORDS: Mosaic, radiometric normalization, seam construction, seamless stitching, high resolution, reference layer, multi sensor, image registration, satellite, remote sensing

1. INTRODUCTION

Image Mosaicking is the process of adding multiple individual scenes to generate one big image. Even though the name mosaic simply says stitching the adjacent scenes together, it holds many implicit sub processes like feature mapping in overlap areas, radiometric adjustment for neighboring scenes, seam line construction, global radiometry adjustment etc. Overview of mosaic system based on feature matching and blending is projected (M. Brown, 2007). Due to availability of high resolution images, the area covered by satellite in an orbit is limited. In order to create maps of wider areas, one needs to stitch these individual scenes to form one big mosaicked image. Today in the era of digital world one image representing larger canvas seamlessly is important goal in the process of creating city, district, state and country wide maps or to generate a reference layer for future uses like GCP collections etc. Disaster management applications demand larger areas to monitor where single image can't solve the purpose. Time series, change detection, urban development planning and other mapping applications requires Region of Interest (ROI), which may not be covered by single sensor, single orbit and single day.

Image mosaic is not a new technique, but the change in technology brought many challenges to achieve seamless mosaic. Due to the high agility of the satellites image acquired in different dates have different view angles, which may cause discontinuity / break in high raised features. The changes in the illumination conditions, seasonal variations, atmospheric effects create radiometric mismatch in the overlap and adjacent scenes. Constellation of satellites being used to create reference layers for the purpose of cartographic mapping applications. So the relative radiometric differences due to non-uniformity across sensors are common problem to be addressed for mosaicking. Different image based stitching are explained in the paper (Shikha Arya, 2015). Due to availability of more number of satellites, the number of images to be stitched and image sizes is also large due to use of high resolution images for the above said applications. So, mosaicking involves handling of huge volume of data to create big canvas image. For large-scale applications of remote sensing image mosaicking usually requires significant computational capabilities. Several studies have been attempted (Lajiao Chen, 2015) to apply parallel computing to improve image mosaicking algorithms and to speed up the calculation process.

The success of automatic mosaic process to get seamless product depends on the selection of images, establishing of feature continuity in the overlap regions, global radiometry between the adjacent scenes, seam line construction and correction. Based on these requirements and limitations at every stage, we proposed suitable and efficient techniques in every process of correction. Optimal sequencing of individual products is established to get better overlaps and better radiometric normalization and stitching. Robust automatic registration tool is used for establishing feature continuity. Automatic irregular seam line construction is proposed to avoid the limitations that arise with high rise building features in high resolution images. Multiresolution based approach is proposed for seam correction to overcome the limitations with α -blending and averaging techniques.

This paper describes how to overcome the above said challenges to achieve seamless mosaic of multi date, multi sensor high resolution remote sensing images. The methodology section is categorized to subsections to address each challenge in detail. This methodology is applied for various modes of acquisitions like mosaic of paint brush mode images, partial products acquired in

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different orbits, multiple products acquired by different sensors to create reference layers. The outputs of various multi date, multi sensor mosaics are presented in the paper.

2. METHODOLOGY

As Mosaicking is not a single step or single technique, in order to get better results one has to take care of radiometric and geometric continuity in the overlap areas rigorously instead of simply stitching of images directly. Fully automatic mosaic chain is proposed because the mosaic will have multiple large images i.e. many overlaps. Handling all these overlaps manually is very tedious job. Also, registration of features in overlap areas, radiometric adjustments and seam line constructions manually is very time consuming process. To address these issues in better way, the mosaicking process is divided into many steps. Accordingly, the proposed image mosaic architecture is depicted in figure 1. The following sections explain about each process.

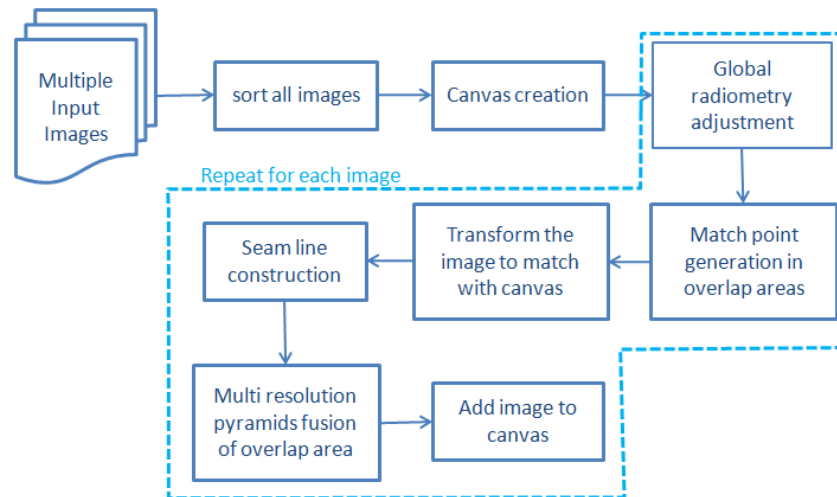


Figure 1. Block diagram for Image mosaic architecture

2.1 Sorting and canvas creation

Input images can be multispectral or panchromatic. They can be from multiple satellites, sensors and dates. But nearly equal resolutions are recommended to avoid blurring of the images with low resolutions. Ortho rectified input images are mostly preferred. Any number of input images can be mosaicked; the only assumption is that all input images should have geographical information. To get a proper final mosaic product one needs to properly arrange, rotate and scale these images relative to one another. Since satellite images holds the auxiliary information like latitude, longitude and resolutions, the task of arranging the individual images can be achieved by sorting the input images based on their minimum and maximum latitude and longitudes onto the final output canvas that is to be created. As shown in the below figure 2, input images can be considered in any order, but sorting process will handle based on the lat-lon information and calculating the overlaps across the images. This ordering is very important to adjust the local radiometry in the overlap areas. Figure 2 shows that the images are sorted as per their lat-lon information and overlap information though order of selection of input images differs. The background yellow color represents the canvas, which is the bounding box of all input images after applying transformation to bring to proper orientation and scale.

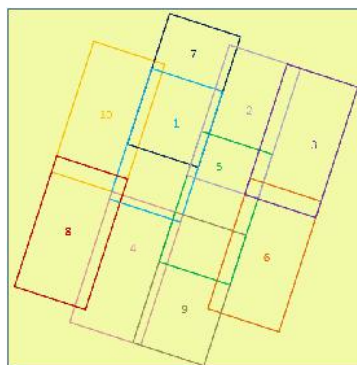


Figure 2. Sorting based on the overlap on multiple images

2.2 Global Radiometric adjustment

The next process is to adjust the global radiometry. Radiometric normalization minimizes radiometric differences among images caused by inconsistencies of acquisition conditions (Xiaojun Yang, 2000). The main idea behind this is to adjust the radiometric difference across the images. Since the images can be from multiple satellites and dates, due to their different radiometric resolutions, illumination conditions, weather conditions, and electronic equipments used to capture the photons, the overall image mean between them differs. For achieving uniform radiometric visualization across scenes in global canvas it is necessary to apply global offset corrections. In this process one image among the all input images is considered as reference image. The reference best image will be chosen by automatically calculating the statistics like mean, Dynamic Range, Standard deviation, SNR etc. Several approaches are available for Radiometric normalization (Yongjun Zhang, 2017) (S. Gehrkeah, 2016). Here histogram matching in terms of adjusting mean and standard deviations only is proposed to bring uniform radiometry globally. Figure 3a shows the block diagram for global radiometric correction. Figure 3b shows the multispectral images with and without radiometric correction after mosaic.

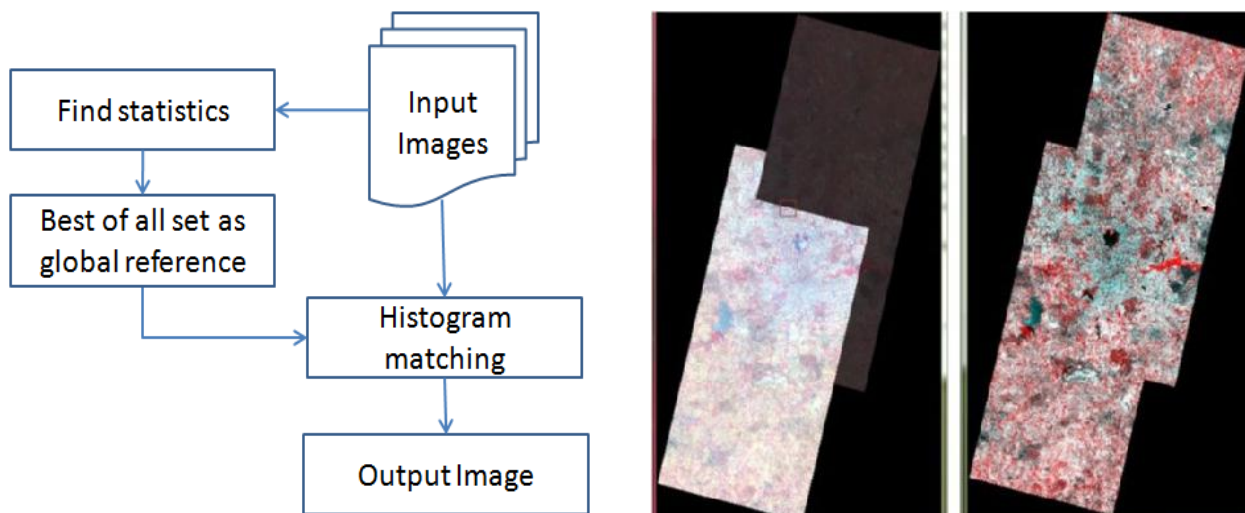


Figure 3a. Block diagram for global radiometric correction Figure 3b: Images of before and after global radiometric corrections

2.3 Overlap area registration

The products are acquired on different dates by different satellites, individual scenes will have different location accuracies. The locational inaccuracy may be very small, but not to the extent of non-visibility of feature breaks and discontinuities in the final mosaic product. So, due to mis-registration in the overlap areas two issues arises, a) Feature discontinuities/ disturbances across seam line b) Double exposure of the features in overlap areas. In order to avoid such feature breaks every image needs to be co-registered with adjacent scenes available in the background image. Several papers discussed automatic image to image registration from the point of selection of control points assuming that the images of corresponding regions are extracted and made available (Alexander Wong 2007, Jordi Inglada 2004, Youcef Bantoutou 2005, Siavash Zokai 2005). The survey on registration techniques also available (Brown, 1992). In this a robust image registration algorithm (Suresh Kumar, 2012) is used to register the current image to be mosaicked with the background image which is already added to canvas and is overlapping with the current image. A generalized search scheme for automatic registration of multi-resolution and multi-sensor remote sensing of data was explained in the paper based on mutual information as a similarity measure and a non-rigid transformation Thin Plate Spline (TPS) for achieving subpixel registration accuracies. For every block of pixels from the match points available locally, a local transformation is fitted and applied to match with the background canvas. Using this approach, well-established feature continuity is possible without disturbing the other overlap regions. Figure 4 depicts the importance of registration in the overlap areas up to sub pixel level accuracies. Figures 4a & 4c show the feature disturbance without geometric correction. Figures 4b & 4d show feature continuity with geometric correction. Figures 4e & 4g shows double exposure of features due to mis-registration and figures 4f & 4h shows feature continuity after local geometric adjustments.

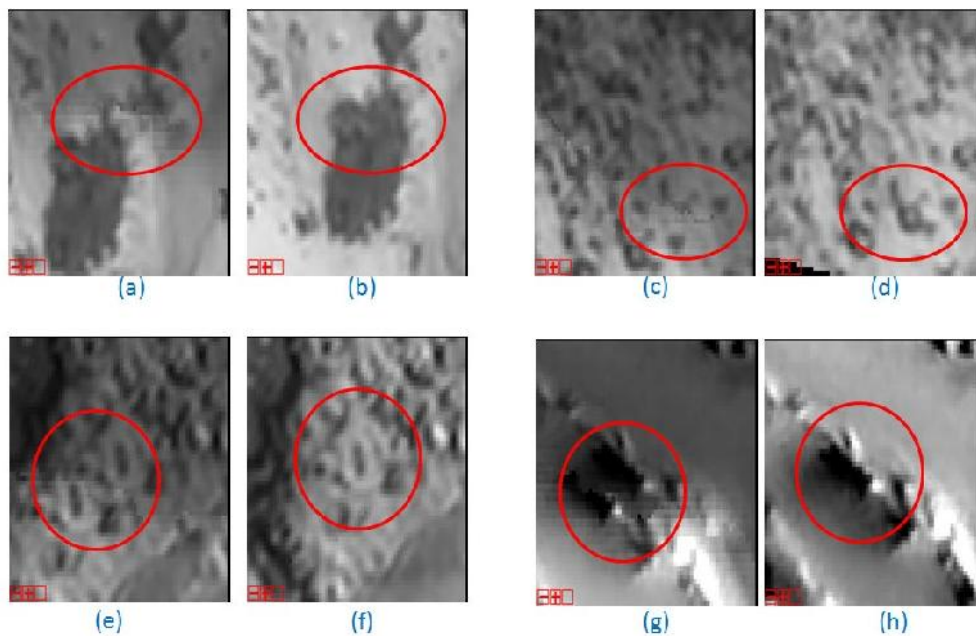


Figure 4. Sets of image pairs showing the effect of mis-registration before and after mosaic with local registration

2.4 Seam line Construction

Seam line is the border line which defines the output image contents either to be added from left image or right image. Seam line must pass through the path of least resistance/ gradient in overlap areas with low radiometric differences. Seam lines must not intersect with break lines as that will lead to visible geometric artifacts. The seam line can be straight or irregular. By default, many mosaic algorithms will apply straight seam line which is at 50% from left and 50% from right images i.e. at the center of the overlap region. The problem with this approach is, due to availability of high resolution images with different view angles, features like high raised buildings forms different perspectives in the image. When mosaic happens with straight seam line, the features which fall across seam line creates feature distortion as shown in figure 5. The figure shows very clearly only the high raised feature has the break and all other features in the overlap region are matching with adjacent scene. It clearly indicates that it is not due to geometric shift, but it is due to different view angles and thereby when seam line is going through the building, half part of the building was added from one image and another half from other image which resulted in feature distortions. To avoid such artifacts in the final mosaic, an irregular seam line is required instead of straight seam line such that seam line should not pass through the high raise buildings. An approach based on the water shed segmentation and graphs is explained (M. Al-Durgham, 2016). In this paper a new technique proposed for automatic irregular seam line construction using gradient optimization technique.

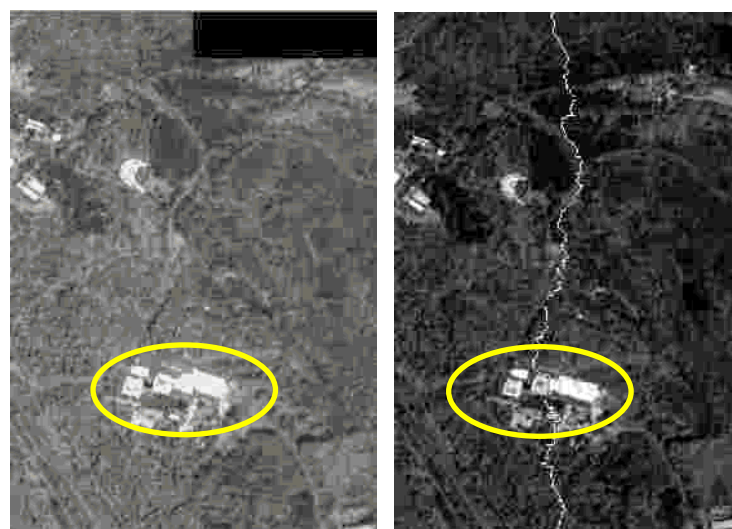


Figure 5. Effect of straight seam line after mosaic

The automatic irregular seam line construction searches for the edges and avoid going through the edges, and tries to go through homogeneous patches. Here we need to consider different overlaps directions and automatically should be able to generate seam line. The input images may have blank areas around the borders and seam line should not go through this blank portions. All conditions are to be taken while implementing this algorithm. Figure 6 shows subset of different overlaps and how the irregular seam line passes through them automatically. Red color is the irregular seam line and cross hatched portion is overlap area and rest is the non-overlapping area.

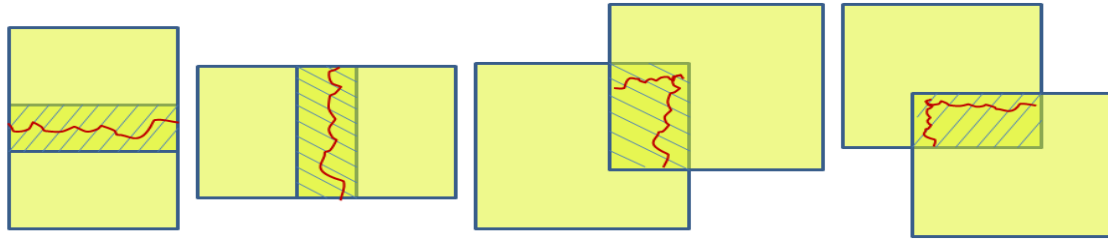


Figure 6. Handling of irregular seam line for different direction overlaps

To avoid edges across the seam line, minimum gradient path flow is implemented. At the edges the gradient will be high and at homogeneous regions the gradient will be low. For any high raised features like building there will be an edge. Thus, using this information an irregular seam line is constructed automatically by avoiding the edges. This approach finally results in selection of a feature like building in the overlap areas from one of the images only. Figure-7 presents the seam line construction algorithm for images which is having horizontal overlap. It is evident that the edges are avoided and the features will come as a whole from one of the images. The flow chart explains about the steps. The seed point can be taken automatically as top pixel / left pixel by leaving few pixels at border. At every step the optimal gradient pixel should be pushed to stack and pop the pixel from stack and again find the optimal gradient. This should be repeated till you reach bottom or right. This has to be carried out for horizontal, vertical, and different corner directions separately based on the overlaps as shown in figure 6.

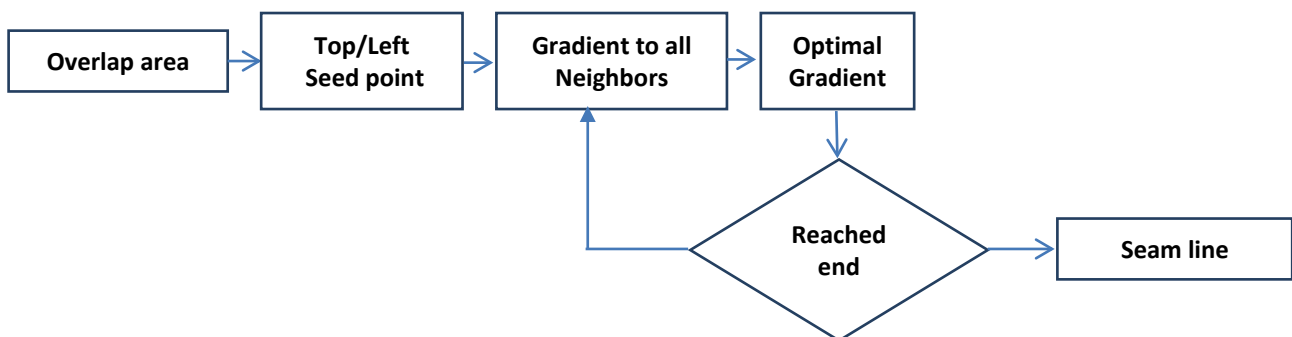


Figure 7. Flow diagram for construction of automatic seam line

Automatic Seam line construction is tested on different terrain feature images like roads, buildings, open land etc. The results are very efficient. Using this one can avoid the limitations that occur in mosaic of high resolution images. Figure 8 shows the automatic seam line extracted on different features like buildings, open land with limited buildings and roads. Figure 9 shows the mosaic of two paint brush mode images acquired in different view angles. From figure 9 it is very clearly evident that for high resolution image mosaic irregular seam line is very important step to be followed to avoid limitations with straight seam line.



Figure 8. Automatic seam line extraction on different features.



Figure 9. Mosaic of two images with straight seam line and irregular seam line

2.5 Local radiometric correction using multiresolution pyramids

After constructing the optimal seam line, one has to correct the radiometry along the seam line between the images such that a smooth transition occurs between the images though global radiometric correction is done as explained above. A technical problem common to all applications of photo mosaics is joining two images so that the edge between them is not visible. The most direct method for combining them is to concatenate the left image with the right image. In this case the boundary is clearly visible as a sharp step in gray level. Commonly used approach for this purpose is feathering & averaging of the common pixels. In feathering and averaging approaches it is to join image components smoothly by averaging pixel values within a transition zone centered on the seamline. If the transition zone is too narrow, the transition will still be visible as a somewhat blurred step. If it is too wide, features from both images will be visible within the transition zone as in a photographic double exposure. The feathering approach considers the weights decreasing from left to right for left image and vice versa for right image. Weights are multiplied with pixel gray values from left and right images and adds to the output canvas. The problem with this approach is that the diagonal edges will get disturbed as shown in below figure10. The blurred-edge effect is due to a mismatch of low frequencies along the mosaic boundary while the double exposure effect is due to a mismatch in high frequencies. So in this case the width of the transition zone is then a critical parameter. To avoid such issues a new concept of mosaic in overlap areas was introduced based on multi resolution pyramids (P. Burt., 1983b) In this approach each image is first decomposed into a set for spatial frequency bands, then a band pass mosaic can be constructed in each band by use of transition zone that is comparable in width to the wavelengths represented in the band.

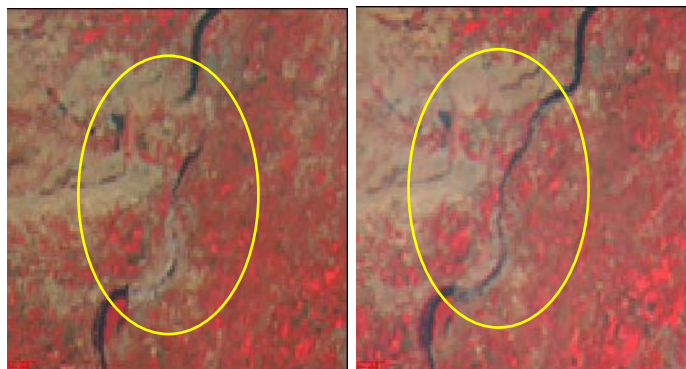
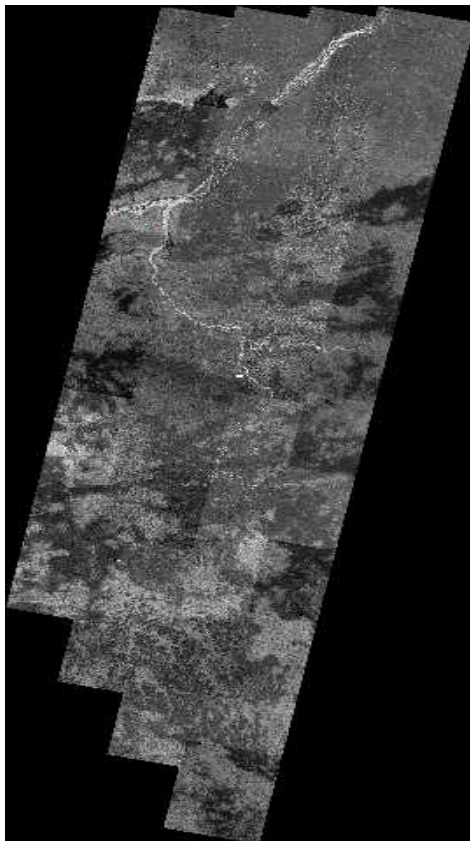


Figure 10. a) feathering using weighted averaging b) Feathering using Multi resolution Pyramids

Multiresolution pyramids (E. H. Adelson, 1984) are one of the most efficient mathematical tools in Image Processing. Many basic image operations may be performed efficiently with in a pyramid structure. The main concept, which plays a role in this pyramid structure, is multi-resolution representation. A pyramid is a set of smoothed and down sampled versions of the original Image (P Burt., 1983a) Pyramidal architectures supply the same image at different resolution levels, thus ensuring the use of the most appropriate resolution for the operation task and image at hand. The term pyramid is used to clarify the hierarchical connection between adjacent grid layers. Multiresolution spline technique is for combining two or more image in to a larger image mosaic. In this the images to be splined are first decomposed into a set of band-pass filtered component images. Next, the component images in each spatial frequency band are assembled into a corresponding band pass mosaic. In this component images are joined using a weighted average within transition zone, which is proportional in size to the wavelengths represented in the band. Finally, these band-pass mosaic images are summed to obtain the desired image mosaic. In this way, the spline is matched to the scale of features within the images themselves. When coarse features occur near borders, these are blended gradually over a relatively large distance without blurring or otherwise degrading finer image details in the neighborhood of the border.

3. RESULTS

The methodology is applied on different PAN and multispectral images with different resolutions. In this paper results on PAN and multispectral data mosaic are presented. Figure 11 shows the mosaic of 60 carto- (PAN) data products and mosaic of 20 Liss-3 (Multispectral) data products.



Mosaic of Carto-1 data Products



Mosaic of Liss-3 data products

Figure 11. Mosaic of PAN (Carto-1) and Multispectral (Liss-3) data products

4. CONCLUSION

The proposed methodology was found to be very efficient and systematic in mosaicking of images. The component images are mosaicked in accordance with the level of detail present in them. This works well even for images of high radiometric differences without any edge effect in the transition zone. The multiresolution approach avoids artifacts such as the blurred edge and double exposure effects obtained with a simple weighted average. This will work fine even when the component images are very different or of irregular shape. The multi resolution spline appears to be a practical and quite general technique for forming image mosaics efficiently. Automatic seam line construction avoids the artifacts caused due to high raise buildings. This methodology is very useful in current high resolution images for creating reference layers. This methodology is applied on several modes of images like mosaic of paint brush mode images, partial products acquired on different dates, multiple products to create district/state/country products.

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URBAN MAPPING, E-GOVERNANCE, SMART CITIES & DIGITAL CARTOGRAPHY: SECURITY CHALLENGES AND MITIGATION TECHNIQUES FOR BLE TECHNOLOGY BASED SENSOR DEVELOPMENT FOR SMART CITY

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ABSTRACT

A Smart city can be defined as one which uses technologies to increase performance while optimally consuming available scarce resources. Key 'smart' sectors include transport, energy, health care, water and waste. The basic thumb rule is "Be it any amount of high-tech lights or digitized wares they will not be of any benefit if they can't communicate on their own". The digital and physical worlds must be bridged. By this we mean if a sensor is triggered, the digitally-powered response should be there and it should be instantaneous. All these things require automation. In order for smart cities to work, there is huge requirement that our gadgets and devices must be able to communicate. Smart sensors used in development of smart cities are equipped with various communication protocols in IEEE 802.15 section. IEEE 802.15 [1] is a set of standard which caters to personal area network for short range communication from 1 m to 100m. Standardization between devices will paramount to making this happen. That's where Bluetooth comes in. These days it is highly popular with the advent of Smart City and is used extensively in sensor development. BLE sensors are contributing in a variety of areas. Bluetooth-equipped devices [5] in the world not only include just tablets and smart phones but lots and lots of sensors and IOTs. With billions of Bluetooth Low Energy (BLE) devices for Wireless Sensor Network [7] for Smart City, there is a huge responsibility to secure them. In this paper we will discuss the various security challenges including security attacks on BLE based sensors and mitigation techniques, we can incur in development of sensors for smart city using BLE technology.

KEYWORDS: Smart City, BLE, Zigbee, IEEE 802.15, LTE

1. INTRODUCTION

Information technology is ubiquitous, and can chase us from continent to continent in seconds. As the world goes digital, with more and more raw information about individuals available electronically, the need for security increases. Bluetooth is a wireless technology which uses short-range radio designed to cater the specific needs of wireless interconnections between different personal devices, which are very popular in today's society. Now personal devices can be a PC, mouse, and mobile, PDA, printer and a sensor as well. Bluetooth was developed with the objective to replace the cable(s) connecting portable and/or fixed electronic devices. Bluetooth operates in the unlicensed ISM (Industrial Scientific and Medical) band at 2.4 GHz. It has gradually become popular and to large extent has been effective in replacing existing wire connections with short-range wireless interconnectivity. Bluetooth has also come up as an enabling technology for new types of applications and has targeted devices with particular needs and constraints. In this paper, we discuss the various security challenges including security attacks on BLE based sensors [10] and mitigation techniques, we can incur in development of sensors for smart city using BLE technology.

2. STUDY

A. SMART CITY

Every city has its own history, culture and identity. There is no doubt that we need to nurture, preserve and renew the urban fabric with changing times. However, there is also a need to build new cities. A city is an economy of agglomeration; it provides various advantages and opportunities. Smart City can be defined as one which can drive economic growth and improve the quality of life of people by enabling local area development and harnessing technology, especially technology that leads to Smart outcomes. Area-based development will transform existing areas (retrofit and redevelop), into better planned ones, and in turn improve livability of the whole City. New areas especially greenery, will be developed around cities in order to accommodate the expanding population in urban areas. Such development uses technology, information and data to improve infrastructure and services. Comprehensive development in this way will improve quality of life, create employment and enhance incomes for all, especially the poor and the disadvantaged, leading to inclusive cities. A Smart City can have the following features in it.

1. Monitoring of parking spaces availability in the city.
2. Monitoring of vibrations and material conditions in buildings, bridges and historical monuments.
3. Monitoring of vehicles and pedestrian levels to optimize driving and walking routes.
4. Intelligent and weather adaptive lighting in street lights.
5. Detection of rubbish levels in containers to optimize the trash collection routes.

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The above mentioned features are few examples which can be there in a Smart City, but to implement these features we require sensors. These sensors can be a Zigbee sensor, a Bluetooth sensor, a NFC sensor or even a UWB sensor.

BLUETOOTH AND BLE

Bluetooth is the emerging technology for wireless communication. Each Bluetooth device is a Master or Slave. A Master initiates an exchange of data and the Slave responds to the Master. Communicating Bluetooth devices must use same sequence of frequency hops. Slaves synchronize to frequency hop sequence used by Master. Networks are formed using a star topology in Bluetooth. Not more than eight simultaneous devices can participate in one of these networks. Such networks are called piconets. The central node of the piconet is called a master and the other nodes are called slaves. Thus, a piconet will have exactly one master and at least one but at most seven slaves. The Time division multiplexing (TDM) allows a slave in one piconet to act as the master for another piconet simultaneously, thus creating a chain of networks (or a group of Bluetooth piconets joined together by devices that are in more than one piconet). This chain is called a scatternet. We can also define scatternet as a group of piconets in which connections exists between different piconets [11] in such a way that a master or slave can become a slave in another piconet by being paged by the master of this other piconet.

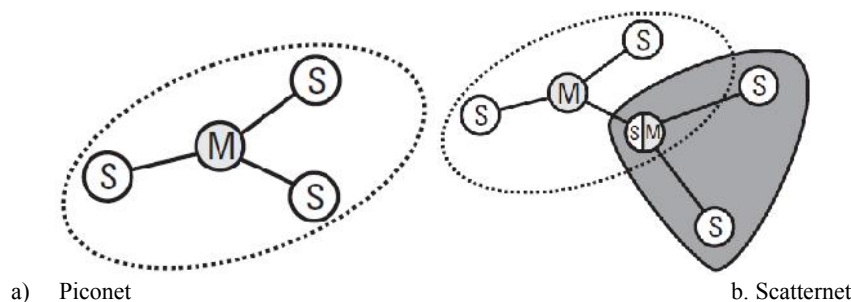


Figure 1. Bluetooth network types

BLE or Bluetooth Low Bluetooth LE is a dynamic feature of the Bluetooth 4.0 specification. It was designed for low-power usage. BLE or wibree as it was known as initially have lots of similarities with classic Bluetooth. Bluetooth LE defines a star topology. Once two devices are connected, a Time Division Multiple Access (TDMA) [13] scheme is used by the master for scheduling the start of connection events, in which communication between master and slave takes place. The Connection Request message serves as a reference for synchronization between master and slave.

B. BLE security

In BLE stack, Link Manager Protocol (LMP) [14][15][16] manages security. Consequently, security services are enforced on the link layer. The BLE supports authentication, confidentiality, integrity and authorization security objectives. For the authentication purposes, a link key is required, which is established by pairing devices. Secure Simple Pairing (SSP) [17][18] standard proposes alternative means for pairing by: comparing (or inputting) strings, which devices display; using out-of-band solution (e.g. touching NFC devices); using PIN in legacy devices; or just connecting devices without security checks (unauthenticated mechanism). BLE contains four security modes [20][21] – supported modes vary between BLE security[4] is affected by three encryption [22] modes and three service security levels. In addition to the security modes discussed above, there are two levels of trust for BLE devices, trusted and untrusted[23]. They are described as follows:

1. Trusted—A trusted device [6] has established a fixed relationship with another device and has unrestricted access to all services.
2. Untrusted—An untrusted device only has access to a restricted set of services. Although the device has passed authentication successfully, it does not have a fixed relationship with another device.

The pairing process for BLE, also known as LE Legacy pairing, uses a custom key exchange protocol unique to the BLE standard. In this setup, the devices exchange a Temporary Key (TK) [27] and use it to create a Short Term Key (STK) which is used to encrypt the connection. How secure this process is depends greatly on the pairing method used to exchange the TK.

C. Common Attacks on BLE Sensors

The pairing process is a main contributor to security issues found in BLE [2]. Attacks can be performed during different stages of the pairing process including before the pairing process has completed and after devices are paired [2]. For example, attackers may be able to carry out Man-in-the-Middle attacks based on information they collected after pairing [2].

Some of the more common attacks on BLE are described below:

1. MAC Spoofing Attack: The attack is performed before encryption is established and during the formation of the piconet when link keys are being generated [8]. Devices are able to authenticate each other by generating link-keys [3, 22].

During the attack, attackers can imitate another user [8]. They also have the ability to terminate connections or intercept/modify data with the use of special tools

2. **PIN Cracking Attack:** The attack occurs during the device pairing and authentication process. An attacker uses a frequency sniffer tool to collect the RAND and the BD_ADDR of the targeted device. A brute-force algorithm (E22 algorithm) is then used to test all possible permutations of the PIN with the data previously collected until the correct PIN is found [8]. Figure 8 below illustrates the PIN cracking attack structure [24].
3. **Man-in-the-Middle Attack:** Man-in-the-Middle Attacks such as the one illustrated in Figure 9 below occur when devices are attempting to pair [25]. During the attack, messages are relayed unknowingly between the devices [9]. This enables authentication without the shared secret keys [9]. In a successful attack, the user believes the pairing was successful; however, this is not the case, as the two devices are paired to the attacker [8, 9]. Normal MitM won't work in BLE because a BLE adapter cannot serve as both ends. One will have to serve as the client application and another as the server BLE device. After each BLE-adapter (component) is connected to the designated device—they communicate with each other over WebSocket which gives them the ability to serve as MitM.

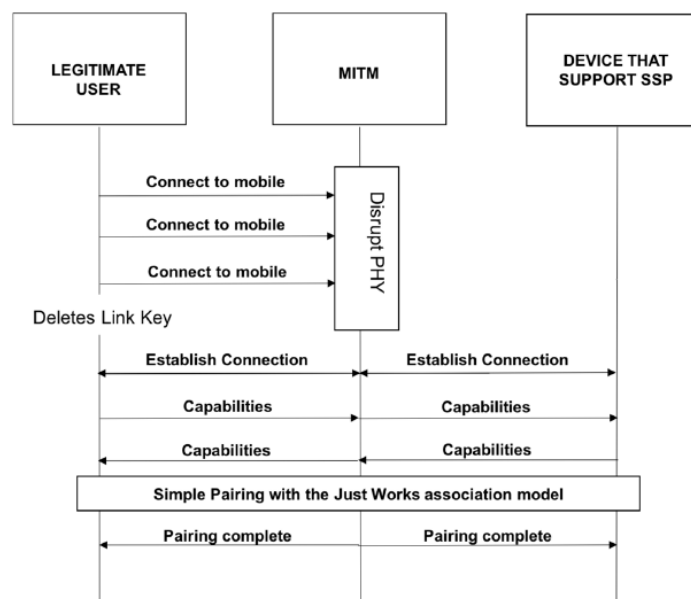


Figure 5. Man in the middle attack in BLE sensors

1. **BlueJacking Attack:** During a BlueJacking attack, the attacker sends unsolicited messages to a device to trick the user into using an access code [8]. This enables the adversary to access files on the targeted device. The devices involved in the attack and the exact source of the message received need to be within a specific range, 10 m, for the attack to be successful [8]. This attack is commonly used in crowded areas (e.g., airports, shopping malls, and train stations) [8]. While it does not usually involve the alteration of data, it could make devices susceptible to other attacks [8].



Figure 6. Man in the middle attack in a normal sensor and a BLE sensor

1. **BlueSnarfing Attack:** The attack involves hacking into a sensor and stealing any of the data stored in the sensor's memory, such as contacts, calendar entries, images, etc. [8]. During the attack, the attacker connects by exploiting the OBEX File Transfer Protocol, a file transfer program used in BLE [26]. This enables the attacker to pair with the user's device.

2. BlueBugging Attack: The attack occurs in the RFCOMM protocol [28][29]. Physical connections are made via L2CAP +base band and it emulates serial RS-232 connections [28]. During the attack, the attacker connects to the target device without the knowledge of the owner [8]. The attacker then takes over the device by gaining access to the device's set of "AT" commands, which are attention commands that send instructions to the module [8]. This enables the attacker to execute commands as if he was the device owner [8]. The attacker can also steal information and access the sensor's services and settings [8].
3. BlueBump Attack: The attack occurs when there is a weakness in the handling of link keys [29, 30]. During the attack a business card is sent between the attacker and user [30]. By forcing the user to accept the card, a trusted and authenticated connection is made [30]. After the pairing, the user then has the ability to delete the link key; however, the user unknowingly still has an active connection to the attacker [30].The attacker is then able to pair with the device later without authenticating by simply requesting link-key regenerations [30]. The attacker can continue to pair with the target device if the key is not deleted [30].
4. BlueDump Attack: During the attack, the attacker spoofs the BD_ADDR of one of the devices to connect with the other [31][32]. During pairing, the target device sends an authentication request [31]. The attacker responds with 'HCI_Link_Key_Request_Negative_Reply [31]. This is a result of the attacker not having a link key. In some cases, the device targeted deletes its link key [31]. It then goes into pairing mode [31].
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8. BluePrinting Attack: The attack is carried out by combining the information that is revealed about a device to gain additional information, such as the manufacturer, device model, and firmware version [8, 32].This attack can only be performed when the BD_ADDR of the device is known [8].
9. Blueover Attack: Blueover and its successor Blueover II are auditing tools that are used to determine if a BLE device is vulnerable, but they can also be used to initiate a BlueBugging attack [8].
10. BlueBorne Attack: The attack is conducted by exploiting a stack buffer overflow flaw [33]. By targeting the processing of pending client L2CAP configuration responses, the attacker is able to hijack BLE connections [33]. This enables them to control a targeted device's embedded content and functions. For the attack to be successful, only MAC and BLE addresses are needed [34].
11. Fuzzing Attack: The attack occurs when the adversary attempts to cause a device to behave abnormally by sending malformed data packets and non-standard data to a device's BLE radio [3, 35]. The attacker then watches how the device reacts to the data packets being sent [3]. If the device's operations become sluggish or stop during these attacks, the attacker could infer that the protocol stack has vulnerabilities [3].
12. Off-Line PIN Recovery Attack: During the attack, the attacker tries to intercept the IN_RANDOM value, LK_RANDOM values, AU_RANDOM value, and SRES (signed response) value [9]. The SRES value is a matching variable needed for authentication [9]. The attacker then uses brute-force to obtain a PIN that could be used to determine the correct SRES value, which is equal to the intercepted SRES value [9].N. Brute-Force BD_ADDR Attack This attack is a scanning attack on the last three bytes of the BD_ADDR of a device [8]. It is important to note that the first three bytes, which are known publicly, can be set as fixed [8, 9].
13. Denial of Service Attacks: DDoS (Distributed Denial of Service) and ordinary DoS are two types of Denial of Service attacks [36]. For ordinary DoS attacks, the attacker tries to crash the network or restart the system by sending packets to the targeted system [36]. DDoS attacks can be done by a single attacker [36].These attacks can disable a network [36].

They also can restrict networks accessibility to a largernetwork [36]. The attacks target the Physical Layer in the protocol stack or those above the PhysicalLayer. Some typical Denial of Service (DoS) attacks are BD_ADDR duplication, BlueSmack, BlueChop,L2 CAP guaranteed service, battery exhaustion, and Big NAK (Negative Acknowledgement), which is an attack using a continuous retransmission loop [37].

14. Worm Attacks: The attacks occur when a malicious software or Trojan file sends itself to available BLE devices. Examples of these attacks are:
 - i. Cabir Worm: malicious software that targets Bluetooth technology. Mobile sensors that use the Symbian series 60 interface platforms are vulnerable to the attacks [8]. For the attacks to be successful, the user must accept the worm [8]. This causes the malware to install on the device [8]. The worms are usually disguised in applications, which results in users unknowingly accepting them [8]. Once installed, the software is able to use the compromised device to search for and send itself to other available devices [38]. The Mabir worm is a form of the Cabir worm [8]. This worm replicates by using Multimedia Messaging Service messages and Bluetooth [8].
 - ii. Skulls Worm: The Skulls Worm, a malicious SIS (Symbian Installation System) Trojan file, targets Symbian mobile sensors with the Series 60 platform [8]. The worm poses as a Macromedia Flashplayer [8]. The user must open and install the SIS file for the worm to become active [8]. It then searches for additional devices to infect and the process repeats itself [8, 38].
 - iii. LascoWorm: The Lasco worm is a combination of a BLE worm and SIS file [8]. It targets and infects Symbian mobile sensors that support the Series 60 platform [8]. The user must open and install the velasco.sis file [8]. This prompts the activation of the worm [8]. It can then begin searching for additional devices to infect and the process repeats itself [8, 38].
15. Bluesmack Attack: The attack is a DoS attack on BLE devices and is similar to the “Ping of Death” attacks that are carried out on IP-based devices, which are networked devices [39]. It is done by sending pings that are approximately 600 bytes, as well as L2CAP echo requests to BLE devices [19]. This results in the input buffer to overflow and the targeted device to be knocked out.
16. Bluecasing/War Nibbling Attack: The attack occurs when a phreaker, a telephone network hacker, uses laptops or PCs with high gain antennas and special software to discover and exploit vulnerabilities in Bluetooth sensors to obtain access [35]. The ability to identify and describe these different attacks enable us to better understand the threats surrounding IoT BLE devices [36][42]. In addition, by classifying the threats, we can determine the severity of the various BLE attacks. Next, we discuss ways to mitigate the risks and identify potential countermeasures used in response to these threats.

D. Bluetooth Risk Mitigation and Countermeasures

The attacks that are described in the previous section discuss BLE flaws [43] that result in vulnerabilities, which can be exploited by an attacker to steal data, send messages, make phone calls, and connect to the Internet using the compromised device [2]. We now discuss risk mitigation techniques and counter measures. Mitigating BLE vulnerabilities [44] [45] differ significantly from mitigating vulnerabilities in a computer system. While application software patches are used to resolve vulnerabilities in computer systems, BLE devices require upgrades in device firmware [2]. These upgrades cannot be developed by the general public and/or user community [2]. BLE attacks can be prevented, and security can be assured as there are many counter measures that can be used to secure BLE communications [2].

Some of those mitigation techniques are described below:

- 1) Default settings should be updated to achieve optimal standards [2].
- 2) Ensuring devices are in and remain in a secure range. This is done by setting devices to the lowest power level [2].
- 3) Using long and random PIN codes, which make the codes less susceptible to brute-force attacks [2].
- 4) Changing the default PIN for devices and frequently updating this PIN (i.e., once every other month). Setting devices to undiscoverable mode by default, except as needed for pairing [2]. Most active discovery tools require that devices be in discoverable mode to be identified. Devices set to undiscoverable mode will not be visible to other BLE devices. Devices previously configured, better known as trusted devices, will be able to connect and communicate while in this hidden mode.
- 5) Turning off a device’s BLE when not needed or in use, especially while in certain public areas such as shopping malls, coffee shops, public transportation, clubs, bars, etc [2]. This can prevent users from receiving advertisements from other Blue jackers.
- 6) Refraining from entering passkeys or PINs when unexpectedly prompted to do so.
- 7) Frequently updating software and drivers to have the most recent product improvements and security fixes.
- 8) It is recommended that users refrain from using non-supported or not secure BLE-enabled devices or modules.
- 9) Pairing devices as needed [2]. Users need to maintain that any pairing should take place in a secure non-public setting [2]. This will help prevent attackers from intercepting pairing messages [2]. As previously mentioned, a crucial part of BLE security is pairing, so users should have knowledge regarding eavesdropping [2].

- 10) Users should use SSP instead of legacy PIN authentication for the pairing exchange process when it is possible. This will help mitigate PIN cracking attacks.
- 11) All lost or stolen BLE devices should be unpaired from devices they had previously been paired with [2]. Unpairing will prevent an attacker from accessing the users other devices through the BLE pairing [2].
- 12) Users should never accept transmissions from unknown or suspicious devices [2]. Content should only be accepted from trusted devices [2, 8].
- 13) All devices that are paired should be removed immediately after use.
- 14) Devices should be monitored and kept at close range.

B. Instead of basing link keys on unit keys, they should be based on combination keys [2]. This will prevent Man-in-the-Middle attacks [2].

C. Use link encryption for all data transmissions to prevent any eavesdropping, including passive eaves dropping [2]. Use of the HID boot mode mechanism, a connectionless human interface device, should be avoided, as it sends traffic in plaintext.

D. Users should ensure all links are encryption-enabled when using multi-hop communication [2]. Failure to do so could result in the entire communication chain being compromised [2].

E. Require mutual authentication for network connected devices [2]. This will provide confirmation that the network connections are legitimate [2].

F. Lower the risk of broadcast interceptions by encrypting the broadcasts [2].

G. The maximum encryption key size should be used [2]. In addition, a minimum key size should also be set—128 bits is recommended [2]. The utilization of these minimum and maximum keys will protect devices from brute-force attacks [2].

H. To provide the highest level of security, Security Mode 3 is highly recommended [2]. This mode of security, which is implemented at the link level, is one of the highest levels of BLE security [2].

I. Applications for Protecting BLE Devices can be used. These applications include Bluetooth firewall. The BLE Firewall application protects devices, specifically Android devices, from all BLE related attacks [42]. Users are alerted upon any Bluetooth activity [42]. The application also enables you to see Bluetooth capabilities on devices or specific apps [42]. Bluetooth file transfer is an application which only enables authorized devices to be connected [40].

E. Recommendations for Secure BLE Communications for Smart City Development

While not all attacks can be prevented, it is important to take the necessary steps to secure BLE communications. Users should educate themselves on BLE technology and proper security practices. Before using BLE sensors, users should do their due diligence on the sensors security features and capabilities. Device or sensor owners should frequently visit the device manufacturer's website to be cognizant of firmware updates or patches that have been issued. Engineers [46] should identify security principles and apply them throughout the development of a sensor. Developing threat models and applying knowledge learned from previous attacks could help prevent repeat attacks, as well as new foreseeable threats. They should be aware of present Vulnerabilities and update firmware [47][49][50] and issue patches as necessary. Manufacturers should be sure to inform users of these updates via their website or email for registered users. They should also ensure devices have the most recent version of BLE. Finally, they should develop documentation for users to help increase their awareness on how to secure their devices.

3. CONCLUSION

Security has been a great concern for BLE sensors in a smart city network because they are connected to public networks via gateways. With the rapid growth of the sensor technology market and the smart city concept [48], Bluetooth Low Energy (BLE) has become the de-facto standard for all kinds of devices, sensors to beacons and connected cars. The protocol, however, appears to be prone to serious security issues developers need to be aware of when designing new hardware and software solutions. Potential harm of the data from getting in hands of wrong people is quite significant. In a smart city many users would share their information publicly in social networks, but it cannot be all the information. Many of the information may be private information. People don't want everyone around to know about their health issues, their everyday commuting routes. Most importantly the data to and from these sensors can be modified and disrupted by hackers present in both public network and personal network. Even the sensors itself can be controlled by hackers if security is not implemented properly. With the introduction of new BLE 4.2, security is enhanced between the gateway and the BLE device using stronger encryption algorithms like ECDH but the other components of the network [12] can still be insecure. So, an end-to-end security approach is needed for this kind of sensor network, which will be ultimately helpful for a secure sensor development [41] in a smart city network [35].

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MILIND-1: CUSTOM BUILT DRONE PLATFORM FOR REMOTE SENSING APPLICATIONS WITH SWAPPABLE PAYLOAD AND SENSORS

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ABSTRACT

In recent years, unmanned solutions UAV/drone technology is becoming ubiquitous in various fields ranging from commercial segments like filming, entertainment, to aerial based safety and security services, to remote sensing applications like surveying, environmental, disaster study etc. Many COTS based solutions exist today in the market which provides integrated solutions by combining sensors like GPS, camera, flight controller, IMU etc. However, such solutions have many limitations such as lack of configurability, customization and security. Hence, a custom based solution based on open standard protocols provides larger configurability and better security.

Here, in this paper we present *Milind-1* a totally custom built multi rotor octocopter developed using COTS components, built on open standard/protocols and open source software. *Milind-1* uses open source based PIXHAWK flight controller, with on board computing (SOC), navigation from GPS/GAGAN, GPS tracker, swappable payload camera, followed by camera controlling operations through the Software Development Kit (SDK) from the on board computer SOC. In this paper we also present the auto mode of image acquisition with the mission/flight planning software, image collection techniques with the overlapping across the images using the Camera SDK, and illustrate COTS and Open source based aerial image processing software tools to generated 3D models from such collected overlapped images for further applications to use for geospatial study and analysis.

KEYWORDS: UAV, UAS, Drone, GAGAN, Aerial Image Processing, Remote Sensing, Custom Drone, Aerial Imaging Cameras.

1. INTRODUCTION

There are many different opinions on Unmanned Aerial Vehicle (UAV), Unmanned Aerial System (UAS) and drones. UAV as per Unmanned Aerial Vehicle System Association [2012b] is an aerial vehicle without a pilot, means the vehicle do neither have a pilot on board nor a pilot on the ground control centre/ground control station. Similarly, an UAS is a vehicle which has a pilot on ground who can communicate with the vehicle during flight. As drone can be operated both in auto mode and manual mode depending on the mode of flight operations, they are interchangeably used. Here, in this paper we use drone, UAV and UAS interchangeably.

The use of drones and UAV based platforms in the aerial imaging is increasing rapidly, and aerial remote sensing with drones is becoming as a preferred method for acquiring qualitative aerial data on demand. Recently, the UAV based image recording is becoming as an established data acquisition method in photogrammetry and geodesy (Cramer et.al,2017) for on demand high resolution image capture, processing, delivery and analysis. Disaster management is another potential application area where Drones are being deployed (AgostonRestas, 2015).Unmanned Aerial Vehicles (UAV) / Drone are quickly becoming omnipresent in our lives with the new dimensions of UAVs entering into the new emerging markets. Below, we describe the classification of UAV's based on the All Up Weight (AUW) they can carry and discuss by the major application sectors they are operated. This classification however may have small variations across nations.

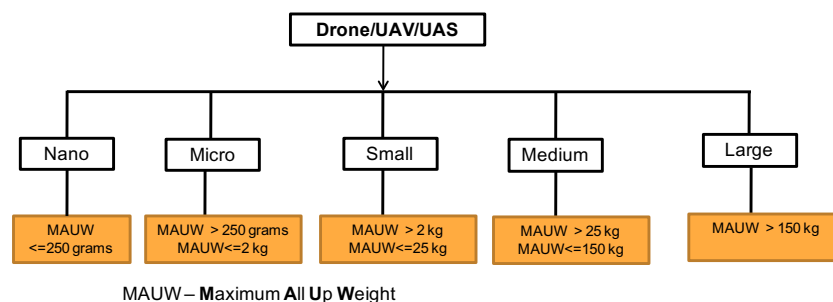


Figure 1. Drone Categories/classification as per Civil Aviation, India

1.1 Drones/UAV Classification

Drones are classified into five major categories as shown in Figure 1(Director of Civil Aviation, 2018) to operate in India. The classifications are purely based on the maximum AUW (i.e. including payload weight) that drone can carry during the

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flight, and these classifications are stated as a part of drone regulations to operate unmanned aerial systems in India by December 2018. The drone regulations also mention to have the unique ID for each drone from micro category to large category class to operate with the license being taken by the certified drone operator for operating the drone.

1.2 Drone Major Sectors and Applications

There are a variety of use cases for the drones such as: military, agriculture, law enforcement, natural resources, entertainment, commercial delivery and hobby usage (JoergSchlinkheider et.al, 2014) based on AUV they can carry. The several applications of drone in various major sectors are shown in Figure 2, they are classified into the major sectors viz. Security applications to use in national security applications, traffic monitoring, and accessing to the remote areas, rescue operations etc. The second major sector is surveillance such as aerial Survey- to use in very high resolution image acquisition on demand and processing them to generate 3D images to use for several applications like disaster management, oil and gas exploration, Urban mapping, water resource monitoring etc.

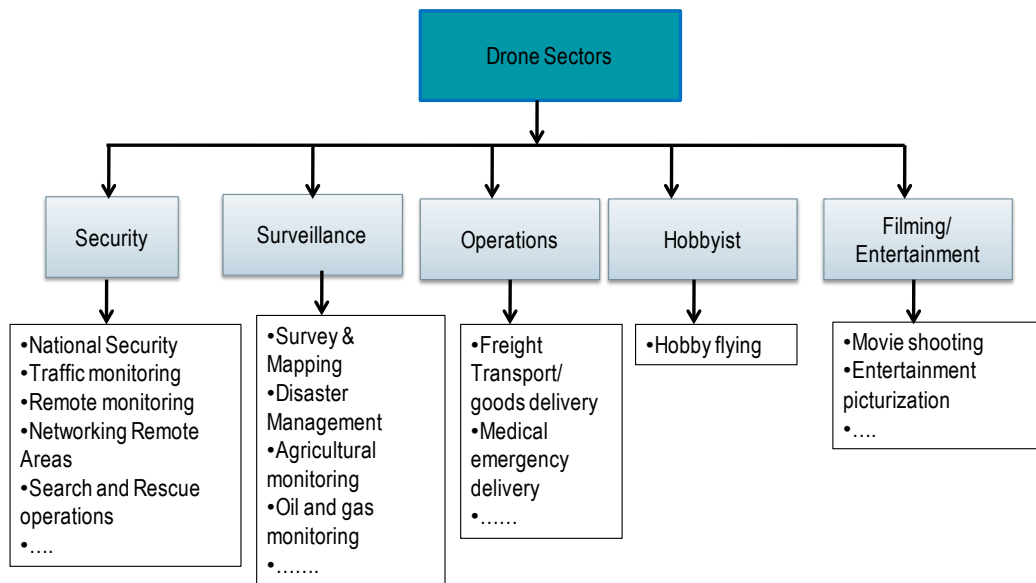


Figure 2. Drone sectors and applications

The aerial survey applications are further can be classified into three major areas such as

- Short range surveillance - Conducting short range surveillance, image capture, and analytics
- Long range surveillance - Conducting long-range surveillance, image capture and analytics
- Filming and Entertainment - Filming and entertaining industry where the drones are used for film shooting.
- Commercial service sector - To use for freight transport, goods delivery, emergency medical equipment delivery from one place to another etc.

1.3 Anatomy of Drone

The drone and its several components involved to build/integrate UAS are depicted in Figure 3. The major components required are Frame – around which all other parts get mounted, Arms – used for mounting the motors, Motors- Brushless DC motor with specified RPM to rotate for lifting of the drone, Power Distribution board – to supply the necessary essential power to all the sensors with necessary power connectors, Propellers – the major element to vertical lift off the drone with the proper pitch, Battery- another essential element for the drone to operate, Navigation or GPS – for the drone to navigate in the auto pilot mode, On Board computing (SOC) –used for computing purpose, Flight Planner – the mission planning element for the mission to fly, payload – sensor payload which can be a camera in the case of aerial remote sensing applications with gimbals mount, telemetry – radio frequency device for monitoring the flight logs during the mission, Radio controller to operate the drone in manual mode and emergency cases and during lift off time, flight controller – the essential element to operate the drone, IMU sensors, and ESC – for supplying the current to the motors. The elements used in customizing the drone Milind-1 is explained in section 3 under *Milind-1* customization.

Drone are being manufactured and are being used increasingly in surveying and GIS, Construction, Mining, Agriculture, Insurance and Structural inspection, Search and Rescue operations etc. Though Drones are being used increasingly in aerial surveillance to save time and costs on surveying and mapping projects, but they pose major challenges in customization of payload sensors, stability of the drone platform, imaging and flight planning techniques, collection of the data and processing techniques. These challenges are discussed in Section 3, illustrating the several components of the drone, and building an integrated UAS for aerial mapping applications.

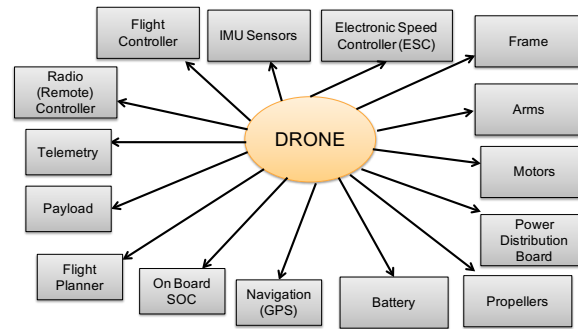


Figure 3. Anatomy of Drone

2. LITERATURE SURVEY

The literature survey is majorly conducted in three areas – i) The commercial manufactures/vendors of the drones who offer COTS drone in several drone market segments, which are ready to unbox and use ii) major parts offered by several vendors /third party providers for building the custom drone iii) open source software tools required in building the drone and iv) major third party and open source software tools in processing the aerial imagery data.

Drones (Self-flying planes / robotic flight) are becoming as the recent automation of vehicles such as cars and planes promise to fundamentally alter the microelectronics of transporting people and goods, and several collision avoidances through air traffic control research methods while drones are operated are discussed (Aislan, 2015). Surveyors and GIS professionals are using drone mapping to achieve tremendous time and cost savings on surveying and mapping projects. Time spent on collecting accurate data is vastly reduced, by acquiring data from the sky in the form of geo referenced digital aerial images – surveyors can gather millions of data points on one short flight (An overview of Drone Applications, 2016). The paper also discussed about the several applications to use the drones and several commercial players for the drone manufacturing and service providers. DJI (DJI Drones web link) is one such commercial vendor builds different classes/range of drones to operate in several segments varying from hobby to filming industry. DJI provides several types of drones to operate in several segments of the markets ranging from filming/TV industry to aerial survey etc. One major limitation with all these DJI drones are vendor lock in and prone to security issues, as the flight logs can be transmitted over a network while the flight controller is connected to internet for flight planning. Here, first we describe several major commercial players in the drone manufacturing followed by the several open source and third party software tools used for mapping applications.

Recently DJI has opened up (An overview of Drone Applications, 2016) drones on board software systems, introducing an Application programming Interface (API), which meant third parties could now develop apps to fly and control the aircraft in different ways. This is the key to developers coming up with the flight control Apps specifically for land surveying and mapping. However, these Apps are still vendor lock in and does operate with the GPS signal and the flight logs can be monitored, hence these kind of systems are not ideal suited for any security applications. Yeneec, is another Chinese drone manufacturer, and which is similar to DJI in the professional drone market. However, Yuneec has yet to offer an API for third party developers and at present the focus is primarily the video and film market, with limited applications in land mapping and surveying (Introducing MANTIS Q, weblink).

Trimble Navigation has been producing drones specifically for surveying and aerial data collection for a few years (Trimble, weblink). There are two fixed wing models and one multi rotor model, along with associated processing software packages for producing high resolution orthomosaics, digital surface models (DSM), and coloured point clouds. However, these drones are highly vendor lock in solutions. 3DR from 3D robotics (3DR, 2014) is another promising solution provider with back end support from Qualcomm, and have two drone models available. Solo quadcopter uses an integrated GoPro Hero 4 Camera, along with their Site Scan application, cloud based post processing of image sets, and integration with Autodesk Recap 360. This is also vendor lock and not suitable for serious mapping applications.

All the above said drone models from major drone companies produce drones which are often highly vendor lock in, prone to security breaches, often locked with the camera models and flight planning software tools. The proposed Drone **Milind-I** is completely built on open standard software protocols, integrated and custom built Octocopter drone with the swappable payload camera. **Milind-I**'s flight controller and mission planning software tools are also based on open standard along with open source software. Hence, it is highly secured and configurable with any third party plug and play components. For example, GPS used is a third party component, GAGAN (Inside GNSS, 2016) Satellite Based Augmentation System (SBAS) to provide precise location with corrections applied to produce more/accurate imaging positional and height accuracies. The essential hardware/software architecture and tools required for drones' payloads and mission control is described in (Enric, 2006). Drone/Aircraft hardware components include batteries, Gimbals, frame, motors, payloads, IMU sensors, flight controller etc. The parts have been manufactured and sold by several manufactures who in turn indicates the specifications of the items being manufactured for the drones. The software for surveillance, mapping, 3D modelling and various other data acquisition applications are presented (Khaula, 2017). Once the flight mission is completed and the site fully photographed and mapped, the photographs and the geo-data need to be processed into a usable orthomosaic map. This can be done with desktop software solutions, or increasingly, with cloud based solutions (The Rise of the Drones, 2016). Pix4D (Pix4D

Mapper, Web link), is one of the popular drone data processing software which offers a range of desktop processing packages for aerial mapping applications for various sectors, including structure and site surveying, agriculture, and 3D rendering.

In this paper we discuss one such indigenously integrated with the body frame parts and other sensors from COTS hardware and built using open source technologies and software tools for better configurability and security during the flight and also enable us to use the swappable payload camera operated through the programming SDK or auto scripts loaded in the camera. *Milind-1* also uses the on board computing for receiving the signal from GAGAN and stamping of the information to the Images being captured during the flight time.

3. *MILIND-1*—CUSTOM DRONE PLATFORM FOR REMOTE SENSING APPLICATIONS

In this section we first illustrate the back ground and motivation for development of *Milind-1*, followed by hardware components and software tools used in the development of *Milind-1* UAS are described.

3.1 Back ground and motivation

Though, the COTS drones have many advantages like stability, more proven, handy to use, however, they have major drawbacks in usage especially in terms of configurability and security, because the hardware, software modules supplied/bundled along with the drone are closed box which are based on vendor lock in technology. In majority of the cases, the APIs and internal hardware/software details are not provided for the developers/integrators. Also, the payload cameras to use are mostly from the same vendor, and majority of the cases the cameras come with integrated to the system, which does not allow any other camera operations for imaging. Hence, the above said aspects have led to the development of an indigenous UAS system *Milind-1*, which provides configurability in terms of swappable payload camera, change of indigenous navigation and finally data processing both on board as well as on ground.

Below, we describe the salient features of *Milind-1* followed by several major components used for building the drone and open standard software and hardware protocols.

3.2 The salient features of *Milind-1*

The salient features of *Milind-1* are i) the custom built drone for aerial applications ii) Do It Yourself (DIY) drone built with COTS hardware iii) Maximum All Up Weight (AUW) is 16 kg, with 1.5 mtr diameter Octocopter iv) 30 Ah Battery, however can be swappable/configurable battery depending on the flight time required v) able to fly from several meters to 1 km altitude vi) swappable payload camera and with a provision for programmable camera to operate during the flight time vii) endurance of 25 minutes for a payload of 6 kg with 30Ah battery for an altitude of 500 m viii) GPS/GAGAN/IRNSS sensor for precise positioning ix) mission planning open source based software module x) secured flight path and flight logs xi) provision for on board processing for compression, image enhancement etc xii) Image processing software tools for Point Cloud, DSM and Ortho mosaic generation.

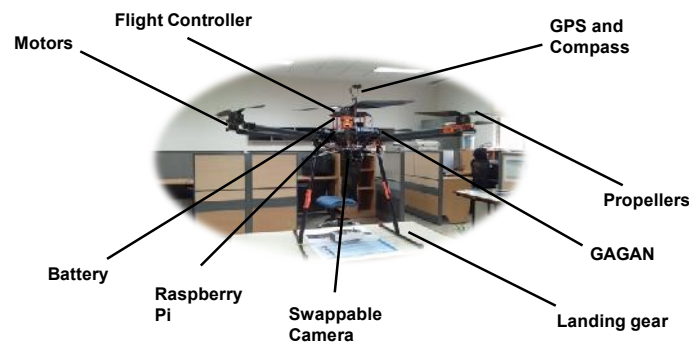


Figure 4. Components of *Milind-1*- Octocopter

3.3 Custom drone tailored for Aerial surveillance - *Milind-1*: Components, System Architecture and interfacing

Drones rely on a number of sophisticated technologies, but many of these are still under development both in technical and functional aspects. Building the drone for custom/tailored applications still pose many challenges as they demand both technical and functional challenges to bring them in force/action. Here, we discuss one such drone namely *Milind-1* built for aerial surveying applications with swappable payload camera and geo stamping on the image with GAGAN sensor. We first describe the components of the *Milind-1* Octocopter followed by system architecture and interfacing of the components. The Components of *Milind-1* and their arrangement on the octocopter frame are shown in Figure 4.

3.1 Essential Elements for building customization drone – Technical challenges

The essential elements/parts used for building the *Milind-1* are described in Table 1, which presents the brief description of the sensors and the specifications of the sensors used.

7	Propeller	Propellers play a vital role in vertical lifting of the drone. The propellers are usually measured in inches. The smaller propellers are usually selected for higher Kv motor to have more speed, and larger propeller with correspondingly low Kv rating of the motor is used for nominal flight speed, which is generally suitable for imaging applications.	Carbon fibre propellers are used here, with twin blade 18 inch in length, with pitch of 5.5 inch. Here, 4 propellers rotate in clock wise and other 4 in anti clock wise direction.
8	Battery	Drone batteries majorly used are Lithium Polymer (LiPO) or Lithium-ion type (Li-Io). Usually LiPO batteries are well suited for most of the drones due to their light weight, compact in size, and high discharge rate Lithium-polymer (LiPO) batteries, relatively light weight, compact, and offering high discharge rates, LiPOs are well suited for multi-rotors.	LiPO battery with 6 Cell, 30 Ah capacity with maximum continuous discharge of 25C and maximum burst of 50C is used with a voltage of 22.2 V to 25.2 V.
9	Remote/Radio Controller	Remote / Radio controller is (RC) used for controlling the drone from the ground. Usually RC operate in a certain radio frequency mostly in WiFi range.	RC operating in 2.4 GZ frequency is used for operating the drone. The ground module is 8 channel configured to operate for throttle, pitch, roll, yaw and other control parameters like Return to Home (RTH), hovering, GPS lock mode, auto mode set. The module on the drone placed is 2.4 GHZ transceiver.
10	Telemetry	The device used for monitoring the information about the aircraft. During the flight the logs are transmitted to the ground module for monitoring the important flight logs like location at which the flight is operating, altitude, speed, distance etc. Usually they operate in ISM band.	Telemetry used here is 915 MHz ISM band with both on board and ground module. The telemetry used here provides a range of approximately 2 km. The telemetry is also used for loading the mission planner/flight path way points to the flight controller.
11	Flight Controller	Flight Controller is a an important which is an important component in the drone. Usually flight controller are microcontroller running Real Time operating System (RTOS) to operate the drone as they receive command from the operator. They contains IMU sensors and provides other interfaces to connect ESC, GPS, telemetry and RC flight modules etc.	Here, we used PIXHAWK 2.4.8 ardupilot supported flight controller.
12	GPS, GAGAN, and other sensors like compass, and gyro etc.	GPS sensor provides the position information to the drone, which is very essential for the drone to operate in auto flight mode. Compass offers the direction to the flight and other IMU sensors like gyro and barometer provides the movement and air pressures to the flight. IMU sensors are part of the Flight controller and GPS and compass is interfaced to the flight controller as an external interface.	Ublox Neo6M GPS with compass is used with ceramic patch antenna with 6-pin D13 connector to connect flight controller. The device is with water resistant casing and protective case. GAGAN information is logged to the on board SOC and subsequently the images would be time stamped on the ground after the flight.

13	Flight mission planning software	Flight mission planner is used to plan the flight and dump/transfer the generated transects to the flight controller. The flight travels in the predefined path as defined in the transect files. For aerial imaging the missions are planned with the overlap across the image frames both in horizontal (along track) and side overlap across track).	Ardupilot mission planner is used for planning the mission. The generated mission planner files/transects are in turn transferred to the flight controller via USB interface or telemetry module.
14	Programmable camera	Cameras play a major role for capturing the good quality and stable images during the flight. There are many COTS cameras in the market which are suitable for aerial imaging.	The cameras we use are programmable cameras operated through Software Development Kit (SDK) supported by the respective vendor.

In the below section we describe the image planning methods, data acquisition and processing techniques for **Milind-1**.

4. MISSION PLANNING, IMAGE ACQUISITION AND PROCESSING

In this section we describe the methods for mission planning the mission using the open source ardupilot software, and image acquisition using COTS point and shoot DSLR programmable cameras and data processing methodology. Here, we also present the methods for geo stamping the images using GAGAN signal to the Image frame using Exif Tool. There are three major steps to be carried out viz a) mission planning b) image acquisition ii) geo stamping and iii) processing as described below.



Figure 7. Mission Planning - Ardupilot



Figure 6. Way point grid

4.1 Mission Planning

Mission planning is carried out using Ardupilot mission planning software. The sample diagram of the Ardupilot mission planner is shown in Figure 6. The right side of the picture depicts the google maps which are used as the back drop map for the mission planning. The left side top indicates the gyro movement, and left bottom box indicates the telemetry signals (Ardupilot, weblink). Figure 7 depicts the sample planned mission planning file for one of the test flights, during the planning, the payload camera configuration parameters are to be set with the mission planner, as explained in the Ardupilot mission planner guide (Ardupilot, weblink).

4.2 Image Acquisition

Image acquisition is carried out during the flight, however, before the mission flight it is essential to set the payload camera settings in the mission planner before the generation of way point grid file. After the waypoint selection is made, the survey grid is generated to check the flight path, flight endurance and height/altitude to be flown from the ground level etc. During the survey grid generation, the overlap (side and adjacent) is to be setup as a parameter, in general the overlap parameter is set such that is not less than 60%, which is essential required to generate the point cloud data. Here, we use programmable DSLR cameras which can be operated via script or through Camera SDK (CSDK) APIs. **Milind-1** is tested with Sony camera offer Camera Software Development Kit (CSDK) for operating the camera through the WiFi mode with REST (Representational State Transfer) APIs calls. The on board computing system can talk to the Camera and operate the camera with the built in programs working through the CSDK. Here, NvidiaTegra TK1 (Jetson TK1 Development Kit, web link) board as well as Raspberry Pi as on board computing device are tested via Wi-Fi module interface to the camera. The modules running on board will send a command to the camera at the regular intervals (which is configurable) and subsequently reads the on board data from the GAGAN receiver. The camera setting/programs are used to operate the camera at regular intervals of time say 5 seconds, and is flown at an altitude to achieve with the at an altitude required based on the best Ground Sampling Distance (GSD) required, and the height of built up facilities to avoid collisions if any.

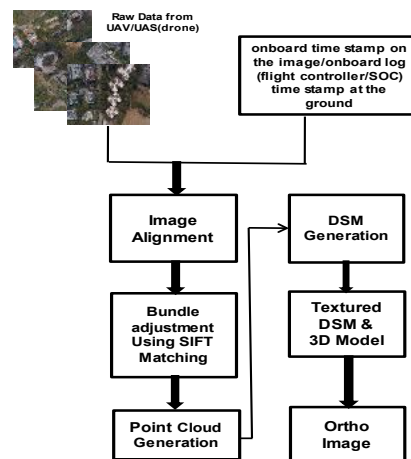


Figure 8. Flow - Drone data processing methodology

4.3 Drone Aerial Data Processing (Map making with drones)

Aerial mapping software plays a vital role in processing the image/frames imaged by the on board camera on board. There are many types of software tools both COTS and Open Sources are available for aerial data processing. Like Pix4D, PhotoScan, ARCGIS drone2map and Open source software packages like OpenDroneMap. The data flow diagram for generating DSM and ortho mosaic for *Milind-1* data processing software is depicted in Figure 8. Here, the raw data frames from the camera memory card are transferred to the ground based data processing system after the flight, to carry out the data processing operations. At first, the raw data frames are updated with the exif Meta data information with the geo location and the corresponding time stamp. This updation is carried out by in house built software module for the mission flown with GAGAN on board with Ardupilot mission planner for the missions with GPS only. Such time stamped raw data is transferred to image alignment module for computing the correspondence across the image frames. Image alignment process computes the correspondence relationship among images with varying degrees of overlap; the technique is based on the feature matching as explained (Richard, 2006). The matched features are given as input for Bundle Adjustment process for stitching the images. The stitched images are transferred to point cloud generation process, which uses triangulation method to generate the dense point clouds. The generate points clouds are used for generating the Digital Surface Model (DSM), and Textured 3D model and Ortho mosaic as described in Photoscan manual(Agisoft 2013).



Figure 11. Flight Sample 2



Figure 10. Flight Sample 2

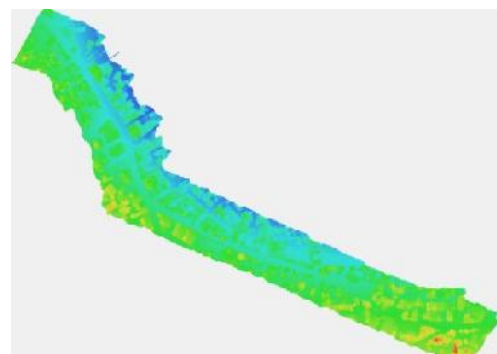


Figure 9. Digital Surface Model (DSM)

The sample flight flown in auto pilot mode having Canon 16 Mega Pixel DSLR programmable point and shoot camera as on board for the generation of Ortho image, Digital Surface Model (DSM) and 3D models is presented here. Two missions are flown; one is in the morning and another in the evening for the applications of change detection. Here, the scope is to process the data and generation of ortho and other related images, but not to study the change detection process. Each mission has resulted around 140 images, for total flight duration of 12 minutes. The flight is flown at an altitude of 100 mtr with a speed of 5 m/second with an overlap of side and adjacent approximately 60% for each frame of the image during the flight. The altitude flown is around 100 m from the ground level this resulted in 3 cm of ground sampling distance approximately. On board GAGAN is used for getting the position and location information, and will be time stamped after the mission as EXIF information using the custom built Exif tool. The images are processed using Photoscan software package for point Clouds, 3D models, and ortho photos generation of still images from each flight in Figure 9, Figure 10 and Figure 11 depicting ortho maps and Digital Surface Model (DSM) respectively.

5. CONCLUSIONS AND FUTURE WORK

The drone *Milind-1* discussed is a custom built, configurable and secured UAS with the swappable payload camera and on board computing platform for limited processing and logging essential parameters. The solution provides high configurability in terms of selection of COTS components, selection of payload for different applications and finally use of ground processing software for generating desired result. Milind-1 platform is built using COTS based frame, motors, arms, ESC etc., and open source Pixhawk flight controller. A case study for mapping a corridor is performed where the flight path is planned using the ardupilot software and data is acquired using Canon A2500 camera. For ground processing we have used COTS package Photoscan and open source opendronemap software. The results are verified with ground truth and results are found to be satisfactory. At present, GPS ground truth is not used for processing, however, in future; it is proposed to use PPK and RTK GPS for achieving higher accuracies. At present, the system is operating with a LiPO battery, in future it is planned to extend or build for operating with both Battery and generator to have the improved endurance flight. It is planned to test the mission with different types of payloads ranging from multispectral to thermal for applications like agriculture, security/surveillance etc. Also, it is planned to use the communication payload such as UHF device to establish ADHOC communication to provide the communication facility in the non-reachable zone areas.

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