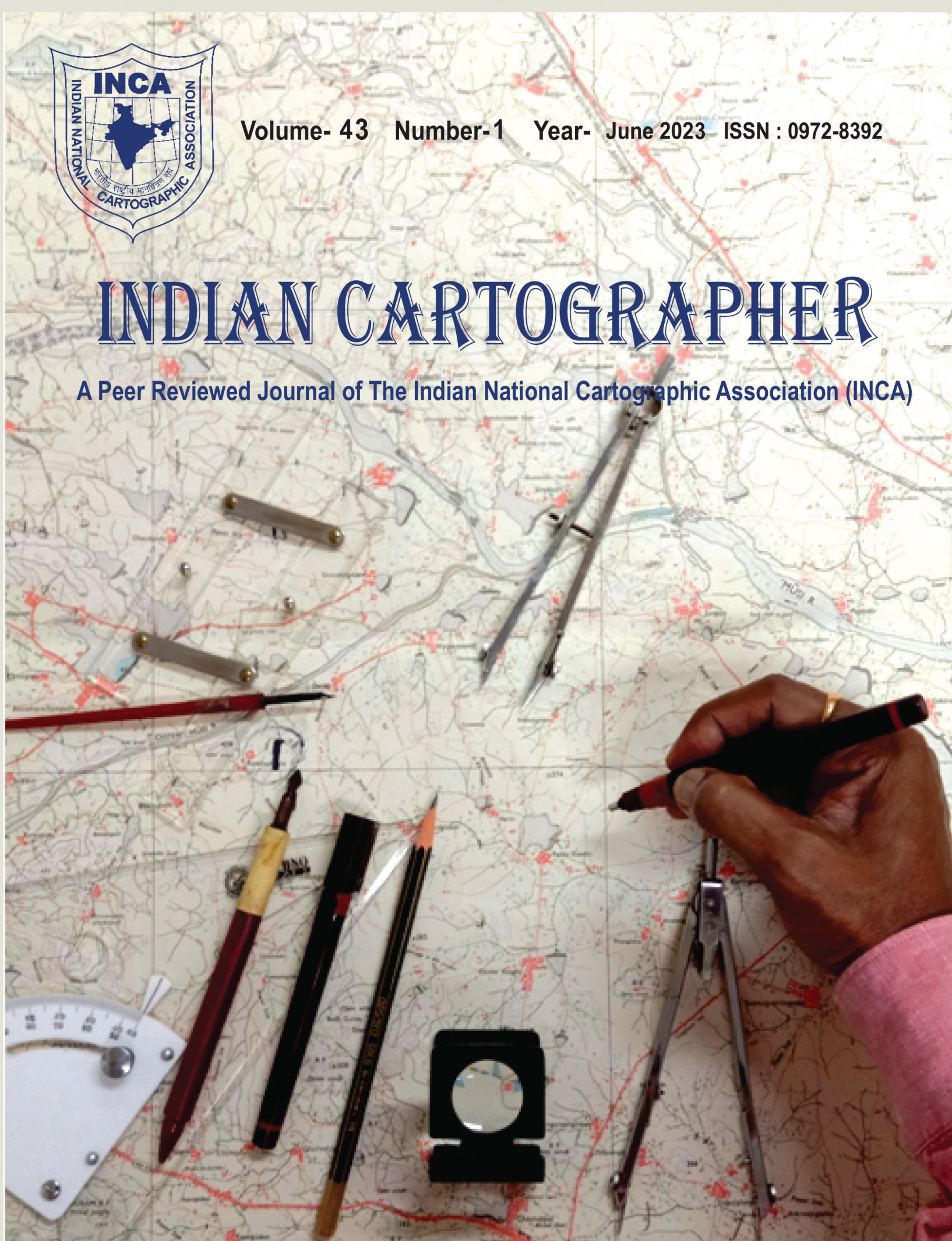




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The **INDIAN CARTOGRAPHER** is a peer reviewed journal (of the INCA, Hyderabad) published bi annually( June and December) and fulfilling the UGC – CARE List criteria. It considers research articles from diverse disciplines which employ cartographic techniques as part of its investigation and analysis to report conclusive findings. The research articles addressing the nature, scale and extent of the maps, digitalization and influence that citizenry have on local, focal, regional and global aspects of the Earth are welcome. Indian Cartographer is an open access journal focusing on cartography i.e. art and science of mapmaking, and therefore research and review papers of significance that are written clearly and well organized will be given preference. All papers, solicited and unsolicited, will be first assessed by a Reviewing Editor. Papers found unsuitable in terms of the overall requirements of the journal will be returned to the authors. The others will be sent for detailed peer-review. Authors of these papers will be notified of acceptance, need for revision or rejection of the paper. It may be noted that papers once rejected cannot be resubmitted. Illustrations and other materials to be reproduced from other publications must be properly credited. It is the authors' responsibility to obtain permission for reproduction of figures, tables, etc. from published sources (copies of letters of permission should be sent to the editor).

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## **Editor's Note**

The communication of spatial data giving locational details using, science, mathematics, aesthetics and now modern technology like the geospatial bouquet is the basis for cartography. The present day necessity for locational data and analysis of locational based natural phenomena have increased the need for cartographic analysis manifold. We are now in an era where the need for cartographic precision analysis governs our decisions in terms of time, distance and area be it at individual or policy making levels by governments. We communicate through maps on apps and it has encompassed every sphere of our lives. The change from analog to digital mapping and then digital publishing has made cumbersome handscribed charts obsolete. Today the physical world is approached by scientists with the help of cartographers who map landform features, processes operating upon them and estimate future extrapolations to help planning and management of resources and help sustainable practices. It is an exercise that has transdisciplinary scope and caters to multiple disciplines that are interested in physical states and features of planets.

Maps have spearheaded explorations, influenced geopolitical decisions and drawn boundaries among nations with a complete changeover in its trajectory when Earth resource monitoring was considered crucial in the 1960s to know more about those locations that were inaccessible physically. Since then cartography has blazed forward through each decade setting forth new explored dimensions making resource studies and explorations beyond our planet. We have traversed a long way since 700 to 500 B.C. that was the first spatial depiction of locations- "Babylonian Map of the World," a clay tablet made in Mesopotamia. Map making or cartography now is precision science utilizing real time data to tackle a cliodynamic world today and offering scope for exploration of celestial bodies beyond our planet. Cartography now ceases to be just a two dimensional exercise.

This issue of the Indian Cartographer has gathered together research articles from diverse fields to put forward that we are all interconnected in our spatial locations and have significant impact upon the environment encompassing us. The article by Mathews provides insight for India tapping its Blue Economy, Guha, Aitch and Bhandari discuss the hazards of Sundarban mangroves using geospatial and geostatistical data sets. Bhaskaran, Sundaram, Harikrishna and Tamilselvan discuss about sustainable water lake management in Chennai city, Patra discusses about the Nagal Gad basin in the upper Himalayas and how structural controls affect channel flow using detailed digital cartographic techniques. The evaluation of pan shaped imagery using CARTOSAT imagery by Srivally, Sachan and Ghosh speaks volumes about the dynamic nature of modern cartography. Mountainscapes have forever intrigued and challenged us and drones are a boon for estimating natural conditions as successfully discussed by Stalin and offers a very detailed perspective of North eastern Indian mountain forests. Das, Bandyopadhyay, Maity and Acharyya use SENTINEL data for wetland mapping in Sundarbans, a notable study of the region while Tyagi and Kumar discusses destripping of images based on feature classification approach.

The article by Chaturvedi tries to link together cultural practices, locational analysis and mapping as part of a geographical analysis to explain the nature dominated practices of the Tharu tribe in Madhya Pradesh.

This issue brings to fore a plethora of techniques and methods used by authors to bring forward concerns that relate to our planet and how best to safeguard it with proper scientific and locational data that are the result of dynamic digitized cartography. I sincerely hope the articles intrigue and draw the reader's attention to appreciate the role of cartography in our daily lives.

**Prof. Vibhash C. Jha**  
Chief Editor  
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## Contents

1. Hydrography- Providing Framework for Coastal Zone Management for Effective Land Sea Governance in Support of Blue Economy 1-7  
**Capt Mathew G Abraham**
2. Identification of major hazard or cyclone prone regions of Indian Sundarban by amalgamation of geospatial and geostatistical techniques 8-23  
**Papia Guha** ✉  
**Pritam Aitch , Gupinath Bhandari**
3. Catchment Assessment for Sustainable Lake Water Management in Kolavai Lake, Peri-urban area of Chennai City 24-32  
**G. Bhaskaran** ✉  
**Dr.S.S.Sundaram, Mr.Harikrishna and P.Tamilselvan**
4. Structural controls and drainage character of Nagal Gad Basin in Chamoli district Garhwal Himalaya 33-46  
**Gopinath Patra**
5. Evaluation of pan-sharpened image quality with special emphasis on cartosat-2s/3 imagery 47-58  
**M.V. Srivally** ✉  
**Ashish Sachan and Sujata Ghosh**
6. Challenges and Solutions for Large scale mapping of Mountainous and Forest covered areas of North Eastern India using High Resolution Drone Images 59-67  
**Stalin M**
7. A Comparative study on Sentinel-1A SAR and Sentinel-2A Optical data for wetland mapping : A case study in G Plot and L Block of Sundarban, West Bengal, India 68-84  
**Suman Das** ✉  
**Jatisankar Bandyopadhyay, Saroj Maity, Nirupam Acharyya**
8. A Novel method for Image destripping based on Feature Classification Approach 85-94  
**Vikash Tyagi** ✉  
**P Suresh Kumar** ✉  
**T Sushma Leela, Dr. R Chandrakanth, Dr. PV Radhadevi**
9. Popularity of Liquor in Tharu Tribe of Balrampur District : A Geographical Analysis 95-100  
**Richa Chaturvedi**

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# Hydrography- Providing Framework for Coastal Zone Management for Effective Land Sea Governance in Support of Blue Economy

*Capt Mathew G Abraham*

## *Abstract*

*The social, economic and biological value of coastal zones does not require any emphasis. It is estimated that the coastal economy will grow to more than 3 trillion US\$ which is contributed by near coast activities. These include providing a variety of resources such as food, energy, shoreline protection with mangroves, ocean recreation, tourism and coastal livelihoods in support of blue economy while maintaining and balancing the critical coastal ecosystem. However, this fragile ecosystem is constantly under threat from both natural and manmade disasters. A continuous monitoring of the various met-ocean variables along with various modelling techniques can give an accurate indication of the condition of the coastal zone. With the redefinition of hydrography by IHO, it is evident that hydrography can play a vital role in coastal zone management by providing the data for various modelling and also providing the required framework for area-based management tools. It is imperative that utilisation of hydrographic data be diversified from just making charts and coastal zone demarcation, to area-based management and spatial planning in support of Blue Economy.*

**Keywords:** Coastal Economy, ecosystem, modelling, hydrography, area-based management

## **Introduction**

Coastal areas are the most densely populated areas on the planet. It is estimated that approximately 38% of the world's population lives in coastal areas

i.e within 100km of the coast. Thus this zone is under tremendous pressure from human activity. There is no specific definition of a coastal zone and neither there are clear cut zones defined both at the seaward and the landward end. However as per US Commission on Marine Science, Engineering and Resources, 1969 the coastal zone is defined as '*that part of the land affected by its proximity to the sea, and that part of the sea affected by its proximity to the land as the extent to which man's land-based activities have a measurable influence on water chemistry and marine ecology.*'

It is estimated that the coastal economy will grow to more than trillion US\$ which is contributed by near coast activities. Thus any economic development will come at a cost and that cost is the environmental impact of this development. Coastal zones are the most ecologically sensitive zones on the planet. As the population density in coastal area increases, the pressure on the coastal zone keeps increasing due to the associated economic activity. It is further exasperated by the fact that all activities including social, economic and development is without adequate planning.

Hydrographic surveys are undertaken to primarily to make charts and ENC's for safety of navigation and in support of maritime trade. But IHO has recognised the extensive utility of hydrographic data and has redefined hydrography as '*That branch of applied sciences which deals with the measurement and description of the features of the seas and coastal areas for the primary purpose of navigation and all other marine purposes and activities, including –inter alia- offshore activities, research, protection of the environment, and prediction services*'. The highlighted part of the definition indicates the growing acceptance of the wider application of the hydrographic

data. Whilst production of charts and ENCs remains the primary purpose, the ancillary data collected during the course of hydrographic surveys which eventually does not make to the charts and the ENCs has vast application. The ancillary data like sound velocity, wreck investigations, sediment data, sub- bottom profiles, sea bottom samples, tides and currents remain with the hydrographic offices due to limitations of the display standards of charts and ENCs. This data can be used for a variety of purposes including providing the framework for Coastal Zone Management.

## Threats to Coastal Zone

Threats to coastal erosion can be categorised in to two parts- The Human Activities (Driving Forces) and Environmental Impact. These Driving Forces can be further subdivided into factors with minor or no impact and factors with major impact. The Environmental Impact is further sub grouped in three categories. These are physical changes, pollution and habitat loss/ degradation. The physical changes comprise of erosion of floods, fresh surface water and ground water depletion. The physical changes comprise of erosion of floods, fresh surface water and ground water depletion.

The pollution in the coastal zones affects surface water, ground water, soil, air and marine pollution. The habitat degradation in the coastal zone is due to the physical destruction of habitat, isolation of habitat, noise pollution and flora fauna destruction. The diagrammatic representation of the driving forces vs its Impact is as shown.

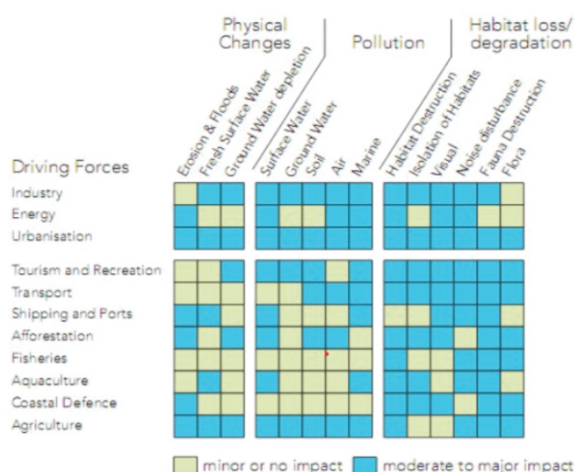


Fig.1 General impact of human activities on coastal zones<sup>5</sup>

Industry and urban growth is a major factor as it has a direct impact with the increase in settlement close to the coast. This increased settlement changes the land utility pattern close to the coast impacting the natural habitat, beach erosion and reduction in mangrove cover and increased population.

Energy Industry with oil industry being the primary source continues to be a direct threat to the coastal zones. The offshore oil rigs are established purely based on the availability of oil and gas without due regard to the environmental impact such as the effect of such man-made structure on marine flora and fauna, impact of the industrial waste on the physical characteristics in the area and in the unforeseen situation of an accident the impact of the oil pollution in the area.

Tourism and recreation provides revenue to the states and provides employment to population directly and indirectly. However, the erection of restaurants, resorts and marinas close to the coast including temporary



structure has direct impact on the salinity levels of the waters in the area which affects the marine habitat. The change in runoff patterns of the water effects the sedimentation and natural erosion pattern in the area thereby altering the coastline itself in the long run.

Transport Shipping and Ports alter the coastline in the coastal zone permanently by way of artificial structures such as jetties, marinas, break waters which alter the natural flow of water including river runoffs thereby changing the siltation and erosion patterns. Pollution from such sites directly entering the fragile coastal zone need not be reemphasized.

Fisheries and Aquaculture impacts the coastal resources as the marine species farmed for aquaculture are directly dependent on the mangrove's ecosystem for their habitat. The consequent degradation of the mangrove forests results in increased beach erosion and pollution. The overfishing of one particular species over a long period imbalance the homogenous habitat which has a direct bearing on the fragile marine ecology in the area, Sovereignty and exercising the same in its waters is vital for most countries and to exercise the same coastal defence is the key. Organisations and establishments enforcing the law of the land develop infrastructure such as having Navy, Coast Guard and Marine Police. The infrastructure so developed alters coastline, changes the siltation patterns. Erosion of the shoreline and dunes, caused by ocean currents, tidal movements and wave and wind action, is a common natural phenomenon which impacts the fragile coastal zone.

## **Hydrography- Providing Data for Mitigating Adverse Impact of Driving Forces**

The hydrographic data can be used to study the impact of each of these Driving Forces and formulate mitigation measures to reduce the impact of these driving forces in the long term to arrive at a sustainable model of coastal zone development which is in harmony with nature and in accordance with the principles of Blue Economy.

In the energy sector, modern hydrographic systems such as multibeam echosounders, backscatter data forms a secondary data product and the backscatter analysis software and interpretation by a geologist can provide preliminary inputs for oil exploration blocks. In addition, the hydrographic data provides inputs for the route along which underwater pipelines and cables can be laid. The information on underwater wrecks and obstructions can be provided by the side scan sonar data which in turn provides an input for laying of pipelines and cables. Positioning a pipeline over coral heads or rocky outcrops may place additional stress on the pipeline and there is a possibility of breakage and release of the pipeline's contents into the marine environment is one such example. This information is also vital for positioning of the offshore oil rigs. Overall, with hydrographic base data, the offshore oil and gas exploration can be conducted in a far more systematic manner while minimising the environmental impact on the coastal zone. Similarly on land, the urbanization and Industrialisation on the coastal region can be undertaken in a planned manner by planning infrastructure development in such a manner that it has minimal impact on the water flow and erosion patterns.

In the case a design of an offshore wind farm, seabed properties including underlying geology is required to be ascertained to understand the seabed dynamics which can be easily achieved through hydrographic surveys using multibeam and side scan sonars. Soil parameters determine the optimal design of the suction piles. Sand waves migration helps analyse the changes in short-term vertical position in the of the seabed by several metres. The short-term vertical dynamics can be assessed the advanced (Fourier) analysis of multi- beam echo sounder data and/or side-scan sonar data provides inputs for determining the burial depth for power cables and designing of the foundation of Self Installing Wind Turbines. Similarly inputs on tides and currents which are collected as a part of routine hydrographic surveys will provide inputs for selection of sites for generation of electricity from winds, waves and currents. Based on this data, the environmental impact of the offshore installation can be studied for change in current patterns and there by its effects on coastal erosion and mitigation measures put in place to

conserve the sensitive coastal zones.

Hydrography plays a crucial role in coastal tourism in the identification and development of potential sites for coastal tourism. It includes identification of underwater heritage sites, dive sites and wreck diving. These areas can be marked on charts and ENC's as tourism sites and be provided as a non-SOLAS product to small tourist boats and crafts. The designation of such tourist site and planned routes aid in rapid and safe transit from ferry points to these tourist sites increasing efficiency of operations and also aid in systematic conduct of ancillary tourist activities including development in the coastal zones of marinas, resorts and restaurants which hitherto are developed in a haphazard manner in the coastal zone.

With regards to marine transport first and foremost, adequately surveyed modern charts and ENC's present the opportunity of shorter maritime routes and allows for increase the loading of the ships thereby increasing efficiency and reducing carbon footprint by reducing the consumption of fuel. Seasonal changing of shipping lanes would also contribute to natural recovery of the affected area as compared to maintaining one constant sea routes and options for the same can also be facilitated by hydrography. Even for mitigation of disasters, hydrography plays an important role as high density bathymetry data along with current patterns is used in data models to predict the extent of oil spills, direction of movement of the spill and undertake pollution control measures based on such models.

To develop a green sustainable shipbuilding complex, a suitable site is to be identified primarily. This is determined mainly by factors such as a sheltered coastline protecting from the elements of weather, suitable bathymetry, depending on which the draught of the ship that can built will be determined, tides and currents which will determine the dry-docking capabilities. This entire range of data is provided by the hydrographic surveys. Thus, availability of this data can be used to undertake primary site selection. Another important aspect for the ship building is obtaining environmental clearances in accordance with various Coastal Regulatory Zone (CRZ) rules. The hydrographic data provides the base data for the environmental impact studies like current and siltation patterns, effects in area of confluence of rivers and sea, types of structures required to be built to minimize the effects based on tides and currents etc and undertake the development in accordance with the CRZ rules. Impact of such artificial construction can also be studied on the marine flora and fauna and mitigation measures put in place at the planning stage itself for sustainability.

Hydrography can make fishing and aquaculture sustainable in the long run. Location and dimensions of the aquaculture area and fish habitats are a function of bathymetry and type of seafloor, and in turn hydrography. The delineation of such areas based on the above characteristics along with submerged aquatic vegetation, salt marsh wetlands estuaries, anadromous streams and riparian zones will provide a fair idea about the likely habitat for a particular species of fish. Mapping these spatially will provide an accurate idea about the species in the area, which can then be monitored periodically to assess overfishing and fishing bans can be ensured periodically with shifting habitats to ensure a healthy population of all species and to prevent overfishing. Selection of appropriate aquaculture sites can be undertaken based on accurate hydrographic information which in turn provides assistance for sustainable harvest conserving for the future whilst enhancing a nation's ability to plan efficiently. These sites can be periodically earmarked on the charts to provide various fishing related information including seasonal variations and no fishing periods with designation of Marine Protected Areas (MPAs). Thus, the marine flora and fauna will be protected by this sustainable and efficient model of fishing, thereby minimising the ecological impact on the fragile coastal zone ecosystem.

This pollution can be mitigated through spatial and temporal analysis of hydrographic data modelled with the analysis of waste flow to arrive at the quantum of waste at a particular site which can then further be extrapolated at regional and global levels. In fact, these models can be studied to understand the flow of each of the pollutants. These models require hydrographic inputs such as high-resolution bathymetry, tides and current flow

patterns to determine the vectors, quantum and frequency of pollutants passing through waterways and to accurately quantify the amount and type of litter on riverbanks, coastlines and estuarine areas. Large areas can be covered for modelling using remote sensing and drone technology in different spectral and temporal resolutions for qualitative and quantitative data analysis of pollution and using advanced algorithm and models to arrive at mitigation techniques. The ground truthing of these models can be undertaken by in situ studies of tides, currents and high-resolution bathymetry. All in all, hydrographic survey provides the base data for impact modelling, environmental monitoring and consequent mitigation and management resulting in better Coastal Zone Management at land-sea interface.

To exercise sovereignty, Navy, Coast Guard and other law enforcement agencies should have various coastal zones provided in charts and ENC's to monitor maritime activities. Hydrography thus provides the requisite tools to undertake surveillance against illegal activities such as piracy, drugs smuggling, poaching, Illegal, Unregulated and Unreported fishing(IUU) and armed robbery at sea. It also provides tools for prosecution in the court of law, as for the above crimes, the jurisdiction of the coastal state needs to be established in the court of law. Enforcement of law improves efficiency, cuts losses due to illegal activities and thus reduces the various risk to coastal zones from these illegal activities which includes pollution, unregulated fishing and unregulated development in the coastal zones.

## **Hydrography for Marine Spatial Planning- Providing Framework for Coastal Zone Management for Effective Land Sea Governance in Support of Blue Economy**

Human activities in the coastal zone have been conducted on *ad hoc* basis. This has resulted in various stakeholders pursuing their own developmental agenda without any care for the other. The lack of coordinated approach and future planning has adversely impacted not only the interests of the stake holders but also has adverse impact on the coastal zone. Hydrography plays a key role in overall management of marine space for all these activities of Blue Economy in the coastal zone under the ambit of Marine Spatial Planning (MSP). It is amply clear by now that with so many stake holders pursuing various activities in competing marine space, there is a need to de-conflict space for each of the players, manage jurisdiction of space and monitor/regulate all activities at sea. MSP comes as an aid to planners, executors and regulators for the marine space management. Planners are the policy makers like the government ministries, executors are the various players working in the marine space to extract products and regulators are Navy, Coast guard and other law enforcement agencies.

MSP provides for area-based management of the coastal zone which partitions the ocean space into various zones in which certain activities are permitted and certain activities are prohibited. These activities are decided on the basis of the data such as bathymetry, geology, winds, tides, currents, bottom sediment type and nature of the coast. Most of this data is collected as a part of hydrographic surveys. It also identifies stake holders with common interests in order to optimize resources and stakeholders with diversified interests to de- conflict space so as to not interfere with each other. Such zones can be designated in a variety of methods ranging from exclusive, mixed zones and prohibited zones. Where the exact utility of the zone is not identified, temporary zones can be designated in a limited area for a limited period of time to undertake feasibility studies for a particular activity. MSP is also a regulatory tool where regulating mechanisms such as permits, licenses, pollution control, standards and compliances can be enforced. These plans can only be undertaken with a chart or an ENC as a backdrop which will provide the requisite base data for zoning and which can further be utilized for depiction and display for all stakeholders. Hydrography i.e., charts and ENC's provide the basic planning tools for MSP. In the long run, a Marine Spatial Data Infrastructure (MSDI) can be created in which various stake holders can dump their data and this data can be directly imported for Marine Spatial Planning. With the rapid development in the field of Artificial



Intelligence (AI), it may possible that the data in the MSDI is auto analyzed by AI and changes in the MSP is incorporated based on this analysis. It may also recommend de-confliction of marine spaces based on this analysis without any human interference solely based on the data available in the MSDI and various decision-making criteria fed in by the user.

## Conclusion

The climate change is no longer a myth and the seasonal anomalies that have been observed a period of time are direct indicators of the same. Coastal zone is the most critical area in the planets ecosystem as it provides vital balance between the landmass and the oceans. The rising global temperatures and melting of glaciers in turn has disturbed this critical balance between the land and oceans. It not just has climatic implications but also physical, chemical and biological implications for survival of mankind.

With rapidly advancing computer technology including machine learning and AI, hydrographic data can be utilized to study and model each activity undertaken in the coastal zone and understand its impact. The study of sediments and sub bottom profiles is a good indicator of the potential for oil and minerals in the sea bed. The study of tides, tidal streams and currents gives an estimate of the flow, erosion and siltation pattern which can be put to use to identify suitable sites for port development and associated infrastructure. The study of waves and winds can be used to identify suitable sites for renewable energy generation from waves and off shore wind mills.

High resolution bathymetric data along with the ancillary data collected during surveys combined with remote sensing and drone technology can be used for modelling to understand the implications of development in the coastal zones. These models can simulate the changes in sand erosion patterns, change rate and direction of currents, rise in sea water temperature, change in siltation and its effects on flora and fauna due to various development activities in the coastal zone. Mitigation measures can be put in place at the planning stage itself to minimize the adverse effects of development in coastal zones.

AMSDI can be developed with hydrographic bathymetric data forming its base layer. All stakeholders operating in the maritime domain can add or superimpose their data collected in to this MSDI. This includes various ministries like the shipping ministry (for port limits data, restricted anchorages etc), tourism ministry (for recreational areas), Ministry of Earth Sciences (for scientific data collected including designation of marine protected areas), Ministry of Petroleum and Natural Gas (for designation of Oil Exploration Areas), Ministry of Defense (for designation of exercise areas) state governments and all other agencies operating in maritime sphere. AI and machine learning can extract relevant data from MSDI for MSP and plan, design, designate and de-conflict the various areas based on suitability, priority and environmental impact. Mitigation measures on adverse climatic impact can also be recommended to the stakeholders based on the various models created from this data.

It is clearly evident that hydrographic data collected has wider application in every sphere and especially in coastal zones as majority of the hydrographic surveys are concentrated in this zone. Hydrographic offices need to put this data for wider application rather than restricting it to production of charts and ENCs. Blue Economy aims at sustainable use of the oceans. To make any activity in coastal zone sustainable, environmental impact assessment is the key. Hydrographic data can provide the frame work for the impact studies. This data combined with all other data collected from each of the stakeholders will allow a comprehensive study on developments in coastal zones, its impact assessment and the mitigation measures required to be put in place. In the long term, it will provide the model for sustainable development in the coastal zone.

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# Identification of major hazard or cyclone prone regions of Indian Sundarban by amalgamation of geospatial and geostatistical Techniques

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**Pritam Aitch , Gupinath Bhandari**

## Abstract

*Unprecedented increase in natural hazards in the 21st century is witching a line of threat for human or living society. India is no such exception. Moreover the coastal regions of India majorly the Indian Sundarban are being getting drowned under heavy hazard attack or impact. Present research is being focussed for Indian Sundarban coast. Being a part of 10,000 sqkm , Indian Sundarban comprise of 38% of the total area whereas the 62% spans over Bangladesh . Demarcated by the international boundary Indian Sundarban consists of webbed network of rivers and creeks. Diversified topographical jonors make the region a significant landmass and complex at the same time. With the largest count of mangrove Sundarban is designated as the natural barrier for saving the land from attacks of hazards. But, under threatening increase of hazard count, with loss of ecosystem services due to climatic aberration, the region is becoming bare to hazards. This in turn has increased the threat for inland areas and majorly for the dense city of Kolkata. An immediate management is necessary for which the identification of major hazard and its impact scenario need to be analyzed .Present research focussed this and with the aid of geospatial technology depicted the major hazard or cyclone impact scenario in Indian Sundarban. Such in turn helped to scrutinize the most risky areas of concern and the count of population in threat. Implication of geospatial or GIS technology with integration of geostatistical technique has laid a strong bond of hazard impact identification. With the ascertaining of risky areas, the quantification of threat have been made in terms of the population count of each of the 19 blocks of Indian Sundarban. Research thus tried to pave the way for sustainable management of hazard impact in fragile ecosystem by implantation of the advanced technology.*

**Keywords:** Cyclone impact, risk prone zones, geospatial, geostatistical, population, Indian Sundarban

## Introduction

21st century is an era that marks a period of increasing climatological to disaster threat over the living community. With the passage of time the gentleness of water, the greenness of nature and purity of air has got lost with increasing technological advancement. In this form hardly the advancement took an eye towards mother nature! and now when the earth is drwoning , inhabitants are becoming concern but the task is difficult.

An eye to the world with the 1.5 billion hazard impact and \$13 trillion economic loss due to hazards (Sendai Framework for Disaster Risk Reduction 2015-2030, 2021) is indicating to the increasing severity.

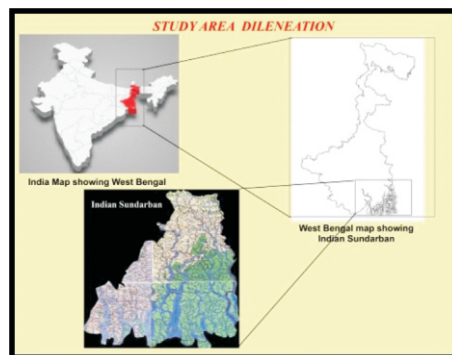
Viewed to the coastal hazards, it is reviewed that from 1990 till 2015 Bangladesh faced a death toll of 99.53% over coastal districts (M.S, M and T.-S, 2019). Cyclone is one of the most severe coastal hazards. And in case of Asian countries it im pounds its threatening severity. In Orissa, cyclone shows heavy disruptions. As studied from 1970- 2017 , it has been found that annual average death due to cyclones is 414 with the loss of property at of Rs. 662 million on average annual basis (Behera and Panda, 2020). In India, about 7516 Km coastline is under cyclone attack. Out of the Indian States along with Odisha , West Bengal coast is severely impacted due to Bay of Bengal cyclone occurrences. Bay of Bengal again proves to be the den of cyclonic storms with the recent severes like Bulbul, Amphan, Yaas.



Due to Amphan severely impacted is the West Bengal where 21560 sq km of thae are with millions of people has been impacted (Tandon, 2022), along with economic losses equivalent to Rs 1 lakh crore (Cyclone Amphan: West Bengal takes Rs 1 lakh crore hit, 61% of state revenues, 2022). Cyclone Yaas , however was devastating mainly due to surge , and with the rise of 5 to 6 feet water above normal levels , it breached emabnkments at 135 places causing severe inundation (News and News, 2022) And majority of such cyclones are having their landfalls on the south west coasts of Indian Sundarban. Hence, to make Indian Sundarban the most sustainable barrier with mangroves against hazards , it is essential to have adetailed cyclone hazard analysis on behalf of impact. With this principal view present research focussed on its analysis.

## Study Area

Spanning on both India and Bangladesh Sundarban is exhibited as the luxuriant front of biodiversity of the world. Covering a total area of 25,500 sq Km, this region is located in between 21°40'04"N and 22°09'21"N latitude, and 88°01'56"E and 89°06'01"E longitude, and is stamped as the UNESCO world heritage site in 1987.(Centre, 2021). This largest deltaic halophytic region is coasted at confluence of the Ganga, Brahmaputra and Meghna rivers. With a complex network of tidal waterways, mudflats, and small islands of salt- tolerant mangrove forests Indian Sundarban (Figure 1) covers an area of about 9630 sq. km.



**Figure 1: Study Area.**

The constant process of erosion and accretion of lands by tidal influence majorly makes the geomorphic set-up of the region a complex one. With 300 species of flora and 425 wildlife species species (Barik and Chowdhury, 2014).

But this highly enriched nature's den is susceptible to coastal hazards majorly the cyclones. With "Aila" in 2009 and then with "Bulbul in 2019", "Fani in 2019", "Amphan in 2020", "Yaas in 2021" Indian Sundarban coast got squeezed under vulnerability of hazard impacts and attacks. Economic losses pounded high shivering the state's socio-economic condition as seen principally in case of Amphan cyclone in 2020 with loss of \$14 billion (Cyclone Amphan led to \$14 billion economic losses, says the global report, 2021).

With 54 inhabited islands , Indian Sundarban is home to 4.5 billion people. This population is a threat . Moreover the increasing trend of population is even more threatening as suggested by census reports - in 2001 the total count was 3757356 whereas in 2011 it grew to 4426259 (Directorate of Census Operations, West Bengal, 2011). This growth of population with increasing hazard majorly cyclone occurrences is making the region a highly risky area. And as the major barrier is becoming risky, then the metro city of Kolkata along with other parts of state of West Bengal is also becoming threatened.

Data Sources

- 1. Hazard Data = Combined hazards data (Department of Geology, Presidency University, West Bengal, 2011); Combined hazard data on occurrences. (Mandal, 2018) ;Cyclone hazard data from IMD generated annual cyclone reports from year 1991 to 2021. (Annual RSMC Report, n.d.) ; Surge hazard data from IMD generated annual cyclone reports from year 1991 to 2021 (Annual RSMC Report, n.d.) and Inundation data – Again from annual cyclone reports by IMD (Annual RSMC Report, n.d.), from annual flood reports by West Bengal government irrigation and waterways department from 1991 to 2021. (Annual Flood Report, n.d.).
- 2. Population Data= Data have been archived for both South 24 Parganas (Census of India, along with the Royal Bengal Tiger region is physiographically bounded by the Baleswar River on the east in Bangladesh and Hooghly river on the west in India. Being the largest den of mangroves, Indian Sundarban comprises of 24 true mangrove 2011) as well as for North 24 Parganas (Census of India, 2011).

Materials & Methods

In order to reach the major objective of the present research work formulating the methodology is measured to be one of the most important section. Following figure (Fig 2.) is giving an overview of steps followed in this research.

Description of methodological steps:

- 1.1 Identification of the major hazard:  
On the basis of 439 years of data the analysis has been made. Simple excel analysis have been made to find the major occurring hazard of the Indian Sundarban.
- 1.2 Nature of hazards of Indian Sundarban:  
Present research inquisitively and crucially tried to identified that if the major hazard is the cause of other occurung coastal hazards of Indian Sundarban. And also wanted to depict that if the nature of hazards are cascading. This has been done on basis of mathematical set theory . Software used is Venny 2.1.

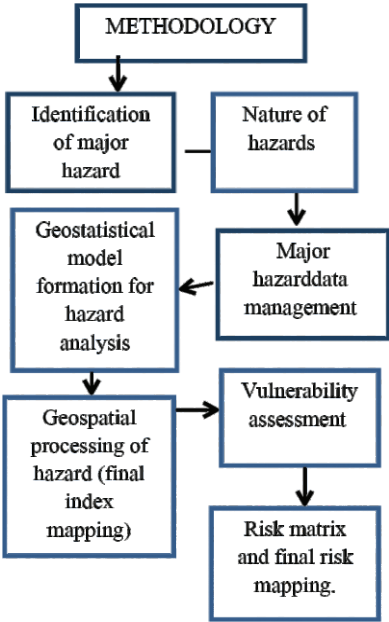


Figure 2 : Overview of steps followed.

### 1.3 Major hazard data management:

With the identification of major hazard. Now its time for sorting and managing the data of work on excel format.

### 1.4 Geostatistical model based hazard analysis:

After the sorting of data. Research progressed at hazard analysis. Hazard analysis took place on basis of the 30 years of data. In this respect, research relied on geostatistics. The modelling have been done on Geospatial analyst wizard of ARC GIS software. The modelling followed the ordinary kriging procedure for developing the model on basis of semivariogram. Following is the brief description of kriging:

Kriging is the procedure of estimating the study parameter values on unknown locations on basis of variograms. Variograms not only provide information but act as one of the major geostatistical calculation tools.

Kriging beliefs that the variation on the surface can be explained on the basis of distance between sample points. On this base kriging follows the number of following steps: Fitting of a mathematical formula, statistical analysis of data, variogram modelling, surface creation and creation of variation.

Kriging fits into the formula (How Kriging works—Help | ArcGIS for Desktop, 2022) –

$$\hat{Z}(S_0) = \sum_{i=1}^N \lambda_i Z(S_i)$$

Where,

$Z(S_i)$ =ith location

$\lambda_i$ =unknown weight.

$S_0$ = Prediction.

$N$ = the number of measured values.

With the incorporation with kriging the next major part is of variogram leading to prediction of unknowns. Variogram opens up with fitting of a spatial model. In such domain the empirical semivariogram graph is being computed with the locationally distance of  $h$ , as:

Semivariogram(distance)= $0.5 \times \text{average}((\text{value}_i - \text{value}_j)^2)$ .

After the computation of the graph, its next to fit the model. It is the most important step for spatial predictions. The modelling includes – circular, spherical, exponential, Gaussian and linear models. Most commonly used for the geospatial modelling in Arc GIS is in case of ordinary kriging is the spherical model. Model depends on the progressive decrease with distance of spatial autocorrelation.

Kriging again are many types of which the most used is the ordinary kriging which deals with assuming that constant mean is unknown.

In briefing the above geostatistical procedure present research via geospatial modelling also undergone such steps .

### 1.5 Geospatial processing of hazard(Final index mapping)

With the kriging output on basis of the wind speed it indicated the zonings. Then for the classifying criteria on basis of the IMD classification (Table.1) of cyclone wind speed, the final classification has been made. Reclassification led to the indexing of blocks on linear scale of 4 : low impact = 1, moderate impact = 2, high impact = 3 and extreme high impact=4. On the basis of the indexing, the final cyclone hazard index map for

Indian Sundarban has been formed. Need to be mentioned that the analysis have taken place on basis of 30 years of cyclone data i.e., from 1991 till 2021.

**Table1: IMD**  
Classification.(Source:Mohapatra, 2021)

| Type of Disturbance               | Associated Maximum Sustained Wind      |
|-----------------------------------|----------------------------------------|
| 1.Low Pressure Area               | Not exceeding 17 knots(<31kmph)        |
| 2.Depression                      | 17 to 27 knots (31-49 kmph)            |
| 3.Deep Depression                 | 28 to 33 Knots (50-61kmph )            |
| 4.Cyclonic Storm                  | 34 to 47 Knots (62-88kmph )            |
| 5.Severe Cyclonic Storm           | 48 to 63 Knots (89-117kmph )           |
| 6.Very Severe Cyclonic Storm      | 64 to 90 Knots (118- 167 kmph )        |
| 7.Extremely Severe Cyclonic Storm | 91 to 119 Knots (168- 221 kmph )       |
| 8. Super Cyclonic Storm           | 120 Knots and above( $\geq$ 222 kmph ) |

### 1.6. Vulnerability indexing

In case of the natural hazard impact , the most threatened is the living population . Hence for vulnerability assessment present research relied upon the population density based vulnerability index map. After being calculating the population density, research on the basis of the quartile range of 4, indexed the blocks following the same linear scaling as followed in previous section of geospatial processing of hazard. And after indexing the final vulnerability scenario is ascertained.

### 1.7 Risk matrix and final risk mapping:

Final risk indexing and spatial mapping in this research has been based upon the risk matrix(Greiving, 2006). Here the matrix has been formulated as per the research demanded in Table 2. In Table.2, E-L stands for Extremely Low, V-L stands for Very Low, L stands for Low, M stands for Moderate, H stands for High, V-H stands for Very High and E-H stands for Extremely High.

**Table 2 : Risk Matrix**

| <div style="border: 1px solid black; padding: 5px; display: inline-block;">V.I</div> <div style="border: 1px solid black; padding: 5px; display: inline-block; margin-top: 10px;">H.I</div> | Low<br>1  | Moderate<br>2 | High<br>3 | Extreme High<br>4 |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|---------------|-----------|-------------------|
| Low 1                                                                                                                                                                                       | 1 (E-L)   | 1.5 (V-L)     | 2 (L)     | 2.5 (M)           |
| Moderate 2                                                                                                                                                                                  | 1.5 (V-L) | 2 (L)         | 2.5 (M)   | 3 (H)             |
| High 3                                                                                                                                                                                      | 2 (L)     | 2.5 (M)       | 3 (H)     | 3.5 (V-H)         |
| Extreme High                                                                                                                                                                                | 2.5 (M)   | 3 (H)         | 3.5 (V-H) | 4 (E-H)           |



## Results and Discussion

With the successful implication of the methodologies, research reached to its results. In this section discussion on such results is being made. Such in turn will help to fulfil the objective of the present research work.

Discussion follows the following segments:

- Major hazard identification.
- Nature of the hazards of the region.
- Geostatistical model formation.
- Implication of geostatistical model for geospatial hazard analysis.
- Vulnerability assessment.
- Risk identification and mapping.

In detail result and its necessitate discussion now thus commence on:

### Major hazard identification:

This section study dealt with 439 years of data(Department of Geology , Presidency University, West Bengal, 2011 and Mandal, 2018 and Annual RSMC Report, n.d.).On the basis of such data simple excel statistics have been performed and the results are shown in Figure 3. The result from Figure.3 is clearly notifying that cyclone is the major hazard of the region followed by inundation and storm surge. But, if viewed to the occurrence of these hazards on Indian Sundarban coast it will be observed that cyclone is followed majorly by storm surge and inundation. As in cases of Amphan, Bulbul, Yaas etc. Hence research inquisitively tried to depict the nature of occurring hazards of Indian Sundarban so as to depict in what way the management of hazard impact must proceed.

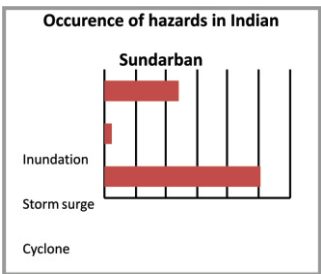


Figure 3: Occurrence scenario of hazards of Indian Sundarban.

### Nature of the hazards of the region:

The hazard occurrence of 439 years via mathematical set theory lead to the output as in Figure 4.

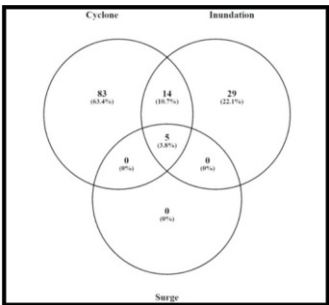


Figure 4: Venn diagram representing Hazard nature of Indian Sundarban.

Figure.4 , is clearly indicating that cyclone with 63.4% occurrence has proved to be the major hazard of the region. Storm surge is a lined and intra-connected phenomenon. Storm surge never occur single. 14.5% of the inundation occurrence has its count with cyclone and surge.10.7% of inundation occur with cyclone and 3.8% with storm surge.

This scenario is indicating that hazards of Indian Sundarban is cascading in nature. Cyclone is the principal hazard due to which inundation and surge occurs.

Hence, cyclone management is the major factor for controlling hazard impact in Indian Sundarban.

**Geostatistical model formation:**

For cyclone to be managed, present research focussed on the impact control. As such the cyclone related impact is due to the wind speed. Therefore, concerned research focussed on the cyclone wind speed of 30 years from 1991 in the region. In accordance to the IMD classification, wind speeds here included all forms starting from low pressure area to super cyclonic storm.A glimpse of such inclusion is given in Table3.

**Table 3: Series of cyclonic events in Indian Sundarban.**

| SL. | Year | Cyclonic Events                                                            |
|-----|------|----------------------------------------------------------------------------|
| 1   | 1992 | Depression                                                                 |
| 2   | 1995 | Depression,depression                                                      |
| 3   | 1997 | Deep depression                                                            |
| 4   | 1998 | Very severe cyclonicstorm                                                  |
| 5   | 1999 | Deep depression                                                            |
| 6   | 2002 | Cyclone                                                                    |
| 7   | 2004 | Land depression                                                            |
| 8   | 2007 | Deep depression                                                            |
| 9   | 2008 | Depression                                                                 |
| 10  | 2009 | Deep depression,Severe cyclonic storm Aila                                 |
| 11  | 2010 | Depression                                                                 |
| 12  | 2011 | Deep depression                                                            |
| 13  | 2013 | Land depression, depression                                                |
| 14  | 2014 | Deep depression, land depression                                           |
| 15  | 2016 | Deep depression                                                            |
| 16  | 2017 | Deep depression depression                                                 |
| 17  | 2018 | Deep depression depression                                                 |
| 18  | 2019 | Very severe cyclonicstorm– Bulbul,<br>Extremelyseverecyclonic storm – Fani |
| 19  | 2020 | Super cyclonic storm –Amphan, depression                                   |
| 20  | 2021 | Very severe cyclonicstorm – Yaas                                           |

Now, in accordance to the occurred event's wind

**1193.3\*Nugget+2233.7\*Stable(338000,1.6766).. (Model 1)**

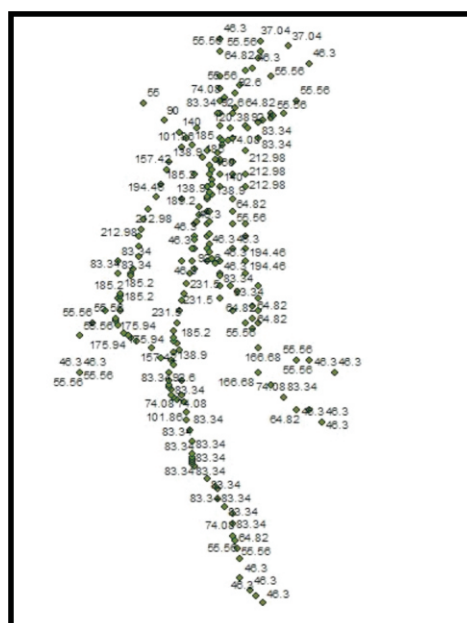


Figure 5: Cyclone wind speed considered for geostatistical modelling being represented along pathways as in events.

Figure 5 is showing the wind speeds. This as considered in ordinary kriging lead formation to the following Semi-variogram model (Model. 1) This developed model is designated to be the typical for Indian Sundarban cyclone analysis.

On the basis of the model the semivariogram working graph is being given in the Figure 6. .

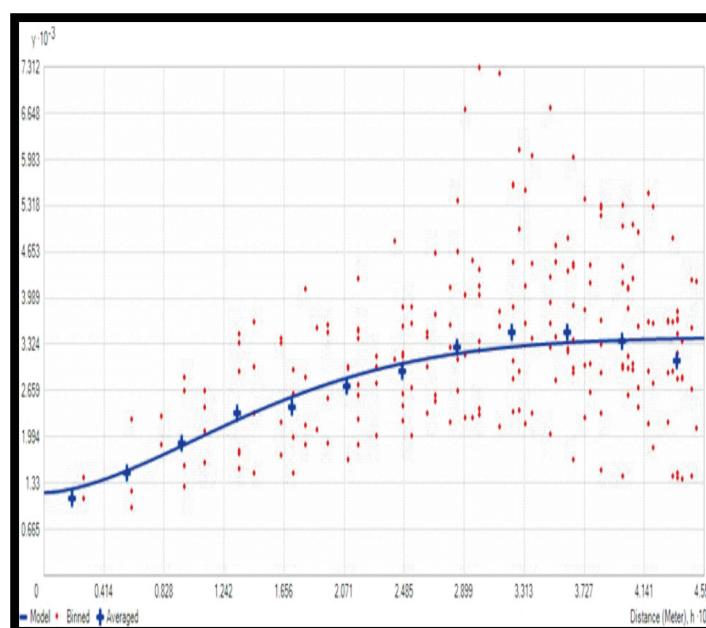


Figure 6: Semivariogram representation- graphically.

Following table 4, is representing the most necessitate model parameters utilized in forming the wind impact map over the region on basis of 30 years of concerned wind speed.

Table 4: Model parameter count.

| Model Parameters | Count              |
|------------------|--------------------|
| Nugget           | 1193.253085932628  |
| Partial Sill     | 2233.665119534313  |
| Major Range      | 337999.92527028616 |
| Lag Size         | 37960.037317544666 |
| Number of Lags   | 12                 |

On the basis of the created geostatistical model, the prediction for unknown values have been made with the major working consideration as –Modelling done on basis of recorded maximum wind speed at observation point over last 30 years.

**Implication of geostatistical model for geo- Spatial hazard analysis:**

With the development of model and its implication, the necessitate output oozed out. Output is being the 10 class divisions on the region of Indian Sundarban on basis of wind speed.(Figure 7). The range of wind speed is between 65.26 km/hr. as lowest to 240.76 km/hr.

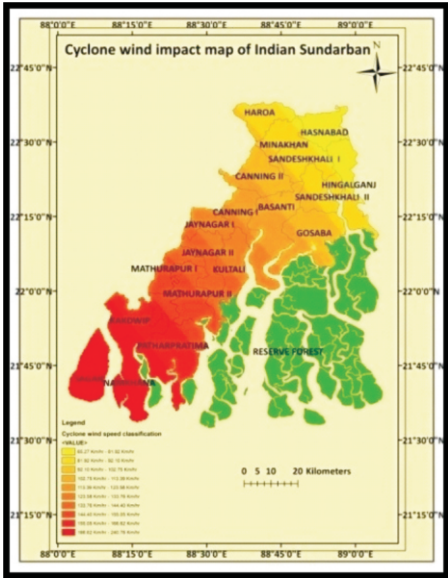


Figure 7:Geostatistical model output of cyclone wind speed impact.

But in order to get the final cyclone hazard scenario the wind speed is reclassified for 4 class divisions.(Figure. 8)



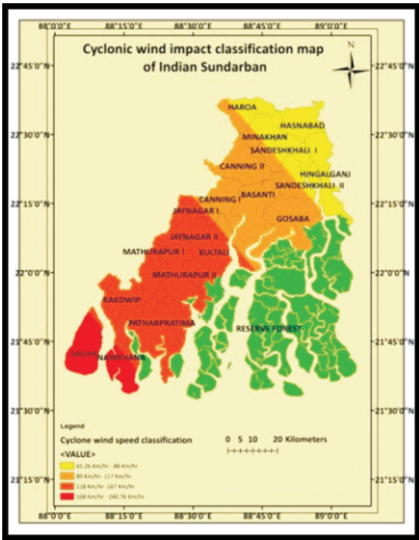


Figure 8 : On basis of four classes the final cyclone hazard map.

But with the classification result as in Figure 8. .it can be seen that there are many blocks which are having dual wind speed impact. Now, since in this research, the risk is being calculated, hence in case of blocks having dual impact, the larger wind speed impact is considered.

With the same logic the final cyclone hazard indexing is being made on Table 5.

Table 5: Cyclone Hazard Index of Indian Sundarban

| Blocks          | Cyclone Hazard Index |
|-----------------|----------------------|
| Sagar           | 4                    |
| Namkhana        | 4                    |
| Patharpratima   | 3                    |
| Kakdwip         | 3                    |
| Mathurapur I    | 3                    |
| Mathurapur II   | 3                    |
| Jaynagar I      | 3                    |
| Jaynagar II     | 3                    |
| Kultali         | 3                    |
| Basanti         | 3                    |
| Canning I       | 2                    |
| Canning II      | 2                    |
| Gosaba          | 2                    |
| Minakhan        | 2                    |
| Sandeshkhali I  | 2                    |
| Sandeshkhali II | 2                    |
| Haroa           | 2                    |
| Hasnabad        | 1                    |
| Hingalganj      | 1                    |

Along with the index, research finally depicts the cyclone hazard index map of Indian Sundarban in Figure 9.

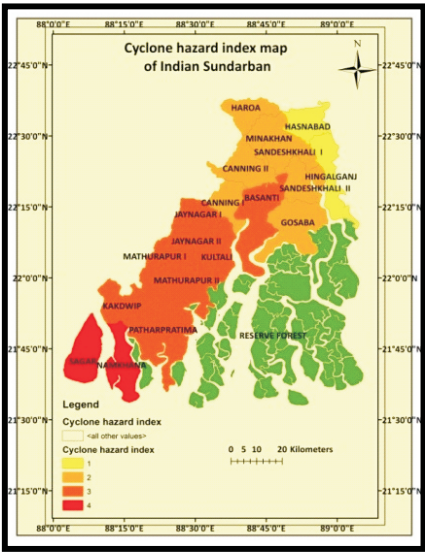


Figure 9: Spatial representation of cyclone impact severity.

From the Figure 9 and table 5 , it can be seen that the open bare coasts of Sagar, Namkhana are extreme high impacted . These are not only the bare coasts but the coasts that receives the cyclone attacks first. And since there is no barrier to reduce the impact or break down the wind speed hence, the interior blocks of Patharpratima, Kakdwip, Mathurapur I, Mathurapur II, Jaynagar I, JaynagarII, Kultali and Bsanti also are highly impacted. And thus it can be noticed that unless and until the first landfall attack cannot be reduced sustainably then the severity impedes inside leading to the detrimental impacts even to the metro city and huge population of the state of West Bengal. This output will provide the administration, stakeholders, researchers with the complete knowledge of how and which blocks are impacted by cyclone wind speed.

**Vulnerability assessment:**

As the cyclone strikes the major impacted are the lives or population. Hence, research here emphasized the population for vulnerability assessment. Research calculated the population density of each block (Table 6). On the basis of population density the quartile classification has been made (Table 7).Quartile counted from minimum to maximum. In regard to the quartile classification the indexing of vulnerability has taken place (Table8)

Table 6: Population Density Indian Sundarban.

| Block          | Area (Sq Km) | Popula tion | Popula tion Density |
|----------------|--------------|-------------|---------------------|
| Sagar          | 282.11       | 212037      | 751.61              |
| Namkhana       | 370.61       | 182830      | 493.32              |
| Pathar-Pratima | 484.47       | 331823      | 684.91              |
| Kakdwip        | 252.74       | 281963      | 1115.62             |
| Mathurapur I   | 147.3        | 195104      | 1324.53             |
| MathurapurII   | 227.45       | 220839      | 970.93              |

|                 |        |        |         |
|-----------------|--------|--------|---------|
| Jaynagar I      | 131.01 | 263151 | 2008.63 |
| Jaynagar II     | 186.25 | 252164 | 1353.90 |
| Kultali         | 306.18 | 229053 | 748.09  |
| Basanti         | 404.21 | 336717 | 833.02  |
| Canning I       | 187.86 | 304724 | 1622.80 |
| Canning II      | 214.93 | 252523 | 1174.90 |
| Gosaba          | 296.73 | 246598 | 831.05  |
| Minakhan        | 158.82 | 199084 | 1253.51 |
| Sandeshkhali I  | 182.3  | 164465 | 902.16  |
| Sandeshkhali II | 197.21 | 160976 | 816.26  |
| Haroa           | 152.73 | 214401 | 1403.79 |
| Hasnabad        | 153.07 | 203262 | 1327.90 |
| Hingalganj      | 238.8  | 174545 | 730.925 |

**Table 7: Quartile classification.**

| Quartile   | Classification values |
|------------|-----------------------|
| Quartile 0 | 493.32                |
| Quartile 1 | 783.93                |
| Quartile 2 | 970.93                |
| Quartile 3 | 1326.21               |
| Quartile 4 | 2008.63               |

**Table 8: Vulnerability index.**

| Block           | Vulnerability Index |
|-----------------|---------------------|
| Sagar           | 1                   |
| Namkhana        | 1                   |
| Pathar-Pratima  | 1                   |
| Kakdwip         | 3                   |
| Mathurapur I    | 3                   |
| MathurapurII    | 3                   |
| Jaynagar I      | 4                   |
| Jaynagar II     | 4                   |
| Sagar           | 1                   |
| Namkhana        | 1                   |
| Pathar- Pratima | 1                   |
| Kakdwip         | 3                   |
| Mathurapur I    | 3                   |
| MathurapurII    | 3                   |
| Jaynagar I      | 4                   |
| Jaynagar II     | 4                   |

With the vulnerability indexing,(vulnerability indexing have been done in the same scale as in case of cyclone indexing) the spatial scenario of vulnerability again has been done and represented in Figure 10.

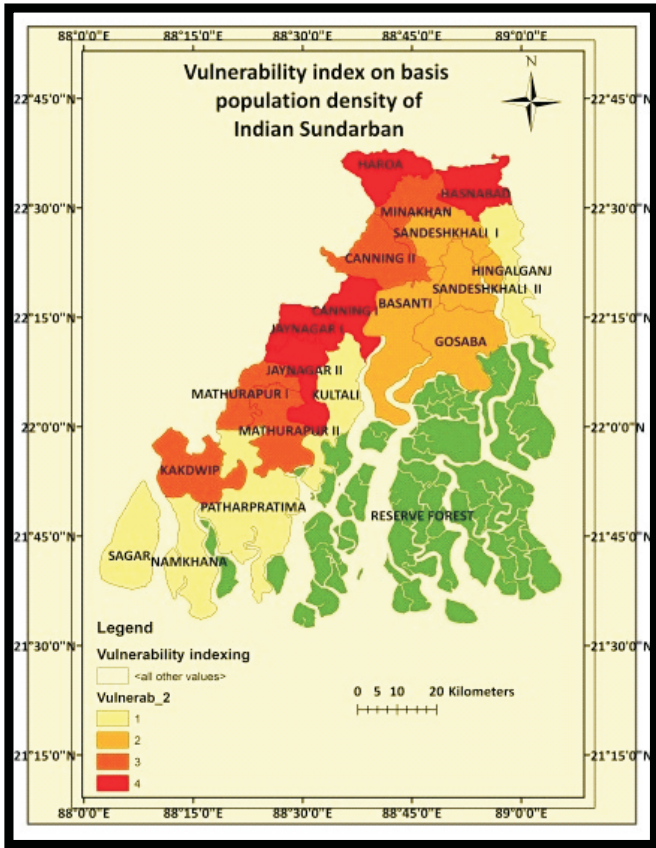


Figure 10: Spatial representation of vulnerability on basis of population density.

More the population density more will be the severity of that block at times of hazard impact. From Figure 10, it can be seen that the blocks of Jaynagar I , Jaynagar II and Canning I are the extreme vulnerable followed by highly vulnerable blocks of Kakdwip,Mathurapur I, Mathurapur II, Canning II and Minakhan. With this scenario research then proceeded for the final risk assessment.

**Final risk assessment:**

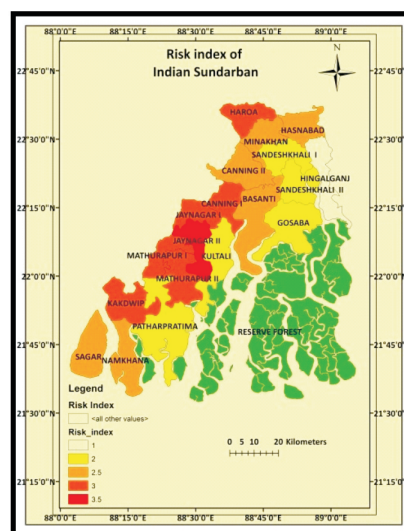
Risk assessment as already be mentioned in the methodology section under 3.7, has been made on basis of risk matrix. Table 2 thus channelized the final risk indexing..And in Table 9 also the blocks as per risk indexing got entitled as: E-L=Extremely Low, V-L=Very Low, L= Low, M=Moderate, H=High, V-H=Very High and E-H=Extremely High.



**Table 9 :** Final risk indexing.

| Block           | Cyclone Hazard Index | Vulnerability Index | Risk Index |
|-----------------|----------------------|---------------------|------------|
| Sagar           | 4                    | 1                   | 2.5(M)     |
| Namkhana        | 4                    | 1                   | 2.5(M)     |
| Patharpratima   | 3                    | 1                   | 2(L)       |
| Kakdwip         | 3                    | 3                   | 3(H)       |
| Mathurapur I    | 3                    | 3                   | 3(H)       |
| Mathurapur II   | 3                    | 3                   | 3(H)       |
| Jaynagar I      | 3                    | 4                   | 3.5(V-H)   |
| Jaynagar II     | 3                    | 4                   | 3.5(V-H)   |
| Kultali         | 3                    | 1                   | 2(L)       |
| Basanti         | 3                    | 2                   | 2.5(M)     |
| Canning I       | 2                    | 4                   | 3(H)       |
| Canning II      | 2                    | 3                   | 2.5(M)     |
| Gosaba          | 2                    | 2                   | 2(L)       |
| Minakhan        | 2                    | 3                   | 2.5(M)     |
| Sandeshkhali I  | 2                    | 2                   | 2(L)       |
| Sandeshkhali II | 2                    | 2                   | 2(L)       |
| Haroa           | 2                    | 4                   | 3(H)       |
| Hasnabad        | 1                    | 4                   | 2.5(M)     |
| Hingalgaanj     | 1                    | 1                   | 1(E-L)     |

With the indexing as in Table 9, research here proceeded for the final spatial map on risk induced due to cyclone in Indian Sundarban in Figure 11.



**Figure 11:** Risk index.

From, the spatial representation it must be clear that south western and central stretch of Indian Sundarbans are regions of concern. The most concern ones though are Jaynagar I and Jaynagar II, followed by Kakdwip, Mathurapur I, Mathurapur II, Canning I and Haroa. And then Sagar, Namkhana, Basanti, Canning II, Minakhan and Hasnabad. With such scenario it can be thus stated that though vulnerability plays an important role yet the major issue is to reduce the hazard impact.

## Conclusion

Firstly, the alarming site of the region has been ascertained in the present research under two broad sections of hazard as well as vulnerability. Intendant for determination of the risk of Indian Sundarban coast, present research dwelt in identifying the capstone concerned sites of hazard and vulnerability. With the identification of cyclone as major hazard, geostatistics application on geospatial scenario lead to the conclusion that majorly the bare coasts of Sagar and Namkhana are extremely highly impacted. With no barrier the wind force as strikes such coasts under the pattern from south to north it extends and exhibits its evil impacts. For the administration to be concern, present research revealed that population content is increasing the vulnerability of central and northern blocks of Indian Sundarban. Under such scenario risk indicated that Jaynagar I, Jaynagar II, Kakdwip, Mathurapur I, Mathurapur II, Canning I and Haroa along with Sagar and Namkhana are concerned regions for measures to be taken. This research has created a scientific basis for management, administration and researchers for taking immediate sustainable management option for saving Indian Sundarban which acts as the major natural barrier to crores of people.

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# Catchment Assessment for Sustainable Lake Water Management in Kolavai Lake, Peri-urban area of Chennai City

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## Abstract

*Due to swift urban and peri-urban expansion, numerous industries and industrial colonies have emerged in the lake catchment, leading to contamination of the lake water and its surroundings. Consequently, there is an immediate requirement to evaluate the lake catchment using geospatial tools to ensure sustainability. The study focuses on the Kolavai Lake in the peri-urban region of Chennai, where water quality deterioration and encroachments are prevalent. Multi-temporal satellite data has been employed to analyze the Level-II land use/land cover classification of the catchment. Seven water sample locations were selected, collected, and analyzed. The Water Quality Index (WQI) was computed, revealing that the water of Kolavai Lake is unsuitable for drinking as the WQI values surpass 100. It is strongly recommended to conduct a comprehensive ecological audit of the catchment area and implement continuous monitoring of land use/land cover practices.*

**Keywords:** Catchment assessment, Peri-urban, Water Quality Index, Sustainable Water usage, land use/land cover, Water pollution.

## Introduction

Water is a vital resource for human survival, particularly in agricultural and domestic applications for food production and animal rearing. It is imperative to manage this resource sustainably for the well-being of both current and future generations. Unfortunately, water quality has deteriorated over the years, largely due to anthropogenic activities driven by population growth, urbanization, and industrialization. These activities, including excessive water usage, encroachment on water bodies, industrial waste disposal, domestic sewage, and unchecked siltation, contribute to the degradation of water and its catchment areas.

Lakes, enclosed bodies of water without access to the ocean or sea, serve as crucial reservoirs for runoff from urban areas, providing water during times of need. Urban and peri-urban lakes, however, face significant challenges, including sewage from domestic sources, industrial effluents, and non-point runoff from agriculture, leading to issues like eutrophication from excessive nutrient inputs. Hydrological changes, physical alterations, and siltation from catchment activities contribute to the decline of these water bodies.

Urban lakes, lacking proper waste disposal infrastructure, suffer from pollution due to the natural topography and as collection points for waste from disorganized urban settlements. Consequently, many urban lakes are degrading beyond recovery due to encroachments, silt accumulation, weed infestation, sewage discharge, and industrial effluents. Declining water quality, algae blooms, weed overgrowth, fisheries deterioration, sedimentation, eutrophication, and various conflicts related to water use are common issues resulting from human activities in and around these lakes.

These factors lead to the loss or reduction of lakes, deprivation of aquatic life, and the proliferation of aquatic weeds, causing oxygen depletion and the release of harmful gases through anaerobic reactions in the lake water. Mosquito breeding in these environments contributes to vector-borne diseases in surrounding areas.



Numerous studies have investigated the causes behind the alarming eutrophication of lakes. However, an analysis is lacking in understanding this phenomenon through establishing statistical relationships between changing land use/land cover (LULC) and water quality (WQ). Consequently, this study aims to comprehend the degrading condition of the lake by establishing long-term relationships between changing LULC and WQ. This information can empower policymakers with insights for informed decision-making to devise strategies that can reverse the changes leading to lake degradation.

## Study Area

The research focuses on Kolavai Lake, depicted in Figure-1, situated near Chengalpattu in Tamil Nadu, India, approximately 60 kilometers from Chennai. Positioned between longitudes 79°58'40.235"E and 80°0'690"E and latitudes 12°41'18.003"N and 12°43'25.749"N, the lake covers an area of 63 km<sup>2</sup> with a drainage area of 27 km, exhibiting relief ranging from 42m in the west to 221m in the east. Streams originating from east and south-east hillocks flow into the lake from the west. The water spread area is 894 hectares, benefiting 12 villages. The lake boasts an annual storage capacity of 476.69 Mcft, a depth of 4.59 meters, and a total discharging capacity of 5131 cusecs through five sluices. Surplus water flows into the Palar, Neenjal, and Madura rivers. Historically, the lake served as an additional water source for Chennai during summer water shortages. It hosts migratory birds and yields around 200 kilograms of fish per day. However, the lake is currently facing pollution from agricultural, domestic, hospital, and industrial wastes. The Mahindra World City Industrial Park extracts five million gallons of water daily from the lake. The population of Chengalpattu town is 64,136, contributing to the daily dumping of 1,450 liters of municipal wastewater and 48 tonnes of garbage, causing pollution, especially during the rainy season.

## Materials & Methods

The methodology employed in this study is visually represented in Figure.2. The Survey of India 1:50,000 topographical maps served as the basis for delineating the Kolavai Lake area. The slope aspect was generated using SRTM DEM (30m.) and ALOS PALSAR (10m. HH, VV) satellite data, aided by a limited number of Ground Control Points obtained through GNSS. Subsequently, ALOS PALSAR data, processed through the Arc hydro tool (Fig.3.1 and 3.2), was utilized to derive essential features such as the drainage network, flow direction, flow accumulation, and catchment boundary of Kolavai Lake.

Morphometric analyses encompassing linear, areal, and relief aspects were conducted for the entire catchment. Remote sensing data, particularly Landsat imagery, played a pivotal role in mapping land use and land cover across three distinct time periods (2000, 2010, and 2020). The NRSC's level-II classification scheme was adopted for land use/land cover mapping, and subsequent calculations provided insights into changes over time. Additionally, indices like the Normalised Difference Vegetation Index (NDVI: Fig.5) and Normalised Difference Turbidity Index (NDTI: Fig.6) were derived from remote sensing data, contributing to the catchment analysis.

Seven strategic water sample locations (Figure.7a) were selected within the lake, considering varied land use practices and stream morphometry. These samples underwent laboratory testing, adhering to Central Pollution Control Board (CPCB) norms. Thirteen physicochemical parameters, including pH, TDS, Nitrate, Calcium, Magnesium, Total hardness, Chloride, Fluoride, Sulphate, DO, COD, and BOD, were utilized to compute the Water Quality Index (WQI, Table No.2). The WQI results were correlated with land use/land cover and stream morphometry to ascertain the lake's pollution levels.

## Results and Discussion

### Lake Catchment Morphometry

The morphometric analysis furnishes precise insights into various characteristics of the lake catchment.

Analyzing the Kolavai Lake Catchment with a three-fold approach (Linear, Areal, and Relief) using the Arc Hydro tool yielded the following interpretations:

***(a) Linear Aspects***

The linear aspect encompasses features like Stream Order (w), Stream Number (Nu), Bifurcation Ratio (RbF), Stream Length (km), and their means. The Kolavai Lake Catchment adheres partially to Horton's first law, where the number of streams in each category follows a geometric sequence. The catchment exhibits a total of third-order streams, with a total of 25 streams covering a length of 93.17 km. The bifurcation ratio ranges between 1.2 to 3.81, indicating structural control and a low to medium flood risk.

***(b) Areal Aspects***

Areal aspects involve components like Area (km<sup>2</sup>), Perimeter (km), Drainage Density (Dd), Elongation Ratio (Re), Stream Frequency (Fs), Form Factor (Ff), Circulatory Ratio (Rc), and Drainage Texture (T). The total area of the Kolavai Lake catchment is 63 km<sup>2</sup>, with a perimeter of 21.12 km. The elongation ratio of 0.38 suggests a moderately elongated shape with moderate relief. The circulatory ratio's lower value (0.18) indicates a less circular or more elongated catchment. A calculated form factor of 0.16 implies very low flow intensity. Moreover, a stream frequency of 2.81 and drainage density of 1.94 km/km<sup>2</sup> suggest a direct relationship, while the drainage texture value of 8.27 indicates a coarse drainage texture with highly resistant permeable rock on low relief.

***(c) Relief Aspects***

Relief aspects pertain to the three-dimensional properties of the lake catchment and involve the elevation difference between reference points. The relief ratio, which is the ratio of basin relief to basin length, reveals that the lake catchment has a relief of 221 m and a relief ratio of 22.32. This suggests a low to moderate relief with a gentle slope.

**Analysis of Land Use/Land Cover in Kolavai Lake Catchment**

Land use (LU) refers to the deliberate utilization of land, embodying planned strategies for its employment and management devised by humans (Pradhan 2010). In contrast, land cover (LC) encompasses the natural cover on land dictated by natural processes, encompassing vegetation distribution, water, deserts, ice, and the immediate subsurface, including biota, soil, topography, surface, and groundwater (Meraj et al. 2012). The dynamic process of Land Use/Land Cover (LULC) change is propelled by natural phenomena and anthropogenic activities, leading to deviations that impact natural ecosystems (Skilodimou et al. 2003). Changes in LULC significantly influence earth system processes, such as hydrology, climate, and biogeochemical cycles, potentially resulting in adverse environmental consequences if left unchecked (Bhat et al. 2016). Numerous urban land use studies have employed satellite images to generate accurate maps and detect changes in urban land use/land cover (Javed et al. 2009). The short- and long-term monitoring of LULC change is crucial for establishing links between policy decision-making, regulatory actions, and subsequent land use planning activities aimed at managing natural resources.

Landsat multi-resolution/multi-temporal satellite data were utilized for LULC analysis, comprising Landsat ETM (19 September 2000, 14.25 m), ETM+ (24 October 2010, 30 m), and OLI (27 September 2020, 30 m). Additionally, PAN sharpening was applied to bring all period images to a 15m resolution with multispectral images. The National Natural Resource Management Scheme (NNRMS) standards for land use/land cover mapping were adhered to in the entire LULC classification process. Supervised classification was employed to prepare LULC classifications for the years 2000, 2010, and 2020. The reliability of the LULC was assessed using the accuracy assessment technique, as indicated by the Kappa coefficient. The Kappa coefficients of 0.9, 0.88, and 0.91 for 2000, 2010, and 2020, respectively, demonstrated significant accuracy in the LULC prepared for the

present study. The area of the LULC categories was calculated for individual years, and change detection analysis was conducted between the years.

The results of the LULC analysis of the Kolavai Lake catchment, along with change analysis, are presented in Table 1. The LULC analysis for the year 2000 revealed that out of the six LULC classes, Agriculture and Forest were dominant categories in the study area, covering 23% and 20% of the total geographical area, respectively. Land with and without scrub covered 19% and 16% of the total geographical area. Water bodies occupied about 14%, and the Built-up area comprised a minimum of 8% of the total geographical area. In 2010, there were changes in the LULC classes, with Land with scrub and Land without scrub becoming dominant categories, constituting about 21% and 19% of the total geographical area of the catchment. This was followed by Agricultural land (18%), Built-up area (15%), Forest (15%), and water bodies (12%). In 2020, the Built-up area emerged as the dominant category in the study area, constituting about 27% of the total geographical area of the catchment. This was followed by Land without scrub (20%), Land with scrub (19%), Agricultural land (13%), Water bodies (11%), and Forest (10%).

### **Decadal LULC change analysis of the Kolavai Lake catchment**

Significant transformations have occurred in all six land use/land cover categories identified and mapped since 2000. The expanse of agriculture, forests, and water bodies has consistently dwindled between 2000 and 2010. Conversely, Land with scrub, Land without scrub, and Built-up area have exhibited consistent growth during this period. The findings presented in Table-1 disclose that forest area reduced from 20% in 1980 to 15% in 2010, signifying a negative growth rate of -5%. Agriculture has experienced a decline from 23% in 2000 to 18% in 2010, reflecting a negative growth rate of -5%. Water bodies have also witnessed a diminishing trend, decreasing from 14% in 2000 to 12% in 2010, with a negative growth rate of -2%. In contrast, the Built-up area surged from 8% in 2000 to 15% in 2010, indicating a positive growth rate of +7%. Additionally, Land with scrub increased from 19% in 2000 to 21% in 2010, showcasing a positive growth rate of +2%, while Land without scrub escalated from 16% in 2000 to 19% in 2010, demonstrating a positive growth rate of +3%.

A profound shift is observed in the six land use/land cover categories since 2000. Agriculture, forests, and water bodies persistently diminished between 2000 and 2020, while Land without scrub and Built-up area exhibited consistent growth. The outcomes, as depicted in Table-1, highlight that forest area decreased from 20% in 2000 to 10% in 2010, indicating a negative growth rate of -10%. Agriculture showcased a declining trend, diminishing from 23% in 2000 to 13% in 2020, with a negative growth rate of -10%. Water bodies experienced a diminishing trend, decreasing from 14% in 2000 to 11% in 2010, with a negative growth rate of -3%. In contrast, the Built-up area surged from 8% in 2000 to 27% in 2020, recording a positive growth rate of +19%, followed by Land without scrub, which increased from 16% in 2000 to 20% in 2020, exhibiting a positive growth rate of +4%. Notably, Land with scrub remained unchanged at 19% from 2000 to 2020.

The change detection analysis underscores a drastic 19% increase in the Built-up area compared to 2000-2020. Evidently, a substantial portion of agricultural, forest, and water bodies has been transformed into industrial and urban areas. The 4% increase in land without scrub is attributed to water and soil stress over the 2000-2020 period.

### **NDVI Analysis of Kolavai Lake Catchment**

The assessment of land use/land cover changes over time in a region often relies on key parameters, with vegetation playing a crucial role. Contemporary literature affirms the utility of the Normalised Difference Vegetation Index (NDVI) for discerning land use/land cover changes induced by human activities such as construction and developmental projects (Aburas et al., 2015). The NDVI, derived from the balance between energy absorption and emission by Earth objects in the Red and Near-Infrared (NIR) bands (Backlund et al., 2008),

is computed using the formula:

$$NDVI = (NIR - RED) / (NIR + RED)$$

The NDVI values, ranging from -1 to 1, were utilized to reclassify NDVI maps, categorizing them based on vegetation rates derived from spectral reflections. The four NDVI classes were delineated as follows: non-vegetation (-1 to 0.199), low vegetation (0.2 to 0.3), moderate vegetation (0.31-0.6), and high vegetation (0.61 to 1.0) for the years 2000, 2010, and 2020.

The NDVI analysis depicted in Figure 5 reveals an escalating trend in the non-vegetation class by 10%, 24%, and 39% during 2000, 2010, and 2020, respectively. This trend underscores the close relationship between vegetation and the escalating urbanization and industrialization in the lake catchment area over two decades. Similarly, the low vegetation class exhibits an increasing pattern of 12%, 23%, and 32% for the years 2000, 2010, and 2020, respectively. This provides evidence of the diminishing agricultural activities, thinning out, and encroachment of natural vegetation associated with the ongoing urbanization process in the study area. In contrast, the moderate vegetation class experiences a reduction of 42%, 36%, and 18% during 2000, 2010, and 2020. Furthermore, the high vegetation class demonstrates a declining trend of 36%, 17%, and 11% between 2000, 2010, and 2020. The diminishing trends in moderate and high vegetation classes indicate vegetation stress resulting from urbanization and groundwater depletion over the two-decade period in the study area.

### **Normalised Difference Turbidity Index (NDTI) of Kolavai Lake Catchment**

Turbidity serves as a parameter for examining human activities within the catchment area and their impact on water contamination in the lake. It also acts as an indicator to gauge the rate of sediments and municipal wastes transported by streams from the catchment, particularly during rainy periods, which eventually enter the lake. As the concentration of suspended solids or sediments in water rises, turbidity increases, and elevated turbidity levels can adversely affect the aquatic ecosystem within the water body (Garg et al., 2017; Quang et al., 2017). Turbidity, being a significant optical property of water, reduces the energy required for aquatic growth. Elevated turbidity can impede the growth of aquatic flora and fauna, leading to a reduction in photosynthesis and a subsequent decline in the productivity of the aquatic flora system.

The development of the Normalised Difference Turbidity Index (NDTI) aimed to evaluate water turbidity in ponds and inland lakes using remote sensing data. The NDTI formula utilizes red and green bands, with values ranging between -1 and +1 (Lacaux et al., 2007). NDTI maps were generated using the equation:

$$NDTI = \frac{R_{\text{g}} - R_{\text{r}}}{R_{\text{g}} + R_{\text{r}}}$$

where  $R_{\text{r}}$  and  $R_{\text{g}}$  represent reflectance in the red band and green band, respectively.

The NDTI values, ranging from -1 to 1, were utilized to reclassify NDTI maps, categorizing them into turbidity levels based on spectral reflections. Three classes were established: clear water (-1 to 0.199), low turbidity (0.2 to 0.5), and high turbidity (0.51 to 1.0) for the years 2000, 2010, and 2020. The NDTI analysis (Figure 6) indicates a rise in high turbidity from 21% to 69% between 2000 and 2010, followed by a decrease from 69% to 39% between 2010 and 2020. This escalating trend signifies the growing anthropogenic activities in the catchment area. Conversely, there is a reduction in turbidity in the year 2020. The low turbidity class diminished from 79% to 31% from 2000 to 2010, and subsequently, it increased from 31% to 61% from 2010 to 2020. The surge in turbidity aligns with the expanding urban settlement in the catchment from 2010 to 2020.

### **Water Quality Analysis of Kolavai Lake Catchment**

The Water Quality Index results, encompassing thirteen physicochemical parameters (Table 2), unequivocally illustrate the degradation of lake water due to the mismanagement induced by the processes of urbanization and industrialization. The pH values were higher in sample location 4 and lower in sample locations 6 and 7 (Figure 7b,c,d), indicating lower pH concentrations in the deeper areas of the lake. Dissolved Oxygen (DO), a



crucial parameter in water quality assessments (Solanki et al., 2006), exhibited decreased levels in sample locations 3, 4, and 6. This decline may be attributed to the utilization of dissolved oxygen for the decomposition of autochthonous materials and substances dumped into the water (Radhika et al., 2004). The lower value of dissolved oxygen can also be linked to increased microbial activity, and the depiction of dissolved oxygen may be influenced by phytoplankton respiration and sediment oxygen demand (Wani et al., 2002; Watson-Leung et al., 2021).

Biological Oxygen Demand (BOD) values, indicative of pollution levels in water samples, exceeded permissible levels suggested by CPCB for drinking, bathing, and swimming in sample locations 1, 4, 5, 2, and 6. The elevated BOD values may be attributed to a higher rate of organic decomposition (Bhatt et al., 1999; Vasistha et al., 2020). Low Chemical Oxygen Demand (COD) values recorded in sample locations 2 and 7 might result from the sedimentation of organic materials to the bottom.

Calcium, a vital element influencing the ecosystem's flora, playing a potential role in metabolism and growth, displayed levels below the permissible limit of CPCB (1995) in sample locations 5, 6, and 7. Very low nitrate concentration in sample locations 1 and 7 may be due to nitrate utilization for the luxuriant growth of macrophytes. Fluoride concentration in the water source indicated organic pollution by domestic sewage (Chandrashekar et al., 2003), and the low concentrations in sample locations 2, 3, 6, and 7 suggested minimal organic waste of animal origin, while high fluoride concentrations in sample locations 1, 4, and 5 can result in an undesirable taste of water. Water hardness was higher in all samples except sample location 2.

The analysis of physicochemical characteristics from seven water sample locations in Kolavai Lake reveals that DO, BOD, and fluoride values exceeded permissible limits for drinking water standards set by CPCB (1995), signifying a high level of pollution in the lake. Sample location 4, being the entry point of industrial and domestic waste, exhibited higher pollution levels than the other six sample locations.

### **Suggestions for Sustainable Catchment Management**

- Prioritize resource sustainability and local water resource development in urban water body management.
- Rejuvenate water bodies by analyzing catchments, managing stormwater, and enhancing water quality.
- Delineate and protect catchment areas, feeder channels, and command areas during urbanization.
- Emphasize land use planning and water body inventory for sub-urban protection and future use.
- Implement a fluid and continuous 'Lake Management Plan' with stakeholder participation.
- Integrate biodiversity concepts for successful water body rejuvenation.
- Include representatives from all stakeholders in decision-making processes.
- Promote extensive stakeholder participation and capacity building for better water body management.

### **Conclusion**

Over the span of two decades, the land use/land cover dynamics within the Kolavai Lake catchment have undergone substantial modifications, significantly reshaping its landscape. The results of the LULC change analysis highlight a notable 19% increase in the built-up area and a 4% expansion in land without scrub from 2000 to 2020. Conversely, there is a concerning decreasing trend in agricultural land by 10%, forest land by 10%, and water bodies by 3% during the same period. This transformation, marked by the conversion of agricultural and forested areas into built-up zones, poses a threat to ecological balance and exacerbates water stress in the catchment.

The disappearance of natural streams and small ponds, attributed to urbanization and industrialization, contributes to surface water flow blockages and subsequent flooding during rainy periods. Sewage drains channeling wastewater into Kolavai Lake further exacerbate surface water contamination. Water Quality Index (WQI) analyses underscore the impact of upstream anthropogenic activities, municipal waste, and hospital waste on the lake's water quality. Elevated concentrations of nitrate-nitrogen, total phosphorus, and COD indicate severe



ecological damage, adversely affecting the flora and fauna of the lake. Turbidity indices reveal an influx of sediments and sludge, reducing the lake's carrying capacity.

The findings emphasize the urgent need for conservation efforts, focusing on the physical, chemical, and biological aspects of the lake, with active community participation. This study underscores the efficacy of remote sensing data and techniques in comprehensively analyzing the lake's catchment, providing valuable insights for ensuring sustainability for future generations.

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**Table 1.**  
Percentage statistics of Landuse/Lanccover categories of Kolavai Lake for the period 2000, 2010 and 2020

| <b>LULC Categories</b> | <b>2000</b> | <b>2010</b> | <b>2020</b> |
|------------------------|-------------|-------------|-------------|
| Built-up Area          | 08          | 15          | 27          |
| Agricultural land      | 23          | 18          | 13          |
| Forest                 | 20          | 15          | 10          |
| Land with scrub        | 19          | 21          | 19          |
| Land without scrub     | 16          | 19          | 20          |
| Water bodies           | 14          | 12          | 11          |
| <b>Percentage</b>      | <b>100</b>  | <b>100</b>  | <b>100</b>  |

**Table 2.**  
Details of Water Quality Index (WQI) values for selected parameter in the seven sample locations of the study area

| <b>Sample location</b> | <b>pH</b> | <b>Ca</b> | <b>Mg</b> | <b>CO3</b> | <b>TDS</b> | <b>Chloride</b> | <b>Sulphate</b> | <b>Fluoride</b> | <b>Nitrate</b> |
|------------------------|-----------|-----------|-----------|------------|------------|-----------------|-----------------|-----------------|----------------|
| 1                      | 47.53     | 61.45     | 38.82     | 61.63      | 87.56      | 33.57           | 58.12           | 35.20           | 38.61          |
| 2                      | 49.15     | 66.23     | 36.27     | 66.78      | 96.23      | 48.46           | 53.47           | 28.75           | 46.10          |
| 3                      | 56.87     | 65.76     | 42.53     | 74.25      | 98.37      | 47.53           | 51.36           | 21.49           | 42.36          |
| 4                      | 62.30     | 67.21     | 47.19     | 78.53      | 106.34     | 54.79           | 59.81           | 47.16           | 69.32          |
| 5                      | 40.02     | 59.93     | 43.32     | 64.71      | 98.43      | 57.32           | 54.39           | 39.43           | 47.38          |
| 6                      | 35.72     | 58.53     | 39.43     | 72.14      | 105.91     | 45.61           | 52.75           | 22.64           | 42.93          |
| 7                      | 32.15     | 51.32     | 31.76     | 67.16      | 94.26      | 48.10           | 46.32           | 22.30           | 36.45          |

**Table 3.**  
Details of Water Quality Index (WQI) values for selected parameter in the seven sample locations of the study area

| Sample location | BOD    | COD    | DO    | Hardness |
|-----------------|--------|--------|-------|----------|
| 1               | 221.95 | 208.71 | 66.21 | 69.21    |
| 2               | 206.56 | 202.85 | 63.15 | 57.10    |
| 3               | 209.43 | 227.65 | 58.19 | 72.54    |
| 4               | 227.10 | 248.30 | 52.31 | 81.58    |
| 5               | 212.78 | 219.20 | 61.50 | 78.56    |
| 6               | 219.41 | 228.76 | 57.86 | 69.86    |
| 7               | 210.50 | 201.70 | 62.49 | 71.10    |

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## Structural controls and drainage character of Nagal Gad Basin in Chamoli district Garhwal Himalaya

Gopinath Patra

### Abstract

*The climate, lithology, tectonics, vegetation cover and geomorphic processes of a region influence the drainage network development. The present work was completed by using Alos Palsar DEM (12.5 m) and SOI toposheet 1:50,000 (53N/3 and 53N/7) to analyse the drainage morphometry and its impact on hydrological characteristics of Nagal Gad Basin. The Nagal Gad is a 5<sup>th</sup> order drainage basin, encompassing an area of 128.12 sq. km. The upper part of the basin is influenced by Munsiyari thrust and middle and lower part is influenced by Ramgarh Thrust. Comparatively low to moderate drainage density and stream frequency reveals that the sub – surface is permeable in nature. The elongation ratio indicates that the basin is elongated with dendritic, sub – dendritic and parallel drainage pattern. The relief parameters of Nagal Gad basin indicates that the basin area is characterized by high relief and steep slopes. All the morphometric parameters shows structure and lithology control the drainage development of the study.*

**Keywords:** Morphometric analysis, Garhwal Himalaya, Geospatial technique.

### Introduction

The melting glaciers of the Himalayan mountain systems give rise to the largest network of freshwater drainage channels in the Indian subcontinent. The vast network provides water for agriculture, drinking, navigation within the subcontinent and the numerous tributaries that supply water to hamlets situated in the river valleys. These small tributaries also bring down immense volumes of water in a flash when they are deluged with rapidly melting glaciers and sudden cloudbursts. Therefore it is necessary to understand the hydrological characteristics, drainage network and basin characteristics that influence drainage development. The morphometric analysis of drainage basin best helps to understand the complete nature of drainage basins. The previous study using morphometric parameters was done by R.E. Horton (1932, 1945) an American civil engineer by profession. His method of analysis was followed Miller (1953) and Strahler (1964). Later, all the other workers of basin morphometry have been following their principles. The notable works in this field have been carried out by Smith (1950), Dury (1951), Schumm (1956, 1963), Morisawa (1957), Melton (1957), Gregory and Walling (1973), Nag and Chakraborty (2003), Altafet *et al* (2013), Vandana (2013), Biswas *et al.* (2014). Although many researchers have carried out the morphometric study, an insufficient number of work describe the relationship of drainage morphometry with respect to the climate, lithology and tectonics of an area (Daset *al.* 2018). GIS and image processing techniques can be employed for the identification of morphological features and analyzing the properties of the basin (Waikar&Nilawar, 2014). It helps in accurate delineation and analysis of terrain features aided by methods of applied geomorphological studies (Patra *et al.*, 2021). Geomorphometry is the measurement and mathematical investigation of the earth's surface, dimension and its landforms (Clarke, 1996). Such studies on the drainage characteristics of a watershed in a region provide an authentic idea about its denudation history, sub-surface material, geological structure, soil types and vegetation status etc. (Strahler, 1964). The present study analyses the hydro-geomorphic characteristics and the stage of drainage basin development through the study of drainage



network, relief parameters, climate, tectonics and lithology of Nagal Gad basin.

Aims and Objectives

The aim of this work is to understand the geological structure, sub-surface material, denudation history, soil types and natural vegetation capability to prevent loosening of surface and sub surface soil in light of morphometric analysis of the drainage basin. The preparation and analyse of DEM, stream order map, slope map and hypsometric curve will help in the preparation and management of probable disasters like flash floods, landslides due to slope failures, ascertaining channel form and draining capacity of drainage channel to estimate and minimize soil loss, floods, selection of suitable sites for settlement development.

Study Area

The Nagal Gad basin occupies the Pokhri and Dasholi CD blocks of Chamoli district of Garhwal division of Uttarakhand. It lies between 30° 18A 20° N- 30° 29A 30° N & 79° 9A40° E to 79° 18A23° E (Fig. 1). It originates from Chandrasila mountain range (79° 13AA 21° E & 30° 29A16° N) and confluence with Alaknanda at Kamd village (79° 18A 11° E & 30° 19A 10° N).The total area of the basin is 128.12 sq.km, the basin length and perimeter is 19.79 km. and59.50 km respectively. The general elevation of the Nagal Gad basin varies from 860 mto 3560 m. The slope of this basin is oriented north-west to south-east ward. The structure of the basin is influenced by the Munsiyari thrust and Ramgarh thrust (Fig.4). Major rock type of this region are Quartzite and slate with basic meta volcanics, Chlorite Schist, Quartzite, Calcsilicate, Phyllite, Porphyritic non foliated Granite, Quartz mica schist, Slate with basic metavolcanics, Slate, Gneiss, Marble and Basic intrusive, Schistose Grit, Slate, Quartzite with Volcanics. (Fig.3).

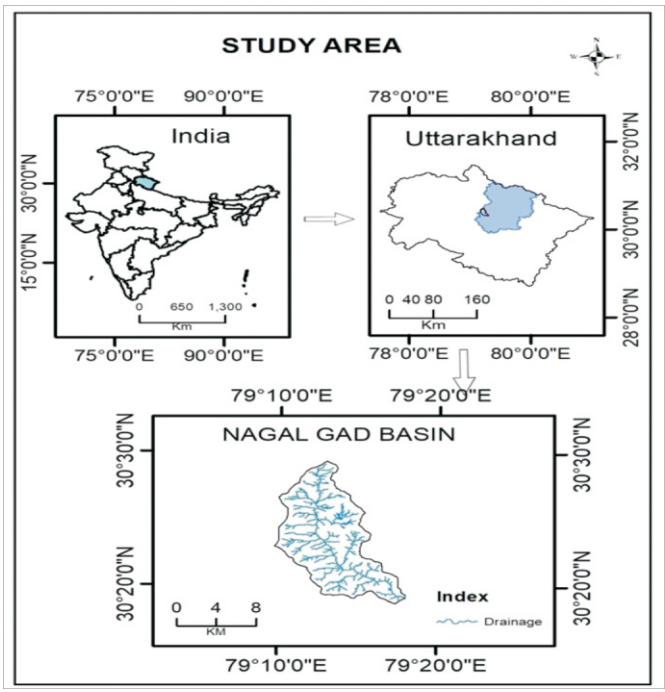


Figure 1: Location of the study area with drainage network

Database and Methodology

Earlier morphometric calculation were carried out by using topographical map and field survey. In late twentieth century, advancement of technology introduced remote sensing and GIS, by which analysis of morphometric data for large drainage basin area became much easier than before (Das and Pardeshi 2018). In this present study SOI toposheet 1:50000 (53N/3, 53N/7) and Alos Palsar DEM (12.5 m resolution) data and ArcGIS 10.5 software were used. The Alos Palsar DEM is downloaded from [www.asf.alaska.edu](http://www.asf.alaska.edu). Fig. 2 shows the methodology by which streams are generated from DEM. Alos Palsar DEM are filled in ArcGIS software for DEM correction. Flow direction, flow accumulation and stream order tools were used to generate streams from DEM followed by the Strahler’s method of stream ordering (1952). The highest drainage order found in this basin is of the 5th (fifth) order. The morphometric parameters such as basin area, basin perimeter, stream length, bifurcation ratio, drainage density, stream frequency, relief ratio, elongation ratio etc. were calculated to analyse the basin characteristics and the stage of drainage development.

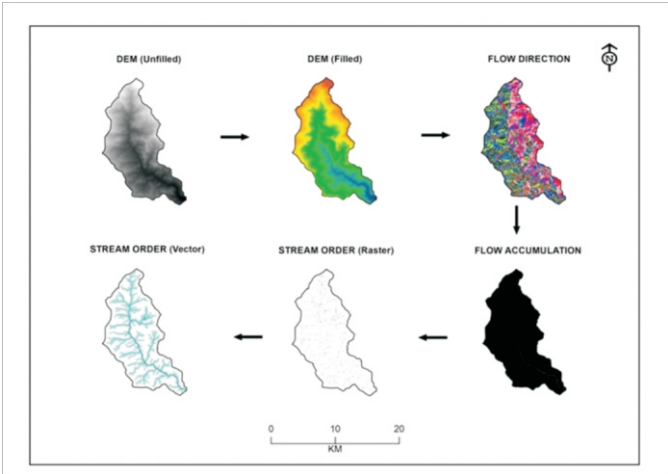


Figure 2: Methodology carried out to generate the drainage network

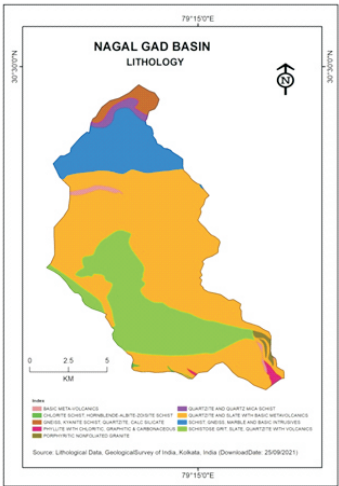


Figure 3: Map showing lithological characteristics Of Nagal Gad basin

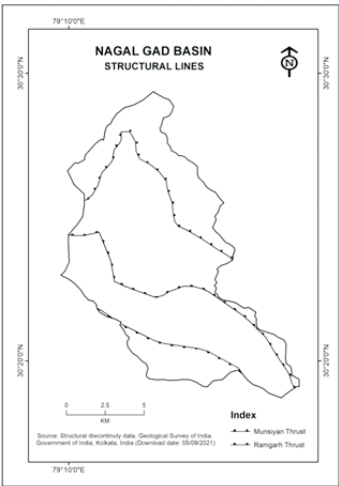


Figure4: Map showing structural line of Nagal Gad Basin

Structural controls and drainage character of Nagal Gad Basin in Chamoli district Garhwal Himalaya

Gopinath Patra

Results and Discussion

The details of morphometric analysis of the study area under linear, areal and relief aspects and their results are discussed below-

Linear Aspects

Drainage lines of an area not only explain the existing three-dimensional geometry of the region but also help to narrate its evolutionary process (Singh 1980, Rai et al 2017).

**Stream order (u):** Horton introduced the concept of Stream Order in 1932, later it was Modified by Strahler (1952), Scheidegger (1965), Woldenberg (1966) and Shreve (1967). Stream ordering is a method which is used to classify the streams in a drainage basin. The stream segment of Nagal Gad basin is ranked by Strahler's Stream ordering method (1952). In the study area, there are total 518 streams linked with 1st, 2nd, 3rd, 4th and 5th level drainage order. The maximum number of streams 417 are identified in 1st order, then 77 in 2nd order, 19 in 3rd order, 4 in 4th order and 1 in 5th order drainage (Fig. 5).

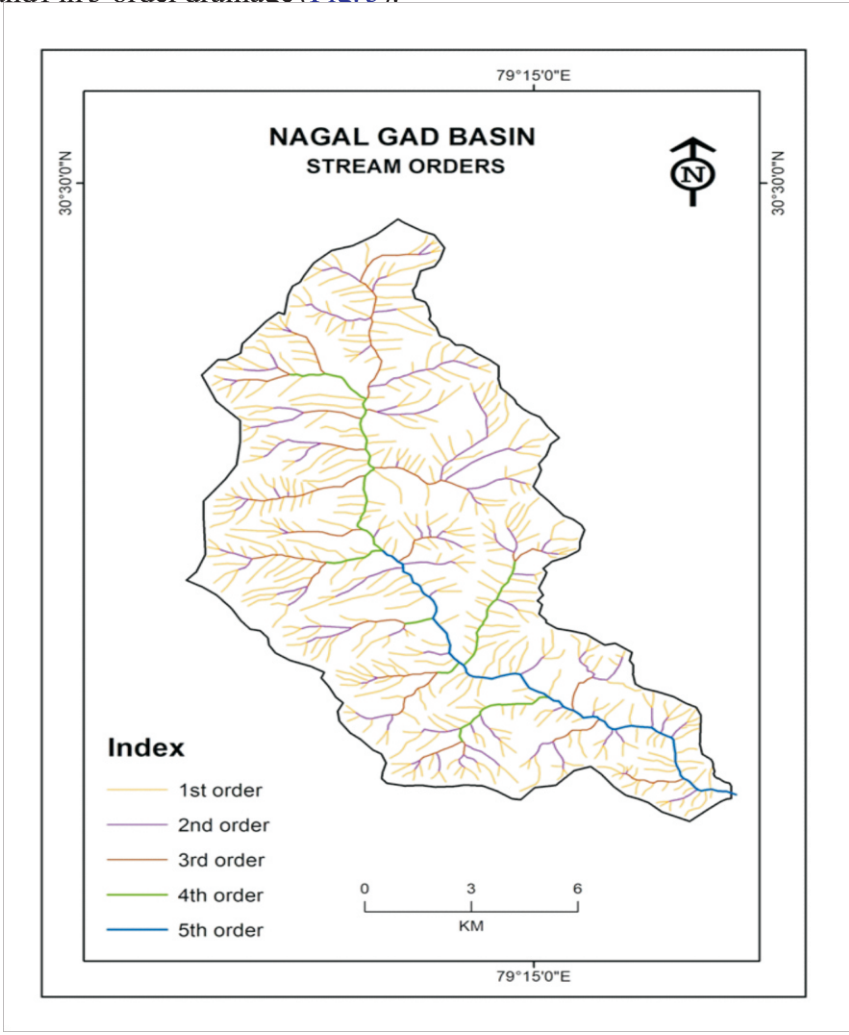


Figure 5: Stream Order of Nagal Gad Basin

**Table 1: Linear aspects of Nagal Gad Basin**

| Category of Parameter | Name and Notation of Morphometric Parameters | Formula                                                                                                                                                                                                                                                                                                                                                                                                                                   | Reference                       | Results               |
|-----------------------|----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------|-----------------------|
| Linear Parameters     | Stream Order (u)                             | Hierarchical rank                                                                                                                                                                                                                                                                                                                                                                                                                         | <a href="#">Strahler (1964)</a> | 5 <sup>th</sup> Order |
|                       | Stream Number (Nu)                           | $Nu = N_1 + N_2 + \dots + N_n$                                                                                                                                                                                                                                                                                                                                                                                                            | <a href="#">Horton (1945)</a>   | 518                   |
|                       | Stream Length (L)                            | Length of the Stream                                                                                                                                                                                                                                                                                                                                                                                                                      | <a href="#">Horton (1945)</a>   | 397.03                |
|                       | Mean Stream Length ( $L_\mu$ )               | $L_\mu = \Sigma L / Nu$<br>Where, $L_\mu$ is the mean stream length, $\Sigma L$ is the total stream length and $Nu$ is the number of segments (N) of stream order (u).                                                                                                                                                                                                                                                                    | <a href="#">Strahler (1964)</a> | 0.65 – 13.78          |
|                       | Bifur- cation Ratio (Rb)                     | $Rb = Nu / Nu + 1$<br>Where, $Rb$ is the bifurcation ratio, $Nu$ is the number of segments of a given order and $Nu + 1$ is the number of segments of the next higher order.                                                                                                                                                                                                                                                              | <a href="#">Schumm (1956)</a>   | 4 - 5.42              |
|                       | Weighted Mean Bifurcation Ratio (Rbw)        | $Rbw = Rb_1 \times n_1 + Rb_2 \times n_2 + \dots + Rb_n \times n_n$<br>Where, $Rbw$ is the Weighted mean bifurcation ratio, $Rb_1$ is the bifurcation ratio between 1st and 2nd order streams, $n$ is the total number of stream segments involved in $Rb_1$ calculation, and similarly $Rb_2$ is the bifurcation ratio between 2nd and 3rd order streams and $n_2$ is the total number of stream segments involved in $Rb_2$ and so on.. | <a href="#">Strahler (1952)</a> | 5.17                  |

**Stream Number (Nu):** Stream number refers to order wise the total number of stream segments. Horton (1945) stated that, “the number of stream segments of each order forms an inverse geometric sequence with order number”. The total stream numbers in the Nagal Gad are 518 (Table 1). The correlation graph between stream

order and stream number states inverse relationship (Fig. 6a) i.e. higher the order lesser the number of streams.

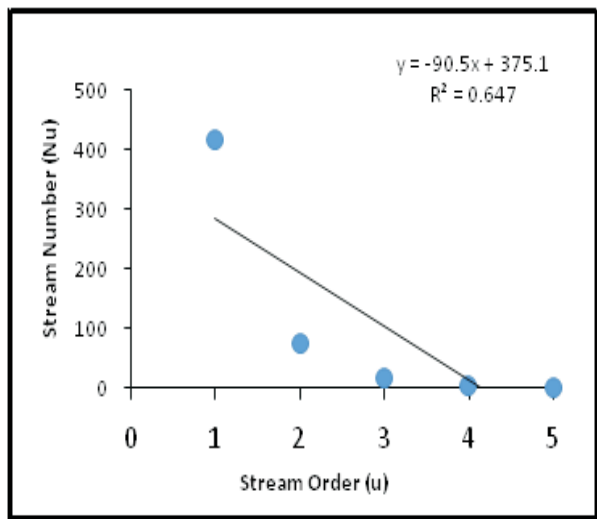


Figure 6a: The relation between stream order and stream number;

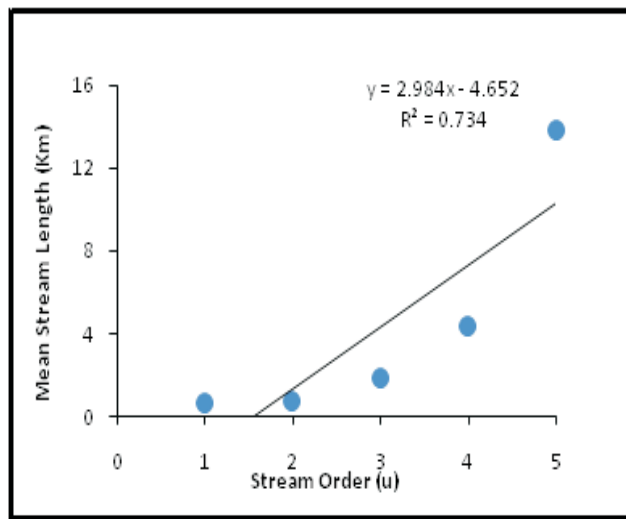


Figure 6b: The relation between stream order and mean stream length

**Stream Length (L):** The streams of relatively smaller lengths are characteristic of areas with larger slopes and finer textures, however, the longer lengths of the streams indicate flatter gradients (Jasmin & Mallikarjuna, 2013). The headwaters streams (first order to third order streams) contributing to increase in water volume of the stream of the next higher order. Generally the stream lengths decrease with increase in the stream order and this character is maintained in the Nagal Gad basin also. In the upper catchment the steepness of slope aids to bring water quickly down through fingerlike channels. Some 4<sup>th</sup> order channels have 1<sup>st</sup> order streams which join at right angles due to the flattening of relief and presence of quartzite and slate rocks through which the fourth order stream flows past. The total stream length of all orders in Nagal Gad basin is 397.03 km.

Table 2: Order wise stream number. stream length. mean stream length.

| Basin name | Stream Order (u) | Stream Number (Nu) | Stream Length (L) (km) | Mean Stream Length (L <sub>μ</sub> ) (km) | Bifurcation Ratio (Rb) | Weighted Mean Bifurcation Ratio (Rbw) |
|------------|------------------|--------------------|------------------------|-------------------------------------------|------------------------|---------------------------------------|
| Nagal Gad  | I                | 417                | 269.13                 | 0.65                                      | -                      | 5.17                                  |
|            | II               | 77                 | 60.45                  | 0.79                                      | 5.42                   |                                       |
|            | III              | 19                 | 36.20                  | 1.91                                      | 4.05                   |                                       |
|            | IV               | 4                  | 17.47                  | 4.37                                      | 4.75                   |                                       |
|            | V                | 1                  | 13.78                  | 13.78                                     | 4.0                    |                                       |



**Mean Stream Length (Lu):** The Mean stream length is a dimensionless property revealing the characteristic size of components of drainage network and its associated surface (Strahler,1964). Mean Stream Length refers to the ratio between total stream length of any order of a basin and the number of stream segments of that particular order. In Nagal Gad basin mean stream length varies from 0.65 (1<sup>st</sup> order) to 13.78 (5<sup>th</sup> order) (Table2). Generally the mean stream length of a given order is greater than that of the lower order. This law is maintained in all orders of Nagal Gad basin. It indicates the trunk stream of an order is comparatively longer than its previous tributary streams (Das and Pardeshi 2018).

**Bifurcation Ratio (Rb):** Bifurcation ratio is calculated by the ratio of the total number of streams of a given order to the number of streams in the next higher order (Schumm,1956). It is a dimensionless property and generally ranges in between 3 to 5 (Ozdemir&Bird, 2009; Pareta & Pareta, 2012). High value of the ratio indicates lower degree of drainage integration and vice- versa (Jha, 1996) The Rb value indicate the influence of geological structure on the drainage basin. Bifurcation ratio more than 5 indicates significant structural disturbances and the substantial influence of geological structures to the drainage network (Das and Pardeshi, 2018). The bifurcation ratio of Nagal Gad basin ranges from 4 to 5.42 and the mean bifurcation ratio (Rbw) is 5.17 (Table1),which indicates low to moderate structural control in Nagal Gad basin.

### Areal Aspect

The morphometric analysis of the areal aspect of the basin reveals that the basin has very slight potential for flooding. Soil erosion takes place more on the steeper slopes aided by gravity and minimal tree cover because of thin soil cover. This results in frequent runoff generated from the upland areas of the watershed. The run-off percolates down the surface and infiltrates the gentle slopes. In the lower basin area, ample ground water reserves are built up.

Table 3: Areal aspects of Nagal Gad basin

| Category of Parameter | Name and Notation of Morphometric Parameters | Formula                                                                                                                                        | Reference     | Results |
|-----------------------|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------|---------------|---------|
| Areal Parameters      | Drainage Density (D)                         | $D = \Sigma L / A$<br>Where, D = Drainage density, $\Sigma L$ = Total stream length of all orders, A = Area of the basin (in Sq. km.).         | Horton (1932) | 3.10    |
|                       | Stream Frequency (F)                         | $F = \Sigma Nu / A$<br>Where, F = Stream frequency, $\Sigma Nu$ = Total no. of stream of all orders, A = Area of the basin (Sq. km.)           | Horton (1932) | 4.04    |
|                       | Drainage Texture (Rt)                        | $Rt = Nu / P$<br>Where, Rt = Drainage texture, Nu = Total no. of stream of all orders, P = Perimeter of the basin (km.).                       | Horton (1945) | 8.71    |
|                       | Infiltration Number (If)                     | $If = Fs \times Dd$<br>Where, If = Infiltration number, Fs = Stream frequency, Dd = Drainage Density                                           | Fanira (1968) | 8.53    |
|                       | Texture Ratio (Rt)                           | $Rt = N_{10} / P$<br>Where, Rt = Texture Ratio, $N_{10}$ = Total number of the 1st order stream, P = perimeter of the basin.                   | Schumm (1956) | 7.01    |
|                       | Elongation Ratio (Re)                        | $Re = (2\sqrt{A}/\pi) / Lb$<br>Where, Re = Elongation Ratio, A = Area of the basin (sq. km.), $\pi$ = pi value that is 3.14; Lb = Basin length | Schumm (1956) | 0.65    |

**Drainage Density (Dd):** Drainage density (Dd) of a basin indicates the closeness of spacing of streams (Horton 1932). It may be defined as a ratio of total length of all stream segments of a given drainage basin to the total area of that basin. Weak or impermeable subsurface material, mountainous relief and sparse vegetation lead to high drainage density. (Choudhuri et al, 2018) This aspect is a significant indicator of landform element and it gives a numerical measurement of landscape dissection, runoff potential and closeness of channel spacing and therefore gives an idea about the relationship between climate and geology (Ritter et al. 1995). Lithology, rainfall, soil moisture and vegetation cover control the drainage density of a basin. The moderate drainage density value 3.10 km./sq. km. of Nagal Gad basin indicates it has moderate slope, relative relief, moderate to dense vegetation cover and negligible to moderate permeability of the underlying rock. Figure 7 shows the distribution of drainage density of Nagal Gad basin. Higher drainage density is chiefly found in the upper middle and middle part of the basin and low drainage density is observed in the peripheral area of the basin.

**Stream Frequency (Fs):** Stream frequency is the ratio between total number of channels of all orders and the total area of the drainage basin. It is controlled by the rainfall intensity, vegetation cover, structure and nature of underlying rock permeability, infiltration capacity and relief of the watershed. Higher the drainage density and stream frequency in a basin, the faster the runoff and therefore, flooding is more likely to be quick in such basin (Pankaj & Kumar, 2009). The low stream frequency in the study area signifies the presence of permeable sub-soil material, low relief and more or less control of the rainfall and temperature condition (Varade et al., 2017). In the present study the stream frequency of the Nagal Gad basin is moderate, i.e 4.04/sq. km.(Table3), signifying negligibly permeability and moderate runoff thereby allowing only minimal infiltration.

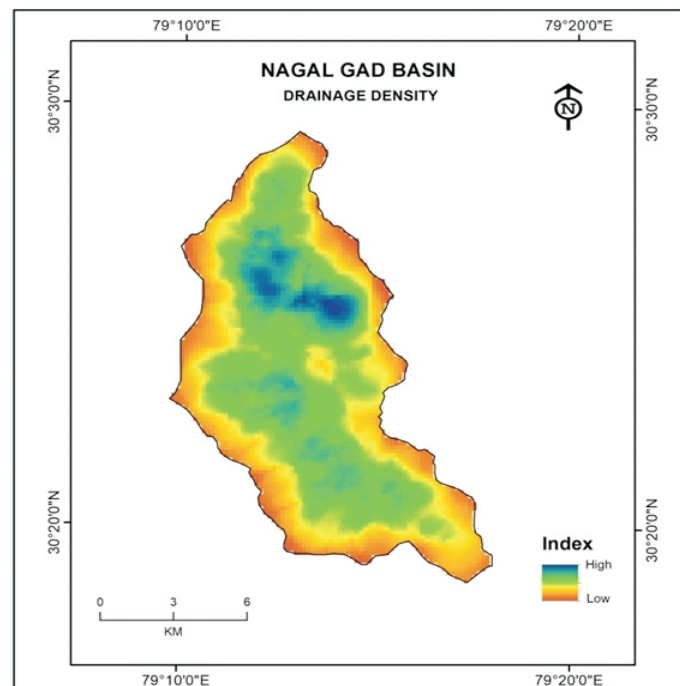


Figure:7 Distribution of Drainage density in Nagal Gad Basin

**Drainage Texture (T):** Drainage texture (T) influenced by a number of factors such as climate, lithology, relief, infiltration capacity, vegetation covers and the stage of drainage development ([Smith 1950](#)). Drainage Texture is the total number of stream segments of all orders per perimeter of that area ([Horton, 1945](#)). It signifies the relative spacing of streams. ([Bharath et al 2021, p. 5](#)) Smith (1950), classified drainage texture into five classes, these are Very Coarse (<2), Coarse (2-4), Moderate (4-6), Fine (6-8), Very Fine (>8). The drainage texture of Nagal Gad basin is 8.71 ([Table 3](#)), which indicate very fine texture pointing to moderate surface run-off due to relief and rock type.

**Infiltration Number (If):** Infiltration number is the product of drainage density and stream frequency of the drainage basin, demonstrating the infiltration characteristics of a drainage basin ([Smith, 1950](#)). It helps us to analyse the infiltration characteristics of a drainage basin. The higher value of infiltration number, it indicates lower capacity for infiltration and higher runoff ([Das & Mukherjee, 2005](#)). The infiltration number of Nagal Gad basin is high as 8.53 ([Table 3](#)), indicates low infiltration and high run-off. This indicates presence of hard rocks like Gneiss, Quartzites, Schistose Grit, control the infiltration characteristics of the basin.

**Texture Ratio (Rt):** Texture ratio is a ratio between the first order stream and perimeter of the basin ([Schumm, 1956](#)). The relief, geology, structure, rainfall, infiltration capacity influences the texture ratio of a drainage basin. The texture ratio in a watershed relates to factors such as vegetation, climate and relief. ([Sharma & Mahajan, 2020, p 163](#)) It is an important factor in the drainage morphometric analysis due to its relationship with the underlying lithology, infiltration capacity and relief aspects of the terrain ([Rao et al., 2010](#)). The Nagal Gad basin has a texture ratio value of 7.01 and hence categorized under fine (6-8) ([Table 3](#)) in nature, which specify high relief and high undulating area.

**Elongation Ratio (Re):** The elongation ratio reveals the shape of the basin and is defined as the ratio between the diameters of a circle of the same area as the basin to the maximum basin length ([Schumm, 1956](#)). Generally this ratio runs between 0.6 and 1.0 over a wide variety of geologic and climatic types. Values near 1.0 are typical of regions of very low relief, whereas values in the range 0.6 to 0.8 are generally associated with strong relief and steep ground slopes ([Strahler, 1964](#)). The value of elongation ratio can be classified into five groups, these are- i) Circular (>0.9), ii) Oval (0.8- 0.9), iii) Less Elongated (0.7-0.8), iv) Elongated (0.5-0.7), v) More Elongated (<0.5) ([Schumm 1956](#)). The value of Elongation ratio of Nagal Gad basin is 0.65, that indicates elongated type of drainage basin.

## Relief Aspect

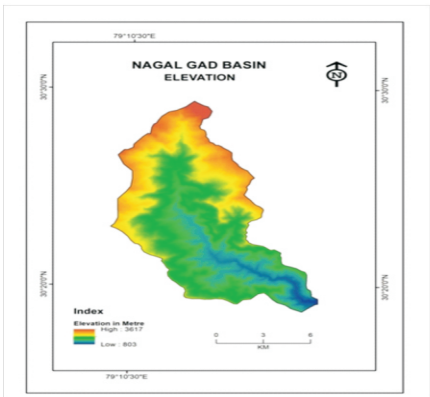
**Basin Relief (Bh):** The difference between the maximum and minimum altitude of a drainage basin is called Basin relief. It is a significant factor that controls the stream gradient and therefore influences flood patterns and the amount of transported sediments ([Schumm, 1956](#)). The highest and lowest elevation point of Nagal Gad basin are 3560 metre and 860 metre, thus the elevation difference is (3560 m – 860 m) 2700 metre, reflecting high basin relief indicates steep slope and hillslope are dominating processes along with high-velocity runoff and less infiltration potential over the basin area.

Table 4: Relief aspects of Nagal Gad basin

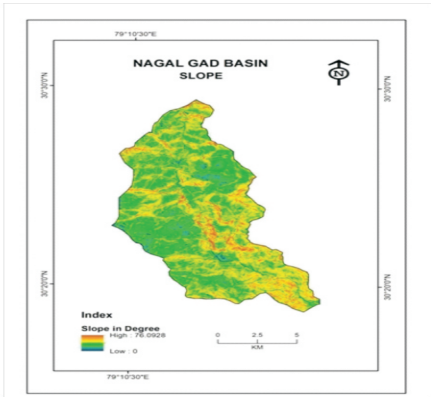
| Category of Parameter | Name and Notation of Morphometric Parameters | Formula                                                                                                                                                                                                                                               | Reference                      | Results |
|-----------------------|----------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------|---------|
| Relief Parameters     | Relief Ratio (Rh)                            | $Rh = H/Lb$<br>Where, Rh = Relief ratio, H = Total relief (relative relief) in km. Lb = Basin length                                                                                                                                                  | <a href="#">Schumm(1956)</a>   | 0.14    |
|                       | Hypsometric Analysis (HI)                    | Graphical representation of a/A and h/H in 'x' axis and 'y' axis respectively<br>Where, a = area enclosed by a pair of contours; A = Total basin area; h = the highest elevation between each pair of contours above the base; H = Total basin height | <a href="#">Langbein(1947)</a> | 51.73   |
|                       | Ruggedness Number (Rn)                       | $Rn = Dd \times (H/1000)$<br>Where, Dd = Drainage density (km/km <sup>2</sup> ) H = Basin Relief (m)                                                                                                                                                  | <a href="#">Strahler(1964)</a> | 8.37    |

**Relief Ratio (Rh):** Schumm (1956), defined Relief Ratio (Rh) as, the ratio between maximum relief and horizontal distance along the longest dimension of the basin parallel to the principal drainage line. The ratio normally increases with decreasing drainage area and size of the watersheds of a given drainage basin ([Varadeet al. 2017](#)). The low value of relief ratio indicates gentle slope, low relief and vice-a-versa. The Rh value of Nagal Gad basin is high (0.14) (Table, 4) indicating high channel gradient with intense erosional processes operating due to steep gradient.

**Ruggedness Number (Rn):** It is a product of basin relief and its drainage density that significantly combines slope steepness with its length (Strahler, 1964). The ruggedness number of the Nagal Gad basin is high (8.37) (Table-4), indicates high relief with steep slope.



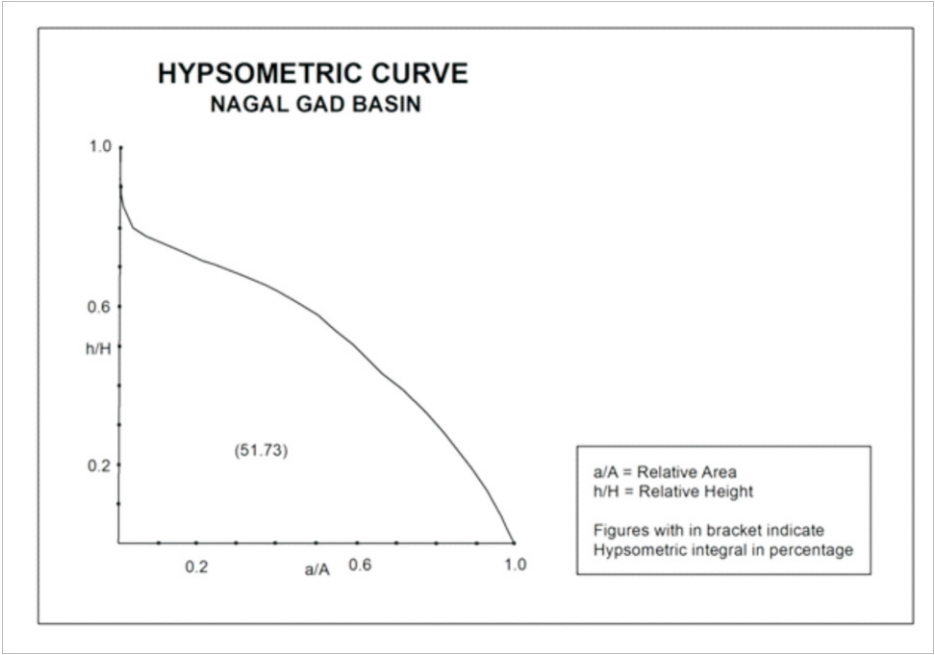
Figure, 8: DEM showing the elevation of Nagal Gad basin



Figure,9: Slope map of the Nagal Gad basin

**Slope:** Slope refers to the degree of inclination of land surface with respect to the horizontal surface. Slope analysis is significantly important in geomorphologic studies for the development of watershed and morphometric analysis. (Khurana et al 2019, p 169)The understanding slope is essential because it provides valuable information for agriculture, planning, engineering structures, etc., (Sreedevi et al. 2005). Slope map of Nagal Gad basin has been prepared by using Alos Palsar DEM (12.5 m resolution) data in ArcGIS 10.5software. The map shows the variation of slope in the basin, ranging from 0° to 76.09°(Fig. 9), Steep slope is observed in some patches in the middle-east, southern and south-eastern portion of the basin on the other hand middle-west and middle north-eastern portion characterized by moderate slope zone. Higher variation of slope represents steep scarp with rapid runoff and high erosion vulnerability (Das and Pardeshi 2018).

**Hypsometric Curve:** The percentage Hypsometric Curve is a ratio of relative height and relative area with respect to the total height and the total area of a drainage basin (Jha,1996). To show the overall slope and forms of drainage basin Langbein and Basil introduced the idea of Hypsometry in 1947. The graphical shape of a hypsometric curve indicates the stage of geomorphic development of a basin area (Patra et al, 2021). According to Strahler (1952), “A basin with upward convex hypsometric curve is indicate youth stage, S-shape curve indicates mature stage and down ward concave curves indicate the basin on peneplain or old stage of landscape evolution.” Figure10 shows the hypsometric curve of Nagal Gad basin. Schumm (1956) has tried to identify the stage of geomorphic development with the help of Hypsometric Integral, which is calculated from the percentage hypsometric curve. The value of hypsometric integral can be grouped into the following categories which indicate the typical stage of geomorphic development, these are– i) Early Youth (>80%), ii) Middle Youth (70%-80%),iii) Late Youth (60%-70%),iv) Early Maturity (50%-60%), v) Middle Maturity (40%-50%), vi) Late Maturity (35%-40%) vii) Old Stage (<35%) (Langbein,1947).The hypsometric integral of Nagal Gad basin is 51.73 % that indicates *early mature stage* of geomorphic development.



Figure, 10: Percentage hypsometric curve of Nagal Gad basin



## Conclusion

The values of the selected morphometric parameters helps to analyze the terrain characteristics, hydrological behavior and water resource potential of the Nagal Gad basin. According to some researchers (Vittala et al. 2004; Chopra et al. 2005; Kant et al. 2015; Radwan et al. 2017) if the basin is without geological control then mean bifurcation ratio varies between 3 to 5. The mean Rb value of Nagal Gad basin is 5.17, indicate the basin is highly geological controlled. The moderate value of drainage density (3.10 km./sq. km.) indicates the surface of the basin being minimally permeable, thereby resulting in rapid and large volume of runoff. The moderate value of stream frequency and infiltration numbers indicate rugged relief conditions and the basin being characterized by low to high grade metamorphic rocks like slate, marble, quartzites, quartz mica schist, chlorite schist, kyanite schist, schist and gneiss. The result of elongation ratio reveals that the basin is elongated in shape. Bull and McFadden (1977) have shown that basins draining the tectonically active areas are generally elongated. Presence of Munsiyari Thrust and Ramgarh Thrust also indicate that the basin is tectonically active. Similarly, the parameters, like fine drainage texture ratio, relief ratio, high ruggedness value and high relief also moderately minimizes the infiltration capacity of the basin area thereby scope for ground water extraction being limited.

From the above discussion it may be concluded that, the Nagal Gad basin is elongated in shape, structural controlled, moderately permeable surface and at early maturity stage of the drainage development. The present study can be directly applied for the future planning and management of Nagal Gad basin.

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## Evaluation of PAN-Sharpened Image Quality With Special Emphasis on Cartosat -2S/3 Imagery

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### Abstract

*Image with high spatial and spectral resolution is a prime requirement for urban analysis (with temporal changes) to perform tasks of footprint extraction, mapping and analysis of objects with smaller sizes in dense urban area, infrastructure and utility mapping etc. High resolution temporal images acquired by same or different satellites/ sensors provide necessary details to meet this requirement. High resolution optical data from Cartosat-2S/3 series provide simultaneous acquisitions of sub-meter pan and <2m multispectral images. Different image-fusion techniques are being developed to combine the prominent geometric features/shapes of the panchromatic image and the colour information of the multispectral image. Image quality of the Pan-sharpened image are of prime concern as some amount of information from one or both the images are distorted or/and lost depending on the used method. This paper evaluates the quality of Pan-sharpened images by four pixel based fusion techniques (developed in-house), namely, Enhanced Brovey transformation, Multiresolution Pyramid, Subtractive Resolution and Gram Schmidt transformation. Output Pan-sharpened products from different sensors are analyzed quantitatively with statistical parameters as well as assessed in qualitative way for information extraction. Test areas covering different terrain types (like urban, snow, vegetation, barren, island/ water) situated at different locations. It also provides some insight on the performance and robustness of statistical parameters for assessing high resolution data acquired from single and multiple sensors.*

**Keywords:** Pan-sharpening, Cartosat-2/3, High resolution, Spectral information, Quantitative analysis, statistical parameters

### Introduction

Evaluation of satellite image quality of optical sensors acquired by same or different satellites play a vital role in analysis and information extraction. It is more relevant for high resolution Pan-sharpening as the data quality of input images and robustness/efficiency of Pan-sharpening method contributes together for quality of Pan-sharpened output. These techniques integrate the geometric/edge detail of a high- resolution pan image and the color information of low- resolution Multi-spectral image, to produce a high- resolution Multi-spectral image. Important pre- requisites to obtain a good quality Pan-sharpened image are -

- Spectral range of pan band should be similar to spectral range of all Multi-spectral bands used.
- Accurate and precise co-registration of Multi- spectral image among bands and with pan image.
- Pan-sharpening algorithm should be able to preserve the spatial details from the input image without introducing any spectral distortions and artifacts.

The assessment of satellite image quality with different statistical measures are mentioned in literatures. It is important to mention the protocols established earlier. A quantitative assessment for pan- sharpened data quality was first established in 1997 (Wald, Ranchin, and Mangolini, 1997). The ideal output image is supposed to be ‘an



image that resembles a theoretically sensed image with an ideal sensor (high spatial and high spectral resolution)'.

Existence of such a sensor is not in reality. So it is considered that the output image should be as similar as possible to the input Multi-spectral image. Some of the established protocols are-

a) Zhou's protocol: Created by Zhou et al (1998), where spectral and spatial qualities are evaluated separately. The spectral assessment is done band by band. Final results are an average value of image differences between the original and the Pan- sharpened image. High frequency details of pan and Pan-sharpened images as well as correlation coefficient (CC) indicate the image quality

b) Quality with No Reference (QNR): A protocol developed (Alparone et al. 2008) without a reference image, as ideal/ appropriate reference image is not available/ accessible in most of the cases. Here two separate indices describe the spatial and spectral distortions in the Pan-sharpened image. Universal Image Quality Index (UIQI) by Wang and Bovik (2002) and QNR Index indicate spatial and spectral distortion indices. It allows modification to concentrate either on spatial or spectral improvement, depending on the user's preference (Alparone et al. 2015).

c) Khan's Protocol: Developed by Khan et al(2009) by integrating Wald's, Zhou's and QNR protocols. It is comprising the consistency criteria (Wald), high frequency components from the panchromatic to the Pan-sharpened image (Zhou) and spectral distortion (QNR protocol). It assesses the overall quality of Pan-sharpened images. Khan et al (2009) integrates an index (Q4) to obtain a comparable quantitative value in the form of spectral and spatial distortion index.

The reliability of these protocols need to be checked on large number of datasets of multiple sensors. The main objective of this paper is to evaluate the objective and subjective quality of Pan-sharpened images, generated by four pixel-based methods, using high, medium and low resolutions optical satellite data as input. A number of statistical parameters (from different protocols mentioned earlier) are used for this purpose. The results can help to identify the suitable Pan-sharpening method for different sensor/ resolutions with various terrain features. It also evaluates the relevance and performance of each statistical parameter for quality evaluation of different resolution images.

## Study Area

Simultaneous acquisitions of sub-meter pan and <2m Multi-spectral images with Cartosat-2S/3 series provide high resolution data. Cartosat-2S sensors have 4 bands in VNIR region (B1- 0.49, B2- 0.56, B3- 0.66, B4- 0.82  $\mu\text{m}$ ) and a Pan band (0.50 - 0.675  $\mu\text{m}$ ) covering a large portion of same spectral bands. Sentinel-2 and LDCM (Landsat-8) provide medium and coarse resolution datasets. Sentinel-2 datasets are with 13 bands at VNIR and SWIR region in different resolutions along with coastal aerosol and atmospheric bands. Among these 3 bands from NIR and SWIR region (B5-0.705, B8A-0.864, and B12-2.19  $\mu\text{m}$ ) are used as Multi-spectral data. As it doesn't provide a separate panchromatic data, a synthetic pan band is created using high resolution bands (10 m resolution). Synthetic Pan band outputs are generated using different methods (as per literature) and the most suitable (generated from B4 and B8) output is chosen as input for Pan-sharpening. LDCM provides 10 bands in VNIR, SWIR and thermal region, among which 4 bands in VNIR region (B2- 0.475, B3- 0.565, B4- 0.655 and B5- 0.870  $\mu\text{m}$ ) are used as inputs along with panchromatic (0.50-0.675  $\mu\text{m}$ ) data. The study area in Sentinel-2 and LDCM data are covering part of Hyderabad City with urban structures, road and waterbody. Cartosat-2S/3 datasets represent different terrain feature and infrastructures pertaining to urban/ rural area. Both pan and Multi-spectral data of same satellite are acquired simultaneously to assure time-lag fidelity. The datasets used in this study are without any visible atmospheric effects (like fog) and cloud-free.



## Methodology and Test datasets

Catost-2S/3 pan and Multi-spectral ortho-products are generated in-house and Sentinel-2, LDCM ortho products are obtained from USGS site. These datasets of respective sensors are used as inputs for Pan- sharpened output generation using Brovey, Multi- resolution Pyramid, Subtractive Resolution Merge (SRM) and Gram-Schmidt method. Output images are generated at same resolution as input pan data. Pan sharpened outputs, of each satellites are evaluated for ‘performances of image fusion methods’ as well as the relevance of various quality metrics involved in quantitative analysis. The datasets for a single satellite acquired on same-date simultaneously to assure the fidelity of content and atmospheric conditions.

It is assured that the input datasets are free of registration error. Algorithms and tools used for Pan-sharpening are developed in-house, as a part of Pan- sharpening module in DES s/w (version 5.1) at ADRIN. Quantitative indicators/ descriptors for analysis of output image quality, are developed in C# as part of in-house ‘Data Quality Testing’ module. For qualitative analysis visual inspection is carried out for assessments of spectral quality, noise content including detector noise and object information extractions. A Flowchart in Fig.1 is depicting the workflow for Cartosat-3 satellite. Same workflow is implemented for other satellites.

## Quantitative analysis

Image quality matrix (IQM) is a formula or algorithm that assigns a numerical or categorical value to a given image for its perceived level of quality. Different image quality matrices are used to evaluate the quality and contents of Pan-sharpened images generated by these four pixel-based methods. Evaluation can be ‘with reference’ (as benchmark for comparison) or ‘without reference’ image. As the ‘high resolution Multi-spectral product’ (which is equivalent to Pan- sharpened product from the same sensor) is not available, the Pan-sharpened output is degraded to Multispectral image for comparison with input images (though it is not the ideal case). Pan-sharpened outputs generated by different methods are compared for an objective analysis of fusion effect as given in Table 1.

The histograms of the input Multispectral and Pan- sharpened bands are evaluated to understand the preservation of spectral information (closely resemblance in shape indicate better preservation). Parameters based on individual image, e.g. - Mean (average brightness), Standard deviation (contrast/amount of variation), Entropy (quantity of information content and complexity), Average gradient (sensitive to reflect the small details) are preliminary indicator of an image quality. But entropy (high value indicate rich information) and average gradient (higher is better) has poor sensitivity to color distortion/ local degradation. Spatial Frequency indicates the clarity of Pan-sharpened image. Parameters mentioned below in Table 2a, 3a, 4a, 5a and 6a indicate statistical characteristics of an image independently.

Several other statistical parameters are derived by taking into account of statistics using input Multi-spectral image (reference) and a Pan-sharpened output (target). Ratio between information and noise is measured by Signal to noise ratio (SNR). Higher value indicates that both the reference and fused images are similar. Peak signal to noise ratio (PSNR) is ratio (in dB) between the maximum possible signal power and the power of distorting noise which affects the image quality. Signal is considered as the original data and the noise is the error yielded by fusion. Mean square error (MSE), indicating image quality (lower is better), is computed by mean square difference between the Pan-sharpened and reference image. PSNR has a relation with MSE. Root Mean Square Error (RMSE) evaluates the spectral distortion by the fusion process in the form of error magnitude (lower is better) of a varying quantity. Normalized Least Square Error (NLSE) represents the normalized difference between the gray values of pan-sharpened and reference images (lower is better). Erreur Relative Globale Adimensionnelle de Synthèse (ERGAS) is an evaluation index that measures the quality of spectral information by indicating normalized average error (Using RMSE and mean) of each band. Relative Average Spectral Error

(RASE) characterizes the average performance of a method in the considered spectral bands. It is independent of number of bands and instrument bias (value is expressed in % and decrease as the quality increases). The value of ERGAS and RASE approaching zero indicate greater similarity in the spectral characteristics of reference and Pan-sharpened images. Cross entropy (CE) is used to compute the difference in information contained between the reference and Pan-sharpened image. Lower value is better indicating both image containing the same information. Union entropy (UE) indicate the information shared between the Pan-sharpened and the reference image using the joint histogram (higher is better). Correlation coefficient (CC) is considered as a clue of spectral degradations by computing the similarity of spectral features between the reference and Pan-sharpened images (+1 is indicating both images are perfectly same). Variation increases when the value of CC is less than 1 (range is +1 to -1). Universal Image Quality Index (UIQI) is an index of similarity between two images by correlating luminosity and intensity distortions. It evaluates amount of transformation of relevant data from reference image into Pan-sharpened image (1 is ideal, indicating no loss of information. Mutual Information (MI) is used to measure the similarity of image intensity between the Pan-sharpened image and reference image using histogram (higher is better). Quality Index based on local variance (QILV) parameter is dealing with the global statistics of the local variance (derived from neighboring pixels) between original and pan-sharpened image (higher is better). Structured Similarity Indexing Method (SSIM) of each bands compare the image degradation and blurring between original and Pan-sharpened image by comparing the local patterns of spatially closed pixel intensities (change in perception of structural information). It is defined as a function of luminance, contrast and structural information comparison (for strongly inter-dependent pixels which refers information about the visual objects in image domain). Ideal value is 1, indicating the reference and Pan-sharpened images are similar. These statistical parameters are representative of image quality index (in Table-2b, 2c, 3b, 3c, 4b, 4c, 5b, 5c and 6b, 6c) in comparison with a reference image. Literatures are indicative about observations that sometimes quantitative measures are very mismatched to perceived visual quality.

## Qualitative analysis

Qualitative analysis is subjective assessment involving image interpreter's experience and capability of information/feature extraction. It evaluates the clarity of Pan-sharpened images, the degree of spectral retention, preservation of object details and with noise reduction (specific for high resolution data). Amount of spatial details and blur near the edges are examined also.

The details of quantitative and qualitative assessment for output Pan-sharpened images (coarse, medium and high resolution), generated through different methods, are presented in Section-4.

## Results and Discussion

Different subsets (ROI) from input pan and Multi- spectral scenes of respective sensors covering different features are extracted. The results are presented subsequently.

### LDCM data –

The subset area of LDCM FCC image (Fig.2) depicts a part of Hyderabad city around Musi river and Imliban bus-station. Visual inspection indicate that all Pan-sharpened images are with higher spatial detail compared to input Multi-spectral image. Major roads and bridges appear sharper in Pan-sharpened images generated by all four methods. Musi river-course is prominent in Pyramid, Gram-Schmidt and Brovey output with better contrast. SRM output has better spectral content on urban structures but showing less edge details compared to other outputs. Vegetation at riverside and parks at urban area appeared comparatively dark in SRM and Brovey output.

Entropy for all Pan-sharpened images are almost equal to input multi-spectral image (Table 2a.) indicating information content of input data is maintained to what extent. Increased Average-Gradient and Spatial frequency is responsible for edge details in all Pan- sharpening output (highest in Pyramid output). No major difference is

observed in average brightness and contrast except in Pyramid output. Ratio of mean and standard deviation is maximum for SRM output (10.57) and minimum for Pyramid output (7.02) in comparison to input data (9.2). Brovey and Gram-Schmidt output have ratio of mean and standard deviation similar to input data.

Brovey output is with higher noise component (low SNR, PSNR), higher errors (MSE, RMSE and NLSE) compared to other outputs (Table 2b.). Higher value of SNR, PSNR and lower value in ERGAS, RASE in SRM and Gram-Schmidt output indicate images with less noise and better preservation of spectral content (ideal is <3). Though amount of shared information (Union Entropy) is similar in all Pan-sharpened output, difference of information (Cross entropy) is more in Brovey and less in Pyramid as well as SRM output.

MI, CC and SSIM values (of different bands) are slightly higher at Brovey output (Table 2c.) indicate better spectral similarity with input image but it also has more noise and error component which may not be considered as best output. QILV indicate a higher value for Gram-Schmidt output. Overall SRM appeared to have better preservation of spectral content indicated by maximum parameters (SNR, PSNR, MSE, RMSE, NLSE ERGAS, RASE, QILV and SSIM).

#### **Sentinel-2 data –**

The subset area of Sentinel-2 NCC image (Fig.3) is representing same part of Hyderabad city as it is shown in LDCM image earlier. Visual inspection

indicate that all Pan-sharpened images are with increased spatial details and edges (prominently visible for major roads, bridges and river course). Vegetation within urban area and riverside appeared in vigor of green without any spectral distortion in Pan-sharpened outputs. Brovey output depicts a red hue for urban structures. Pyramid, SRM output and Gram-Schmidt outputs are closure to input Multi-spectral data. Spatial details are slightly sharp at Gram-Schmidt output (prominent for Musi river course in blue color).

Entropy maintain same trend as it is in LDCM data. Increased Average-Gradient and Spatial frequency (Table 3a.) is responsible for small details in all Pan-sharpening output (higher in Gram Schmidt output). Ratio of mean and standard deviation is maximum for SRM output (3.0) and minimum for Pyramid output (2.5) are very similar to input data (2.8) indicate closure spectral distribution to input data (2.8).

Pyramid output (Table 3b.) depicts lesser noise content (higher SNR, PSNR), lower errors (MSE, RMSE, NLSE) and lower cross entropy (CE). SRM and Pyramid output indicate better spectral component with low ERGAS, RASE value. Brovey output depicts higher noise component (low SNR, PSNR) and lowest preservation of spectral component (highest ERGAS, RASE). SRM output represent lowest ERGAS and RASE value but far from ideal.

Gram-Schmidt output depicts higher errors (MSE, RMSE, NLSE), highest CE, lower CC but with higher MI (Table 3c.). SRM output depicts better spectral quality with lowest ERGAS, RASE and high QILV. Pyramid output appeared to have lower errors (MSE, RMSE and NLSE), high signal content (SNR, PSNR), lowest CE, higher CC and SSIM. The clear trend like LDCM data is missing here.

#### **Cartosat-2S data –**

The subset area on Cartosat-2S FCC (Fig.4) image is representing a semi-urban area with concrete buildings, sheds, open areas, metaled road, roadside trees and vehicles. Enhanced spatial details and edges are observed in all Pan-sharpened outputs. Blurred vehicles and edges of buildings in input Multi-spectral image are appearing sharper-edged in all Pan-sharpened imageries. Prominent spectral distortion for color in Pan-sharpened images are not observed at open areas, rooftop sheds and roadside trees. Color distortion is observed at edges of the vehicles on road at Pyramid output.

All Pan-sharpened outputs are with much higher spatial frequency and Average gradient (indicating more spatial details and edges) in comparison to input Multi-spectral image (Table 4a.). This is highest in Brovey and

lowest in Gram-Schmidt output. Mean and standard deviation of all the Pan-sharpened output is close to input Multi-spectral data indicating not much change in brightness and contrast of the images. Ratio of mean and standard deviation is maximum for Gram-Schmidt (5.5) and minimum for Brovey (4.6) output. Pyramid and Gram-Schmidt output represent relatively lower noise (higher SNR, PSNR), lesser error (lower MSE, RMSE and NLSE) component (Table 4b.) than Brovey and SRM output. Pyramid output is with low value of ERGAS, RASE indicating a better preservation of spectral content (far from ideal) and SRM output has higher value. Though amount of shared information (UE) is similar in all Pan-sharpened output, difference of information (CE) is more in Brovey and less in Gram-Schmidt output. MI and UIQI is almost equal for all Pan-sharpened outputs (Table 4c.). CC and SSIM (for each band and overall) indicate Pyramid output has slightly better spectral quality but outputs from other methods are not showing much difference. QILV is highest in Gram-Schmidt and lowest in Brovey output. Though pyramid output indicates better spectral similarity with input image from statistical indicators, visual inspection indicates that spatial details (edges of the vehicles on road) are slightly noisy. Gram-Schmidt output is representing overall a good spectral and spatial component.

### **Cartosat-3 data –**

Results of two subsets from different scenes are presented below-

**Subset-1:** The subset area on Cartosat-3 FCC image (Fig.5) represent urban infrastructures at port area. Different infrastructure like sheds, buildings, metaled road with road divider, concrete area, roadside trees, cargo units of different colors, electric masts, transportation (cargo) vehicles and cars are detected on the imagery. All Pan-sharpened outputs have increased spatial details and sharpness which is very prominent for rooftop edges/details, shadow of electric masts, cargos and smaller vehicles etc. Spectral distortion is not observed in vegetation or open area in any of the Pan-sharpened outputs. SRM output depicts a bluish hue on rooftops with metaled sheds. Pyramid output depicts blur at certain spots (seen at edge of small vehicles in parking area).

Brovey output also has very high Average gradient and Spatial frequency in comparison with input Multi-spectral data (Table 5a.). This might have been contributed by noise components along with spatial details as Brovey is a Ratio method. Gram-Schmidt output has comparatively lowest Average Gradient and spatial frequency. Mean and standard deviation of Gram-Schmidt output is close to input Multi-spectral data and Brovey output is with maximum deviation. Ratio of mean and standard deviation in Gram-Schmidt Pan-sharpened output (12.26) is close to input data (12.31) and it is minimum for Brovey output (8.38).

Gram-Schmidt and Pyramid output are with lower noise component (higher SNR, PSNR) and lesser error (lower MSE, RMSE and NLSE), better preservation of spectral content (Lower value in ERGAS, RASE) indicating a better image content (Table 5b.). Brovey output depicting very high noise and higher error and component and more spectral distortion. Amount of shared information (UE) is higher in Pyramid and Gram-Schmidt output.

Though Brovey output is with highest MI, on the contrary lowest CC, QILV, UIQI, SSIM, indicate that the output may have more local structural noise- content compared to other outputs (Table 5c.). Gram-Schmidt output represents highest CC, UIQI, QILV and SSIM. Gram-Schmidt output is representing overall better image quality with good signal content, less error and less spectral distortion.

**Subset-2:** The subset area on Cartosat-3 FCC image (Fig.6) representing a rural area with vegetation (trees/bushes), single/dual-storied buildings, open area adjacent to road etc. Vegetation appeared comparatively dark on Brovey output and appeared with more vigor in Pyramid output and looks similar in Gram-Schmidt output. All Pan sharpened outputs has increased spatial details and sharper edges which is very prominent for edges and details of rooftops, road center-line etc.

Similar trend for Average gradient and Spatial frequency is observed here like subset-1 of Cartosat-3. Mean and standard deviation (Table 6a.) of SRM output is close to input Multi-spectral data and Brovey output is with



maximum deviation. Ratio of mean and standard deviation is maximum for Gram-Schmidt output (14.1) and minimum for Brovey output (7.27). Brovey output depicting very high noise component, higher error and more spectral distortion. Lower noise component (higher SNR, PSNR), lesser error (lower MSE, RMSE and NLSE) better preservation of spectral content (Lower value of ERGAS, RASE) indicating a better image content in Gram-Schmidt output (Table 6b.). It is also indicating a similar trend like Cartosat-3 subset-1.

All Pan-sharpened outputs have shown similar MI except Brovey output (Table 6c.). Higher UIQI is observed in Gram Schmidt and SRM output. All Pan- sharpened outputs represent good SSIM value (for each band and overall) except Brovey output. Gram- Schmidt output represents highest CC, UIQI, QILV and SSIM. Overall Gram Schmidt representing overall better image quality with good signal content, less error and less spectral distortion.

## Conclusions

Pan-sharpened images from four different satellites (with Multi-spectral and Pan sensors) are evaluated for image quality by statistical measures (quantitative) as well as visual assessment (qualitative). These satellites are LDCM (coarse resolution), Sentinel-2 (medium resolution), Cartosat-2S and Cartosat-3 (High resolution). Around 20 statistical parameters are assessed to understand the quality of Pan-sharpened output generated by four methods, namely, Brovey, Multiresolution Pyramid, Subtraction Resolution Merge and Gram-Schmidt. This study also presents some insight on statistical parameters which appear to be a deciding factor for satellite image quality.

- Major observations related to quality of Pan- sharpened outputs are -

- d) Coarse resolution LDCM data – Statistical parameters indicate that SRM Pan-sharpened output appears to have better preservation of spectral content (ERGAS, RASE, QILV, SSIM), better information content (SNR, PSNR) and lower errors (MSE, RMSE and NLSE) which is indicated by maximum statistical parameters. Visual assessment also indicates same trend for spectral content of imagery. Gram- Schmidt output represent slightly better spatial details.

- e) Medium resolution Sentinel-2 data – Statistical parameters indicate that Pyramid output appears to be better in terms of spectral component which is indicated by ERGAS, RASE, CC, SSIM, lower errors (MSE, RMSE and NLSE). Visual inspection indicates Gram-Schmidt output to be more appealing and similar to input multispectral data. Overall the lack of clear-cut conclusion for Sentinel-2 data might have contributed by synthetic PAN band. Testing on more number of datasets may give conclusive result.

- f) High resolution Cartosat-2S data – As per statistical indicator Pyramid output have better spectral similarity with input image but visual inspection indicates that spatial details (edges of the vehicles on road) are slightly noisy. Gram-Schmidt output is representing overall a good spectral (next best as per statistical indicators) and spatial quality.

- g) High resolution Cartosat-3 data – Gram-Schmidt and Pyramid outputs are with higher information content (higher SNR, PSNR), lesser errors (lower MSE, RMSE and NLSE), less spectral distortion (Lower value in ERGAS, RASE), which indicate a better image content. Visual inspection for urban area indicate vegetation in Gram-Schmidt output is more close to input multi-spectral data. Edge information (spatial details) are good in SRM and Gram-Schmidt output. Overall by combining all parameters the Gram Schmidt output is better. Similar trend is

observed for multiple scenes containing different objects (urban structures, vegetation, open area, road, etc.)

- It is observed that Brovey Pan-sharpened output image is with more noise and more spectral distortion than other outputs in different resolutions. Brovey being a ratio method, along with edge details probably noise in input data get transferred in the output. Brovey method may not suitable for Pan- sharpening of high resolution images as the errors are exaggerated. Overall Gram-Schmidt appeared to be good method with a reasonable performance in different statistical parameters and visual assessment.

- It is also observed that some of the statistical parameters appeared to be a major indicator for determining image quality in all resolutions. They are noise based parameters (SNR, PSNR), different types of errors (MSE, RMSE, NLSE), spectral quality indices ERGAS, RASE, SSIM (band-wise and overall). Sometimes combinations of these parameters with CC and QILV determines the quality of Pan-sharpened satellite images.



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## Tables :

**Table 1.** Statistical parameters used to assess the image quality

| SI No.                                                                          | Category                      | Quality measure                                              |
|---------------------------------------------------------------------------------|-------------------------------|--------------------------------------------------------------|
| <i>Parameters based on individual image</i>                                     |                               |                                                              |
| 1                                                                               | Information and Clarity Based | Mean, Std. deviation, Entropy, Average Gradient              |
| <i>Parameters based on difference between reference and Pan-sharpened image</i> |                               |                                                              |
| 2                                                                               | Noise                         | SNR, PSNR                                                    |
| 3                                                                               | Error                         | MSE, RMSE, NI.SF                                             |
| 4                                                                               | Overall Spectral Quality      | ERGAS, RASE, Warp Degree, Cross Entropy, Relative mean Shift |
| 5                                                                               | Similarity Based              | CC, UIQI, MI, SSIM                                           |

**Table 2a.** Statistical characteristics of LDCM images

| Parameters       | Reference (LDCM) | Pan-sharpened output Image |           |           |              |
|------------------|------------------|----------------------------|-----------|-----------|--------------|
|                  | Multispectral    | Brovay                     | Pyramid   | SRM       | Gram-Schmidt |
| Average Gradient | 240.070          | 469.735                    | 655.516   | 434.308   | 561.594      |
| Entropy          | 12.618           | 12.522                     | 12.937    | 12.487    | 12.761       |
| Spatial Frequncy | 705803           | 1313715                    | 2833161   | 1239494   | 1910522      |
| Std. Deviation   | 1791.322         | 1515.604                   | 2353.831  | 1562.775  | 1774.933     |
| Mean             | 16632.890        | 14740.130                  | 16532.390 | 16517.520 | 17137.140    |

**Table 2b and 2c.** indicate difference-based Statistical parameters of LDCM Pan-sharpened outputs (below)

| Method        | UE     | CC    | UIQI  | MI     | QILV  | SSIM- B2 | SSIM- B3 | SSIM- B4 |
|---------------|--------|-------|-------|--------|-------|----------|----------|----------|
| Brovey        | 12.534 | 0.776 | 0.001 | 13.237 | 0.896 | 0.856    | 0.937    | 0.926    |
| Pyramid       | 12.568 | 0.758 | 0.000 | 12.617 | 0.752 | 0.839    | 0.890    | 0.872    |
| SRM           | 12.328 | 0.704 | 0.001 | 12.361 | 0.929 | 0.843    | 0.929    | 0.943    |
| Gram- Schmidt | 12.437 | 0.708 | 0.000 | 12.501 | 1.000 | 0.818    | 0.896    | 0.901    |

| Method        | SNR    | PSNR   | MSE     | RMSE     | NLSE  | ERGAS  | RASE   | CE    |
|---------------|--------|--------|---------|----------|-------|--------|--------|-------|
| Brovey        | 16.534 | 29.447 | 4877502 | 2208.507 | 0.017 | 12.582 | 14.880 | 1.234 |
| Pyramid       | 20.305 | 32.172 | 2604691 | 1613.905 | 0.009 | 9.581  | 11.235 | 0.061 |
| SRM           | 21.895 | 33.823 | 1780994 | 1334.539 | 0.006 | 6.629  | 8.042  | 0.066 |
| Gram- Schmidt | 21.469 | 33.073 | 2116543 | 1454.834 | 0.008 | 8.568  | 10.127 | 0.123 |

**Table 3a.** Statistical characteristics of Sentinel-2(S2) images

| Parameters        | Reference (S2) | Pan-sharpened output Image |            |           |              |
|-------------------|----------------|----------------------------|------------|-----------|--------------|
|                   | Multispectral  | Brovey                     | Pyramid    | SRM       | Gram-Schmidt |
| Average Gradient  | 64.346         | 93.363                     | 138.684    | 112.221   | 155.5308     |
| Entropy           | 10.898         | 10.697                     | 11.090     | 10.934    | 11.17612     |
| Spatial Frequency | 43833.050      | 48737.740                  | 120917.700 | 70387.040 | 134759.2     |
| St. Deviation     | 529.039        | 438.339                    | 598.816    | 508.940   | 600.0019     |
| Mean              | 1506.932       | 1276.043                   | 1510.534   | 1528.827  | 1701.853     |

**Table 3b and 3c.** indicate difference-based Statistical parameters of Sentinel-2 Pan-sharpened outputs (below)

| Method        | SNR    | PSNR   | MSE    | RMSE   | NLSE  | ERGAS  | RASE   | CE    |
|---------------|--------|--------|--------|--------|-------|--------|--------|-------|
| Brovey        | 13.044 | 46.778 | 93535  | 303.14 | 0.036 | 21.021 | 24.515 | 0.315 |
| Pyramid       | 18.015 | 50.131 | 42720  | 205.38 | 0.017 | 14.015 | 16.282 | 0.037 |
| SRM           | 16.719 | 48.912 | 55594  | 235.33 | 0.022 | 12.792 | 14.700 | 0.198 |
| Gram- Schmidt | 14.389 | 45.602 | 122864 | 347.37 | 0.049 | 18.185 | 21.035 | 0.352 |

| Method        | UE     | CC    | UIQI  | MI     | QILV  | SSIM- B2 | SSIM- B3 | SSIM- B4 |
|---------------|--------|-------|-------|--------|-------|----------|----------|----------|
| Brovey        | 10.801 | 0.935 | 0.002 | 11.002 | 0.871 | 0.979    | 0.973    | 0.981    |
| Pyramid       | 10.962 | 0.940 | 0.002 | 10.984 | 0.935 | 0.991    | 0.986    | 0.992    |
| SRM           | 10.852 | 0.902 | 0.002 | 10.993 | 0.983 | 0.917    | 0.967    | 0.985    |
| Gram- Schmidt | 10.862 | 0.881 | 0.002 | 11.008 | 0.918 | 0.976    | 0.977    | 0.988    |

**Table 4a.** Statistical characteristics of Cartosat-2S(C2S) images

| Parameters        | Reference (C2S) | Pan-sharpened output Image |         |         |              |
|-------------------|-----------------|----------------------------|---------|---------|--------------|
|                   | Multispectral   | Brovey                     | Pyramid | SRM     | Gram-Schmidt |
| Average Gradient  | 3.567           | 8.486                      | 7.905   | 7.519   | 6.121        |
| Entropy           | 7.213           | 7.521                      | 7.454   | 7.307   | 7.253        |
| Spatial Frequency | 97.193          | 511.671                    | 437.996 | 397.576 | 254.795      |
| St. Deviation     | 39.462          | 48.434                     | 46.526  | 42.624  | 39.234       |
| Mean              | 216.512         | 224.568                    | 216.134 | 215.805 | 216.620      |

**Table 4b and 4c.** indicate difference-based Statistical parameters of Cartosat-2S Pan-sharpened outputs (below)

| Method        | SNR    | PSNR   | MSE     | RMSE   | NLSE  | ERGAS  | RASE   | CE    |
|---------------|--------|--------|---------|--------|-------|--------|--------|-------|
| Brovey        | 19.205 | 68.312 | 650.588 | 25.340 | 0.014 | 11.973 | 12.396 | 0.199 |
| Pyramid       | 21.755 | 71.195 | 357.811 | 18.493 | 0.008 | 8.918  | 9.238  | 0.135 |
| SRM           | 19.794 | 69.276 | 528.879 | 22.764 | 0.011 | 13.576 | 14.504 | 0.069 |
| Gram- Schmidt | 21.610 | 71.089 | 370.889 | 18.762 | 0.008 | 11.165 | 12.037 | 0.034 |

| Method       | UE    | CC    | UIQI  | MI    | QILV  | SSIM- B2 | SSIM- B3 | SSIM- B4 | SSIM- B5 |
|--------------|-------|-------|-------|-------|-------|----------|----------|----------|----------|
| Brovey       | 7.393 | 0.871 | 0.021 | 7.488 | 0.841 | 1.000    | 0.999    | 0.999    | 1.000    |
| Pyramid      | 7.335 | 0.918 | 0.022 | 7.400 | 0.887 | 1.000    | 1.000    | 1.000    | 1.000    |
| SRM          | 7.237 | 0.852 | 0.023 | 7.272 | 0.956 | 1.000    | 0.999    | 0.999    | 1.000    |
| Gram-Schmidt | 7.227 | 0.882 | 0.024 | 7.250 | 0.987 | 1.000    | 1.000    | 0.999    | 1.000    |

**Table 5a.** Statistical characteristics of Cartosat-3 (C3) images

| Parameters        | Reference (C3) | Pan-sharpened output Image |         |         |              |
|-------------------|----------------|----------------------------|---------|---------|--------------|
|                   | Multispectral  | Brovey                     | Pyramid | SRM     | Gram-Schmidt |
| Average Gradient  | 2.664          | 14.119                     | 6.130   | 4.027   | 2.432        |
| Entropy           | 5.948          | 7.589                      | 6.156   | 5.940   | 5.965        |
| Spatial Frequency | 27.425         | 792.763                    | 139.970 | 76.381  | 50.643       |
| St. Deviation     | 19.429         | 60.076                     | 22.588  | 20.699  | 19.809       |
| Mean              | 234.001        | 503.020                    | 233.909 | 233.267 | 233.815      |

**Table- 5b and 5c** indicate difference-based Statistical parameters of Cartosat-3 Pan-sharpened outputs (below)

| Method        | SNR    | PSNR   | MSE     | RMSE    | NLSE    | ERGAS   | RASE    | CE    |
|---------------|--------|--------|---------|---------|---------|---------|---------|-------|
| Brovey        | 5.357  | 47.592 | 74778   | 273.456 | 1.356   | 118.846 | 121.887 | 8.373 |
| Pyramid       | 26.350 | 75.257 | 128.063 | 11.315  | 0.002   | 5.061   | 5.164   | 0.053 |
| SRM           | 24.104 | 73.041 | 215.034 | 14.633  | 0.004   | 12.296  | 11.784  | 0.025 |
| Gram- Schmidt | 26.605 | 75.526 | 123.922 | 11.051  | 0.00225 | 10.340  | 9.959   | 0.013 |

| Method       | UE    | CC    | UIQI  | MI     | QILV  | SSIM- B2 | SSIM- B3 | SSIM- B4 | SSIM- B5 |
|--------------|-------|-------|-------|--------|-------|----------|----------|----------|----------|
| Brovey       | 4.109 | 0.694 | 0.011 | 11.854 | 0.044 | 0.901    | 0.873    | 0.909    | 0.948    |
| Pyramid      | 6.054 | 0.871 | 0.045 | 6.079  | 0.914 | 1.000    | 1.000    | 1.000    | 1.000    |
| SRM          | 5.941 | 0.746 | 0.044 | 5.954  | 0.983 | 1.000    | 1.000    | 1.000    | 1.000    |
| Gram-Schmidt | 5.955 | 0.842 | 0.047 | 5.961  | 0.998 | 1.000    | 1.000    | 1.000    | 1.000    |

**Table 6a.** Statistical characteristics of Cartosat-3 images

| Parameters        | Reference (C3) | Pan-sharpened output Image |         |         |               |
|-------------------|----------------|----------------------------|---------|---------|---------------|
|                   | Multispectral  | Brovey                     | Pyramid | SRM     | Gram- Schmidt |
| Average Gradient  | 1.732          | 16.643                     | 3.503   | 2.568   | 1.338         |
| Entropy           | 5.477          | 8.394                      | 5.683   | 5.518   | 5.388         |
| Spatial Frequency | 6.233          | 698.753                    | 40.227  | 23.152  | 10.701        |
| St. Deviation     | 11.584         | 84.661                     | 14.400  | 11.936  | 10.643        |
| Mean              | 138.898        | 611.103                    | 138.487 | 140.446 | 141.994       |

Table 6b and 6c indicate difference-based Statistical parameters of Cartosat-3 Pan-sharpened outputs (below)

| Method        | SNR    | PSNR   | MSE    | RMSE    | NLSE   | ERGAS   | RASE    | CE     |
|---------------|--------|--------|--------|---------|--------|---------|---------|--------|
| Brovey        | 2.215  | 42.740 | 228537 | 478.056 | 11.764 | 339.110 | 341.725 | -0.000 |
| Pyramid       | 24.022 | 77.472 | 76.868 | 8.767   | 0.004  | 6.961   | 7.009   | 0.050  |
| SRM           | 25.491 | 78.837 | 56.131 | 7.492   | 0.003  | 8.795   | 9.102   | 0.026  |
| Gram- Schmidt | 29.171 | 82.432 | 24.936 | 4.973   | 0.001  | 6.264   | 6.534   | 0.033  |

| Method        | UE    | CC    | UIQI  | MI    | QILV  | SSIM- B2 | SSIM- B3 | SSIM- B4 | SSIM- B5 |
|---------------|-------|-------|-------|-------|-------|----------|----------|----------|----------|
| Brovey        | 0.002 | 0.891 | 0.004 | 0.003 | 0.001 | 0.728    | 0.660    | 0.711    | 0.744    |
| Pyramid       | 5.576 | 0.815 | 0.070 | 5.601 | 0.832 | 1.000    | 1.000    | 1.000    | 1.000    |
| SRM           | 5.498 | 0.814 | 0.078 | 5.513 | 0.996 | 1.000    | 1.000    | 1.000    | 1.000    |
| Gram- Schmidt | 5.408 | 0.905 | 0.089 | 5.426 | 0.993 | 1.000    | 1.000    | 1.000    | 1.000    |

Figures :

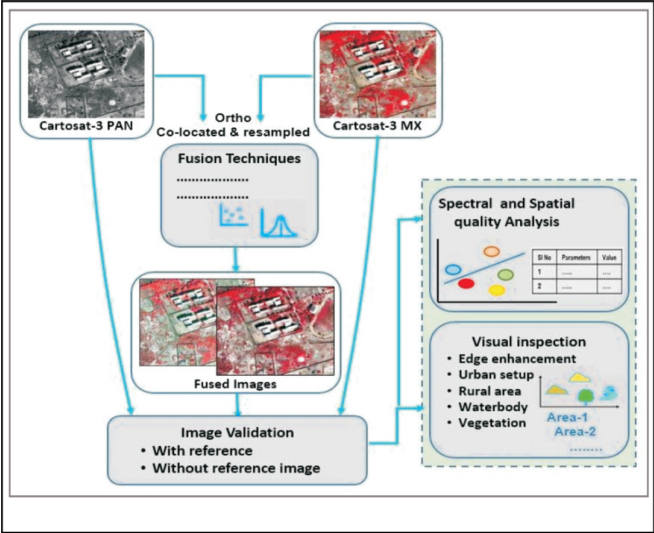


Fig.1. Flowchart depicting workflow

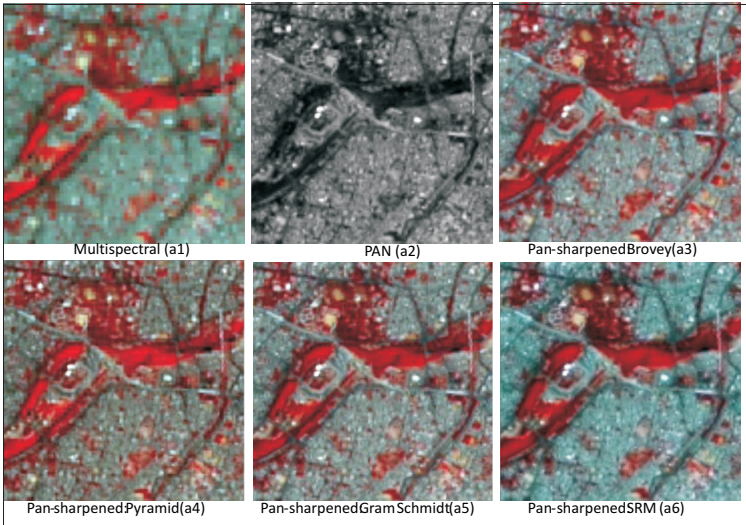
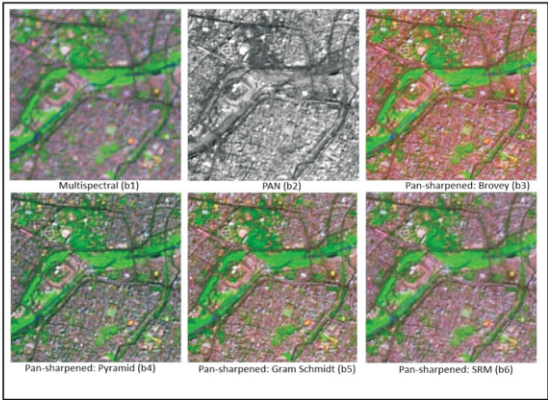


Fig.2. Input (a1 and a2) and Output Pan-sharpened images (a3, a4, a5, a6) of LDCM data

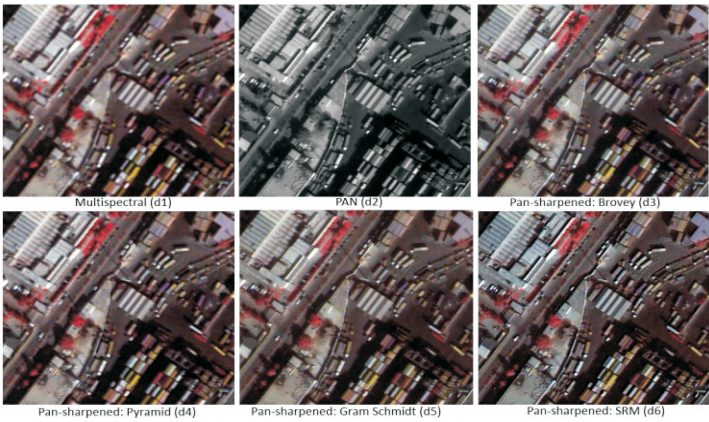




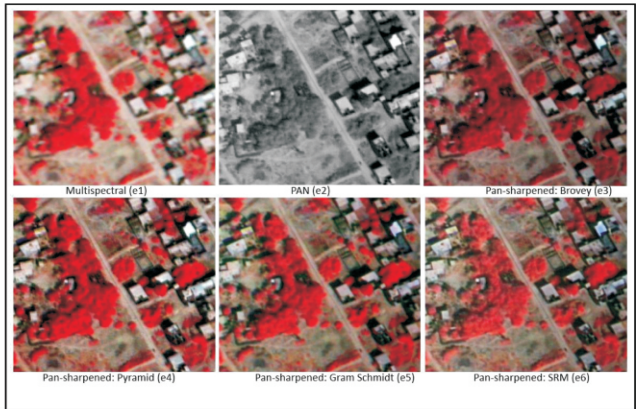
**Fig.3** Input (b1 and b2) and Output Pan-sharpened images + (b3, b4, b5, b6) of Sentinel-2 data



**Fig.4** Input (c1 and c2) and Output Pan-sharpened images (c4, c4, c5, c6) of Cartosat-2S data



**Fig.5.** Input (d1 and d2) and Output Pan-sharpened images (d3, d4, d5, d6) of Cartosat-3 data



**Fig.6.** Input (e1, e2) and Output Pan-sharpened images (e3, e4, e5, e6) of Cartosat-3 data

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# Challenges and Solutions for Large scale mapping of Mountainous and Forest covered areas of North Eastern India using High Resolution Drone Images

Stalin M

## Abstract

North Eastern India is an important sensitive region of India, both strategically, politically and economically. The region has international borders with four countries namely China, Myanmar, Bhutan and Bangladesh. Because of these strategic locations, the region deserves serious attention in the foreign policy decisions of India. India's North Eastern Region (NER) comprises of eight states, which constitutes 8% of the country's geographical area. The NER has immense natural resources, accounting for 34% of the country's water resources and almost 40% of the India's hydro power potential. The NER accounts for over 17 MHa, constituting one fourth of the forest area of the country. The main aim of this study is to identify the challenges and to offer solutions for mapping on large scale, using high resolution Drone imageries of UAV remote sensing platform mounted with Optical (RGB)sensor (GSD = 5cm). The optical RGB sensor is not feasible to capture data in dense canopy areas. Mapping of the NER is a challenging task due to the dense forest cover, irregular mountain slope, dense canopy of trees and varying types of weather. The terrain of NER has wide variations of slope, as the altitude varies from 0 to 6000 m above MSL. The entire NER can be divided into three geographical divisions viz Mountains and Hills, Valley and Plateau. To overcome the above challenges, various alternate solutions were proposed to resolve the issues in large scale mapping accordingly.

**Keywords:** UAV Technology, Drone Mapping, Optical Sensor (RGB), Topography, LSM, RS & GIS

## Introduction

North Eastern Region (NER) of India comprising of eight states considered to be most unique and one of the most challenging regions to govern due to its unique physiographic condition, rich biodiversity, disaster prone and diverse socio-economic characteristics. It comprises 7.98% of the total geographical area of the country and has 3.78% of its total population, with the population density varying from 17 per square km in Arunachal Pradesh to 398 per sq km in Assam. It has long international borders with Nepal, Bhutan, China, Myanmar, and Bangladesh. The NER is one of the less developed regions of the country. It faces many challenges; the important ones being poor infrastructure, particularly in the area of connectivity; remoteness; hilly and difficult terrain; high operational costs; lack of employment opportunities; subsistence farming; resource constraints, etc. On many critical parameters in the fields of health, education, infrastructure, etc, the states in the North East are below the national average. Not only is the North East less developed as compared to other states and union territories, but there are also wide interstate and intra-state disparities in terms of the level of development. However, the NER has immense potential for development.

The remote sensing technology has been playing an important role in providing detailed information of the land features in a spatial format and in determining, enhancing and monitoring the natural resources of the region. Databases generated using satellite remote sensing techniques over land, atmosphere, and during natural and human-induced hazards have become crucial for management of natural resources, reducing disaster losses, and

achieving sustainable development in the region. In short, the advancements in spectral imaging, aviation, and space technology-fuelled exponential growth in remote sensing technology. Remote sensing evolved from using pigeons, kites, blimps to aircraft, helicopters, satellites, and UAVs as a platform for earth observations. A wide range of optical /microwave remote sensing sensors are available, which are capable of imaging earth surfaces with a spatial resolution ranging from a few kilometres to centimetres in multispectral bands. Due to the availability of many options chosen, it is always good to narrow down the suitable techniques based on the objective of the project.

UAVs (Unmanned Aerial Vehicles), also called as drones are nowadays commonly used as platforms for acquiring aerial imagery due to cost efficient over small areas and more flexible for deployment which otherwise alternative to the conventional manned aerial Photogrammetry. The Application of UAV and benefits for promoting space technology tools for governance and various developmental activities and it has taken up a leading role in the initiate use of Unmanned Aerial Vehicle for large number of applications such as natural resources management, project monitoring, infrastructure development, research and development, disaster response and rescue, etc. and also they said that the Capacity building, training and outreach are important activities taken up by NESAC for promoting use of UAV remote sensing at central /state /academic/ research institutions and individual level (P.L.N. Raju, 2014).

## **Aim and Objectives**

The primary objective of this study is to carry out the Large Scale Mapping (LSM) of NES in India. Due to this reason, that LSM involves extracting very fine details with greater accuracy, the images produced by the remote sensing sensor or platform used should be capable of showing minute details that exist on the ground i.e., the spatial resolution should be higher.

The spatial resolution mainly depends on

(i) the altitude of the remote sensing platform and (ii) optics used in the sensor for optical remote sensing, or wavelength and length of the antenna in the case of RADAR. Among the remote sensing platforms discussed above, UAV remote sensing can produce very high-resolution images/datasets rapidly in comparison to other platforms.

The main objectives of this study is to investigate the suitability of a UAV remote sensing platform mounted with Optical (RGB) sensors for LSM (GSD=5cm) which is shown in figure 1 of NES in India and to study the issues and imitations of using UAV mounted Optical for LSM (GSD=5cm).



**Fig.1 Drone Q6 with optical RGB camera**



### Study Area

The North East Region (NER) of India lies between 20° – 29°N latitude and 88°– 98°E longitude and the region consists of Arunachal Pradesh (AP), Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura and Sikkim covering 255.08 million hectares, which is 8% of country's land mass. Dilkhan has been taken as a study area for testing purpose (Figure 2). Dilkhan is a medium size Village in Thingsulthliah Block in Aizawl District of Mizoram State under North Eastern state region of India. It is located 29 km towards East from District headquarters Aizawl. 10 km from Thingsulthliah. Total population of Dilkhan Village is 225 and number of houses are 48. As per constitution of India and PanchyatiRaaj Act, Dilkhan village is administrated by Sarpanch (Head of Village) who is elected representative of village.

**Table1.**  
Specification of Drone and Sensors used

| Q6 Drone                                      |                                                                |
|-----------------------------------------------|----------------------------------------------------------------|
| Type                                          | Survey grade fixed wing                                        |
| Endurance                                     | 25–40 minutes @MSL                                             |
| Range                                         | Upto 2 to 4km Line of Sight                                    |
| Functional Temp Range                         | 12°C to +50°C                                                  |
| Max launch altitude                           | 3000m AMSL                                                     |
| Max operating altitude                        | 400 m AGL                                                      |
| Wind Resistance                               | 36km/h                                                         |
| GNSS grade                                    | PPK enabled with GNSS base station—including Quantum PPKi base |
| <b>Payload: Optical Camera with RGB bands</b> |                                                                |
| Thermal Payload (Black/White hot)             | 320 x 240 pixels                                               |
| HD Imaging Payload                            | 15+ MP (PPK Module Optional)                                   |
| Daylight Payload                              | 1280 x 720 pixels 10x Optical zoom                             |
| Thermal Payload                               | 640 x 480 pixels (Radiometric)                                 |



Methodology

UAV is used with the payload of OpticalRGB camera to survey the area covering Dilkhan village. The details of sensor specifications are listed in the Table 1. The data of optical acquired by changing payload. Q6 with optical RGB camera is shown in figure 1. The flow chart of methodology is shown in figure 3.

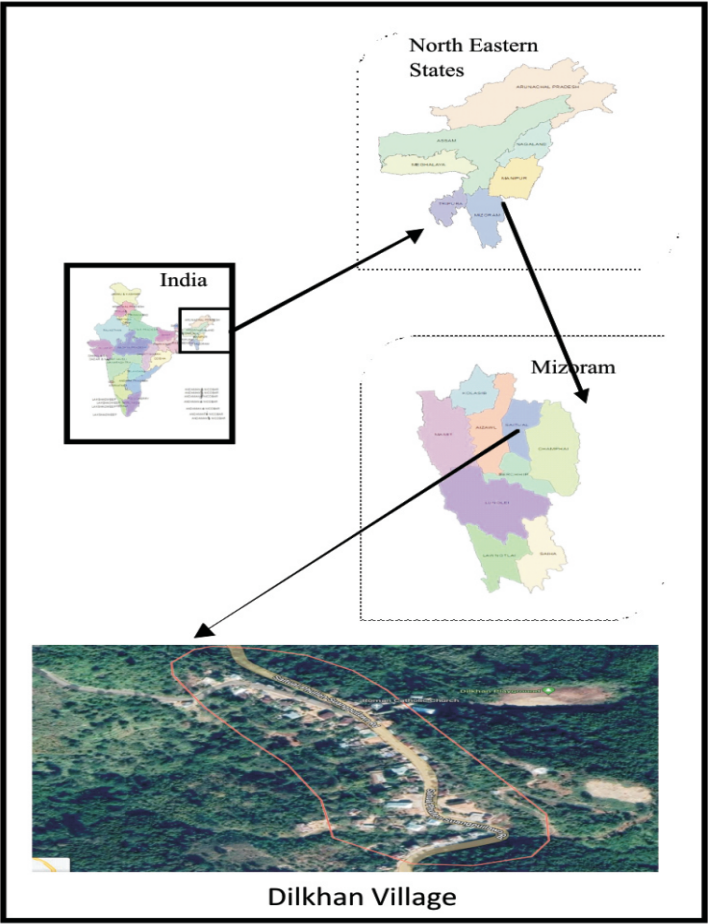


Fig 2.Study area map

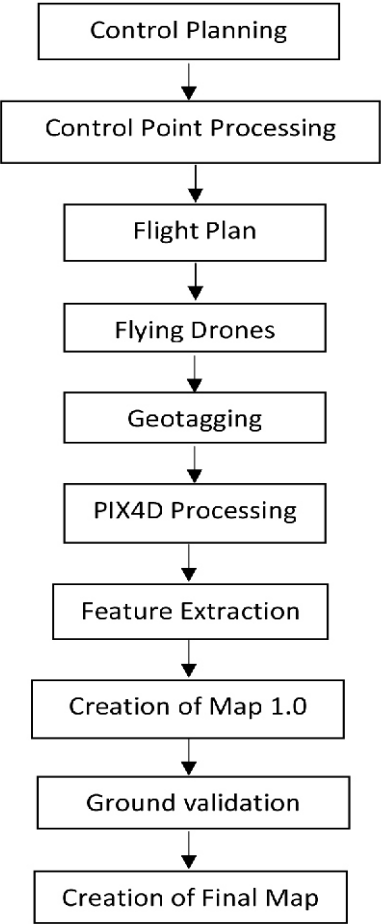


Fig.3 Flow chart of methodology

Control Planning

To produce an accurate map is to cover the whole area with a number of determined points which will form a framework on which to base the ensuing survey of the physical detail in the area. The basis of a survey consists of points fixed by one, or a combination of the following methods:-

- (1) By Global Positioning System (GPS)
- (2) Trilateration
- (3) Triangulation
- (4) Astronomical observations.
- (5) Traverse.

## **Control Point Processing**

For GPS Baselines Processing, the main control points having 24 hours GPS observation, data could be processed with scientific software i.e. BERNESE and Trimble Geomatics Office Software with precise ephemeris.

## **Flight Plan**

Flight planning should be done in the software suitable for the Drone and SOP should be followed strictly.

## **Drone Flying**

All the guidelines should be followed by the Pilot before flying the drone besides all clearance taken from AAI flight plan should be checked thoroughly. Take off and Landing Area should be ideal for drone flying and visibility should also be ensured.

## **Geotagging**

Geotagging allows to associate each photo to its own geographical coordinates (latitude, longitude and altitude) so as to organize and visualize them on maps. Q Base offers the possibility to geotag the pictures that were taken during the mission with geodata. This enables the user to post-process the pictures with the help of a photogrammetry software.

## **PIX4D Processing**

This method is used when the image geolocation and the GCPs are in a known coordinate system that can be selected from Pix4Dmapper's coordinate system database. The two systems do not need to be the same as Pix4Dmapper is able to do the conversion between two known coordinate systems. This is the MOST COMMON CASE and makes it possible to mark the GCPs on the images with little manual intervention. However, this method is not suited for "overnight" processing during which the different processing steps start automatically in a row and do not require any supervision by the user.

## **Feature Extraction**

Extraction of 2D topographical features from Ortho-rectified images (ORI). Feature Extraction was done by using hardware and software (ArcGIS). Features like Road (Gram Panchayat Road, Metalled Road, Unmetalled Road etc.), Parcel Area marked by "Chuna", Built up Space etc. are given primary importance during feature extraction. Feature extraction was done as per norms and specification. After completion of feature extraction primary QA / QC (Topology clean up) was carried out.

## **Creation of Map 1.0**

A map layout was created using the .pdf file of the digitized data keeping the ORI in background on scale 1:500 of the villages with the suitable legend.

## **Ground validation**

Generated MAP 1.0 was taken as per records for ground-truthing and validation of Land Parcel maps and layers pertaining to feature list. After validating MAP 1.0, it will be sent back with attribute data for GIS creation.

## Creation of Final Map

MAP 1.0 was scanned and georeferenced then corrections were carried out. Land Parcel Maps/ Boundaries were corrected as per ground truthing. Attribute data were linked with Geo database of villages to incorporate all the attributes with the respective features. A digital spatial library was created of all the features with the respective information. QA/QC was carried out to prepare seamless data with the help of Topology rules Final Map was generated in .pdf format keeping the ORI in background on scale 1:500

## Results and discussions

Remote sensing, which uses the visible to Infrared portion of the EMR spectrum is known as optical remote sensing. The RADAR remote sensing uses a microwave portion in the EMR spectrum. It is capable of penetration through clouds and dense canopy of vegetation depending upon the wavelength used.

LiDAR remotesensing is a new addition to the remote sensing of earth observations. It uses laser light either visible or infrared radiation to capture the primary elevation information of terrain.

UAV mapping was carried out in the village Dilkhan. The RGB camera with optical sensors was mounted on the Q6 UAV and flown at a height of 400 m AGL flight altitude (Figure 4).



Fig.4 Show ingsignal and Cross flyover DilkhanVillage.

The mission was planned using the Q base software by keeping 80% forward overlap and 60% lateral overlap. The PPK mode(Post-Processed Kinematic), wherein raw GNSS data were recorded during the flight and subsequently used for post- processing with the precise coordinates received from GNSS relative to a static observation.

After processing the Drone imagery Ortho rectified image was generated for the Dilkhan village and depicted in Figure 5.

## Constraints of Remote Sensing in NER (Satellite and UAV Remote Sensing)

Mapping of the NER is a challenging task due to the dense forest cover, irregular mountain slope, dense canopy of trees, and varying types of weather. While the benefits outweigh the drawbacks, it is prudent to consider the limitations of satellite remote sensing before capitalizing on this technology in NER.

Hilly terrain, subsistence agriculture and fragmented land holdings are the common traits in the farming community of the region. As a whole, satellite remote sensing techniques can be a fairly expensive method of farm level analysis and monitoring. Moreover, the acquisition of cloud-free optical images is one of the biggest challenges for this region. Cloud shadow affects the accuracy of vegetation estimates.

In recent years, UAVs or drones have emerged as potential alternative to traditional space borne and airborne platforms. The UAVs are competing with satellites and aircrafts because of their lower initial investment, higher

flexibility of flying and diversified applications. The use of drones in NER has thereby cut much leg work that ground surveyors must take up. With the developments of UAV technology and data analytics, it has been emphasized to refine the satellite- based estimates.



**Fig.5 Orthomosaic Map from Q6 Drone with optical sensor**

However, the usage of this technology has been hindered due to legal, safety and ethical concerns. Some technical difficulties include the requirement of more flights to cover large areas, large rotational and angular variations in the acquired imagery limits their usage. In addition, UAV platforms are heavily dependent on good weather conditions, as under rainy or windy weather conditions, it is not advisable to fly drones. Processing of the acquired imagery also demands a powerful setup as the volume of the acquired data can be very huge.

Space technology can be instrumental in getting fast and unbiased information about crop condition in a challenging area like the NER of India. As it provides a synoptic view, it can provide images of the whole region in a very short duration. The digital data can be harnessed for various programmes, which need information on crop type, acreage, condition assessment etc. Spatial information can also help in estimating the agricultural produces and thus contingency plans can be made for mitigating extreme weather and climatic conditions which are becoming very evident with time. The NER has specific requirements, which can be addressed by possible space technology interventions by taking the probable challenges into consideration. Though various studies on agriculture, horticulture, sericulture, land- use suitability, shifting cultivation, ground water, soil, plantation crops etc. of NER has been carried out with the aid of space technologies, the scope of further research is unlimited with the tremendous growth in geospatial technologies.

The unprecedented combination of temporal and spatial resolutions of high resolution satellite data will offer newer opportunities for innovative solutions to fulfil specific user needs in the agriculture and allied sector in NER.



The diversity and cost effectiveness of remote-sensing solutions to monitor agricultural systems are increasing worldwide and therefore individuals, institutions engaged in RS and GIS domain in NER should leverage these advanced technologies.

## Recommendations

This study evaluated the suitability of UAV-mounted Optical sensors for LSM (GSD=5cm) of NE of India. The results show that Orthomosaics found to be suitable for large-scale mapping of NES of India at a scale of 1:500 or better, covering abadi areas (both in the scenario under dense and sparse tree/vegetation canopy).

The selection of the technology i.e. LiDAR or Optical or LiDAR with Optical sensors using different platforms such as UAV, Aircraft, or Helicopter depends on the use case, environmental conditions, delivery terms, and budget, among other effecting factors of the project.

In order to obtain high-resolution images for LSM of the NER, which is mostly composed of mountains and forests, it is recommended to use a combination of Optical and LiDAR sensors technology as their combination can result in more accurate imagery with an improved feature identification for feature extraction.

For small areas like the abadi area, a UAV base platform equipped with optical and LiDAR sensors is recommended.

## Conclusion

For obtaining high-resolution imageries for carrying out LSM (GSD=5cm) of NER having mountainous and forest-covered areas, the combined use of Optical + LiDAR sensors will be suitable approach to generate accurate imagery with better feature identification and extraction.

However, due to slower coverage rate, resource-intensive operation, High Ground control net work handling and increased cost associated with it, handling of huge voluminous data, High data storage needs, requirement of high-capacity work stations, and non-availability of UAV which are capable of carrying both the payloads i.e. optical and LiDAR simultaneously. Also, the flight operation of UAVs in mountainous terrain will be challenging because of the lack of active terrain tracing capabilities of drones, the inconsistent height of trees prevalent in the NE region, and the low flying height of drones with LiDAR sensors. A combination of these reasons may lead to frequent accidents of the drone as well as in serious and financial challenges.

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# A Comparative study on Sentinel-1A SAR and Sentinel-2A Optical data for wetland mapping: A case study in G Plot and L Block of Sundarban, West Bengal, India

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Jatisankar Bandyopadhyay, Saroj Maity, Nirupam Acharyya

## Abstract

Wetlands are recognized for their valuable importance to the ecosystem and protect our coastline from natural calamities like floods, drought, cyclones, and so on. This comparative study was carried out to extract the wetland area using Sentinel-1A Synthetic Aperture Radar (SAR) data and Sentinel-2A multispectral data over G Plot and L block of Sundarban, India. The thresholding method was applied to VV polarization of SAR data and Normalized Difference Water Index (NDWI) in Sentinel-2A data. Land Use Land Cover (LULC) map and accuracy assessment were evaluated by Random Forest (RF) classifier algorithm for Sentinel-1A with an overall accuracy of 93.75% and a kappa coefficient of 0.85 and Spectral Angle Mapper (SAM) for Sentinel-2A data has obtained an overall accuracy of 81.03% and 0.68. These results indicate that the SAR-based classified map and wetland map are more precise and give a satisfactory results compared to multispectral data.

**Keywords:** Wetland, SAR, NDWI, LULC, SAM Classifiers, RF Classifiers, Overall accuracy

## Introduction

Wetlands are generally covered with water and flooded periodically. Water resources are crucial for aquatic life and it is therefore imperative to protect them (1). They play a key role in hydrological cycles and are especially responsible to the expected worldwide weather changes (2). Tropical and subtropical wetlands encompass each of the inland freshwater and coastal saltwater wetland kinds (3). For a complete understanding of wetland characteristics, which are made of shallow waters, moors, and dunes, dedicated models are required (4). The coastal depressional wetlands, which are no longer connected to the tidal regime, store the excess water in the wet season and release it to the groundwater and sea at some stage in the dry season (5). A huge variety of fluvial and tidal lands are included in the Sundarban landscape, which is primarily created by Ganga and also the Brahmaputra and Meghna Rivers (6). Due to natural disasters like floods, cyclones, shoreline changes, and many geomorphological changes, the Sundarban area is highly vulnerable to destruction (7).

The coastal aquaculture wetland has made notable contributions to enhancing food security but has additionally triggered a sequence of ecological and environmental issues (8). Environmental and climatic conditions in this region are most favourable for producing different agricultural and aquatic products (9). Estimation of water bodies' area and assessing the present scenarios of water resources and their availability is an urgent need for devising efficient water resource management strategies (10). Therefore, remote sensing becomes the best alternative for their identity in larger scenarios. Remote sensing has repetitive observation ability and large-scale spatial coverage, which is suitable for mapping the spatial distribution of wetlands at a large scale (11).

Wetland mapping studies have mostly depended on SAR sensors, and optical sensors are being applied regularly (12,13,14, 15). For regional wetland mapping, remotely sensed imagery from optical sensors such as Sentinel-2 (MSI), Landsat Thematic Mapper (TM)/ Landsat Enhanced Thematic Mapper (ETM+)/ Operational Land Imager (OLI), SPOT, QuickBird, and Ikonos has been widely used (11; 16; 17; 18; 19). SAR sensors, it has

given the capability to penetrate the cloud cover, darkness and plant canopy, in addition to their sensitivity to water content (20). Elnabwy et al. 2020 (21) have used the multi-temporal Sentinel-1A (SAR) data for coastal aquaculture mapping in Vietnam. This study suggests that the backscatter coefficients can appropriately map wetland areas together with aquaculture ponds on a large scale. SAR images can distinguish water bodies primarily based on the return strengths of radar waves because SAR backscatters from smooth water surfaces are very low or weak. Likewise, several studies have applied numerous SAR datasets for wetland mapping (3; 8; 17; 20; 21).

The Normalized Difference Water Index (NDWI), is the foremost elementary index developed by Mcfeeters S.K (22). The green and near-infrared (NIR) bands were utilized in Landsat Thematic Mapper (TM) images to maximize water feature identification (22). To extract the water features, the vegetation indices have also been used in various studies (23). The Normalized Difference Vegetation Index (NDVI) was proposed by Kriegler et al. and its use of near-infrared (NIR) and red band with the mathematical formula of NDVI is near-infrared minus red divided by near-infrared plus red (24). Several researchers applied the combined approach of different water indices such as NDWI, Modified Normalized Difference Water Index (MNDWI), Automated Water Extraction Index (AWEI), etc., and different vegetation indices similar to Enhanced Vegetation Index (EVI), NDVI has been used to extract the water features (19; 21; 23; 24; 25; 26).

For LULC mapping, the utility of machine-learning algorithms has been attracting significant attention on remotely-sensed imageries (27; 28). Machine-learning techniques have been classified into two sub-types: supervised and unsupervised techniques (29; 30). The supervised classification includes Support Vector Machine (SVM), Random Forest (RF), Spectral Angle Mapper (SAM), Fuzzy Adaptive Resonance Theory-Supervised Predictive Mapping (Fuzzy ARTMAP), Mahalanobis Distance (MD), Radial Basis Function (RBF), Decision Tree (DT), Multilayer Perception (MLP), maximum likelihood classifier (MLC), (31; 32; 33; 34; 35) while the unsupervised classification techniques include the Affinity Propagation (AP) cluster algorithm, K-means algorithm, fuzzy c-means algorithms, ISODATA (iterative self-organizing data), etc. (27; 36). Wetland mapping and LULC mapping were also carried out using SAM and RF classification algorithms. Many researchers applied SAM and RF classification algorithms to wetland extraction in coastal areas (37; 38; 39; 40; 41; 42; 43; 44). The results showed that the RF classification techniques accurately identified coastal wetlands.

This paper thoroughly compared the application of the Sentinel-1A image and Sentinel-2A image for coastal wetlands mapping in small areas of the Indian Sundarban. The overarching objectives of the study were wetland mapping using both Sentinel-1A and Sentinel-2A satellite data over the G Plot and L Block in Sundarban, West Bengal.

## Study area

Sundarban regions consist of the world's largest contiguous mangrove wetlands and the world's largest tiger reserve area. Geologically, the area comprises sub-recent and recent alluvium of the Ganga river system, which is mainly formed of a mixture of sand, silt and clay materials of varying proportions (45). The Sundarban, characterized by dense mangrove forest and a low-lying area that lies between 0.9 and 2.1 m above mean sea level (MSL), is intersected by a complex network of river channels, islands and mudflats (46). The tropical climate with the monsoon season extends from May to October (47). The present study was undertaken on the G Plot (latitude 21°36'10.33" to 21°45'17.02" N and longitude 88°22'03.41" to 88°25'48.42" E) and L Block (latitude 21°42'11.95" to 21°48'01.12" N and longitude 88°25'14.35" to 88°28'29.59" E) of the Pathar Pratima Block in the South 24 Parganas of West Bengal, India (Fig.1). Periodically, this area is hit by cyclones and floods, which cause considerable losses in both lives and property. Both the islands are located at the confluence of the Saptamukhi, Thakuran and the Bay of Bengal.



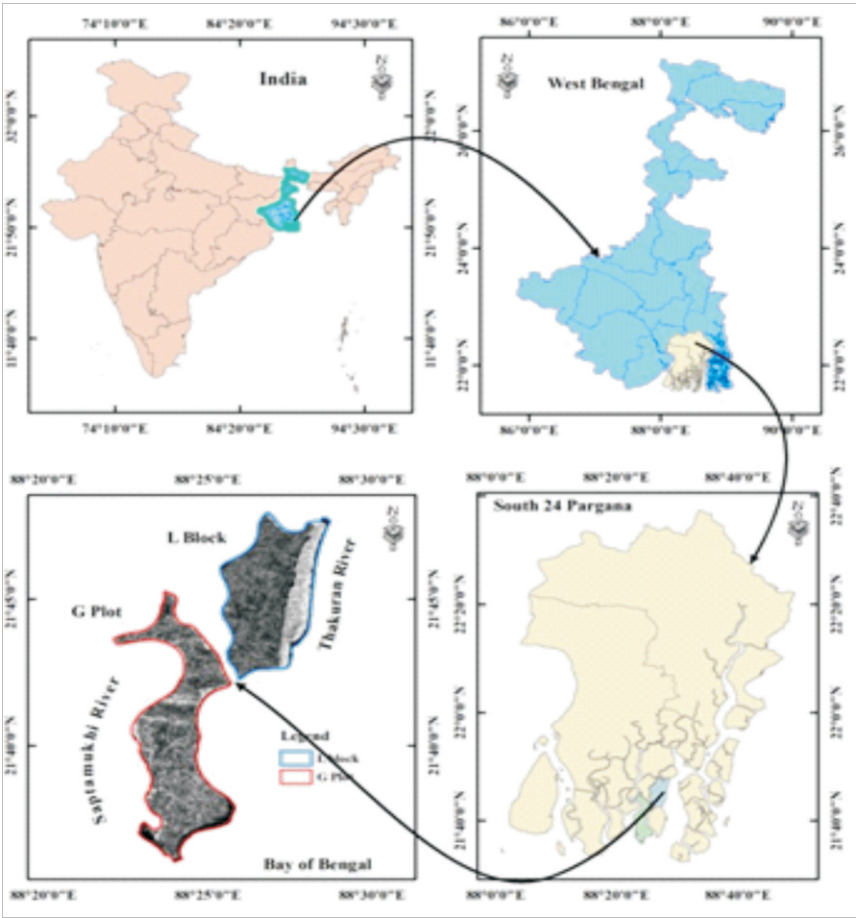


Fig.1. Location map of the study area.

### Materials and Method

**Satellite data and field-based data:** For this study, both satellite-based remote sensing data and field-based survey data were used for wetland mapping and extractions, wetland characteristics and characterizations, and also LULC mapping. In particular, the Sentinel-2A (MSI) and Sentinel-1A (SAR) satellite data have been acquired from <https://scihub.copernicus.eu/> and <https://search.asf.alaska.edu/>. This data is utilized and processed using ERDAS IMAGINE 2014 (Hexagon Geospatial), ENVI (L3Harris Geospatial), Arc GIS 10.4 (Environmental Systems Research Institute, known as ESRI) and SNAP (European Space Agency, known as ESA) software. The field-based study was conducted to collect the geographic location (latitude and longitude) of wetland areas and wetland types across the study area. Total numbers of 30 GPS locations of wetland areas were collected and details of geo-locations have been provided in (Fig. 2). These GPS points were used to create wetland types and for accuracy assessment of the classified LULC maps, obtained from the Sentinel-2A and Sentinel-1A satellite data

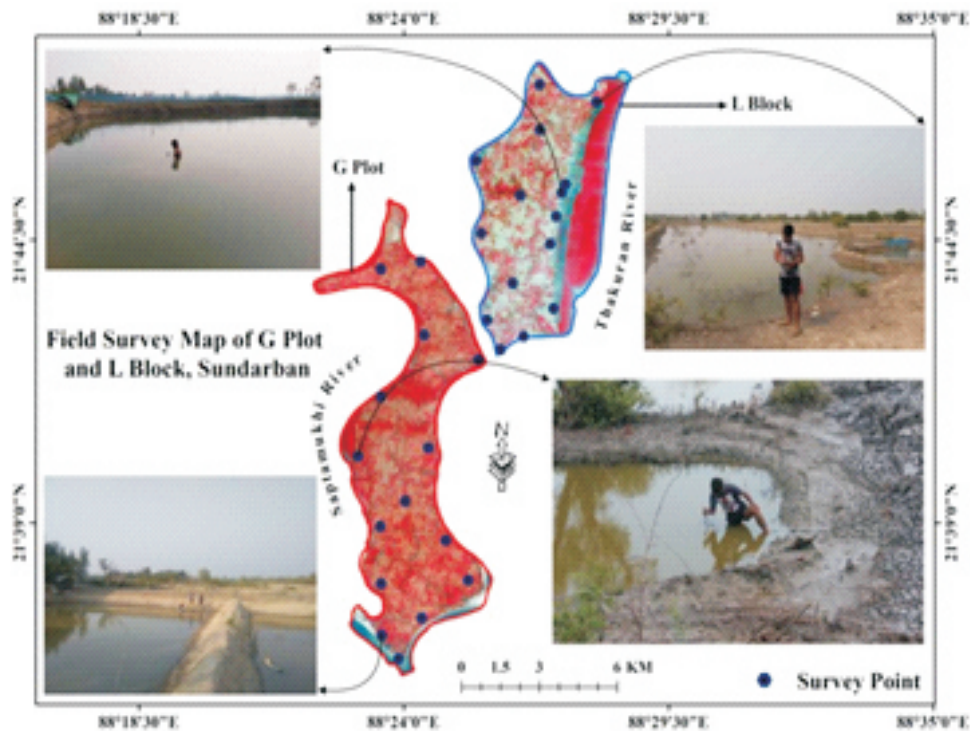


Fig.2 Field survey map of the study area.

Pre-processing of Sentinel-2A (MSI) data

The Sentinel-2A (MSI) has data having 13 spectral bands in the visible (VIS), red edge, NIR, and SWIR portion. The 13 bands are represented in an overview in Table 1. In this study, pre-processing of the Sentinel-2A spectral data included eliminating B1, B5, B6, B7, B8A, B9, B10, B11 and B12 since these were not relevant for this work and layer stacking of the bands to 10 m and used for the wetland mapping and analysis. The atmospheric correction had performed to the 2A level using the Sen2Cor algorithm in the SNAP toolbox to remove atmospheric effects and to convert pixel values for surface reflectance. Band 2, 3, 4 and 8 were chosen to create the NDVI and NDWI map.

**Calculating NDVI:** In remote sensing, NDVI is the most extensively applied vegetation index for studying vegetation cover and is also used for waterbody identification. The light reflected from vegetation in the near-infrared and the red band is used by NDVI. The results from NDVI values vary between (-1) to plus one (+1). NDVI is calculated by using this formula:

**Calculating NDWI:** NDWI was utilized to explain water bodies based on the reflectance bands. Green band and NIR band of Sentinel-2A with a 10 meter resolution each were applied to analyse the waterbody or wetland area of this study area. The resulting NDWI value ranges between minus one (- 1) to plus one (+1).

NDWI was calculated by using the formula:

### ***Pre-processing of Sentinel-1A (SAR) data***

In the Sentinel-1A SAR data processing, a Level-1 GRD product was applied to remove the noise and other uncertainties such as orbital errors and geometric distortion to improve the SAR data quality(48). In this present study, pre-processing of the Sentinel-1A image was done by using the open- source SNAP Toolbox developed by ESA. The processing step such as thermal noise removal, speckle filtering(Lee sigma filtering), radiometric calibration, and terrain correction were accomplished for VV and VH polarization image using the SNAP software developed by European Space Agency (ESA) (49; 50).At first, Thermal noise corrections have been carried out to Sentinel- 1A (Level-1) GRDH data. We used thermal noise removal operator to remove the thermal noises of SAR data. In SAR satellite data; there have a few inherent salt and pepper-like textures in the image that is usually known as speckles. For speckle removes, we carried out the speckle filtering with a Median filter and window size of  $5 \times 5$  pixels was utilized and with Refined Lee filtering in the SNAP toolbox(51; 52).

Afterward, the radiometric calibration was applied to convert the digital pixel values to radiometrically calibrated backscatter values from the target. Laur et al, Bioresita et al and Schmitt were used sigma nought images for surface water mapping, (53; 54; 55) In this study, we selected sigma-nought image because the sigma-nought image provides better separation between water and land surfaces (Fig. 4a and 4b). Then, the sigma nought images were converted into decibel (dB) images (Fig. 5a and 5b).To remove geometric distortions and consequently geo-location errors, it is necessary to perform terrain correction using the Range-Doppler terrain correction tool in SNAP software. For appropriate geo-location information, the 1 arc second, 30 m shuttle radar topographic mission (SRTM) data is resampled into 10 m and provided to Range Doppler terrain correction.

**RF classification:** The Random Forest (RF) or Random decision forests classification is a new non-parametric supervised ensemble machine- learning algorithm developed by Breiman (56). It can operate various datasets, like satellite imageries, and numerical data (57). This classification is an ensemble learning method based on a decision tree, which combines massive ensemble regression and classification trees (58). Breiman (56) stated that a new and promising group of classifiers does perform better classifications than an individual classifier. So the classifier is named RF, which has many advantages for its application using remote sensing satellite data. The significance of RF classifier includes non-parametric nature and high classification accuracy (56). In SNAP tool, Random Forest classifier had number of training samples (5000), number of trees (10) and evaluate feature power set that consist of minimum power set size (2) and maximum power set size (7). In this study, the RF classification technique was used using the SNAP software that takes the signature of specific features as training samples and runs the iteration till it attained the optimum accuracy level (48). The accuracy assessment is important to validate the result of classified satellite imagery. In this study, RF classifier has been employed to prepare the LULC mapping with accuracy assessment and wetland mapping

**SAM Classification:** Spectral Angle Mapper (SAM) is an auto-generated supervised spectral classifier machine learning technique that is relatively insensitive to illumination and albedo effects when used on calibrated reflectance data (58). End member spectra, which are usually utilized by SAM, can come from ASCII files or spectral libraries, and also be extracted directly from an image (as ROI average spectra) (59). Reference spectra can be taken either through field visits or directly from satellite imagery. For the LULC classification, reference spectra are often taken as a signature from the satellite imagery (60). In the present study, SAM has been applied using the ENVI 5.2 image processing environment for the LULC classification and also the most important wetland mapping. The detailed flowchart of the methodology for wetland mapping of the study area is given in Fig.3.



Fig.3 Detailed methodological flowchart for wetland mapping



**Accuracy Assessment:**Accuracy is generally used to state the degree of "correctness" of a classification result (61). It is carried out once the interpretation and classification have been completed. Between the correspondence of class labels and the 'true' class, accuracy is concerned. A 'true' class is defined during field surveys as what is observed on the ground. Here, we have applied the process to assess the accuracy of LULC maps derived from Sentinel-1 A and Sentinel-2A images.

**Kappa coefficient :** The Kappa coefficient is not only a diagonal element but one of the elements in the confusion matrix (62). According to Altman, Kappa value is the most important for accuracy assessment (63). The values of kappa are not only the calculating factor of a single classifier but also the evaluation classifiers (Table 1).

Table -1 Scale of kappa co-efficient.

| Sl. no. | Value of K | Strength of agreement |
|---------|------------|-----------------------|
| 1       | <0.20      | Poor                  |
| 2       | 0.21-0.40  | Fair                  |
| 3       | 0.41-0.60  | Moderate              |
| 4       | 0.61-0.80  | Good                  |
| 5       | 0.81-1.00  | Very Good             |

The kappa Co-efficient is expressed as (Cohen 1968):

$$K = \frac{(\text{Observed accuracy}-\text{Chance accuracy})}{(1 - \text{Chance accuracy})}$$

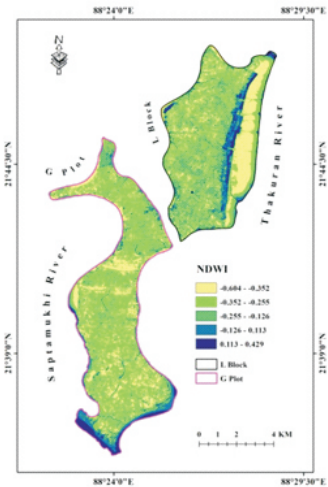
Where, K means Kappa value.

## Results and Discussion

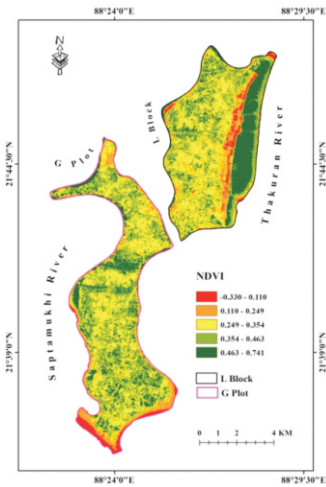
**Wetland Extraction using Sentinel-2A and Sentientl-1A data:** The NDWI images have been generated for the G plot and L Block wetlands for 2020. The index values of NDWI ranges from - 0.604 to + 0.429 of the study area. The highest value consists of wetlands; most of the wetlands are aquaculture ponds, tidal creeks, and fresh inland ponds. The lowest value corresponds with the vegetation, agricultural land, marshy land, and other non-waterbody show negative values. In this study area, the NDVI had higher values because of high vegetation cover such as mangrove cover. However, most of the places of central point of the area had lower NDVI values because the area lack of vegetation cover and radiation-exposed agricultural land with bare surface dominate the area. The index value of NDVI in the study area is ranges between – 0.330 to + 0.741. The area computed for wetland through NDWI is found to be higher than that derived from NDVI. Wetland covered under weeds and marshy land also showed positive value in NDWI. The NDWI and NDVI values for G Plot and L Block wetland range from - 0.604 to + 0.429 and - 0.382 to + 0.741, respectively, and in both the indices the results for waterbody and non-waterbody are similar and NDWI gives better results than NDVI. The output of wetland extraction from NDWI for the study area's wetlands is presented in Fig. 4. The estimated area of NDWI was 220.88 hectares for G Plot and 140.29 hectares in the L block (Table 2). The NDWI and NDVI image both, of the study area's wetlands, clearly show open water features as the result of enhancement (Fig. 4 and 5). Nevertheless, the NDWI produced a better result as compared to NDVI.

**Table.2**  
**Distribution of extracted wetland area based on Sentinel-2A and Sentinel-1A data of the study area.**

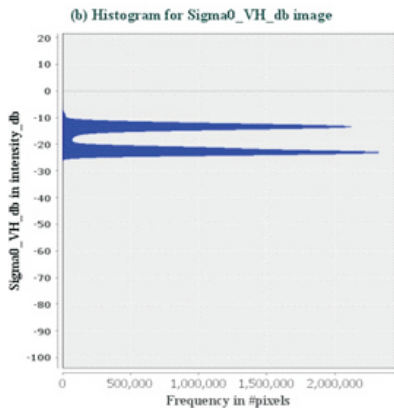
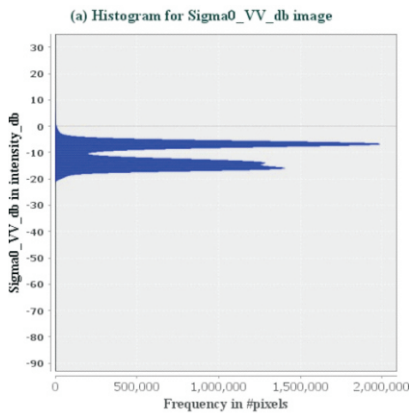
| Place   | wetland area<br>(in hectare)<br>Sentinel-2A | wetland area (in<br>hectare)<br>Sentinel-1A |
|---------|---------------------------------------------|---------------------------------------------|
| G Plot  | 220.88                                      | 428.63                                      |
| L Block | 140.29                                      | 263.82                                      |



**Fig.4** Extracted wetland map using Sentinel-2A through NDWI



**Fig.5** Extracted wetland map using Sentinel-2A through NDVI



**Fig.6** The histogram of backscatter value (a) Sigma naught VV dB images (b) Sigma naught VH dB images.

**Table. 3**  
The areal distribution of LULC map based on Sentinel-1A and Sentinel-2A of G Plot, Sundarban

| LULC<br>Classes              | G Plot         |             |                |             |
|------------------------------|----------------|-------------|----------------|-------------|
|                              | S- 2A          |             | S-1A           |             |
|                              | Area<br>(Hec.) | Area<br>(%) | Area<br>(Hec.) | Area<br>(%) |
| Forest/Natural<br>Vegetation | 853.19         | 19.33       | 1211.93        | 27.46       |
| Waterbody/<br>Wetland        | 323.5          | 7.33        | 481.98         | 10.92       |
| Others                       | 3236.66        | 73.34       | 2719.87        | 61.62       |
| Total                        | 4413.35        | 100         | 4413.78        | 100         |

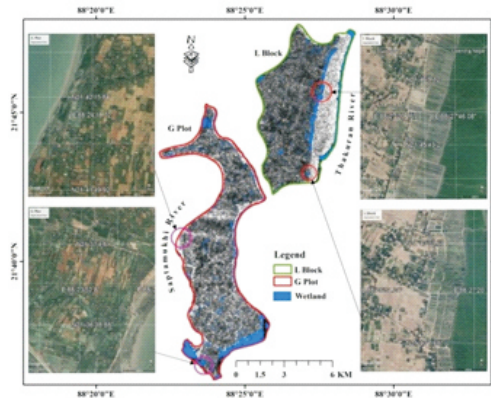


Fig.7. Showing wetland map using Sentinel-1A data over the study area.

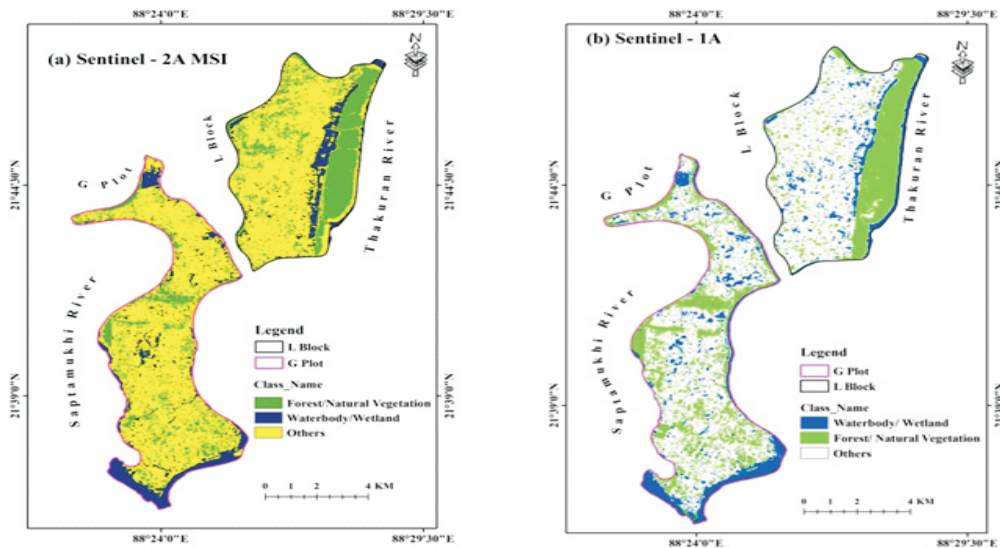


Fig. 8 Land use land cover maps (a) Sentinel-2A based on SAM classifier  
(b) Sentinel-1A based on RF classifier over the study area.

### Comparative analysis of LULC map based on Sentinel-2A and Sentinel-1A data

The LULC maps of the year 2020 have been generated using SAR (Sentinel-1A) satellite data based on the RF classification. The predominant LULC classes of the study area were forest/natural vegetation, waterbody/wetland and others. Due to the similarities of the spectral signature of classes, such as settlement, barren land, sandy soil, and agricultural land, all these classes have been merged into the "Others" class. On the other hand, the LULC maps, which have been processed using MTSolIta(lSentinel-2A)44sa1t3e.l3li5te da1ta00of th4e41y3e.a7r820210,00 are based on the SAM classification. Both LULC maps of this study area were shown in Fig. 10a and Fig. 10b, respectively. The LULC maps showing that, most of the areas were covered by forests/natural vegetation and Others Classes. Most of the wetland/water bodies were present in the eastern part of the L block. In case of G Plot, the wetland/water bodies such as aquaculture ponds were situated in all the parts of the area. The Saptamukhi and Thakuranmainly two rivers areflowing in this study area. These rivers are playing a major role in inland wetland activities.

The detailed area-wise distribution of LULC classes is shown in Table 3. In G Plot, Sentinel 2A MSI-based LULC map showing that the area of forest/natural vegetation is 853.19 hectares (19.33%) and on the other hand in case of Sentinel-1A SAR LULC map, the forest/natural vegetation is 1211.93 hectares (27.46 %) of the total area. In both MSI and SAR-based LULC maps, represented that the area of forest/natural vegetation are 1150.97 and 1224.52 hectares (30.69% and 32.65%), respectively in L Block (Table 4). This class mostly comprised in L Block throughout the western portion of this area. Both of the areas, this class have dominantly covered with mangrove forest, mangrove scrub, shrubs, brackish water mixed forest and also natural vegetation.

**Table. 4**

The areal distribution of LULC map based on Sentinel-1A (S-1A) and Sentinel-2A (S-2A) of L Block, Sundarban. data (Sentinel-2A), whereas 481.98 hectares (10.92%) was based on SAR data (Sentinel-1A).

| LULC<br>Classes              | L Block       |             |               |             |
|------------------------------|---------------|-------------|---------------|-------------|
|                              | S-2A          |             | S-1A          |             |
|                              | Area<br>(Hec) | Area<br>(%) | Area<br>(Hec) | Area<br>(%) |
| Forest/Natural<br>Vegetation | 1150.97       | 30.69       | 1224.52       | 32.65       |
| Waterbody/<br>Wetland        | 295.92        | 7.89        | 335.69        | 8.95        |
| Others                       | 2303.1        | 61.42       | 2190.04       | 58.40       |
| Total                        | 3749.99       | 100         | 3750.25       | 100         |

In G Plot, the classified LULC map derived from Sentinel-2A and Sentinel-1A shows that the area of water body/wetland are 323.5 hectares and 481.98 hectares (7.33% and 10.92%), respectively (Table 3). Areal distribution of waterbody/wetland was classified as 295.92 hectares and 335.69 hectares area (7.89% and 8.95%) of the total area of L Block. Here, the class others have been classified as 3236.66 hectares and 2719.87 hectares area (73.34% – 61.62%) based on Sentinel-2A and 1A in G Plot, respectively. On the other hand, the class others were classified as 2303.1 hectares and 2190.04 hectares area (61.42% - 58.40%) in L Block (Table 4), respectively. These differences in area-wise proportion are because of the response of spectral characteristics of optical and SAR datasets (Fig. 9). The spatial distribution of "others" class in optical data has been observed along the whole area and dominantly located in



the north-east to the south-east portion of the L Block and also the middle portion of G Plot. These portions typically consist of agricultural land, settlement with home orchards, beach area, bare soil, sands, and mudflats. Comparatively, the Sentinel-1A (SAR) data represented as "others" class across the whole part of both study areas. Moreover, the Sentinel-2A (optical) showed that the "others" class was dominantly distributed in the northeast to the southeast portion of the L Block and also the middle portion of the G Plot. It was noticed that the "others" class has been reasonably more distributed in Sentinel-2A (MSI) as compared to Sentinel-1A (SAR). These results suggest that optical MSI (Sentinel-2A) data is more appropriate to classify the bare land/sandy soil/settlement/mining area using SAM classification than the SAR-based RF classification. From these classified LULC maps based on SAM classifier and RF classifier, the waterbody/wetland maps were extracted using both MSI and SAR data. The comparative spatial distribution of waterbody/wetland maps has shown in Fig. 10. The results show that the waterbody/wetland area was 325.5 hectares (7.33%) in G Plot based on optical

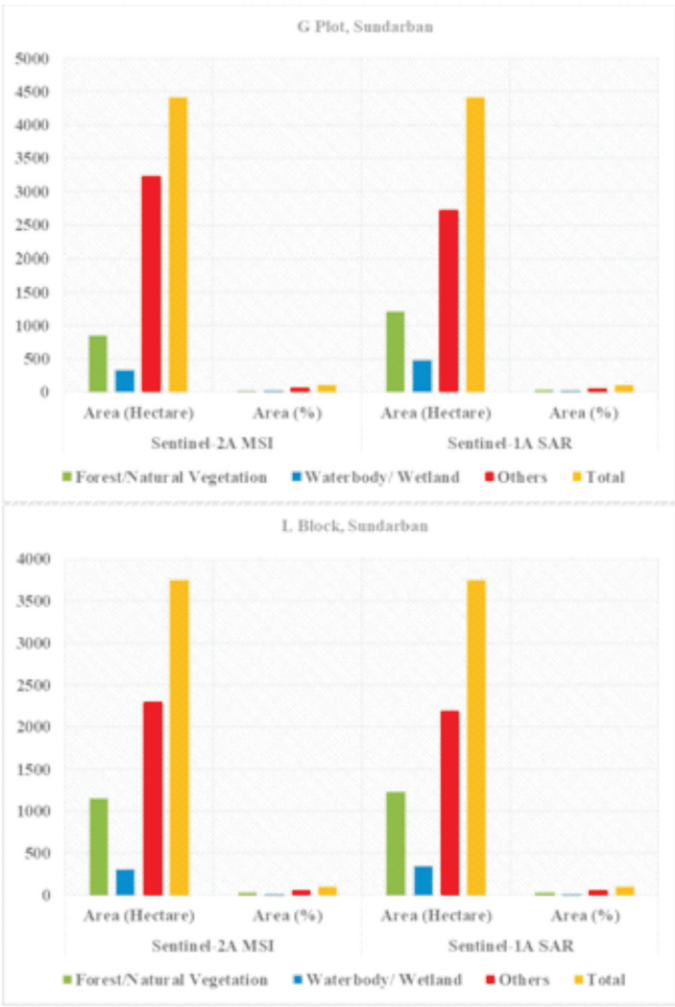


Fig.9 Spatial distribution of LULC classes based on Sentinel-1A and Sentinel-2A of G Plot and L Block

On the other hand, the waterbody/wetland area was 295.92 hectares (7.89 %) in L Block based on optical data, whereas 335.69 hectares (8.95%) was based on SAR data. In the waterbody/wetland maps, some uncertainties have been identified in waterbody/wetland map because of the spectral similarity of a tidal creek, tidal flat, aquaculture, saltpans, etc. Due to the cloud coverage in optical satellite imagery during the rainy season, we had used only one optical data (Sentinel-2A) image(29th Feb 2020). Contrastingly, Sentinel- 1A data were more effective to delineate the waterbody/wetland map along the study area of Sundarban. During field visits, numerous aquaculture plots, tidal creek, tidal flat and mangrove swamp, etc. have been observed throughout the region and represented in Fig. 11. Comparatively, in case of both wetland maps, it has been experienced that SAR (Sentinel-1A) data has more remarkable capability to extract the waterbody/wetland as compared to optical(Sentinel-2A) data.

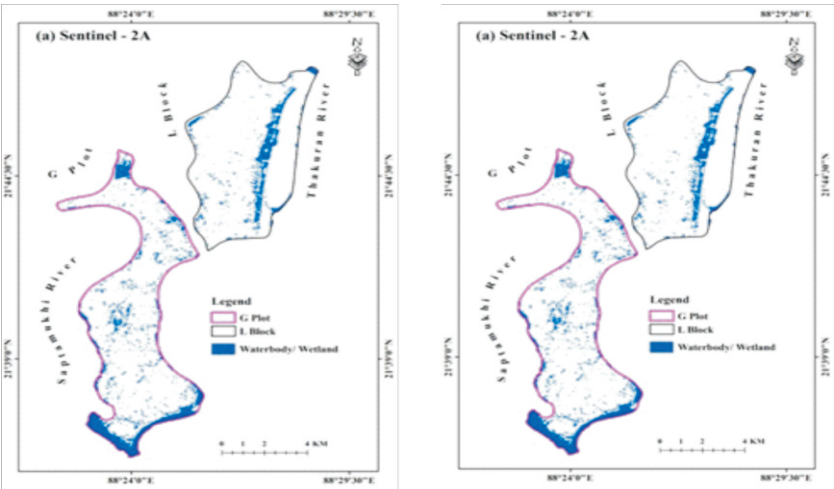


Fig.10 The comparative wetland maps (a) Sentinel- 2A based (b) Sentinel-1A based over the study area.

Table.5

Confusion matrix of the classified LULC map using SAM and RF classifier, derived from Sentinel-2A and Sentinel-1A

| LULC Classes              | Producer's Accuracy (%) |       | User's Accuracy (%) |       | Overall Accuracy (%) |       | Kappa co-efficient |      |
|---------------------------|-------------------------|-------|---------------------|-------|----------------------|-------|--------------------|------|
|                           | S-2A                    | S-1A  | S-2A                | S-1A  | S-2A                 | S-1A  | S-2A               | S-1A |
| Forest/Natural Vegetation | 79.17                   | 88.89 | 82.61               | 88.89 | 81.03                | 93.75 | 0.68               | 0.85 |
| Waterbody/ Wetland        | 71.43                   | 75    | 100                 | 100   |                      |       |                    |      |
| Others                    | 85.19                   | 97.14 | 76.67               | 94.44 |                      |       |                    |      |

The confusion matrix was prepared with the help of GPS-based aquaculture plots as well as random sample points. For the accuracy assessment of classified images, these samples were used in the post-classification technique. The overall accuracy of all LULC classes derived from Sentinel-1A and Sentinel-2A were calculated as 81.03 and 93.75%, wherein the kappa coefficients were calculated as 0.68 and 0.85, respectively (Table 5). The individual class error components, such as user's and producer's

accuracy were provided in Table 8. In the kappa coefficient, both imageries delivered a notable accuracy of LULC classes. However, we inferred that the optical (Sentinel-2A) data was more suitable to depict the "Forest/Naturalsoil/settlement/mining area" classes. Overall, it has been perceived that the optical (Sentinel-2A) data is more appropriate for LULC classification using SAM classifier, but SAR (Sentinel-1A) data were derived very good results for waterbody/wetland mapping using RF classifier.



Fig.11 Some photos of field survey, (a) Aquaculture pond; (b) Tidal flat; (c) Sweet water pond; (d) Mangroves; (e) Active tidal creek; (f) Soil sample collection from aquaculture pond.

**Discussion**

The present study intended to the mapping of coastal wetlands over the G plot and L block of Sundarban, West Bengal, India. These areas were covered with mangroves, aquaculture, inland water bodies, agricultural land, and settlement with home orchards, tidal creek, tidal flat, and other LULC classes. The adopted methodology was quite apprehensive and provided a clear insight into the wetland mapping. The present study identified the potential of SAR data in addition to optical data to improve our understanding of wetland mapping.

Notably, various studies have utilized both high- resolution SAR and optical data for qualitative and quantitative assessment of wetland extraction, LULC classification, and wetland mapping. However, these data have some limitations such as optical sensors cannot capture the satellite images that were typically contaminated by cloud cover. For this reason, wetland extraction, LULC classification, and wetland mapping need the integration of SAR data in conjunction with optical data. Following the described methodology, we have been able to detect water bodies or wetland areas using Sentinel-2A data. The results of this study indicated the potential of the NDWI

index calculated from Sentinel-2A images (bands 3 and 8) to extract open water bodies in delimited wetlands. It is essential to highlight the NDWI index which is not capable to identify the water bodies underlying the swamp vegetation area of this region. On the other hand, the potential of microwave sensors can discriminate the land and water surface in all seasons without cloud coverage or any other weather condition. In the case of SAR data, we have used the VV polarization image. This image has given a better result to extract the wetland area using the band math thresholding method. It is noted that this study was conducted to examine the LULC mapping and wetland mapping using the SAR and optical data. The result shows that the SAR-based RF classifier was given better results for wetland classification as compared to the optical-based SAM classifier. For SAR, the kappa coefficient is relatively higher than the optical data as is revealed by the accuracy assessment. The Kappa Coefficient for Sentinel-1A and Sentinel-2A are 0.85 and 0.68, respectively, indicating that the Sentinel-1A image is classified more accurately. Our key findings revealed that the result for wetland mapping shows the superiority of combining Sentinel-1A and -2A data over the study area. Also, it is found that the use of Sentinel-2A data is not enough for accurate wetland delineations, wetland mapping, and classifications.

## Conclusion

This study presented the use of multi-temporal C band Sentinel-1A and 2A data for comprehensive wetland mapping. It is observed that the band math thresholding methods using SAR data perform better in most of the cases in this study area while NDWI and NDVI indices using optical data give good results in wetland extraction. The area-wise distribution and accuracy assessment of wetland and LULC classified maps exhibited that the SAR-based classified map is more reliable than the optical data. The comparative study of Sentinel-1A and Sentinel-2A for LULC mapping in the study area is also analyzed. The final results revealed that the classification accuracies of SAR data are more precise for wetland mapping compared to the optical datasets. The comparative study of the RF classifier has the more effective potentiality to extract the detailed wetland from the SAR-based satellite data in comparison to the SAM classifier of optical data. Overall, this study has concluded and demonstrated that remote sensing satellite data can be successfully preferred for wetland mapping instead of the traditional survey-based method, and also this study successfully provides detailed information about the wetlands including wetland extraction, wetland types, and surface water dynamics which were applied over the study area.

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A Comparative study on Sentinel-1A SAR and Sentinel-2A Optical data for wetland mapping : A case study in G Plot and L Block of Sundarban, West Bengal, India

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## A Novel method for Image destripping based on Feature Classification Approach

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### Abstract

Remote Sensing images are widely used in Urban mapping, rural cadastral mapping, Farm level agricultural Management and Planning, Disaster management etc. Achieving a seamless and accurate radiometric quality in data processing of remote sensing images is still a challenging problem which includes further sub problems like non-uniformity of photon response, degraded detector, line loss, framing, noise, residual stripe, banding etc. If one detector of an array has a slightly modified or unbalanced responsivity from that of its neighbors or from its normal conditions, it results in a residual stripe. Residual stripe has different overall brightness relative to that of their neighborhood pixels. The random unsystematic stripes affect both visual interpretation and radiometric integrity of remotely sensed data. Residual stripes hide the true radiation information and decrease the accuracy in the remote sensing images. Apart from striping, banding is another problem that occur due to different charge coupled device array, bright target saturation, scan-angle effects and systematic droop. Striping and banding limit the interpretation of the remote sensing images. Despite there are different existing statistical approaches like offset method, slope method, Mean variance method, common histogram method available in literature. Non linearity response of charged coupled device limit existing statistical approaches to remove all stripes and banding mostly in areas of bright and lower intensity levels like clouds and water. In this paper we are proposing a new novel method which works with challenging situations like presence of cloud and water in the remote sensing images. We have proposed a novel method to remove banding based on z-score classification method. In this method first we are classifying the image into three class and then applying different statistics to each class to remove stripes and banding more efficiently. In comparison it had been found out that this method gives good results than existing methods and results are presented in the paper and achieved an accuracy of 0.1 % of Relative Radiometry Accuracy.

**Keywords:** Z-score, Destripping, Banding, Classification.

### Introduction

Stripes lead to significant radiometric uncertainties in reflectance and radiance data. Hence, without correction, stripes are creating problems in higher-level remote sensing applications such as the normalized difference vegetation index, land surface temperature, classification, target detection etc [1,2]. Remote sensing images contain stripes and banding which affect the quality of the image. Stripe occurs due to differential sensitivities of the detector elements to incoming radiation. The stripes affect the visual effect and quantitative interpretability. The stripes have different characteristics based on the scanning instrument. Push broom type imaging instruments are designed to acquire complete rows of images using a linear CCD array placed across track



[3]. Whiskbroom instrument obtain the image by scanning forward and backward across-track using all the detectors at a time [4]. If one detector of an array has a slightly modified or unbalanced responsivity form that of its neighbors or from its normal conditions resulting in a vertical column stripe and if unbalanced responsivity is in horizontal direction results in horizontal stripe. The nonlinear stripes are those whose degradation parameters change with the ground objects, and the irregular stripes are those in which only some of the pixels are contaminated. Periodic stripes are caused by poor radiometric calibration of the relative gain and offset of the individual's detectors of the acquisition system. The deviation between the input/output transfer function of neighboring elements of detector matrix remain constant with time. Periodic stripes originate in fine variation in the width of the slit. Random stripes are caused by thermal noise or random fluctuations in the sensor response. This type of disturbance results in bright and dark stripes with random length across the track. Due to stripes the result of various post processing operation will become vague for example if images contain stripe and classification operation is performed then one class related to stripe will occur. Stripe can be find out automatically by dark pixel (if certain threshold of dark pixel is present in column whose radiance value is less than the local neighborhood pixels), by computing mean and variance of the row and by greythreshold method. The correction of image stripes is commonly known as image destripping. Banding is undesired structure that appears within and between the focal plane array assemblies. There are different causes of banding. Scan Correlated Shift (SCS) causes banding by forcing each scan to randomly choose one of the two or more bias states. This banding has a stable magnitude across each scan. Banding is also caused by a large radiance transition in the scanning direction, from bright target to dark or from dark target to bright. Calibration Error Banding, also known as "True Banding" or "Sweep Striping," is caused by errors in calibration algorithms that treat forward and reverse scans separately, so that one direction of scan has a different bias than the other. These errors create a Banding artifact that is stable across the scan and consistently alternates between high and low bias.

In recent decades many destripping techniques had been proposed and divided into digital filtering-based methods, statistics-based methods and optimization-based methods. frequency domain or spatial domain algorithm. Filtering based methods removes the stripes of remote sensing image by designing filter on transformed domain, such as Fourier Transform [5] which used to process the image data with a low pass filter using discrete Fourier Transform, the advantage of this method is that it is useable on geo-rectified images, but it does not remove all stripes and lead to significant blurring within the image. Wavelet Analysis [6,7] remove stripes by taking advantage of the scaling and directional properties to detect and eliminate striping patterns. Filtering based methods assume that stripping is periodic in nature and can be observed in power spectrum of the image. But the filter used to eliminate stripes may affect the spatial details with the same frequencies as stripes related to useful signal may result in blurring or ringing artefacts of destripped images.

To remove the limitation of blurring or ringing artefact scholars had gradually turned to statistical methods which depends on the statistical characteristics of the digital number of each sensor [8]. These algorithms examine the distribution of digital numbers for each sensor and adjusts this distribution to some reference distribution). Statistical-based methods all have certain assumptions and are limited by image size, terrain distribution, and other conditions. Histogram matching [9] assumes that the histogram of each column in the image has the same distribution. Moment matching [10] assumes that the standard deviation and mean value of each column in the image are the same. If the image size is too small or the terrain difference is too large, these statistical-based methods cannot achieve satisfactory results. The destripping effect of statistical-based methods depends on the universality and rationality of their assumptions. Since the assumption of moment matching is more general, its processing effect will be better than histogram matching. Recently, some optimization-based destripping methods regard the stripe noise removal issue as an ill-posed inverse problem [11–14]. To find a better solution, prior knowledge of the ideal image is used to regularize the destripping problem. Introducing prior information, an

estimation of the desired image can be computed by minimizing an energy function under a constrain term. In [11], Shen and Zhang proposed a maximum a posterior framework based on Huber-Markov regularization for both destripping and inpainting problems. Considering stripe noise has a clear direction signature, Bouali and Ladjal [12] developed a sophisticated unidirectional total variation(TV) model for stripe noise removal in MODIS data. Later, many researchers have proposed some improved unidirectional TV models by using different regularization [13-18]. Chang et al. [13] considered a combined unidirectional TV and frame let regularization method for stripe noise removal as well as preserving more details. Zhang et al. [14] proposed a unidirectional TV-Stokes model, which avoids excessive over-smoothing by distinguishing stripe regions and stripe-free regions. In addition, for destripping of multispectral and hyperspectral images, researchers taken full advantage of the high spectral correlation between the images in different bands [18–20]. In [19], the authors proposed the graph-regularizer low-rank representation (LRR) for destripping of hyperspectral images.

Although the above mentioned methods have achieved satisfactory destripping results, they implement the destripping by directly estimating statistics of the desired images while ignoring the characteristics of stripe noise, which often causes damages to the image details along with the stripes. Relationship between DN and Radiance remain linear but due to high resolution of the image relationship between DN and radiance become non-linear as different range of gray values can have different offsets and slopes. In this paper to deal with nonlinear relationship and preserving the image details we have proposed z score classification method for removing stripping and bright target to dark overshoot banding. Section 2 presents various statistical destripping algorithms. Section 3 presents the proposed framework for elimination of destripping and banding. Section 4 presents the Experiment and results. Section 5 presents the conclusion.

## Statistical Destripping Algorithms

The review of different destripping algorithms are presented as

**Offset method-** Offset method depend on the calculation of the reference mean and column mean in image along the track. The main parameter is reference mean. Reference mean can be global mean (mean of the whole image), window mean (mean of local area, window of 100 or any other size), device mean (mean of the pixels of the device of the image, number of pixels in the device may vary on the sensor characteristics). This method is divided into two categories i.e. local or global. Local method performs better when whole feature is in along track direction. Global method performs better when feature is in across track direction. The calculation of offset and applicability of offset to image is shown in equation 1 & equation 2.  $O(y)$  represent the offset for column  $y$ ,  $M$  is reference mean,  $C(y)$  is the column mean,  $G(x, y)$  is the output image,  $F(x, y)$  is the input image.

$$O(y) = M - C(y) \quad (1)$$

$$G(x, y) = F(x, y) + O(y) \quad (2)$$

**Slope Method-** In this method, slope for each column is calculated by dividing the reference mean by the column mean. The reference mean can be global mean or local mean. Then each pixel is updated by multiplying the pixel with its respective column slope. Slope method gives good results than offset method. Equation 3 & 4 shows calculation of slope and calculation of output image from input image & slope.

$$S(y) = \frac{M}{C(y)} \quad (3)$$

$$G(x, y) = F(x, y) * S(y) \quad (4)$$

$S(y)$  represent the slope for column  $y$ ,  $M$  is reference mean,  $C(y)$  is the column mean,  $G(x, y)$  is the output image,  $F(x, y)$  is the input image.

**Mean and Variance Method-** This method uses first order statistics(mean) and second order statistics(variance) of each column of the image that is reference mean and reference variance. Based on the reference mean & variation, method can be global or local. Equation 5 explains Mean and Variance method.  $G(x,y)$  represent output image,  $F(x,y)$  represent input image,  $\mu_{reference}$  represent reference mean(global or local),  $\mu_y$  represent mean for column y,  $\sigma_{reference}$  represent reference variance (global or local),  $\sigma_y$  represent variance of column y.

**Histogram matching-** The assumption in this method is that sub scene detected by different detector for one band have same histogram. First a reference histogram is chosen and then all other histogram of other sub scene is matched to reference histogram. The matching procedure is implemented by means of cumulative distribution functions. There had been three methods for creating the reference histogram for an individual band. Firstly, creating the reference histogram by using the entire image for a band. Second way is to create the reference histogram by using those sub scenes which have similar histogram. This is further extended to choose one histogram of scene which is more stable and has less noise. Histogram matching deals with possible nonlinearity of a detector's transfer functions. The accuracy of histogram matching depends upon the accurate reference histogram which in turn provides better de-stripping results.

## Proposed Framework

In this section we are explaining z score classification method for destripping and banding.

**Z-Score Classification based residual destripping and banding Method-** Classification basically mean categorizing different objects in an image on the basis of different feature. Z-score classification categorize the image on the basis of z-score values. Z-score is calculated from first order statistics and second order statistics of the image. First order statistics used here is mean and second order statistics used is standard deviation. In this method first step is to calculate the column mean and column standard deviation for all column in the image. z-score is calculated by using column mean and column standard deviation. The equation of first order statistics, second order statistics and z-score is shown in equation 6,7,8.

$$\mu_y = \frac{\sum_{i=1}^M I(x, y)}{M} \quad (6)$$

$$\sigma_y = \sqrt{\frac{\sum_{i=1}^M (I(x, y) - \mu_y)^2}{M - 1}} \quad (7)$$

$$z \text{ score}(x, y)_y = \frac{I(x, y) - \mu_y}{\sigma_y} \quad (8)$$

where  $\mu_y$  represent the mean for column number y in the image,  $I(x,y)$  is two dimensional image, M is total number of pixels in column of image,  $\sigma_y$  is the standard deviation for the column number y in the image,  $z \text{ score}(x, y)_y$  is the z-score value of the pixel located at row number x and column number y which is calculated by taking statistics of the column y.

**Criteria** for classes- Noisy image described in flowchart contain stipes and banding. z-score is the measure of dispersion/relative deviance of the data from the mean/median value. z-score values are positive as well as negative. Classification of class depend on z-score values of the pixels in the image. Based on non-linearity observation of feature in the image, image is divided into three classes. Class 1(lower class contain features like water) contain those pixels of the image whose z-score values are less than -1. Class 2(middle class contain features like urban area) contain pixels of image whose z-score values lie between -1 and 1. Class 3(high class which contain feature like clouds) contain those pixels whose z-score values are greater than 1 same is shown in Equation (9).

$$I(x, y) = \begin{cases} \text{Class 1} & z \text{ score}(x, y)_y < -1 \\ \text{Class 2} & -1 \leq z \text{ score}(x, y)_y \leq 1 \\ \text{Class 3} & z \text{ score}(x, y)_y > 1 \end{cases} \quad (9)$$

**Slope function;** - After classification of Image into three classes we have to apply slope function on each class to remove stripe. As we have classified the image into three classes on the basis of column statistics, we will calculate local mean for each column for each class. Global mean will be calculated separately for each class. After calculation of means we will calculate slope for each column in reference to each class. Slope is applied to respective class to get stripe free image. The entire procedure for applying slope function is explained in figure 2, where  $C(x, y)_{p\_in}$  denote the  $p^{th}$  input class,  $L(y)_p$  denote the local mean of the class p for the column y,  $G_p$  denote the global mean of the class p,  $S(y)_p$  denote the slope of class p for column y,  $C(x, y)_{p\_out}$  denote destriped class p.

## Experiment and Result:

We have tested the proposed method using various sets of cartosat-2S data. Before applying the proposed method different methods to remove noise were applied like Look up

Table updation, ghost noise removal & adaptive noise removal. In this experiment we compared the performance of existing methods like offset, slope and proposed method as z-score method for residual destripping and banding.

**Offset Method.** - This method gives good result on images which contain uniform features as evident in figure 3(a), but fails in those case in which image do not contain homogenous feature. Figure 3(a) represent an image which contain stripe, 3(b) is destripe image with offset window method, 3(c) is destripe image with offset global method. In this case both method either offset window or offset global are giving same result. But in figure 4(a) which contain feature like water and land, offset window method (figure 4(b)) remove certain portion of stripe but not totally removed them, in figure 4(c) offset global method changes the total statistics of the image and bring the statistics of one feature like land into another feature like water. In figure 4(d) we have plotted horizontal profile of figure 4(a),4(b),4(c) to show the comparison between destriped and striped image. Red color shows the image containing stripes. Blue color shows the image after offset window method, green color shows the image after offset global method. Blue profile is becoming somewhat constant throughout the image, while green profile is



deviated from original mean due to statistics of land which change the mean of green profile. Hence we can conclude that offset method remove stripes in images which contain only homogenous features & fails in case of image containing heterogeneous feature.

**Slope Method:** - Slope window method removes the limitation of offset method of removing stripe from images which contain features like water and land. Slope method is different from offset method as it tries to bring proportionate change to reduce stripe instead of adding offset to remove stripe. Figure 5(a) shows image with stripe, 5(b) shows image after applying slope window method, 5(c) shows image after applying slope global method. Here slope window method performs better, but it has the limitation as it is not able to remove stripe from image which contain features like cloud and water which is shown in figure 6 & 7. 6(a) represent image with stripe, 6(b) after applicability of slope window method, 6(c) after applicability of slope global method. 7(a) is the image with residual stripe, 7(b) is the result after slope method generating bad result resulting in large number of stripes.

**Z-score-classification Method.** To remove the limitation of slope method z-score classification based residual destripping method was implemented. Figure 7(a) represent image containing water and land with stripe, 7(b) represent the image after applying slope window method, 7(c) represent the image after applying z-score classification method. In 7(c) all the stripe which are present in 7(a) are removed and true color of land and water is restored. Figure 8(a) represent the stripe image which contain feature like urban area and desert with banding problem and 9(a) represent the image which contain cloud with banding and in 8(a) and 9(a) banding has been formed due to which color of certain portion of image has changed to blue color where banding is present. 8(c) and 9(c) are the images after applying z-score classification method. In 9(c) image true color of features (for example forest and cloud) have been restored after removing banding. In 8(c) the color of urban area changes from blue to true color and similarly for desert portion. Relative Radiometry Accuracy parameter is a parameter used to identify percentage of stripes & banding in the image as shown in equation 10 and it has been found that zscore classification method has lower relative radiometric accuracy as compared to offset and slope method. Zscore classification method achieved a relative radiometric accuracy of 0.1%.

$$RRA = \frac{\sum_{j=0}^{PIXELS} \sum_{l=0}^{SCANS} (DATA[l][j] - DATA[l][j+1])}{\sum_{l=0}^{SCANS} DATA[l][j]} \quad (10)$$

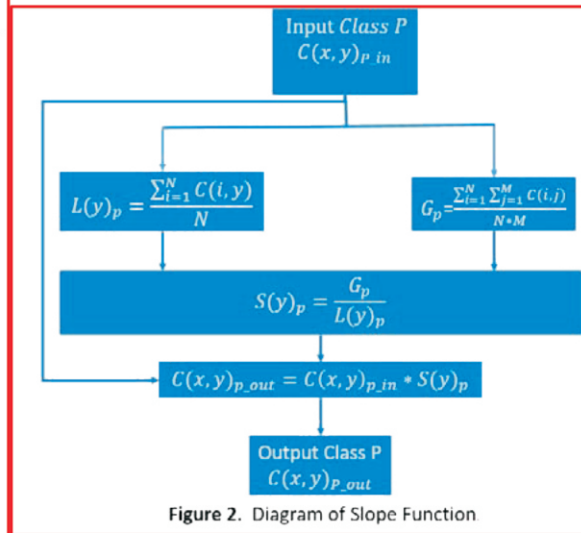
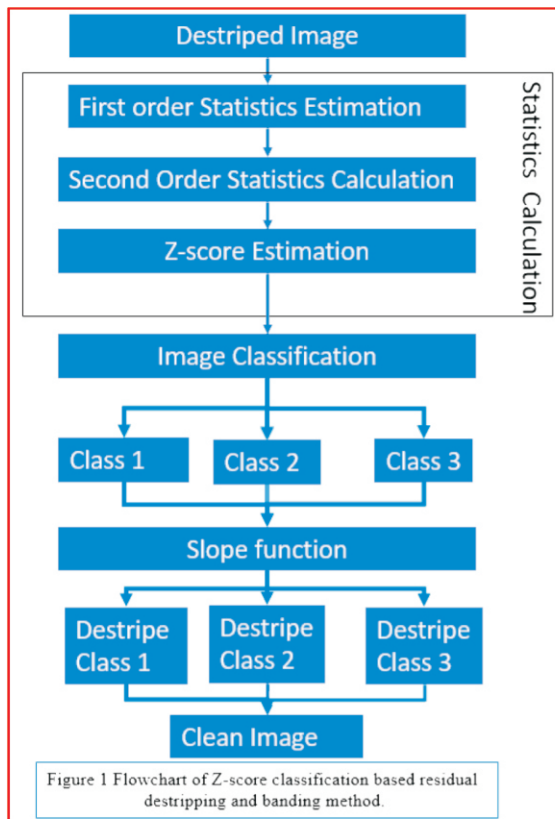
## Conclusion

Destripping is the process of removing stripes or streaks from images. A new destripping technique called z-score classification based residual destripping and banding method is described in this paper for the removal of the striping artifacts. The result of three methods offset, slope and z-score are presented in this paper. Offset method work well only when the feature in the full image is uniform, if there are more features in the image then this method fails and tried to bring the statistics of one feature to another feature. Slope method perform better than offset method but it did not remove the residual stripe in image which contain cloud and water. In some cases, slope method when applied locally remove the residual stripe, but depending upon the image window size may be changed for calculating reference mean. Z-score classification based residual destripping method produced good result when the feature in image is uniform or it contain water or cloud which is shown in the figure 6. This method can automatically destripe an entire remote sensing image without requiring the user to manually specify image columns, wavelength ranges and corresponding applicable window sizes for the image, it leaves the image content effectively unchanged. The benefit of z-score classification based method is that it does not bring statistics of one

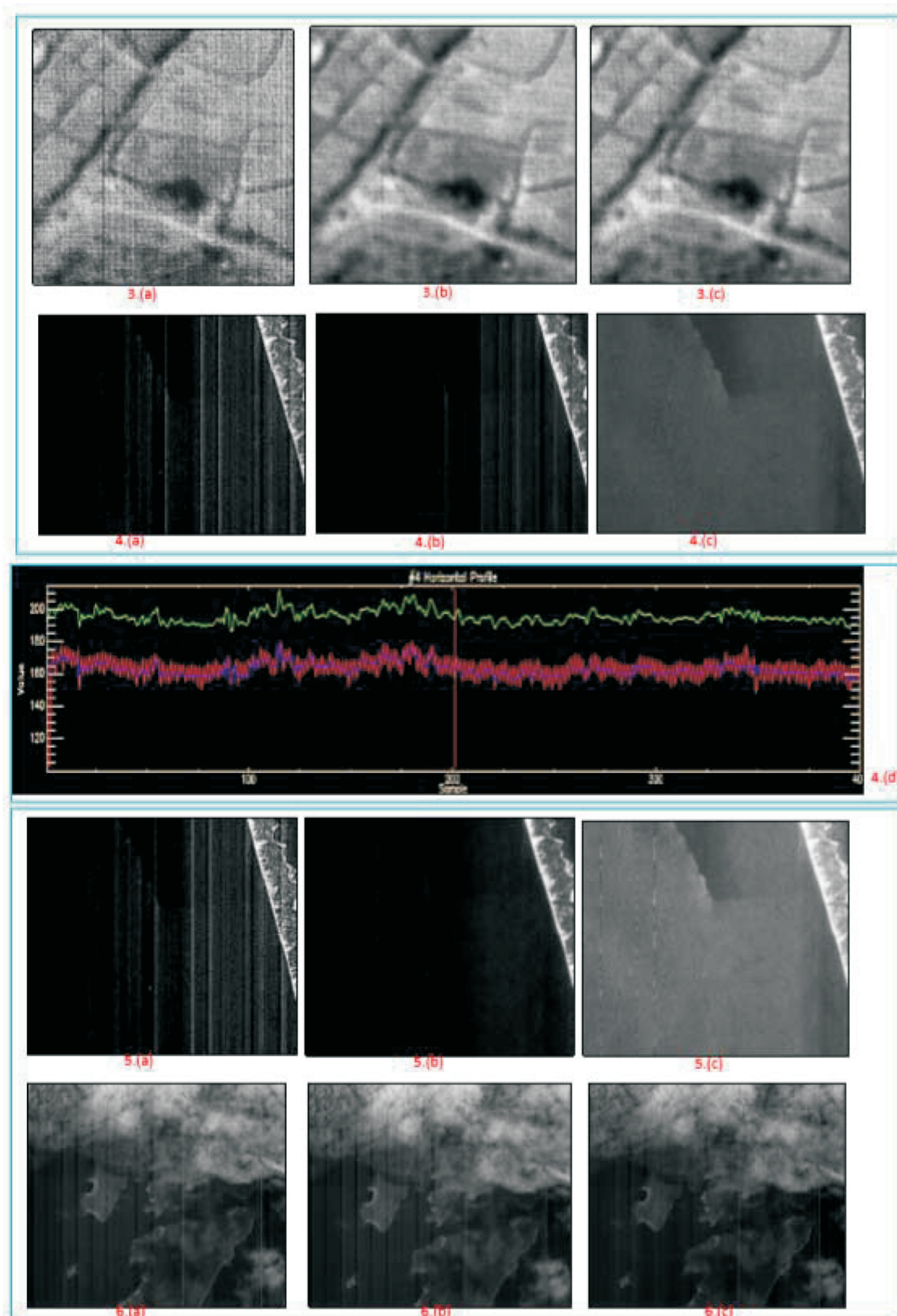
feature to another feature, it removes stripe by using the statistics of uniform feature of certain class of the image. The results produced by z-score classification based residual destriping method are very effective and good.

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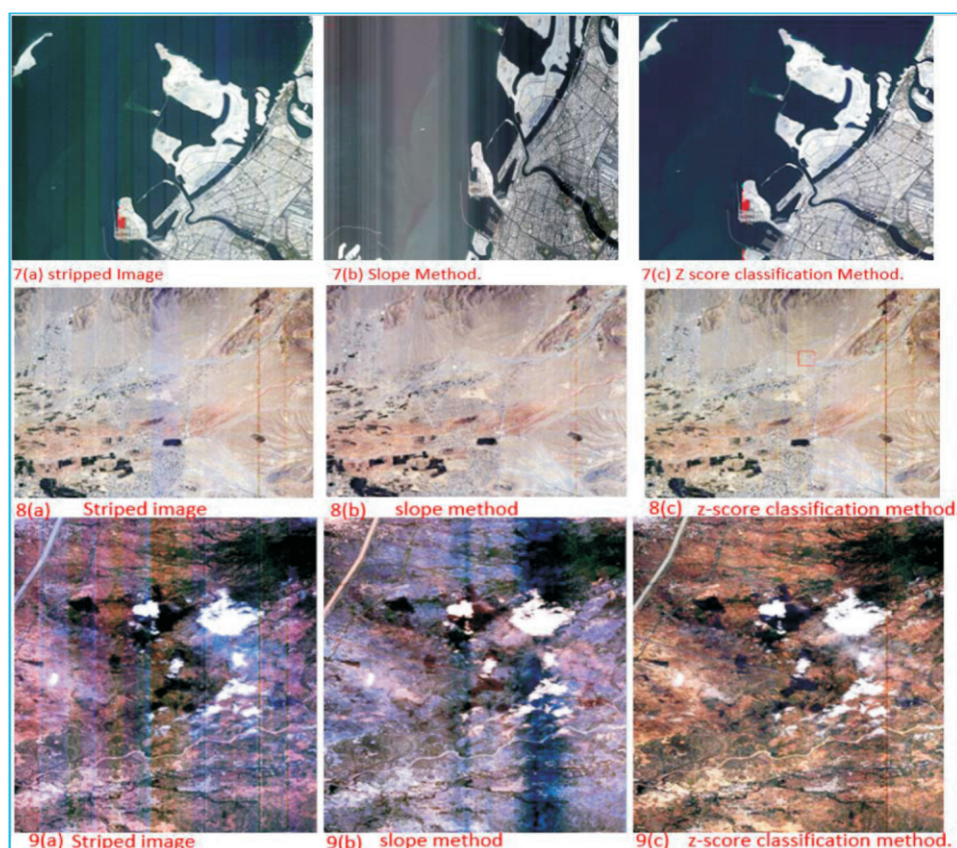
- 3(a):Image with stripe
- 3(b):offset window method
- 3(c):offset global method
- 4(a): Feature like water and land
- 4(b):offset window method
- 4(c): offset global method
- 4(d):Horizontal profile
- 5(a) : image with stripe
- 5(b) :slope window method
- 5(c):slope global method
- 6(a): image with stripe
- 6(b) :slope window method
- 6(c) : slope global method
- 7(a):image containing water and land with stripe
- 7(b): slope window method
- 7(c): z-score classification method



A Novel method for Image destripping based on Feature Classification Approach

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| Method                        | Relative Radiometry Accuracy |
|-------------------------------|------------------------------|
| Offset method                 | 0.3                          |
| Slope method                  | 0.2                          |
| Zscore classification Method. | 0.1                          |

Table 1. showing methods and relative radiometry accuracy.

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## Popularity of Liquor in Tharu Tribe of Balrampur District : A Geographical Analysis

*Dr. Richa Chaturvedi*

### *Abstract*

*‘Jaha Tharu Waha Daru’ these utterances reflect the popularity of liquor in the Tharu community. The word ‘Daru’ is a very popular word for liquor among Tharu tribe. It is consumed less by women than men, but women do not hesitate to consume it at all. During field observation, it was found that in Tharu society, the importance of liquor has been seen in many places, such as marriage ceremonies, birth ceremonies, death ceremonies, and different festivals. It was also seen in the study area that both men and women sit and drink together as it is a condemnable act in our society but it is not in Tharu community. 72.20 per cent Tharu take liquor per day whereas 27.80 per cent take it on the only festival, marriage ceremony or another ceremony. In the Tharu community of Balrampur district, only 62.30 percent of women drink alcohol as compared to 90.80 percent of men.*

**Keywords:** Tharu, Liquor, Daru,

### **Introduction**

The world discovered alcohol many thousands of years ago through its natural occurrence in decaying fruit or fermenting bowls of grain in which air-borne yeasts and natural sugars combined. Though the discovery of alcoholic drinks may have been accidental, humans soon learned how to deliberately produce it. Alcoholic beverages became common in virtually all cultures (Korhonen, 2004). In Hindu civilization, if we track back to the Vedic civilization there were two kinds of drinks *Soma* and *Sura*. *Soma* was used to offer to the God and goddess whereas *Sura* was a secular drink (Basham, 1951). In epic period, people used to take it as food or with food for recreation. The attempts have been made to find the meaning of words Tharu which can be a clue towards the knowledge about the origin of Tharu people. Among these, a view suggests that the term Tharu is derived from Sthera which represents a sect of Buddhists. Second view, the word Tharu is derived from the word *Thara* of Magar language, which means the plain. Third view, suggests that the people who have come from *Thar* in Rajasthan, India are called Tharu (Archarya, Tharu, Khadka and Chaudhary, 2008). Societies have long used alcohol consumption and its effects as important ways to differentiate, symbolize and regulate gender roles (Joffe, 1998, Warner, 1997). In India drinking habits closely associated with different ethno-religious communities and socio-economic classes. *Jaha daru vaha tharu* ..... It is very true for Tharu people. Drinking practices vary greatly from tribe to tribe as a result of cultural, social, economic, and lifestyle differences. Drinking of indigenous liquor, ‘*Daru*’, was a popular practice among Tharu in study area. Generally every Tharu family has a better skill of making/producing *Daru*. In *Tarai* region where Tharu people live, their cultural as well as environment or natural surrounding provide them ample opportunities to consume it.

### **Study Area**

Balrampur (28° 2’ N to 28° 54’ N) and (82° 3’ E to 82° 49’ E) is one of the most backward District of Devipatan division of the eastern region of Uttar Pradesh at the foothill of Himalayas, India (Fig 1). Its boundary is formed by

the 3 district of U.P such as Sidharthnagar (east), Shrawasti (west), Gonda (south) and north of the district is formed by the international boundary (Nepal). Administratively, the present Balrampur district occupies an area of 3419.50 km<sup>2</sup> with a population of 1,6,82,350 persons (2011). It has been divided into Three Tahsils namely (Balrampur Sadar, Tulsipur and Utraula) and 9 Developmental blocks. There are mainly two distinct blocks, Pachperwa and Gainsari, of Tharu concentration.

Objective

The Present study has been undertaken with the following major objectives:

- (1) To assess the level of heavy drinking liquor in Tharu people.
- (2) To compare drinking pattern between men and women.

Methodology

The study is based on a primary survey using direct participation and interview methods to arrive at the conclusion. The available secondary resources have also been used. Interview and closed ended questionnaire have been used as a research tool for primary data collection. As stated the area under study comes under the two blocks Pachperwa and Gainsari where maximum Tharu tribe concentrated. It comprises of 54 villages out of which 15 falls in Gainsari block, 34 villages in Pachperwa block and 5 villages are under the forest area. Villages are selected through random sampling procedure. Overall 403 households were surveyed in these villages covering a population of 3,549 in which 1,657 are female. The data were collected by trained investigators through questionnaire. Collected data has tabulated and it has analyzed through SPSS (Statistical Package for Social Science) programm.

LOCATION MAP

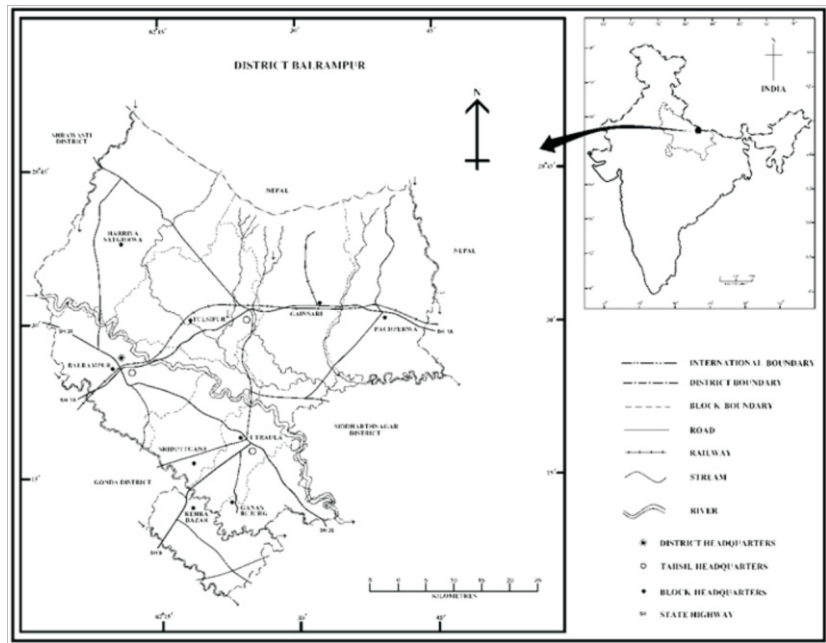


Fig-1

## Results and Discussion

After obtaining and analysing the all preliminary information, the detailed information from both male and female members of the families was sought pertaining to the making and consuming the liquor to their socio-cultural pattern. In study area, generally every Tharu family has a better skill of making liquor. Male and female both take liquor interestly. Even teenager boys also take liquor.

## How to make Liquor

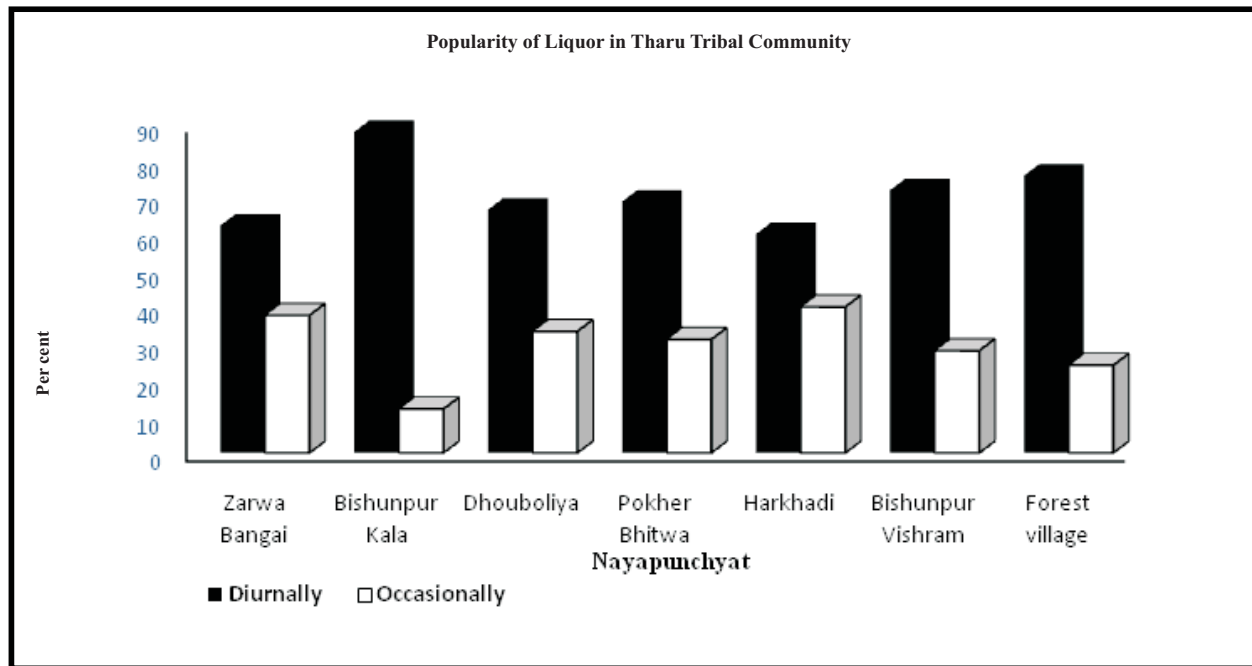
They locally prepare the liquor on an improvised distillery in Tharu society, mainly two varieties of local fragmented drinks or Liquor like *Jand* and *Daru* are popular and they are purely brewed at home. *Jand* has a very low alcoholic content, which is used as a traditional local beer in Tharu society. In this case, *Aanandi* rice is used for the preparation of alcoholic beverage *Jand*. For the preparation of *Jand* the *Aanandi* rice with leaves of jack fruit, root of Kurla (thorny makhana) and other *jari buti* (harbals) grinding is done in a mortar till it become powder. After that, mixture of rice flour with water is made into small cubes or tablets form (*Litti/ Bhouri*) and powder of another *litti* spread on it. The prepared tablets are placed on *Payal* of it and are again covered with this *Payal* for 2-3 days. After 2-3 days *fafundi* (*Gurwana*) has become on small cubes or tablets (*Litti/ Bhouri*). After which the prepared tablets are sun dried the material is completely dried. After this, in this boiled *Aanandi* rice the water is added and it deep mixed by hand continuous till it gets liquid (*Paniha*). A small cube (*litti*) is also added in it, and then it is covered by muslin cloth or polythene and kept for one day and one night without any disturbance. After that the mixture is kept in earthen pot (*Golara*), so *Jad* is ready to drink after 1 day and 1 night but this will give a very light drink but at long time. It gives mild test of banana and can be stored in cool, dry place for over a year. *Daru* is another wine which is made from *Mahua*.

**Table 1:**  
**Popularity of Liquor in Tharu Tribal Community, Balrampur District**

| Nayapunchyat      | Use of Liquor |              |
|-------------------|---------------|--------------|
|                   | Diurnally     | Occasionally |
| Zarwa Bangai      | 62.30         | 37.70        |
| Bishunpur Kala    | 88.00         | 12.00        |
| Dhouboliya        | 66.70         | 33.30        |
| Pokher Bhitwa     | 68.90         | 31.10        |
| Harkhadi          | 60.00         | 40.00        |
| Bishunpur Vishram | 72.00         | 28.00        |
| Forest village    | 76.00         | 24.00        |
| <b>Total</b>      | <b>72.20</b>  | <b>27.80</b> |

**Source: Personal survey and computation, 2018**





Above table, (Table1) reveal that 72.20 per cent Tharu take liquor per day whereas 27.80 per cent take it on only festival, marriage ceremony or other ceremony. It was observed from table 1 that maximum percentage (88.00) has found in Bishunpur Kala whereas minimum percentage (60.00) in Harkhadi Nayapunchyat. During field investigation it was found that Tharus take liquor after dinner with their whole family member in male, female, old and children all are involve. In *Tarai* region, Habitat climate is the major factor of liquor drinking in Tharus. Liquor taking make them not only disease less but also remove their loneliness, tiredness, make them cold resistant and help to increase social friendship. During the field investigation, some observations have been found regarding the uses of liquor:

**During Worship:** liquor or wine is essential for god worship and they try to satisfy god at worship with wine. Tharu, offering liquor to gods, and goddesses and consuming the same too in good measure considering it as God's Prasad.

**Welcome of Guests:** In Tharu society, liquor is very essential with food for the welcome guest. Without liquor, the welcome of guests is not considered in Tharu society.

**Ceremony:** Consumption of alcohol is essential in festivals, birth ceremonies, marriage festivals and death ceremonies. During the field investigation, I found that any festival in Tharu community is considered incomplete without the use of liquor.

**Delivery:** Women in the Tharu community also drink wine after delivery as it helps to control labor pains. After delivery, both mother and child are massaged with alcohol (Malis) which strengthens them and relieves body pain.

**Festival:** Without liquor, there are no festivals are completed in Tharu society. Here, Every festival starts by offering liquor and ends also with offering liquor to each other.

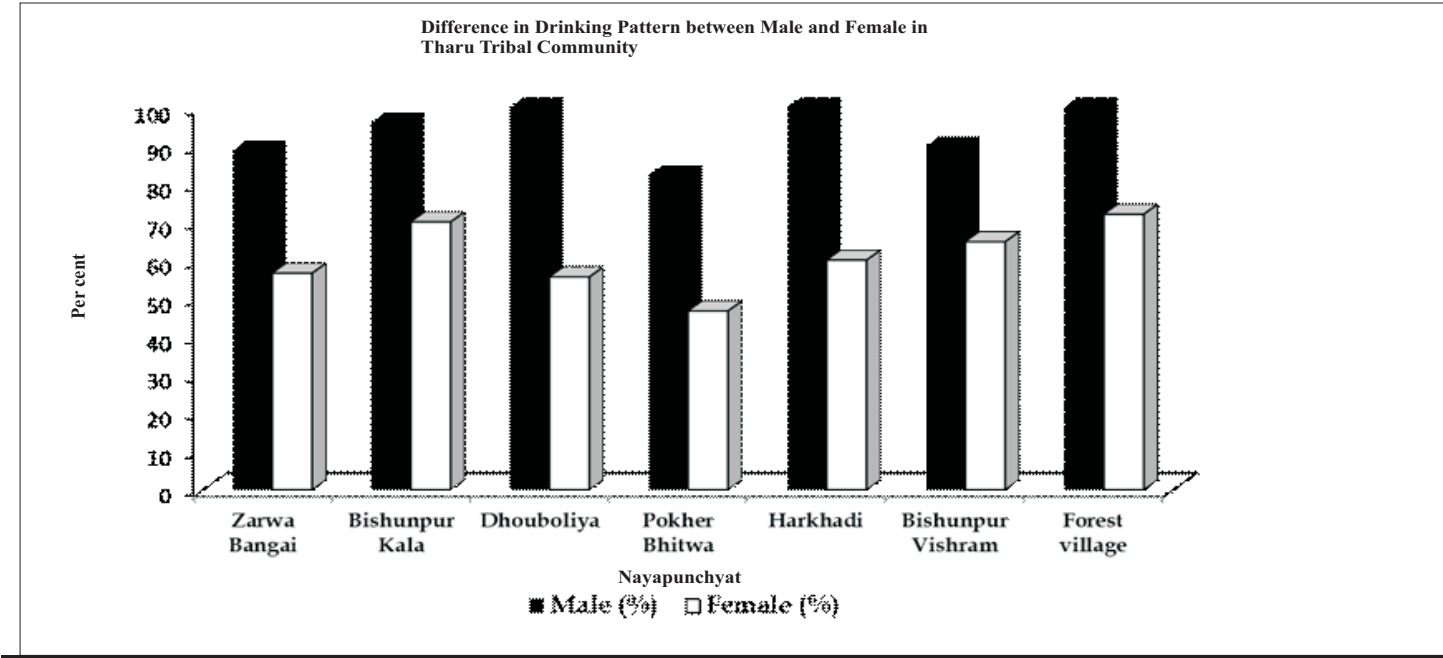
Difference in Drinking Pattern between Male and Female

Gender differences in liquor consumption are based on the ways each culture sees male and female roles and their power. Women’s alcohol problems have been neglected, being either viewed as not needing or deserving help, or resulting in punishment rather than treatment. On the other hand, man frequently regards their own drinking as normal it impairs their behaviour and social relations (Correa et.al. 2005). Alcohol has a socio-religious sanctity and Tharu male are habitual drinker and female consume twice or thrice per week.

Table 2:  
Difference in Drinking Pattern between Male and Female in Tharu Tribal Community, Balrampur District

| Nayapunchyat      | Drinking Pattern |            |
|-------------------|------------------|------------|
|                   | Male (%)         | Female (%) |
| Zarwa Bangai      | 88.70            | 56.60      |
| Bishunpur Kala    | 96.00            | 70.00      |
| Dhouboliya        | 100.00           | 55.60      |
| Pokher Bhitwa     | 82.20            | 46.70      |
| Harkhadi          | 100.00           | 60.00      |
| Bishunpur Vishram | 89.90            | 64.80      |
| Forest village    | 100.00           | 72.00      |
| Total             | 90.80            | 62.30      |

Source: Personal survey and computation, 2018



Above table (Table 2) shows that in Tharu community, female drinking is low. Only 62.30 per cent of female were current drinkers compared to 90.80 per cent of males. The highest proportion of female drinkers (72.00 %) was reported from forest village whereas the second highest proportion female drinkers (70.00 %) was reported from the Bishunpur Kala Nayapunchyat. Considering the male drinkers in Dhouboliya Nayapunchyat, Harkhadi Nayapunchyat and Forest village noticed 100.00 per cent Tharu intake the liquor frequently. The lowest proportion of male drinkers (82.20 %) was reported from Pokher Bhitwa Nayapunchyat. In study area, male were found to be habitual drinker and consumed almost daily in a good measure, while the female consume occasionally and during festivals and ceremonial days.

During field investigation I found that some important reasons for gender differences in drinking behavior may occur together such as alcohol consumption enhances men's greater power relative to women and it has been an emblem of male superiority, men drink more than women do because men are generally more willing or motivated to take risks than women other reason is that men's and women's drinking are differently affected by social responsibilities.

## Conclusion

Alcoholism is a terrible evil in our society, but in tribal community they take it frequently often, that is, we can say that its consumption is a compulsion of their society. It is clear from the study of drinking habits, that majority of Tharu people consume alcohol regularly in which male percentage is higher than that of females. Women in Tharu society consume alcohol at a high level and they have no hesitation in consuming it. Due to the influence of modernity, their attractiveness is has increased like English wine, but their weak economic condition has also hindered the extent of their use.

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## Contents

1. Hydrography- Providing Framework for Coastal Zone Management for Effective Land Sea Governance in Support of Blue Economy 1-7  
**Capt Mathew G Abraham**
2. Identification of major hazard or cyclone prone regions of Indian Sundarban by amalgamation of geospatial and geostatistical techniques 8-23  
**Papia Guha** ✉  
**Pritam Aitch, Gupinath Bhandari**
3. Catchment Assessment for Sustainable Lake Water Management in Kolavai Lake, Peri-urban area of Chennai City 24-32  
**G. Bhaskaran** ✉  
**Dr.S.S.Sundaram, Mr.Harikrishna and P. Tamilselvan**
4. Structural controls and drainage character of Nagal Gad Basin in Chamoli district Garhwal Himalaya 33-46  
**Gopinath Patra**
5. Evaluation of pan-sharpened image quality with special emphasis on cartosat-2s/3 imagery 47-58  
**M.V. Srivally** ✉  
**Ashish Sachan and Sujata Ghosh**
6. Challenges and Solutions for Large scale mapping of Mountainous and Forest covered areas of North Eastern India using High Resolution Drone Images 59-67  
**Stalin M**
7. A Comparative study on Sentinel-1A SAR and Sentinel-2A Optical data for wetland mapping : A case study in G Plot and L Block of Sundarban, West Bengal, India 68-84  
**Suman Das** ✉  
**Jatisankar Bandyopadhyay, Saroj Maity, Nirupam Acharyya**
8. A Novel method for Image destripping based on Feature Classification Approach 85-94  
**Vikash Tyagi** ✉  
**P Suresh Kumar** ✉  
**T Sushma Leela, Dr. R Chandrakanth, Dr. PV Radhadevi**
9. Popularity of Liquor in Tharu Tribe of Balrampur District : A Geographical Analysis 95-100  
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