Improving management strategies for flood and river bank erosion employing artificial intelligence (AI) and explainable artificial intelligence (XAI)

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Submission Date : 08-Aug-2023

PROPOSAL DETAILS

(PDF/2023/000865)

Principal Investigator	Mentor & Host Institution
Dr. Md Nawaj Sarif nawaj.stout@gmail.com NA(Geography) **Contact No** : +918447139174 **Date of Birth** : 09-Oct-1991 **Name of Father/Spouse :** Md Hasimuddin Biswas	**Narayan Chandra Jana** jana.narayan@gmail.com Professor(Geography) **The University of Burdwan** Burdwan rajbati, raiganj, bardhaman, Bardhaman, West bengal-713104 **Contact No.** : +919547789019 **Registrar Email** : registrar@buruniv.ac.in **No. of PHD Scholars** : 7 **No. Post-Doctoral Fellow** : 0

Details of Post Doctorate

Ph.D. (Geography)[Degree Awarded on : 17-May-2022]

Impact of Bank Erosion on the Socio-economic Condition of the People: A Case Study of Ganga from Rajmahal to Dhulian Town

Research Supervisor/Guide & Institution :

Prof. Lubna Siddiqui

Jamia Millia Islamia

Brief details of Thesis work :

1. My Ph.D. work is dedicated to a comprehensive exploration of the intricate dynamics surrounding river bank erosion, a matter of utmost significance for the communities residing in deltaic regions. Focusing my investigation on the lower Ganga plain, I adopt a multidisciplinary approach that integrates various fields of study. This holistic perspective allows for a thorough examination of key aspects, including the evolution of the Ganga River, its susceptibility to erosion, socio-economic vulnerabilities, and the profound and far-reaching impacts exerted upon the local inhabitants.
2. To ensure a meticulous and accurate analysis, I employ a meticulous methodology. By integrating historical maps with contemporary satellite images onto a unified platform, I eliminate any discrepancies in projection and scale. This harmonization of data facilitates a precise assessment of the river's sinuosity and course changes spanning back over the past two centuries. This historical perspective is crucial for a comprehensive understanding of the river's morphological transformations.
3. The meticulous quantification of spatio-temporal alterations in erosion and deposition patterns reveals distinct trends that emerge along the riverbanks. Specifically, the east bank emerges as a site of heightened erosion and deposition, with variations becoming evident across different block levels. These findings serve as a stark reminder of the inherently dynamic nature of the Ganga River. The implications of these trends emphasize the urgent need for adaptive and sustainable riverbank management strategies.
4. Leveraging the Digital Shoreline Analysis Model (DSAS), I construct erosion susceptibility maps that offer a comprehensive visualization of the east bank's vulnerability to erosion. This mapping approach, characterized by its robustness, goes beyond a mere representation of erosion-prone areas. It factors in key variables such as physiography, water discharge, and sedimentation, which exert significant influence on the erosion process. This integrative approach provides a nuanced understanding of vulnerability.
5. Transitioning into the realm of socio-economic vulnerabilities, my study incorporates a comprehensive framework that spans three dimensions and encompasses a total of 34 indicators. This thorough assessment reveals specific areas characterized by high exposure, sensitivity, and limited adaptive capacity. Notably, more than 60% of the selected villages exhibit a pronounced vulnerability, with factors such as proximity to the river, soil composition, economic conditions, and social status contributing significantly.
6. An intriguing facet of my research involves an impact analysis that sheds light on the substantial socio-economic ramifications stemming from river bank erosion. This analysis captures the intricate interplay of factors, showcasing how occupation shifts, income fluctuations, and alterations in land use collectively reflect the profound and lasting impact on affected communities. This exploration serves as a poignant reminder of the challenges posed by erosion-induced disruptions and emphasizes the imperative of implementing resilience-building strategies.
7. My research is characterized by a thorough acknowledgment of certain limitations inherent in the study. Notably, the precision of the study is influenced by data availability, with parameters such as water discharge and sedimentation representing areas for potential improvement. Furthermore, the utilization of advanced statistical techniques could offer deeper insights and a more nuanced understanding of the complex relationships that underlie the impact analysis.
8. In conclusion, the work, emerges as a significant and comprehensive endeavor that navigates the intricate interplay between river dynamics, erosion susceptibility, socio-economic vulnerabilities, and their enduring impacts on both deltaic ecosystems and the riparian societies they support. This holistic exploration holds immense potential for actionable insights that contribute to effective riverbank management, disaster mitigation, and the cultivation of resilient development strategies. By safeguarding the environment and the communities reliant upon it, this research stands as a beacon of progress and a catalyst for positive change.

Technical Details :

Research Area : Earth & Atmospheric Sciences (Earth & Atmospheric Sciences)

Project Summary :

In the alluvial floodplain, floods and river bank erosion are persistent and significant hazards, resulting in devastating consequences such as loss of life, displacement of people, and damage to property and infrastructure. As land use patterns change, the impact of these natural hazards continues to increase. To effectively manage these challenges, it is crucial to develop flood and river bank erosion susceptibility mapping. In the past, various studies have explored flood and river bank erosion susceptibility mapping using different machine learning algorithms. While these models exhibit high accuracy, their adoption by stakeholders is limited due to their black-box nature, which hampers interpretability. To address this issue, our research proposal aims to develop an Explainable Artificial Intelligence (XAI) framework for managing these hazards. The XAI will offer interpretable insights into the outcomes of various machine learning, ensemble machine, and deep learning models, as well as the influence of conditioning factors on susceptibility mapping. The proposed study area is part of the Lower Ganga Plain. The study will consider a range of topographic, climatic, soil, and land use/land cover factors for assessing flood and river bank erosion susceptibility. Flood susceptibility inventory maps will be generated by integrating flood inundation maps, while Digital Shoreline Analysis System (DSAS) models will be utilized for river bank erosion inventory mapping. Flood and non-flood points will be used as target variables for flood susceptibility mapping, while erosion and non-erosion points will be employed for river bank erosion susceptibility. For flood probability assessment, we will employ Classification and Regression Trees (CART), Random Forest (RF), and Convolutional Neural Network (CNN) models. Additionally, for river bank erosion probability assessment, Multivariate Adaptive Regression Splines (MARS), Extreme Gradient Boosting (XGBoost), and Deep Neural Network (DNN) models will be employed. Our research strives to create impactful contributions by building robust and scientifically grounded flood and river bank erosion models, leveraging diverse machine learning and deep learning techniques. By integrating XAI into these models, we will elevate outcome interpretability, fostering trust among stakeholders in their decision-making endeavors. Overall, this research proposal seeks to bridge the gap between accurate model performance and stakeholder confidence, ultimately contributing to more effective and informed flood and river bank erosion management strategies.

Objectives :

- To assess the flood and river bank erosion susceptibility by utilizing various machine learning and deep learning algorithms.
- To develop explainable AI (XAI) for the interpretation of the outcome of flood and river bank erosion model.
- To evaluate the contribution and behavioral pattern of the factors for flood and river bank erosion under different conditions.
- To formulate effective hazard management strategies based on the study findings.

Keywords :
Flood, River bank erosion, Susceptibility mapping, Explainable AI (XAI), Machine learning, Management

Expected Output and Outcome of the proposal :

We expect that several publications will be produced from the proposal in international peer-reviewed journals such as the International Journal of Disaster Risk Reduction, International Journal of Disaster Risk Science, Natural Hazards, etc. The research aims to significantly advance flood and river bank erosion management in the lower Ganga alluvial floodplain. By developing an Explainable Artificial Intelligence (XAI) framework integrated with advanced machine learning and deep learning models, the study seeks to provide interpretable and trustworthy flood and river bank erosion susceptibility maps. These maps will accurately identify high-risk areas, facilitating targeted and effective hazard management strategies. Additionally, the research will unveil the behavioral patterns and the importance of contributing factors, empowering stakeholders to prioritize key drivers for mitigation efforts. The XAI-based approach bridges the gap between model predictions and stakeholder comprehension, fostering better decision-making and building resilience against flood and river bank erosion events. Ultimately, the research contributes to a comprehensive and adaptive flood and river bank erosion management strategy, ensuring safety and sustainability in the lower Ganga plain.

Reference Details :

S.No	Reference Details
1	**Name- Prof. Lubna Siddiqui** **Room No- 114, Department of Geography, Jamia Millia Islamia, New Delhi, Pin- 110025[+9350970749]** lsiddiqui@jmi.ac.in
2	**Name - Prof. Masood Ahsan Siddiqui,** **Room No- 119, Department of Geography, Jamia Millia Islamia, New Delhi, Pin- 110025[+9990948270]** siddiqui.jmi@gmail.com

Methodology and Work Plan

Improving management strategies for flood and river bank erosion employing artificial intelligence (AI) and explainable artificial intelligence (XAI)

Md Nawaj Sarif

Mentor: Prof. Narayan Chandra Jana

The University of Burdwan

Methodology:

(i) Selection of the study region

The proposed research area comprises Malda and Murshidabad, part of the lower Ganga plain. The Ganga and its various tributaries flow through the area. The area is dominated by a sub-tropical monsoonal climate. The regions of Malda and Murshidabad are consistently faced with the recurring challenge of enduring floods and the erosion of river banks. The unique physical feature of an eastward incline in the topography leads to the swift convergence of the main tributaries of the Ganga-Padma River. These natural hazards have severe consequences, posing challenges to communities, infrastructure, and ecosystems in the study area.

(ii) Creation of Flood and River Bank Erosion Inventory Map:

The flood inventory map will be developed using remote sensing data and GIS techniques. Satellite imagery and elevation data will delineate flood-affected areas, indicating flood-prone regions. For the river bank erosion inventory map, the DSAS model will analyze riverbank changes over time, identifying erosion-prone areas. Historical records and surveys will identify erosion points and non-erosion points for the erosion susceptibility assessment. Similarly, flood occurrences data will identify flood-prone locations, used as flood susceptibility points for the flood susceptibility assessment.

(iii) Analysis of the factor affecting flood and river bank erosion

The importance and analysis of flood and river bank erosion factors play a pivotal role in our methodology for assessing the susceptibility of the study area (Malda and Murshidabad) to these hazards. Through a comprehensive approach, we will investigate various contributing factors, such as topography, land use/land cover, soil type, hydrological characteristics, and climatic conditions. Leveraging advanced machine learning and deep learning algorithms, we will analyze the significance of each factor in influencing flood and river bank erosion occurrences. By quantifying their relative importance, we aim to gain valuable insights into the dominant drivers of these hazards.

(iv) Assessment of flood and river bank erosion susceptibility

The study will assess flood and river bank erosion susceptibility in the study area (Malda and Murshidabad) by employing advanced machine learning and deep learning models. For flood susceptibility, Classification and Regression Trees (CART), Random Forest (RF), and Convolutional Neural Network (CNN) models will be utilized. CART and RF handle nonlinear relationships, while CNN is ideal for spatial data analysis. For river bank erosion susceptibility, Multivariate Adaptive Regression Splines (MARS), Extreme Gradient Boosting (XGBoost), and Deep Neural Network (DNN) models will be employed. MARS captures complex interactions, while XGBoost and DNN excel in learning intricate patterns. The inventory map of flood and non-flood points will be the target variable for flood susceptibility, and the erosion and non-erosion points will serve as the target variable for river bank erosion susceptibility assessment.

(v) Development of XAI:

The study aims to enhance flood and river bank erosion models' interpretability by developing Explainable Artificial Intelligence (XAI) techniques. XAI bridges the gap between accurate predictions and stakeholders' understanding of decision-making. To achieve this, we will use the Shapley Additive Explanation (SHAP) framework, rooted in cooperative game theory. Game theory analyzes outcomes depending on interactions among agents. In SHAP, the cooperative game involves features (contributing factors) working together to make predictions. SHAP quantifies each feature's contribution, considering all feature combinations as cooperative coalitions. Applying SHAP values to models reveals how specific factors influence hazard occurrence. SHAP's reliance on cooperative game theory ensures fair and consistent feature importance attribution, making it a robust and trustworthy method for XAI in the research.

(vi) Contribution and behavioral pattern of the factors

The contribution and behavioral pattern of contributing factors for flood and river bank erosion susceptibility under various conditions in the study area will be thoroughly investigated. Advanced machine learning and deep learning models, coupled with the Shapley Additive Explanation (SHAP) framework, will be employed to analyze the importance of each feature in influencing flood and river bank erosion occurrences. Through this analysis, valuable insights will be gained into the specific roles played by different factors under diverse scenarios, such as varying hydrological conditions, land use patterns, and climatic variations. Additionally, the interactions between contributing factors and their impact on the occurrence of flood and river bank erosion events will be explored.

(vii) Management strategies

By comprehensively studying the behavioral patterns of the factors, key drivers will be identified, and critical management strategies will be prioritized for mitigating flood and river bank erosion risks in the region. This in-depth understanding will pave the way for more effective and targeted hazard management approaches, enhancing resilience and preparedness for future flood and river bank erosion events.

Work plan

The work plan of the research proposal compose of several steps which illustrate as follows:

Joining - 6 months:

This period will focus on literature review, data collection and database generation.

6 months -12 months:

During this period inventory maps of flood and river bank erosion will be generated as well as the factors contributing these will be analyzed.

12 months - 18 months:

Assessment of flood and river bank erosion susceptibility will be done during this period.

18 months - 24 months:

Development of XAI and study of management of flood and river bank erosion will be done in this period.

Time table of the work plan

	Year 1												Year 2											
Activity	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
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1. Literature review, 2. Data collection and database generation, 3. Flood inventory mapping, 4. River bank erosion inventory mapping, 5. Analysis of the factor affecting flood and river bank erosion, 6. Preparation and pre-processing of the database for susceptibility modelling, 7. Flood susceptibility modelling, 8. River bank erosion susceptibility modelling, 9. Development of XAI, 10.Investigation of the contributing factors, 11. Flood and River bank erosion management, 12. Editing

PROFORMA FOR BIO-DATA (to be uploaded)

1. Name and full correspondence address: Md Nawaj Sarif
At-Garuhat, P.O- Dhuliyan, Dist- Murshidabad,
West Bengal, Pin- 472202

2. Email(s) and contact number(s) – Email: nawaj.stout@gmail.com
Mob: +918447139174

3. Institution: Jamia Millia Islamia (Left in 2022)

4. Date of Birth: 09/10/1991

5. Gender (M/F/T): Male

6. Category Gen/SC/ST/OBC: OBC

7. Whether differently abled (Yes/No): No

8. Academic Qualification (Undergraduate Onwards)

	Degree	Year	Subject	University/Institution	% of marks
1.	PhD	2022	Geography	Jamia Millia Islamia	
2.	M.A	2014	Geography	Jamia Millia Islamia	78.2
3.	B.A	2012	Geography	Aligarh Muslim University	60.73
4.					

9. Ph.D thesis title, Guide's Name, Institute/Organization/University, Year of Award.

Ph.D thesis title: Impact of bank erosion on the socio-economic condition of the people: A case study of Ganga from Rajmahal to Dhuliyan town

Guide's Name: Prof. Lubna Siddiqui

University: Jamia Millia Islamia

Year of Award: 2022

10. Work experience (in chronological order).

S.No.	Positions held	Name of the Institute	From	To	Pay Scale

11. Professional Recognition/ Award/ Prize/ Certificate, Fellowship received by the applicant.

S.No	Name of Award	Awarding Agency	Year
1	MANF	UGC	2017

12. Publications *(List of papers published in SCI Journals, in year wise descending order).*

S.No.	Author(s)	Title	Name of Journal	Volume	Page	Year
1	Tania Nasrin, Mohd Ramiz, Md Nawaj Sarif, Mohd Hashim, Masood Ahsan Siddiqui, Lubna Siddiqui, Sk Mohibul & Sakshi Mankotia	Modeling of impact assessment of super cyclone Amphan with machine learning algorithms in Sundarban Biosphere Reserve, India	Natural Hazards	117	1945–1968	2023
2	Sk Mohibul, Md Nawaj Sarif, Neha Parveen, Nazreen Khanam, Masood Ahsan Siddiqui, Hasan Raja Naqvi, Tania Nasrin & Lubna Siddiqui	Wetland health assessment using DPSI framework: a case study in Kolkata Metropolitan Area	Environmental Science and Pollution Research	-	-	2023
3	Neha Parveen, Lubna Siddiqui, Masood Ahsan Siddiqui, Md Nawaj Sarif, Md Safikul Islam, Shahanshah Khan, Nazreen Khanam, Sk Mohibul & Mohammad Shariq	Monitoring built-up area expansion led by industrial transformation in Delhi using geospatial techniques	Environmental Science and Pollution Research	-	-	2022
4	Neha Parveen, Lubna Siddiqui, Md Nawaj Sarif, Md Safikul Islam, Nazreen Khanam, Sk Mohibul	Industries in Delhi: Air pollution versus respiratory morbidities	Process Safety and Environmental Protection	152	495-512	2021
5	Md Nawaj Sarif a, Lubna Siddiqui b, Md Safikul Islam a, Neha Parveen a, Monojit Saha c	Evolution of river course and morphometric features of the River Ganga: A case study of up and downstream of Farakka Barrage	International Soil and Water Conservation Research	9	578-590	2021

13. Detail of patents.

S.No	Patent Title	Name of Applicant(s)	Patent No.	Award Date	Agency/Country	Status

14. Books/Reports/Chapters/General articles etc.

S.No	Title	Author's Name	Publisher	Year of Publication
1	Household-Based Approach to Assess the Impact of River Bank Erosion on the Socio-economic Condition of People: A Case Study of Lower Ganga Plain	Md Nawaj Sarif, Lubna Siddiqui, Masood Ahsan Siddiqui, Neha Parveen, Md. Safikul Islam, Shahanshah Khan, Nazreen Khanam, Sk. Mohibul, Mohammad Shariq & Tania Nasrin	Springer	2022
2	Spatio-temporal Analysis of Land Use / Land Cover Change Using STAR Method in Kolkata Urban Agglomeration	Sk Mohibul, Lubna Siddiqui, Masood Ahsan Siddiqui, Md. Nawaj Sarif, Neha Parveen, Md. Safikul Islam, Shahanshah Khan, Nazreen Khanam, Mohammad Shariq & Tania Nasrin	Springer	2022

15. Any other Information (maximum 500 words)

Conference:

- **"Vulnerable Health Conditions of Slum People in Urban Environment; A case study of South- East Delhi"** in national conference on Agriculture, Environment and Sustainable Development Organized by Department of Geography, Aligarh Muslim University (March, 2016)
- **"Assessment of Water Resources and Impact of Water Pollution on Human Health in India"** in International Conference on Spatial Decision Support Systems for United Nations Sustainable Development Goals (February 1- 2, 2017) at Kalindi College, University of Delhi.
- **"Change Detection of River Ganga in the District of Murshidabad, West Bengal"** in National Conference on Geoinformatics for Natural Resource Management (February 7-8, 2017) at Department of Geography, Faculty of Natural Sciences, Jamia Millia Islamia University, New Delhi.
- **"Assessment of Water Resources and status of water quality of water in India"** in National Seminar on Adaption and Implementation of Paris Agreement: National Initiatives towards Climate Change Mission (April 21-22, 2017) at Shaheed Bhagat Singh Evening College, University of Delhi.
- **"Bank erosion along river Ganga: A comparative case study of upper and downstream of Farraka Barrage"** in National Conference on Climate Change: Sustainable Agriculture and Environment (17- 18, March 2018), Organised by Department of Geography, Aligarh Muslim University, Aligarh.
- **"Assessing Shifting River Course and Channel Dynamic of River Ganga: A Study on Upper and Down Stream of Farakka Barrage"** in 30th National Conference of IGI on Geomorphology, Environment and Society organized by Department of Geography, Jamia Millia Islamia, New Delhi, 3 to 5 October 2018.

Undertaking by the Principal Investigator

To

The Secretary
SERB, New Delhi

Sir

I **Md Nawaj Sarif** herby certify that the research proposal titled **Improving management strategies for flood and river bank erosion employing artificial intelligence (AI) and explainable artificial intelligence (XAI)** submitted for possible funding by SERB, New Delhi is my original idea and has not been copied/taken verbatim from anyone or from any other sources. I further certify that this proposal has been checked for plagiarism through a plagiarism detection tool i.e.. 'Turnitin' approved by the Institute and the contents are original and not copied/taken from any one or many other sources. I am aware of the UGCs Regulations on prevention of Plagiarism i.e. University Grant Commission (Promotion of Academic Integrity and Prevention of Plagiarism in Higher Educational Institutions) Regulation, 2018. I also declare that there are no plagiarism charges established or pending against me in the last five years. If the funding agency notices any plagiarism or any other discrepancies in the above proposal of mine, I would abide by whatsoever action taken against me by SERB, as deemed necessary.

Md Nawaj Sarif
08.08.2023

MD NAWAJ SARIF
Signature of PI with date
Name / designation

GOVERNMENT OF WEST BENGAL
OFFICE OF THE SUB-DIVISIONAL OFFICER
JANGIPUR SUB-DIVISION,
DIST MURSHIDABAD

CERTIFICATE FOR OTHER BACKWARD CLASSES

Certificate No. *21694* **Date:** 02/02/2012

This is to certify that MD NAWAJ SARIF

son/daughter of MD HASIMUDDIN BISWAS *of*

village MOHESPUR *P.O.* MOMREJPUR

P.S. FARAKKA *in the district Murshidabad of the state of West Bengal belongs to the* Jolah (Ansari-Momin) *community which is recognized as a Other Backward Class (Category* A*) by the Government of West Bengal, under:-*

NO. 705-TW/EC DT. 13/12/94

and by the Government of India for the State of West Bengal, Under:-

NO. 12011/96/94/BCC DT. 09/03/1996

MD NAWAJ SARIF *and his family ordinarily reside(s) in the District of Murshidabad of the state West Bengal.*

This is also to Certify that he does not belongs to the category of persons/section (Creamy Layer) to whom reservation shall not apply as per provision contained in the schedule mentioned in Order No 347-TW/EC. Dt. 13-07-94 and subsequently modified vide Order No 1518-BCW, dated the 20th May, 2009 of the Backward Classes Welfare Department or in Column No. 3 of the Schedule to the Govt. of India, Department of personnel .Training O M. No. 36012/22/93-Estt(SCT) Dated 8-9-93, subsequently revised vide O.M. No. 36033/3/2004-Estt (Res) dated the 9the March, 2004 and O.M. No. 1-1/2008-U.I.A. dated the 13th October, 2008.

Place : Raghunathganj

Date: 02/02/2012

SUB-DIVISIONAL OFFICER MURSHIDABAD

Sub-Divisional Officer
Jangipur, Murshidabad

Sub-Divisional Off...
Jangipur
P.C. Raghun...nj
Dist. Mursh...bad

Note ... t used here shall have the same meaning as in the section 20 of the Representation of the People Act, 1950 (43 of 1950)

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Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/iswcr

Original Research Article

Evolution of river course and morphometric features of the River Ganga: A case study of up and downstream of Farakka Barrage

Md Nawaj Sarif [a, *], Lubna Siddiqui [b], Md Safikul Islam [a], Neha Parveen [a], Monojit Saha [c]

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Ganga
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Landsat

ABSTRACT

River channel shifting in the deltaic regime is an unabated occurrence. Channel shifting has become one of the concerns as it influences land use/land cover along the riverbank in various ways. For the management of the river, it is indispensable to study the pattern of river course change both in qualitative and quantitative methods. This study is an attempt to understand the pattern of shifting and to quantify erosion and deposition of the river Ganga at upstream and downstream of Farakka Barrage during 1794–2017. The study has been carried out by using various historical maps, aerial photographs, satellite imagery, and remote sensing and GIS technique to understand the dynamic of the river. Over 223 years period shifting of the river accentuates the remarkable oscillation of the river. Perimeter of the river is determined to understand the area covered by the river course in the study area. To evaluate the meandering of the river sinuosity of the river has been computed in this study. The amount of erosion and deposition was calculated in this study by using ArcGIS 10.6. The study found a higher amount of erosion at the east bank where Manikchak, Kaliachak II and Kaliachak III blocks are situated between 1965 and 2017. At the west bank of the river, especially the Rajmahal block, the occurrence of deposition was remarkable during the same period.

1. Introduction

The Ganga river system is one of the largest river systems in the world covering 1.09 million km^2 catchment area which is fed by its numerous tributaries throughout its course (Dewan et al., 2017). As the river passes through different geomorphic characters in the deltaic region, the river repeatedly adjusts itself which leads to erosion and deposition (Mondal & Satpati, 2012). River Ganga has been changing its course for the last three centuries causing inactive channels to be left behind (Rudra, 2009). Das et al. (2017) have observed that the erosion process is very fast in west Bengal since the last few decades. The erosion takes place mainly in the monsoon season which is between June and September and pre and in the post-floods both at the up and downstream of Farakka Barrage (Rudra, 2006). In the last five decades, bank failure has become one of the most problematic natural events in the district of Malda and Murshidabad along the river Ganga (Das et al., 2012). Riverbank erosion is not only influenced by climate change, amount of water discharge, type of soil, hydrological and physiological variation, but also anthropological activities, such as different construction along river, dam construction on river, land-use change, etc. (Li et al., 2007; Roy & Sahu, 2016; Surian et al., 2011). River Bank erosion has a great impact on livelihood in the form of losses of agricultural land, infrastructural losses, population displacement, etc (Hassan et al., 2017). While other disasters such as floods and cyclone allows people to recover from the damage to infrastructures, river erosion often causes total loss of households which is often irrecoverable (Howlader & Rahman, 2016). Therefore, the assessment of the river dynamics and the quantification of erosion and deposition is indispensable for the management of a river.

As the river carries different quantities of water and sediments at different stages in response to its topographic and other

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geomorphological conditions, the shape of the river also varies (Abidin et al., 2017; Laha, 2015). When the river is not capable of carrying its sediments, it becomes sluggish and deposition of alluvium occurs on the inner bend. Direct flow against the bank induces cutting of the bank and resulting sediment deposits on the other sides as the river doesn't have sufficient energy to carry its sediments at that stage (Laha & Bandyapadhyay, 2013).

Farakka Barrage was constructed in 1975 for diverting 40,000 cusec (1132.67 m^3/s) water, which led to changes in the sediment dynamics causing accelerated bank erosion at both the upstream and downstream of the Farakka Barrage (Debanshi & Mandal, 2014). After the construction of Farakka barrage, the size of sediment texture has been increasing since 1975 at the downstream of the barrage due to the increasing water content and its capacity and competence (Roy & Sengupta, 2019). About 700 million tons sediments per annum are carried by the river Ganga and 300 tons of it is being trapped by the pond near the Farakka Barrage-which encourages river to change its course by cutting its bank (Rudra, 2006). Siltation and sedimentation with discharge variation leads to bank shifting at the upstream of Farakka Barrage (Mandal, 2017). Depth of the river Ganga decreases when it traverses in West Bengal due to depositions of millions of tons of sediments and in the monsoonal season when the water discharge increases due to pressure on the banks which induces bank erosion (Thakur et al., 2012). According to Rudra (2009) due to the intervention of Farakka Barrage, approximately 87 million m^3water per year is entering the barrage, this flow of water is obstructed which leads to increased pressure to the natural flow both in the upstream and downstream of the barrage leading to increased erosions. According to Ghosh (2007), soil material at the east bank of the upstream of Farakka Barrage and both sides of the bank at the downstream of Farakka Barrage is not capable to prevent erosion like pave and spur. Ghosh (2007) found in the downstream of Farakka depth of the river at West Bengal is high as compared to the east bank. Banerjee (1999) reported till 1990 river Ganga erosion affected 47 villages at Manikchak, 17 villages at Kaliachak II and 66 villages at Kaliachak III of Malda district. Therefore, in light of the impacts of the barrage which is situated in the study area, it is necessary to

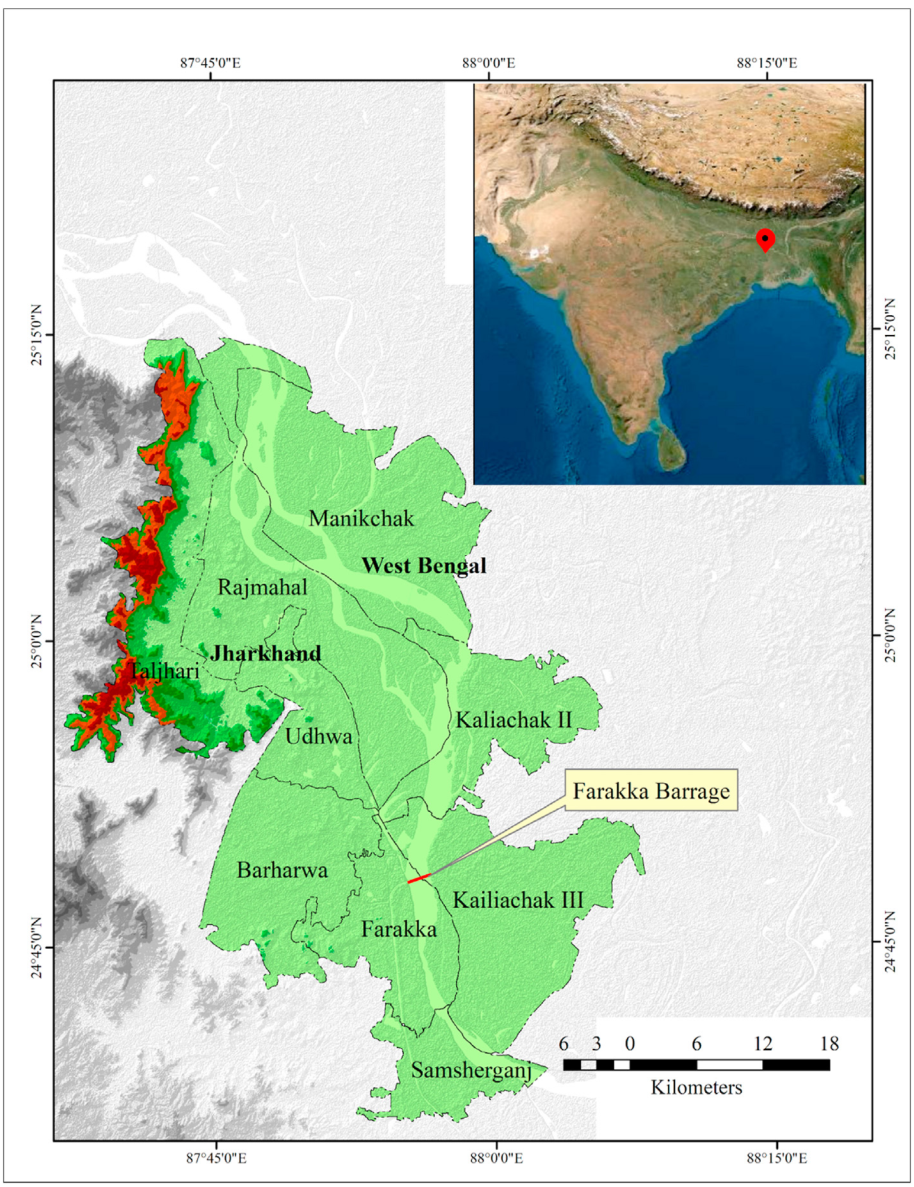

Fig. 1. Location of the study area.

Table 1
Brief administrative detail of the study area.

Sl. No.	Name of the block	District	Total population	Population Density (km^2)
1	Farakka	Murshidabad	274,111	132.72
2	Samsherganj	Murshidabad	284,072	84.21
3	Kaliachak III	Malda	359,071	259.99
4	Kaliachak II	Malda	210,105	222.73
5	Manikchak	Malda	269,813	321.78
6	Rajmahal	Sahibganj	145,899	140.76
7	Udhwa	Sahibganj	177,263	214.83
8	Taljhari	Sahibganj	763,30	273.03
9	Barharwa	Sahibganj	180,770	187.33

Source: Census of India, Sahibganj, (2011); DISTRICT CENSUS HANDBOOK MURSHIDABAD (2011): District Census Hand Book, Maldah, (2011).

study the morphological evolution of the Ganga river.

Remote Sensing and GIS techniques applied using multi-temporal satellite images and aerial photography gives good results for the study of river course change (Kumar Pal et al., 2017; Sarma et al., 2007). Aerial photography and satellite images offer a better understanding of river morphology and its Spatio-temporal changes (Gilvear and Bryant, 2016). For the monitoring of oscillation of river channel, remote sensing and GIS are is very efficient and cost-efficient, unlike traditional geomorphological investigation because it provides integration of data and general view of whole coverage (Langat et al., 2019). Remote sensing and GIS tools extract information and obtain specific measurements about the spatio-temporal changes in the river course (Aher et al., 2012) and affords a comprehensive view of the whole area for riverbank line shifting monitoring (Sarkar et al., 2012). Geo-spatial technique provides an excellent framework for data synthesis, measurement, and analysis which are very important for the assessment of river dynamics (Yang et al., 1999). The quantification of the channel sinuosity of a river is a vital part of the morphometric analysis as it is an indicator of channel flow and morphology characteristics (Karki & Nakagawa, 2019). Earlier different scholars like Ghosh (2007); Laha and Bandyapadhyay (2013); Thakur et al. (2012) attempted to quantify the sinuosity index of the river in the study area, however, the method for determining centerline of the river is not done using established GIS technique.

This study incorporates a novel GIS technique for the determination of the centerline of the river channel and subsequent calculation of the sinuosity index of the Ganga River in the study area. In the previous studies, various methods had been used to show erosion and deposition but the computation of eroded and deposited land was not clearly quantified according to the affected administrative unit, therefore in order to address this research gap, land erosion and deposition was calculated for the corresponding administrative areas in a systematic manner in this study.

The paper aims at exploring the river course shifting dynamics between 1794 and 2017 using historical maps and remote sensing. The sinuosity is calculated as a measure of the extent of the morphometric changes. The erosion and accretion dynamics are explored between 1965 and 2017 and the river dynamics and spatial distribution is depicted considering the local administrative unit i.e. Blocks. The study shall, therefore, be vital for future spatial planning considering historical river dynamism and erosion-accretion dynamics.

1.1. Study area

The concerned area of the study extends between latitude from 24°37′ N to 25°13′30″ N and longitude from 87°44′ E to 88°0′32″ E. The lower River Ganga flood plain covers part of West Bengal and Jharkhand states of India. The Indian administrative hierarchy consists of 35 States/Union which are further divided into districts and then sub-districts which are often called “Blocks” (Government of India, 2011). The river stretches from the Rajmahal block to the end of the Samsherganj block (Fig. 1). The study area comprises part of four blocks from the Sahibganj district of Jharkhand, two blocks from Murshidabad and three blocks from the Malda district of West Bengal. Rajmahal along the river Ganga (Table 1).

At Rajmahal the east bank of the river is enclosed by the hilly region and the west bank is dominated by alluvial flood plain (Mitra, 2015; Sinha & Ghosh, 2012). At Farakka 2.62 km Barrage was constructed in 1975 to boost the Bhagirathi river for improvement of navigation status of Kolkata port (Rudra, 2006). Different layers of alluvial are deposited in the study area in different time periods which can be characterized by old and active flood plain sediment characteristics (Laha, 2015). At the upstream of Farakka Barrage three tributaries, Udhua Bahadubi, Kadalkati, and Gumani, are situated and at the downstream of Farakka barrage, Baghmari tributary joins the west side of river Ganga in the study area (Ghosh, 2007).

1.2. Database and methodology

The present study is was carried out with the help of cartographic and geospatial techniques. Block and district level maps were collected from different government organizations and online galleries. Satellite images were acquired from Landsat 5 for 1996 and Landsat 8 OLI/TIRS for 2017 while Corona images were obtained for the years 1965 and 1980 (Tables 2 and 3). The river course change was examined in the present study for 223 years from 1794 to 2017.

1.2.1. Geo-processing and image processing of the data/ preprocessing of satellite imageries

Cartographic maps and aerial photography were georeferenced by raster to raster rectification by selecting ground control points. All the maps and aerial photography were referenced in UTM projection with WGS84 datum (Akter et al., 2017). Block maps were provided by land record office and satellite images were the base of geo-referencing. RMS (root square mean) error is estimated after georeferencing. In the map of *Bengal, Bihar & c north* in 1794, RMS error is 7.8 m, for *District Malda* and *District of Moorshedabad it* is 6.6 m and for *The Provinces of Bengal* is 5.9 m. Eq. (1) is used for estimating the RMS error:

$$\mathrm{RMSE}=\sqrt{\frac{\sum_{i=1}^{n}(p_i-O_i)^2}{n}} \tag{1}$$

Where, p_i is the predicted ground point, $O_i$is the observed ground point and n represents the number of selected ground points.

ATCOR model was run for atmospheric correction using ERDAS IMAGINE 14 (Nazeer et al., 2014; Pflug et al., 2014). All the satellite

Table 2
Data sources and characteristics.

Data	Source	Resolution/Scale	Year
LANDSAT- 5 -TM	USGS	30	1996
LANDSAT -8 - OLI/TIRS	USGS	15	2017
Block Maps of Malda District	Land Record Office, Malda	1:50,000	–
Block Maps Murshidabad District	Land Record Office, Murshidabad	1:50,000	–
Block Map Sahibganj District District	Census of India	1:20,000	2011
Bengal, Bahar & c north	David Rumsey Historical Map Collection	1:750,000	1794
District Moorshedabad	Online gallery of British Library	1 : 253440	1875
District Maldah	Online gallery of British Library	1 : 253440	1875
The Province of Bengal	Online gallery of British Library	1 : 1013760	1907

Table 3
Aerial photographs used in the study.

Entity ID	Acquisition year	Ground resolution
DS1021-2134DF035	1965	2.74 m (9 feet)
DS1021-2134DF036	1965	2.74 m (9 feet)
DS1025-2134DF102	1965	2.74 m (9 feet)
DS1021-2134DF033	1965	2.74 m (9 feet)
DS1021-2134DF032	1965	2.74 m (9 feet)
DZB1216-500514L004001	1980	6.096 m (20 feet)

Note: All the imageries are Corona data from USGS.

images maps and aerial photography were clipped to the study area by subsetting using ERDAS IMAGINE 14 and ArcGIS 10.6. The spatial resolution of the maps from different sources and resolutions were resampled to 30 m resolution in coherence with the Landsat TM spatial resolution.

1.2.2. Delineation of the river course

Analysis of the river course change was performed by comparing historical maps and current aerial photography and satellite images (Roccati et al., 2019). River course was defined by visual interpretation by on-screen manual digitization in (Hassan et al., 2017; Laliberte et al., 2001; Sarker et al., 2014) Single user digitization was employed by maintaining a constant zoom level of 1:5000 for all the different maps and satellite images that were used, this ensured consistency in terms of visual interpretation.

1.2.3. Morphometric analysis

1.2.3.1. Method for measuring sinuosity. River sinuosity determines the degree of meandering of a river channel. The sinuosity of a river is the ratio between the length of the river bed (which is channel length) and the shortest distance of the river bed from beginning to the end (which is valley length). Sinuosity increases with increasing the meandering. (Brice, 1964).

$$SI = \frac{LC}{LV} \tag{2}$$

Where,

SI – Sinuosity index
LC -Length of the channel
LV- length of the valley

After defining the mid-channel line of river courses, the sinuosity of the river was calculated using the HWATH's tool which is also an ArcGIS extension using Eq. (2) (García, 2014).

In order to determine the centerline of the river channel in different years, the 'polygon to centerline tool' was used in ArcGIS 10.6 (Karrasch et al., 2015) (Fig. 2). Due to the presence of several sand bars and islands in the study area, river Ganga forms multiple channels which creates difficulty to determine the centerline. Here in this study centerline of the widest channel has been considered for the calculation of the sinuosity index (Dabasis Ghosh, 2007).

1.2.3.2. Delineating river dynamics between 1794 and 2017. Rudra (2006) discussed in his study how the distance between the railway track and part of river Ganga is decreasing from last few decades. In this paper, the river channels were defined and the perpendicular distances of the railway stations from either the east and west bank was measured for the different years. Here, we consider the position of the railway stations to be constant for the entire period of the study. We measured the perpendicular distance between each railway station and the adjacent riverbank line for several years (1794, 1857, 1907, 1965 and 2017). Increasing or decreasing distance between the railway station and river Ganga in the study area gives us a general idea of river dynamicity.

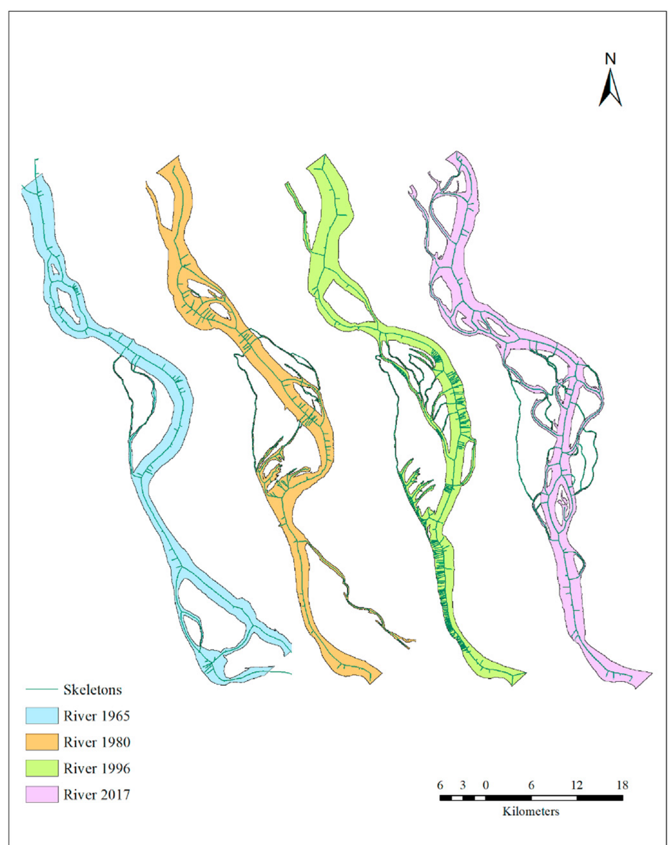

Fig. 2. Skeleton of river courses for extraction of centerline.

1.2.3.3. Mapping of erosion and deposition. River course polygons of 1965, 1980, 1996 and 2017 were superimposed. After superimposing these polygons of river channel erosion and deposition of the study area due to river course change was calculated for both the east and west banks (Deb & Ferreira, 2015). As the river is flowing from north to southward, instead of using left and right banks in the study, east and west bank term have been used for better convenience. The area of erosion and deposition of the river was extracted by overlay tool in ArcGIS 10.6 between the years 1965–1980, 1980–1996, 1996–2017 and 1965–2017 (Mukherjee et al., 2017). By clipping these eroded and deposited land polygons, block-wise bank erosion and deposition was calculated in ArcGIS 10.6 (Fig. 3).

2. Results

2.1. River course dynamics between 1794 and 2017

It has been observed that river Ganga is adjusting its course over a period of time. Thus, in the present study, an attempt has been made to detect the river course change in the study area from 1794 to 2017. Fig. 4 depicts the change of the river channel at different particular times from nearest railway station.

Total of 14 nearest stations along the river Ganga from both the east and west banks were selected for the study of change detection of the river (Fig. 4). In Table 4 historical analysis of river course change over the period of 223 has been done which reveals a drastic change of the river course between the years 1794–2017. The distance of the station from the river Ganga for 223 years has been changing drastically. Higher the variation of the distance from the stations to river Ganga higher the shifting in the river course. Table 4 reveals that Jamir Ghata, Gour Malda, Malda and Adina stations on the east bank side and Dhulian Ganga, Sankopara station distance varies more than 10 km from 1794 to 2017. Concerning the increase or decrease of distance, changing distance from the stations to the river is not gradual except Dhulian Ganga and Sakhopara station. In the case of Malda station, distance from Ganga to Station decreased from 30.62 to 14.72 during 1794–1857 but in 2017 again the distance has increased up to 19.99 km. On the other hand, the distance from the present Dhulian Ganga station has decreased from 14.64 km to 2.11 km from 1794 to 2017 respectively and it is gradual.

2.2. Morphometric changes in the River Ganga from 1965 to 2017

From 1965 to 2017 river Ganga in the study area is changing its morphometry in different aspects. Here one aspect of morphometry of the river was discussed as follows:

To the downstream of Farakka, the river bifurcated into two branches. One of the braches used to flow from north to southeast and another from north to south (Fig. 5). It can be identified from the aerial photography of 1965 that the river flowing north to the southeast was the main channel and the other was a sub-channel. In 1980, the channel which was flowing from north to south became the main channel and another became sub-channel (Fig. 5). A lot of siltation can be identified to the sub-channel in 1980. It was the post-Farakka Barrage scenario of downstream of Farakka Barrage. In satellite images of 1996 and 2017, the channel which was more active in 1965 is now moribund. The paleochannel is known as '*Mora Ganga*' (Dead Ganga) by the local people. However, in the monsoonal season, waterlogging in some of the areas of paleochannel takes place; it is not connected with the present active channel due to avulsion.

Sinuosity is categorized into four categories such as straight

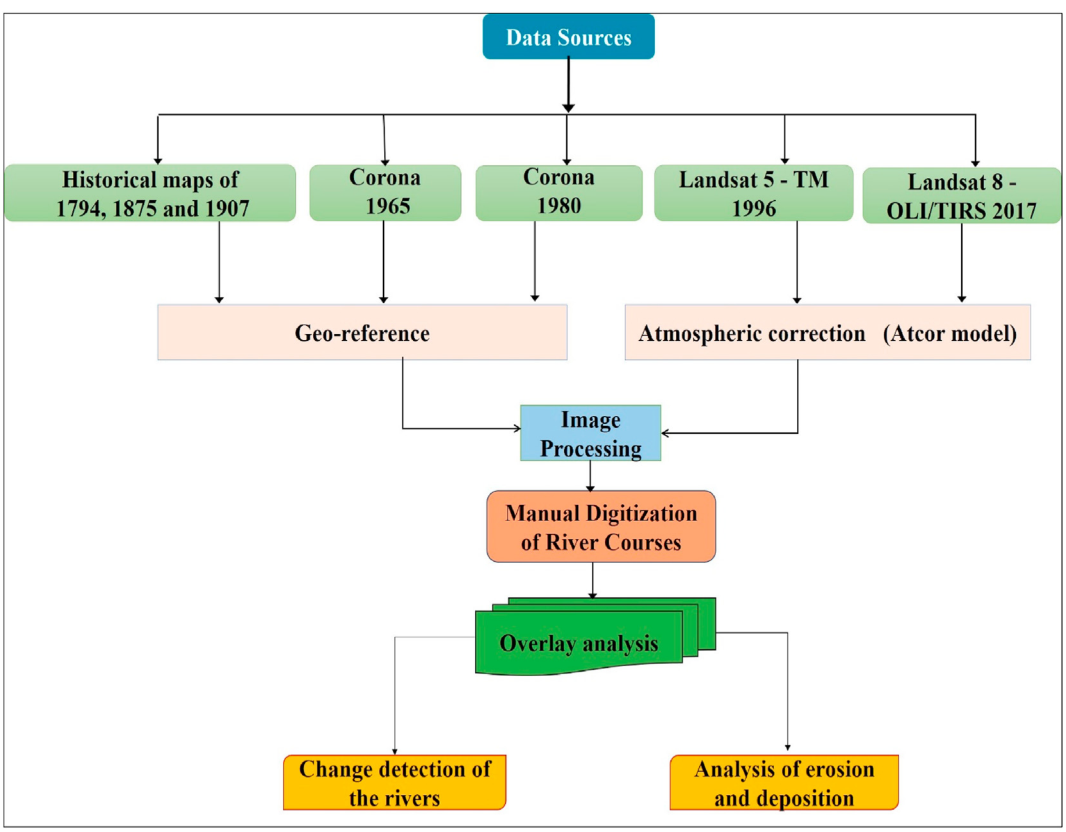

Fig. 3. Flow chart of river course study.

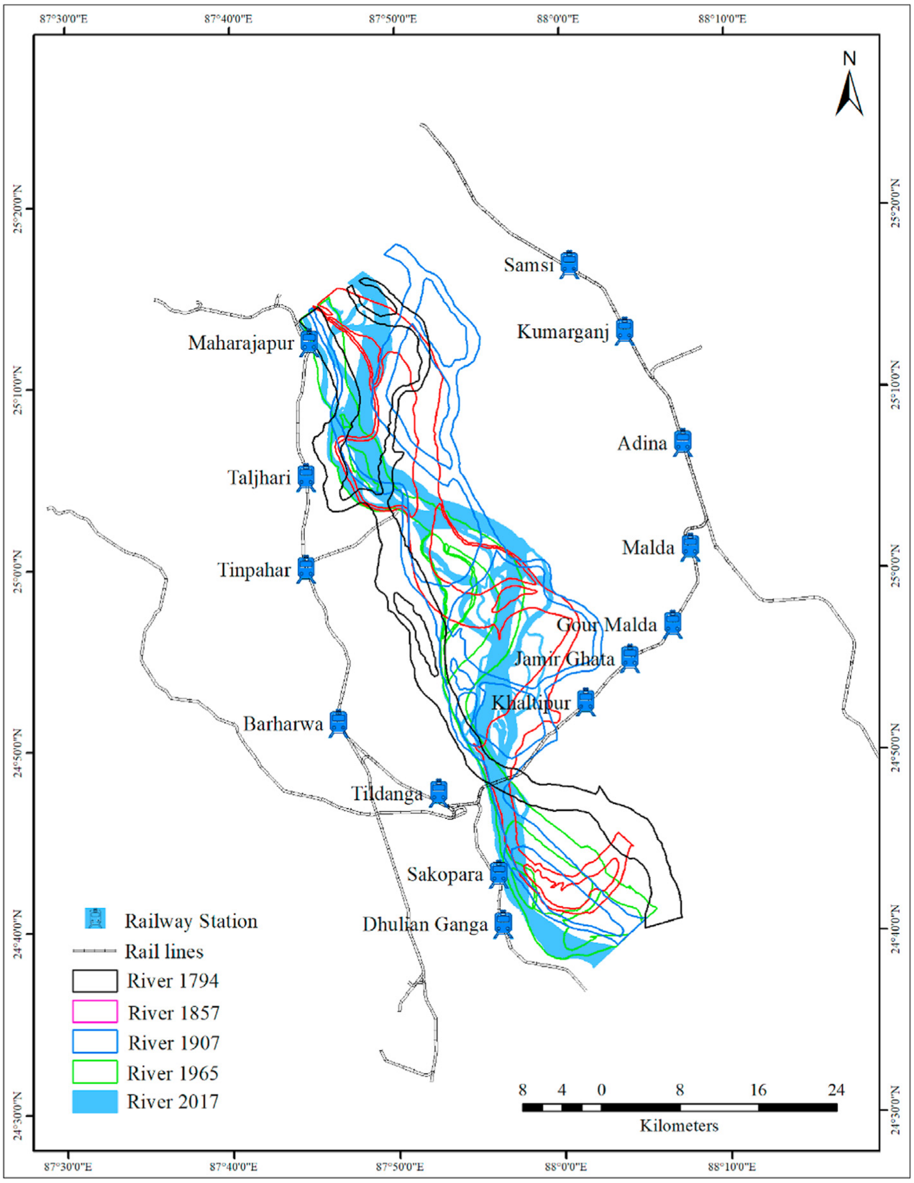

Fig. 4. Stations along the River Ganga of 1794, 1857, 1907, 1965 and 2017 in the study area.

Table 4
Approximate distance (kilometer) between River Ganga and nearest stations in different periods.

S. No.	Name of the station	Year				
		1794	1857	1907	1965	2017
1	Samsi	17.73	18.51	12.99	28.18	23.59
2	Malda	30.62	14.72	13.32	22.15	19.99
3	Khaltipur	12.68	3.316	4.36	12.43	8.38
4	Sakopara	10.34	2.32	1.616	1.05	0.58
5	Dhulian Ganga	14.64	4.73	4.1	2.53	2.11
6	Barharwa	10.25	18.36	13.57	13.73	13.67
7	Tinpahar	9.22	12.18	12.55	11.93	11.93
8	Taljhari	2.341	4.26	4.77	3.38	3.29
9	Tildanga	5.348	6.94	6.94	6.44	6.29
10	Maharajapur	0.49	3.41	1.44	0.24	0.18
11	Adina	32.26	22.99	22.82	22.91	20.96
12	Gour Malda	25.97	11.02	8.06	18.37	14.78
13	Jamir Ghata	20.42	8.66	4.16	19.32	10.81
14	Kumarganj	28.21	24.19	22.25	30.75	30.09

(<1.05), sinuous (1.05–1.3), moderate meandering (1.3–1.5) and meandering (>5) (García, 2014). In the study area, river sinuosity varies from 1.19 to 1.24 from 1965 to 2017 (Table 5). The calculated value is indicating that river Ganga is sinuous in the study area. Among the river of four-time periods such as 1965, 1980, 1996 and 2017 the river Ganga of 2017 is more sinuous (1.24) as compared to the previous year's river (Fig. 6).

2.3. Erosion and deposition mapping of River Ganga in the study area

In the study area, both erosion and deposition took place during 1965–2017. In fact, both the west and east bank of the river have experienced river bank erosion as well as accretion or deposition (Fig. 7).

During this time period, the river Ganga continued to oscillate its course. The east bank of upstream and downstream of the Barrakka Barrage covers about 67.09 kms and 24.06 kms stretch respectively. This part of the river experienced lateral erosion of

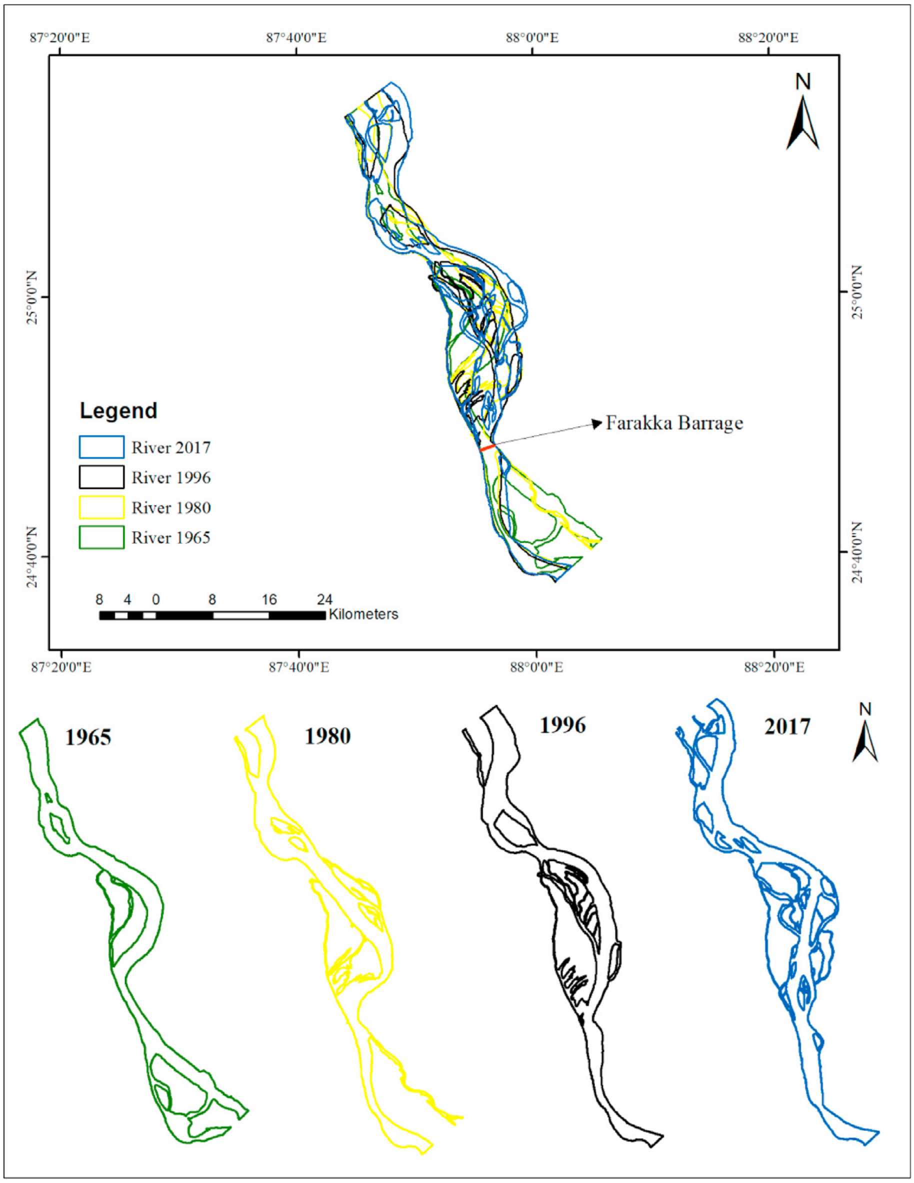

Fig. 5. Courses of river Ganga at a glance in 1965, 1980, 1996 and 2017 at the study area.

Table 5
Sinuosity index.

Year	Sinuosity
1965	1.21
1980	1.19
1996	1.19
2017	1.24

62.64 km^2 whereas 26.7 km^2 land deposited in these sections between 1965 and 1980 (Tables 6 and 7). In the same time span the west bank which covers 66.72 km at the upstream and 25.51 kms stretches at the downstream of Farakka Barrage eroded 30.13 km^2 and 6.72 km^2 respectively. In the time span, the amount of deposited land at the west bank of upstream was 36.32 km^2 while the downstream of the west bank experienced no deposition of land. It can be manifested that the river Ganga is not stable at the east side of the upstream of Farakka Barrage. However, some of the areas of east bank experienced deposition during 1965–1980 but part of this deposited land was again engulfed by the river from 1980 to 1996 (Fig. 7(a) and (b)). Fig. 7(b) reveals that the bifurcated channel started fading from 1965 to 1980 became moribund during 1980–1996. In the time period of 1996–2017, the east bank experienced lateral erosion of 61.99 km^2 at the upstream of Farakka Barrage and 11.66 km^2 at the downstream. During the same period west bank of upstream and downstream of the Barrage experienced 57.55 and 1.62 km^2 deposition. Meanwhile, deposition occurs over 31.91 km^2 land at the east bank and over 59.17 km^2 land at the west bank (Table 7). The overall erosion of the river during 1965–2017 was 99.54 km^2 at the east bank upstream while at the downstream it is 13.39 km^2 (Table 6). The overall erosion at the upstream and downstream of the Barrage during this period was 18.98 km^2 and 7.9 km^2 respectively. In the same duration east bank of upstream and downstream of the Barrage experienced 6.1 km^2 and 45.45 km^2 deposition while the amount of deposited land at the east bank of the upstream and downstream was 75.48 and 1.62 km^2 (Tables 6 and 7).

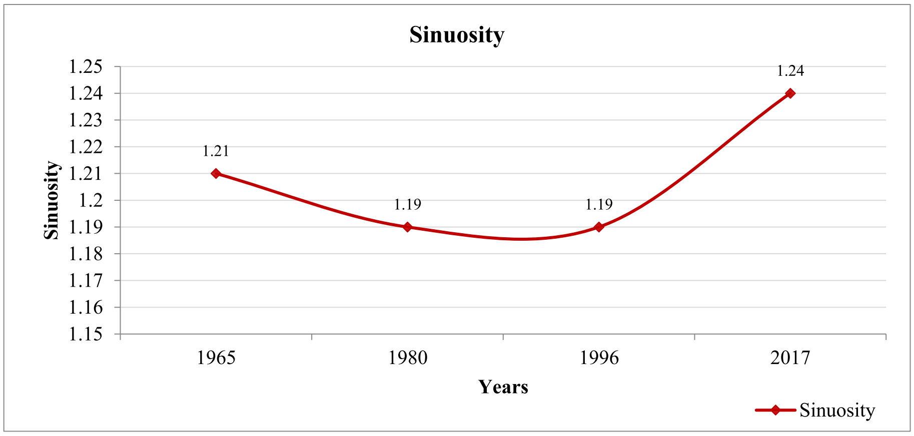

Fig. 6. The sinuosity of the river in the study area.

2.3.1. Block wise erosion and deposition mapping from 1965 to 2017

As discussed, the east bank of river Ganga experienced higher bank erosion leading to Manikchak, Kaliachak I and Kaliachak II blocks being severely affected by riverbank erosion. It can be confirmed that the amount of erosion on the west bank is less than the amount of deposition.

Manikchak block is situated in the Malda district, experienced immense land loss due to bank erosion between 1965 and 2017. Around 40 km length of river Ganga passes through this block which covers the western side of the block. As reported in Table 8, in the period between 1980-1996 and 1996–2017, this block experienced erosion of 35.42 km^2 and 30.68 km^2 respectively. Fig. 7(a), 7(b), 7(c), and 7(d) reveals that during 1980–1996 and 1996 to 2017, the amount of deposition in this block was also significant (Table 9) but most of the deposited lands formed as islands which are detached from the bank.

In the Kalichak II block of the Malda district, there is a high variation in erosion and deposition during 1965–2017 (Fig. 8). Table 8 highlights that between 1965 and 1980, the erosion was found over 28.04 km2land but the deposition at this block was high as well that of 5.93 and 12.68 km^2. In the period 1996–2017 deposition (23.10 km^2) was substantially higher compared to erosion (11.93 km^2).

In the Kaliachak III block, the river bifurcated into two wide channels in 1965 which became moribund later resulting in a significant amount of deposition to this block (Fig. 7(a) and (b), Table 9).

The Samsherganj block is situated at the west bank of the river in Murshidabad district. Dhulian town which is one of the most important trade centers in Murshidabad is situated at the bank of the river in this block. In the interval of 1965–80, erosion in Samsherganj block was 52.9 km^2 (Table 8). The overall erosion from 1965 to 2017 is 5.34 km^2 where deposition is comparatively very less.

River Ganga passes a stretch of 19 km west bank and about 10 km of its east bank through the Farakka which is one of the blocks of the Murshidabad district in West Bengal. Areas adjacent to the west bank of this river are densely populated and erosion during 1965–80 and 1996–2017 was 724.49 and 14.85 km^2 (Table 8). From 1965 to 1980 deposition was about 4.61 km^2 which occur to the east bank of the river which was not densely populated at that period (Table 9). It can be found in Fig. 7(a), 7(b), 7(c), and 7(d) that throughout the period of 1965–2017, west bank line of river Ganga in this block is comparatively less curved and it is also noticeable that in the same period due to westward shifting of the river, west bank line is becoming straight.

The Barharwa block is part of the Sahibganj district which is situated at the west bank of the riverbank. Less than 1 km of the Ganga passes through this block. Erosion and deposition are not as significant as other blocks. During 1965–1980, the eroded land from this block was 0.09 km^2.

Udhwa block is also a part of the Sahibganj district which covers about 8 km strip of the river. Table 8 and 9 reveals that from 1965 to 1980 erosion was significant (1.01 km^2) but after that erosion was reduced in this block. However, this block experiences a good amount of deposition during 1996–2017 (20 km^2). Part of the main channel at the study area traversed at the southern part of Udhwa block in 1965 but in the interval of 1965–1980, the river shifted eastward due to meandering and since then only anabranches of the river are found in this block.

In the Rajmahal block, part of the Sahibganj district, both erosion and deposition are high. About 55 km stretch is covered by river Ganga in this block. During 1965–1980 and 1996–2017 erosion from this block is 31.93 km^2 and 33.61 km^2 respectively (Table 8). During 1965-80 some area of the southeast portion of the block was eroded by the river and land was deposited in the same area during 1980–96. Overall deposition is higher as compared to erosion between 1965 and 2017 in this block (Table 8 and 9). In Fig. 7(d), it can be seen that the river splayed in a number of anabranches from 1965 to 2017 which leads to the higher complexity of the morphological dynamic in this block. The southern stretch of the block is very unstable while between 1965 and 1985, the deposition was prominent but from 1996 to 2017, erosion was higher. Oscillation of narrow anabranches in this block can be found (Fig. 7(c) and 7(d)) which also induces many river islands, sandbars, and sandbanks.

About 7–8 km strip along the Ganga River is going through the Taljhari block situated in Sahibganj District. During 1965–1980, erosion was less (0.19 km^2) however deposition was 0.74 km^2 was significantly higher.

3. Discussion

Stretching from the immediate upstream of Farakka Barrage to Rajmahal hills, the Ganga erodes more at the east bank as compared to the west bank due to the presence of hard rock of Rajmahal hill at the west bank (Thakur et al., 2012). In this study, we noticed that the river is relatively more stable in the blocks in the western bank i.e. Barharwa, Tinpahar, Maharajapur, and Tildanga stations of Sahiganj district between 1796 and 2017, which is reflected in the relatively less variation of distance between the railway stations and the west bank. Laha (2015) compared old channel and present

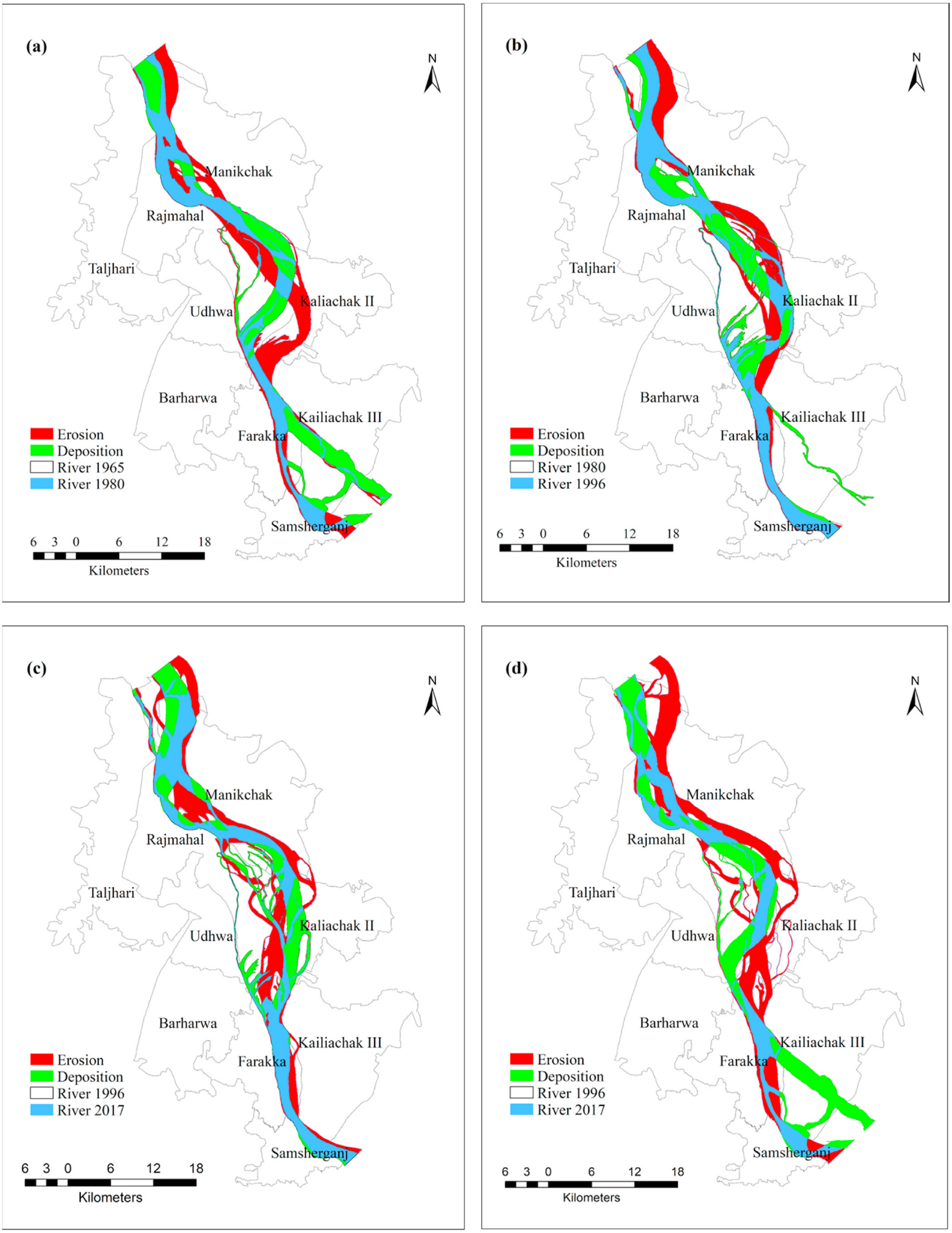

Fig. 7. Erosion and deposition of river Ganga in the study area during (a) 1965–1980, (b) 1980–1996, (c) 1996–2017 and (d) 1965–2017.

Table 6
Erosion in upstream and downstream of both banks from 1965 to 2017 in km^2.

Year	East Bank		Total	West Bank		Total
	Upstream of Farakka Barrage	Downstream of Farakka Barrage		Upstream of Farakka Barrage	Downstream of Farakka Barrage	
1965–1980	62.64	8.54	**71.18**	30.13	6.72	**36.85**
1980–1996	64.86	3.67	**68.53**	17.49	1.32	**18.81**
1996–2017	61.99	11.66	**73.65**	34.46	0.39	**34.85**
1965–2017	99.54	13.29	**112.83**	18.98	7.90	**26.88**

Table 7
Deposition in upstream and downstream of both banks from 1965 to 2017 in km^2.

Year	East Bank		Total	West Bank		Total
	Upstream of Farakka Barrage	Downstream of Farakka Barrage		Upstream of Farakka Barrage	Downstream of Farakka Barrage	
1965–1980	26.7	45.86	**72.56**	36.26	–	**36.26**
1980–1996	8.27	9.41	**17.68**	69.78	–	**69.78**
1996–2017	31.6	0.31	**31.91**	57.55	1.62	**59.18**
1965–2017	6.1	45.45	**51.55**	75.48	1.62	**77.11**

Table 8
Blockwise erosion in different time periods (in km2).

Block	Year			
	1965–1980	1980–1996	1996–1917	1965–1917
Taljhari	0.19	0.35	0.36	0.24
Rajmahal	31.93	18.72	33.61	28.79
Udhwa	1.01	0.10	0.002	0.48
Barharwa	0.09	0.01	0	0
Farakka	7.24	3.81	7.78	14.85
Samsherganj	5.29	0.70	0.85	5.34
Kaliachak2	28.0	16.37	11.93	19.34
Kailiachak3	7.96	7.28	7.087	10.42
Manikchak	21.39	35.42	30.68	49.55

Table 9
Block wise deposition in different time period (in km^2).

Block	Year			
	1965–1980	1980–1996	1996–1917	1965–1917
Taljhari	0.74	1.13	0.94	2.14
Rajmahal	36.96	36.16	31.12	48.76
Udhwa	0.80	0.48	1.35	2.00
Barharwa	0.003	0.01	0.22	0.13
Farakka	4.61	0.68	1.03	2.36.
Samsherganj	0.26	0.48	1.45	0.69
Kaliachak III	30.32	12.55	2.86	33.84
Kaliachak II	5.93	12.68	23.10	4.74
Manikchak	17.46	20.26	21.85	21.62

channel with the help of secondary maps and satellite image at the west bank of the river in Malda district and calculated the distance between Gour Malda and the river was about 20 km which is corroborated by our study which finds that the distance from the Gour Malda station and river Ganga in 1796 was about 25 km (Table 4). Ghosh (2007); Rudra (2014) mentioned Dhulian town is one of the largest settlement along river Ganga which is shifting with the river course from more than last two centuries which can also be established with this study where the distance from Dhulian Ganga station to river Ganga decreased by 12.11 km from 1794 to 2017.

Several factors are responsible for the erosion and deposition in the study area. Among the factors variation in discharge of water, stratigraphy of the bank, geometry of the channel and nature of sedimentation play key role in the erosion and deposition dynamics in the study area. Year wise discharge and sedimentation data could not be obtained becausedata is restricted by Government of India due to some sensitive international issues related to Farakka Barrage. However, in the District Human Development Report: Malda (Government of West Bengal, 2007) mentioned in the lean season (March–April) the discharge of water in this area is about 55 thousand cusec (1557.42 m^3/s) and in the monsoonseason (August–September) its 18–27 lakh cusec (50970.32 m^3/s - 76455.48 m^3/s). The huge variation in the seasonal flow of the river erodes its concave bank first. As huge amount of sediments are trapped in the Farakka Barrage retention pond at the upstream of Farakka Barrage number of avulsion, anabranch and cut off are formed. The problem of siltation increased after the construction of Farakka Barrage at the downstream of Farkka Barrage. The deposited sedimentation on the river bed decreases its channel depth (Rudra, 2014). In the monsoonseason when the discharge of water is high, shallow depth of river bed is less capable of carrying water which creates pressure on the bank leading to erosion.

The east bank of upstream of Farrakka Barrage lies on the active flood plain. The soil is mostly fine sand, silt and clay and is often very deep and loamy in texture (Table 10). These physical character makes this portion highly erodible. In case of west bank of the upstream Farakka Barrage presence of Rajmahal hill makes this area complex in terms of geological and geomorphological character. Southern part of the upstream of the Barrage is covered by older flood plain and north and northern most part is covered by pediment-Pedi plain and moderately dissected hills and valleys. Erosion in this portion of bank occurred at the southern part which is constituted with alternating layers of sand silt and clay. Northern portion of upstream Farakka Barrage is occupied by very deep poorly drained soil and basaltic lithology of Rajmahal Trap. The amount of erosion is very low in this portion of the bank. Having similar bank material and geomorphology like upstream Farakka Barrage, the section downstream of Farakka Barrage also experienced high erosion between 1965 and 2017. The west bank of downstream of Farakka Barrage lies on older alluvium flood plain. Due to fine silty soil character, this area experienced lesser but gradual erosion (Table 10).

Some anthropogenic factors are also responsible for erosion in the study area. Apart from construction of Farakka barrage, long term land use change in the upper Gangetic palin influences the magnitude of erosion. The river Ganga passes through large parts of northern India. Excess use of river water for irrigation and other human utilization of river causes the lean season discharge of water

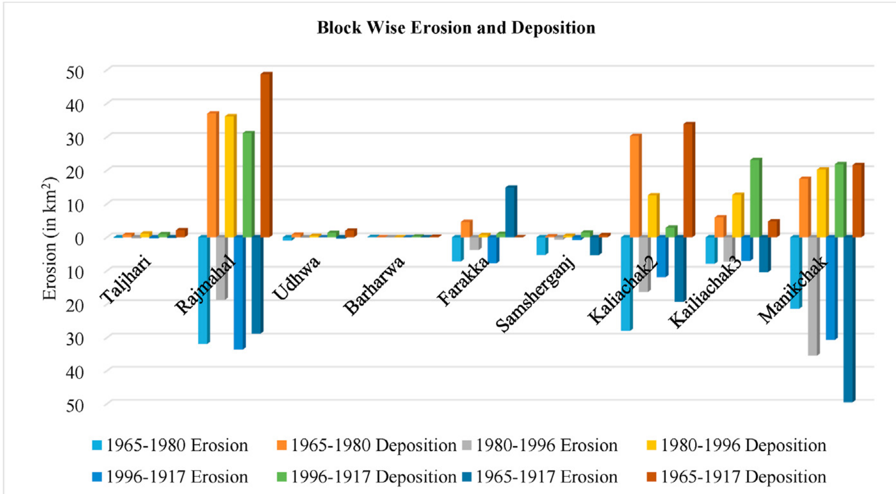

Fig. 8. Blockwise erosion and deposition from 1965 to 2017.

Table 10
Geomorpholgy and soil character of the study area.

	River Bank	Geomorphology	Description of Soil	Lithology
1	Upstream of the Farakka Barrage, West Bank	1. Older flood plain 2. Pediment-Pedi plain complex, 3. Moderately dissected hills and valleys,	1. Very deep, moderately well drained and fine silty soil. 2. Very deep, poorly drained, fine soils	1,Alternating layers of sand, silt and clay, 2. Sand, silt, clay and calcareous concentration. 3. Basic lava (Northern most part of the study area)
2	Upstream of the Farakka Barrage, East Bank	Active flood plain	Very deep, moderately well drained, coarse loamy soils.	Fine sand, silt and clay
3	Downstream of the Farakka Barrage, West Bank	Older flood plain	Very deep, moderately well drained and fine silty soil.	Alternating layers of sand, silt and clay
4	Downstream of the Farakka Barrage, East Bank	Active flood plain	Very deep, moderately well drained, coarse loamy soils.	Fine sand silt and clay

Sources: i. District Malda hydrogeological map (Government of West Bengal).
ii. District Murshidabad hydrological map (Government of West Bengal).
iii. Assessment and Mapping of Some Important Soil Parameteres Including Soil Acidity for the State of Jharkhand (1:50,000 Scale) T owards Rational Land Use Plan: Sahibganj District (Government of Jharkhand).

to be decreased significantly. The variation of water discharge between lean season and peak monsoonseason becomes higher playing a vital role in sedimentation and erosion.

Changing the sinuosity index value from 1965 to 2017 in this study is indicating the meandering of the river is fluctuating during this period. The study of Laha, 2015; Thakur et al. (2012) found the river from Rajmhal to Farakka is varying the sinuosity index from 1.12 to 1.25 from 1977 to 2010 and Dabasis Ghosh (2007)found the river sinuosity of the Ganga in West Bengal fluctuating from 1.16 to 1.26 from 1977 to 2003. In the current study, the fluctuation is 1.21–1.24 from Rajamhal to Samsherganj block from 1965 to 2017. From Figs. 2 and 5 it can be analysed that with the increase of sinuosity at the east bank of the upstream of Farakka Barrage, concavity of the river also increased during 1965–2017. This change in geometry of the river not only induced river bank erosion at the east bank of upstream of Farakka Barrage but also formed many islands, avulsions and cut offs. Deviation from the straight line of the river at the upstream of Farakka is more as compared to downstream of Farakka Barrage. This variation in meandering between upstream and downstream of Farakka barrage may be attributed to the control of water discharge by the Barrage and to the erodible soil character and geomorphology of both the banks at downstream of the barrage.

The study finds that the Manikchak block faced high erosion between 1965 and 2017 which corresponds with the findings from Das et al. (2017); Debanshi and Mandal (2014); Sinha and Ghosh (2012). As reported by Rudra (2006) many shops houses and agricultural lands were engulfed by the river due to bank failure in September 2005 in the study area. Being a densely populated area along the riverbank, Farakka block experienced agricultural land loss, human displacement and other commercial establishment loss (Ghosh & Sahu, 2019). Fig. 4 and Table 4 show the river is bending towards westward in Dhulian town for the last two centuries which leads to many commercial establishments, settlements, and other infrastructure being affected by erosion (Ghosh, 2007; Ghosh & Sahu, 2019; Rudra, 2009). Deposition is prominent at the east bank as compared to the west bank which also corresponds with the findings of Ghosh (2007) (Fig. 7).

Several sandbanks, sand bars, and islands were formed from 1965 to 2017 due to the deposition of the river in the study area. Mature sandbank became suitable for the cultivation and settlement. A small portion of landis used by the people who lost their homes and land due to bank erosion. Mukherjee (2011) reported that people living in the newly formed land known as '*Char*' are deprived of different government schemes. The unstable character of these 'Chars' makes their life more difficult. There are issues regarding the ownership of these land (Islam & Guchhait, 2017). According to the Land Record Office of Murshidabad district, these island and sandbanks are the government's property. The government gives these land to the people according to their needs.

However, during the field survey, we came to know these lands are still disputed and these are not recognized by the government. By the discussion with local people, we came to know that most of the deposited lands are used by the people who are financially well off and have power. District Human Development Report: Malda also mentioned that there are some kind of lawlessness regarding occupying these lands. As per the information of Land Record Office of Malda and Murshidabad District (West Bengal) the deposited lands are two types, deluviated and eluviated. The deluviated lands are cultivable in non-monsoon season but in the monsoonal season these lands comes under the water. These eluviated lands is not affected by the water flow in the monsoon season. The government doesnt have proper socio-economic data of the people who lost their property and livelihood due to river bank erosion. By preparing database of affected people government can distribute the eluviated land according to the loss. As these lands are occupied, the government needs to intervene to ensure equal distribution and proper management of the land. The deluviated land can be given to the agricultural labours in seasonal basis contract with the government. Another issue of these deposited land can be found in the Bengal-Jharkhand border region, where the boundary of these two states was demarcated along the river Ganga. Due to instability of the river channel, new sandbanks and island at the boundary areas have become disputed land (Rudra, 2006). Therefore, erosion and deposition process created environmental refugees who are deprived from the supply of basic rights as citizen which leads to their dire socio-economic status. The simultaneous claim on these deposited lands by the Government of Jharkhand and Government of West Bengal has made this issue more complex. If this unsolved matter can be solved by the government of India, people who are living in these lands may have some basic facilities like ration, school, health facilities etc.

4. Conclusion

The current study finds that river Ganga is highly dynamic in the study area throughout the last two centuries. By quantifying the amount of land erosion in the study area, the study affirms that the dynamic river has been the cause of large quantities of damage in the adjacent river banks. The greater dynamicity of the river is associated with changes in erosion and deposition patterns. Therefore, the spatial distribution and temporal changes in the erosion and deposition have been quantified. There is a need for further studies considering the proper management and utilization of the land deposited by river Ganga and the findings from this study may be used for such planning. A limitation of the study has been the use of historical maps that had been produced in different scales and projections and therefore their accuracies may be questionable. It can be manifested by the result that the fluvial process of river Ganga in the study area is very complex. Some of the parameters like river braiding index, percentage of island formed should also be studied for further understandings of the river morphology. The study only deals with the morphometric change of the river but factors behind the change were not studied in detail. River management authorities may consider the findings of the study before initiating development programs along the river. The block-wise quantifications will facilitate regional planning efforts in the area. Therefore, the results might be helpful for the concerned authorities for the incorporation of spatial dimensions for effective disaster management and disaster sensitive planning in the future.

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DOCTOR OF PHILOSOPHY [Ph.D.]

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Faculty: FACULTY OF NATURAL SCIENCES

The above candidate is declared eligible for the award of the Degree of Doctor of Philosophy.

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ORIGINAL PAPER

Modeling of impact assessment of super cyclone Amphan with machine learning algorithms in Sundarban Biosphere Reserve, India

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Abstract
Coastal areas play an important role in the global food and economic system, but are vulnerable to a number of coastal hazards such as cyclones and storm surges. The Sundarban Biosphere Reserve (SBR) is located on the east coast of India and has a rich diversity of aquatic and terrestrial flora and fauna. The region is frequently affected by coastal hazards such as cyclones and storm surges. The objective of this study is to investigate the impact of Super Cyclone Amphan on land use land cover (LULC) in SBR. For this purpose, the land use land cover (LULC) map of the study area before and after the cyclone was first constructed using four machine learning algorithms: Support Vector Machine (SVM), Spectral Angle Mapper and Maximum Likelihood Classifier. In addition, the accuracy of these methods was evaluated using the confusion matrix. The result shows that the SVM basis provides better accuracy than the other methods. After evaluating the accuracy, the detection of changes in the LULC was analysed. The result shows that forest cover in the region decreased significantly (about 38.8%) due to super cyclone Amphan. In addition, agricultural land, swamps, sandbanks and beaches increased by 49.51%, 39.57%, 17.40% and 6.93% respectively. The findings of this study can be used by local and state disaster management authorities to prepare the effective disaster management plans for the region.

Keywords Land use land cover · Amphan super cyclone · Impact assessment · Machine learning classifiers · Sundarban

1 Introduction

Tropical cyclones are considered as one of the most destructive natural hazards in coastal regions (Bakkensen and Mendelsohn 2019; Hoque et al. 2019). This natural hazard is characterised by remarkable destructive features such as strong winds, intense rainfall, billowy storm surges and coastal flooding, which endanger human lives, destroy property on a large scale and damage the natural environment (Ali et al. 2020; Hoque

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et al. 2016; Shultz et al. 2005). It is estimated that nearly 1.33 million people have died from tropical cyclones in the last two decades (Doocy et al. 2013). Between 1940 and 2010, the world experienced 637 cyclones, 195 of which were classified as severe (Weinkle et al. 2012). The intensity of hurricanes and their impact on coastal communities is expected to increase significantly as a result of climate change (Hoque et al. 2021; IPCC 2012). Consequently, the impacts of cyclones are expected to be more complicated than in the past (Knutson et al. 2010; Mendelsohn et al. 2012).

Sundarban Biosphere Reserve (SBR) is one of the most cyclone-prone regions in the world, located in the northern part of India's east coast (Sahana and Sajjad 2019; Badhan et al. 2023). Amphan is the first super cyclone to form in the Bay of Bengal since the Odisha super cyclone in 1999. Amphan wreaked havoc in West Bengal, coastal districts of Odisha and parts of Bangladesh on 20 May 2020 (Das et al. 2020). Amphan reached a catastrophic landfall and transformed from a cyclonic storm (CS) to a super cyclonic storm (SuCS) in just 36 h (Mishra et al. 2021). It originated as a depression over the southern Andaman Sea and the adjacent south-eastern Bay of Bengal and then developed into a depression moving north and northwest (Abhijit et al. 2020). In the south-eastern Bay of Bengal, it became a super cyclone after strengthening from a cyclone to a severe to very severe cyclonic storm (Bhowmick et al. 2020). It maintained the intensity of a SuCS with winds of 155–165 km/h and made a devastating landfall over the SBR between 1530 and 1730 h (IST) (Cyclone Warning Division 2021). The strongest 1-min wind gusts of up to 260 km/h and the highest sustained 3 min wind speed of more than 240 km/h (130 knots) were both recorded for SuCS (Khan et al. 2021). Amphan claimed 123 lives and caused $13 billion in property damage in West Bengal (Kumar et al. 2022). The West Bengal government reported severe damage to 2.9 million houses, 1.7 million hectares of farmland, 450,000 electricity poles were also grounded and 158,000 hectares of mangroves in the SBR region were severely damaged (Das et al. 2020). The impact of the cyclone is not limited to the destruction of the economy and infrastructure, but also has a significant impact on various environmental aspects (Hoque et al. 2016, 2021). After a cyclone, cyclone-affected areas are often cut off due to infrastructure damage and it is difficult to reach the affected area (Knutson et al. 2010; Bhattacharya et al. 2014). For the implementation of efficient cyclone impact management strategies, it is essential to assess the overall impact of tropical cyclones (Badhan et al. 2023). Therefore, there is a need to develop technologies that enable rapid assessment of the affected areas.

The majority of earlier research assessing tropical cyclone impacts used a land cover change detection method guided by an on-the-ground impact assessment that focused on specific impacts in the area (Hoque et al. 2016; Klemas 2009; Rodgers et al. 2009). Several researchers used the Normalised Difference Vegetation Index (NDVI) to assess tropical cyclone impacts on forests and other vegetation (Rodgers et al. 2009; Villa et al. 2012; Talukdar et al. 2022). For example, Zhang et al. 2013 extracted the spatial pattern of forests damaged by Typhoon Saomai in 2006 in their study using the vegetation aggregation index (VAI) and the decision tree method (DT). Schmidt et al. 2010 assessed the impact of tropical cyclones by analysing the relationship between wind speed and capital stock index. Haque and Jahan (2016) used the location quotient (LQ) method using input–output data (IO) to examine the impact of Cyclone Sidr (2007) on the economic system. Hoque et al. (2016) used object-based land use mapping of pre- and post-cyclone scenarios using medium to high-resolution satellite imagery to determine the impact of the storm on the landscape. Similarly, Behera et al. (2022) studied the floodplains due to Cyclone Amphan's storm surge from Sentinel-1 data using remote sensing and geospatial techniques.

Remote sensing is a widely used technique for mapping and anaylzing the impact of natural disasters and their spatial distribution (Joyce et al. 2009). In the recent past, remote sensing techniques have been combined with machine learning techniques to monitor and study natural hazards in different parts of the world (Ahmed et al. 2023). Machine learning techniques have proven to be effective in solving complex data problems, making them much more crucial for LULC mapping than traditional algorithms (Bera et al. 2021a, b; Das et al. 2022). Researchers have highlighted the use of machine learning algorithms to monitor LULC changes, such as artificial neural networks (ANN) (Zhang et al. 2023), random forest (RF) (Talukdar et al. 2020), decision tree (DT) (Barros et al. 2022), Support Vector Machine (SVM) (Islam et al. 2021), Spectral Angle Mapper (SAM) (Talukdar et al. 2020), Radial Basis Function (Ustuner et al. 2015), Naive Bayes (Uzun 2022) and Maximum Likelihood Classifier (MLC) (Shahfahad et al. 2022a). MLC is a parametric classifier that assumes that each feature of interest has a normal or near-normal spectral distribution (Lu et al. 2004). However, it is necessary to escape the limitations of the normal distribution and use an advanced classification technique (Rai et al. 2021). Spectral Angle Mapper (SAM) is a software tool that allows the spectral similarity of image spectra to be quickly mapped and used as reference spectra (Kruse et al. 1993). The angles are assigned to the output channels by the algorithm SAM in the Environment for Visualising Images (ENVI), and each pixel is then assigned to the class given by the reference spectrum (Verma et al. 2020).

MLC and SAM are parametric methods that assume a normal distribution of the dataset, which may not be correct in some cases, e.g. classes with multiple subclasses or classes with different spectral properties (Martins et al. 2016). To overcome the aforementioned limitations, Vapnik (1995) introduced the Support Vector Machine (SVM), a promising new tool for pattern classification. SVMs are a widely used machine learning technique and are considered one of the best standard classifiers for supervised learning algorithms (Gove and Faytong 2012; Bera et al. 2022). SVM identifies the boundaries between input classes and input elements by determining the boundaries after constructing hyperplanes (Nayak et al. 2015). It has been found that MLC, SAM and SVM are widely used techniques for LULC classification compared to other traditional classifiers (Rai et al. 2021; Bera et al. 2021a, b). For LULC classification, SVM is the most popular technique and provides better accuracy than the other traditional methods (Talukdar et al. 2022; Shahfahad et al. 2022b). Several studies have been conducted to determine the best machine-learning algorithm for LULC mapping. For example, Talukdar et al. (2020) studied the six machine learning algorithms, i.e. SVM, RF, ANN, Fuzzy ARTMAP, SAM and Mahalanobis distance (MD) in the lower Gangetic plane and found that SVM and RF had the highest accuracy in LULC mapping. Similarly, Masroor et al. (2022) found that RF and SVM were the best classifiers for LULC mapping after studying classification and regression trees (CART), RF, SVM and Continuous Naive (CN), Minimum Distance techniques. Furthermore, Islam et al. (2021) studied M5P, RF, Reduced Error Pruning Tree (REPTree) and SVM algorithms for wetland risk assessment in the north-western part of Bangladesh and found that RF has the best performance in wetland mapping and risk analysis.

Machine learning and deep learning techniques have been utilized for the forecasting and impact assessment of natural hazards like tropical cyclones (Chen et al. 2020). For example, Kim et al. (2019) applied RF, DT and SVM machine learning techniques for detecting tropical cyclones. Further, Zhang et al. (2021) utilized RF machine learning algorithm along with Landsat satellite data for the assessment of the impacts of Typhoon Lekima on the forest cover in Zhejiang Province of China. Further, a few studies have investigated the impact of cyclones in coastal areas of the Bay of Bengal, such as Hoque et al. (2016), who investigated the impact of a tropical cyclone on LULC using an object-based image classification technique in Bangladesh. However, no such studies have been conducted to assess the impact of a super cyclone on LULC patterns in any part of India. The studies on the changes in LULC patterns before and after a cyclone can enable the disaster management authorities and local government agencies to quickly assess the impact of the cyclone. Therefore, this study aims to assess the impact of cyclone Amphan on LULC patterns through change detection of pre-cyclone and post-cyclone satellite data using machine learning techniques. The study makes a unique contribution as it has analysed the impact assessment of hurricanes using the best LULC machine learning classification method. The results would enable us to understand the best machine learning method for LULC to detect changes. Future researchers can use this report to better understand the performance of current classifiers and select the most suitable ones for their work. This research will also be helpful for various governmental and non-governmental organizations in preparing and implementing development plans in cyclone-affected areas.

2 Materials and methods

2.1 Study area

The Sundarban Biosphere Reserve (SBR) is located on the coast of the Ganga–Brahmaputra delta. The biosphere covers parts of India and Bangladesh, with 60% of the area in Bangladesh (Sahana and Sajjad 2019). The Indian Sundarbans extend from 21° 33′ 32.62″ N to 22° 38′ 15.66″ N and 88° 2′ 27.42″ E to 89° 5′ 46.06″ E (Fig. 1). The Indian SBR has a total area of 9630 sq.km, including 4263 sq. km of protected forest and 5367 sq.

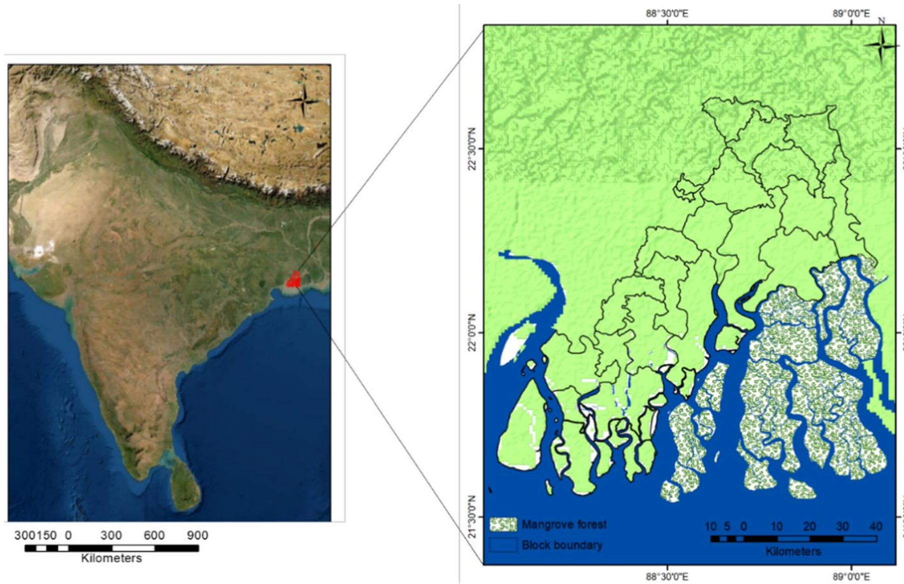

Fig. 1 Locational aspect of the study area

km of cleared settlement area (Sahana et al. 2020). It comprises 19 community development blocks, 13 from the South 24 Parganas and 6 from the North 24 Parganas (Fig. 1). According to the 2011 census, the total population of the Sundarbans is 44,26,259 and the population density is 968 per sq. km (Census of India 2011). The mangroves of the SBR are unique ecosystems that also play an important role in reducing cyclones and cyclone-induced storm surges, protecting against flooding, storing and sequestering carbon, and supporting local livelihoods for food, fuel, timber and building materials (Sahana et al. 2019a, b; Halder et al. 2021). The SBR is home to several species of wildlife, including the Royal Bengal Tiger, Gangetic dolphins, spotted deer, estuarine crocodiles, rhinos, many species of birds and fish, several species of reptiles, innumerable invertebrates and various types of animals (Sahana et al. 2021). The Indian Sundarban consists of 102 islands, of which 54 are habitable and scattered across the buffer and transition zone of the biosphere reserve and 48 are in equilibrium and comprise the forest of the mangrove reserve (Sahana et al. 2021). The region has tropical humid climate with very short and dry winters between November-February. The average annual rainfall in SBR is about 35 °C while the average annual rainfall is about 200 cm, most of which occurs during the monsoon months i.e. June–September (Mitra et al. 2009; Sahana et al. 2019a, b). Due to heavy rainfall and high temperature in the region, the relative humidity remains very high throughout the year.

Due to its location on the edge of the Bay of Bengal, SBR is one of the most cyclone-prone regions in the world (Datta et al. 2012). Since 2007, tropical cyclones have been occurring more frequently and with higher intensity in the northern Bay of Bengal (Sahoo and Bhaskaran 2016). Cyclone activity was highest during the months of April to June and October to December (Girishkumar and Ravichandran 2012). Cyclones that occur between April and June affect people, crops, infrastructure, natural vegetation, communication and animals, but those that occur between October and December affect only people and agriculture (Sahana et al. 2021). In the last 40 years, the Bay of Bengal region has experienced 255 cyclones, ranging from low to severe categories. Cyclone Fani in May 2019 affected about 1 million people in India and Bangladesh (Bhargava and Friess 2022). Bulbul was next in November 2019, with damage of USD 3.37 billion and 41 fatalities across India and Bangladesh (Shamsuzzoha et al. 2021). The most recent cyclone was Amphan, a supercyclone with maximum sustained winds of 230 km/h, which occurred in May 2020. It was the strongest cyclone in the selected study area in the twenty-first century (Team, 19 May 2020). Amphan had the strongest impact in the last two decades, with economic losses of USD 14 billion in India and 129 deaths in India and Bangladesh (Report, 20 April 2021).

2.2 Data sources

For this study, we used satellite data from Sentinel-2A before and after the cyclone (Table 1). The Copernicus Open Obtain Hub was used to access and download the data from Sentinel-2A (https://scihub.copernicus.eu/). Sentinel-2A is equipped with an optical instrument payload that covers 13 spectral bands with spatial resolutions of 10 m, 20 m and 60 m. Super Cyclone Amphan passed over the Sundarban coast on 20 May 2020. The data before the cyclone were collected on 14 May 2020. The post-cyclone data was collected on 5 November 2020, six months after Cyclone Amphan. Although the cyclone made landfall on 20 May 2020, the cloud-free images were not available immediately after the cyclone. Images with clouds can significantly reduce the accuracy of the classification process (Islam et al. 2018). For this reason, we could not select the images from June to October.

Table 1 Details of the satellite data used

Cyclone	Satellite and sensor	Acquisition date	Band	Wavelength (mm)	Resolution (m)
Pre-cyclone	Sentinel-2A MSI	14/05/2020	Blue	0.449	10
			Green	0.560	10
			Red	0.665	10
			NIR	0.842	10
Post-cyclone	Sentinel-2A MSI	05/11/2020	Blue	0.449	10
			Green	0.560	10
			Red	0.665	10
			NIR	0.842	10

Therefore, it was assumed that the interval of image acquisition would have minimal seasonal variation.

2.3 Methodology

In this study, the assessment of the impact of Cyclone Amphan was carried out. For this purpose, two satellite images (Sentinel-2A) from before and after the cyclone were downloaded from Copernicus Open Access Hub. The methodology comprises three main parts. First, pre-processing of the satellite data; second, machine learning based classification along with accuracy assessment; and third, impact analysis through change detection (Fig. 2). According to the objectives of our study, the classification problem requires the identification of nine LULC types (i.e. dense forest, water bodies, open forest, agricultural land, wasteland, waterlogging, settlements, swamp, sand and beaches). This classification was done to compare and consider their relative accuracy. Different GIS and remote sensing software (ENVI Classic, ERDAS Imagine 2015, ArcGIS 10.6 and QGIS 3.16) were used in this study. The individual steps of the methodology are explained in Fig. 2.

2.3.1 Images pre-processing

The delineation of the study area requires a mosaic of four tiles of Sentinel 2A imagery. All satellite images were available in top-of-atmosphere format (TOA) and were converted to bottom-of-atmospheric reflectance (BOA) after mosaicking using the QGIS 3.16 Semi-Automatic Classification plug-in (Rai et al. 2021). A layer stack of the different bands was performed using ERDAS imagine 2015. Subsequently, a subset was performed on the same platform.

2.3.2 Classification algorithms and accuracy assessment

LULC data are produced by classifying raw satellite data into LULC categories based on the return values of satellite imagery (Naikoo et al. 2023; Zain et al. 2021). After pre-processing the images, the study area was divided into nine classes to perform the different classification procedures based on our study objectives (Table 2). Four machine learning based classification algorithms namely SAM, MLC, Sigmoid Function-SVM and Radial Basis Function-SVM were used. Training sets were created for these classification methods using ENVI software (Exelis Visual Information Solutions, Herndon, USA). The training

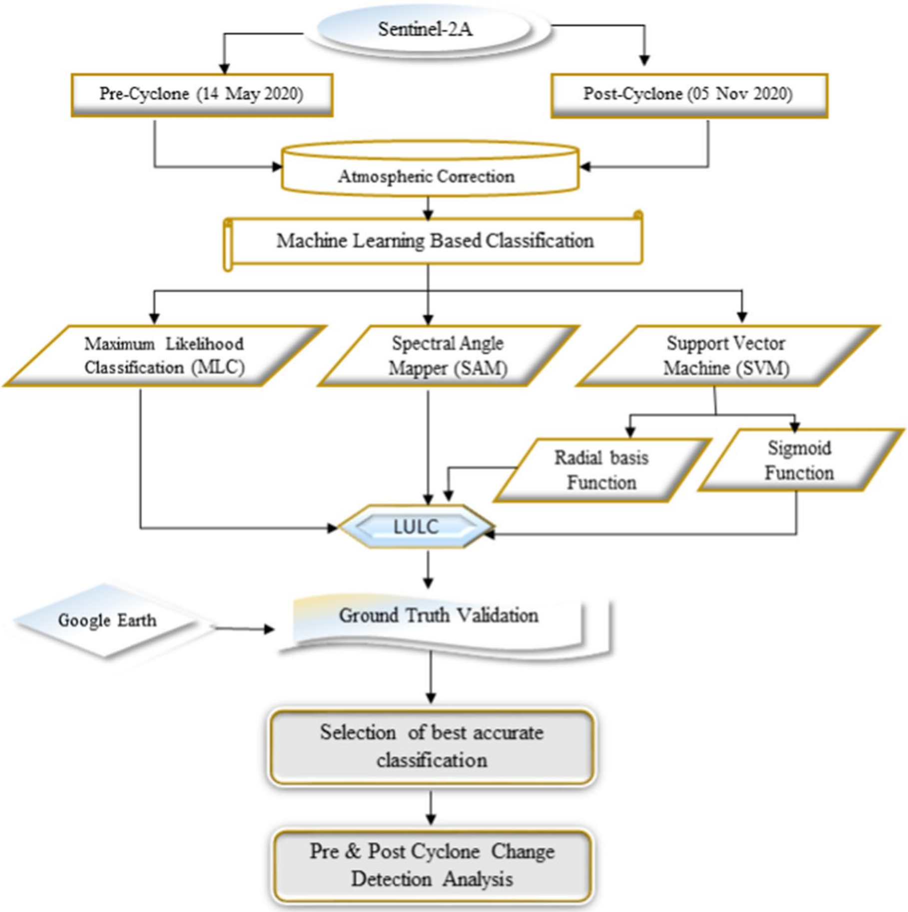

Fig. 2 Flow chart of the methodology

set contained the selected polygons as regions of interest (ROIs) for each class. These ROIs were then used for LULC classification for the study area. Based on the Level-I land use/ land cover classification system of the National Remote Sensing Centre (NRSC), India, nine LU/LC classes including water body, dense forest, waterlogged, open forest, agricultural land, fallow land, settlement, sand and beaches, and swamp were identified in the study area.

LULC classification from satellite data requires an accuracy assessment to check whether the classification is satisfactory or not. The results (maps) must be put to the test using a trustworthy statistical technique to verify accuracy (Alam et al. 2020). Accuracy evaluation assesses how well a classification matches the real world by comparing it to data from ROI or ground truth (Kafi 2014). Cyclone Amphan hit the Sundarban Delta on 20 May 2020, so no reference field data could be collected. An accuracy assessment was carried out to compare the better results of the different classifications using Erdas Imagine software. Using the Accuracy assessment tool, 495 stratified random samples were created for nine different classes, with 55 points set for each class.

Table 2 Details of land use land cover (LULC) classes by NRSC/ISRO

S. No	Class name	Class description
1	Water body	River, stream, canal, Open Ocean
2	Dense forest	Mangrove forest that are densely colonized on coastal tidal flats where the density of the canopy is above 10%
3	Water logged	It includes man made wetlands, seasonal or perennial water logged
4	Open forest	These are seen at the fringes of the forest and settlement were there is biotic and abiotic conflicts
5	Agricultural land	It includes agricultural plantation (e.g. rice) horticultural plantation (e.g. vegetable garden) and Agro-horticultural plantation
6	Fallow land	These areas are taken up for cultivation but temporarily allowed to rest, uncropped for one or more season
7	Settlement	It is an area of human habitation that has cover of buildings, transport and communications etc
8	Sand and beaches	These are coastal sands that accumulated as a strip along the sea coast
9	Swamp	These are tidal flats estuaries salt marshes etc

Each class of classified LULC was compared to the actual classes determined from the Google Earth satellite imagery. The overall accuracy and kappa statistics for all classification techniques used were measured by creating the confusion metrics for each classification.

2.3.3 Change detections

Change detection is a technique to investigate short- and long-term changes in LULC using multi-temporal photographs of an area (Kumar et al. 2020; Naikoo et al. 2023). In order to better manage and utilise resources, change detection allows for a better understanding of the connections and interactions between human and natural events (Lu et al. 2004). In each class, these techniques relied entirely on pixels or rasters. These changes, corresponding to multiple input bands, were accepted as part of the basic concept. Various change detection methods have been systematically investigated, offering excellent explanations and comprehensive analyses (Lu et al. 2004; Asokan and Anitha 2019). Pre-classification and post-classification change detection approaches are the two main types of change detection methods (Asokan and Anitha 2019). These post-classification change detection approaches are based on pixel-by-pixel analysis that determines the magnitude and distribution of LULC changes. The delta change and percentage delta change rate can be used to determine gains and losses of different LULC species (Talukdar et al. 2021). In this study, change detection was done through supervised classification. This study shows the differences detected in each class before and after the cyclone and the amount of area lost and gained as a result of transitions from one class to another. These pre- and post-cyclones change detection maps were created in the QGIS software using the MOLUSCE plug-in. Figure 2 shows the methodological framework of the study.

3 Results

3.1 Machine learning based LULC classification

To test which machine learning classifier has the best performance in LULC mapping of the study area, LULC classification for the pre-cyclone period was performed using four machine learning algorithms. Figure 3 shows the classified LULC maps of the pre-cyclone period using Radial Basis Function-SVM (Fig. 3a), Sigmoid Function-SVM (Fig. 3b), SAM (Fig. 3c) and MLC (Fig. 3d). To help new researchers understand and think critically about this issue, we evaluate the best classifiers. As shown in Table 3, all classifiers were compared based on user accuracy, producer accuracy and kappa coefficient. Based on a comprehensive review of different LULC classification techniques, Barros et al. (2022) also found that SVM has the best performance in LULC classification. The LULC maps of SBR prepared using different classification techniques have some differences in classifying the settlements, swamps and open forests while water bodies and agricultural lands have low differences. Further, the vegetation cover was classified similarly in the LULC maps prepared using radial basis function-SVM, sigmoid function-SVM and MLC but has a clear difference in the LULC map prepared using SAM.

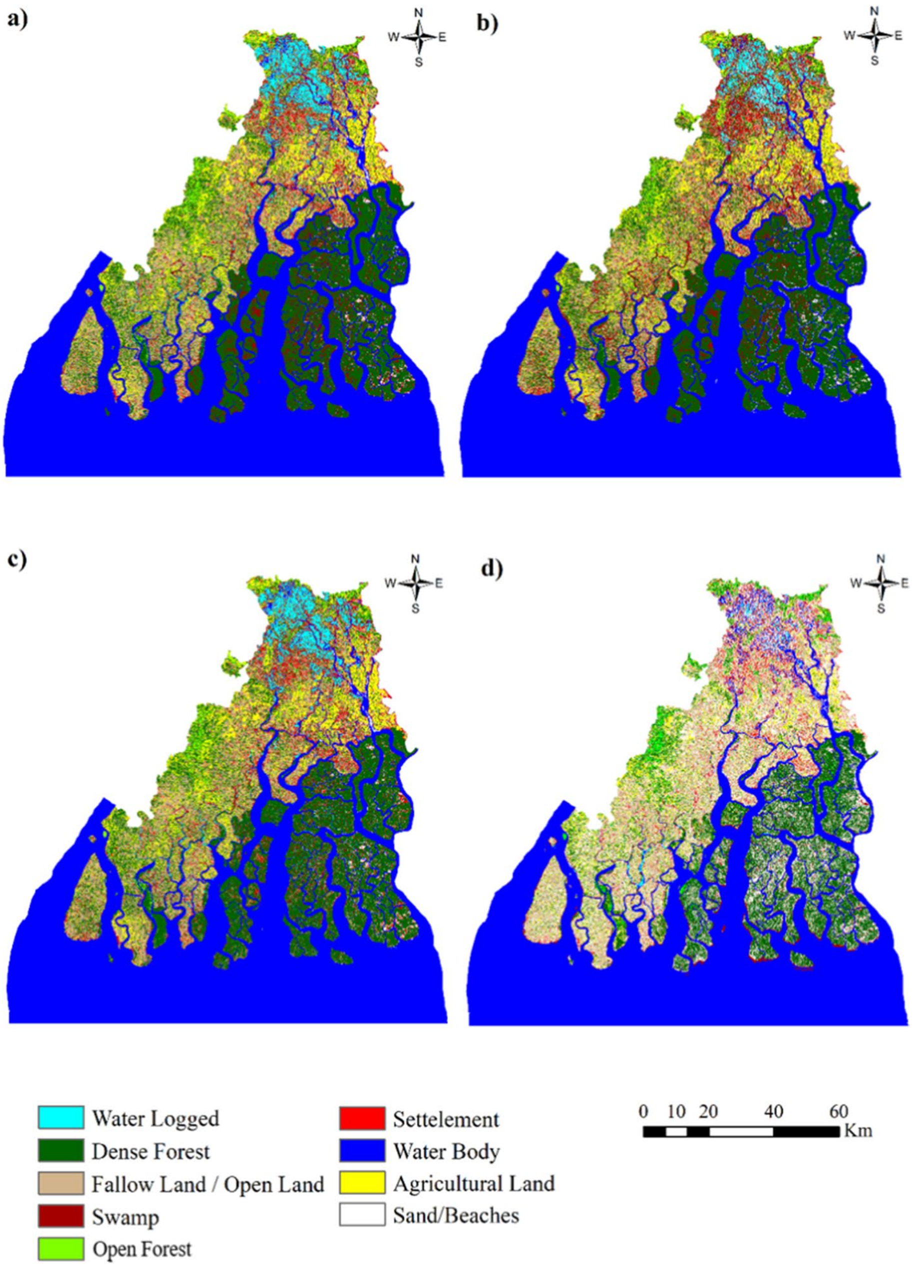

Fig. 3 Supervised Classification of LULC map of Pre-Cyclone Images of Sundarban **a** radial basis function-SVM, **b** sigmoid function-SVM, **c** Maximum Likelihood Classification (MLC), **d** Spectral Angle Mapper (SAM)

Table 3 Accuracy assessment using kappa coefficient

Classes	Pre-cyclone								Post cyclone	
	MLC		SAM		SVM sigmoid function		SVM radial basis function		SVM radial basis function	
	Producers' accuracy (%)	Users' accuracy (%)	Producers' accuracy (%)	Users' accuracy (%)	Producers' accuracy (%)	Users' accuracy (%)	Producers' accuracy (%)	Users' accuracy (%)	Producers' accuracy (%)	Users' accuracy (%)
Water logged	18.75	37.50	31.58	75	90.91	100	58.33	87.5	93.02	100
swamp	41.18	50.00	45.16	50	90	90	85.71	85.71	97.3	90
Water body	86.27	78.57	91.67	85.12	100	100	98.77	95.83	97.5	97.5
Dense forest	83.96	87.25	90.2	90.2	100	70	96.04	95.1	90.91	100
Open forest	25	40	25	40	76.92	100	33.33	40	100	97.5
Land with crop	73.08	40	76	70.37	83.33	100	86.21	92.59	97.56	100
land without crop	75	40	85.11	85.11	90	90	95.65	93.62	90.24	92.5
Sand and beaches	12.5	40	66.67	66.67	100	100	66.67	66.67	100	45
Settlement	44.44	40	44.44	33.33	100	70	66.67	66.67	85.71	90
Overall accuracy	**73.50%**		**80.50%**		**91.11%**		**92.50%**		**91.25%**	
Kappa statistics	**0.64**		**0.73**		**0.89**		**0.91**		**0.90**	

3.2 Analysis of the LULC classification accuracy

The accuracy assessment using the kappa coefficient shows that the LULC classification with all the techniques had satisfactory accuracy. But the LULC map created with Radial Basis Function-SVM had the best accuracy i.e. 92.50% with a corresponding Kappa coefficient of 0.91, followed by Sigmoid Function-SVM (overall accuracy 91.11% and Kappa coefficient 0.89). On the other hand, the LULC map generated using MLC had the lowest accuracy, i.e. 73.50% with a corresponding kappa coefficient of 0.64 (Table 3). Therefore, the Radial Basis Function-SVM was used for LULC classification after a cyclone. The overall accuracy of the post-cyclone images for Radial Basis Function-SVM was 91.50% with a kappa coefficient of 0.90. In addition to this quantitative accuracy assessment, qualitative assessment of all four classifications of Radial Basis Function-SVM, Sigmoid Function-SVM, SAM and MLC were also performed (Fig. 3). Figure 4a and b are the subset of the study area. Figure 4a shows the dense forest and swampy area in the subset of the image. Figure 4a (i) shows the Radial Basis Function-SVM classification, which obtained better results than the other three classifications. In the Sigmoid Function-SVM, the marshy area was misclassified as settlements and wasteland (Fig. 4a (ii)). On the other hand, the MLC confused forest and marshy areas with sand, beaches and settlements (Fig. 4a (iii)). In the SAM classification, most of the areas in the sub-image were classified as wasteland, sand and beaches (Fig. 4a (iv)). Only the Sigmoid Function-SVM correctly classified swampy and dense forests. Another example is shown in Fig. 4b. The Sigmoid Function-SVM, MLC and SAM misclassified the settlement into a different class. The Radial Basis Function-SVM, on the other hand, classified settlements correctly (Fig. 4b).

The LULC classification with SVM for the pre-cyclone and post-cyclone time in the study area is shown in Fig. 5a and b). At the time before the cyclone, the area under water was measured as 4553.84 km^2, under dense forest as 1896.59 km^2, under waterlogging as 466.59 km^2, under open forest as 457.61 km^2, under agricultural land as 1264.95 km^2, under fallow land as 998.11 km^2, under settlements as 523.65 km^2, under sand and beaches as 52.14 km^2 and marsh as 534.09 km^2. After the cyclone, the LULC pattern of the study area changed where water covered 4543.46 km^2, followed by dense forest (1170.63 km^2), waterlogging (336.53 km^2), open forest (444.53 km^2) and marsh. km), open forest (444.05 sq.km), agricultural land (1891.30 sq.km), wasteland (1067.33 sq.km), settlements (487.69 sq.km), sand and beaches (61.21 sq.km) and marsh (745.41 sq.km).

3.3 Analysis of LULC change during the pre and post-cyclone period

The pre and post-cyclone change detection matrix were calculated using QGIS software after the LULC classification was completed (Fig. 5). Table 4 shows the area of each LULC type before and after the cyclone in the study area. The change detection result (Fig. 6) shows some important changes in the study area due to super cyclone Amphan. The pre and post-cyclone change detection matrix (Table 5) shows a detailed change in the identifying classes. The change detection matrix revealed all changes in LULC classes during the cyclone as well as the amount of area lost and gained due to transitions from one class to the next (Fig. 6). The largest changes due to amphibians were mapped in the LULC classes of dense forest, open forest, agricultural land, wasteland, sand and beaches, and marsh. The area of dense forest decreased from 1896.60 km^2 (pre-cyclone) to 1170.63 km^2 (post-cyclone) and wasteland increased from 998.12 km^2 to 1087.33 km^2. The agricultural

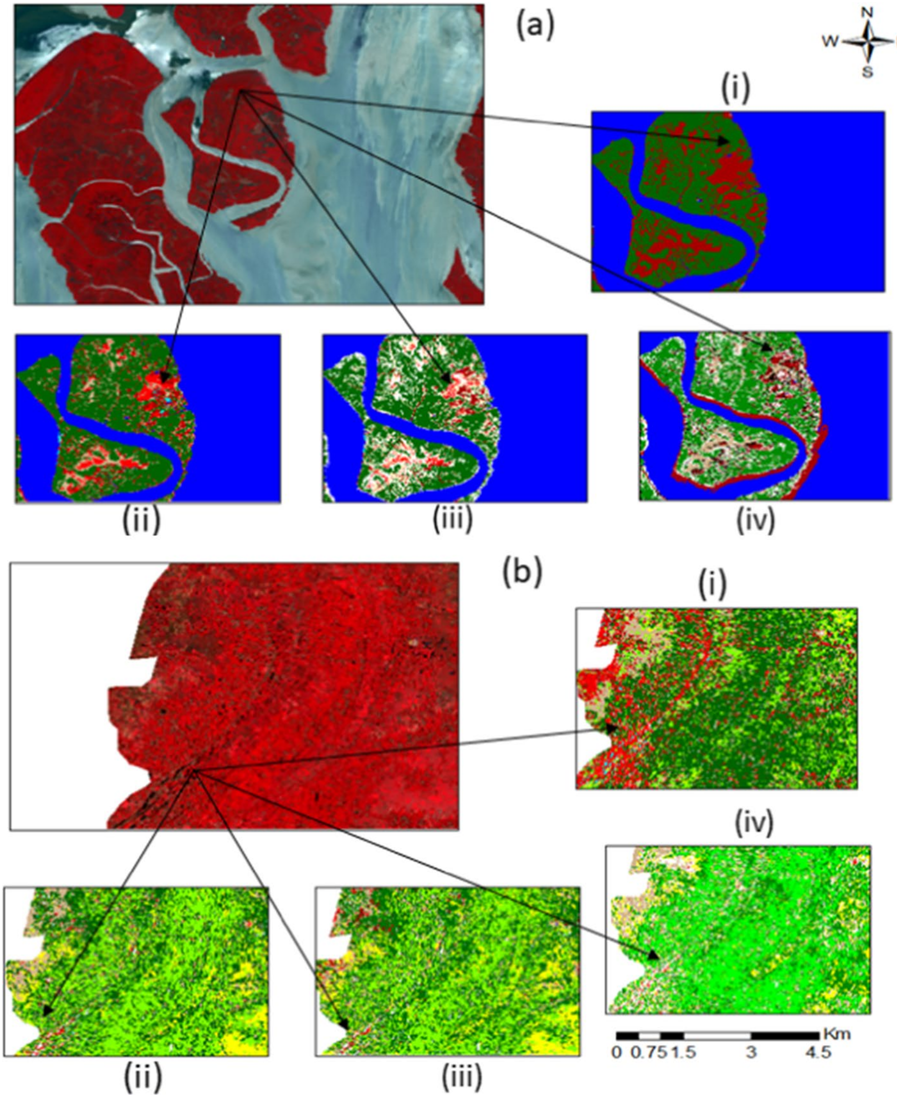

Fig. 4 Ground truth example among all the classification algorithms; Example **a** and **b**: (i)-SVM (Radial Basis Function), (ii)-SVM (Sigmoid Function), (iii) MLC (Maximum Likelihood Classification), (iv) SAM (Spectral Angular Map)

land increased from 1264.95 sq.km (pre-cyclone) to 1891.29 sq.km (post-cyclone) due to seasonal changes. The 538.10 sq.km (pre-cyclone) of wetlands increased by 39.57% to 745.41 sq.km (post-cyclone). Open forest decreased from 457.62 sq.km (pre-cyclone) to 444.05 sq.km (post-cyclone). The most minor changes within the LULC were found in the water body categories. Numerous minor changes were noted in the water bodies and settlements. However, many of these probably indicate an inaccuracy in the classification

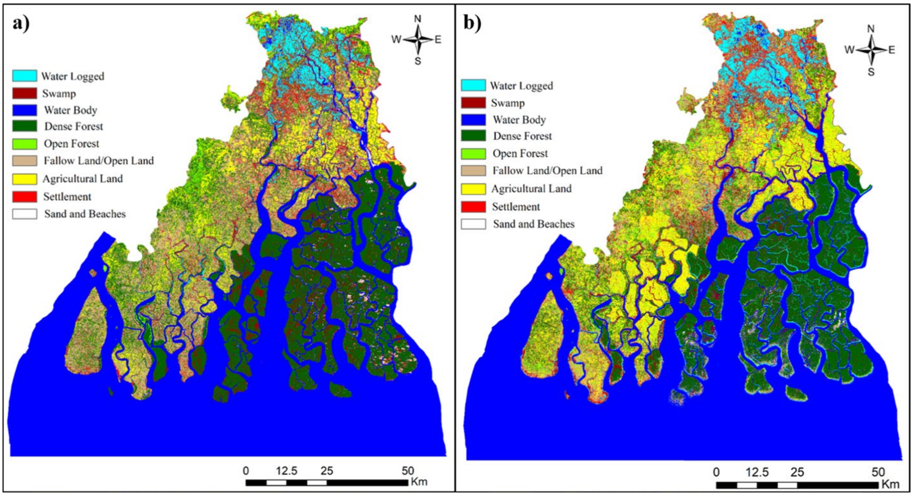

Fig. 5 LULC Classification map of Indian Sundarban based on Support Vector Machine **a**: Pre-Cyclone, **b** Post-Cyclone

Table 4 Area covering before and after the cyclone and rate of change

LULC class	Total area before cyclone		Total area after cyclone		Rate of change
	Area in km^2	Percentage (%)	Area in km^2	Percentage (%)	
Water body	4553.84	42.37	4543.46	42.27	– 0.23
Dense forest	1896.59	17.65	1170.63	10.89	– 38.28
Water logged	466.59	4.34	336.53	3.13	– 27.88
Open forest	457.61	4.26	444.05	4.13	– 2.96
Agricultural land	1264.95	11.77	1891.30	17.60	49.51
Fallow land	998.11	9.29	1067.33	9.93	6.93
Settlement	523.65	4.87	487.69	4.54	– 6.87
Sand and beaches	52.14	0.49	61.21	0.57	17.40
Swamp	534.09	4.97	745.41	6.94	39.57

process (Table 4) from one class to another. The LULC map in Fig. 7 does show some significant changes due to Amphan (Table 5).

This enormous change from fallow land to agricultural land is due to seasonal changes. The main harvesting season in Sundarban is November–December, which is known as Kharif. The conversion of open forest to agricultural land was 133.13 square kilometres. This conversion is mainly for seasonal cultivation. The settlements were reduced by 6.87% from pre-cyclone to post-cyclone. Sand and beaches and swamps increased by 17.40% and 39.57% respectively after the cyclone. Some other changes are also observed in water bodies and waterlogging areas. The images of the field

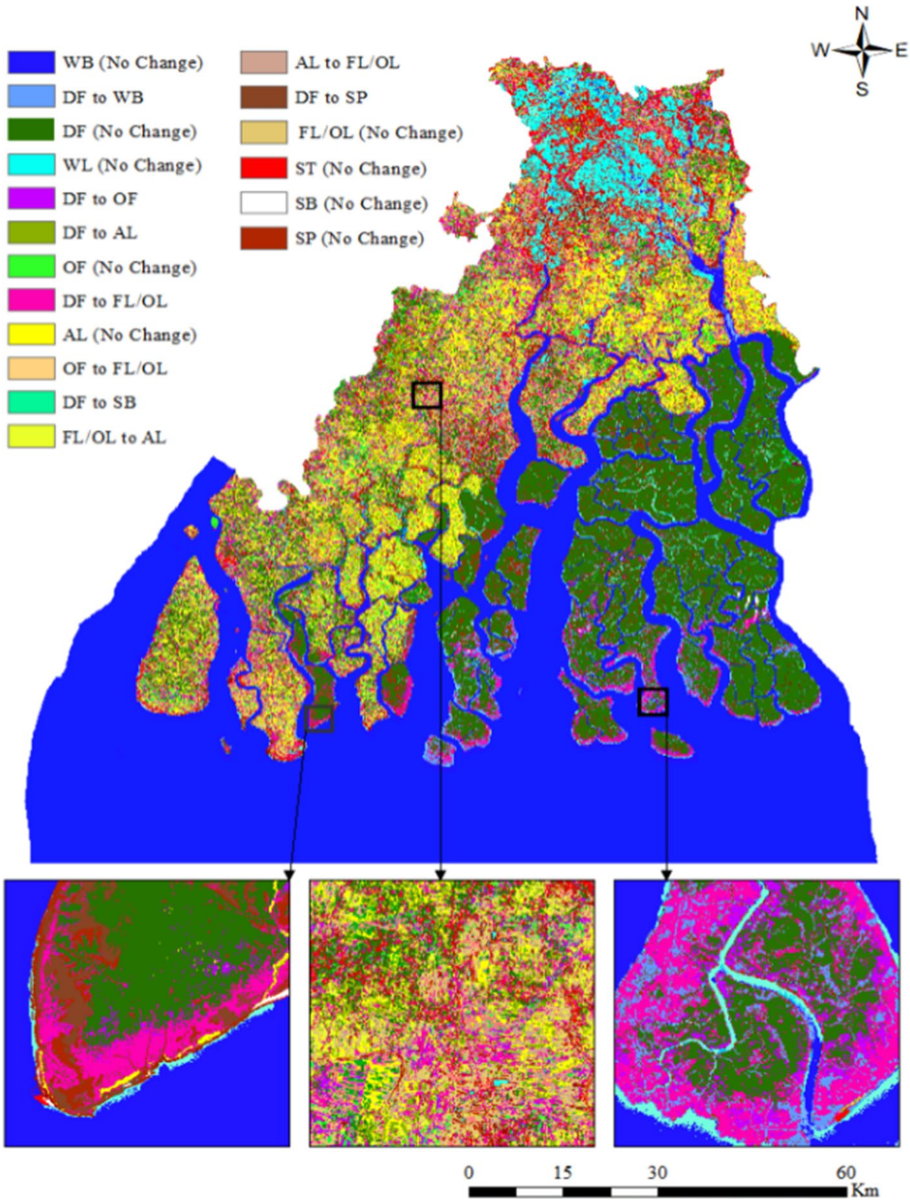

Fig. 6 LULC change pattern in SBR between pre- and post-cyclone periods

survey before and after the cyclone are shown in Fig. 6. These data clearly show the damage caused in the study area by the destructive properties of super cyclone Amphan.

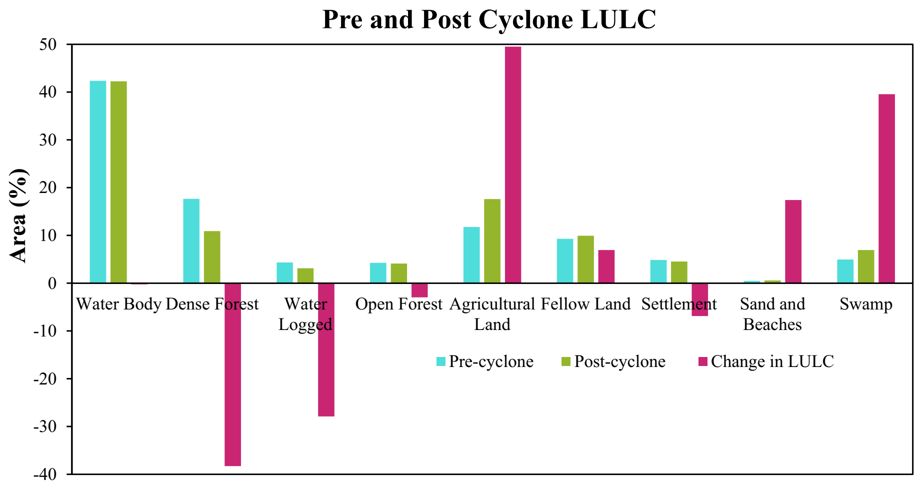

Fig. 7 Area under different LULC classes in pre- and post-cyclone periods

4 Discussion

Every year, coastal areas around the world are hit by a series of natural hazards, of which tropical cyclones are the most destructive (Halder et al. 2021; Helderop and Grubesic 2022). Super Cyclone Amphan hit Sundarban with a wind speed of 230 km/h, which means that the super cyclone had a devastating effect. Sundarban is the largest mangrove forest in the world have historically benefited India and Bangladesh in strategically protecting the coasts of the Bay of Bengal (BoB) (Mishra et al. 2021). Studies have been conducted to assess the devastating impact of Super Cyclone Amphan in the coastal regions of India and Bangladesh (Halder et al. 2021; Sultan and Maharjan 2022). However, its impact on LULC patterns has not yet been studied. The changes in LULC patterns have direct impacts on the livelihoods of people in the coastal region, both spatially and temporally (Kaliraj et al. 2017). Therefore, this study analyzed the changes in LULC pattern due to super cyclone Amphan in the SBR, which provided essential information on the impact of cyclone Amphan in the study region.

Studies have found that the SVM and RF are the best techniques for LULC classification from Earth observation satellite data (Talukdar et al. 2020; Bindajam et al. 2021; Barros et al. 2022). However, the performance of the classification techniques and the accuracy of LULC classification varies depending on the time and space, the data used and the quality of the training samples used (Srivastava et al. 2012). For example, Shahfahad et al. (2022b) used Radial Basis Function-SVM for LULC classification of Landsat 8 (OLI) and Landsat 9 (OLI-2) datasets and found satisfactory accuracy of 83.4% and 92.4%, respectively. Similarly, Das et al. (2022) used SVM for LULC classification in English Bazar, West Bengal for the years 2001, 2011 and 2022 and obtained an accuracy of 90.05, 93.67 and 96.24%, respectively. So, in this study, four machine learning algorithms i.e. SAM, MLC, Sigmoid Function-SVM and Radial Basis Function-SVM were used for LULC classification from Sentinel-2 satellite data to check which technique gives the best results. The result showed that Radial Basis Function-SVM (overall

Table 5 LULC Change matrix (Area in km^2)

LULC class	Water body	Dense forest	Water logged	Open forest	Agricultural land	Fallow land	Settlement	Sand and beaches	Swamp	Total after cyclone
Water body	4414.97	5.72	79.58	0.20	0.30	0.77	9.48	1.24	31.20	4543.46
Dense forest	19.23	1142.39	0.00	1.84	0.30	0.65	0.66	1.06	4.51	1170.63
Water logged	22.11	1.26	281.18	2.92	0.82	3.99	0.55	0.13	23.56	336.53
Open forest	0.01	238.49	0.08	177.70	1.55	0.06	4.37	0.00	1.80	424.05
Agricultural land	0.09	169.44	0.83	163.13	1252.53	269.95	23.63	0.11	11.59	1891.29
Fallow land	0.31	225.83	5.83	100.66	5.35	643.63	94.24	0.28	11.21	1087.33
Settlement	3.10	13.52	0.98	5.33	0.68	72.83	383.85	0.91	6.48	487.69
Sand and beaches	0.27	2.81	7.72	0.13	0.29	0.39	1.17	47.71	0.72	61.21
Swamp	93.76	97.15	90.40	5.70	3.13	5.84	5.71	0.69	443.03	745.41
Total before cyclone	4553.84	1896.60	466.60	457.62	1264.95	998.12	523.66	52.14	534.10	10,747.62

accuracy 92.50%) performed best among all other techniques for LULC classification, followed by Sigmoid Function-SVM (overall accuracy of 91.25%).

The results of the LULC before and after the cyclone demonstrate how the Sundarbans' pattern has changed. The afflicted forest region was most significantly impacted by the cyclone's wind speed parameters (Fig. 5). The influence of cyclone on LULC change detection was also noted by a study conducted by Hoque et al. (2016) who used object-based classification for the cyclone Sidr in Sundarban (Hoque et al. 2016). Strong cyclonic storms and storm surge frequently hit the Sundarbans, destroying the coastline and preventing the Sundarbans from migrating toward the sea as they normally do (Akber et al. 2018; Islam et al. 2020). In comparison to upland forests, mangrove forests are more affected by direct wind energy in terms of mortality and structural alteration (Mandal and Hosaka 2020). The change detection matrix map in Fig. 6 indicates several changes in LULC classes. The LULC change analysis shows the transformation of dense forest to water bodies; dense forest to open forest; dense forest to agricultural land; dense forest to fallow land; dense forest to sand and beaches; fallow land to agricultural land; agricultural land to fallow land; and dense forest to swamp. There was a minimum change for water bodies because it is part of the Bay of Bengal. The present study highlights clearly how cyclone Amphan had the greatest impact on the dense forest. It's also worth noting that storm Amphan wreaked havoc on the Sundarban mangrove forest. Even though the state and federal governments did everything they could, Super Cyclonic Storm Amphan destroyed almost all of the North and South 24 Parganas districts, which include Kolkata (Mishra et al. 2021).

Study shows that the maximum impact of Amphan cyclone was on the forest cover with about 38.28% decline during pre- and post-cyclone period. Mishra et al. (2021) also noted that the super cyclone Amphan made significant destruction to the mangrove forest in SBR, exposing the livelihoods of local people to climate change-related uncertainties. The area under dense forest was partially destroyed which notably increased the area of fallow land or open land by 6.93%. On the other hand, open forests were destroyed by 100.66 sq. km and converted to fallow land. Afterward, 238.49 sq.km of dense forest became an open forest. The data acquisition difference was of 6 months. After the cyclone, the government started a new plantation policy on the fallow land area Fig. 8. Figure 8a shows the dense forest before the cyclone in December 2019 in the Gobardhanpur area while Fig. 8b shows the open land with newly developed vegetation after the super cyclone Amphan in August 2020. Although the cyclone had a severe negative impact on the settlements, this is not reflected in the results as people renovated their houses within a few days after the disaster. Mishra et al. (2021) and Kumar et al. (2021) showed that Super Cyclone Amphan inflicted enormous damage and extensive devastation across South Bengal, especially, particularly in the South 24 Parganas area. The impact of the cyclone on settlement is very high but people renovate it within a few days. As a result, the change of settlement cannot be identified.

Study shows that the super cyclone Amphan made large-scale destruction in the SBR in by altering the natural landscape pattern. The alteration of the LULC pattern due to super cyclone Amphan indicates the spatial pattern of destruction in the SBR region. Thus, the findings of this study may be used for disaster management plans and mitigation of the impacts of coastal hazards such as cyclones and storm surges by the disaster management authorities and other government agencies. For this, the special focus may be provided to those areas where the maximum changes in LULC pattern due to Amphan have been witnessed as they are the most vulnerable areas. Moreover, this study has certain limitations which may have effects on the outcomes. For instance, Sentinel-2 satellite data has been utilized in this study which has a spatial resolution of 10 m and thus may not provide an

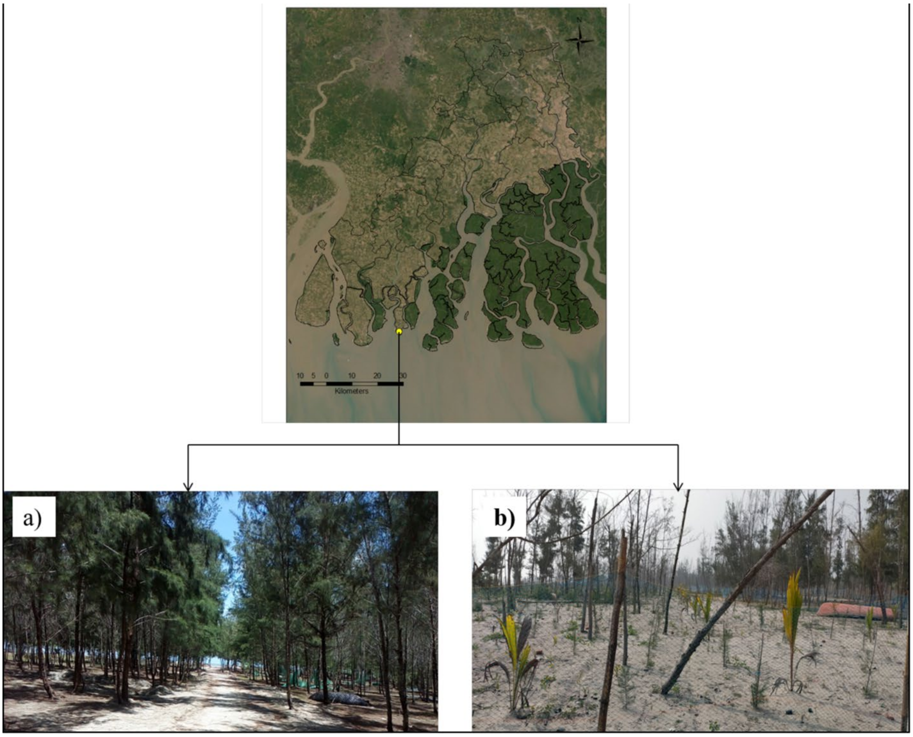

Fig. 8 **a** Pre-cyclone dense forest and **b** post-cyclone open land with newly developed vegetation of Gobardhanpur in Sundarban

accurate picture of destructions made by the super cyclone Amphan. To overcome this limitation, we verified the outcomes of this study through a field visit. In future studies, high and very high-resolution satellite images like Indian Remote Sensing Satellite (IRS) LISS-IV or French satellite SPOT-5 data may be utilized for the analysis of impacts of such natural hazards like cyclones and storm surges.

5 Conclusion

The study aims to examine the impact of the Amphan super cyclone in the SBR region in terms of alteration to the LULC pattern. For this, firstly four machine learning techniques were applied to examine their performance in the LULC mapping in the study area for the pre-cyclone period. The study shows that the Radial Basis Function-SVM technique outperformed the other techniques in LULC mapping with the highest overall accuracy (92.50%). Thus, the Radial Basis Function-SVM technique was employed for the post-cyclone LULC classification due to its high level of accuracy. The impact analysis of cyclone Amphan was conducted by assessing the LULC change during pre-cyclone and post-cyclone. The highest change was found in the dense forest category in the study area. The area under dense forest was destroyed by 38.28% during the pre-and post-cyclone periods, especially in the southern and south-eastern parts of the SBR. The areas of dense forest were partially destroyed which notably increased the area of fallow land or open land by 6.93%. On the other hand, water bodies witnessed a minimum change in the area during pre- and post-cyclone periods. It is also worth noting that storm Amphan wreaked havoc on the Sundarban mangrove forest. The study may improve the quality of results if field data of immediate post-cyclone was available. This study provides the impact of the cyclone which can be specifically explored to define impacts in terms of social, physical, economic and environmental. It provides the base for the management authority to formulate a disaster management plan for the area. To further increase the validity and reliability of this approach, a similar strategy might be used in other impacted locations to support findings drawn straight from the field using data gathered just after the disaster. As a result, this research will undoubtedly help the relevant authority take the necessary and quick action, and it will also encourage other researchers to take similar action against cyclone damage assessment. A comparable method might also be used to evaluate the effects of other natural disasters, such as floods or tsunamis.

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Declarations

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Undertaking by the Fellow

I, --Md Nawaj Sarif-----------, Son of Shri. ---Md Hasimuddin Biswas, resident of P.O- Dhulian, Dist- Murshidabad (W.B) agree to undertake the following, If I am offered the SERB N-PDF

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1. **I shall abide by the rules and regulations of SERB during the entire tenure of the fellowship.**
2. **I shall also abide by the rules, discipline of the institution where I will be implementing my fellowship**
3. **I shall devote full time to research work during the tenure of the fellowship**
4. **I shall prepare the progress report at the end of each year and communicate the same to SERB through the mentor**
5. **I shall send two copies of the consolidated progress report at the end of the fellowship period.**
6. **I further state that I shall have no claim whatsoever for regular/permanent absorption on expiry of the fellowship.**

Md. Nawaj Sarif

Date: 08.08.2023 **Signature**

Endorsement Certificate from the Mentor & Host Institute

This is to certify that:

I. The applicant, **Dr. Md Nawaj Sarif**, will assume full responsibility for implementing the project.
II. The fellowship will start from the date on which the fellow joins University/Institute where he/she implements the fellowship. The mentor will send the joining report to the SERB. SERB will release the funds on receipt of the joining report.
III. The applicant, if selected as SERB-N PDF, will be governed by the rules and regulations of the University/ Institute and will be under administrative control of the University/ Institute for the duration of the Fellowship.
IV. The grant-in-aid by the Science & Engineering Research Board (SERB) will be used to meet the expenditure on the project and for the period for which the project has been sanctioned as indicated in the sanction letter/ order.
V. No administrative or other liability will be attached to the Science & Engineering Research Board (SERB) at the end of the Fellowship.
VI. The University/ Institute will provide basic infrastructure and other required facilities to the fellow for undertaking the research objectives.
VII. The University/ Institute will take into its books all assets received under this sanction and its disposal would be at the discretion of Science & Engineering Research Board (SERB).
VIII. University/ Institute assume to undertake the financial and other management responsibilities of the project.
IX. The University/ Institute shall settle the financial accounts to the SERB as per the prescribed guidelines within three months from the date of termination of the Fellowship.

Dated: 03/08/2023

Signature of the Mentor: Jana

Name & Designation: NARAYAN CHANDRA JANA
Professor

Dr. Narayan Chandra Jana
Professor
Department of Geography
The University of Burdwan
Burdwan- 713104, W.B.

Dated: 8
03/08/23

Signature of the Registrar of University/Head of Institute

Seal of the Institution

REGISTRAR
THE UNIVERSITY OF BURDWAN
BURDWAN - 713104

E3-032

E04311-0033

West Bengal Board Of Secondary Education

MADHYAMIK PARIKSHA (SECONDARY EXAMINATION), 2007

Certified that **MD NAWAJ SARIF**

Son / ~~Daughter~~ / ~~Ward~~ of **MD HASIMUDDIN BISWAS**

appearing from / ~~XX~~ **KANCHANTALA J.D.J.INSTITUTION**

Whose date of birth is **NINTH** *day of* **OCTOBER** *One Thousand Nine Hundred and* **NINETY ONE** *duly passed the Madhyamik Pariksha (Secondary Examination) held in the month of February, 2007 and was placed in the* **FIRST** *division.*

Kolkata-700 016,

Dated, **the 29th May, 2007.**

Swapan Kumar Sarkar
Secretary

Ujjwal Kumar Basu
President

167176

MM1545

SHORT CV OF MENTOR

I. Academic and Research Qualification and Accomplishments of the Mentor

Name: ***Narayan Chandra Jana***

M. A., Ph. D. (Geography), M. Sc. (Disaster Mitigation), PG Diploma (Sustainable Rural Development), Diploma (Tourism Studies)

Post-Doctoral Research: CSRD/SSS, Jawaharlal Nehru University, New Delhi

Present Position: Professor of Geography, The University of Burdwan, Burdwan-713104, West Bengal, India

Phone: 09547789019; E-mail: jana.narayan@gmail.com / ncjana@geo.buruniv.ac.in

Date of Birth: 2nd September 1965

Areas of Research Interest

Applied Geomorphology, Disaster Management, Land Use Studies, Environmental Geography

Publication of Books

1. ***Population Dynamics in Contemporary South Asia: Health, Education and Migration*** (Professor Sudesh Nangia Felicitation Volume), **Springer Nature**, Singapore, 2020, 17 chapters, 437 pages (jointly with Prof. Anuradha Banerjee of JNU, Dr. Vinod Kumar Mishra of IIDS, New Delhi) [ISBN: 978-981-15-1667-2 (print), ISBN: 978-981-15-1668-9 (eBook)]
2. ***Climate, Environment and Disaster in Developing Countries*, Springer Nature**, Singapore, 2022, 27 chapters, 552 pages, ISBN 978-981-16-6966-8 (Editor jointly with Prof. R. B. Singh).
3. ***Livelihood Enhancement through Agriculture, Tourism and Health,* Springer Nature**, Singapore, 2022, 26 chapters, 549 pages, ISBN 978-981-16-7309-2 (Editor jointly with Dr. Anju Singh and Prof. R. B. Singh).
4. ***Sustainable Livelihoods of Tribal Communities in Odisha, India: The Case of Mayurbhanj,* Cambridge Scholars Publishing**, United Kingdom, 2023, ISBN 978-1-5275-9014-4 (Author jointly with Prof. Anuradha Banerjee and Dr. Prasanta Kumar Ghosh).

Publication of Reports: 04

No. of M. Phil Awarded: 11 (on different issues such as flood, wasteland, river bank erosion and soil Erosion etc.)

No. of Ph. D. Awarded: 11 (on different issues such as flood, wasteland, wetland and watershed management etc.)

No. Lectures delivered as Resource Person in UGC-HRDC and sponsored seminars: 125

Position in Academic Bodies

1. ***Member,*** Board of Studies in Geography, Visva Bharati, Santiniketan
2. ***Member,*** PG Board of Studies in Geography, Kazi Nazrul University, Asansol
3. ***Member,*** Board of Research Studies in Geography, Bankura University
4. ***Member,*** Board of Research Studies in Geography, University of Gour Banga, Malda
5. ***Member,*** Board of Research Studies in Geography, Kazi Nazrul University, Asansol

7. ***Academic Expert*** of the Board of Studies of Post Graduate Diploma in Geospatial Data Analytics under UGC National Skill Qualification Framework (NSQF), Kazi Nazrul University, Asansol

Honourable Position in Organizations

1. ***First Fifty Founder*** Club Member & Regional Co-ordinator (Eastern India), *International Geographical Union: Commission on Geography of Commercial Activities*, 1992-1996.
2. ***Vice-President*** (North-Eastern Region), *National Association of Geographers, India* (NAGI), New Delhi (2011-12, 2012-13, 2013-14 & 2019-20).
3. ***Secretary***, Institute of Indian Geographers (IIG), Pune (2016-19)
4. ***Secretary***, Association of Bengal Geographers (ABG) (since 2014)
5. ***Editor***, Contemporary Geographer (Journal of ABG)
6. ***Member*** of Editorial Board, *Indian Journal of Landscape Systems and Ecological Studies*, Kolkata (2007 onwards).
7. ***Member*** of Advisory Board, *Earth Surface Review*, Gorakhpur (2010 onwards).
8. ***Member*** of Editorial Board, *ENSEMBLE*, Dr. Meghnad Saha College, Itahar, West Bengal.
9. ***Member*** of Editorial Board, *Advance Journal of Humanities and Social Sciences*, Midnapore College (Autonomous), West Bengal.

11. ***Steering Committee Member***, International Geographical Union (IGU) Commission on Research Methods in Geography

Country Visited

Nepal (1994), ***Sri Lanka*** (2012), ***Bangladesh*** (2013), ***Thailand*** (2013), ***Russia*** (2015), ***China*** (2016), ***Japan*** (2016), ***Thailand*** (2017)

II. Details about number of Ph.D. and Postdoctoral fellows (from all sources) working at present with the mentor

Number of PhD Scholars working presently

1. Ritabrata Mukhopadhyay: Spatial Significance of Socio-Political Movements in Puruliya District, West Bengal.
2. Arup Kumar Saha: Access to Health Care Services in Dakshin Dinajpur District, West Bengal: A Spatio-Temporal Analysis
3. Tapan Pramanick: Spatio-Temporal Analysis of Tuberculosis in Some Selected Districts of West Bengal.
4. Pranabpati Karmakar: Role of Transport Infrastructure on Sustainable Livelihood of the Sundarban Region –A Case Study of Basirhat Subdivision, West Bengal.
5. Ratan Pal: Estimating Soil Erosion and Its Impacts: A Sustainable Land Utilization Perspective in the Silabati River Basin, Eastern India.
6. Buddhadev Hembram: Impact of Rapid Urban Growth on living Environment in Siliguri Municipal Corporation, India.
7. Manoj Kumar Mahato: Wasteland Management and Sustainable Development in Drought-prone Purulia District, West Bengal.

No Post-Doctoral Fellows working presently: Nil

III. List of papers published (only in SCI indexed journals) in the last five year

1. Limnological profile of Kamal Sagar Wetland of Burdwan Town, West Bengal, India, ***Nusantara Bioscience***, Indonesia, Vol. 9, No. 2, pp. 195-201, May 2017, ISSN: 2087-3948 (Print), E-ISSN: 2087-3956 (Co-author: S.K. Alamgir Badsha).

2. Groundwater potentiality of the Kumari River Basin in drought-prone Purulia upland, Eastern India: a combined approach using quantitative geomorphology and GIS, ***Sustainable Water Resources Management***, **Springer**, 17th June 2017 (Online), ISSN 2363-5037, DOI 10.1007/s40899-017-0142-3 (Co-author: Prasanta Kumar Ghosh).
3. Exploring the potential for development of Geotourism in Rarh Bengal, Eastern India using M-GAM, *International Journal of Geoheritage and Parks*, **Elsevier** ***Special Issue on Exploration of Geoheritage, Geoparks and Geotourism***, 2021 (in press, expected to be published by June 2021) (Co-author: Manoj Kumar Mahato).
4. Quantitative Analysis of Drainage Basin Parameters towards better Management of Damodar River, Eastern India, ***Journal Geological Society of India***, Vol.97, July 2021, pp.711-734, 0016-7622/2021-97-7-711, **Springe**r (Co-authors: Prasanta Kumar Ghosh and Ritendu Mukhopadhyay).
5. Study of river sensitivity for sustainable management of sand quarrying activities in Damodar river, West Bengal, India, ***Current Science***, Vol. 121, No. 6, 25 September 2021, pp. 810-822, ISSN: 0011-3891(Co-author: Prasanta Kumar Ghosh).
6. Late Holocene river dynamics and sedimentation in the Lower Ganga plains, India, ***Geological Journal***, 2023, 1–23, DOI: 10.1002/gj.4678, John Wiley & Sons Ltd (Co-authors: Sujay Bandyopadhyay, Subhajit Sinha, Anil Kumar and Pradeep Srivastava).

Publication of Book Chapters

1. Historical Evidences in the Identification of Palaeochannels of Damodar River in Western Ganga-Brahmaputra Delta in B. C. Das et al (eds) *Quaternary Geomorphology in India: Case Studies from the Lower Ganga Basin*, **Springer**, Switzerland, 2018, pp.127-138, ISBN 978-3-319-90426-9 (Co-author: Prasanta Kumar Ghosh).
2. Trend and Pattern of Infant Mortality in West Bengal, India: A Critical Appraisal in Anuradha Banerjee, Narayan Chandra Jana and Vinod Kumar Mishra (eds) *Population Dynamics in Contemporary South Asia: Health, Education and Migration*, **Springer Nature**, Singapore, 2020, pp. 111-131, ISBN: 978-981-15-1667-2 (print), ISBN: 978-981-15-1668-9 (eBook) (Co-author: Syfujjaman Tarafder)
3. Management of Wastelands in Chotanagpur Plateau Fringe: Lessons from Village-Level Experience in Birbhum District of West Bengal, India, in Rukhsana, Haldar A., Alam A., Satpati L. (eds) *Habitat, Ecology and Ekistics, Advances in Asian Human-Environmental Research*,

Springer Cham., 2021, pp. 293-307, First Online 22 October 2020, ISBN: 978-3-030-49115-4 (Online), 978-3-030-49114-7 (Co-author: Manas Pal).

4. Physical Environmental Impact Assessment of Flood: A Case of Lower Darakeswar-Mundeswari Interfluve in West Bengal, in B. W. Pandey and S. Anand (eds.), Water Science and Sustainability, Sustainable Development Goals Series, **Springer Nature Switzerland AG** 2021, pp. 53-77, ISBN 978-3-030-57488-8 (ebook), ISBN 978-3-030-57487-1 (print) (Co-author: Soumen Mandal).
5. Changing Rainfall Patterns and their Linkage to Floods in Bhagirathi-Hooghly Basin, India: Implications for Water Resource Management, in B. W. Pandey and S. Anand (eds.), Water Science and Sustainability, Sustainable Development Goals Series, **Springer Nature Switzerland AG** 2021, pp. 169-181, ISBN 978-3-030-57488-8 (ebook), ISBN 978-3-030-57487-1 (print) (Co-authors: Sujay Bandyopadhyay, Prasanta Kumar Ghosh and Ritendu Mukhopadhyay).
6. Effects of Sonajhuri (Acaciaauriculiformis) plantation on soil health in Purulia District, West Bengal, India, in Pravat Kumar Shit et al (eds.), *Forest Resources Resilience and Conflicts*, **Elsevier**, 2021, pp. 343-358, ISBN 978-0-12-822931-6 (Co-author: Manoj Kumar Mahato).
7. Micro-Spatial Analysis of Rural Accessibility for Imbricating Regional Development: Exemplifying an Indian District, in Mukunda Mishra, R. B. Singh, Andrews José de Lucena, Soumendu Chatterjee (eds.) *Regional Development Planning and Practice: Contemporary Issues in South Asia*, **Springer Nature** Singapore, 2021, ISBN: 9789811656804 (Co-author: Syfujjaman Tarafder).
8. Land Use-Land Cover Dynamics in Baku Micro-watershed Area of Ausgram Block-II, Purba Bardhaman District, West Bengal, India, in N. C. Jana et al (eds.) *Livelihood Enhancement through Agriculture, Tourism and Health*, **Springer Nature**, Singapore, 2022, pp.167-184, ISBN 978-981-16-7309-2 (print), ISBN 978-981-16-7310-8 (eBook) (Co-author: Raj Kumar Samanta).
9. Tuberculosis Patients in Malda District of West Bengal, Eastern India: Exploring the Ground Reality,in N. C. Jana et al (eds.) *Livelihood Enhancement through Agriculture, Tourism and Health*, **Springer Nature**, Singapore, 2022, pp.425-437, ISBN 978-981-16-7309-2 (print), ISBN 978-981-16-7310-8 (eBook) (Co-authors: Tapan Pramanick and Deb Kumar Maity).
10. Development of Tribal Livelihood in Manbazar-II Block of Purulia District, West Bengal, India, in N. C. Jana et al (eds.) *Livelihood Enhancement through Agriculture, Tourism and Health*, **Springer Nature**, Singapore, 2022, pp.471-493, ISBN 978-981-16-7309-2 (print), ISBN 978-981-16-7310-8 (eBook) (Co-author: Sumanta Kumar Baskey).