INTERNATIONAL RESEARCH JOURNAL OF HUMANITIES AND INTERDISCIPLINARY STUDIES
(Peer-reviewed, Refereed, Indexed & Open Access Journal)
DOI : 03.2021-11278686 ISSN : 2582-8568 IMPACT FACTOR : 8.031 (SJIF 2025)

Monitoring Indian Sundarbans Mangroves through Geospatial Techniques

Dr. Anukul Ch. Mandal
Post Doctoral Research Scholar (D. Sc),
Department of Geography,
Manipur International University,
Imphal (Manipur, India)

DOI No. 03.2021-11278686 **DOI Link ::** https://doi-ds.org/doilink/03.2025-79615765/IRJHIS2503006

Abstract:

Study of vegetation types at the genus level, ranking of vegetation types showed that mixed forests constituted the dominant cover type (16 types) in Indian Sundarbans on the basis of the sum of ground cover in western and eastern Indian Sundarbans, where higher Pole diversity in northern sectors leads to greater influence of fresher water as opposed to lower diversity in southern sectors due to salinity While species diversity assessed with Shannon Diversity Index also indicated higher diversity in northern sectors ranked comparatively lower in southern saline areas. The highest correlation was found between above-ground biomass (AGB) and vegetation indices (OSAVI and SAVI); OSAVI was the best indicator of carbon stock in the watershed's vegetation, indicating that it might be another useful instrument for evaluating carbon sequestration. It predicted a shift towards saline species and a decline in freshwater-dependent mangroves, largely driven by increased salinity and altered patterns of freshwater influx. Such changes appear to correlate with declines in biodiversity, a loss of biomass, and a consequent decrease in carbon sequestration potential. The findings underlined the importance of sustained monitoring and adaptive management to face the ecological challenges posed on the Sundarbans.

Keywords: *Indian Sundarbans, mangrove ecosystems, species diversity, biomass estimation, satellite data.*

1. Introduction:

The Indian Sundarbans, one of the largest mangrove ecosystems globally, is also a major site for biodiversity conservation, coastal protection, and carbon sequestration [1]. But these are vital ecosystems increasingly threatened by rising salinity levels, altered freshwater flows and human activities, which makes a detailed understanding of their ecological dynamics essential. It tries to assess the mangrove vegetation types, species diversity and biomass of the Sundarbans using both satellite data and field surveys. A genus-level classification identified 16 different vegetation types, with mixed forests as the dominant type. Using the Shannon Diversity Index, species richness exhibited regional differences, with the northern regions (influenced by freshwater) displaying greater diversity than the saline southern [2]. Understanding the region's capacity to sequester carbon is essential, as OSAVI is the most accurate measure of carbon stock. This study also looks at the relationship between Above-Ground Biomass (AGB) and other vegetation indices, such as OSAVI and SAVI. As saline-tolerant species spread at the expense of freshwater mussel reefs, the study also shows a dramatic shift in the species that predominate, illustrating the slow anthropogenic stress. These results emphasize how crucial it is to use efficient monitoring and flexible management techniques in order to preserve and uphold the Sundarbans' ecological integrity. [3].

2. Literature Review:

One of the largest and most biodiverse mangrove ecosystems on the planet, the Indian Sundarbans, are essential for carbon sequestration, biodiversity preservation, and coastal protection. But it is threatened by climate change, increasing salinity and human activity. Geospatial methods, such as remote sensing, GIS, and satellite imagery, have become invaluable assets in the observation and evaluation of aforementioned mangroves' health, extent, and dynamics. By highlighting changes in these aspects, these techniques supply key information regarding mangrove ecosystem dynamics that can help understand the dynamics of mangroves, leading conservation efforts, and sustainable management of the Sundarbans.

Summary of Literature Review

Author's	Work Done	Findings
Praharaj, S. (2024)	examined post-cyclonic flood susceptibility and changes in the amount of mangrove forests in the Indian Sundarbans using geospatial analysis and multi-criteria decision-making.	Identified changes in mangrove forest distribution post-cyclone, highlighting physical flood susceptibility and area changes, emphasizing the need for integrated flood management.
Pandey, A. C. (2024)	Used Google Earth Engine (GEE) to quantify shoreline dynamics in the Indian Sundarbans delta.	Automated extraction of shoreline dynamics revealed significant coastal changes, influencing habitat loss and ecological alterations in the Sundarbans.
Alam, B. M. (2024)	Assessed land cover, NDVI, and LST changes in Sundarbans mangrove forests using GIS and remote sensing.	Found significant alterations in land cover and NDVI, highlighting the impact of land use changes and climate variables on mangrove health.
Panda, S. (2024)	Monitored forest cover dynamics in Indian Sundarbans from 2000–	Forest cover showed fluctuating trends, with a general decrease in mangrove area,

	2020 using geospatial tools.	stressing the importance of monitoring for future conservation efforts.
Das, R. (2023)	Applied geospatial techniques for monitoring mangrove ecosystems in Indian Sundarbans.	Identified significant mangrove degradation due to anthropogenic pressures and environmental factors, indicating the need for sustainable management practices.
Das, R. (2023)	Explored the use of indigenous knowledge for mangrove conservation and livelihood sustainability in the Indian Sundarbans.	Emphasized the role of indigenous knowledge in enhancing mangrove conservation efforts and sustaining local livelihoods amidst changing environmental conditions.
Hafsa, B. (2022)	Analyzed multi-decadal land cover change in the Bangladesh Sundarbans using GIS and remote sensing.	Observed a steady decline in mangrove cover, with a shift towards saline species due to increasing salinity and sea-level rise.
Paul, A. K. (2022)	Combined participatory rural appraisal and geospatial techniques to analyze mangrove forest dynamics and livelihood dependencies in the Indian Sundarbans.	Revealed a correlation between mangrove forest health and local livelihoods, indicating the vulnerability of communities to environmental changes.
Ghosh, T. (2021)	Monitored land cover changes in Indian Sundarbans using geospatial science tools.	Found that mangrove loss was correlated with urbanization and rising salinity, pointing to the urgency of targeted interventions.
Dadhwal, V. K. (2021)	examined geospatial resources for coastal mangrove mapping and monitoring.	Concluded that remote sensing and GIS tools are crucial for effective monitoring of mangrove health and distribution.
Pathak, D. (2021)	Studied inter-decade spatial-temporal dynamics of the Sundarban mangrove forest from 1990–2019.	Highlighted significant changes in mangrove forest dynamics, suggesting that human activities and climate change are major drivers of degradation.
Manna, S.(2020)	Mapped the distribution of Sundarban mangroves using	Introduced a new spectral metric for better monitoring of mangrove health, which can

	Sentinel-2 data and a new spectral metric.	aid in early detection of environmental stress.
Chakraborty, A. (2019)	Applied remote sensing and GIS techniques to map and monitor Odisha's mangroves.	Identified key factors influencing mangrove health and growth along the Odisha coast, with implications for sustainable management strategies.

Research Gap:

Although the Indian Sundarbans hold immense ecological significance, few studies have effectively integrated remote sensing with field studies to evaluate the implications of environmental transitions on mangrove biodiversity and biomass. Previous studies have focused mainly on mangrove classification and carbon sequestration, while very little attention has been paid to the potential regional variations of species diversity and the role of vegetation indices (such as OSAVI) in biomass estimation in mangrove ecosystems. Moreover, the changing species assembly from increasing salinity and changing freshwater flows is still poorly understood.

3. Problem Statement:

The Indian Sundarbans' mangrove ecosystem faces increasing threats from rising salinity, altered freshwater flows, and human activities. This study addresses the need for a comprehensive understanding of vegetation types, species diversity, biomass, and their potential impacts on carbon sequestration.

4. Methodology:

Genus-Level Mangrove Classification and Diversity Assessment

In this study, we used satellite data with limited cloud cover to classify mangrove areas for diversity assessment. Cloud identification, scene classification, atmospheric distortion reduction, and bottom-of-atmosphere conversion are all included in the atmospheric correction, which was carried out independently. Spectral bands were selected, processed, and mosaicked for classification. Survey of the field and data collection were carried out for the different ecological zones to ensure sufficient agreement with the satellite revisit period. To ensure that the training dataset was representative, ground reference points were acquired from a variety of locations. Homogeneous species patches with an area of about 100 m^2 were prioritized, while most widely distributed mixed patches were also considered. By using a combination of helicopter and water routes to reach remote areas, the survey covered multiple forested areas. Fieldwork was conducted by supervision in open forest environments.

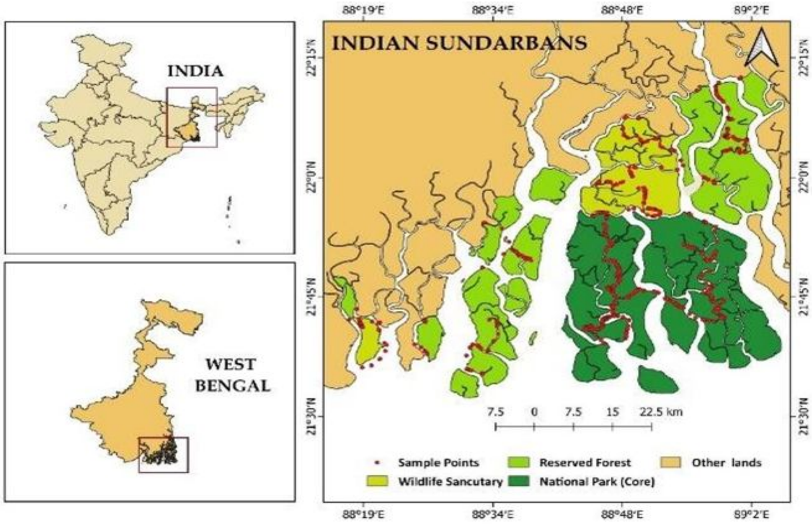

Figure 1 Location of The Study area

To perform the classification accurately, we took pure patches of mangroves to generate training samples. 302619582 sample points were collected, where 70% were assigned for classification and 30% were assigned for validation. Machine learning approaches (supervised classification based on probability decision rules) were used to classify the final layered composite image. Biodiversity indices were then computed using geospatial methods on this genus-level map.

Above-Ground Biomass and Carbon Stock Estimation

Low-cloud satellite data were utilized to evaluate the carbon stock and biomass. The panchromatic sensors' maximum spatial resolution was 15 meters, but the multispectral sensors was 30 meters. Different vegetation indices, which are relevant to biomass estimation, were also calculated using some spectral bands. Well known and widely utilized vegetation indices developed for identifying vegetation health and biomass, soil brightness/atmospheric correction VIs, saline and dry soil condition-based VIs, and ones with less saturation effect such as the SAVI. Field data, including measurements like tree diameter and canopy height, were included as inputs to mangrove species-specific allometric equations. The equations, derived from existing methodologies, used wood density data specific to each species to calculate above-ground biomass and carbon stock in the entire study area. These calculations were able to demonstrate several ecological mechanisms of the mangrove ecosystem.

$$AGB = 0.0673 (\rho \times DBH2 \times H) 0.976 \quad (1)$$

$$AGB = 0.0776 (\rho \times DBH2 \times H)0.940 \quad (2)$$

$$AGB = 0.0509 (\rho \times DBH 2 \times H) \quad (3)$$

Above Ground Biomass in tonnes is what AGB stands for in this context. H is the tree height in meters, ρ is the wood density in grammes per cubic centimeters, and DBH is the diameter at breast height in centimeters.

$$C = AGB \times CF \qquad (4)$$

In this case, CF stands for carbon fraction (0.5), C for carbon stock in tonnes, and AGB for above-ground biomass in tonnes.

5. Result & Discussion:

Change Detection and Prediction Using a Geospatial Model

Geo-spatial modeling approach was applied for carrying out change detection analysis and forecasting [4]. Input layers were extracted from classified vegetation and biomass maps of a past and present class. The model used machine learning methods to examine past fluctuations and project future standards into 2050. It involved the use of advanced algorithms for training as well as validation against data available until.

Genus-Level Classification

By employing multispectral sensors to classify mangrove vegetation to the genus level [5]. The classification process classified 16 different classes, 11 belonging to pure mangrove, 3 to mixed mangrove, and geomorphology features such as saline banks and rivers. Pure mangrove types and mixed dominant classes contain specific combinations of one or more of the genera. The classification indicated that the dominant vegetation type was a dense mixed forest, reversing 334.25 km². The lowest distribution for genus is 2.90 km². The western boundary of the forest is dominated by a single genus influenced by major river systems in that area and the east is dominated by a different mixed vegetation type influenced by another set of river systems [6].

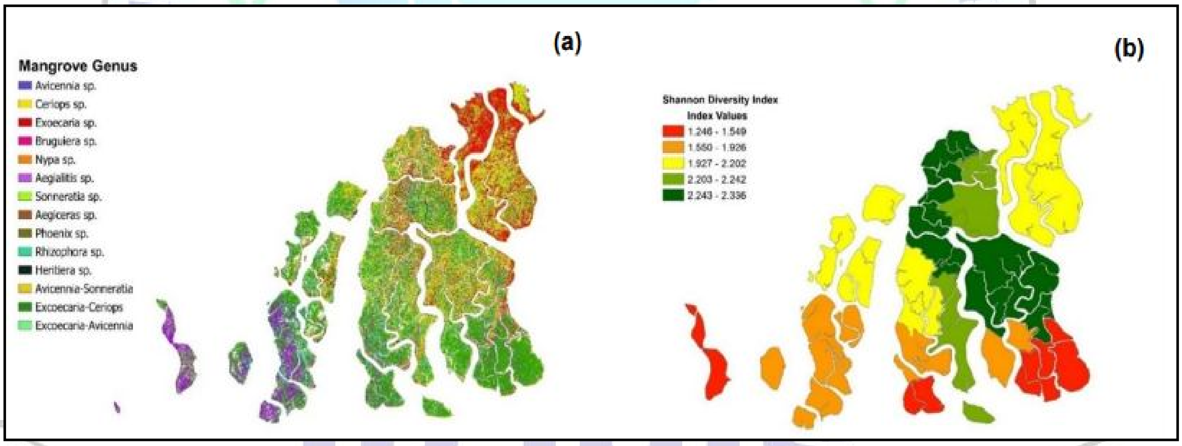

Figure 2 (a) Genus Level Classification of the mangroves (b) Species Diversity of the mangroves.

Species Diversity: The Shannon Diversity Index was used to assess the diversity of all plant species in the various Indian Sundarbans regions, and the results showed some interesting patterns. [7]. The majority of plant species and the highest diversity (H′ = 2.299) were found in the Chand Khali area. On the otherhand, Lothian Island (1.246 which had the lowest diversity 31) not as rich, as the community.

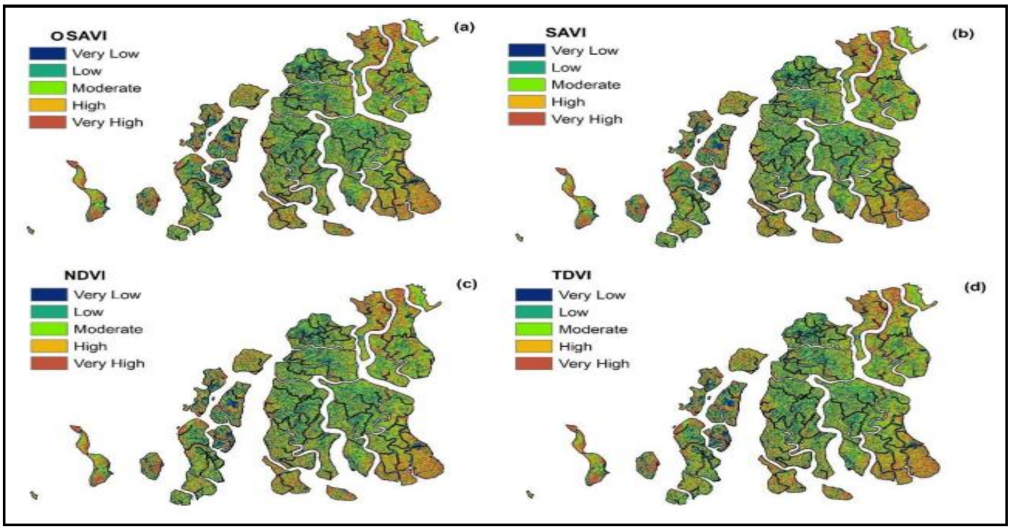

Figure 3 Mangrove Health Indices using (a0 OSAVI (b) SAVI (c) NDVI (d) TDVI.

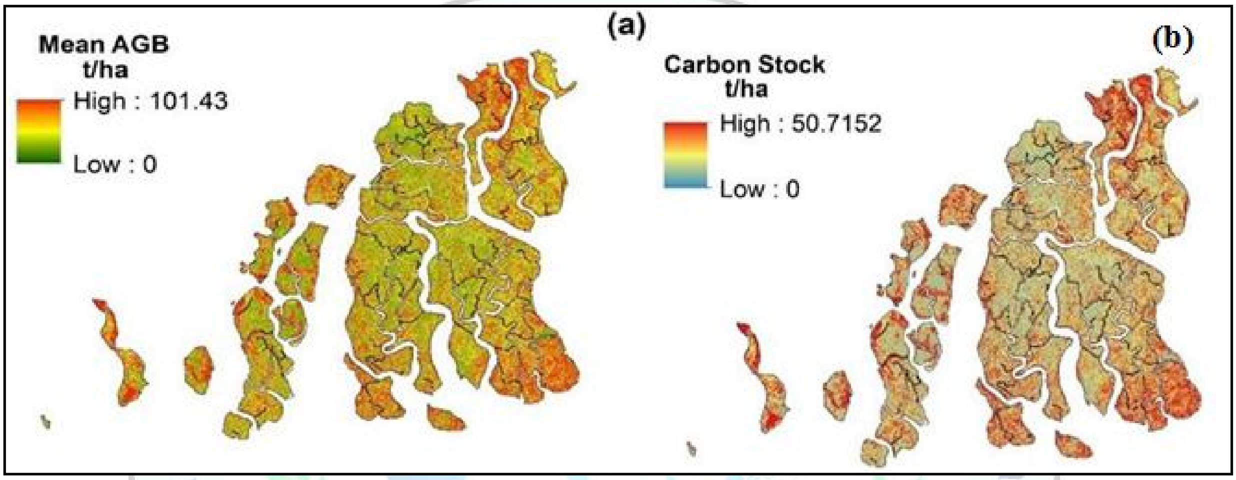

Figure 4 OSAVI based (a) Mean AGB of the Indian Sundarbans (b) Carbon Stock of the Indian Sundarbans

Moreover, previous studies in the Indian Sundarbans demonstrated pronounced spatial variation in plant species richness [8]. The southern portion, which is closest to the water, has higher salinity levels, which reduces the variety of plant species. Nonetheless, the northern region has a wider variety of plant species and biodiversity due to its increased freshwater intake.

Mangrove Health Assessment, Above-Ground Biomass (AGB), and Carbon Stock Estimation

We discovered substantial correlations between field-measured Above-Ground Biomass (AGB) and the vegetation indices NDVI, SAVI, OSAVI, and TDVI using basic linear regression models. OSAVI had the best square correlation ($r^2 = 0.95$, $p < 0.01$), followed by SAVI ($r^2 = 0.95$, $p < 0.01$), NDVI ($r^2 = 0.93$, $p < 0.01$), and TDVI ($r^2 = 0.84$, $p < 0.01$) [9]. The NDVI was 72.61 t ha^{-1}, while the OSAVI and SAVI maximum values of AGB were 101.43 t ha^{-1} and 93.05 t ha^{-1}, respectively. The TDVI model, for example, predicted a maximum AGB of 43.45 t ha^{-1}, making it the most underestimated model. The total carbon stock was then calculated by multiplying field AGB values by a carbon fraction of 0.5. OSAVI, which ranged from 0 to 50.71 t ha^{-1}, was the most effective indicator for assessing carbon stock. With ranges of 0 to 46.52 t ha^{-1} and 0 to 36.30 t ha^{-1}, respectively, SAVI and NDVI came in second and third. In contrast, TDVI had once again a narrower range than we found (0–21.72 t ha^{-1}). The results define OSAVI as the best indicator to assess carbon stock in the region, while SAVI and NDVI provided the 2nd and 3rd best performance, respectively. By contrast, TDVI remained lower than carbon stock as measured in the field [10].

Both low and moderately salt-tolerant species face challenges due to the complex geography of the Indian Sundarbans. Many species, especially those that rely on freshwater, have been able to restrict their spread due to the rapid salinization caused by sea level rise, anomalous freshwater flows, and human activity [11]. As a result, there is less biomass and less capacity to store carbon[12]. The detrimental impact on mangroves and other flora has resulted in lower biomass and a reduced potential to capture carbon, leading to vulnerable ecosystems. The estimated maximum Above-Ground Biomass (AGB) was 101.43 t ha^{-1}, which was less than that of the Bangladesh Sundarbans.

The canopy cover is moderate, and ground can be exposed due to gaps in the overall structure [13]. This arrangement accommodates vegetation indices like OSAVI that minimizes impact of soil background [14]. When it comes to predicting above-ground biomass (AGB) in the Indian Sundarbans, NDVI, which is commonly utilized in dense canopies, performs poorly. Although it understates AGB in this area, TDVI has shown good performance in denser canopies [15].

"Change Detection and Prediction (1990 – 2050)

Mangroves that prefer freshwater, such as Bruguiera sp. and Xylocarpus sp., can be found in the northern Sundarbans. are trending downward, while saltwater-loving species Ceriops and Avicennia are taking over at an accelerating rate, according to change detection and prediction analysis based on the CA Markov Model. Excoecaria sp. still muses almost solely in the same locale. Since 1998, Excoecaria sp. and Ceriops sp. Lothian Island was rich in [16]. The model results estimate that most of freshwater species would decline and high salt tolerant species will constitute the bulk of the Indian Sundarbans by 2050 additional, more environmental / ecological parameters need to be incorporated in the existing model to estimate and predict more accurately the environmental variation of healthy mangrove vegetation, which has been left out in the existing model.

6. Conclusion:

In summary, this study identifies potential areas of mangrove distribution, classification, species diversity, and biomass estimation using a mixed approach of satellite data and field surveys across the Indian Sundarbans. Genus-level classification resulted in 16 different vegetation types; mixed forest was the dominant cover in the study area. The Shannon Diversity Index (H) was calculated as a measurement of species diversity and showed different patterns, with northern sections having higher diversity due to the influence of freshwater and lower diversity in the saline southern segments. AGB and vegetation indices like OSAVI and SAVI showed a remarkable correlation, with OSAVI being shown to be the most accurate indicator of the carbon stock, which is an essential property for calculating the capacity for carbon sequestration. The changes detection and prediction model suggest a change towards saline water-loving species, with freshwater dependent mangroves declining that is mainly contributed by increased salinity and reduced freshwater inflow. This trend carries consequences for biodiversity loss and loss of biomass, with downstream implications for carbon sequestration capacity. This study highlights the interplay of ecological factors including salinity, anthropogenic influence, and climate change in determining mangrove ecosystems. These results highlight the importance of further monitoring and measures which can adapt to prevent possible effects on ecological health of Indian Sundarbans due to changing environment.

Future Scope:

- Conduct continuous satellite and in situ surveys to monitor mangrove shifts from climate change and human influences.
- Improve models of how freshwater flow, sea level rise, and climate change affect mangrove ecosystems.
- Conduct field surveys for a better and more detailed view of mangrove diversity.
- To explore mangrove carbon storage enabling their integration into carbon credits.

7. Reference:

1. Mondal, B. K., Mahata, S., Basu, T., Das, R., Patra, R., Abdelrahman, K., ... & Praharaj, S. (2024). Analysis of the Post-Cyclonic Physical Flood Susceptibility and Changes of Mangrove Forest Area Using Multi-Criteria Decision-Making Process and Geospatial Analysis in Indian Sundarbans. *Atmosphere*, *15*(4), 432.
2. Santra, M., Dwivedi, C. S., & Pandey, A. C. (2024). Quantifying shoreline dynamics in the Indian Sundarban delta with Google Earth Engine (GEE)-based automatic extraction approach. *Tropical Ecology*, *65*(3), 426-442.
3. Kanjin, K., & Alam, B. M. (2024). Assessing changes in land cover, NDVI, and LST in the Sundarbans mangrove forest in Bangladesh and India: A GIS and remote sensing approach. *Remote Sensing Applications: Society and Environment*, *36*, 101289.
4. Islam, J., Sarkar, P. P., Mithun, S., & Panda, S. (2024). Monitoring yearly forest cover dynamics in the Indian Sundarban region during 2000–20: a geospatial approach. In *Vegetation Dynamics and Crop Stress* (pp. 165-184). Academic Press.
5. Bhadra, T., Banerjee, S., Ghosh, S., Saha, A., Mukherjee, K., Sardar, R., ... & Das, R. (2023).

Monitoring the Mangroves of Indian Sundarbans Using Geospatial Techniques. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *48*, 405-412.

6. Mondal, B. K., & Das, R. (2023). Appliance of Indigenous Knowlege in Mangrove Conservation and Sustaining Livelihood in Indian Sundarban Delta: A Geospatial Analysis. In *Traditional ecological knowledge of resource management in Asia* (pp. 77-101). Cham: Springer International Publishing.
7. Chowdhury, M. S., & Hafsa, B. (2022). Multi-decadal land cover change analysis over Sundarbans Mangrove Forest of Bangladesh: A GIS and remote sensing based approach. *Global Ecology and Conservation*, *37*, e02151.
8. Mondal, B. K., & Paul, A. K. (2022). Application of participatory rural appraisal and geospatial techniques for analysing the dynamics of mangrove forest and dependent livelihood in indiansundarban. In *Conservation, management and monitoring of forest resources in India* (pp. 409-455). Cham: Springer International Publishing.Kumar, D., & Ghosh, T. (2021). Monitoring changes in land cover in the Indian sundarbans region, using geospatial sciences. In *Re-envisioning Remote Sensing Applications* (pp. 137-150). CRC Press.
9. Gnanappazham, L., Prasad, K. A., & Dadhwal, V. K. (2021). Geospatial tools for mapping and monitoring coastal mangroves. *Mangroves: Ecology, Biodiversity and Management*, 475-551.
10. Halder, S., Samanta, K., Das, S., & Pathak, D. (2021). Monitoring the inter-decade spatial–temporal dynamics of the Sundarban mangrove forest of India from 1990 to 2019. *Regional Studies in Marine Science*, *44*, 101718.
11. Manna, S., & Raychaudhuri, B. (2020). Mapping distribution of Sundarban mangroves using Sentinel-2 data and new spectral metric for detecting their health condition. *Geocarto International*, *35*(4), 434-452.
12. Roy, S., Mahapatra, M., & Chakraborty, A. (2019). Mapping and monitoring of mangrove along the Odisha coast based on remote sensing and GIS techniques. *Modeling Earth Systems and Environment*, *5*, 217-226.
13. Ranjan, A. K., Sivathanu, V., Verma, S. K., Murmu, L., & Kumar, P. B. S. (2017). Spatio-temporal variation in Indian part of Sundarban Delta over the years 1990–2016 using Geospatial Technology. *International Journal of Geomatics and Geosciences*, *7*(3), 275-292.
14. Pramanik, M. K. (2015). Assessment of the impacts of sea level rise on mangrove dynamics in the Indian part of Sundarbans using geospatial techniques. *Journal of Biodiversity, Bioprospecting and Development*, *3*(155), 2376-0214.

15. Giri, S., Mukhopadhyay, A., Hazra, S., Mukherjee, S., Roy, D., Ghosh, S., ... & Mitra, D. (2014). A study on abundance and distribution of mangrove species in Indian Sundarban using remote sensing technique. *Journal of coastal conservation*, *18*, 359-367.
16. Chellamani, P., Singh, C. P., & Panigrahy, S. (2014). Assessment of the health status of Indian mangrove ecosystems using multi temporal remote sensing data. *Tropical Ecology*, *55*(2), 245-253.