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Research Article

Long term changes of the major coastal wetlands of India using global surface water datasets

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ABSTRACT

Wetlands, which are either periodically or permanently inundated by water, play a crucial role in our ecosystems. They aid in flood control, recharge groundwater, preserve biodiversity, improve water quality, and help to manage climate change. Coastal wetlands are particularly important as they support habitats, reduce erosion, and encourage tourism. However, rapid pace of urbanization and industrialization has resulted in significant degradation of these vital areas. Remote sensing and GIS technologies are helpful in identifying, mapping, and assessing wetland changes, essential for sustainable water management. This study aims to assess the long-term changes in India's major coastal wetlands—Mumbai-Thane Creek (Maharashtra), Mandovi-Zuari Estuary (Goa), Aghanashini Estuary (Karnataka), Vembanadu Lake (Kerala), Vedaranyam Swamp (Tamil Nadu), Pulicat Lake (Andhra Pradesh), and Chilika Lagoon (Odisha)—using the global surface water dataset (1984–2015), Landsat imagery, and GIS tools. The findings suggest varied trends for wetlands: Mumbai-Thane Creek and Mandovi-Zuari Estuary shrank by 8.7% and 0.1%, respectively, while Aghanashini Estuary and Vembanadu Lake increased by 3.8% and 1.8%. Chilika Lagoon noted the highest increase, i.e., 0.9% (1,417 Ha of permanent water). Vedaranyam Swamp and Pulicat Lake presented nominal changes. The changes are influenced by seasonal flooding, beach accretion, and mangrove growth. The study emphasizes the crucial role of geoinformatics in monitoring wetland status and offers valuable insights for sustainable wetland management. The study highlights the importance of targeted environmental policies to protect India's coastal wetland ecosystems and supports decision-making for urban planning, fisheries development, aquaculture, hydrology, and the protection of biodiversity.

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INTRODUCTION

Wetlands are regions where water is found, either on a permanent or temporary basis, and can be either vegetated or non-vegetated. They are found both inland and along coastlines, they act as crucial interfaces between land and water. Historically, wetlands have supported civilizations by providing water resources. As one of the most productive ecosystems, they contribute to eco-hydrological sustainability and offer essential resources such as food, biodiversity, drinking water, recreation, and climate stabilization [1–4]. Wetlands provide drinking water, fish, fodder, fuel, and wildlife habitat, while also controlling runoff, buffering shorelines, and offering recreational opportunities. [2, 5]. They recycle nutrients, purify water, reduce floods, preserve stream flow, and replenish groundwater. Often called the "kidneys of the landscape," wetlands also store water, retain nutrients, sequester carbon, and support plant growth [1, 6, 7].

Wetlands are identified and mapped using a variety of satellites using remote sensing and geographic information systems (GIS). The advantage is that the earth surface and subsurface data can be covered within a short time for accessing, processing, and monitoring the long-term changes [8–14].

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Wetland conservation requires effective environmental management, regular updates of Ramsar sites in India, and scientific, technical, and socio-economic co-operation. The UN's 17 Sustainable Development Goals (SDGs) address critical issues such as energy, consumption, poverty, health, and climate change. Wetlands are vital for achieving several of these goals, especially SDG6 (clean water and sanitation), SDG13 (climate action), and SDG14 (life below water). Coastal wetlands act as natural water filter, conserve resources, and enhance access to clean water (SDG 6). They play a vital role in climate action (SDG13) by sequestering carbon and reducing the effects of rising sea levels and extreme weather. Furthermore, they safeguard marine biodiversity and sustain coastal ecosystems, which aligns with SDG14. A significant challenge in decision-making is the lack of scientific data on natural resources impacted by human and environmental factors [14–17].

Numerous studies based on GIS and RS have provided significant information about wetland and shoreline changes, climate impacts, and vulnerability assessments in a variety of geographic and ecological contexts. Wetland and coastal ecosystems are increasingly vulnerable to climate and human pressures. Mishra et al. [18] studied tidal inlet morpho dynamics in Chilika Lake, while Acharyya et al. [19] studied Cyclone Fani's impact on its morphology. Lehner et al. [14] rationalize the global lakes and wetlands database for better conservation assessments. Cyclonic impacts have caused deforestation and shoreline changes in the Sundarban and Bhitarkanika mangroves [18]. Paul et al. [20] and Mishra, Guria, et al. [21, 22] emphasized erosion risks in cyclone-prone areas. Remote sensing studies by Queiroz et al. [23] and Mishra, Santos, et al. [24] highlight the key role of geospatial tools for wetland conservation and management.

Zhang et al. [5] studied climate change impacts on wetland changes in the Tibetan Plateau. Hossen and Sultana [25] used the digital shoreline analysis system (DSAS) technique to assess the shoreline changes on Saint Martin Island, Bangladesh. Mabwoga and Thukral [26] evaluated the ecosystem degradation in Harike wetland, India, using Landsat data. Jacintha et al. [27] studied wetland dynamics along the Chennai coast with geospatial tools. Dutta et al. [28] evaluated and quantified shoreline variations in the Hooghly estuary using Landsat data and DSAS, while Nandi et al. [29] predicted shoreline chanes on Sagar Island, West Bengal. Mahapatra et al. [3, 30] tracked shoreline changes along South Gujarat's coast and assessed coastal vulnerability. Dehadrai et al. [31] provided early insights into tidal impacts on the Zauri and Mandovi estuaries.

The studies indicate a significant global surface water loss, especially in the Middle East and Central Asia, caused by human activities and climate change [32]. Coastal erosion is exacerbated by human activities and rising sea-levels [8]. Pulicat Lake is experiencing a swift decline due to urban development, industrial growth, and loss of forest cover [33]. These studies underscore the necessity of tackling both natural and human-induced threats in wetlands, highlighting the critical role of geospatial tools in managing wetland and shoreline changes.

Indian coastal wetlands play a significant role in conserving biodiversity, reducing the effects of climate change, and protecting coastal communities from natural calamities. However, urbanization, industrialization, invasive species, and climate-induced sea level rise brought serious threats to habitat degradation and biodiversity loss [18]. Industrial activities degrade the ecological health, while rising sea levels disrupt their protective functions [34, 35]. Integrated conservation strategies are essential to safeguard these wetlands for environmental sustainability and the resilience of human populations [21, 22].

Coastal wetlands can be monitored over an extended period of time using the global surface water (GSW) dataset, which is derived from Landsat imagery and records surface water changes from 1984 to the present. Its global datasets in 30-meter resolution offer comprehensive insights into both seasonal and permanent water changes, which are crucial for comprehending how anthropogenic activity and climate change affect wetlands. It is a useful tool for resource conservation planning, policy development, and climate impact assessments because of its temporal and spatial changes [21].

This study aims to assess the long-term changes in major coastal wetlands of India, such as Mumbai-Thane Creek in Maharashtra, Mandovi-Zuari Estuary in Goa, Aghanashini Estuary in Karnataka, Vembanadu Lake in Kerala, Vedaranyam Swamp in Tamil Nadu, Pulicat Lake in Andhra Pradesh, and Chilika Lagoon in Odisha. By utilizing the Global Surface Water (GSW) dataset (1984-2015), Landsat imagery, and GIS tools such as ArcGIS, the study evaluates the changes in the wetland ecosystems over time. The outcomes are intended to support decision-making for sustainable coastal wetland management and conservation strategies.

MATERIALS AND METHODS

Selected Study Area

The present study assesses the long-term changes in major coastal wetlands in India. Figure 1 illustrates the locations of these major coastal wetlands assessed in the study. Table 1 highlights the key features of identified wetlands.

The methodology provides a robust framework for assessing the long-term changes in coastal wetlands, obtaining the GSW datasets, comprehensive classification techniques and accuracy assessment. The integration of spatial and temporal analyses ensures a detailed understanding of wetland changes over the past three decades.

Data Acquisition

The global surface water (GSW) dataset was used in this research, it shows the distribution and the seasonality of surface water. The GSW dataset was developed from satellite imagery of Landsat 5, 7 and 8 from 1984 to 2015. Figure 2 depicts the Landsat image (Year 2015) of the identified seven major coastal wetlands. Each pixel in the dataset was categorized as water body, land or non-valid observations using an expert system of classifiers. Surface water changes were captured in the dataset at a resolution of 30 m over a period 32 years. Main parameters assessed are water occurrence, seasonality, recurrence, transition, and maximum extent. These parameters are significant for assessment of the spatial and temporal changes in the surface water due to natural factors, human activities and other environmental aspects.

Pre-Processing

The datasets indicating the various parameters that affect the changes in the areal extent of the water bodies under study were processed and analysed using the ArcGIS tools. Initially, the features of the areas under study were extracted by using the "Extract by Mask" option under the Spatial Analyst tools. For those study areas that were present in more than one dataset, the rasters were combined using the "Mosaic to New Raster" option under Data Management tools. After obtaining the desired study area as a single raster dataset, its value and count were calculated using the "Calculate Statistics" option under "Raster Properties" in Data Management tools. The respective layers were then classified into their respective classes based on the percentage that was calculated from the statistics of the respective layer.

Table 1. Key features of identified wetlands

Wetland Name	Key Features
Mumbai-Thane Creek	A coastal inlet along the Arabian Sea, formed due to a seismic fault. Recognized as a bird zone for migratory birds and flamingos.
Mandovi-Zuari Estuary	Located in Goa, includes Mandovi and Zuari rivers. Monsoon-induced changes affect salinity, pH, turbidity, dissolved oxygen, and other parameters [36].
Aghanashini Estuary	Found in Karnataka, this estuary flows through the Western Ghats without dams, maintaining its pristine state. Merges with the Arabian Sea.
Vembanad Lake	India's largest water body located in Kerala, nourished by 10 rivers. Features mangroves, lagoons, and reclaimed lands.
Vedaranyam Swamp	Situated in Tamilnadu, includes eco-sensitive mangroves, tidal streams, and lagoons. Houses the Muthupet Lagoon and wildlife sanctuary [37].
Pulicat Lake	India's second-largest brackish water lake, spanning Andhra Pradesh and Tamil Nadu. Home to diverse ecological zones and bird sanctuaries.
Chilika Lagoon	The largest brackish water lagoon in India, located in Odisha. Known for its ecological importance and tentative UNESCO status.

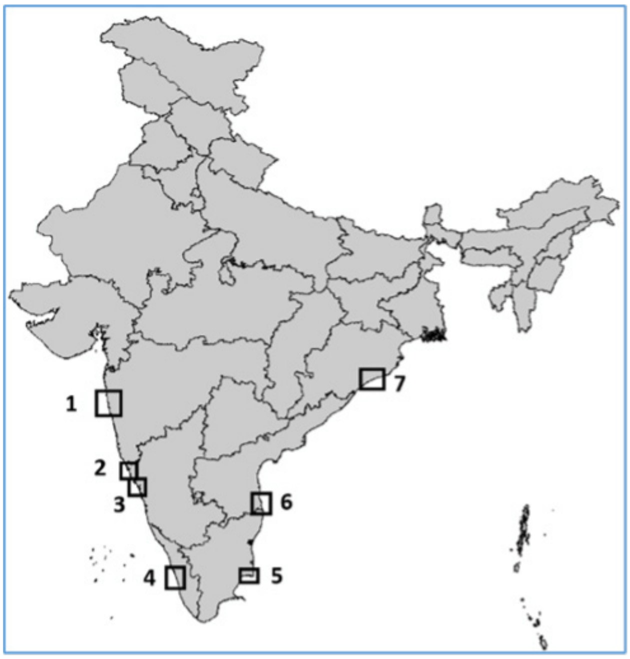

Figure 1. Selected study area i.e., major coastal wetlands of India (Wetlands included for the study are highlighted in rectangle) 1: Mumbai-Thane creek, 2: Mandovi-Zuari estuary, 3: Aghanashini estuary, 4: Vembanadu Lake, 5: Vedaranyam swamp, 6: Pulicat Lake, 7: Chilika Lagoon

Classification

The unified raster dataset was classified into respective classes based on the percentage values derived from the calculated statistics. The classification process adhered to the following metrics:

•Occurrence: The global surface water occurrence (SWO) provides information on water dynamics from 1984 to 2015, capturing intra and interannual variability. To compute SWO, the water detections (WD) and valid observations (VO) from the same months are summed, so that SW month = ∑WD month / ∑VO month. Averaging the results of all monthly SW month calculations gives the long-term overall surface water occurrence.

•Seasonality: The seasonality map shows water surface information annually, dividing permanent and seasonal water. Permanent water remains underwater, while seasonal water appears for less than 12 months. Ice-covered lakes are non-valid observations. Seasonality is calculated annually.

•Recurrence: It measures water surface behavior and frequency, mainly on temporal variability. It defines a 'water period' for each pixel, identifying water seasons based on monthly recurrence. Water recurrence is calculated as the ratio of water years to observation years.

•Transition: It deals with seasonal changes in water seasonality between observations and identifying three water classes: not water, seasonal water, and permanent water. It utilizes thematic maps and temporal profiles to identify transitions, comparing each year with the annual pattern for monthly recurrence. The overall confidence level is determined by the annual sum of monthly long-term recurrences.

•Maximum Extent: The global surface water maximum water extent provides information on all the locations ever detected as water over a 32-year period (1984-2015).

Accuracy Assessment

Accuracy assessment plays a crucial role in ensuring reliable classification results. Independent validation samples were utilized to evaluate the accuracy of water and non-water classifications. A confusion matrix analysis was performed to compare the classified results with reference data, generating key metrics such as overall accuracy, producer's accuracy, user's accuracy, and kappa statistics [27]. Threshold settings were carefully recognized to reduce misclassification errors, ensuring the water and non-water categories. Moreover, temporal validation was done to verify the consistency of classifications across multiple time intervals, ensuring that the results were robust and reflective of long-term trends. This comprehensive approach strengthens the reliability of the study's findings.

Wetland Change Detection

Wetland change detection is one of the fundamental applications in imagery and remote sensing. It is the comparison of multiple raster datasets, typically collected for one area at different times, to determine the type, magnitude, and location of change. Change can occur because of anthropogenic activity, abrupt natural disturbances, or long-term climatological or environmental trends. The output from change detection is a difference raster where each pixel contains the type or magnitude of change. When comparing thematic land-cover rasters, the result contains information about the type of change that occurred. The geoprocessing tools in the change detection toolset allow you to perform simple change detection between raster datasets. You can also use the compute change raster function to perform change detection in real time between two raster datasets.

The methodological approach used in the GSW dataset have several similarities with recent coastal changes studies but also differ in their specific focus and approach. Santos et al. [38, 39] employ multi-decadal remote sensing assessments and sea-level rise scenarios to predict future coastal evolution, aligning with GSW dataset long-term observation framework but with a focus on regional sea-level rises and vulnerability.

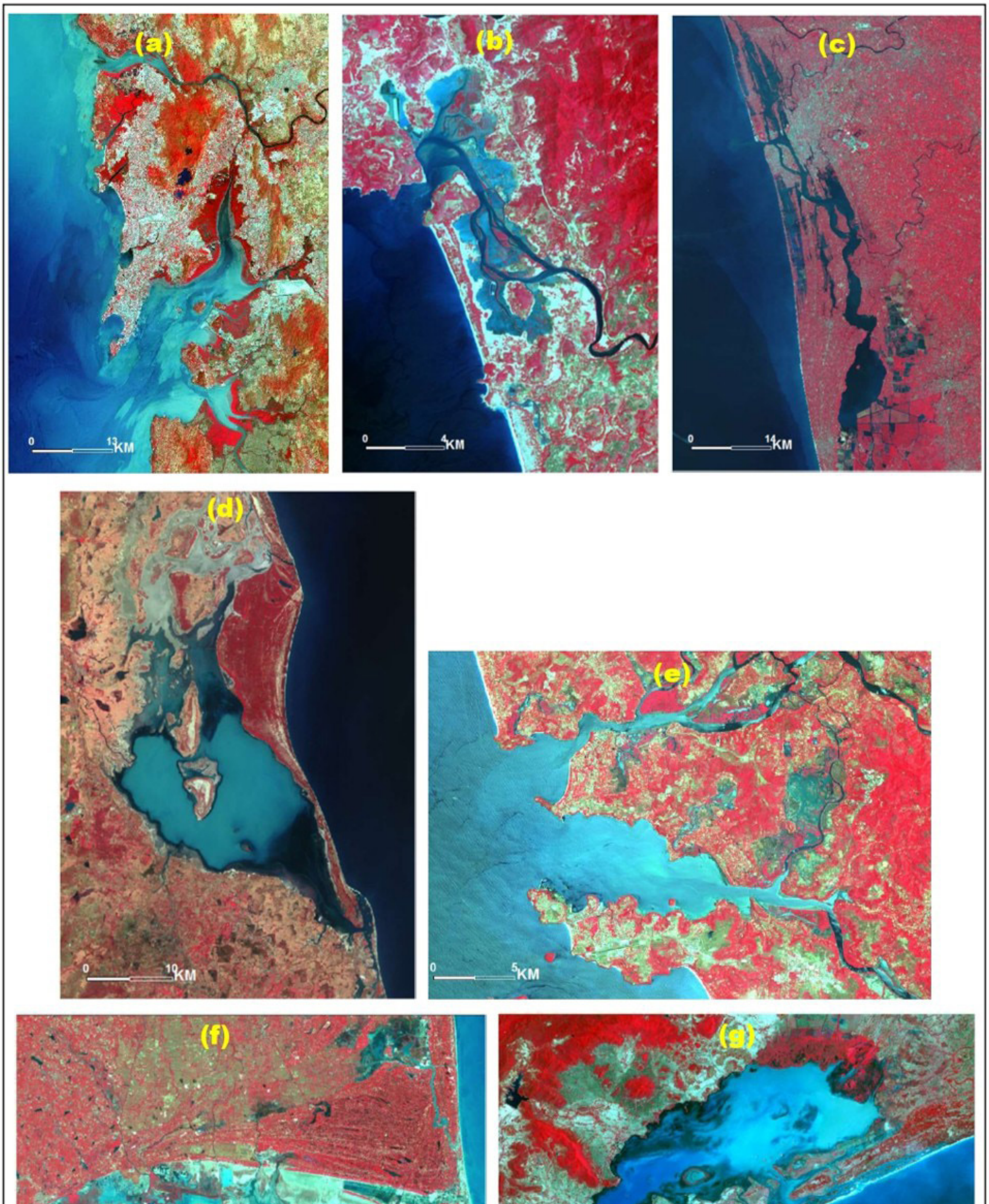

Figure 2. Landsat images of identified seven major coastal wetlands of India ((a) Mumbai-Thane creek, (b) Aghanashini estuary, (c) Vembanadu Lake, (d) Pulicat Lake, (e) Mandovi-Zuari estuary (f) Vedaranyam swamp, (g) Chilika Lagoon)

Table 2. Major coastal wetland area analysed along with its major observations and probable reasons

Sr. No.	Name of wetland	Area Analysed (Ha)	Net decrease in wetland area (Ha)	Net increase in wetland area (Ha)	Main observations for wetlands	Probable Reasons
1	Mumbai-Thane creek	4,262	684	315	Shrink (-8.7%)	Construction of harbour and growth of intertidal zone and mangroves
2	Mandovi-Zuari estuary	15,428	653	636	Shrink (-0.1%)	Construction of harbour and growth of intertidal zone and mangroves
3	Aghanashini estuary	4,207	133	293	Increase (+3.8%)	Conversion of land near the river into aquaculture ponds
4	Vembanadu Lake	31,812	151	731	Increase (+1.8%)	Recovery of land for expansion of settlements and other purposes Seasonal cultivation of fishes, prawns and other aquatic organisms
5	Vedaranyam swamp	34,692	684	315	Shrink (-1.1%)	Construction of harbor and growth of intertidal zone and mangroves
6	Pulicat Lake	58,619	13	9	Shrink (-0.0%)	Construction activities
7	Chilika Lagoon	108,296	480	1,417	Increase (+0.9%)	Fluctuating rainfall patterns, converted permanent water area to seasonal and growth of intertidal zone

Similarly, studies along the Digha coast [20] and Odisha coast [40], [41] employed remote sensing and statistical tools to analyse shoreline changes, erosion, and accretion, a focus that complements the GSW datasets detailed temporal metrics of surface water occurrence and recurrence. GSW dataset recurrence and transition maps offer broader-scale insights into water variability, which could enhance the local-scale analyses done by these studies. Additionally, while the GSW datasets assesses water changes over large areas and decades, studies emphasis on the response of specific coastal regions to both natural and anthropogenic factors, often integrating statistical and GIS-based methods to model shoreline changes and socio-ecological risks [41], [42]. Together, these studies highlight the important roles of global water datasets and localized research using remote sensing and geospatial tools for inclusive coastal management

RESULTS

GSW dataset are analysed for the major coastal wetlands of India to study the changes that have undergone from 1984 to 2015. The statistical parameters estimated under the present study are seasonality, transition from permanent water to land area (net decrease in water area) and land area to permanent water (net increase in water area), increase in surface water occurrence above 75%, and decrease in surface water occurrence above 75%. Figures 3 to Figure 5 show the parameters in pixel count for each wetland system based on GSW datasets are analysed. Table 2 highlights the summary of the identified major coastal wetland area analysed along with its observations as well as its probable reasons for wetland shrinkage and increase.

Around 4,262 ha of the wetland region of the Mumbai-Thane creek is analysed. Figure 3 (a,b) shows the extent and transition from GSW dataset for the Mumbai-Thane creek system.

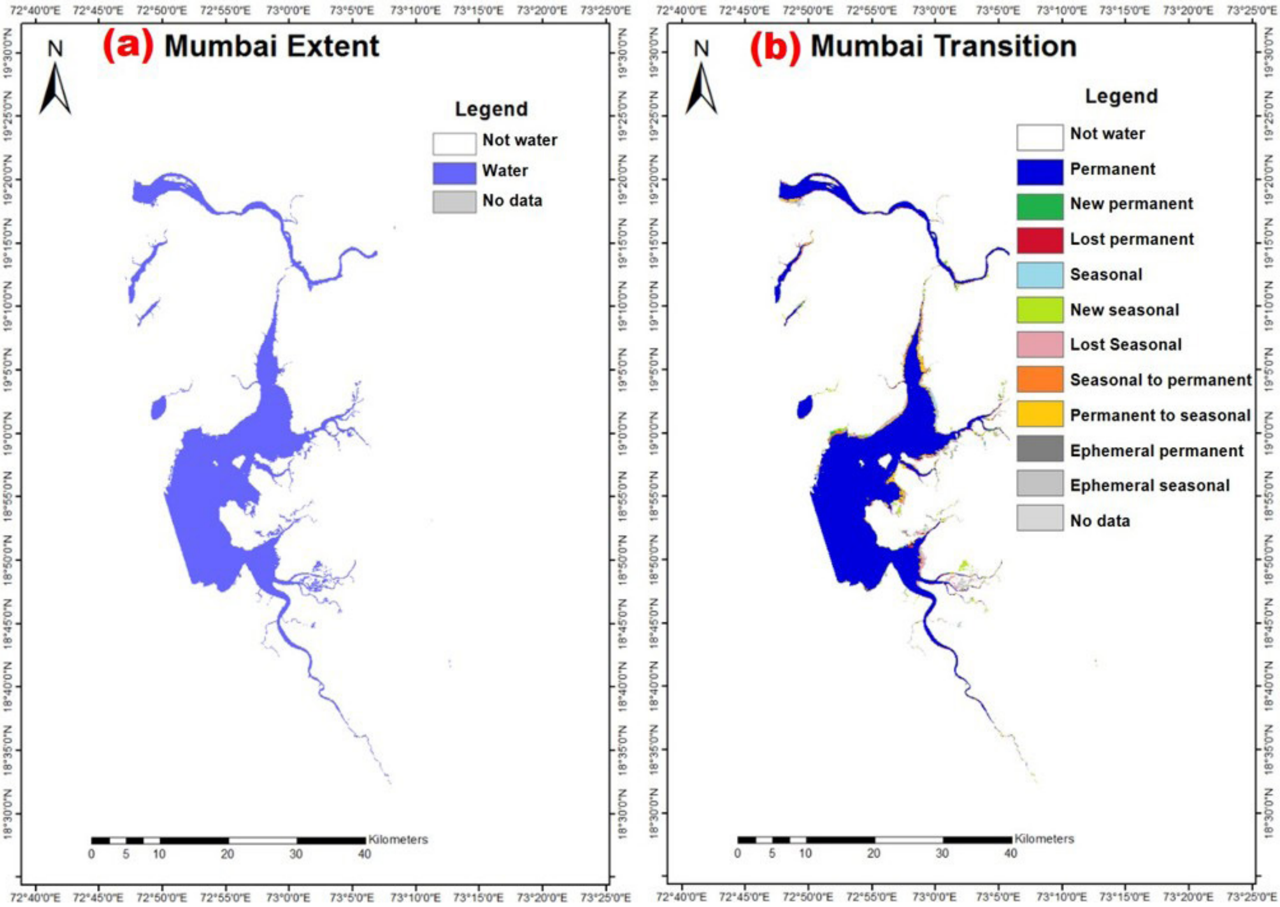

Figure 3.Mumbai-Thane Creek system (a) Extent and (b transition

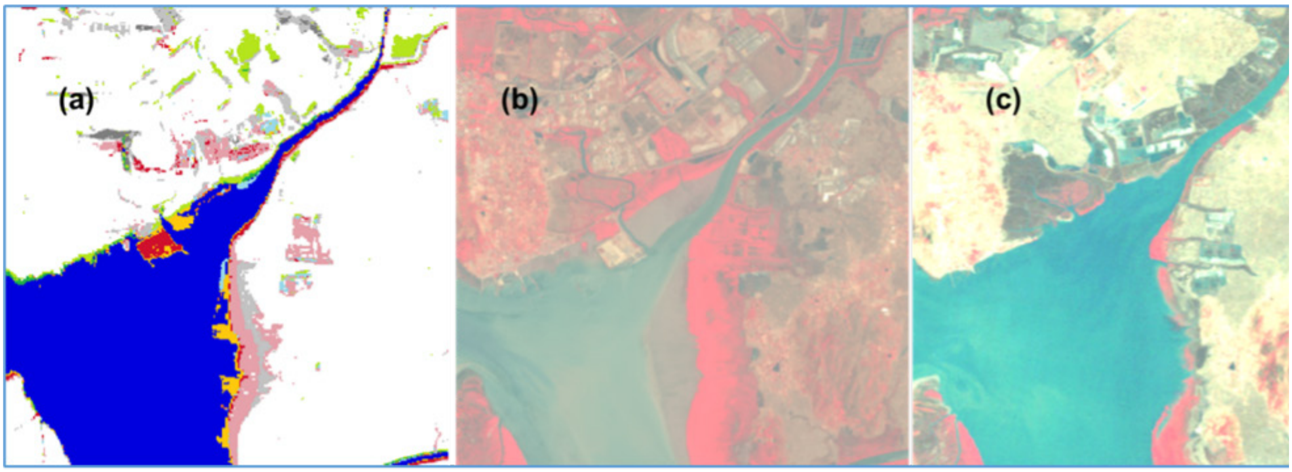

Figure 4.Mumbai-Thane Greek (a) Transition from GSW datasets, (b) Landsat image of 2015 and (c) Landsat image of 1991

The Mumbai-Thane creek is observed to shrink in volume with respect to the decrease in permanent wetland area (Figure 4). The increase in wetland area is observed to be around 315 ha, while the net decrease in wetland area is 684 ha. The net decrease in permanent wetland area is mainly due to the construction of harbours and the growth of intertidal zones and mangroves.

The assessment focused on about 4,207 ha of the Aghanashini River wetland region. Figure 5 (a,b) gives the extent and transitions noted in the GSW datasets for the Aghanashini River. The analysis reveals a net increase of 293 ha in permanent wetland area, while 133 ha of net decrease in wetland area. This increase in the new permanent wetland area is primarily due to land conversion into aquaculture ponds near the river.

The study analyzed approximately 31,812 ha of the Vembanadu Lake wetland region. There is a dynamic change in the waterbody's extent over time. There was an increase of around 731 ha in new permanent wetland area, while 151 ha of net decrease in permanent wetland area, as mentioned in Figure 5 (c,d). The net decrease in permanent wetland was mainly due to land reclamation for settlements and other purposes, while the increase in water bodies was attributed to the seasonal cultivation of fish and other aquatic organisms.

The study assessed nearly 58,619 ha of the Pulicat Lake wetland area. Figure 5 (e,f) depicts the extent and transitions observed in the GSW dataset for the Pulicat Lake. The lake observed a decrease in its volume, with a net increase in wetland area of around 9 ha and a net decrease in wetland area of 13 ha. Overall, there was a net decrease of 4 ha of wetland area during the study period.

In the Mandovi-Zauri Goa wetland region, covering around 15,428 ha, Figure 5 (g,h) shows the extent and transitions noted in the GSW dataset. Similar to Pulicat Lake, the Mandovi-Zauri Goa region experienced a reduction in wetland area. There was a new wetland area of nearly 636 ha, while 653 ha of wetland area were lost. This lost was primarily due to harbor construction, intertidal zone growth, and mangrove expansion. The net decrease in wetland area during the period was 17 ha.

The analysis of the Vedaranyam wetland area, about 34,692 ha, is shown in Figure 5(i,j). The creek observed a decrease in its volume, with a new wetland area of around 315 ha and a decrease of wetland area of 684 ha. This decrease was noted due to harbor construction, intertidal zone growth, and mangrove expansion. The net decrease in wetland area during the period was 369 ha.

Finally, the Chilika Lake wetland region, covering around 108,296 ha, displayed a reduction in wetland area, as shown in Figure 5(k,l). There was a net increase in wetland area of nearly 1,417 ha and a decrease in wetland area of 480 ha. The decrease in wetland was primarily driven by changing rainfall patterns, leading to the conversion of permanent water areas to seasonal areas, as well as the growth of the intertidal zone. The net decrease in wetland area during the period was 937 ha.

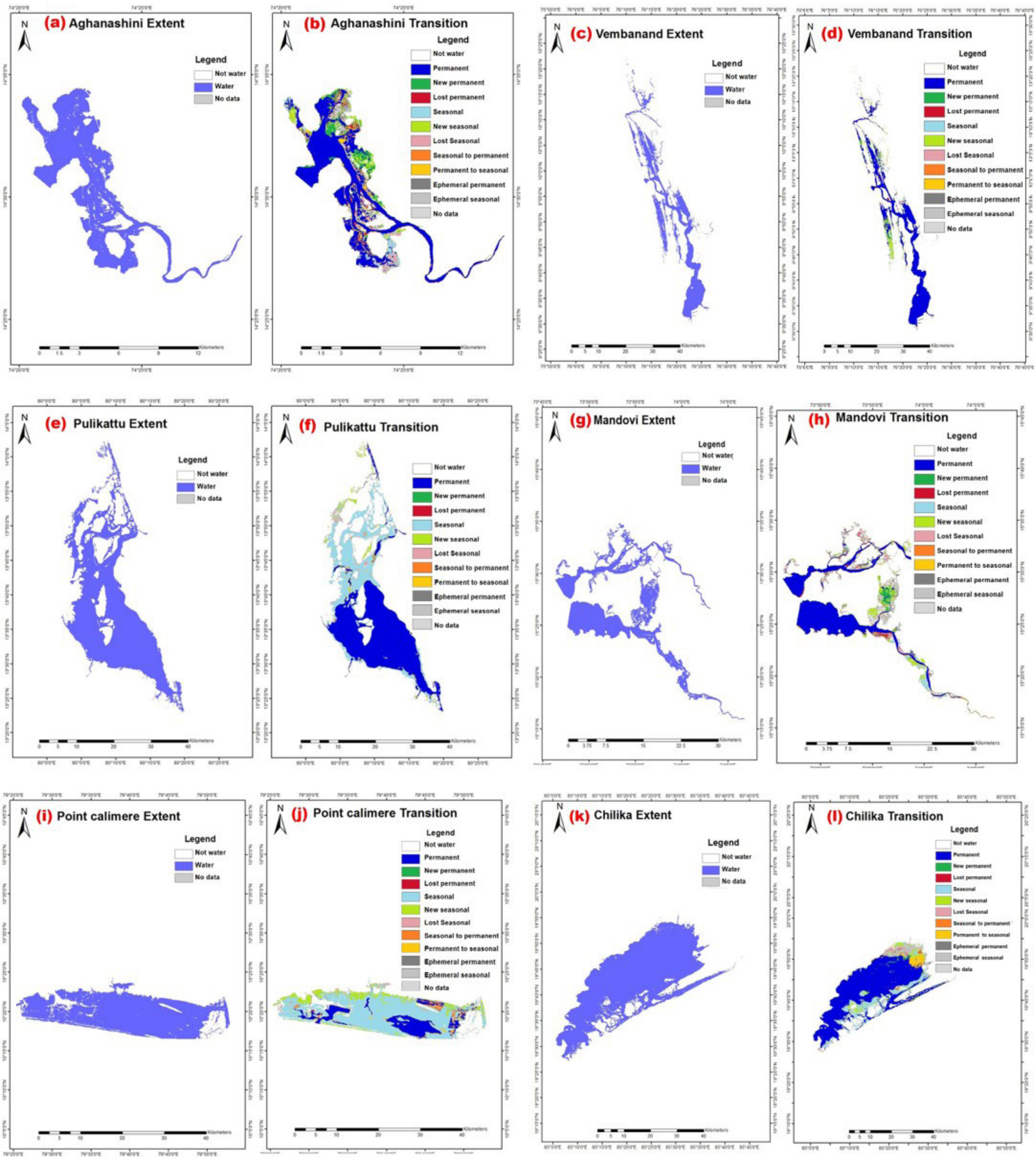

Figure 5.Extent and transition of identified coastal wetlands of India (a,b) Aghanashini estuary, (c,d) Vembanadu Lake (e,f) Pulicat Lake, (g,h) Mandovi-Zuari estuary (i,j) Vedaranyam or Point calimere or Cape calimere swamp, (k,l) Chilika Lagoon

ENHANCED DISCUSSION

The analysis of major coastal wetlands in India determines the varied impacts of both anthropogenic and natural factors on water dynamics, which have resulted in significant changes to wetland areas across the country. These changes are noted human factors such as construction projects, tourism activates etc. and natural environmental factors like changing rainfall patterns and storm events. The results section covers the major coastal wetland areas assessed with its observations and potential reasons for wetland shrinkage or increase. By integrating insights from several studies, it can better to understand the drivers of these changes and their implications on wetland ecosystem.

Mumbai-Thane Creek (4,262 ha) and Mandovi-Zuari Estuary (15,428 ha) both show a net decrease in wetland area by 8.7% and 0.1% due to construction activities, especially harbour development. These findings align with the work of Santos et al.[38], who emphasized how coastal evolution and sea-level rise scenarios in Conde County, Brazil, also pointed to the impacts of harbour development and other infrastructure projects on wetland areas. Furthermore, the growth of intertidal zones and mangroves helped to maintain some ecological balance, is a common observation across several wetlands, reinforcing the importance of natural restoration mechanisms in mitigating human impacts [18, 20].

Aghanashini Estuary (4,207 ha) gives an interesting case of wetland area increase by 3.8% due to the conversion of land for aquaculture. This phenomenon, similar to findings from Acharyya et al. [19] on the impact of land use changes on the Chilika Lake's ecology, highlights how aquaculture can lead to an increase in water bodies while also changing local ecosystems. The change, however, often comes with long-term ecological trade-offs, as aquaculture ponds can disrupt the natural hydrology and biodiversity of wetlands.

Vembanadu Lake (31,812 ha), which has experienced both shrinkage (1.8%), demonstrates the dual nature of human-induced changes. Expansion of settlements and other infrastructure, as well as the seasonal cultivation of aquatic species, have led to increases in water area [34]. This mirrors the findings from Mishra et al. [40] on Odisha's coast, where human activities have resulted in fluctuating shoreline dynamics. Additionally, mixed responses to wetland changes, such as those seen in Vembanadu, are also observed in studies of other Indian wetlands, where both ecological recovery and degradation are occurring simultaneously.

Vedaranyam Swamp (34,692 ha) and Pulicat Lake (58,619 ha) both show shrinkage in wetland area, primarily attributed to harbour construction and other anthropogenic activities. These observations align with the results from studies on cyclone impacts by Mishra, Acharyya, et al. [19], [34] and shoreline erosion, like in the case of Puri's coastline [42], where the construction of infrastructures like ports has led to major erosion and loss of wetland. Furthermore, natural factors like cyclone damage have resulted these losses, as seen in the rapid impact assessments of Cyclone Fani [19] and Cyclone Yaas [43], which have also led to the destruction of wetland vegetation cover and further exacerbated shoreline erosion.

Chilika Lake (108,296 ha) demonstrates the most dynamic changes i.e. increase in 0.9%, with fluctuating wetland area due to both natural and anthropogenic factors. The changing rainfall patterns and growth of intertidal zones have altered the lagoon's hydrology, transitioning permanent water areas into seasonal ones. Similar observations have been made in the long- and short-term tidal inlet morphodynamics of Chilika Lake [18], where storm events and changing tidal regimes have dramatically affected its wetland extent. The lagoon's vulnerability to both climate change and human activities underscores the need for effective management strategies to balance ecological conservation and development.

This study clearly indicates that wetland changes affected by the human development activities like infrastructure project construction and aquaculture have led to significant changes in the water area of Indian wetlands. At the same time, natural phenomena like cyclones and seasonal changes in rainfall also play a vital role in shaping wetland dynamics. As studies such as those by Mishra et al. [21], Santos et al. [35], Ngonidzashe Mangoro et al. [44], and Paul et al. [20] have shown, understanding the complex interaction between these factors is essential for developing sustainable management strategies that can protect and restore these valuable ecosystems. Efforts must focus not only on reducing anthropogenic pressures but also on enhancing the resilience of wetlands to climate change and extreme weather events.

CONCLUSION

The study assesses a long-term change of major coastal wetlands of India, using the global surface water (GSW) dataset (1984–2015), Landsat images, and ArcGIS software tools. The study highlights the application of remote sensing for environmental monitoring. The methods included are data pre-processing, classification, and accuracy assessments. The findings highlight significant spatial and temporal changes over 32 years of the study period, with shrinkage in Mumbai-Thane Creek and Mandovi-Zuari Estuary by 8.7% and 0.1%, respectively, due to urbanization and hydrological changes. In contrast, natural processes like mangrove growth and seasonal flooding increase in the Aghanashini Estuary and Vembanad Lake by 3.8% and 1.8%, respectively, with Chilika Lagoon recording the highest gain in 0.9%. No changes in the Vedaranyam Swamp and Pulicat Lake were noted due to localized stability.

The study emphasizes the benefits of remote sensing datasets in the evaluation of wetland changes over extended periods, which can be a cost-effective approach for ecosystem assessment. However, limitations like image resolution, cloud cover interference, and challenges in extensive ground-based validation for wetland. These results suggest the critical ecological roles of coastal wetlands in biodiversity conservation, flood regulation, and climate mitigation while highlighting growing threats of urbanization, industrialization, and climate change. By integrating geospatial tools, the study highlights the need for informed environmental policies and sustainable wetland management strategies, offering actionable insights for policymakers, urban planners, and conservationists. This research sets a robust baseline for future monitoring and preservation of these vital wetland ecosystems.

LIMITATION OF THE STUDY

It is challenging to extrapolate the noted results over broad regions due to the complexity of coastal wetland changes, which vary in scale and spatial resolution. High-resolution (1 to 10 m) datasets are more effective for precise identification. Data dependency on global surface water datasets and remote sensing databases may not fully represent the complexity of these real coastal changes. Cloud cover and visibility issues can affect the quality of remote sensing data. Uncertainties (misclassification, sensor errors, temporal inconsistencies, etc.) may impact the reliability of the final noted results. The lack of ground truth validation can also impact study results.

FUTURE SCOPE OF WORK

Future studies can be obtained with specific focuses on identification and assessment of coastal wetland changes using multi-source data, region-specific studies (Mangroves, mud flats, etc.), long term climate change impact assessment, socio-economic impact analysis, ecosystem services evaluation, modelling and predictive studies, seasonal and temporal dynamics for coastal vulnerability and sustainability, advanced classification techniques, long-term monitoring programs, biological and ecological responses, and transdisciplinary research. Further, it can use high-resolution satellite imagery, ground-based observations, and advanced LiDAR or radar datasets to enhance accuracy and reliability.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

USE OF AI FOR WRITING ASSISTANCE

Not declared.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

1. S. G. T. Vincent and K. A. Owens, “Coastal wetlands of India: threats and solutions,” Wetlands Ecology and Management, vol. 29(5), pp. 633–639, 2021, doi: 10.1007/s11273-021-09824-6.
2. N. Bassi, M.D. Kumar, A. Sharma, and P. Pardha-Saradhi, “Status of wetlands in India: A review of extent, ecosystem benefits, threats and management strategies, Journal of Hydrology: Regional Studies, vol. 2, pp. 1–19, 2014, doi: 10.1016/j.ejrh.2014.07.001.
3. M. Mahapatra, R. Ramakrishnan, and A.S. Rajawat, “Coastal vulnerability assessment using analytical hierarchical process for South Gujarat coast, India,” Natural Hazards, vol. 76 (1), pp. 139–159, Mar. 2015, doi: 10.1007/s11069-014-1491-y.
4. M. Malik, P. Jakhar, and A. Kadian, “Status of Aquatic Biodiversity of Selected Wetlands in District Hisar: A Case Study of Haryana, India,” Current World Environment Journal, vol. 9(1), pp. 168–173, 2014, doi: 10.12944/CWE.9.1.23.
5. Y. Zhang, J. Yan, X. Cheng, and X. He, “Wetland Changes and Their Relation to Climate Change in the Pumqu Basin, Tibetan Plateau,” International Journal of Environmental Research and Public Health, vol. 18(5), 2021, doi: 10.3390/ijerph18052682.
6. L. Bastin, G. Noel, S. Santiago, B. Bastian, D. Grégoire, F. Marie-Josée, and P. Jean-Francois, “Inland surface waters in protected areas globally: Current coverage and 30-year trends,” PLOS ONE, vol. 14(1), 2019, doi: 10.1371/journal.pone.0210496.
7. T. D. Thiyam, O. Bakimchandra, R.S. Ngangbam, and B.S. Maisnam, “Status of wetlands valleyed in a hilly region of North East India - A review,” International Journal of Water Resources and Environmental Engineering, vol. 9(2), pp. 33–42, 2017, doi: 10.5897/IJWREE2016.0692.
8. L. Mentaschi, M.I. Vousdoukas, J.-F. Pekel, E. Voukouvalas, and L. Feyen, “Global long-term observations of coastal erosion and accretion,” Scientific Reports, vol. 8(1), 2018, doi: 10.1038/s41598-018-30904-w.
9. L. Li, Y. Chen, T. Xu, R. Liu, K. Shi, and C. Huang, “Super-resolution mapping of wetland inundation from remote sensing imagery based on integration of back-propagation neural network and genetic algorithm,” Remote Sensing of Environment, vol. 164, pp. 142–154, 2015, doi: 10.1016/j.rse.2015.04.009.

10. B. Chen, L. Chen, B. Huang, R. Michishita, and B. Xu, "Dynamic monitoring of the Poyang Lake wetland by integrating Landsat and MODIS observations," ISPRS Journal of Photogrammetry and Remote Sensing, vol. 139, pp. 75–87, 2018, doi: 10.1016/j.isprsjprs.2018.02.021.
11. J. Hou, A. I. J. M. Van Dijk, L. J. Renzullo, and P. R. Larraondo, "GloLakes: a database of global lake water storage dynamics from 1984 to present derived using laser and radar altimetry and optical remote sensing," Earth System Science Data, vol. 9, pp. 1–20, 2022, doi: doi.org/10.5194/essd-2022-266.
12. J. Campbell, Introduction to Remote Sensing. The Guilford Press, New York, 1987.
13. M. Guo, J. Li, C. Sheng, J. Xu, and L. Wu, "A Review of Wetland Remote Sensing," Sensors, vol. 17(4), 2017, doi: 10.3390/s17040777.
14. B. Lehner, M. Anand, E. Fluet-Chouinard, F. Tan, F. Aires, G.H. Allen, P. Bousquet, J.G. Canadell, N. Davidson, C.M. Finlayson, T. Gumbricht, L. Hilarides, G. Hugelius, R.B. Jackson, M.C. Korver, P.B. McIntyre, S. Nagy, D. Olefeldt, T.M. Pavelsky, J. Pekel, B. Poulter, C. Prigent, J. Wang, T.A. Worthington, D. Yamazaki, and M. Thieme, "Mapping the world's inland waters: an update to the Global Lakes and Wetlands Database (GLWD v2)," Earth System Science Date (preprint), vol. 7, pp. 1–49, 2024, doi: 10.5194/essd-2024-204.
15. S.Z. Qasim and R. Sen Gupta, "Environmental characteristics of the Mandovi-Zuari estuarine system in Goa," Estuarine, Coastal and Shelf Science, vol. 13, 1981.
16. S.Z. Qasim and R. Sen Gupta, "Environmental characteristics of the Mandovi-Zuari estuarine system in Goa," Estuarine, Coastal and Shelf Science, vol. 13(5), pp. 557–578, 1981, doi: 10.1016/S0302-3524(81)80058-8.
17. R. Visweshwaran, R. Ramsankaran, T.I. Eldho, and M.K. Jha, "Hydrological Impact Assessment of Future Climate Change on a Complex River Basin of Western Ghats, India," Water, vol. 14(21), 2022, doi: 10.3390/w14213571.
18. M. Mishra, T. Acharyya, P. Chand, C.A.G. Santos, R.M. da Silva, C.A.C. dos Santos, S. Pradhan, and D. Kar, "Response of long- to short-term tidal inlet morphodynamics on the ecological ramification of Chilika lake, the tropical Ramsar wetland in India," Science of the Total Environment, vol. 807, 2022, doi: 10.1016/j.scitotenv.2021.150769.
19. T. Acharyya, M. Mishra, and D. Kar, "Rapid impact assessment of extremely severe cyclonic storm Fani on morpho-dynamics & ecology of Chilika Lake, Odisha, India," Journal of Coastal Conservation, vol. 24(3), 2020, doi: 10.1007/s11852-020-00754-8.
20. S. Paul, M. Mishra, R. Guria, S. Pati, B. Baraj, R.M. da Silva, and C.A.G Santos, "A multi-temporal analysis of shoreline dynamics influenced by natural and anthropogenic factors: Erosion and accretion along the Digha Coast, West Bengal, India," Marine Pollution Bulletin, vol. 200(1), 2024, doi: 10.1016/j.marpolbul.2024.116089.
21. M. Mishra, R. Guria, S. Paul, B. Baraj, C.A.G. Santos, C.A. dos Santos, and R.M. Silva, "Geo-ecological, shoreline dynamic, and flooding impacts of Cyclonic Storm Mocha: A geospatial analysis," Science of the Total Environment, vol. 917, 2024, doi: 10.1016/j.scitotenv.2024.170230.
22. S. Paul, M. Mishra, S. Pati, T. Acharyya, C.A.G. Santos, R.M. da Silva, R. Guria, and FX A.T. Laksono, "Evaluation of overwash vulnerability and shoreline dynamics in cyclone-prone Sagar Island, Sundarbans (India)," Science of the Total Environment, vol. 907, 2024, doi: 10.1016/j.scitotenv.2023.167933.
23. H. A. de A. Queiroz, R. M. Gonçalves, and M. Mishra, "Characterizing global satellite-based indicators for coastal vulnerability to erosion management as exemplified by a regional level analysis from Northeast Brazil," Science of the Total Environment, vol. 817. 2022, doi: 10.1016/j.scitotenv.2021.152849.
24. M. Mishra, C. A. G. Santos, R. M. da Silva, N. K. Rana, D. Kar, and N. R. Parida, "Monitoring vegetation loss and shoreline change due to tropical cyclone Fani using Landsat imageries in Balukhand-Konark Wildlife Sanctuary, India," Journal of Coastal Conservation, vol. 25(6), 2021, doi: 10.1007/s11852-021-00840-5.
25. M. F. Hossen and N. Sultana, "Shoreline change detection using DSAS technique: Case of Saint Martin Island, Bangladesh," Remote Sensing Applications: Society and Environment, vol. 30, 2023, doi: 10.1016/j.rsase.2023.100943.
26. S.O. Mabwoga and A.K. Thukral, "Characterization of change in the Harike wetland, a Ramsar site in India, using landsat satellite data," Springerplus, vol. 3(1), 2014, doi: 10.1186/2193-1801-3-576.
27. T. German Amali Jacintha, S.R. Radhika Rajasree, J. Dilip Kumar, and J. Sriganesh, "Assessment of wetland change dynamics of Chennai coast, Tamil Nadu, India, using satellite remote sensing," Indian Journal of Geo-Marine Sciences, vol. 48 (8), pp. 1258–1266, 2019.
28. D. Dutta, T. Kumar, C. Jayaram, and W. Akram, "Shoreline Change Analysis of Hooghly Estuary Using Multi-Temporal Landsat Data and Digital Shoreline Analysis System," in Geographic Information Systems and Applications in Coastal Studies, IntechOpen, 2022.
29. S. Nandi, M. Ghosh, A. Kundu, D. Dutta, and M. Baksi, "Shoreline shifting and its prediction using remote sensing and GIS techniques: a case study of Sagar Island, West Bengal (India)," Journal of Coastal Conservation, vol. 20(1), pp. 61–80, 2016, doi: 10.1007/s11852-015-0418-4.
30. M. Mahapatra, R. Ratheesh, and A.S. Rajawat, "Shoreline Change Analysis along the Coast of South Gujarat, India, Using Digital Shoreline Analy-

sis System," Journal of the Indian Society of Remote Sensing, vol. 42(4), pp. 869–876, 2014, doi: 10.1007/s12524-013-0334-8.

31. P.V. Dehadrai, "Changes in the Environmental Features of the Zauri and Mandovi Esturies in relation to Tides," National Institute of Oceanography, Goa, pp. 68–80, 1969.
32. J.-F. Pekel, A. Cottam, N. Gorelick, and A.S. Belward, "High-resolution mapping of global surface water and its long-term changes," Nature, vol. 540(7633), pp. 418–422, 2016, doi: 10.1038/nature20584.
33. R. Saraswathy and P.K. Pandian, "Pulicat Lake: A Fragile Ecosystem Under Threat," Slovak Journal of Civil Engineering, vol. 24(3), pp. 8–18, 2016, doi: 10.1515/sjce-2016-0012.
34. M. Mishra, T. Acharyya, C.A.G. Santos, R.M. da Silva, D. Kar, A.H.M. Kamal, and S. Raulo, "Geo-ecological impact assessment of severe cyclonic storm Amphan on Sundarban mangrove forest using geospatial technology," Estuarine, Coastal and Shelf Science, vol. 260(3), 2021, doi: 10.1016/j.ecss.2021.107486.
35. M. Mishra, C.A.G. Santos, R.M. da Silva, N.K. Rana, D. Kar, and N.R. Parida, "Monitoring vegetation loss and shoreline change due to tropical cyclone Fani using Landsat imageries in Balukhand-Konark Wildlife Sanctuary, India," Journal of Coastal Conservation, vol. 25(6), 2021, doi: 10.1007/s11852-021-00840-5.
36. A.K. Pratihary, S.W.A. Naqvi, H. Naik, B.R. Thorat, G. Narvenkar, B.R. Manjunatha, and V.P. Rao, "Benthic fluxes in a tropical Estuary and their role in the ecosystem," Estuarine, Coastal and Shelf Science, vol. 85(3), pp. 387–398, 2009, doi: 10.1016/j.ecss.2009.08.012.
37. V. P. Sathiya Bama, S. Rajakumari, and R. Ramesh, "Coastal vulnerability assessment of Vedaranyam swamp coast based on land use and shoreline dynamics," Natural Hazards, vol. 100(2), pp. 829–842, 2020, doi: 10.1007/s11069-019-03844-5.
38. C.A.G. Santos, G.R. do Nascimento, L.M.T. Freitas, L.V. Batista, B. Zerouali, M. Mishra, and R.M. da Silva., "Coastal evolution and future projections in Conde County, Brazil: A multi-decadal assessment via remote sensing and sea-level rise scenarios," Science of the Total Environment, vol. 915(12), 2024, doi: 10.1016/j.scitotenv.2023.169829.
39. C.A.G. Santos, T.V.M. do Nascimento, M. Mishra, and R.M. da Silva, "Analysis of long- and short-term shoreline change dynamics: A study case of João Pessoa city in Brazil," Science of the Total Environment, vol. 769, 2021, doi: 10.1016/j.scitotenv.2020.144889.
40. M. Mishra, P. Chand, S.K. Beja, C.A.G. Santos, R.M. da Silva, I. Ahmed, and A.H.M. Kamal, "Quantitative assessment of present and the future potential threat of coastal erosion along the Odisha coast using geospatial tools and statistical techniques," Science of the Total Environment, vol. 875(2), 2023, doi: 10.1016/j.scitotenv.2023.162488.
41. M. Mishra, T. Acharyya, P. Chand, C.A.G. Santos, D. Kar, P.P. Das, N. Pattnaik, R.M. da Silva, and T.V.M. do Nascimento, "Analyzing shoreline dynamicity and the associated socioecological risk along the Southern Odisha Coast of India using remote sensing-based and statistical approaches," Geocarto International, vol. 37(14), 2022, doi: 10.1080/10106049.2021.1882005.
42. M. Mishra, P. Chand, N. Pattnaik, D.B. Kattel, G.K. Panda, M. Mohanti, U.K. Baruah, S.K. Chandniha, S. Achary, and Tapan Mohanty, "Response of long- to short-term changes of the Puri coastline of Odisha (India) to natural and anthropogenic factors: a remote sensing and statistical assessment," Environmental Earth Sciences, vol. 78(11), pp. 1–23, 2019, doi: 10.1007/s12665-019-8336-7.
43. M. Mishra, T. Acharyya, B. Halder, C.A.G. Santos, R.M. da Silva, N.R. Rout, and D. Bhattacharyya, "Impact assessment of Cyclone Yaas on the mangrove forest area in the Bhitarkanika National Park (India)," Journal of Marine Systems, vol. 242, 2024, doi: 10.1016/j.jmarsys.2023.103947.
44. N. Mangoro, N. S. Kubanza, and M. D. Simatele, "Exploring wetland change in the Gauteng Province, South Africa," Environmental Research, vol. 259, 2024, doi: 10.1016/j.envres.2024.119520.