GIS AND REMOTE SENSING-BASED ANALYSIS OF SALINITY INTRUSION AND LAND USE TRANSFORMATION IN SHYAMNAGAR UPAZILA, BANGLADESH

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ABSTRACT

This research examines salinity intrusion and land use/land cover (LULC) changes in Shyamnagar Upazila, Bangladesh, from 2015 to 2025 using GIS and remote sensing approaches. The findings show a continuous reduction in water bodies (from 2.45% to 1.37%) and built-up areas (from 5.66% to 3.97%), while barren land increased notably (from 8.77% to 11.41%), indicating advancing land degradation. There were only slight changes in vegetation and agricultural land, with agriculture peaking in 2020. Analysis of the salinity index shows that salinity is consistently high, with only a minor decrease in the high salinity index (0.537798 to 0.529147), while the low salinity index further declined (-0.780605 to -0.791439), indicating that salinity is getting worse in less affected areas. With total accuracy surpassing 89% and Kappa values above 0.86, classification dependability was consistently high across all years. In order to lessen environmental stress in coastal ecosystems, the study emphasises the necessity for sustainable land management and adaptive responses by highlighting the spatial patterns of salinity and land alteration.

Keywords: Salinity intrusion, land use/land cover dynamics, salinity index, GIS-based analysis, coastal land degradation

1. INTRODUCTION

In the world, the environmental changes witnessed in coastal areas are extreme due to the natural and man-made factors. Among them, the land use/land cover (LULC) change and saline intrusion can be distinguished, and these are two interconnected problems that significantly affect local socioeconomic realities, agribusiness, and environmental sustainability (Gaur and Singh, 2023). The Bangladesh country that is encircled by the Ganges, Brahmaputra, and Meghna rivers is especially susceptible due to its low topography, a climate based on monsoons, and location on the Bay of Bengal. Southwestern zone coastal area, particularly the Shyamnagar Upazila of Satkhira District has become an important focal area of rising salinity intrusion and soil erosion and thus requires an urgent scientific intervention. Despite a long history of salinity intrusion into the coastal areas of Bangladesh, the degree and extent of salinity intrusion have significantly increased over the last several years because of tide surges, regular cyclones, diminishing upstream freshwater flow, and the expansion of salty agriculture (Abebe et al., 2023). Farm produce reduces, the soil properties deteriorate and most farmers are forced to abandon traditional farming as the salty water moves deeper into the land. Consequently, the land use patterns are transformed with the vegetated areas becoming smaller, agricultural areas becoming smaller and barren land becoming larger which affects the local economy, livelihoods and food security. Previously covered with rice fields and freshwater ponds, the modern picture of Shyamnagar includes clear signs of environmental damage, which include the decrease in water bodies, the difference in developed territories, and the considerable increase in unproductive land (Abebe et al., 2021). Moreover, increasing salinity levels have affected the quality of groundwater and have restricted the possibility of accessing safe drinking water, as well as health risks. These issues were aggravated by population pressure, inadequate infrastructure, and the insufficient availability of policy initiatives (Hussain et al., 2024).

Remote sensing and Geographic Information Systems (GIS) provide invaluable tools when studying, as well as quantifying the variation in the environment in coastal zones. Although GIS eases the process of spatial analysis, mapping and integration of different environmental data, remote sensing provides the opportunity to use the multi-temporal satellite imagery to trace how land cover, vegetation condition and surface water change over time. This research involved the application of satellite images in 2015, 2020, and 2025 in order to generate salinity indexes, and distinguish different LULC classes. In order to ensure reliability and accuracy, the results of categorisation are tested on accuracy measures such as producer accuracy, user accuracy, the overall accuracy, and the Kappa coefficient.

Salinity indices offer althorough information on the picture of the environmental degradation and were formerly used to map the spatial ranges and the severity of the salty intrusion (Tan et al., 2024). Although studies of saline intrusion have been done in coastal Bangladesh previously, with a focus on either hydrological mechanisms or socioeconomic impacts or adaptation mechanisms, most studies have limited themselves to field observations or satellite data in one year, and this limits their temporal resolution. Also, few studies have adopted the multi-temporal remote sensing to integrate salinity evaluation as well as LULC change analysis, and their policy relevance tended to be undermined by the absence of high-resolution geographic validation. To seal these gaps, the current study employs spatial modelling and using validated classification methods, conducts a comprehensive, multi-year analysis of salinity dynamics and land use alteration in the Shyamnagar Upazila.

Shyamnagar is in southwestern Bangladesh and adjacent to Sundarbans, the largest mangrove forest in the world and a UNESCO World Heritage Site, and is also a tropical monsoon climate with a minimum temperature of about 12ºC in winter and maximum temperature of about 35degC in summer. The monsoon rains continue to be low in relation to the freshwater resources due to tidal forces and depletion of the water upstream. Most of the population resides in rural regions and depends on agriculture and aquaculture as a source of income (Kafy et al., 2021). Nonetheless, salinity is increasing thus encouraging the use of prawn farming by many farmers, which worsens the degradation of the soil. Betna and Kholpetua rivers have become increasingly more salty, affecting the use of water to irrigate and drink. The close proximity of the region to Sundarbans combined with the fact that both salinity and land-use changes can have a direct effect on mangroves, and due to increased sea levels, unpredictable rainfall, and frequent cyclones, Bangladesh is highly susceptible to climate change (Azad et al., 2026).The need for effective environmental monitoring is prompted by the fact that the area is highly vulnerable to climate change. The government in reaction has prioritized adaptation, mitigation, and resilience as the leading program in the Bangladesh Climate Change Strategy and Action Plan (BCCSAP). In spite of this, localised studies are indispensable in guiding community based interventions and planning at regional levels. The bigger issues that reflect on coastal are good examples in Shyamnagar Upazila.

Bangladesh, in which both the human and the natural forces behave on the environment. This paper discusses the impact of salt intrusion on the patterns of land use in Shyamnagar in the past decade and the hypothesis to be tested is that with the increase in salinity, the barren land has been increasing and the vegetated and agricultural land decreasing. GIS and remote sensing are also further discussed to determine their usefulness in tracking these changes. The objectives are to classify and measure (LULC changes between years 2015 and 2025, calculate salinity indices, and assess the findings using measures of accuracy. Unlike previous research that focused solely on land use or salinity, this work bridges the gap by combining the two, using verified geospatial approaches, and providing localised insights with larger implications. The findings help to understand environmental trends in vulnerable coastal zones, improve sustainable development, climate resilience, and spatial planning, and provide a reproducible framework for similar places.

2. METHODOLOGY

In this study, the geospatial method was applied in a structured manner to assess the saline intrusion and land use/ land cover (LULC) change within Shyamnagar Upazila, Bangladesh over a period of ten-year (2015-2025). It was done through a technique that involved a series of intertwined activities of data collection to geographical analysis and validation that was developed in order to ensure scientific rigour, spatial accuracy and reproducibility (Akhter and Afroz, 2024).

The first step in the study area must be define. Ecologically sensitive since this is a wetland ecosystem, and also accessible to the Sundarbans mangrove forest due to its proximity. It is located in the south west coast of Bangladesh. The area is approximately in the latitudes 22°15-22°40N and longitudes 89°00-89°20E. It is highly vulnerable to both natural and artificial environmental variations due to its salty soils, tidal waters and seasonal flooding (Miah et al., 2024).

The years 2015, 2020, and 2025 were taken as a satellite imagery. Landsat 8 OLI/TIRS data was used in the first two years, and Landsat 9 OLI/TIRS data was used in 2025. All of the photos were taken during the dry season that lasts between January and March in order to minimize cloud cover and seasonal vegetation changes. A spatial resolution of 30 meters was taken to be sufficient in the case of regional-level research (Chowdhury, 2024). Preprocessing steps that were performed with the help of the Google Earth Engine (GEE) platform involved radiometric and atmospheric correction, cloud masking with the help of QA band and Fmask method, and picture composing (Domingo-Marimon et al., 2024).

The LULC was classified supervised into five classes that included water, built-up, vegetation, agriculture, and barren land. Random Forest approach has been selected because of its high precision and strength. Where possible, observations in the field were supplemented with the training samples, which were obtained through the process of visual interpretation of the high-resolution photography. Spectral bands (Blue, Green, Red, NIR, SWIR1 and SWIR2) are combined with vegetation and water indices (NDVI, EVI, and MNDWI) to enhance the ability of classes to be more reparable and increase their classification performance. Accuracy was measured with high-resolution Google earth and ground truth data and each category was given at least 100 points of validation per year. Computations of measures of accuracy including the Kappa coefficient, Producer Accuracy (PA), User Accuracy (UA) and Overall Accuracy (OA). The results have validated the dependability of the produced LULC maps with an overall accuracy of 89% and Kappa of more than 0.86 indicating good agreement between classified and reference data.

The calculation of salinity indices has followed classification so as to measure the intensity and the spatial pattern of salinity intrusion. The two indexes that were used were the High Salinity Index (HSI) and the Low Salinity Index (LSI). Based on spectral reflectance of the SWIR and the NIR bands these indices were determined by empirical algorithms adopted after previous studies on the mapping of coastal salinity. The indices were computed on an annual basis and spatial distribution maps were drawn in order to observe the salinity hotspots and changes over time (Akhter and Afroz, 2024).

The LULC transitions and salinity shifts are then quantified and later done through change detection analysis. A post-classification comparison technique was used to identify differences in the five LULC classes across the duration of time (three times). To compute the direction and magnitude of land cover change, transition matrices were generated and area statistics were used to compute each class. On the same note, pixels that have increasing or decreasing salinity are determined by pixel-by-pixel comparison of both HSI and LSI data. The results played a significant role in identifying areas that were directly influenced by salinity intrusion in their land use changes (Pandeya et al., 2025).
The spatial analysis of land usage and salinity was done by employing the GIS based spatial analysis. The spatial correlation was examined with the overlay analysis between the salinity indices and the LULC classes. To find out which classes were affected by salinity intrusion the most, means of salinity in each type of land cover were obtained by zonal statistics. To ascertain the level of closeness on the saline levels and land degradation, buffer study was conducted along rivers and shrimp farms (Zaman & Real, 2025).

Various technologies were used in every activity that involved information interpretation and visualisation. Google Earth Engine was utilized in image processing and classification, whereas ArcGIS Pro and QGIS were applied in spatial analysis and map development. R and Microsoft Excel were used in processing and charting tabular data. Salinity distribution maps, accuracy assessment tables, change detection matrices and categorised LULC maps of 2015, 2020 and 2025 were contained in the findings (Weng et al., 2008).

Also concerning, some assumptions and restrictions that were covered by the technique. The problems of accessibility minimized the quantity of ground truth information accessible and certain misclassification might have occurred at transitional zones or mixed pixels. Spectral indices that were believed to have been a good measure of salinity in the unusual environmental conditions of Shyamnagar, and dry season imaging that was believed to have the highest salinity levels (Rimba et al., 2020).

3. RESULTS

3.1 Land Use and Land Cover Transformation

The temporal analysis of LULC reveals significant shifts in land cover across the study period. According to the area statistics, water bodies declined from 37.71 km² (2.45%) in 2015 to 21.15 km² (1.37%) in 2025, indicating a substantial reduction in surface water availability. Built-up areas initially increased from 87.05 km² (5.66%) in 2015 to 94.43 km² (6.14%) in 2020, but subsequently decreased to 61.09 km² (3.97%) by 2025. This fluctuation may reflect both urban expansion and subsequent abandonment or degradation due to environmental stress. Vegetation cover showed a gradual decline, dropping from 1051.96 km² (68.38%) in 2015 to 999.42 km² (64.96%) in 2025. Agricultural land peaked in 2020 at 286.24 km² (18.6%) before slightly decreasing to 281.27 km² (18.28%) in 2025. The most notable change was observed in barren land, which expanded from 134.82 km² (8.77%) in 2015 to 175.56 km² (11.41%) in 2025, suggesting increasing land degradation and reduced productivity. These spatial changes visually represented in the LULC change map.The contraction of the vegetated and agricultural areas and the growth of the bare lands (Figure 2). The findings highlight the dynamic changing nature of the land as a result of environmental stress, especially salinity intrusion.

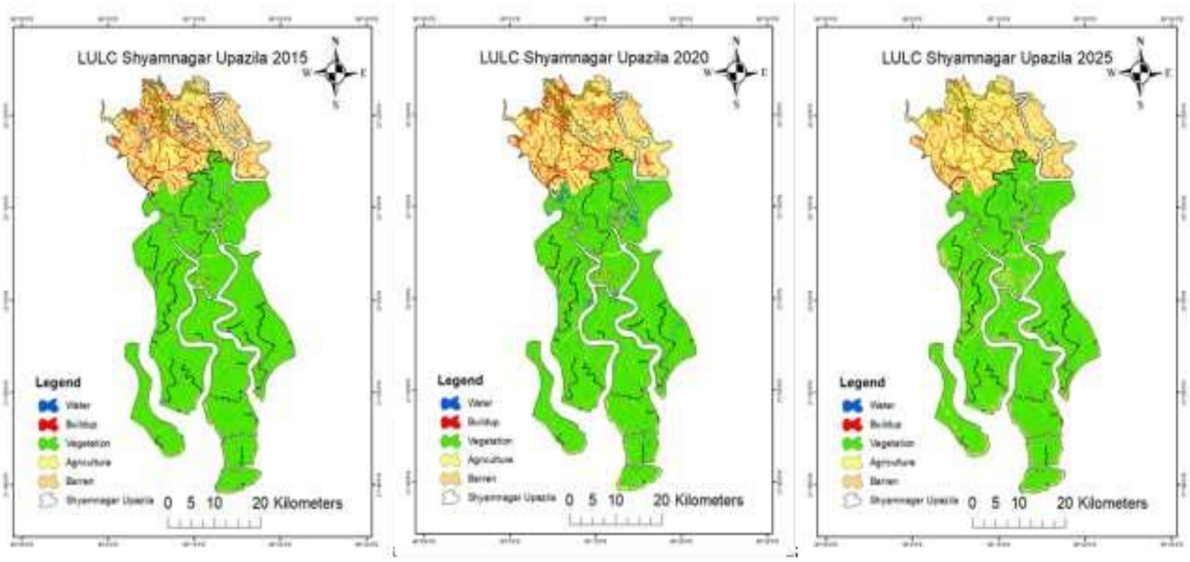

Figure 1: LULC change in Shyamnager Upazila in 2015-2025.

Table 1: LULC change in Shyamnager Upazila in 2015-2025

LULC Class	2015 Area (km²)	2015 (%)	2020 Area (km²)	2020 (%)	2025 Area (km²)	2025 (%)
Water	37.71	2.45	35.64	2.32	21.15	1.37
Buildup	87.05	5.66	94.43	6.14	61.09	3.97
Vegetation	1051.96	68.38	1016.65	66.08	999.42	64.96
Agriculture	226.96	14.75	286.24	18.6	281.27	18.28
Barren	134.82	8.77	105.53	6.86	175.56	11.41

3.2 Salinity Index Trends

The study of salinity index gives more information on the environmental stress that the area is experiencing The High Salinity index (HSI) did not change significantly with a slight decrease in 0.537798 in 2015 down to 0.529147 in 2025. This indicates that there are still high salinity areas but their intensity could have reduced to some degree. Conversely, the Low Salinity Index (LSI) was actually becoming even lower than it was previously, going as low as -0.791439 instead of the amount of -0.780605. Figure 2 has a salinity index map that indicates the distribution of salinity in the region of Shyamnagar Upazila. By 2025, the salinity affected regions had grown especially the areas near rivers that are tidal and low-lying agricultural lands. These are consistent with observations in the field and past research studies and confirm the incursion of salt water to the interior areas gradually (Table 2).

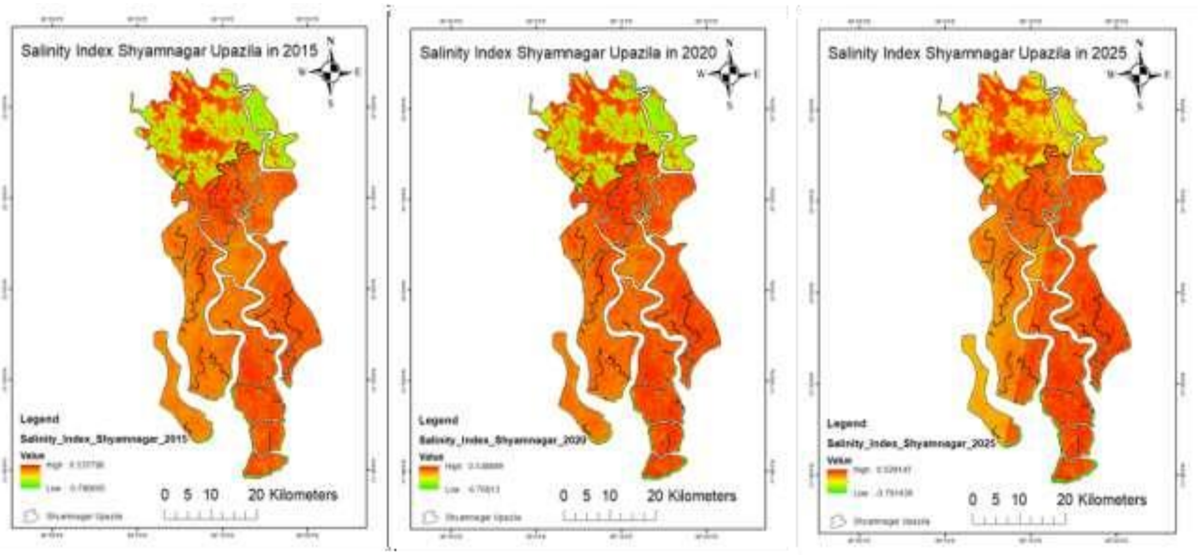

Figure 2: Salinity index in Shyamnager Upazila in 2015-2025.

Table 2: Salinity index in Shyamnager Upazila in 2015-2025

Year	ligh Salinity Index	ow Salinity Index
2015	0.537798	-0.78061
2020	0.538889	-0.76813
2025	0.529147	-0.79144

3.3 Classification Accuracy Assessment

The reliability of the LULC categorization is ensure by standard procedures utilized in an accuracy evaluation. The categorized and reference data demonstrated strong agreement in 2025, with a Kappa coefficient of 0.861 and an overall classification accuracy of 89.3%. Between classes, producers and users' accuracy values varied. The producer accuracy of 61.11% for the Water class shows that it is challenging to distinguish between shallow and mixed water basins in saline conditions. Conversely, with high producer accuracies of 97.92% and 96%, respectively, the Agriculture and Vegetation classes demonstrated excellent categorization performance. The similarly high user accuracy values, with most classifications exceeding 85%, attested to the reliability of the classification outputs. These parameters reflect the effectiveness of the remote sensing approach and support the validity of the spatial analysis performed in this study (Table 3).

Table 3: Accuracy Assessment of the LULC in Shyamnager Upazila in 2015-2025

Year	LULC Class	Producer Accuracy (%)	User Accuracy (%)	Overall Accuracy (%)	Kappa
2015	Water	55.56	83.33	89.89	0.867
	Buildup	88.68	90.38		
	Vegetation	96.15	86.21		
	Agriculture	93.75	93.75		
	Barren	90.48	88.37		
2020	Water	72.73	100	92.55	0.903
	Buildup	95.74	86.54		

	Vegetation	89.29	92.59		
	Agriculture	97.56	95.24		
	Barren	91.18	96.88		
2025	Water	61.11	100	89.3	0.861
	Buildup	86.79	85.19		
	Vegetation	96	85.71		
	Agriculture	97.92	90.38		
	Barren	90.7	92.86		

3.4 Integrated Interpretation

In cases where salinity indices and LULC are considered together, one can find there is a high level of regional relationship between land degradation and saltwater intrusion. Rise in dry areas and loss of crops and vegetation are connected to high salt concentration. The overlay and zonal statistics indicate that areas that degrade to salinity especially tidal river areas and shrimp farming areas are more prone to land use changes and hence there is a dire need to adopt flexible land management methods. The long-term impacts of the salinity intrusion on the environment and livelihoods depicted in the reduction of freshwater sources, the loss of arable lands, and the development of non-productive areas..

4. DISCUSSION

This study demonstrates that there is a complex interaction between the land use/land cover (LULC) change and salinity intrusion in Shyamnagar Upazila between 2015 and 2025. The discussion employs remote sensing and GIS methods to demonstrate in one of the most susceptible coastal districts in Bangladesh how environmental stressors, in particular, salt, affected changes in land productivity, the landscape, and the socioeconomic patterns..

4.1 Drivers of Salinity Intrusion and LULC Change

Salinity intrusion in Shyamnagar is influenced by both the natural and anthropogenic factors. The region is inherently prone to tidal flooding and intrusion of saline water because it is close to the Bay of Bengal. Nonetheless, salinity has been exacerbated by extraction of freshwater upstream by the transboundary rivers more so, the Ganges. To give an example, the Farakka Barrage in India provides the saline water with an opportunity to reach deeper into the interior and to diminish the amount of freshwater flow in the dry season (Mwangi et al., 2018). Storm surges like those of Sidr (2007), Aila (2009), and Amphan (2020) resulted in the overtopping of embankments and agricultural lands that were left with residual saline content that damaged the fertility and integrity of the soil (Mahata et al., 2024). Also, the increase in prawn aquaculture which is dependent on saline water and not always properly drained or with soil remediation procedures has contributed to an increase in land salinization. According to Yang and Zhou, these forces directly influenced the LULC patterns because these are reflected by the decreasing vegetation cover and water bodies, the short-term changes in agricultural land, and the constant rise of barren land (2020 and 2025, respectively). The results indicate the interaction of environmental stressors and unsustainable land management to degradation of the land and low local output.

4.2 Comparison with Previous Studies

The findings of the study are complementary to find outings of other studies conducted in the coastal areas of Bangladesh. The same trends have been experienced in Khulna and Satkhira districts, as Islam et al. (2017) reported that shrimp farming and reduced freshwater flow were the key factors of salinity intrusion. The socioeconomic consequences like reduced food production and growth in population migration, also discussed in their paper. As noted by Rahman and Bhuiyan (2019), the cyclonic events increase the rate at which land is depleted and saline diffuses, particularly in the low-lying regions. Nonetheless, through multi-temporal satellite data and traditional classification criteria, our study offers more comprehensive and spatially explicit analysis. The study is ten years old and presents high accuracy levels, including producer and user accuracy, overall accuracy, and Kappa coefficients, unlike other studies that primarily used field surveys or a one-year imaging (Jiang et al., 2017). To make the analysis more quantitative, salinity indices (HSI and LSI) are employed to show that the salinity trends can be accurately mapped, as well as to address the relationship between salinity trends and the changes in land use. Moreover, the given study closes the gap as it combines environmental monitoring and spatial analysis, but the past work was predominantly focused on hydrological modelling or socio-economic impacts. The land change is triggered by the salinity intrusion, which is visually and statistically expressed by the position of salinity maps and LULC classifications. This combined approach enhances the understanding of the vulnerability of coasts and offers a paradigm that can be copied to other regions of this kind (Gaur & Singh, 2023)..

4.3 Implications for Land Management and Policy

The implications of the findings of this paper on policy making, environmental planning and land management are enormous. There was an urgent need of sustainable land use systems to prevent the growing lack of land degradation, loss of biodiversity and declining agricultural productivity, as shown by the growing barren land and declining agricultural lands. Remedying embankments, promoting crops which are resistant to salt, and managing prawn farming are significant solutions to mitigating the impact of salinity. Also affected by the disappearance of freshwater bodies and plants are local ecosystems (e.g., Sundarbans buffer zone), in which the health of the mangroves is reliant on the presence of freshwater), where high salinity levels pose a threat to the species composition and ecological functions, necessitating the consideration of upstream water management and regional land use practice (Yuan et al., 2020). The socioeconomic consequences of decreasing land productivity are equally significant with decreased incomes and food insecurity and the growing migration. Policymakers should prioritize community-based adaptation solutions such as provision of clean water, sustainable farming education and diversification of livelihoods. The paper also outlines the significance of GIS and remote sensing in environmental monitoring to deliver quick, scalable yet cost-effective information in order to enable proactive decision making. Geospatial capacity building is required to increase the resilience planning in coastal areas by government agencies, non-governmental organisations, and academic institutions (Salah et al., 2024).

4.4 Limitations of the Study

This research has several limitations despite the fact that it provides valuable information. In the first place, the precision of satellite images and the availability of ground truth data defines the precision of LULC classification. Although high-resolution imagery and field samples were applied to validation, there were problems with ground validation (due to the inaccessibility of certain sites), particularly in remote or highly salinised sites. Second, the complexity of soil and water salinity that changes with seasonal changes, soil texture and human activity can be poorly represented by salinity indices produced through spectral measurements. Future research would involve incorporation of field-based observations of salinity into hydrological modelling to improve accuracy. Third, in spite of the representative nature of the study, the scope of the study is confined to a specific upazila, which may not be representative of the heterogeneity in the region in the larger coastal zone. It could be better understood through a more detailed study of the dynamics of salinity and the subsequent changes in the land use that would be acquired by extending the spatial scale of the results to include the adjacent places.

5. CONCLUSIONS

The present study in detail considered the land use/land cover (LULC) changes and intrusion of salinity in Shyamnagar Upazila, Bangladesh, in the timeframe 2015 to 2025. This analysis has revealed that there is a sharp rise in the barren areas, sharp decline in water bodies and vegetated areas and also different trends in agricultural and developed areas. These transformations are closely linked to the increase of salinity particularly in lowlands as well as in agriculturally viable regions. The Low Salinity Index became worse suggesting that there is a decline in the conditions in previously less affected areas and the High Salinity Index remained to be more or less stable. To assess the trends in land use and salinity and to achieve a spatially explicit analysis of the coastal vulnerability, the novel technique of the study is a combination of multi-temporal satellite data, validated metrics of classification, and salinity indices. The findings have great policy implications, environmental planning as well as land management. They point to the need to control saline aquaculture, recover freshwater, and devise sustainable land use practices. In sensitive areas near the Sundarbans, especially those that are environmental sensitive, the spatial knowledge can guide conservation, community based adaptation, and specific interventions. To determine the impact of households and migratory tendencies, further research is necessary to increase the scale of space to include adjacent coastal upazilas, employ field-based salinity measurements and include socioeconomic information. Longitudinal research involving hydrological modelling and participatory mapping would enhance knowledge of climate-induced land change. In general, the paper demonstrates the value of remote sensing and GIS in environmental surveillance and resiliency planning of climate-sensitive coastal regions.

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