

Detection of Environmental Degradation of Satkhira District, Bangladesh Through Remote Sensing Indices



M. Tauhid Ur Rahman and Jannatul Ferdous

Abstract Satkhira is one of the most vulnerable coastal districts of Bangladesh due to both natural disasters and anthropogenic causes, which faces continuous environmental degradation. This study aims to explore the environmental changes in the Upazilas of Satkhira district by employing several remote sensing indices using the Landsat images of the year 2007, 2010, 2013, and 2016. NDVI, NDWI, NDSI, NDBI, and NDBaI are used to extract the spatial information regarding the condition of vegetation, wetlands, soil salinity, built up area and bare lands in the Upazilas respectively. Temporal change of these variables has been monitored and compared among and within the Upazilas on the basis of the threshold values of the indices. Analysis of NDVI has revealed that there was a drastic change in vegetation from 2007 to 2010, which was because of the cyclones. Though NDVI of 2013 showed a positive increase from 2010, it cannot restore its previous state not even in 2016. Analysis of NDBI and NDBaI have revealed that built up area has been increased day by day; whereas, a decreasing trend has been seen in case of bare lands, as the bare lands are occupied either by built up area or by shrimp farming area. Increasing NDWI and NDSI justify the increasing shrimp farming trend in Satkhira. These variables indicate the changing nature of land use land cover and the vulnerability due to environmental degradation in Satkhira district, which reveals a need for immediate land use planning. This study will help the policy makers and land use manager to promote substantial and sustainable development plan for Satkhira district.

Keywords Coastal Bangladesh · Environmental degradation · Shrimp farm Remote sensing indices

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1 Introduction

Environmental degradation is one of the most serious matters of concern worldwide, which is acuter in developing countries due to the lack of effective monitoring system and strong legislation [1, 2]. Environmental degradation or the damage of natural environment is occurred both by the effect of climate change and harmful human activities and results in loss of biodiversity and natural resources, which is a common phenomenon in the southwest coastal region of Bangladesh. Both natural hazards and major land use/land cover change exist together in this area and have significant and adverse effects on the environment [3]. Being one of the most vulnerable coastal areas around the world, this region has been observed to change rapidly since late of twentieth century. Degradation of soil and water condition due to increased salinity, destruction of mangrove forest, unplanned practices of land surface, etc., have been experienced in this region.

Change in land use/land cover has been established as one of the most useful methods to detect environmental degradation [4]. Significant change in the land use/land cover pattern has been observed the southwest region of Bangladesh, especially in Satkhira district. Cultivated land has been decreased about 20% and water bodies have been increased about 10% from 1980 to 2009 [5]. Shifting of occupation from agriculture to shrimp farming has been taken place due to the combined effect of climate change and salinity intrusion and 30% increase in shrimp farming has been seen in the past 13 years [3]. Satkhira district is recognized for its economic and environmental importance and it is now facing several environmental challenges caused by the anthropogenic activities like unplanned land use practices and demographic changes. Economic growth of this region has been proved as detrimental to the environment causing increased salinity both in soil and water, drinking water scarcity, decreased land fertility, increased health hazard, destruction of mangrove forest, and agricultural land loss [1]. Moreover, Satkhira district has been experienced a significant environmental change due to the devastating cyclone Sidr in 2007 and Aila in 2009.

For monitoring and assessing the environmental degradation, long-term prior information about the environmental components are required, which is now easily accessible in the form of satellite images. Remote sensing techniques have provided the opportunity of studying the pattern of environmental change for a long period of time. There are several indices for detecting the environmental change like Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Normalized Difference Salinity Index (NDSI), Normalized Difference Built-up Index (NDBI), and Normalized Difference Bareness Index (NDBaI), which are used to extract the spatial information regarding condition of vegetation, wetlands, soil salinity, built up area and bare lands respectively.

The objectives of this study are to detect the environmental degradation of Satkhira district of Bangladesh in terms of change in different land uses/land covers and to present a comparative scenario of the Upazilas (Sub-districts) on basis of spatiotemporal change pattern. For this, satellite images of the year 2007, 2010,

2013, and 2016 have been employed. The change due to natural hazards (cyclone Sidr and Aila) has been revealed after analyzing the images of 2007 and 2010 and the change occurred in the recent years can be considered mostly due to anthropogenic causes.

2 Study Area

Satkhira District of Khulna division, Bangladesh has been selected as study area. This district is located on the southwest extremity of Bangladesh, in between 21°36' and 22°54' north latitudes and in between 88°54' and 89°20' east longitudes. It is bounded by Jessore district on the north, the Bay of Bengal on the south, Khulna district on the east, West Bengal State of India on the west. There are seven Upazilas in this district named Assasuni, Debhata, Kalaroa, Kaliganj, Satkhira Sadar, Shyamnagar and Tala. Of the seven Upazilas of the district, Shyamnagar is the largest and Debhata is the smallest (Fig. 1).

The total area of the district is 3817.29 km², of which 1534.88 km² is under mangrove forest (The Sundarbans). The rural economy of Satkhira is predominantly agricultural as 62.56% people are engaged in agriculture. Paddy, jute, sugarcane, mustard seed, potato, onion, betel leaf, etc., are the main crops in Satkhira. Besides, Prawn farming is one of the most important economic activities of the households and one of the main export items of Bangladesh, which is abundantly available in the district [6].

3 Methodology

3.1 Acquisition of Satellite Images

To detect the environmental degradation of Satkhira district through remote sensing indices, multi-temporal satellite images (WRS2: 138/44, and 138/45) were collected from the United States Geological Survey (USGS) website. All bands of Landsat Thematic Mapper 5 (TM) (dated 18 March 2007 and 6 February 2010), and Landsat 8 Operational Land Imager (OLI) (dated 28 April 2013 and 26 March 2016) were collected, and all the spatial data layers were registered to the same Universal Transverse Mercator (UTM) coordinate system and resampled to the same pixel resolution of 30 m. In order to use satellite images of different periods, it is essential to acquire images of same dates (especially the same plant growing seasons). Though the acquisition dates are ranged from the month February to April, it covers same plant (e.g., Boro rice and potato) growing seasons in Bangladesh.

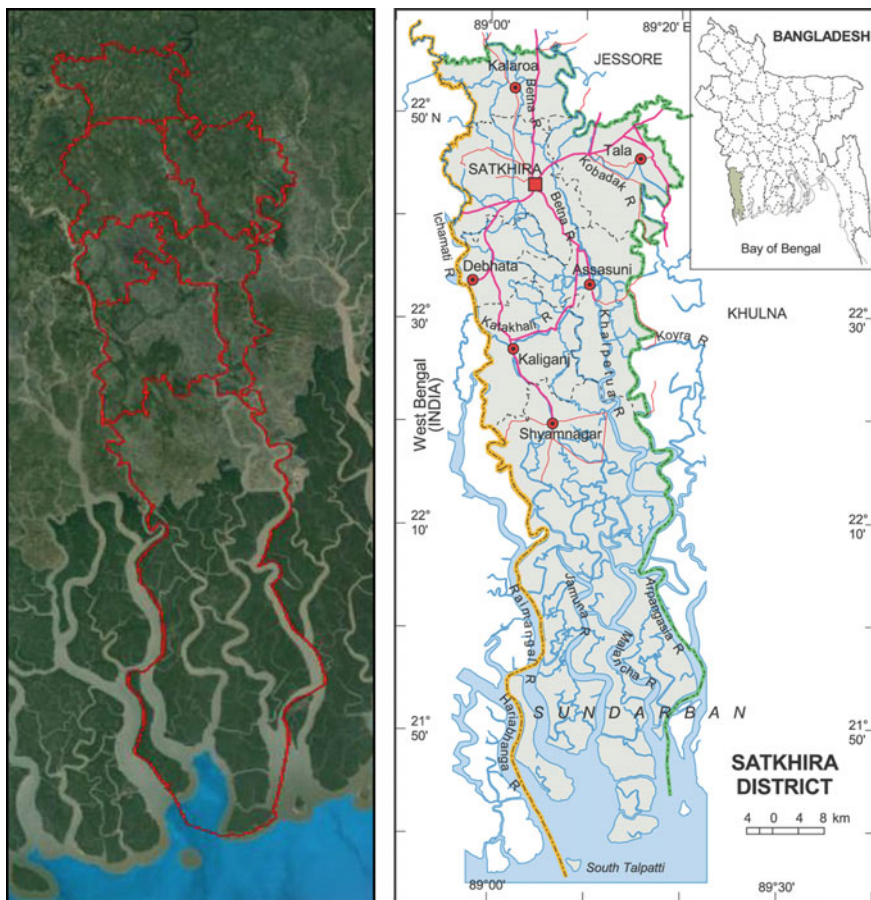


Fig. 1 Location of study area (Satkhira district) [6]

3.2 Processing of Satellite Images

As the raw satellite images are not best suited to calculate remote sensing indices, the radiometric correction has been performed and the Digital Number (DN) values have been converted into reflectance. For Landsat 5 TM, there is a two-step conversion process (Eqs. 1 and 2) and in Landsat 8 it can be done by a single step (Eq. 3). Spectral Radiance Scaling Method has been followed for radiometric correction of Landsat 5 TM. All the necessary data has been found in the header file (metadata) downloaded with the satellite images.

(a) Radiometric Correction of Landsat 5 TM

The formula used in the Spectral Radiance Scaling Method for Landsat 5 TM is as follows [7]:

$$L\lambda = ((LMAX\lambda - LMIN\lambda)/(QCALMAX - QCALMIN)) * (QCAL - QCALMIN) + LMIN\lambda \tag{1}$$

where

- Lλ the cell value as radiance
- QCAL digital number
- LMINλ spectral radiance scales to QCALMIN
- LMAXλ spectral radiance scales to QCALMAX
- QCALMIN the minimum quantized calibrated pixel value (typically = 1)
- QCALMAX the maximum quantized calibrated pixel value (typically = 255).

Then, the radiance value has been converted to reflectance value by using the following formula [8].

$$\rho\lambda = \pi * L\lambda * d^2 / ESUN\lambda * \sin \theta z \tag{2}$$

where

- ρλ Unit less planetary reflectance
- Lλ Spectral radiance (from the earlier step)
- d Earth–Sun distance in astronomical units
- ESUNλ Mean solar exo-atmospheric irradiances
- θz Sun Elevation Angle.

(b) Radiometric Correction of Landsat 8 OLI

For Landsat 8 OLI, DN values have been converted to reflectance by using the following formula [9].

$$\rho\lambda = (M\rho Qcal + A\rho) / \sin \theta z \tag{3}$$

where

- ρλ Unit less planetary reflectance
- Mρ Band-specific multiplicative rescaling factor from the metadata
- Aρ Band-specific additive rescaling factor from the metadata
- Qcal Quantized and calibrated standard product pixel values (DN)
- θz Sun Elevation Angle.

The reflectance values have been used to compute the indices except for Normalized Bareness Index (NDBaI) as it uses the thermal band. For computing NDBaI, DN values of the respective bands have been used. Radiometric correction provides the more accurate result as noise from reflectance is 50% less than noise from DN value [10].

3.3 Calculation of Remote Sensing Indices

Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Normalized Difference Built-up Index (NDBI), Normalized Difference Bareness Index (NDBaI) and Normalized Difference Salinity Index (NDSI) are used to extract the spatial information regarding condition of vegetation, wetlands, built-up area, bare lands, and salinity-affected areas in the Upazilas, respectively. Threshold values have been used to identify the areas with moderate vegetation, water features, salinity-affected areas, built-up area, and bare lands. Formulae and threshold values for these indices are given in Table 1.

G, R, NIR, SWIR, and T are the Green, Red, Near Infrared, Short Wave Infrared, and Thermal Bands, respectively. For Landsat 8 OLI image, band 10 has been used to compute the NDBaI, as NDBaI computed from band 10 and SWIR band gives the best-suited result for extraction of bare soil [11]. Threshold values for Landsat 5 TM and Landsat 8 OLI have been considered same as the DN values are converted to reflectance values. But the threshold values for NDBaI are different for different Landsat, as the DN values of thermal bands cannot be converted into reflectance [11] (Fig. 2).

Table 1 Corresponding remote sensing indices with the formulas and their threshold values

Index used	Formula	Threshold value of the index used
NDVI	$\frac{NIR - R}{NIR + R}$	>0.2
NDWI	$\frac{G - NIR}{G + NIR}$	>0
NDBI	$\frac{SWIR - NIR}{SWIR + NIR}$	0.1-0.3
NDBaI	$\frac{SWIR - T}{SWIR + T}$	>-0.15 (>-0.09 for Landsat 8)
NDSI	$\frac{R - NIR}{R + NIR}$	>0

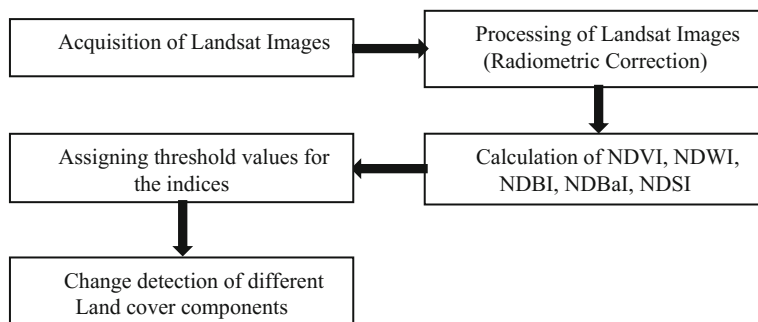


Fig. 2 Methodological approach for the study

3.4 Change Detection of Different Land Cover Components

Threshold values of the indices are the base of change detection analysis. Areas above the threshold values have been calculated and used to compare the changes among the Upazilas during the period 2007–2016.

4 Results and Discussions

The collected satellite images of the study area of the year 2007, 2010, 2013, and 2016 are as follows in false color composite (Fig. 3).

4.1 Spatiotemporal Dynamics of NDVI

For identifying the healthy vegetation area from the satellite images, NDVI has been used and the threshold value for NDVI is 0.2 as greater than this value indicates the vegetation area [12]. Table 2 shows the NDVI statistics for the Upazilas of Satkhira district for the selected years.

The analysis of NDVI has revealed that there was a significant reduction in vegetation area from the year 2007 to 2010, which can be said as the impact of the devastating cyclones Sidr and Aila. Every Upazila has faced a reduction in vegetation area to a great percentage, among which there is about 79% reduction in Assasuni Upazila and 81% in Debhata Upazila. Vegetation areas have been increased in 2013 and even in 2016, but it is not the same as the vegetation area of 2007 (Fig. 4).

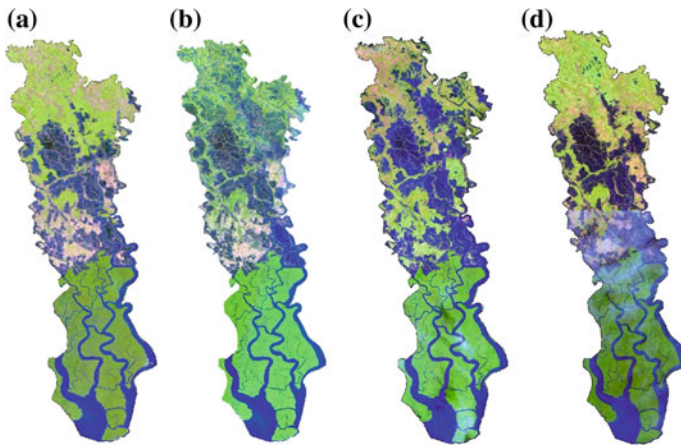


Fig. 3 Satellite images of study area in false color composite (R(SWIR), G(NIR), B(Red)) **a** in 2007; **b** in 2010; **c** 2013; **d** in 2016

Table 2 NDVI statistics of Satkhira district

Upazila	Vegetation area (in % of total area of the Upazila)			
	2007	2010	2013	2016
Assasuni	37.2	7.8	22.1	33.4
Debhata	28.2	5.3	21.7	23.7
Kalaroa	85.3	43.4	57.9	69.6
Kaliganj	30.5	12.2	23.9	27.9
Satkhira Sadar	79.3	49.5	53.7	55.7
Shyamnagar	74.9	49.7	52.4	56.3
Tala	75.6	46.3	52.5	66.2

The bold values represent the corresponding highest and lowest values

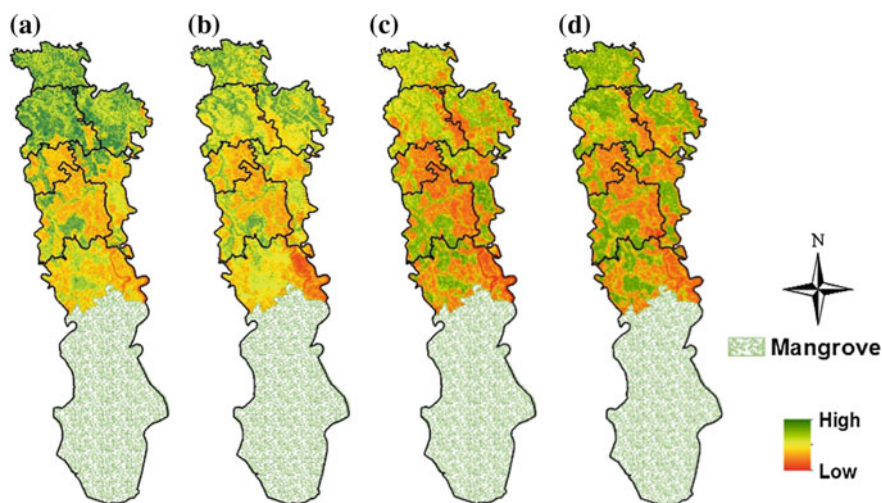


Fig. 4 Spatiotemporal pattern of NDVI **a** in 2007; **b** in 2010; **c** 2013; **d** in 2016

On an average, 20% reduction in vegetation cover has been observed in Satkhira after the cyclone Sidr and more than 30% reduction has been happened in Satkhira due to cyclone Aila in 2009, as Aila mainly hit the Satkhira and Khulna district and affect much on that area [13].

4.2 Spatiotemporal Dynamics of NDWI

For identifying the wetland areas, NDWI has been used and NDWI shows positive value in the areas with water [14].

Table 3 shows the NDWI statistics for the Upazilas of Satkhira district for the selected years. The increasing wetland areas from the year 2007 to 2010 are the

Table 3 NDWI statistics of Satkhira district

Upazila	Wetland areas (in % of total area of Upazila)			
	2007	2010	2013	2016
Assasuni	40.2	53.9	41.2	44.5
Debhata	56.7	69.2	61.7	65.1
Kalaroa	1.7	13.1	11.6	19.8
Kaliganj	52.4	68.9	49	80.5
Satkhira Sadar	8.3	35.3	27.9	47.7
Shyamnagar	85.3	86.2	85.1	82.4
Tala	7.2	32.7	31.6	35.4

The bold values represent the corresponding highest and lowest values

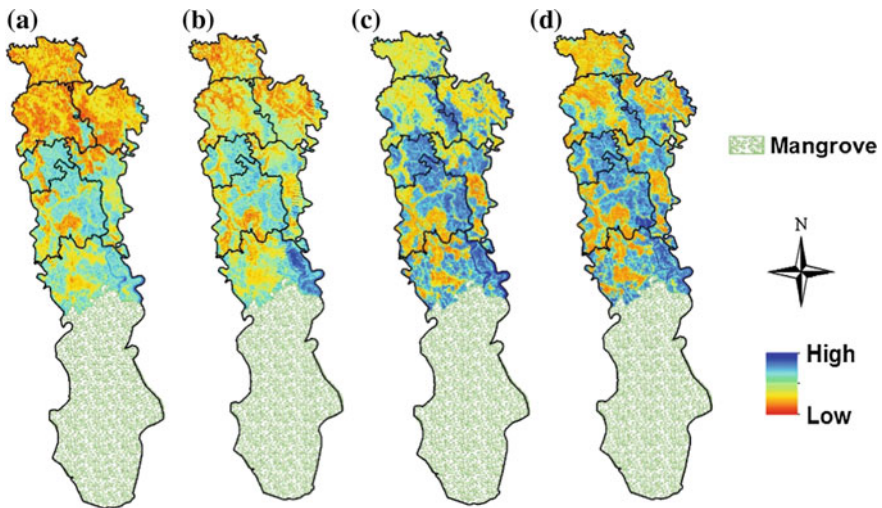


Fig. 5 Spatiotemporal pattern of NDWI **a** in 2007; **b** in 2010; **c** 2013; **d** in 2016

indication of the waterlogged areas due to the cyclones. Wetlands are increasing in all the Upazilas, as shrimp culture is one of the prominent occupations in Satkhira district. Satkhira Sadar Upazila and Tala Upazila have experienced significant increase among the Upazilas (Fig. 5).

4.3 Spatiotemporal Dynamics of NDBI

NDBI is a useful index to identify the built up areas from the satellite images, where the built-up areas have NDBI values ranged from 0.1 to 0.3 [15]. Table 4 shows the NDBI statistics for the Upazilas of Satkhira district for the selected years.

Table 4 NDBI statistics of Satkhira district

Upazila	Built up areas (in % of total area of Upazila)			
	2007	2010	2013	2016
Assasuni	20.6	18.2	22.2	25.3
Debhata	8.8	12.4	15.4	18.2
Kalaroa	22.5	12.7	18.7	20.3
Kaliganj	15.3	18.2	21.4	24.5
Satkhira Sadar	15.6	10.3	18.7	19.2
Shyamnagar	44.8	37.6	40.5	45.8
Tala	23.2	21.9	25.6	27.6

The bold values represent the corresponding highest and lowest values

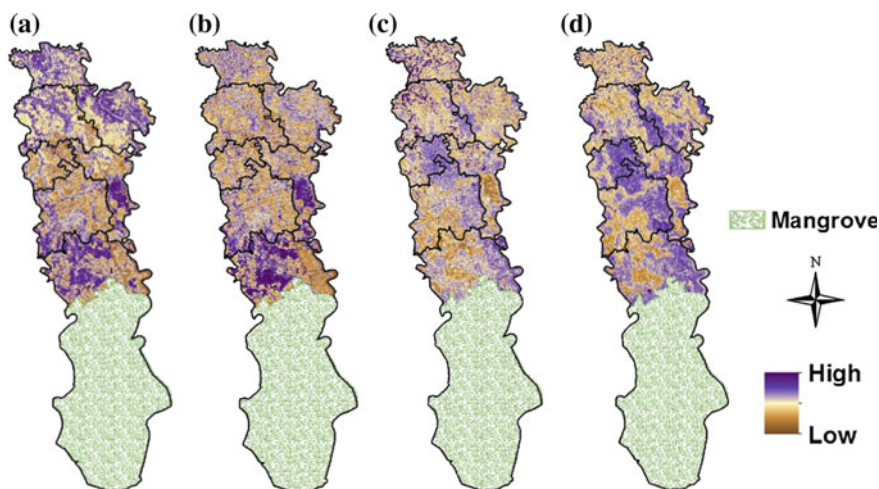


Fig. 6 Spatiotemporal pattern of NDBI **a** in 2007; **b** in 2010; **c** 2013; **d** in 2016

Overall increase in built up areas has been seen from the analysis of NDBI, though there is little reduction in built up areas from the year 2007 to 2010 due to the impact of the cyclones. Increase rate is higher in Debhata and Kaliganj Upazilas. Due to the cyclones, Kalaroa faced more reduction in built up areas due to the cyclones than other Upazilas (Fig. 6).

4.4 Spatiotemporal Dynamics of NDBaI

NDBaI is used to identify the bare lands from the satellite images. For Landsat 5 TM, it has threshold value greater than -0.15 and for Landsat 8 OLI it is -0.09 [11,

Table 5 NDBaI statistics of Satkhira district

Upazila	Bare lands (in % of total area of Upazila)			
	2007	2010	2013	2016
Assasuni	7.5	3.4	2.8	1.9
Debhata	0.36	0.22	0.16	0.1
Kalaroa	1.1	0.93	0.74	0.62
Kaliganj	2.9	1.55	1.2	0.95
Satkhira Sadar	0.7	0.44	0.4	0.32
Shyamnagar	16.1	13.16	10.4	8.9
Tala	1.7	1.14	0.87	0.65

The bold values represent the corresponding highest and lowest values

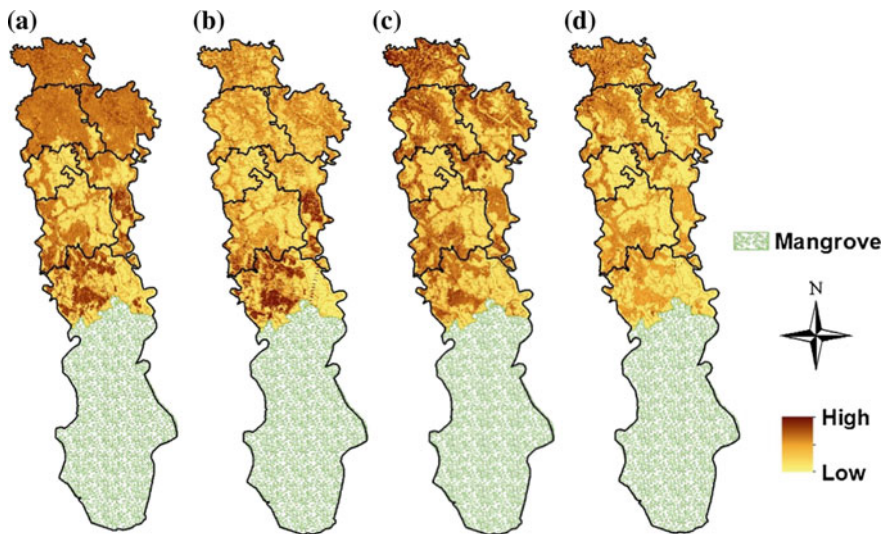


Fig. 7 Spatiotemporal pattern of NDBaI **a** in 2007; **b** in 2010; **c** 2013; **d** in 2016

15]. Table 5 shows the NDBaI statistics for the Upazilas of Satkhira district for the selected years.

Though there were fewer amounts of bare lands in all Upazilas, it shows a decreasing trend at present. Bare lands have been converted into either built-up areas or into shrimp farming lands. Satkhira Sadar and Debhata have the least amount of bare lands as they are close to the main urban area with high population density (Fig. 7).

4.5 Spatiotemporal Dynamics of NDSI

NDSI shows the salinity-affected area from the reflectance value of red and near infrared bands [2]. Table 6 shows the NDSI statistics for the Upazilas of Satkhira district for the selected years.

Analysis of NDSI has revealed that the areas near the water bodies are severely affected by salinity and value of NDSI is increasing. South part of the district (Shyamnagar Upazila) is severely affected due to the proximity to the sea and the salinity intrusion has been spread toward the north (Fig. 8).

Table 6 NDSI statistics of Satkhira District

Upazila	Salinity-affected areas (in % of total area of Upazila)			
	2007	2010	2013	2016
Assasuni	38.2	54.6	32.3	40.5
Debhata	52.1	67.1	52.8	62.8
Kalaroa	1.2	13	8.2	14.7
Kaliganj	50.2	59.5	42.6	47.3
Satkhira Sadar	7.2	31.7	22.9	25.4
Shyamnagar	85	86.6	84	87.4
Tala	7.3	30.8	27.2	32.6

The bold values represent the corresponding highest and lowest values

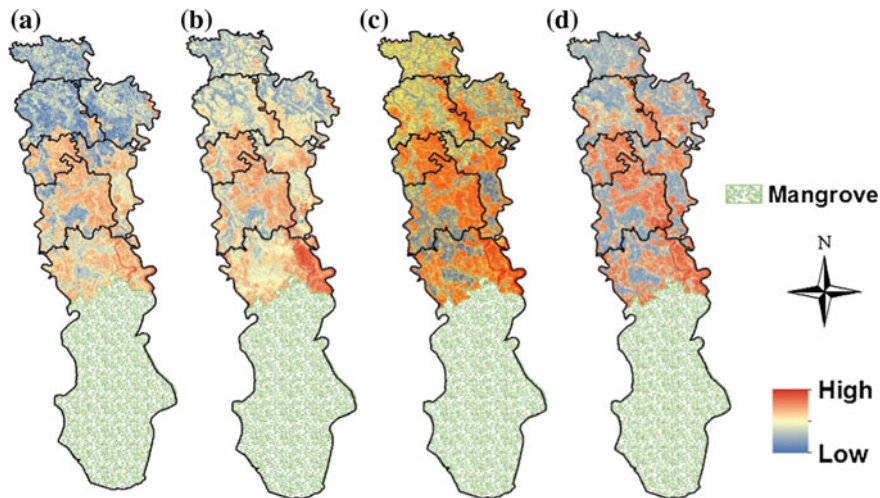


Fig. 8 Spatiotemporal pattern of NDSI **a** in 2007; **b** in 2010; **c** 2013; **d** in 2016

5 Conclusions

This study reveals the changing nature of the environment of Satkhira district, which is one of the most vulnerable coastal districts of Bangladesh. Through the remote sensing indices, it is very realistic to explore the long-term change in environmental components. The decreasing vegetation areas, increasing salinity-affected areas, decreasing bare lands with increasing built-up areas are the result of this study, which indicate the environmental degradation in the study area. To control the environmental degradation in this area, an effective sustainable development plan is in need. Policy makers should give focus on this regard and promote sustainable development in Satkhira district.

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