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Assessment of shoreline change and its relation with Mangrove vegetation: A case study over North Konkan region of Raigad, Maharashtra, India

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Keywords
Shoreline Change
DSAS
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ABSTRACT

Vulnerability of SLR varies from place to place with 20th century observing greatest threat to it. Mangroves along the shore are the one to first sustain this impact of SLR. In the present study, an attempt has been made to understand the relation between shoreline changes with mangrove habitat through remote sensing data and geospatial technique. Shoreline change rate has been calculated for the years 2000, 2012 and 2019, in Digital Shoreline Analysis System by End Point Rate. Change analysis indicates that in last 20 years erosion dominated the study area with an average rate of -0.02m/yr. During 2000 to 2012, relatively higher erosional rates (-0.35m/yr) were observed. While from 2012 to 2019 accretion process dominated this area with a rate of 0.43m/yr. Sonakothakar, Mothe Bhal and Dadar with denudation, have observed landward progradation of mangroves whereas, at Aware, a zone of accretion exhibited a seaward progradation of mangroves. A direct relation with the shoreline change has been observed with mangrove habitat. Mangroves are consider as salt feeder and so spatial changes in their colony is ought to be frequent in the present context of climate change and SLR. This type of integrated study will help to understand active process over the shore and help to conserve mangrove habitat. Such regional scale studies should be carried out before implementing any coastal conservation projects.

1. INTRODUCTION

Shorelines are dynamic in nature and often respond to the changes in sea level. Global mean sea level (GMSL) was envisaged to be accelerating at considerable rate during 19th century with a further leap in its rate in 20th century (Church and White 2006). The speed of GMSL rise during 1900 to 2009 was estimated about 1.7 ± 0.2 mm/year which raise up to 3.2 ± 0.4mm/year at the end of 20th century (Mimura 2013). Vulnerability of Sea Level Rise (SLR) varies from place to place, with developing countries being much more susceptible to it (Dasgupta et al. 2009). In the Indian scenario east coast are much more vulnerable to erosion as compared to west coast, however, 36% of Maharashtra coast is under the process of erosion (Mohanty et al. 2017).

Mangroves thrive on mudflats along the shore intervene by numerous small inlets and creeks. Mangrove habitat is considered as a boon to mankind. However, mangrove habitat is under continuous threat of shoreline change. It was observed that during early Holocene period there was high SLR to which mangroves were able to withstand the effect however, this characteristic of withstanding varies time to time and from place to place (Woodroffe 1990). At places resilient nature of mangroves was noted that was attributed to the anthropogenic pressure and physiographic settings (Nitto et al. 2014). However, certain studies have shown that mangrove ecosystem is very dynamic in nature and they can even migrate landward in order to balance with SLR (McLeod and Salm 2006). Mangrove forest structure exhibits an interesting pattern of transition from

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seaward fringe to land ward, with healthy strong tree near the sea to dwarf forest far inland (Feller et al. 2015).

SLR has eroded considerable parts of coast, wetlands and mudflats in India (Dwivedi and Sharma 2005). However, mangroves act as a stabilizer and protector to SLR, deforestation to which may boost up erosion rate like Alibag coast in Maharashtra (Vidya et al. 2015). Over last two decades it has been observed that mangroves in the study area have increased profusely. There is spatial expansion of mangrove habitat, along within patch increase in density (Das and Dhorde 2021). Over the time span mangrove colony expanded and became dense over the area. This change in the physiography of mangrove habitat do correspond to SLR. Impact of changing shoreline on mangrove vegetation needs to be addressed in order to understand the relation between the two. Thus, present study aims at understanding the relation of mangrove growth with shoreline change. The specific objectives set are i) Detecting the changes in Shoreline and ascertaining the zones of denudation and accretion and ii) assessing the growth/decline in mangroves within the selected patches.

2. STUDY AREA

Raigad district is located on the west coast of Maharashtra, India. This coast is intertwined by rocky and sandy coast. A number of creeks are also observed to have developed marsh ecosystem at places. Within these belts of mudflats and marshes, lining the creeks, clusters of Mangrove patches are observed. In the present study, mangrove patches are located around three main creeks namely, Karanja creek, Dharamtar creek and Rewas creek along with numerous minute creeks intervening the mangrove habitat. Various local newspaper articles cited that in the last two decades these mangrove clusters, especially along the northern Raigad, has shown exponential growth. A few patches of mangroves from the North Raigad region are selected for the present study (fig 1). The study area extends between 18˚ 53' 12.28"N and 18˚ 45' 16.2"N latitudes, and 72˚ 52' 14"E and 73˚ 1' 42.2"E longitudes. In Raigad there are 11 true mangrove species and 15 mangrove associates (Mhatre et al. 2013).

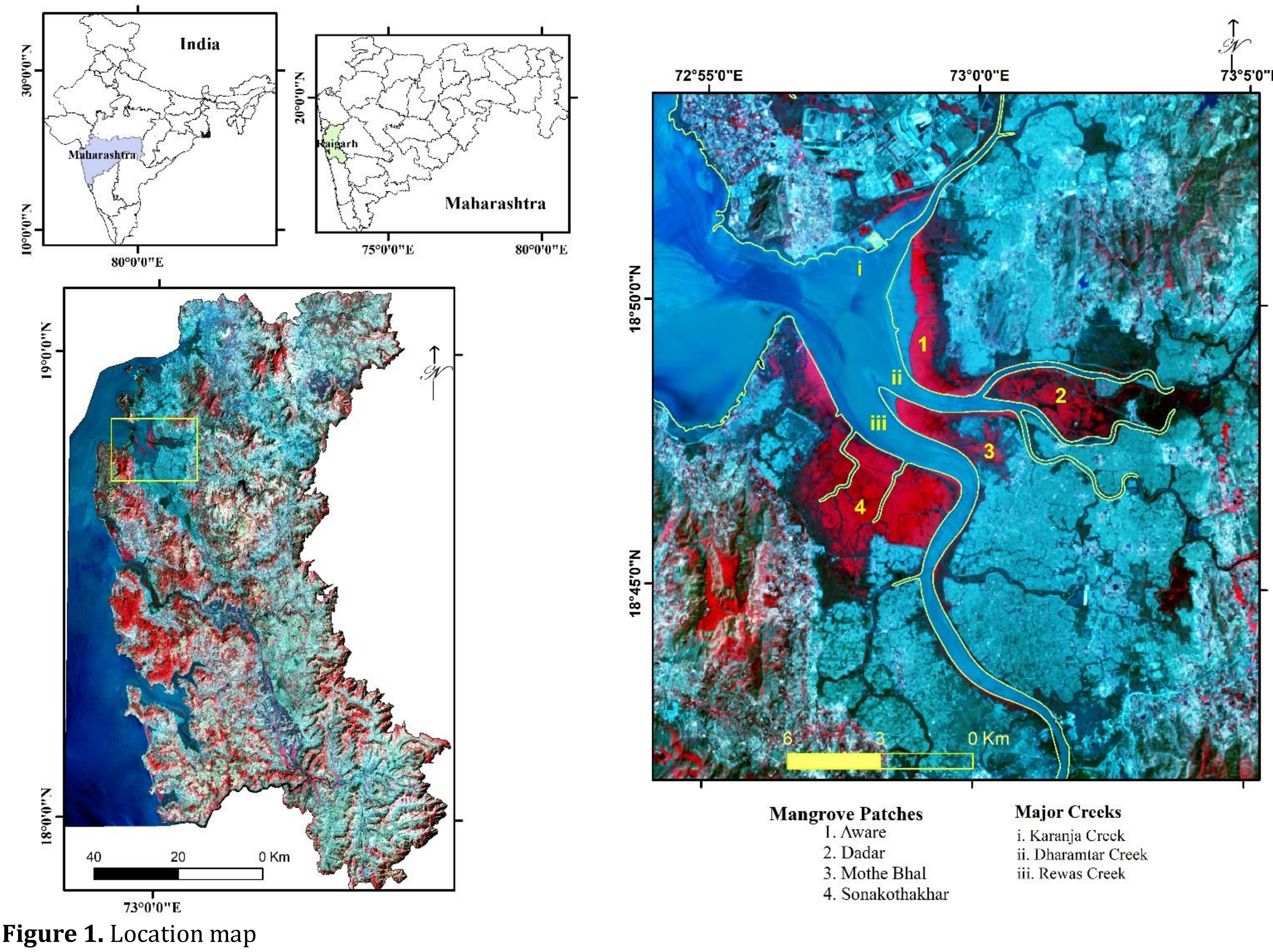


Figure 1. Location map

3. DATA & METHOD

3.1. Data Base

Since shorelines are highly dynamic and exposure of mangroves depends upon the tidal conditions, the level and condition of tides during satellite pass has to be taken into consideration. Table 1 presents the dates and tidal condition selected for retrieving the satellite images. All the images taken into consideration depicts ebbing condition which might give maximum exposure of the land. Moreover, delineation of the land-water boundary would yield better results. Landsat 7 ETM+ and Landsat 8 OLI data have been downloaded from USGS Earth Explorer site. For the study, pre-monsoon season of the year 2000, 2012 and 2019 have been taken into consideration. All the data are cloud free.

Table 1: Detail of Dates selected and Tide condition for each scene

Date & Year	Satellite & Sensor	Approx. Satellite Pass time	Time	Tide Level	Tide Stage
13/04/2000	Landsat 7 TM (Level II)	10:37am	12:29pm	0.72	Ebbing
14/04/2012	Landsat 7 TM (Level I)	10:37am	11:13am	1.40	Ebbing
25/03/2019	Landsat 8 OLI (Level II)	10:37am	10:58am	0.96	Ebbing

3.2. Image processing

Image pre-processing was carried out for all the images wherein the images were subjected to geometric and radiometric corrections. The image of 2012 was processed for image correction as it had problem of scan line error. This problem was fixed with the help of Landsat toolbox plugin in ArcGIS. Sacn line error has been fixed separately for all the bands. Post processing was carried out over the images for layer stacking and obtaining certain indices which were essential for further analysis. Green (G), Red (R), Near Infra-Red (NIR) and Shortwave Infra-Red (SWIR) bands were layer stacked to derive False Color Composite (FCC) image for respective years (fig 2a,2b and 2c). Various band combiation and ratios were deployed to derive indices like

Normalized Difference Vegetation Index (NDVI),

$$\boldsymbol{NDVI} = \frac{\boldsymbol{NIR - R}}{\boldsymbol{NIR + R}} \tag{1}$$

Normalized Difference Moisture Index (NDMI),

$$\boldsymbol{NDMI} = \frac{\boldsymbol{NIR - SWIR}}{\boldsymbol{NIR + SWIR}} \tag{2}$$

Normalized Difference Water Index (NDWI)

$$\boldsymbol{NDWI} = \frac{\boldsymbol{G - NIR}}{\boldsymbol{G + NIR}} \tag{3}$$

Table 2. Tasseled cap coefficients for Landsat 7 ETM+ (Huang et al. 2002)

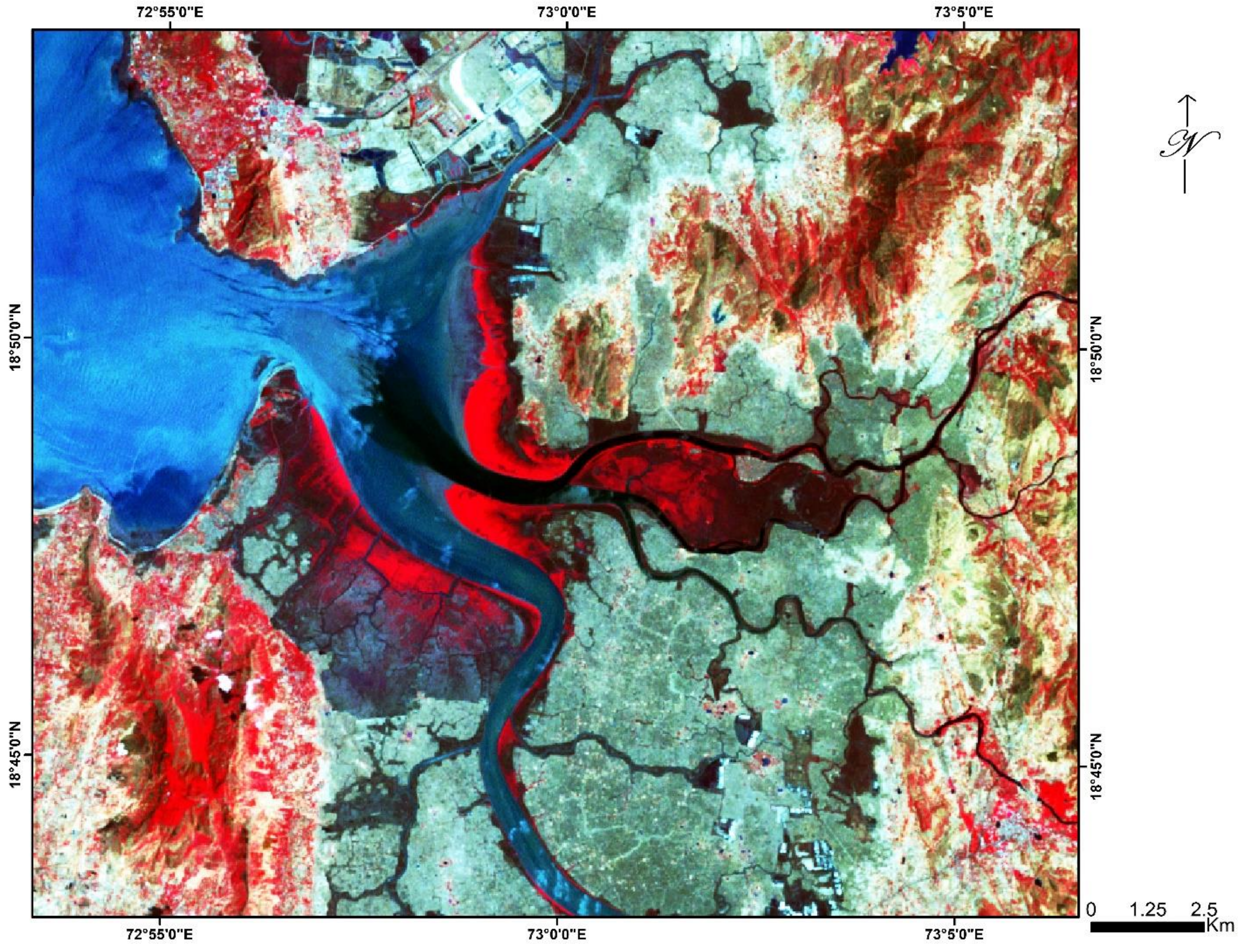
Index	Band 1	Band 2	Band 3	Band 4	Band 5	Band 7
Brightness	0.3561	0.3972	0.3904	0.6966	0.2286	0.1596
Greenness	-0.3344	-0.3544	-0.4556	0.6966	-0.0242	-0.2630
Wetness	0.2626	0.2141	0.0926	0.0656	-0.7629	-0.5388

Table 3. Tasseled cap coefficients for Landsat 8 OLI (Baig et al. 2014)

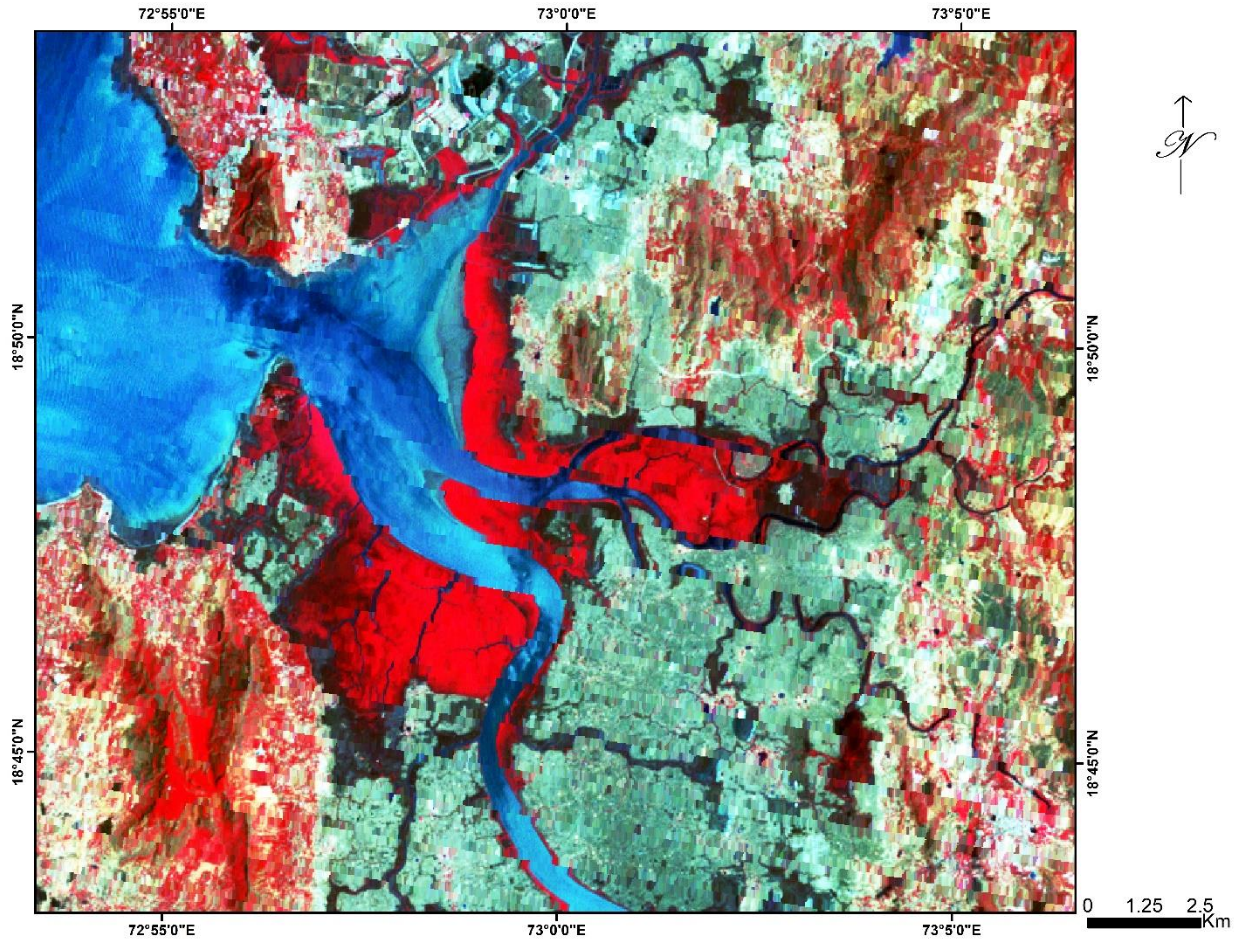
Index	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
Brightness	0.3029	0.2786	0.4733	0.5599	0.5080	0.1872
Greenness	-0.2941	-0.2430	-0.5424	0.7276	0.0713	-0.1608
Wetness	0.1511	0.1973	0.3283	0.3407	-0.7117	-0.4559

All the indices were computed in ArcGIS 10.3.1. Separation of land pixel to that of water pixel yield shoreline. Shoreline delineation from satellite image is difficult task as the pixel represents mixed spectra of features. Remote sensing based indices like NDVI, NDMI, TC and NDWI yields better result as far as discrimination of various features are concern. NDVI index quantify the pixel based on the presence of greenness. Its range varies from +1 to -1 with negative value indicating absence of vegetation and positive range indicating presence of vegetation. NDMI quantify the pixel based on the moisture content and many times yield better result as conmpared to NDVI (Wilson and Sader 2002). TC with the help of the coeeficient given in Table 2 and 3, calculate Brightness, Greenness and Wetness of a scene for Landsat 7 and Landsat 8 respectively. Brightness is associated with bare land surface, Greenness is associated with vegetation cover and Wetness indicates soil moisture content (Huang et al. 2002). NDWI index enhance water features by subduing soil and other terrestrial features (Mcfeeters 1996). Images derived from these indices enhance different features and thus objects can be segregated and classified.

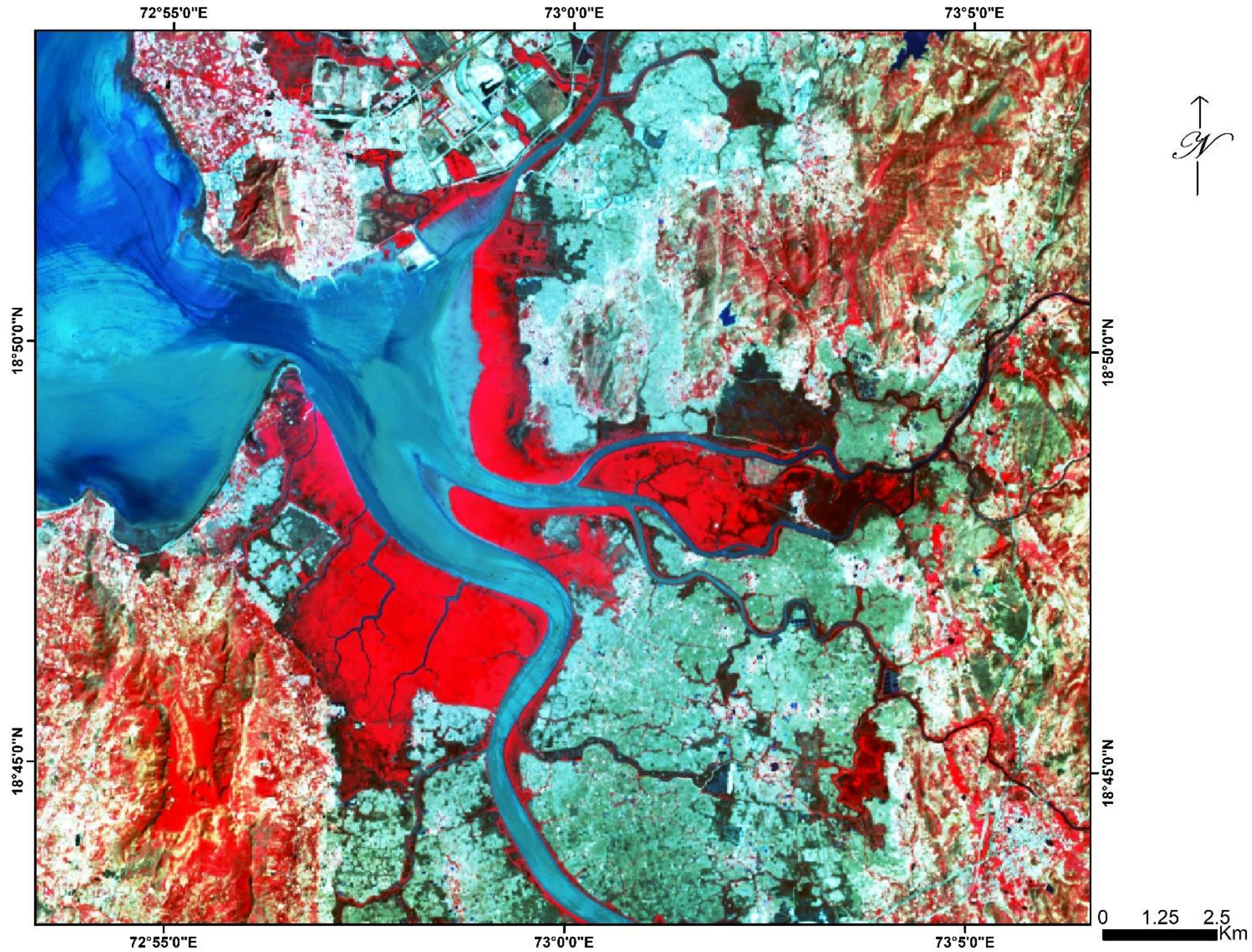
In order to delineate the shoreline and obtain the erosional and depositional rates along the shoreline, Digital Shoreline Analysis System (DSAS) was employed.


72°55'0"E
73°0'0"E
73°5'0"E
18°50'0"N
18°45'0"N
0 1.25 2.5
Km

(a)


72°55'0"E
73°0'0"E
73°5'0"E
18°50'0"N
18°45'0"N
0 1.25 2.5
Km

(b)



(c)

Figure 2. False Color Composite image of **(a)** 2000, **(b)** 2012 and **(c)** 2019

3.3. Shoreline Extraction and Rates calculation

The general methodology adopted for the present study is outlined in figure 3. Manual digitization was performed on FCC image to obtain shoreline. For automated shorelines DSAS plugin which is an extension of Arc GIS has been employed. The unsupervised Iterative Self Organized Data Analysis (ISODATA) clustering algorithm is consider as highly accepted and successful method to classify complex areas (Braud and Feng 1998). In the present study, an attempt has been made to classify the combined image i.e. NDVI_TC, NDMI _TC and NDWI image with help of ISODATA approach. This classifies raster images are then converted to binary image of only two class i.e., land and sea. Vector to raster conversion then applied on binary image to generate line that abut land and water.

For each raster image i.e., NDVI_TC, NDMI _TC and NDWI a separate shoreline has been derived. These shorelines were then compared with the manually digitized shorelines to obtain the deviation statistics (Table 4). Shoreline with minimum deviation in respective year was taken into consideration for further work of change detection analysis (fig 4). It has been observed that shoreline generated on NDVI-TC combined image has minimum deviation of 0.23 m and 0 m for the year 2000 and 2012 respectively. Whereas, for the year 2019 NDMI-TC combined image generates shoreline with the minimum deviation of 0.03 m. Rate of changes along the selected stretches of shoreline were obtained in the DSAS software. Keeping the time section into consideration, automated shoreline for two years has been merged for further rate calculation i.e. 2000-2019, 2000-2012 and 2012-2019. Baseline plays an important role in rate calculation. Baseline has been generated with 150m buffer from the merged automated shoreline. DSAS employ several perpendicular transect from a baseline (in this study 150m away from the merged automated shoreline) and records point of intersection between transect and shorelines for different years. The transect is of 1000 m in length with 100 m spacing. As an example, to transect and baseline year 2000-2019 has been shown (fig 5). DSAS automatically calculate several statistical methods for shoreline change viz. End Point Rate (ERP), Jackknife Rate (JKR), Linear Regression Rate (LRR), Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), Least Median of Square (LMS) and Weighted Linear Regression (WLR). All these methods have some advantages and disadvantages. In the present study shoreline change by ERP rate is taken into consideration as for relatively small data it gives good results (Esmail et al., 2019). Moreover, it shows normal distribution and is simple and universally prevalent method (Nassar et al. 2018).

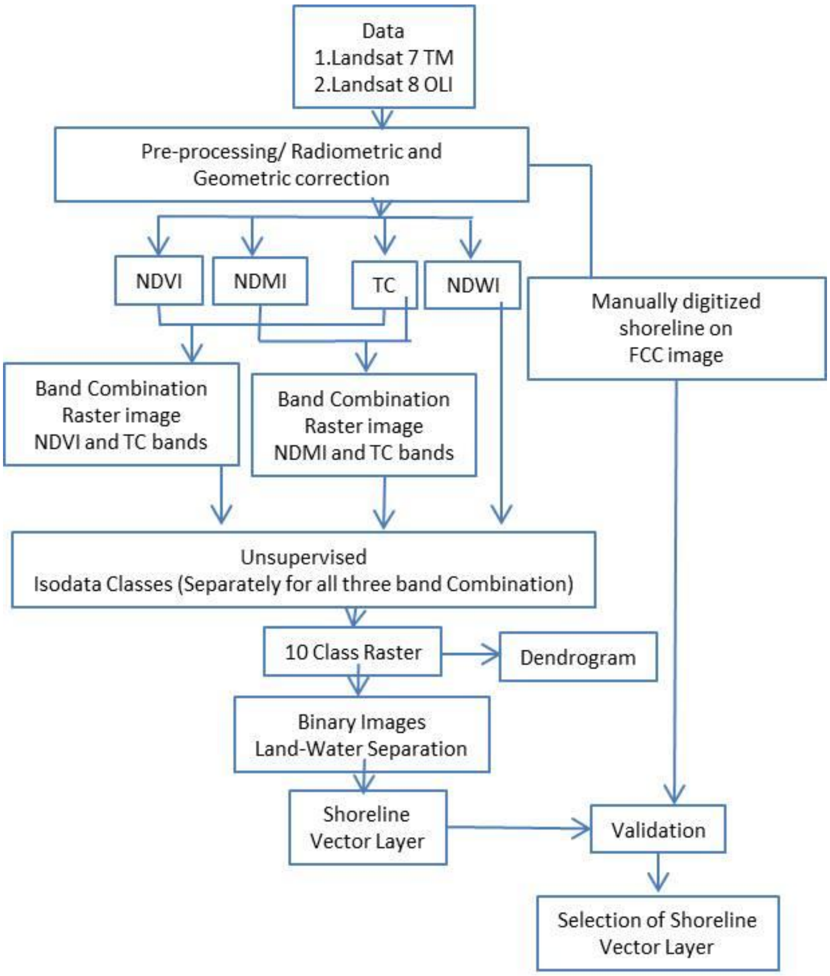
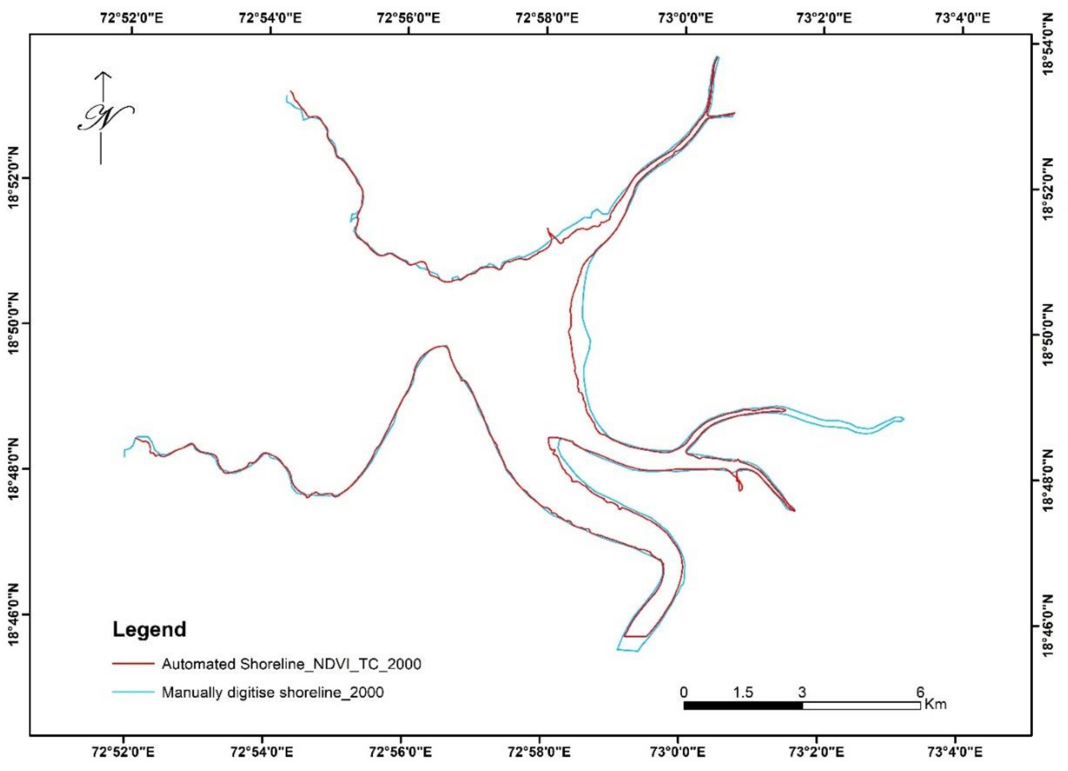
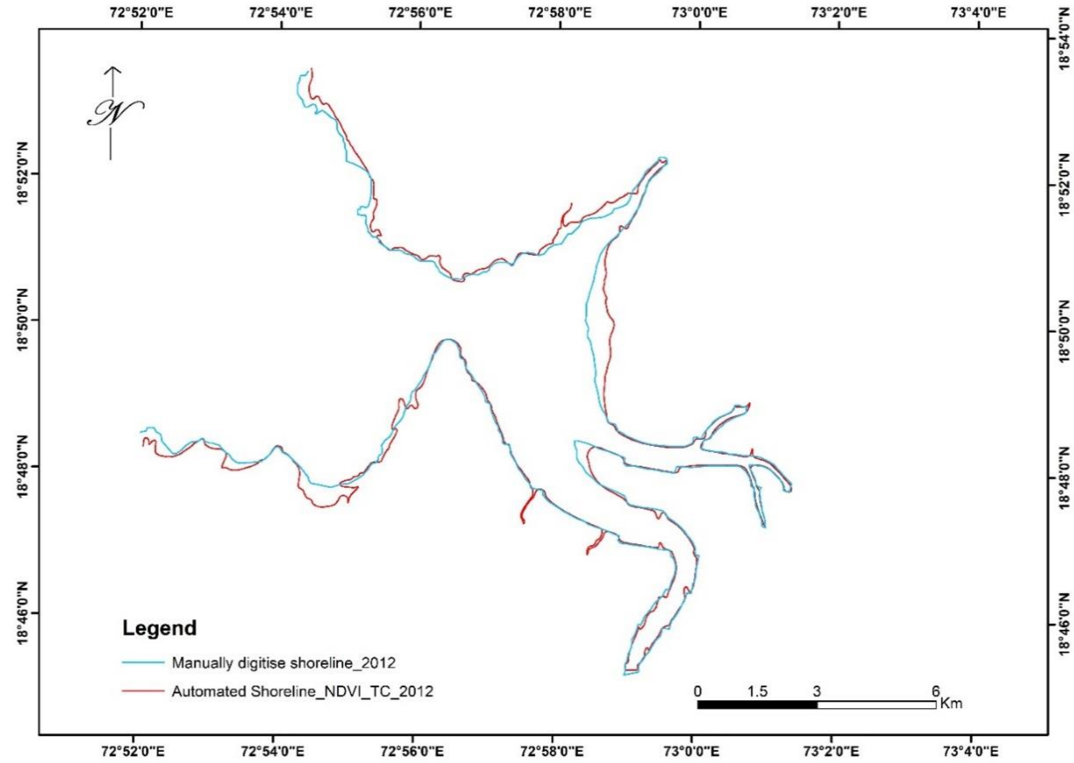


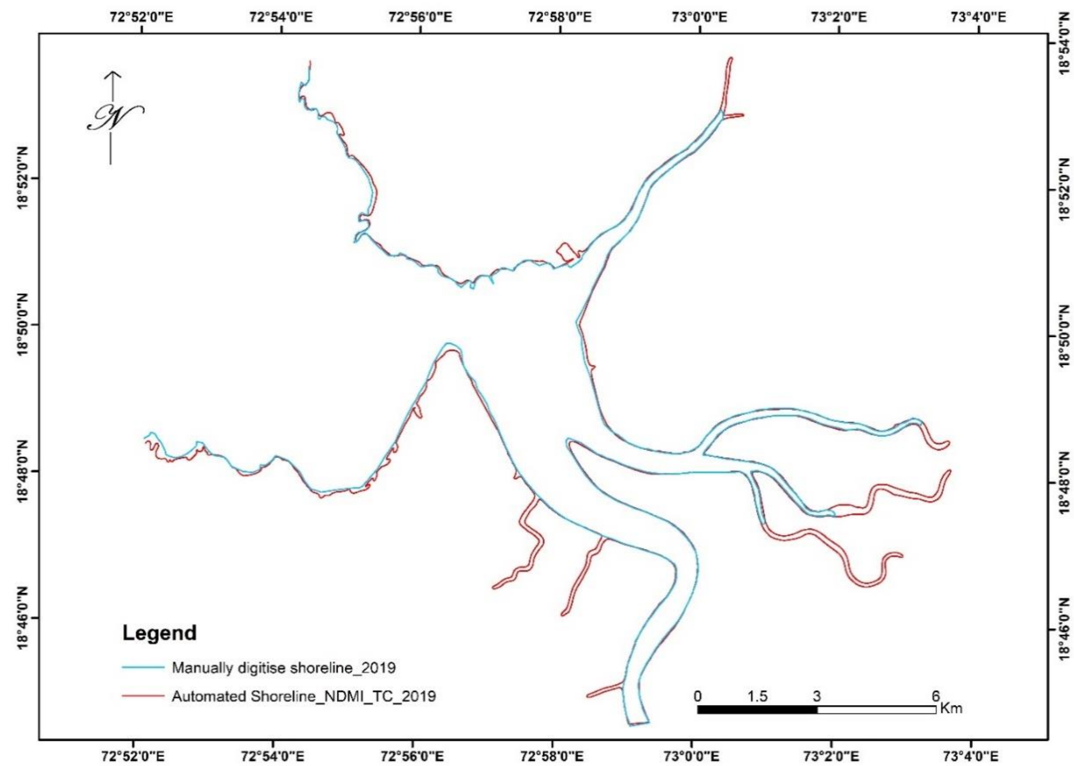
Figure 3. Methodology for Shoreline Extraction



(a)



(b)



(c)

Figure 4. Shoreline with minimum deviation from manually digitize Shoreline (a) NDVI TC 2000, (b) NDVI_TC 2012 and (c) NDMI_TC 2019

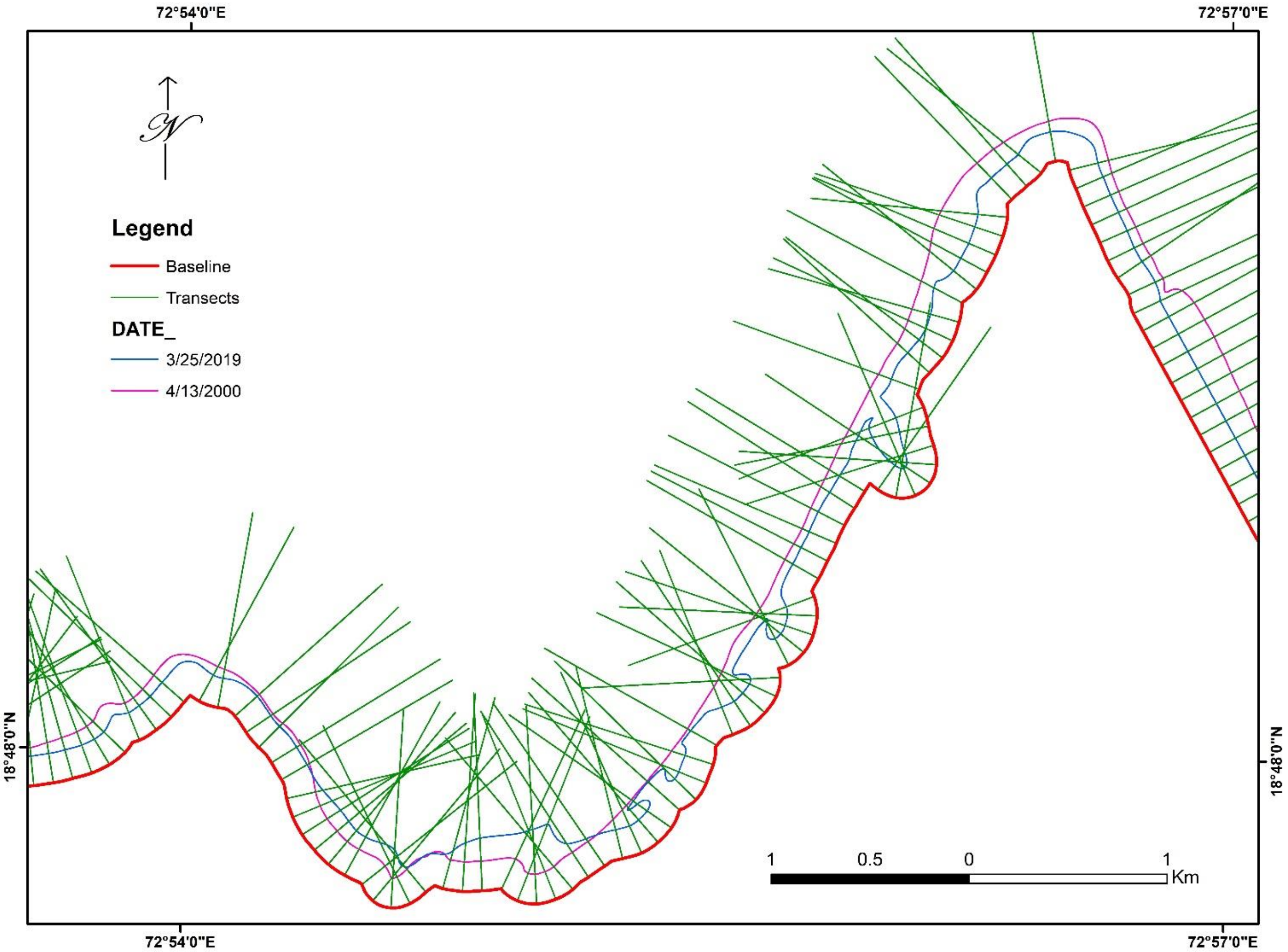


Figure 5. Transect along the baseline for the year 2000-2019

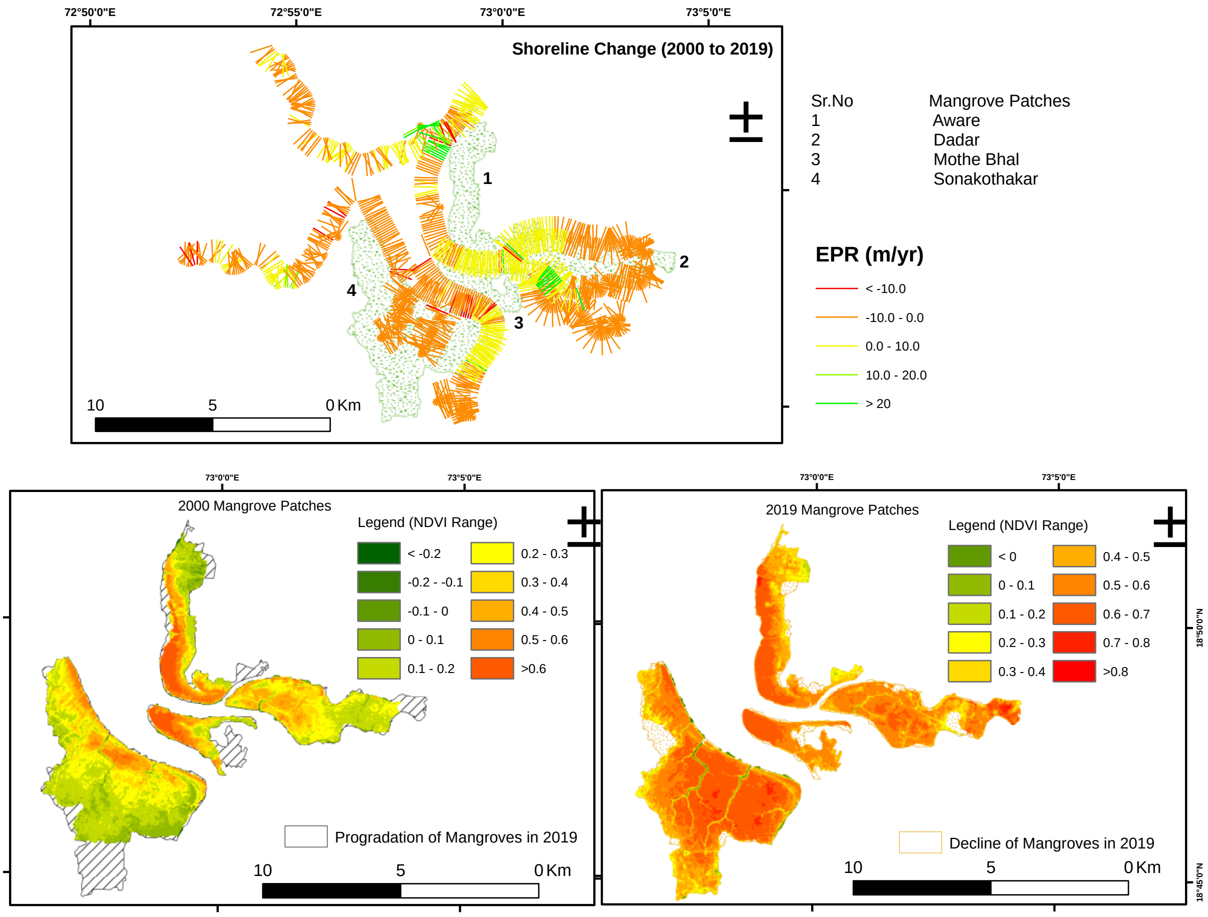
Table 4. Within pair difference between manually created shoreline and other methods.

Method	Deviation from Manually Digitized Shoreline		
	2000	2012	2019
NDWI	Min = 0.62 Mean=210.85 Max=999.18	Min = 0.17 Mean=256.38 Max=998.28	Min = 0.06 Mean=324.86 Max=999.73
NDVI_TC	Min = 0.23 Mean=243.3 Max=998.47	Min = 0.00 Mean=236.50 Max=999.83	Min = 0.14 Mean=151.20 Max=997.78
NDMI_TC	Min = 0.54 Mean=339.77 Max=999.64	Min = 0.32 Mean=386.98 Max=999.73	Min = 0.03 Mean=143.40 Max=998.91

4. RESULTS & DISCUSSION

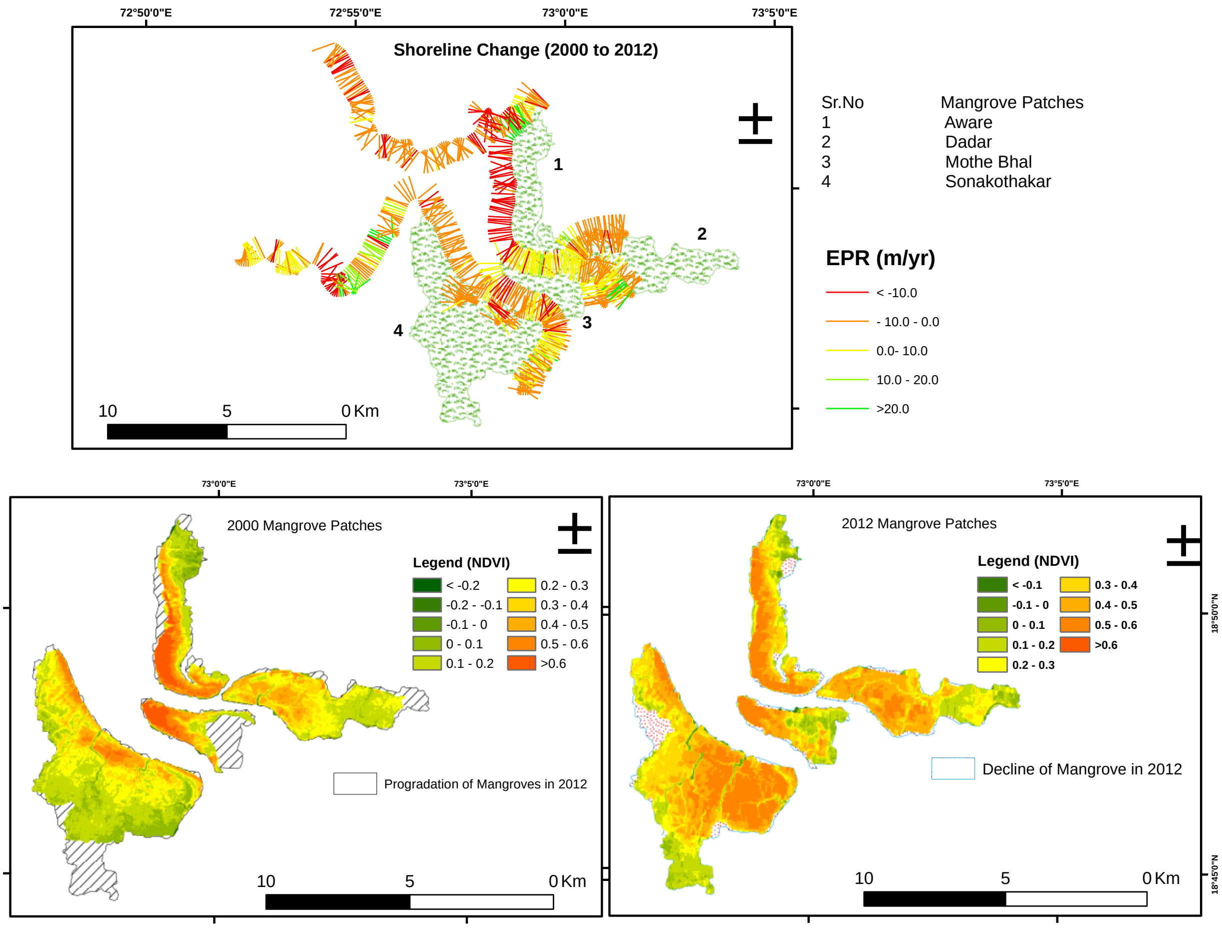
Shoreline change analysis for the present study has been carried over a span of 20 years ranging from 2000 to 2019. A time sectional analysis was also attempted between 2000 to 2012 and 2012 to 2019. Change detection analysis of the study area indicated that the shoreline has undergone both accretion and denudation process in last 20 years. Transects demarcated for accretion and denudation rates, indicates that almost 70.99% of the area has undergone erosion during the entire study period (2000 to 2019). While, almost 71.41% (2000 to 2012) and 67.79% (2012 to 2019) of the transects were subjected to erosion. However, during 2012 to 2019 it was observed that although 67.79% area was under erosion but the rate of erosion was relatively less than the rate of accretion.

Change analysis indicated that in the last 20 years erosion process dominated over the study area with an average rate of -0.02m/yr. During 2000 to 2012, erosion rate was high with -0.35m/yr whereas, from 2012 to 2019 accretion process dominated over denudation with a rate of 0.43m/yr (fig 6). Overlay of NDVI for mangrove patches clearly depicts that mangrove colony have undergone changes. During 2000 to 2019 it has been observed that overall NDVI value leap up spatially. İn the year 2000 NDVI value about < 0.4 dominate spatially over the patches whereas in the year 2019 NDVI value about <0.8 dominate the mangrove patches. Year 2012 shows a slow transition in NDVI value indicating healthy mangrove habitat.



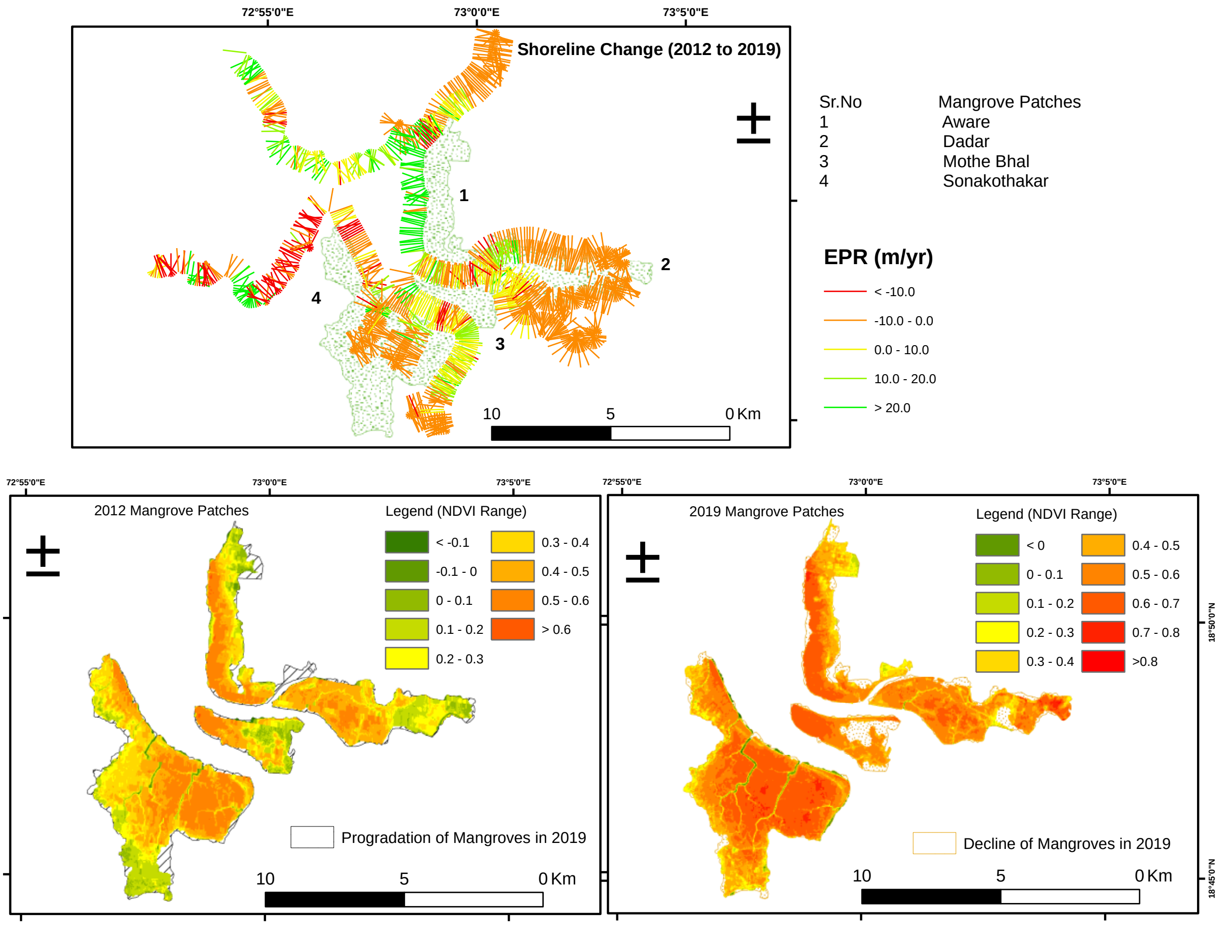
72°50'0"E
72°55'0"E
73°0'0"E
73°5'0"E
Shoreline Change (2000 to 2019)
1
2
3
4
10
5
0 Km
Sr.No Mangrove Patches
1 Aware
2 Dadar
3 Mothe Bhal
4 Sonakothakar
EPR (m/yr)
< -10.0
-10.0 - 0.0
0.0 - 10.0
10.0 - 20.0
> 20
2000 Mangrove Patches
Legend (NDVI Range)
< -0.2
-0.2 - -0.1
-0.1 - 0
0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
>0.6
Progradation of Mangroves in 2019
2019 Mangrove Patches
Legend (NDVI Range)
< 0
0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
0.6 - 0.7
0.7 - 0.8
>0.8
Decline of Mangroves in 2019
18°50'0"N
18°45'0"N

(a)



72°50'0"E
72°55'0"E
73°0'0"E
73°5'0"E
Shoreline Change (2000 to 2012)
1
2
3
4
10
5
0 Km
Sr.No Mangrove Patches
1 Aware
2 Dadar
3 Mothe Bhal
4 Sonakothakar
EPR (m/yr)
< -10.0
- 10.0 - 0.0
0.0- 10.0
10.0 - 20.0
>20.0
2000 Mangrove Patches
Legend (NDVI)
< -0.2
-0.2 - -0.1
-0.1 - 0
0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
>0.6
Progradation of Mangroves in 2012
2012 Mangrove Patches
Legend (NDVI)
< -0.1
-0.1 - 0
0 - 0.1
0.1 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.6
>0.6
Decline of Mangrove in 2012
18°50'0"N
18°45'0"N

(b)



(c)

Figure 6. Shoreline change and Mangrove spatial extent transformation during **(a)** 2000-2019, **(b)** 2000-2012 and **(c)** 2012-2019

In the regions of denudation like Sonakothakar, Mothe Bhal and Dadar, it was observed that there is landward progradation of mangrove habitat whereas accretion dominated over Aware region with no major landward progradation but a seaward progradation was observed. This is mainly due to the stable shoreline as a result of accretion. NDVI values overall have risen from 0.6 to 0.8 during 2000 to 2019. However, steady inter patch transformation was observed during the time with major part of the patch reaching towards higher NDVI values. This leap in NDVI values during the time span indicates the healthy status of mangrove vegetation. Mangroves are salt tolerant species. Inland shift of shoreline often leads to saltwater penetration through soil and creeks, in such cases, mangroves then act as a feeder to salinity (Prerna et al. 2015; Lambs et al. 2015) which is reflected in their overall health status. Minor decline of the mangroves was also observed in the study area it is only because of anthropogenic pressure over the region.

5. CONCLUSION

The present study concludes that shoreline over north Konkan region is under immense impact of shoreline change with processes of accretion and denudation varying from time to time. Process of erosion increased over Sonakothakar, Mothe Bhal and Dadar whereas Aware observed accretion. This change has direct relation with mangrove habitat. Areas with denudation clearly witnessed an inland encroachment of mangrove vegetation over time whereas seaward progradation of mangroves was observed in the areas dominated by accretion processes. Over the time span, whether erosion or deposition zone, mangrove NDVI values exhibited an increasing trend indicating overall good health of the species. With intensified effect of climate change, sea level ought to increase, leading to landward migration of mangroves (Gilman et al. 2008). This type of integrated study not only will help to understand active process over the shore but also will help to conserve mangrove habitat. Such regional scale studies should be carried out before implementing any coastal conservation projects.

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Author contributions

Barnali Das: Conceptualization, Methodology, Analysis, Mapping, Compilation, Writing-Original draft and its preparation. **Anargha Dhorde:** Visualization, Checking draft and Editing.

Conflicts of interest

The work is original and authors declare no conflicts of interest.

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