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ORIGINAL ARTICLE

Analyzing land surface temperature distribution in response to land use/land cover change using split window algorithm and spectral radiance model in Sundarban Biosphere Reserve, India

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Abstract The paper utilized Landsat 5 TM and Landsat 8 OLI for analyzing land use/land cover change and its impact on land surface temperature in Sundarban Biosphere Reserve, India. Split window algorithm and spectral radiance model were used for determining land surface temperature from Landsat 8 OLI and Landsat 5 TM, respectively. The land use land cover change analysis revealed phenomenal increase in the waterlogged areas followed by settlement and paddy and a decrease in open forest followed by deposition and water body. The distribution of average change in land surface temperature shows that water recorded highest increase in temperature followed by deposition, open forest and settlement. Overlay of the transect profiles drawn on land use/land cover change map over land surface temperature map revealed that the land surface temperature has increased in those areas which were transformed from open forest to paddy, open forest to settlement, paddy to settlement and deposition to settlement. The study demonstrated that increase in non-evaporating surfaces and decrease in vegetation have increased the surface temperature and modified the temperature of the study area.

Keywords Land use changes · Land surface temperature · Split window algorithm · Spectral radiance model · Sundarban Biosphere Reserve

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Introduction

Large scale human activities are continuously decreasing the vegetative cover of the earth's surface. Consequently, the concentration of carbon dioxide is increasing in the atmosphere which in turn affecting the surface energy budget thereby producing changes in local, regional and global climate (Marland et al. 2003; Islam and Islam 2013). Such changes have far reaching implications for the health and resilience of ecosystems and for human society. Land surface temperature is one of the key parameters for estimating surface energy budget assessing land cover changes and other characteristics of the earth's surface (Srivastava et al. 2010). Review articles have demonstrated the impact of land use/land cover changes on land surface temperature distribution (Ahmed et al. 2013; Buyadi et al. 2013; Islam and Islam 2013; Julien et al. 2011). Various methods to measurement and analysis of surface temperature have been proposed by different authors using different approaches (Cristobal et al. 2009; Kumar et al. 2012; McMillin 1975; Rozenstein et al. 2014).

Intensity of climate change of Sundarban Biosphere Reserve is more than that of the global average and the surface temperature here is rising higher at the rate of 0.5 °C per decade which is higher than the global average (Mitra et al. 2009). Living and non-living conditions of coastal environment are being drastically degraded due to large scale land use/land cover changes in Sundarban Biosphere (Mondal and Bandyopadhyay 2014). Rising sea surface temperature is directly related with the increased frequency and severity of cyclonic storms and depression in the Bay of Bengal. Mondal and Bandyopadhyay (2014) suggested that increasing trend in sea surface temperature may result in changes to the chemical composition of sea water, leading to increased acidification and decreased dissolved Oxygen level in Indian Sundarban. Many regions in south and south-eastern parts of the Reserve have been exposed to land erosion rendering poor people homeless. Sagar, Namkhana, and Pathar Pratima, Kakdwip blocks (administrative divisions of the district) are severely affected by the river encroachment (Bera 2013). Landscape of Indian Sundarban has experienced fast and remarkable changes in response to high population growth, soil erosion, bank embankment, deforestation and deposition within short span of time. These natural and man induced processes have modified the sea and land surface temperature of the region.

Measuring and analysing of surface temperature and surface emissivity by using remote sensing data and GIS analysis is virtually used by various scholars over the world. For example remote sensing and GIS techniques have been used to examine the effect of land use on land surface temperature in Netherlands by Jalili (2013), Hong Kong city, China by Liu and Zhang (2011), Dhaka Bangladesh by Ahmed et al. (2013) Al Habbaniyah, Lake by Sameen and Kubaisy (2014), Addis Ababa City, Ethiopia by Mbithi et al. (2010), Egypt by Omran (2012), Temperature modelling of Indus basin by Abbasi et al. (2012), Hyderabad city by Kumar et al. (2012), Delhi city by Mallick et al. (2010), Mahananda river basin by Srivastava et al. (2010), Dindigul drought prone district of Tamilnadu by Rajeshwari and Mani (2014), Indian Sundarban by Mondal and Bandyopadhyay (2014). This paper makes an attempt to analyze land use/land cover change and land surface temperature relationship in Sundarban Biosphere Reserve which is the home of distinct mangrove vegetation. This study makes a unique contribution as it analyzed a relation of land surface temperature with changing land use land cover in the study area The specific objectives of this study are (1) to examine the land use/land cover change (2) assessing land surface temperature change (3) to established the relationship of land use land cover change with land surface temperature.

Study area

Sundarban Biosphere Reserve (SBR) spreads over 13 blocks (administrative division of the district) of South 24 Parganas and 6 blocks of North 24 Parganas districts of West Bengal in India. It lies between 21°40′04″N and 22°09′21″N latitude, and 88°01′56″E and 89°06′01″E longitude (Fig. 1). Indian Sundarban Biosphere Reserve consists of 10,200 km^2 of mangrove forest, 4200 km^2 of reserved forest and another 5400 km^2 inhabited region (Buffer and Transition zone of Sundarban Biosphere Reserve. The study area is bounded on the west by river Muriganga and on the east by rivers Harinbhahga and Raimangal. It is part of the tide dominated lower deltaic plain. The Sundarbans eco-region can be categorized into three distinct divisions—the beach/sea face, the swamp forests and the mature delta—based on the bio-geophysical attributes.

Indian Sundarban has been divided into three main broad geographical regions viz. core zone, buffer zone and transition zone. There are 102 islands comprising Indian Sundarban, out of which 54 are habited spread over buffer and transition zone of the biosphere reserve and balanced 48 islands are inhabited contain mangrove reserve forest. Although the region is situated south of the Tropic of Cancer, the temperature is moderate due to this region's proximity to the Bay of Bengal in the south. Average annual maximum air temperature is around 35 °C. The summer (pre-monsoon) extends from the middle of March to mid-June, and the winter (post-monsoon) from mid-November to February. The monsoon usually sets in around the middle of June and lasts up to the middle of October. Rough weather with frequent cyclonic depressions lasts from mid- March to mid-September. Average annual rainfall is 1920 mm. Average humidity is about 82 % and is more or less uniform throughout the year. Thirty-four true mangrove species and some 62 mangrove associated species are found here (Banerjee 2013). It is the home to 4.5 million people of India (Census of India 2011). Due to non availability of sweet water except in monsoon and soil salinity, agriculture is mono cropping in Sundarban Biosphere Reserve. People's life of Sundarban islands revolves around land, water and forest. Although agriculture remains a source of livelihood for the people living in islands, the brackishness of rivers makes agriculture unsuitable and uncertain. Winter cultivation is virtually non-existent for want of fresh water.

Database and methodology

Landsat Satellite image (LANDSAT 5 TM, 1990) and (LANDSAT 8 OLI, 2014) of Sundarban Biosphere Reserve were used for assessing land use changes and their impact on land surface temperature. The detailed methodology is reveled in Fig. 2 and the steps followed in methodology are presented in sub sections.

Land use land cover maps of the study area for 1990 and 2014 were generated by supervised classification and maximum likelihood method was used for this classification. The pixel sample ware selected from various spectral classes and run the data using maximum likelihood method. Final groping of similar pixels was done on the basis of sampled pixels for various land use/land cover classes. The generalized images were reclassified to reduce classification error and improve the accuracy of the classification. The overall accuracy of the classifications for 1990 and 2014 was assessed using confusion matrix and

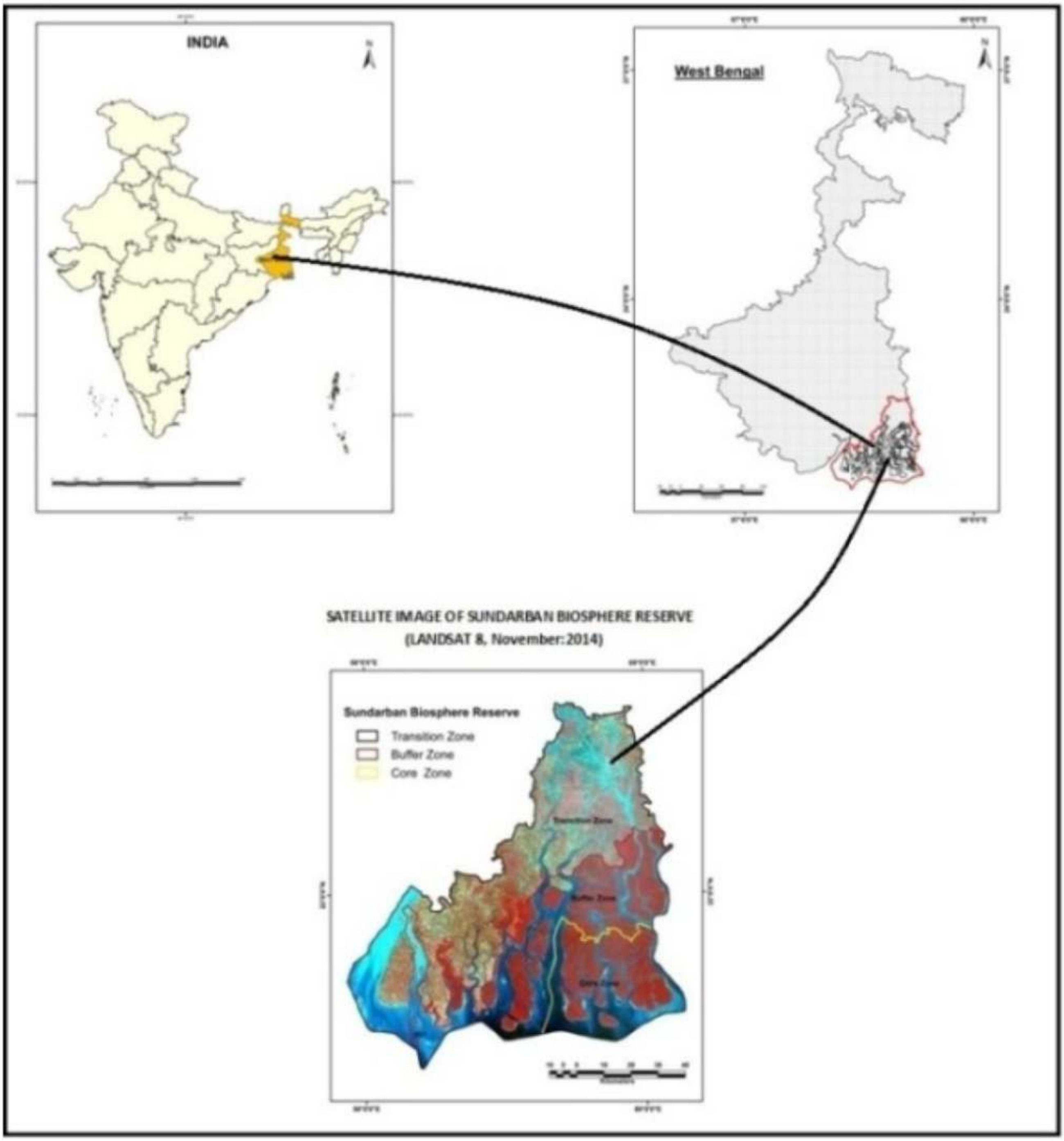

Fig. 1 Location of Sundarban Biosphere Reserve

was determined as 98.0 and 99.0 %, respectively. Land use/land cover change map was prepared using overlay function in Erdas Imagine.

Surface temperature was derived from geometrically corrected Landsat 5 TM (band 6) and Landsat 8 TIRS (band 10 and 11). Spectral radiance model was used to retrieve surface temperature from Landsat 5 TM and split-window method was used to retrieve surface temperature from LANDSAT 8 TIRS. A three step process was followed to derive surface temperature from Landsat TM 5 Image. Spectral radiance was calculated using following equation:

$$\boldsymbol{L} = \boldsymbol{LMIN} + (\boldsymbol{LMAX} - \boldsymbol{LMIN}) \times \boldsymbol{DN}/255$$

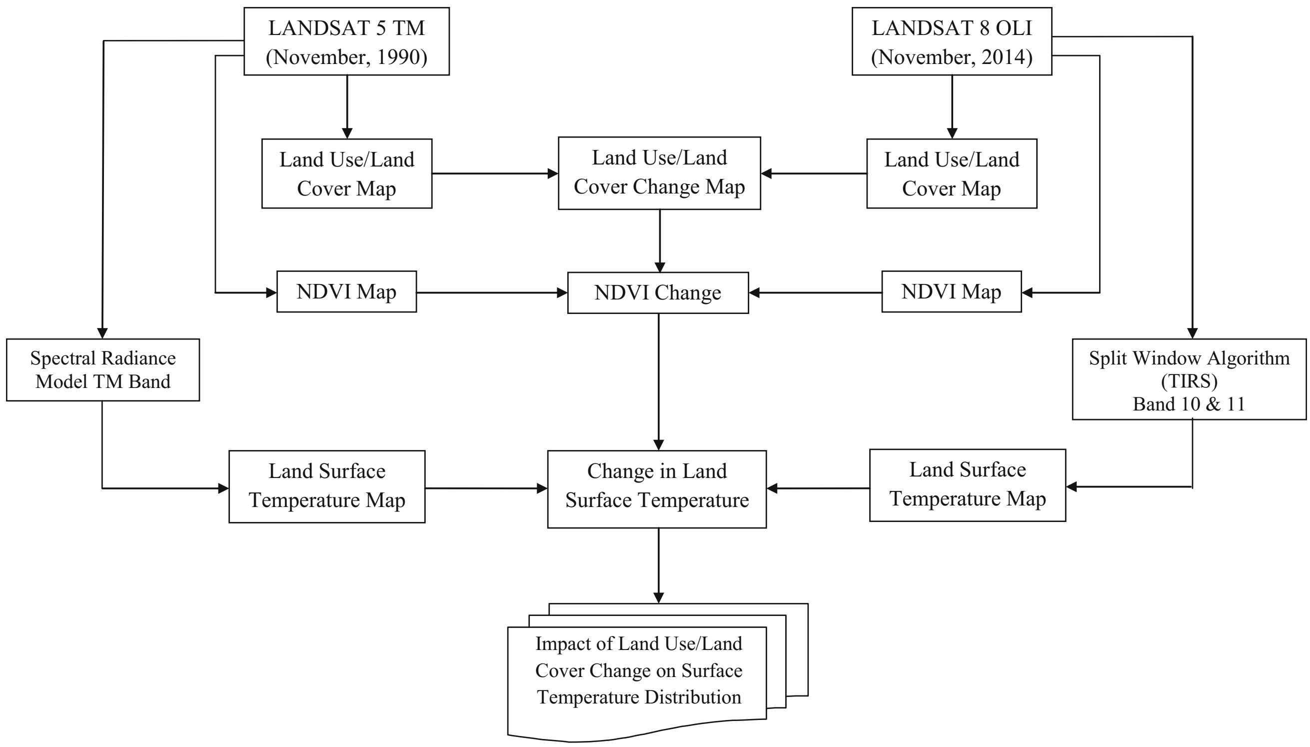

Fig. 2 Methodological framework adopted for analyzing variation in land surface temperature distribution in response to land use/land cover change using Split window Algorithm (TIRS, Landsat-8) and spectral radiance model (TM, Landsat-5) on Sundarban Biosphere Reserve, India

where L = Spectral Radiance, $LMIN = 1.238$, $LMAX = 15.600$, DN = Digital Number.

Spectral Radiance (L) to Temperature in Kelvin may be expressed as:

$$T_B = \frac{K_2}{ln\left(\frac{K_1}{L} + 1\right)}$$

where K_1 = Calibration Constant 1 (607.76), K_2 = Calibration Constant 1 (1260.56), T_B = Surface Temperature

Surface temperature from Landsat 8 TIRS was derived using band 10 and 11 following the split-window method first proposed by Mc Millin in 1975.

The algorithm is:

$$LST = TB_{10} + C_1(TB_{10} - TB_{11}) + C_2(TB_{10} - TB_{11})2 + C_0 + (C_3 + C_4W)(1 - \varepsilon) + (C_5 + C_6W)\Delta\varepsilon$$

where LST = Land surface temperature, C0–C6 = Split-window coefficient values (Table 5), TB_{10} and TB_{11} = Brightness temperature of band 10 and band 11, ε = Mband 10 and band 11, ε = Mean LSE of TIR bands, W = Atmospheric water vapor content, $\Delta\varepsilon$ = Difference in LSE .

Constant	Value
C0	−0.268
C1	1.378
C2	0.183
C3	54.3
C4	−2.238
C5	−129.2
C6	16.4

Thermal constant	Band 10	Band 11
K_1	1321.08	1201.14
K_2	777.89	480.89
Radiance multiplier (M_L)	0.0003342	0.0003342
Radiance add (A_L)	0.01	0.01

The value of Top Atmospheric Spectral Radiance (TOAr) was determined by converting original DNs and TIRS into atmospheric radiance. The original Digital Numbers (DN) of Landsat 8 TIR is converted into radiance based on the methods provided by Chander and Markham (2003):

$$TOAr = M_L \times DN + A_L$$

where A_L = Radiance add, M_L = Radiance multiplier, DN = Digital number.

The Brightness temperature (TB) for both TIR bands was calculated by adapting the following formula:

$$TB = \frac{K2}{Ln\left[\left(\frac{K1}{TOAr}\right) + 1\right]}$$

where K1 and K2 = Thermal constant for TIR bands, TB = Brightness temperature, TOAr = Atmospheric spectral radiance.

NDVI is a most widely used vegetation index for monitoring the earth's vegetation cover using satellite imagery. Here NDVI is calculated from the visible and near-infrared light reflected by vegetation cover. Leaf cells scatter (i.e., reflect and transmit) solar radiation in near-infrared spectral region strong absorption would overheat the plant possibly damaging the tissues. Live green plants appear relatively dark in the PAR and relatively bright in the near-infrared. Clouds and snow tend to be rather bright in the red (as well as other visible wavelengths) and quite dark in the near-infrared.

NDVI is calculated from these individual measurements as follows:

$$\boldsymbol{NDVI} = (\boldsymbol{NIR} - \boldsymbol{Red})/(\boldsymbol{NIR} + \boldsymbol{Red})$$

Red and NIR stand for the spectral reflectance measurements acquired in the red and near-infrared regions, respectively. NDVI itself thus varies between −1.0 and +1.0.

A land surface transit profile was drawn to generalize the relationship between land use/land cover change and surface temperature distribution. Three transit profiles were generated in east to west direction in land surface temperature map. Land use and land cover maps were then overlaid on surface temperature transit profile. Land use/-land cover relationship with surface temperature was established by overlaying land use/land cover change map on land surface temperature transit profile of current date.

Results and discussion

Patterns of land use land cover changes

Land use and land cover maps of Sundarban Biosphere Reserve for 1990 and 2014 are shown in Fig. 3. The total area of every land use category and percentage of each class between 1990 and 2014 were calculated and are presented in Table 1. Over the last 24 years there was a drastic and rapid increase in settlement and waterlogged area and a decrease in deposition and open forest area. One of the most conspicuous changes was noticed in waterlogged of upper part of the biosphere reserve which has gone up from 1.14 to 4.24 % at the rate of 272 % over the period. This change is

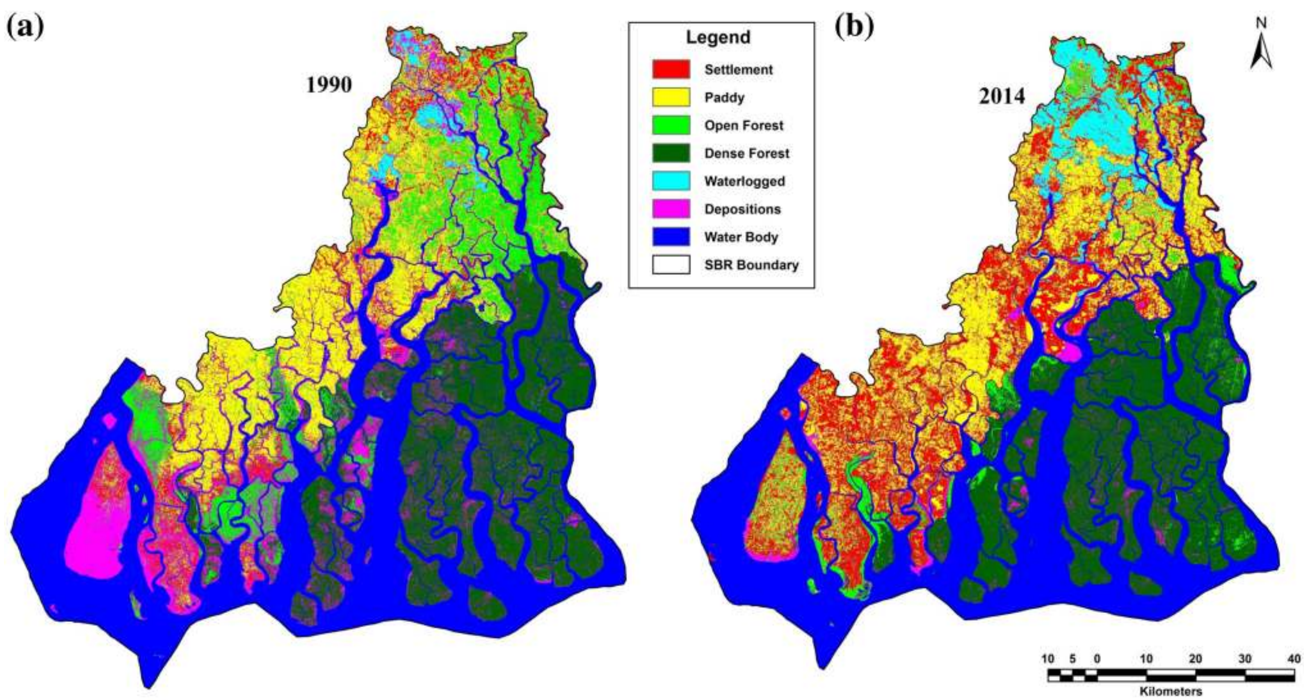

Fig. 3 Map obtained through overlying land use/land cover maps of 1990 and 2014. It is showing changes in land use/land cover classes during study period in Sundarban Biosphere Reserve. *White* colour is the unchanged area in the map

Table 1 Area under land use/land cover classes (1990 and 2014)

LULC class	1990		2014		1990–2014	
	Area (ha)	% to total area	Area (ha)	% to total area	Change (ha)	Change in %
Water body	301,612.36	34.28	29,3154.4	33.32	−8457.96	−3
Deposition	112,068.29	12.74	17,519.36	1.99	−94,548.93	−84
Waterlogged	10,036.1	1.14	37,313.57	4.24	27,277.47	272
Open forest	91,252.28	10.37	29,540.12	3.36	−61,712.16	−68
Settlement	45,238.51	5.14	167,662.8	19.06	122,424.29	271
Paddy	142,044.83	16.14	145,966.07	16.59	3921.24	3
Dense forest	177,622.87	20.19	188,718.92	21.45	11,096.05	6
Total	879875.24		879875.24			

attributed to river erosion particularly in the northern part of the study area. The study further indicates that settlement area has increased from 5.15 % in 1990 to 19.06 % in 2014 registering an increase of 271 % and indicating the land conversion and pressure on natural recourses of the study area. This change is remarkable in the transition and buffer zones and attributed to reckless cutting of open forest as a consequence of growth of population. The area under paddy cultivation has a slight increase at the rate of 3 %. This is mainly due to spread of salinity. Deposition area is found to be significantly reduced from 12.74 to 1.99 % within the followed by open forest from 10.37 % in 1990 to 3.36 % in 2014 (Table 1. and Fig. 4). Land use/land cover change matrix shows that of the total area under deposition (112068 h), 102133 h has been converted into settlement, dense forest, paddy, water body, open forest and waterlogged during 1990–2014 (Table 2.). Owing to the demand for settlement 59239 h paddy, 34652 h deposition and 24720 h open forest have been converted into settlement. A significant finding of the study is that 4098 h of settlement and 10758 h of paddy have been transformed into waterlogged area. This change is prevalent in the upper part of the study area due to frequent floods and tides. Nearly 6576 h of dense forest and 9071 h of settlement have been transformed into water body due to large scale erosion particularly in the lower part of the Sundarban islands. Open forests have been converted into paddy (46125 h) and settlement (24270 h). This shows that paddy has witnessed intensification mainly through the transformation of open forests.

NDVI

The NDVI values of the pixel vary between −1 and +1. The highest values of NDVI more than 0.3 are indicate the richest or healthy vegetation. NDVI value like below 0 is indicate the water body and from 0.01 to 0.02 are non vegetated area followed by 0.02–0.03 are unhealthy vegetation. According to Fig. 7 the healthy vegetation are decline in Sundarban Biosphere Reserve but the non vegetated cover are increase gradually over the time period. And a slight increase in unhealthy vegetation cover is shown by Fig. 5. due to paddy cultivation in these seasons. In 1990 the NDVI range between −0.59 and +0.68, which is gradually reduced to between −0.16 and 0.41 in 2014. Therefore, it can be said that the NDVI is decreasing in Sundarban Biosphere Reserve over the time.

Changes in land surface temperature

The average surface temperature of the study area has increased at the rate of 0.54 °C per decade. Table 1 shows that all the land use land cover classes identified recorded increase in the surface temperature over the study period. Spatio-temporal distribution of surface temperature shows that settlement has recorded the highest average temperature 20.77 °C in 1990 and 21.86 °C in 2014 followed by waterlogged 20.64 °C in 1990 and river deposition 20.98 °C in 2014. This implies that growth of settlement does bring up surface temperature by replacing vegetation with non-evaporating surface. The lowest average temperature was recorded in water body is 18.03 °C in 1990 and 20.05 °C in 2014 followed by open forest 18.97 °C in 1990–20.57 °C in 2014 and dense forest 19.13 °C in 1990–20.80 °C in 2014 (Fig. 6 and Table 3). Vegetation shows a considerably low radiant temperature in both years because vegetation can reduce amount of heat stored in the soil and surface through transpiration. Vegetation has low temperature because the amount of heat stored is reduced through transpiration (Omran 2012). Surface temperature of water was low compared to other classes but the increase rate was high because the date of the data acquisition was November and the radiant reflected from the water body was lower than other objects in winter seasons. Rate of increase of surface temperature was highest over water body (0.84 °C) followed by river deposition (0.73 °C), dense forest (0.69 °C), open forest (0.67 °C) and settlement (0.66 °C). Waterlogged areas and paddy experienced low rate of temperature being 0.10 and 0.13 °C, respectively (Table 4).

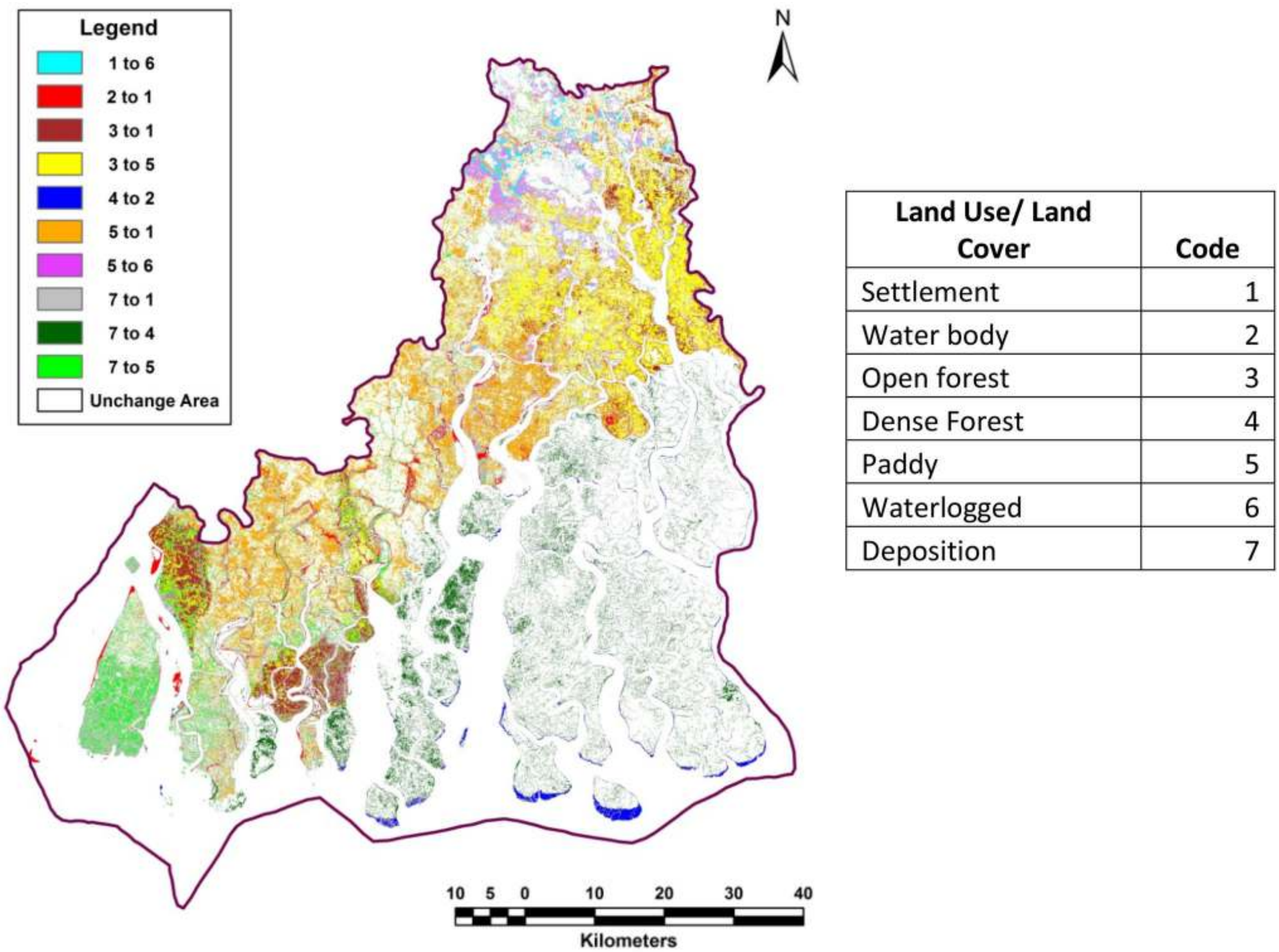

Fig. 4 Land use/land cover map of Sundarban Biosphere Reserve in Indian in 1990 (**a**) and 2014 (**b**) showing the different land use/land cover types

Table 2 Land use/land cover change matrix

Class	Water body	Deposit	Waterlogged	Open Forest	Settlement	Paddy	Dense Forest	LULCC 1990
Water body	275,784	1210	2437	2377	9071	4291	6442	301,612
Deposition	8078	9936	6301	7483	34,652	18,550	27,069	112,068
Waterlogged	241	100	7974	227	897	595	3	10,036
Open forest	1374	463	5676	7321	24,720	46,125	5574	91,252
Settlement	599	426	4098	1291	37,775	954	96	45,239
Paddy	503	348	10,758	3126	59,239	67,835	236	142,045
Dense forest	6576	5036	69	7716	1310	7616	149,299	177,623
LULCC 2014	293,154	17,519	37,314	29,540	167,663	145,966	188,719	879,875

Land use/land cover change and land surface temperature relations

Land use/land cover change map revealed that the surface temperature has increased at high rate in those areas where land use/land cover classes were converted to settlement. Highest increase of temperature was observed where open forests were converted into settlement (2.07 °C) followed by paddy to settlement (1.80 °C) and deposition to settlement (1.66 °C) while a decrease of land surface temperature is observed where settlements were transformed into waterlogged (0.19 °C) (Table 5).

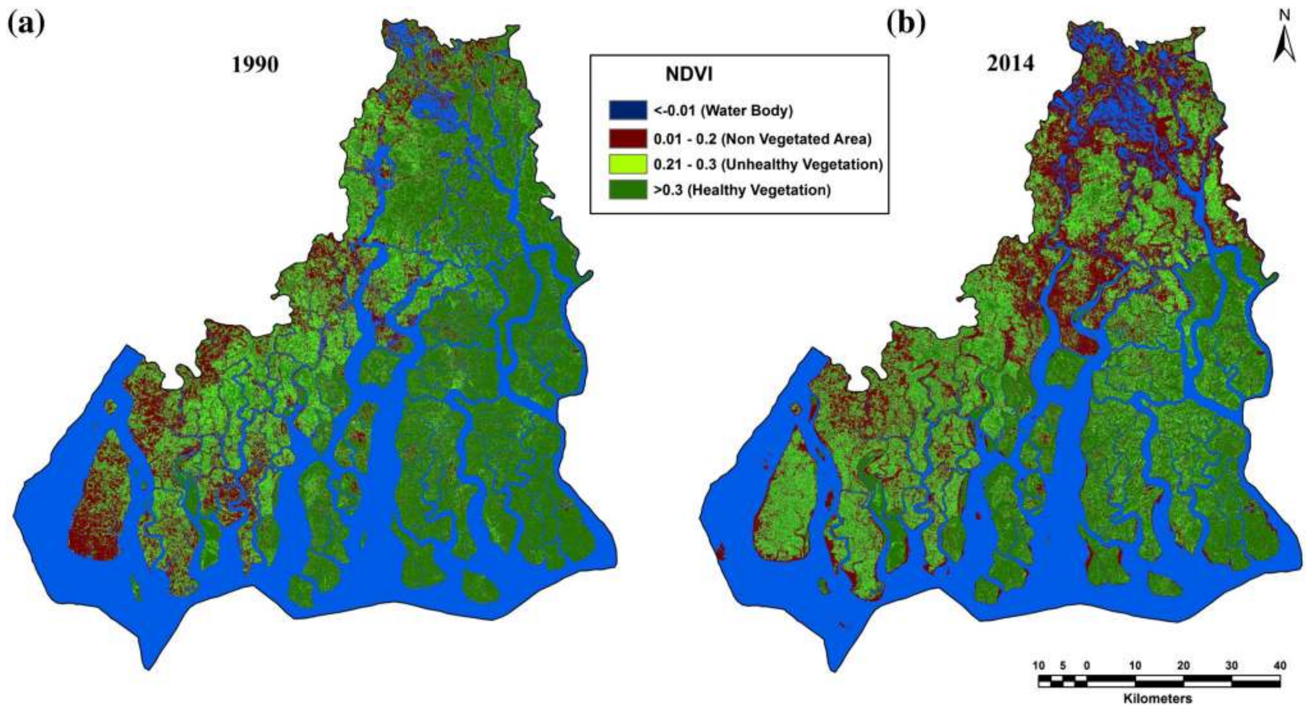

Fig. 5 Normalized different water index (NVDI) map of Sundarban Biosphere Reserve in 1990 (**a**) and 2014 (**b**) showing the four NDVI classes based on NDVI threshold values to identify the vegetation types within the study area

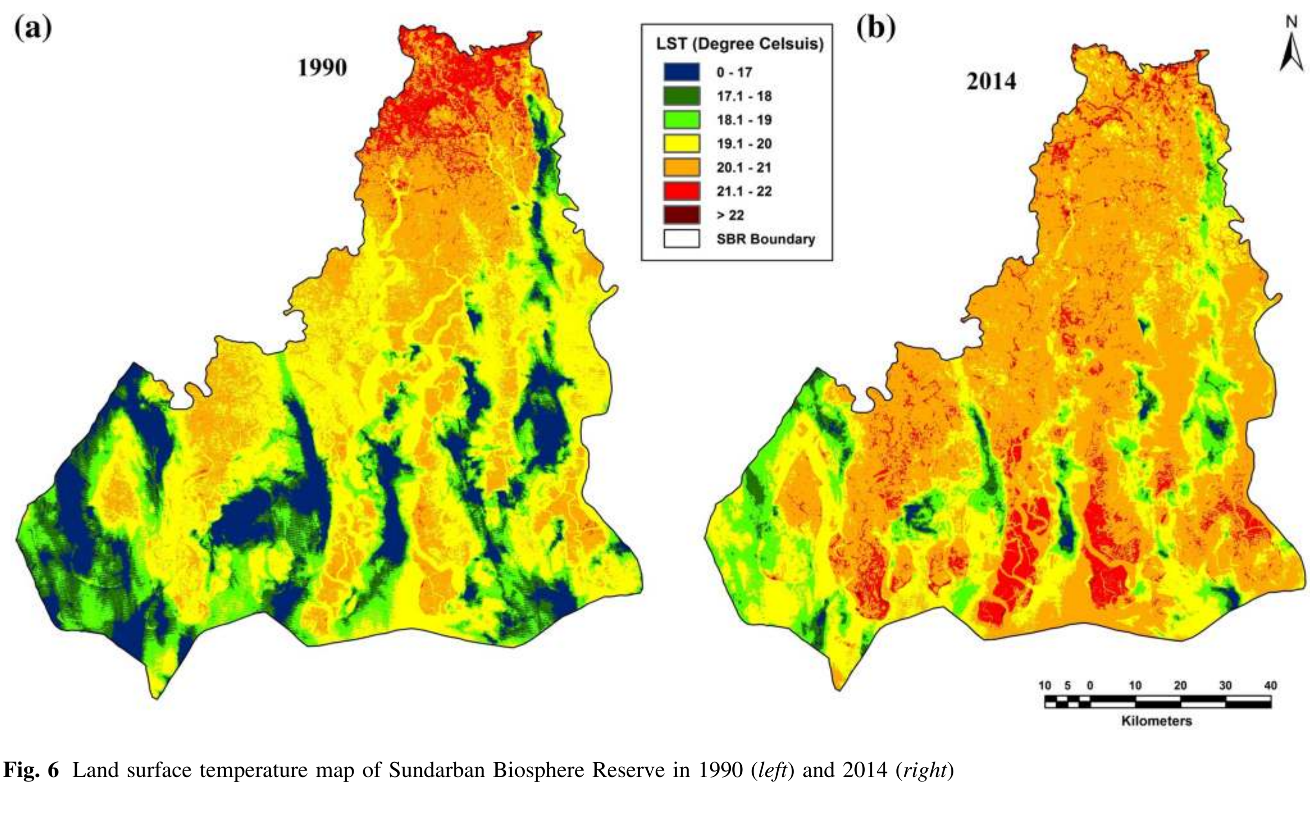

Fig. 6 Land surface temperature map of Sundarban Biosphere Reserve in 1990 (*left*) and 2014 (*right*)

Table 3 Land surface temperature distribution over LULC classes 1990 and 2014

Land use land cover class	Land surface temperature in °C					
	1990			2014		
	MIN	MAX	MEAN	MIN	MAX	MEAN
Water body	6.49	22.2	18.03	11.16	22.89	20.05
Deposition	10.5	23.09	19.22	12.65	24.04	20.98
Waterlogged area	17.2	22.64	20.64	13.69	23.52	20.87
Open forest	6.49	22.2	18.97	10.32	25.11	20.57
Settlement	11.48	23.09	20.37	15.91	25.6	21.86
Paddy	17.66	22.64	20.33	15.65	22.94	20.64
Dense forest	7	22.2	19.13	13.54	24.78	20.80

Table 4 Nature of surface temperature increase in different land use/land cover classes

Class	Increase in °C	Yearly increase	Decadal increase
Water	2.02	0.08	0.84
River deposits	1.75	0.07	0.73
Waterlogged	0.23	0.01	0.10
Open forest	1.60	0.07	0.67
Settlement	1.59	0.07	0.66
Paddy	0.31	0.01	0.13
Dense Forest	1.67	0.07	0.69

Three transit profiles were generated across the study area from east to west direction to validate the changes in surface temperature as a result of land use/land cover change (Fig. 7). It is seen from the profiles that surface temperature has increased due to transformation of land use/land cover classes into non-evaporating surfaces. Land surface temperature has increased due to transformation of deposition and open forest into settlement (Profile A), conversion of paddy into settlement (Profile A, B and C) while it has decreased due to transformation of settlement into waterlogged areas and conversion of open forest into paddy (Profile C). It is inferred from the analysis that surface temperature has increased in response to different land use/land cover changes in different zones of the study area. For example, in core area the temperature increased due to increase in deposition (Profile A). Buffer zone recorded high surface temperature due to transformation of open forest to settlement while in transition zone surface temperature has decreased only in those areas which are characterized with waterlogged areas.

Table 5 Change in surface temperature in response to land use/land cover changes

Land use land cover change	Area (In hectares)	Mean Temp. (°C) 1990	Mean Temp. (°C) 2014	Average change in land surface temperature (°C) 1990–2014
Water body to settlement	90,198,736	19.37	20.82	1.45
Deposition to dense forest	269,051,330	19.40	20.04	0.64
Deposition to settlement	347,059,010	19.10	20.76	1.66
Deposition to paddy	185,510,590	19.84	20.44	0.60
Open forest to settlement	245,748,670	17.96	20.03	2.07
Open forest to paddy	422,815,100	19.29	20.29	1.00
Settlement to waterlogged	40,744,084	21.24	21.05	−0.19
Paddy to waterlogged	107,567,890	20.98	20.93	−0.04
Paddy to settlement	591,793,150	19.30	21.10	1.80
Dense forest to water body	64,019,920	18.75	19.53	0.78

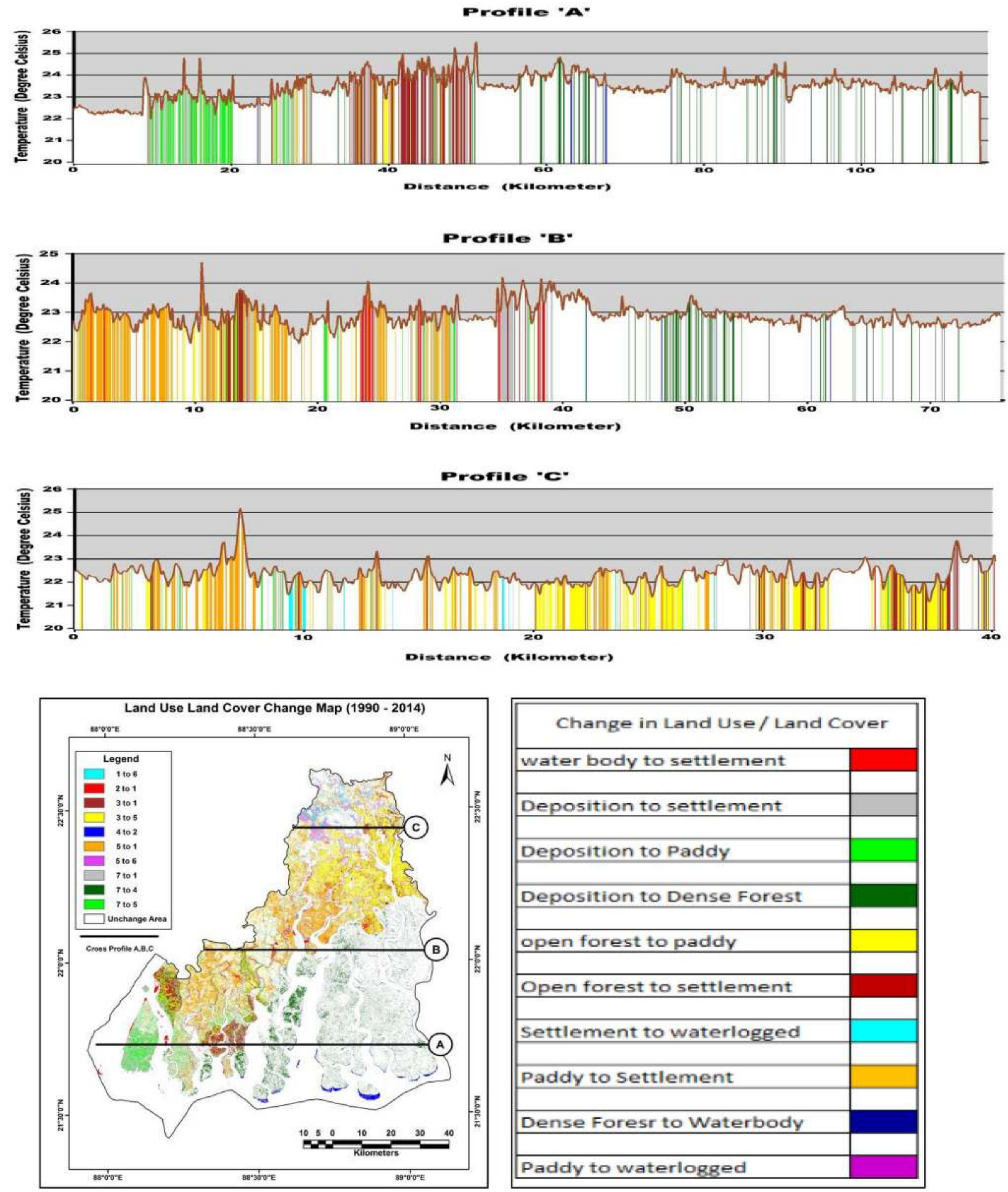

Fig. 7 The transect profile (*A*, *B* and *C*) were drawn for examining the relation of land surface temperature with land use land cover change. Transect profiles were drawn by overlying land use land cover change map on land surface temperature map (2014)

Conclusion

The study demonstrates drastic changes in land use land cover in the study area. Surface energy budget of the study experienced alteration considerably in response to large scale land use/land cover changes. One of the distinct changes was observed in the northern part of the reserve where unprecedented increase in seasonal waterlogged area was recorded due to high tidal water. Another important change was observed as the expansion of settlement due to exponential growth of population. The area under paddy has increased to feed the million mouths. While open forest, deposition and water body experienced decrease in their respective areas. The changes in land use/land cover modified the radiant surface temperature and consequently surface energy budget. These changes in land surface temperature were validated by transect profiles and land use change map drawn in three parts of the study area. These profiles revealed that the land surface temperature has increased in those areas which are transformed from open forest to paddy, open forest to settlement, paddy to settlement and deposition to settlement. Thus, increase in non-evaporating surfaces and decrease in vegetation has increased the land surface temperature of the study area. Hence land surface temperature acts an important function of land use/land cover and modifies the temperature of surrounding areas.

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