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Assessing Coastal Hazards and Climate Change Vulnerability in Sundarban Biosphere Reserve, West Bengal, India

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Abstract:
The Sundarban coastal region, in South Asia, is prone to cyclones, storms, erosion and storm surge flood. Coastal areas are the most productive and transitional areas between land and sea. In these areas the ecosystems are more vulnerable to climate change induced natural hazards like coastal inundation, storm surge, tsunamis, shoreline change, sea level rising, cyclone and typhoon etc. The concept of vulnerability is a holistic approach and it navigates across the ecological and socio-economic systems of a region. Ecological and socio-economic vulnerability of a region can effectively be assessed using multi-hazards events. To understand the ecological and socio-economic vulnerability to climate change of any region, it is essential to find out the intensity of climate change. This paper makes an attempt to analyze spatio-temporal weather and climate variability in Sundarban Biosphere Reserve.

Index Terms: **Coastal areas, ecology, vulnerability, climate change, NDVI.**

Introduction

Coastal areas are the most productive and transitional areas between land and sea. These ecosystems are more vulnerable to climate change induced natural hazards like coastal inundation, storm surge, tsunamis, shoreline change, sea level rising, cyclone and typhoon globally (Torresan et al., 2008; Nicholls and Cazenave, 2010). The Sundarban coastal region, in South Asia, is prone to cyclones, storms, erosion and storm surge flood (Chaudhuri AB, Choudhury A 1994). It is intensively affectedby extreme weather events among all the surrounding rims of Bay of Bengal (Chittibabu, 1999; Gonnert et al., 2001). Several geo-physical and geo-hydrological factors such as tidal drainage system, estuary, deltaic shape, shallow coastal water, tidal creeks, convergence of the bay, high astronomical tides and inlets have beenmain drivers of disastrous storm surges in Sundarban (Dube et al., 2009).

Recent studies have indicated that the South Asian countries including India are most vulnerable countries to climate change impact (Hijioka et al., 2014). India occupiesthird rank in global climate risk index of 2013 (Kreft et al., 2014) andits coastal zones are more prone to climate change impact. Climate variability and anthropogenic activities have posed serious threats to the biotic and abiotic communities of deltaic ecosystems of India (Das et al., 2004). The intensity of weather and climatic variability is higher than the global average inIndian Sundarban. Increase in temperature, rainfall, salinity intrusion, frequent cyclones, sea level rise, storm surge and coastal erosion are the major threats in the deltaic ecosystem of Sundarban coast. The Sundarban coast has experienced an increase in the average air temperature by 0.50°C over the past 100 years. If the present rate of increase continues, the average air temperate will be expected to rise by 1 °C by 2050 (Hazra et al., 2002). The rainfall during monsoon (–3.84 mm per year) and post monsoon rainfall (−4.42 mm per year) has decreased while the pre monsoon rainfall has increased (+0.98 mm per year) during last 40 years (Mandal et al., 2013). This indicates changes in weather conditions in the Indian Sundarban. Heavy rainfall during *Kharif*season and delayed monsoon are also frequent features in SBR (Mandal et al., 2015). Variability of air temperature, rainfall, potential evapotranspiration and frequencyof wet days was analyzed using 115 years climatic data.

The concept of vulnerability is a holistic approach and it navigates across the ecological and socio-economic systems of a region. Ecological and socio-economic vulnerability of a region can effectively be assessed using multi-hazards events. The concept of vulnerability has been addressed by academicians, scientists, environmentalists, ecologists, economists, social scientists and policy makers from different points of view. To understand the ecological and socio-economic vulnerability to climate change of any region, it is essential to find out the intensity of climate change. This paper makes an attempt to analyze spatio-temporal weather and climate variability in Sundarban Biosphere Reserve.

Study Area

Sundarban Biosphere Reserve (SBR) is located in the lower part of the Ganga- Brahmaputra and Meghna delta (Sharma et al. 2010). It spreads over 9,630 km^2 area and bounded by the Dampier Hodges line in the north, Bay of Bengal in the south. It covers South and North 24 Parganas districts of West Bengal stretching over 21^o 31′N and 22^o 30′N latitudes and 88^o 10′E and 89^o 51′E longitudes. Of the total islands in the Reserve, 48 islands are uninhabited covered by mangrove forest and 54 inhabited.

Cyclones and storm surge

Tropical cyclones of different intensities (63–120 km/h) are a regular and recurring phenomenon in the SBR during July and September almost every year. On the basis of the intensity and the time periods of occurrence of the tropical cyclones in the Bay of Bengal, thesecan be classified into two types: “cyclonic storms” with the wind speed between 63 and 87 km/h and “severe cyclones” with wind speed between 90 and 120 km/h. The historical records of the occurrence of cyclones in the study arearevealed that the cyclone which occurred in 1976 and the ‘Aila’ cyclone which occurred in 2009 were the most destructive cyclones during the periods 1891-2010. Historical data of 120 years was used for analyzing cyclonic storms, severe cyclones and storm surge height in the study area. The result revealed that the SBR has registered a 26% increase in tropical cyclones during last 120 years. The frequency of tropical cyclones has further increased during the last 10 years. The number of tropical cyclones making landfall on the different blocks of SBR and their return periods have been shown in Figure. Gosaba, Kultali, Patharpratima, Namkhana and Sagar were found to be the most severe cyclone affected blocks in SBR with less than 10 years return periods. The storm surge during the cyclone Aila (2009) reached inland up to 120 km. The blocks situated in the northern part of the SBR are less affected by the severe cyclones. The maximum surge height over 120 years return periods was found to be 15.6 meters in the study area. The surge height was recorded to be the maximum during the severe cyclones. Sagar, Gosaba, Namkhana, Patharpratima and Kultali blocks have recorded more than 12 meters surge height. The blocks situated in the northern part of the reserve have recorded less than 4 meters surge height during last 120 years (Figure 1).

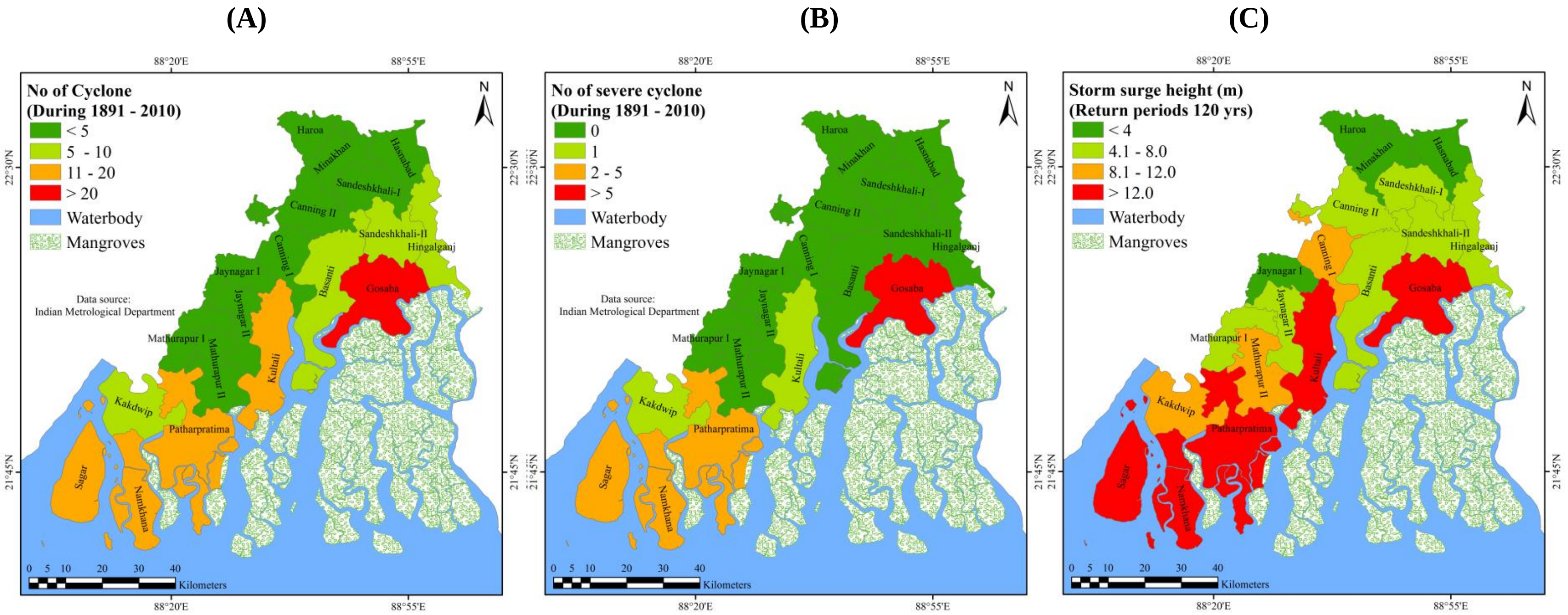


Figure 1: Number of cyclones (A), number of severe cyclones (B) and storm surge height (C) in SBR during 1891-2010.

Change in surface water quality

Salinity

The surface water salinity data during 1980-2015 of Sagar Island and Canning station were used to assess the trend of surface water salinity in SBR. The Sagar Island showed a significant declining rate of salinity for both the pre monsoon (0.076 psu) and post monsoon (0.050 psu) seasons (Figure 2) while the Canning station showed increasing trend in the surface water salinity for pre monsoon (0.21 psu) and post monsoon (0.28 psu) seasons during 1980-2015. This difference in the rate of change of salinity for Sagar and Canning stations is mainly due to their geographical location. Sagar is located in the western part of the Reserve and Canning station is located in eastern part. The rivers like *Hooghly and Muriganga*flow in the western part of Sundarban and receive the snow melt water from Himalayas. Sagar Island is experiencing a decline in salinity due to receding of Gangotri glacier over last three decades (Hasnain et al. 2002; Curry et al. 2003). An increasing trend in salinity (0.02 psu/decade) in Canning station was observed (Figure 2.10). The increase in salinity at this station is attributed to heavy siltation and solid waste disposal received from the city of Kolkata and the connected estuaries and channels. Intrusion of saline water from the adjacent Bay of Bengal is another reason for increased rate of salinity at this station. The increasing rate of salinity at this station is higher than the average increase rate of the Indian Ocean (IPCC 2007).The spatial distribution of surface water salinity is shown in the Figure 4a. The data for analyzing spatial distribution of salinity was collected throughfield survey and analyzed in the laboratory during 2018. The salinity map shows that salinity decreases with an increase in distance from the coastal tidal rivers. High salinity was observed in the lower part of the Reservecovered with the mangroves. *River Matla* is an important cause for high salinity in middle part of the Reserve. This finding is in accordance with the findings from the Department of Marine Science (1980-2015). High salinity patches are found in the inhabited islands of Hingalganj and Gosaba blocks due to flowing of tidal riversthrough these blocks. Salinity intrusion is one of the major threats to the mangroves.

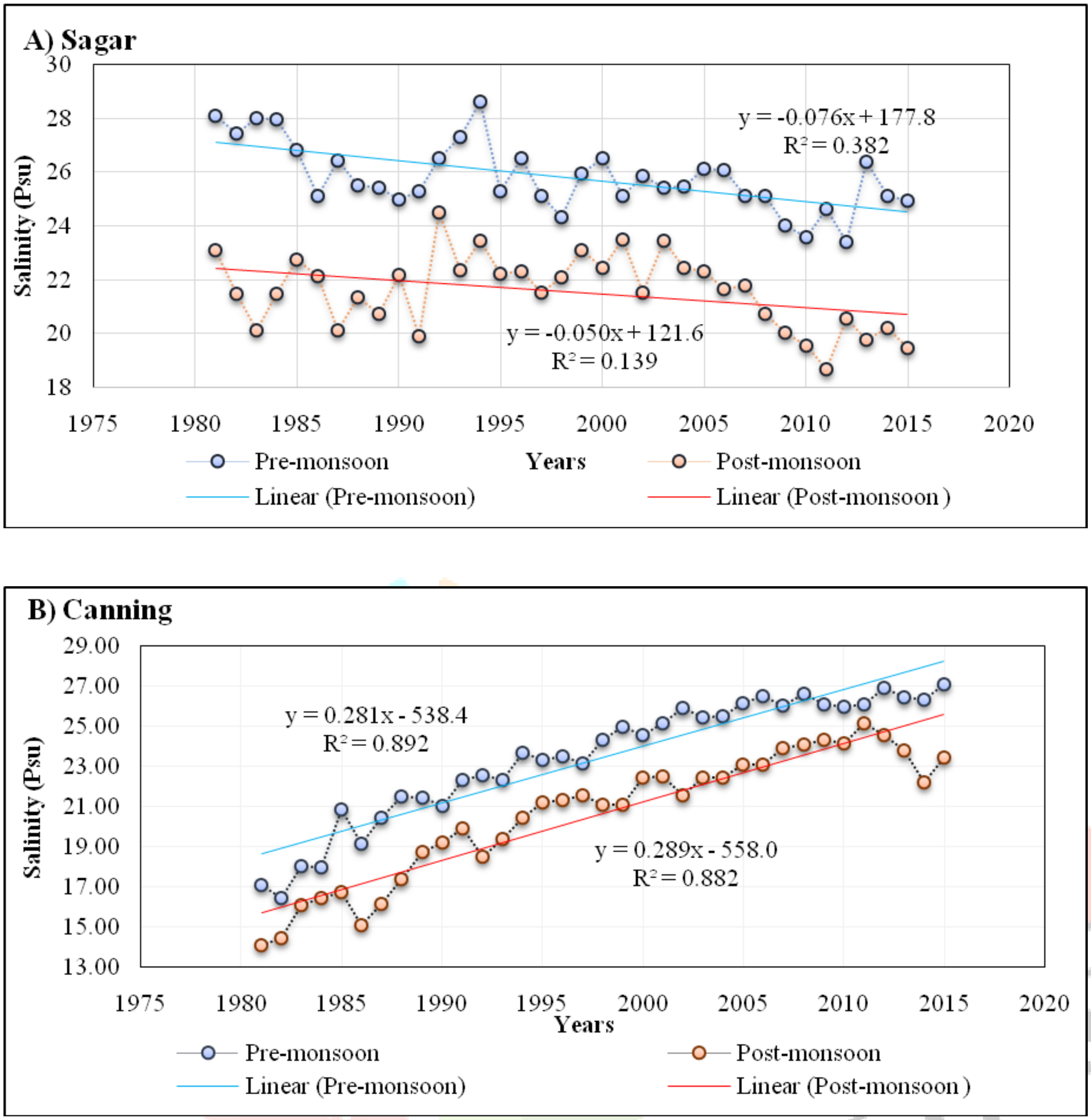


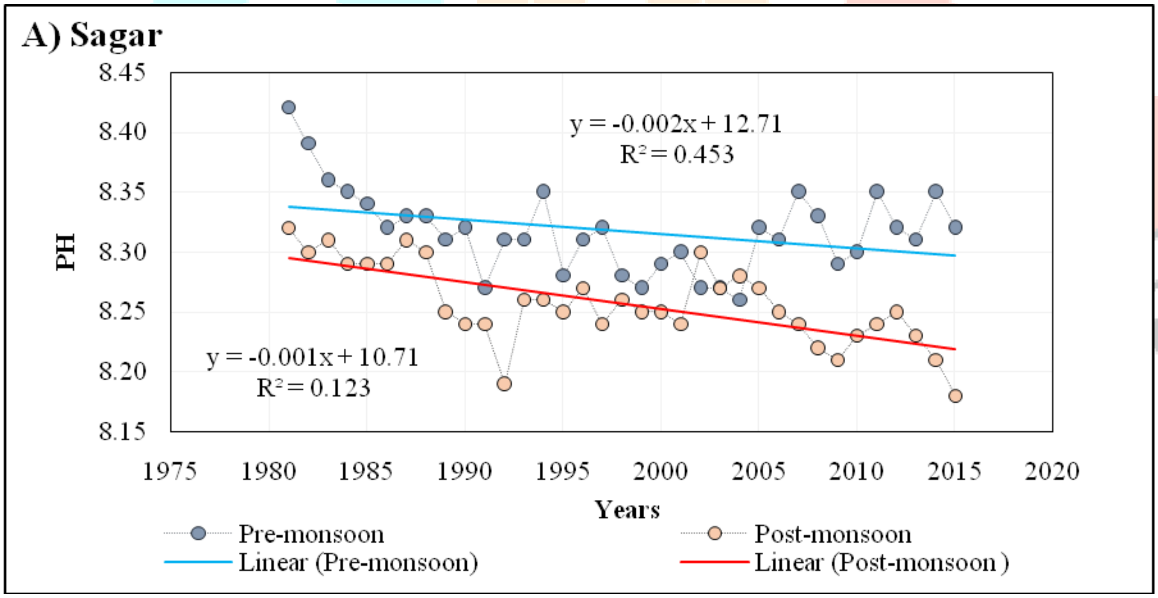
Figure 2: Trend of surface water salinity (Psu) for the station Sagar (A) and Canning (B) during 1980 and 2015

Surface water *pH*

Surface water pH of Sagar Island and Canning stations have shown decreasing trend during the last 30 years. The pH range in SBR (8.25–8.33) was found higher than the global average (8.179) for both the stations. Rate of decrease in surface water pH was higher in Sagar Island than Canning (Figure 3). Overall decrease in pH may be due to anthropogenic sources. The Sagar Island experienced continuous decrease in pHwhile Canning station has shown slight increase inpH during 2005-2015. The decrease of pH in Sagar Island could directly link with the waste martial in the Hooghly industrial areas.Spatial distribution map of surface water pHshows decreasing trend of pH towards land due to increase in alkalinity (Figure 4a).

Surface water temperature

The surface water temperature of Sagar and Canning stations in Sundarban Biosphere Reserve has shown significant rising trend for both pre monsoon and post monsoon seasons. The rate of increase in surface water temperature for Sagar Island wasdetermined as 0.048°C/year during pre-monsoon and 0.055°C/year during post monsoon seasons (Figure 4). Canning station experienced increase in surface water temperature at the rate of 0.04°C/year during pre-monsoon and 0.49°C/year during post monsoon seasons. The rate of increase in average surface water temperature (0.40°C/year) in SBR was found much higher than the world average (0.006°C/year). The spatial distribution of surface temperature revealed that the mangrove areas have less surfacewater temperature than the non-mangrove areas. Surface water temperature increased with the increase in the distance from the coast (Figure 4a).



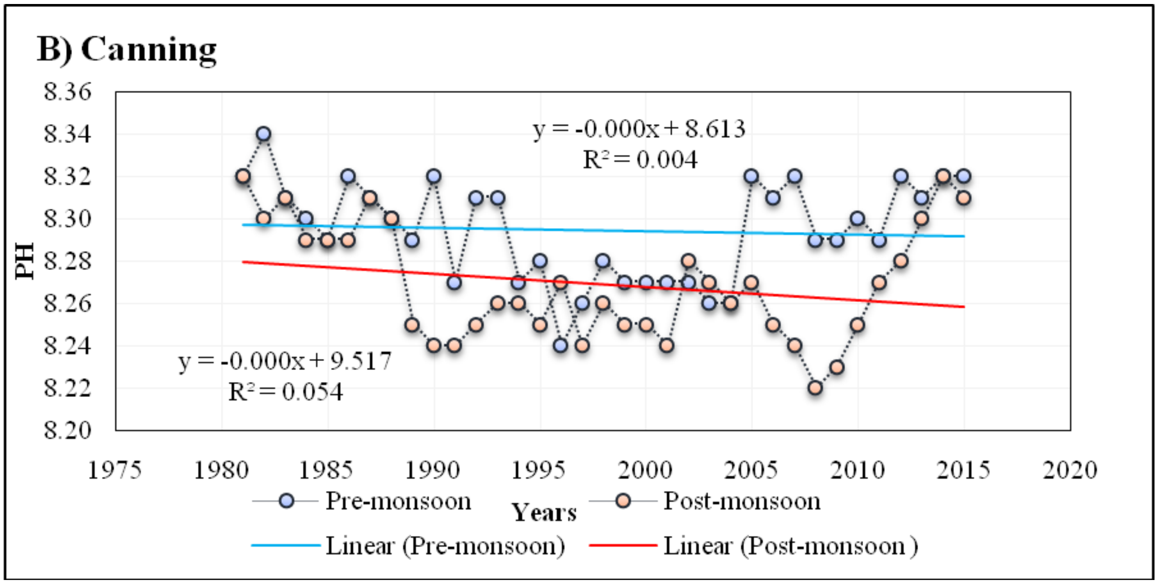
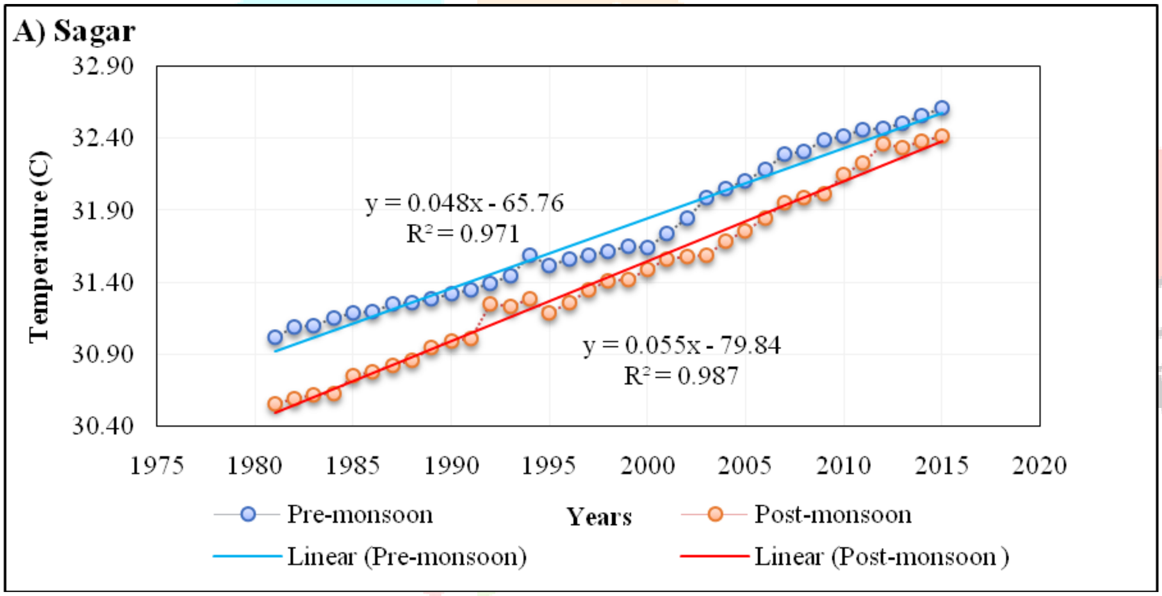


Figure 3: Trend of surface water pH for the station Sagar (A) and Canning (B) during 1980 and 2015



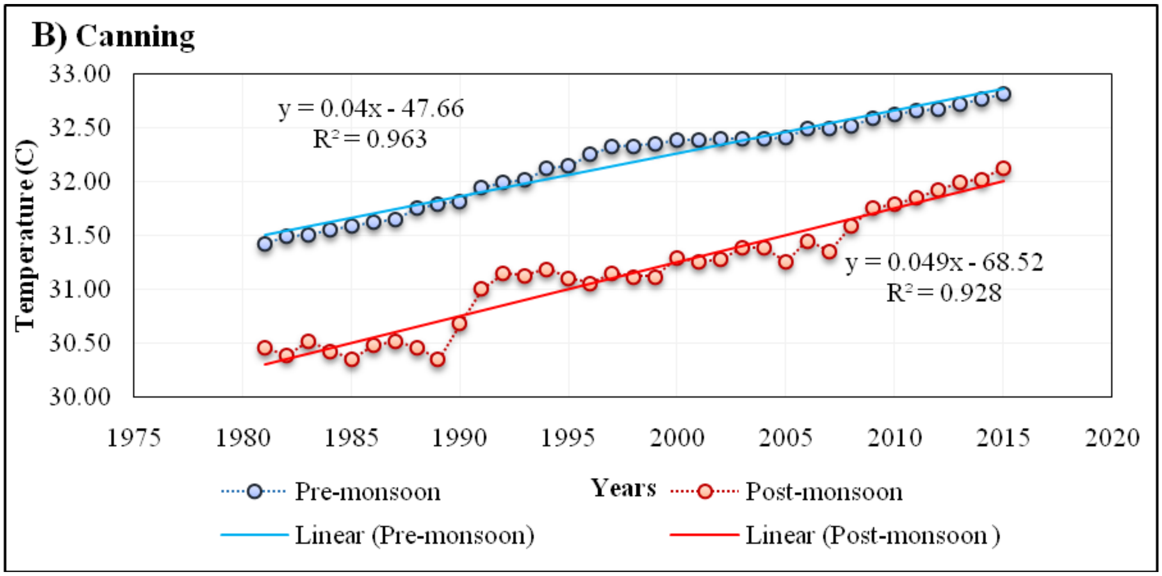


Figure 4: Trend of surface water temperature for the station Sagar (A) and Canning (B) during 1980 and 2015

Land surface temperature

Spatial distribution of LST was retrieved from Landsat images using mono-window algorithm for the month of January of 1990, 2000 and 2015 (Figure 5). LST frequency curves were drawn to analyze representative relation explicitly between temperature range and number of pixels (Figure 6). The main purpose of pixel to pixel analysis of LST was to assess the difference in spatial distribution of LST in Sundarban Biosphere Reserve. It is clearly evident that maximum pixels are concentrated between 20°C and 21°C temperature range during 1990 which represents the average as well as weightage concentration of surface temperature in this specific range. The LST range has increased from 21°C to 23°C in 2000 and from 22°C to 24°C in 2015. The upper limit of the temperature range increased by 2°C each in the year 2000 and 2015 indicating sharp increase in pixel-wise surface temperature. Area under coastal creeks, cultivated land and mangroves exhibited low LST (i.e., below 28°C) in 1990. With continuing increase in surface temperature range the whole range of pixel concentration positively shifted enormously to 22°C - 24°C temperature range in 2015 (Figure 6). Dispersed patches under water-bodies and mangroves recorded comparatively low LST. The average surface temperature of the study area has increased at the rate of 0.54°C per decade. Vegetation showed a considerably low radiant temperature in both years because vegetation can reduce amount of heat stored in the soil and surface through transpiration. Surface temperature of water was low compared with other classes but the increasing rate was high because the date of the data acquisition was January and the radiance reflected from the water body was lower than that from other objects in winter season.

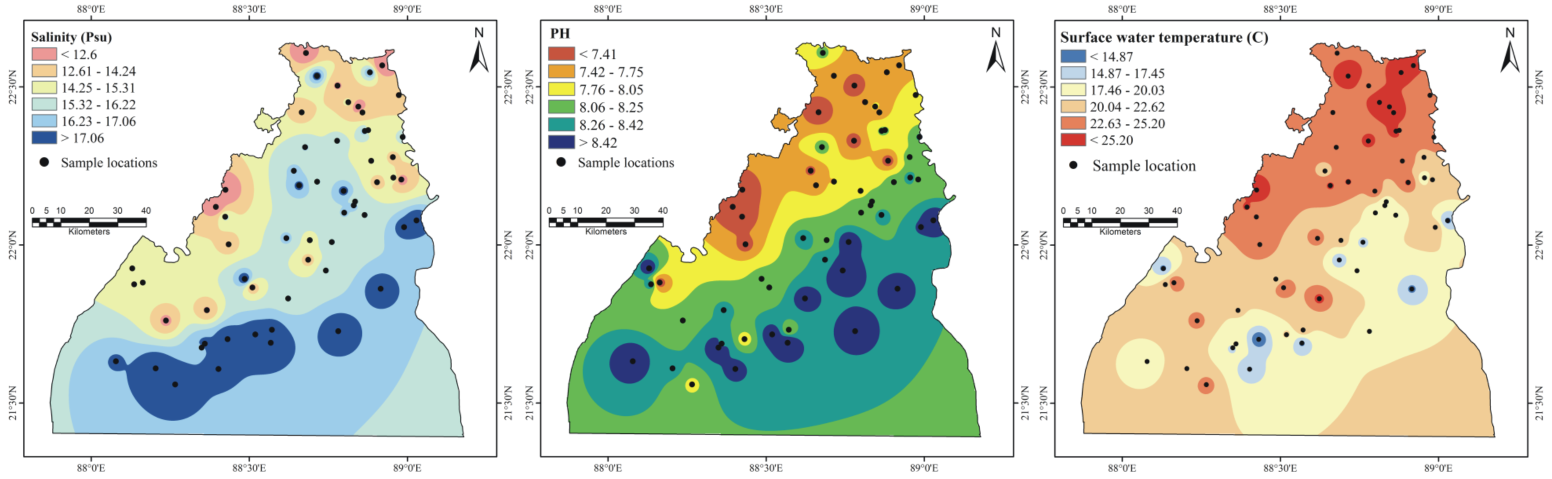


Figure 4a: Spatial distribution of salinity, pH and surface water temperature in SBR during January 2018

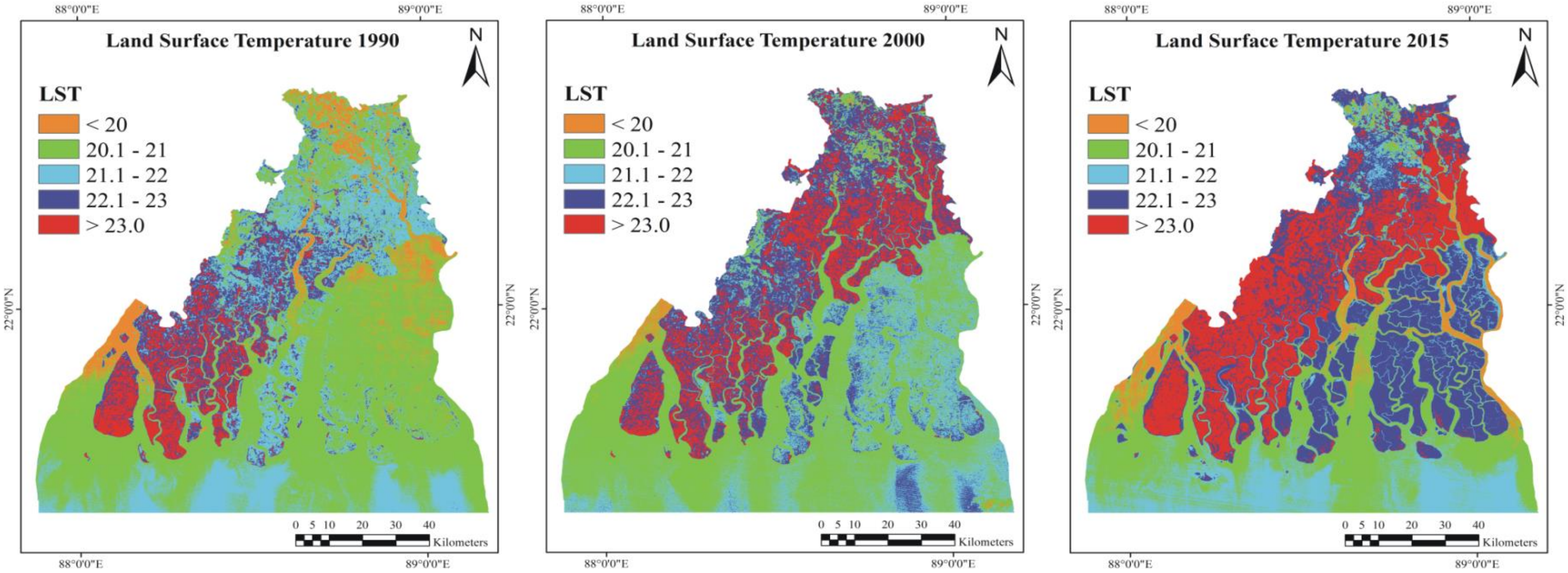


Figure 5 : Spatial distribution of LST in SBR during 1990, 2000 and 2015

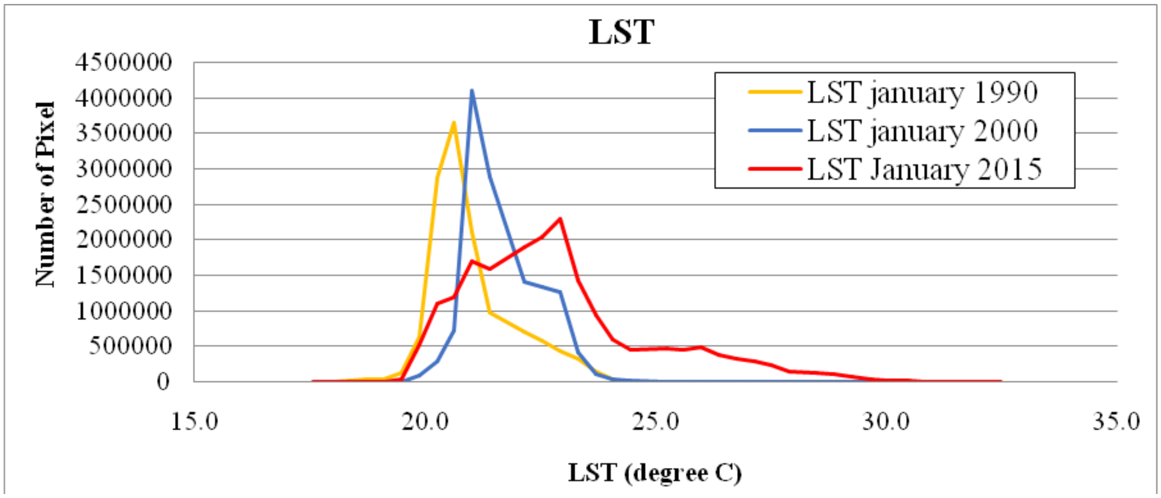
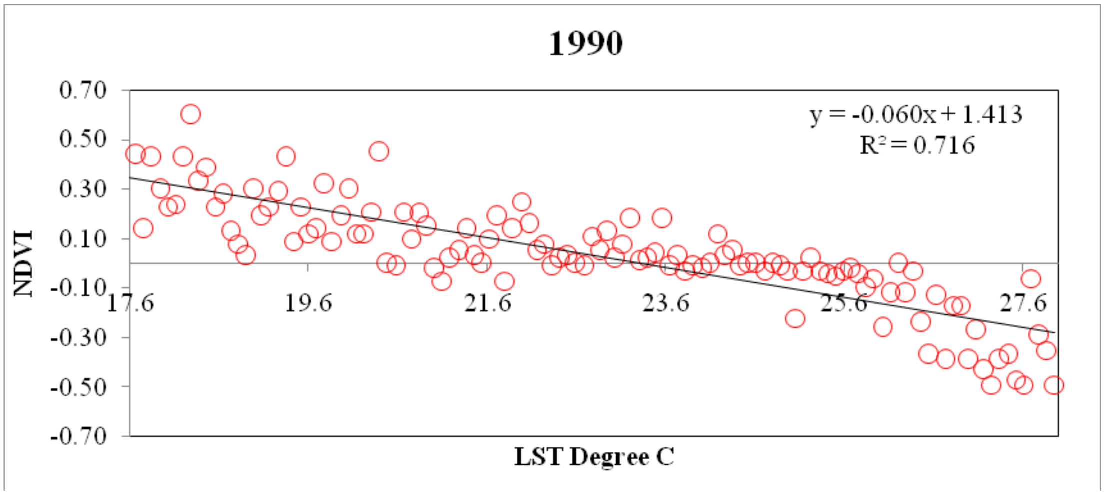


Figure 6 : Land surface temperature of January in SBR during 1990, 2000 and 2015

Spatial Relation of LST with NDVI, NDMI, MNDWI

The NDVI values of the pixel vary between -1 to +1. The highest values of NDVI (more than 0.3) indicated the healthy vegetation. NDVI range (-0.59 and +0.68) during 1990 gradually reduced to (-0.16 and 0.41) during 2015. This is indicative of the decrease of mangrovesin Sundarban Biosphere Reserve over the years. The mangrove forest area has shown an enormous increase in LST indicating decrease of density of mangrove forest. A negative trend was found between LST and NDVI values form the linear regression analysis (Figure 7). Higher NDVI values (vegetation) have shown low surface temperature and low NDVI values have shown high LST. The linear correlation analysis of LST and NDVI revealed decline of vegetative surface in the study region. The maximum increase in LST was recorded between 0.2 and 0.3 NDVI range as LST increased from 20^{o} C to 24^{o} C during 1990-2015. No remarkable changes were observed in LST in water body (NDVI values < 0).



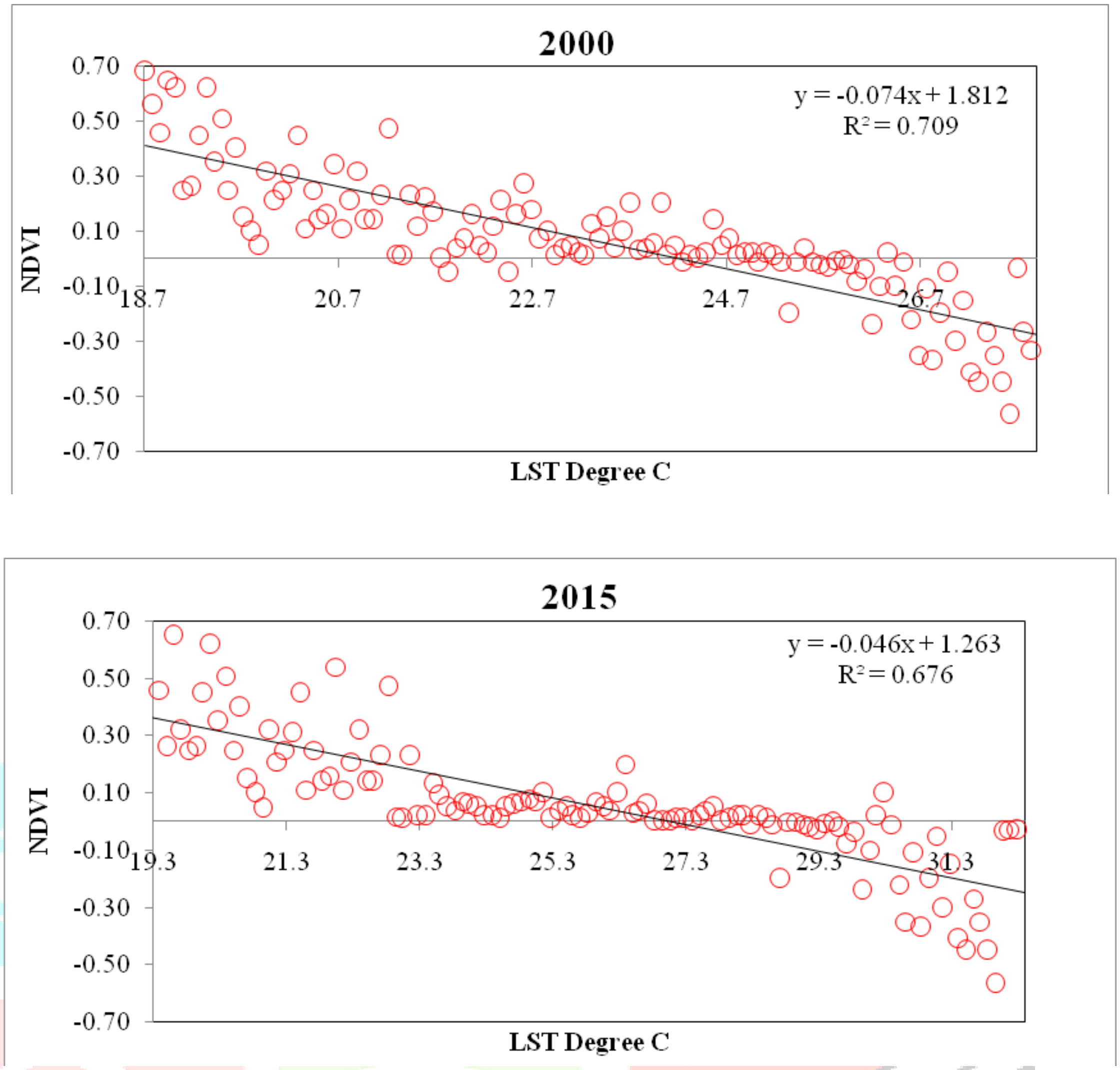
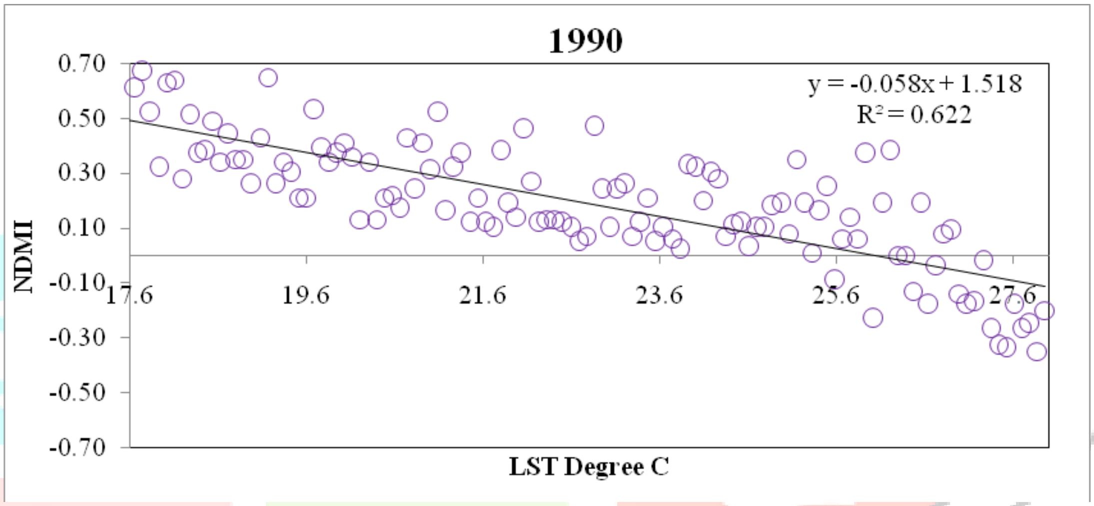
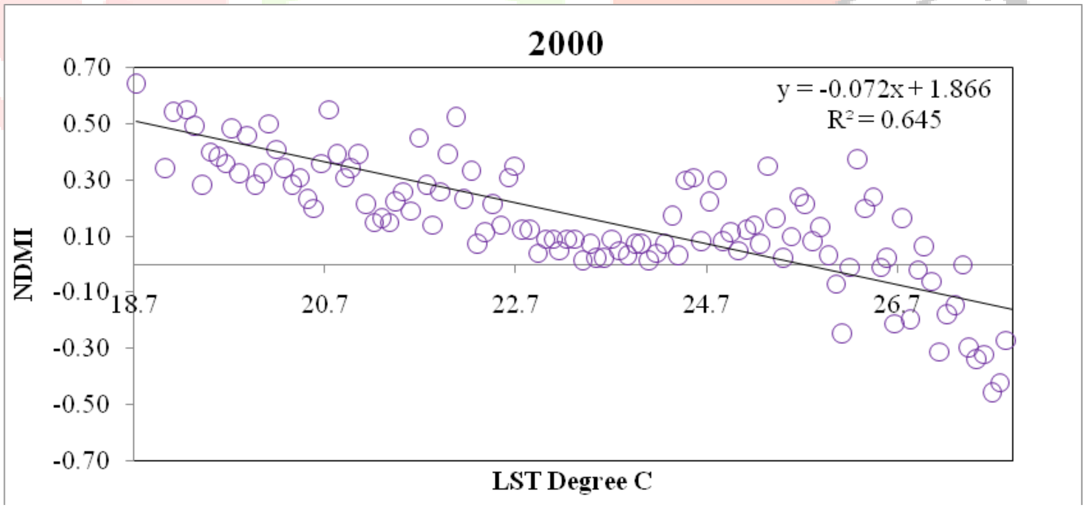


Figure 7 : Relationship between LST and NDVI

High humid water body and wetlands are represented by NDMI values (more than 0.5). The values lying between 0-0.5 represent vegetation cover and another pervious surface. NDMI values between 0 and 0.30 indicate low humid areas and values below 0 represent the impervious surface. It is evident from Figure 8 that the high moisture is concentrated in the south eastern part of the Reserve where mostly dense mangrove forest is found as well as in the eastern and south eastern parts predominated by vast wetlands and coastal creeks. Decreasing pattern of LST was observed with increasing values of NDMI. LST has increased from 32°C to 38° C in the low humid areas during 1990-2015 and from 22° C to 27° C in high humid areas during 1990-2015. The LST has increased from 35° C to 41° C in low humid areas and from 23° C to 29° C in high humid areas in the month of June while it has increased from 31° C to 39° C in low humid areas and from 25° C to 31° C in high humid areas. Fluctuation of year-wise curves especially in the NDMI zone (-0.15 to -0.50) is worth mentioning (Figure 8). Variation in three curves (e.g., 1990, 2000 and 2015) clearly indicates the moisture content in air adjoining the surface under different land use/land cover.

The values of MNDWI close to -1 indicate high water content and the values close to +1 indicate impervious surface. Coastal rivers, braded channel, creeks mostly influenced the surface temperature of the land areas. The areas adjoining the creeks and channels are characterized with low LST due to influence of water-content (Figure 9).





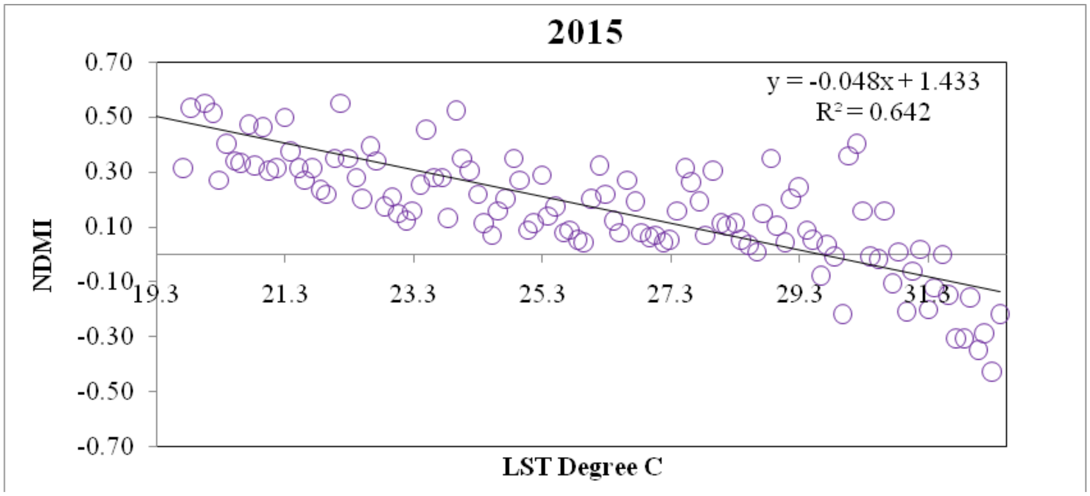
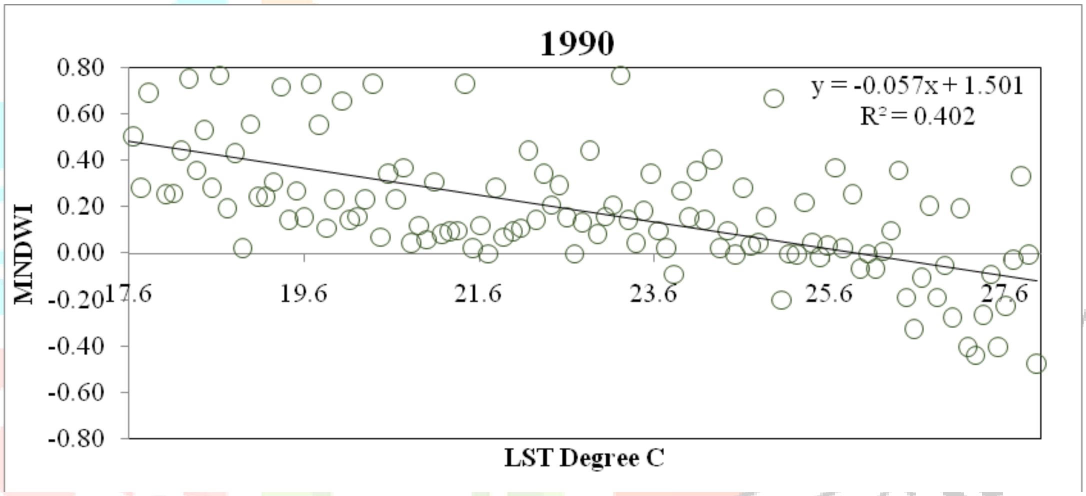
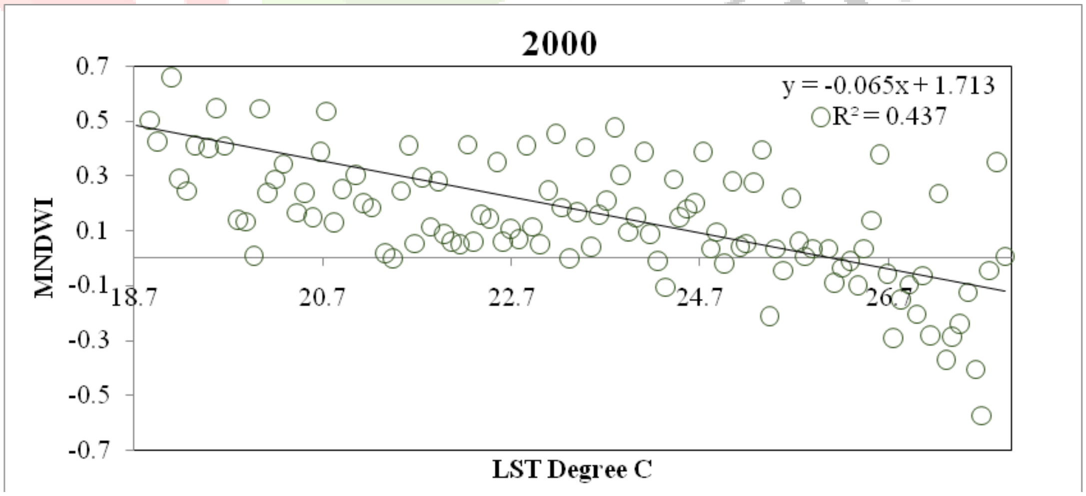


Figure 8 : Relationships between LST and NDMI





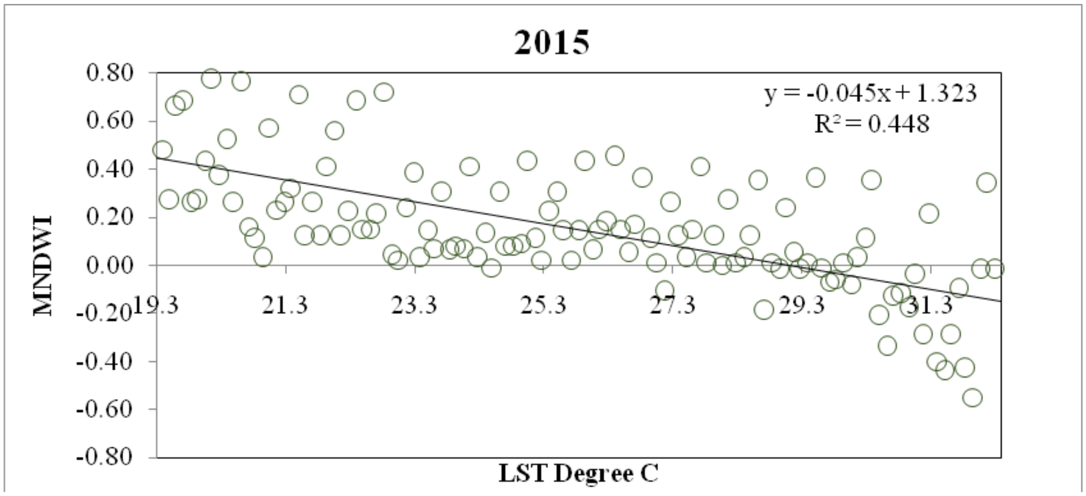


Figure 9: Relationship between LST and MNDWI

Land surface temperature was found sensitive to vegetation, soil moisture, water bodies, wetlands and coastal environment with the continuous decrease of vegetation cover over the study period. Decrease in the values of NDVI during 1990-2015 indicated significant decrease in the vegetation cover and mangrove forest. Decrease in the values of MNDWI and NDMI also influenced the surface water and moisture content of the study area. The southern part of the study area which comprises vegetation cover witnessed LST below 22°C. The area under coastal creeks and wetlands has shown high MNDWI values (>0.5) and high NDMI values (>0.4) experienced low surface temperature. Hence, it is likely that LST will increase in the northern and south western parts of the study areas in future due to the influence of anthropogenic activities.

Conclusion

The present study is an attempt to analyze the Coastal hazards and Climate Change vulnerability in Sundarban Biosphere Reserve, India using geospatial techniques. Sundarban Biosphere Reserve has constantly been under threat due to storms surge flood, cyclones, salinity intrusion, seal level rise, land subsidence, water-logging and coastal erosion. The main conclusion arises from the forgoing analysis is that climate change induced multi hazards events have created large scale ecological degradation in Sundarban Biosphere Researve. The socio-economic vulnerability of the community in this region has increased due to the multi hazards events and climate change.

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