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SHORT NOTE

Disappearance of the New Moore Island from the Southernmost Coastal Fringe of the Sundarban Delta - A Case Study

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Abstract Loss of two small estuarine islands, Lohachara and Suparibhanga has been reported earlier from the Indian Sundarban lying adjacent to the northern Bay of Bengal. The present paper reports the loss of another offshore island, New Moore, popularly known as Purbasha at the border of India and Bangladesh. The island came into existence after a cyclone in 1970. This study reveals the loss of New Moore Island within the time period of 1985 to 2000 from the analysis of multi-temporal satellite images. The rate of erosion, of two other offshore islands, Jambu Dwip (0.187 sq. km $yr.^{-1}$) and Maya Dwip (0.508 sq. km $yr.^{-1}$) situated along the same latitude of New Moore, were also estimated within the same time period. A close relationship was observed between the rate of erosion of small islands and the rate of rising sea level in this region as measured from the tide data at the Sagar Island and other observatories during the study period. The sea surface temperature analysis from the year 1990 to 1998 showed a slight increase (~ 0.8 °C increase), indicating the thermal expansion of the sea surface. Moreover, the sea surface height analyzed during the period 1993–2000 using satellite altimeter data of TOPEX/POSEIDON revealed a steady increase of 1.23 cm $yr.^{-1}$ sea level acceleration.

Keywords New Moore Island · Sundarban · Delta erosion · Sea level rise

Introduction

Based on several scientific evidences it has been clearly established that the incessant anthropogenic emission of greenhouse gases are having a discernible effect on the earth's climate (Houghton et al. 1996). Along with many other consequences of such human induced climate change, the rise in global mean sea level is expected to intensify in the twenty-first century (Warrick et al. 1996). Unfortunately human settlements throughout the globe is much more concentrated in the coastal zones and the population within 30 km from coastline tends to increase twice the rate of global population (WCC'93 1994). Due to such a scenario, rising sea level and the corresponding loss of land mass in the coastal peripheries has currently become a matter of concern (Bijlsma et al. 1996).

Sundarban, in this regard, is one the most vulnerable and adversely affected coastal terrains of the world. It is the world's largest single continuous stretch of mangrove forest located along the coast of northern Bay of Bengal. At present the Sundarban mangrove forest is shared between the neighbouring countries, India (40 %) and Bangladesh (60 %). It supports a very rich and diverse flora and fauna. Moreover, it plays an important role in the local and national economy (Islam and Gnauck 2009). Ecologically, this forest reserve is very important for the region as it acts as a barrier against damages by cyclones and soil erosion (Mahmud and Barbier 2010). Sundarban has been increasingly threatened in recent years by intense human interventions and natural hazards (Mahmud and Barbier 2010). In the last two decades, parts of Sundarban in Bangladesh have also experienced

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cyclones of increased frequency and severity, probably due to global climate change (Dasgupta et al. 2009). Already several dense human settlements have been hard hit by cyclones like Sidr (in the year 2007) and Aila (in the year 2009). In near future, climate change along with the subsidence of the delta together is expected to bring forth more devastation upon the local people of these regions (O'Donnell and Wodon 2015). Sundarban is one of the world's vulnerable geographical regions having a population density of more than 1100 person per square kilometre. Loss of habitat along with destruction of settlements have displaced thousands of climatic or environmental refugees and forced them to migrate in the recent past (Hazra et al. 2002; Bose 2009).

It is evident that mangrove forests have reduced at substantial level towards the north of deltaic parts (Giri et al. 2007). Toward the sea, the mangrove forest cover is also changing in different islands of Sundarban area (namely Nayachara, Ghoramara, Sagar, New Moore) owing to the changing dynamics of Bay of Bengal. Several river channels (Matla, Bidyadhari, Raimangal, Saptamukhi, Muriganga and Hooghly) criss-crossed the Sundarban delta. They play a major role in accretion as well as erosion dynamics of this deltaic estuary.

Deltaic erosion is dominant in various islands in the Sundarban region. Morphological changes were seen in the Ghoramara islands between 1967 and 1995 (Ghosh and Sengupta 1997; Ghosh et al. 2003). The area of the island in 1967 and 1995 were measured from Survey of India toposheet and IRS 1B LISS II data respectively, and a substantial decrease in area was observed. Extensive erosion was found in the western part and deposition occurred in the eastern part and a net loss of 3.19 km^2 island area was observed within 28 years. Sagar Island is also undergoing erosion and its morphology is changing. In the eastern and western part, the island is facing erosion while the southern part is accreting (Ghosh et al. 2003). It was found that within 1989 to 1995 the island has experienced 3.88 km^2 of area loss. The annual rate of erosion in the shoreline was estimated 4.54 m $yr.^{-1}$ in 1995 and it increased to 18.75 m $yr.^{-1}$ in 1999 which resulted in a net areal loss of 33.62 km^2 in 30 years (1969–1999). Previous studies also indicated a total loss of ≈163 km^2 estuarine island area due to the rising sea level (at the rate of 3.14 mm $yr.^{-1}$) within the time span of thirty years (Hazra et al. 2002). The New Moore Island emerged in the estuary of the River Harinbhanga and River Raimangal (21° 36′ 20″ to 21 ° 36′ 30.1″ N, 89 ° 08′ 1.21″ to 89 ° 09′ 15.63″ E, 1975), most probably after the cyclone and tidal bore that took place in the year 1970. It was a new terrain, rising initially as a low-tide elevation (Keesing's Contemporary Archives 1981). The Indian authorities named this island New Moore and claim to have notified the British Admiralty about its location in 1971 (Rahman 1984).

Loss of two small estuarine islands, Lohachara and Suparibhanga was reported earlier from the Indian Sundarban, northern Bay of Bengal (Hazra et al. 2002; Raha et al. 2014). The present paper reports the loss of another offshore island, New Moore, from this deltaic region during the time period of 1985 to 2000 by analyzing several multi-temporal satellite images. The rate of erosion, of two other offshore islands Jambu Dwip and Maya Dwip situated along the same latitude of New Moore, has also been studied.

Materials and Methods

Study Area

The mangrove forest of Indian Sundarban lies between 21° 32 and 22° 40 N latitudes and between 88° 05 and 89° E longitudes comprising at present an area of ~9630 km^2 out of which ~4,264 km^2 is under the arena of reserve forest. It extends up to the Bay of Bengal towards south and stretches up to the Dampier-Hodges line (the line demarcating the limit of Sundarban towards main land mass) in the north. It is a part of the largest delta on the globe situated in the estuarine phase of River Ganges and having a unique bio-climatic zone in the land–ocean boundary of the Bay of Bengal. This region is known to be a "well-mixed" meso-macro tidal estuary characterized by an intense semidiurnal tide (2.5–7 m) having mean current velocities varying between 117 and 108 cm s^{-1} during low and high tide, respectively (De et al. 2011). The climate in this area is generally distinguished as pre-monsoon (February–May), monsoon (June–September) and post-monsoon (October–January) season respectively. Almost 70–80 % of the annual rainfall occurs during the summer monsoon which leads to high river discharge (ranging between 2,952 and 11,897 m^3 s^{-1}) and it generally declines steadily during non-monsoonal months (varying from 900 to 1,500 m^3 s^{-1}) (Mukhopadhyay et al. 2006).

The present study is focused on the New Moore Island popularly known as Purbasha situated at the border of India and Bangladesh (Fig. 1). The rate of erosion of two other offshore islands namely Jambu Dwip and Maya Dwip situated along the same latitude of New Moore, were also estimated within the same time period.

Images and Data Used

In the present study, five satellite imageries were taken into consideration over the 25 years time period (1975–2010). The

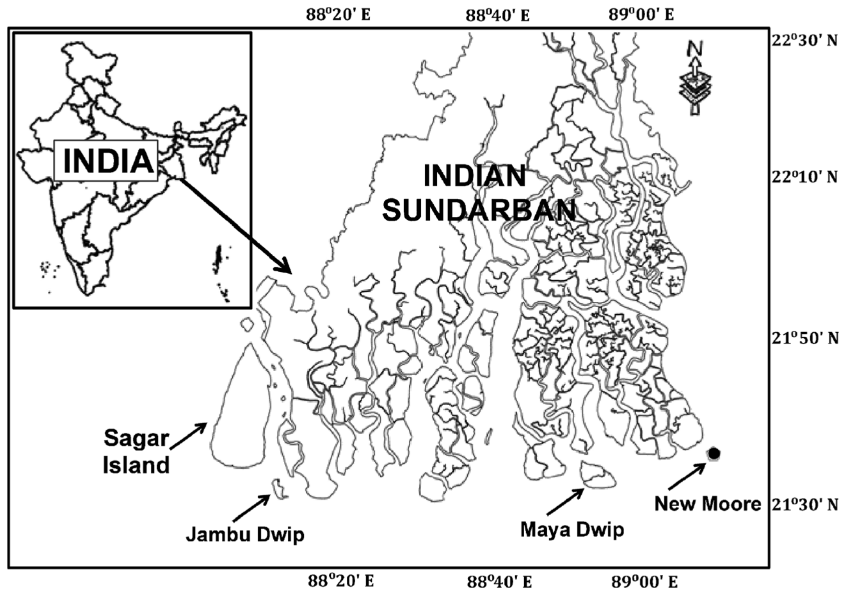

Fig. 1 The study area showing the locations of the New Moore Island, Jambu Dwip and Maya Dwip

datasets were acquired from the USGS website http://glovis.usgs.gov. Multi resolution satellite data such as Landsat MSS and Landsat TM-5 were used in this study because of the unavailability of same resolution imagery over the chosen period. The details of the satellite imagery, acquisition details and resolution are given in the Table 1. Various other data were used in this study for the analysis of sea surface temperature (SST), tide height and sea surface topography. The details of the ancillary data set are given in the Table 2.

Satellite Data Processing

The multi-temporal satellite imageries (for the year 1975, 1989, 1998, 2000 and 2010) were utilized to identify the morphological change. Landsat MSS image of 1975 (spatial resolution 60 m) was re-sampled to 30 m to match the spatial resolution of Landsat TM-5 imagery for area change detection. All the data sets were projected in UTM projection with zone no. 44 and WGS 84 datum.

Measurement of SST and Sea Surface Height (SSH) Variation from Satellite Data

The variability of SST in the Bay of Bengal was analysed for 9 years time span (1990 1998) from NOAA AVHRR satellite SST product data sets. The mean monthly surface temperature data sets (NOAA–17) were taken and annual mean SST was calculated and plotted. A trend line was fitted in order to identify the short term trend of SST of Bay of Bengal.

In order to measure the regional mean sea level, the satellite altimeter data of TOPEX (NASA-built Nadir Pointing Radar Altimeter which use 5.3 GHz frequency C band and 13.6 GHz frequency Ku band) and POSEIDON (CNES-built solid state Nadir Pointing Radar Altimeter using Ku band with 13.65 GHz frequency) were analyzed from the year 1992 to 2000. In this study a 25 × 25 km area lying 50 km south of Sagar Island was taken as a sample station. Inverted barometer correction was applied to improve the data quality.

Estimation of Islands Erosion

The extent of erosion in the Islands of Jambu Dwip and Maya Dwip has been estimated from the multi-temporal satellite data for the period of 1975–1990, 1990–2000 and 2000–2010 using binary change detection approach. The images were classified into 1 bit classified image (two classes: land and water) using the ISODATA classification. The multi-temporal classified images were combined to extract the pixels of the eroded areas. Finally, the eroded pixels were multiplied with spatial resolution of the images to calculate the total eroded area.

Table 1 Details of satellite data, date of acquisition and resolution

Satellite and Sensor	Date of acquisition	Band used	Spatial resolution
Landsat MSS	05-Dec.-1975	Visible and near infrared band	60 m
Landsat TM	03-Jan.-1989, 24-Aug.-1992, 24-Apr.-1998, 07-Nov.-2000 and 07-Nov.-2000	Visible and near infrared band	30 m

Table 2 Details of ancillary data, source and usage

Data description	Source	Usage
Sea surface height (SSH)	Satellite altimeter data of TOPEX (NASA)	Measurement of regional mean sea level using Nadir pointing Radar Altimeter
Sea surface temperature (SST)	NOAA AVHRR satellite data of 1990 to 1998	Annual mean sea surface temperature analysis of 1990–1998
Tide height	Tide gauge measurement. Station: Sagar Island, India and Hiron Point, Bangladesh observatory	Measurement of tide height during the satellite over pass to observe the inundation of island area
Surface air temperature data	Sandhead observatory	Measurement of surface air temperature anomaly from 1965 to 2000
Rainfall data	Indian Meteorological Department (IMD)	Variation in annual and Monsoon rainfall from 1990 to 1999 in 24 Pgs. South

Results and Discussion

From the Landsat MSS data of 5th December 1975 (Fig. 2a), the total island area of New Moore above the high tide level (local time of satellite overpass was around 10:00 am, tide level 4.13 m) was estimated to be 1.30 sq. km. The island had a crescent shaped opening to the north and sandy beaches to the south facing the Bay of Bengal. There were some mangrove vegetations on the fringe of the beach and on the tidal flat. It was reported that the island grew in size during the late 70s. However, according to the Landsat TM image of the year 1989 (Fig. 2b), the total island area during mid tide (tide level: 2.45 m) was found to be less than 1 sq. km. This indicates that the island started losing its area before 1989. During the 90s, the island could be found as almost submerged during mid to high tide time. This can be confirmed by the satellite data of 24th August 1992 (tide level: 3.06 m) and 24th April 1998 (tide level: 3.88 m) (Fig. 2c & 2d). In the satellite image of the year 2000 (tide level: 2.74 m) the island appeared to be completely submerged (Fig. 2e). It could not be traced in any imagery (5th February 2010) of subsequent times (Fig. 2f).

Two other small islands Jambu Dwip (21° 34′ 17.5″ N, 88° 10′ 59″ E) and Maya Dwip (21° 34′ 21.47″ N, 88° 51′ 40.44″ E) located in western and central part of Sundarban were subjected to severe coastal erosion during the year 1975 to 2010. According to the change detection analysis of satellite imagery, total land loss in Jambu Dwip and Maya Dwip were estimated to be 4.67 sq. km. and 12.75 sq. km. respectively during the time span 1975–2000. During the year 2000–2010 the land loss was 2.15 sq. km. and 5.63 sq. km. respectively (Fig. 3). The rate of erosion during the period 1975 to 2002 was found to increase from the west (0.187 sq. km $yr.^{-1}$ at Jambu Dwip) to the east (0.508 sq. km $yr.^{-1}$ at Maya Dwip). This appears to be sufficient for a small island like New Moore east of Maya Dwip to be completely washed off by the sea.

Apart from the factors like rate of sediment supply, size and shape of the islands, globally, the major driver of coastal erosion is considered to be sea level rise, especially the amplitude of regional changes in sea level (Nicholls and Cazenave 2010). Hazra et al. (2002) observed a relative sea level rise of 3.14 mm $yr.^{-1}$ in the western Sundarban near Sagar Island, while Singh (2001) in the same time observed

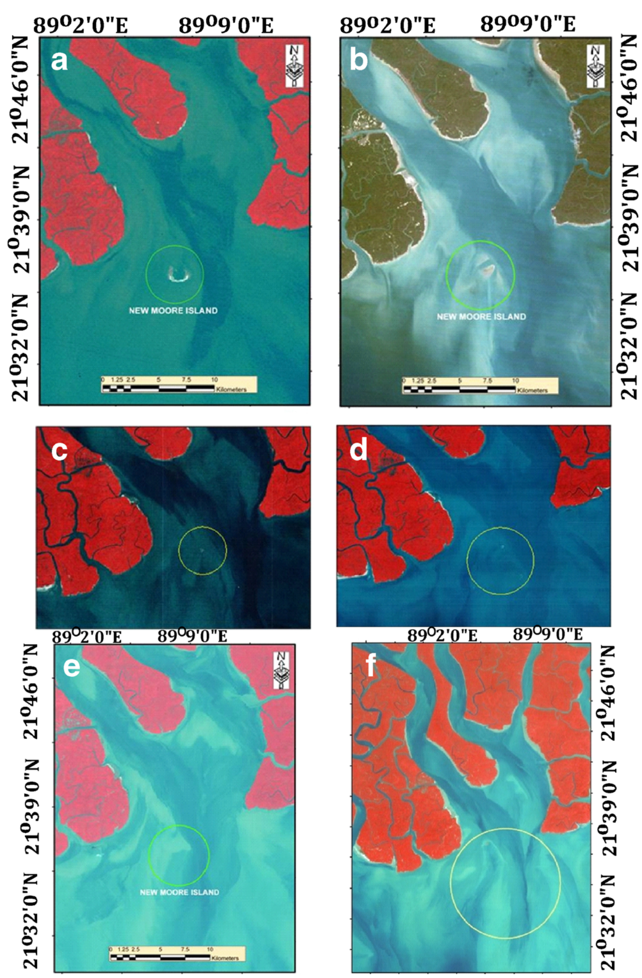

Fig. 2 The satellite images of the New Moore Island on **a** 5th December, 1975, **b** 3rd January, 1989, **c** 24th August, 1992, **d** 24th April, 1998, **e** 17th November, 2000 and **f** 15th February 2010

an accelerating rate in SLR of 4 mm yr.$^{-1}$ at Hiron Point and 6 mm yr.$^{-1}$ at Char Changa lying further east towards Bangladesh. Thus, a close relationship is observed between the rising relative sea level and the rising rate of coastal erosion, when one moves from west to east, across the Sundarban delta up to the swatch of no ground. These rates of relative sea level rise are much higher than the global estimate of 1.3 to 2.3 mm yr.$^{-1}$ over the years 1961 to 2003, or even 2.4 to 3.8 mm yr.$^{-1}$ over the years 1993 to 2003 (IPCC 2007). The tide level at the Hiron point (21.783° N, 89.466° E) during the period 1990–2000 was analysed and a significantly increasing trend was observed.

Another important aspect of the sea level rising is the thermal expansion of sea water (IPCC 2007). Thermal expansion is the increase in volume or decrease in density of sea water as a result of increased temperature. It was observed since 1960 that 25 % of the increase in sea level was due to global warming, which in turn caused thermal expansion of the oceans (Levitus et al. 2009). Based on the ocean temperature data acquired during the past decades it could be ascertained that ocean thermal expansion has significantly increased during the second half of the 20th century (Domingues et al. 2008; Cazenave and Llovel 2010). The annual mean SST of the Bay of Bengal during the years 1990 to 1998 was analyzed. The annual mean SST of 1998 was ~0.8 °C higher than that of 1990. This observation further justifies the possibility of increasing SSH.

The SSH was analyzed using satellite altimeter data of TOPEX/POSEIDON which showed a steady increase during the period 1993 to 2000. It has been calculated that SSH acceleration at the rate of 1.23 cm yr.$^{-1}$ took place in the sample station between 1993 and 2000. For low lying (slope around 0.5°) coastal plains like Sundarban, 1 cm rise in SSH can induce 1 m coastal retreat. Thus a 5 cm rise (in 15 years) may induce 5 m coastal retreat, which can be sufficient to cause New Moore Island to vanish from the map. However, the average magnitude of coastal erosion in the Jambu Dwip and Maya Dwip is considerably higher because of episodic erosion by storm, tidal surges and wave action.

Conclusions

Based on the facts assembled above it could be concluded that the land-ocean boundary of Sundarban facing the Bay of Bengal is undergoing incessant erosion and the eastern part is more vulnerable. Along with the earlier reported loss of Lohachara and Suparibhanga Islands, another Island named

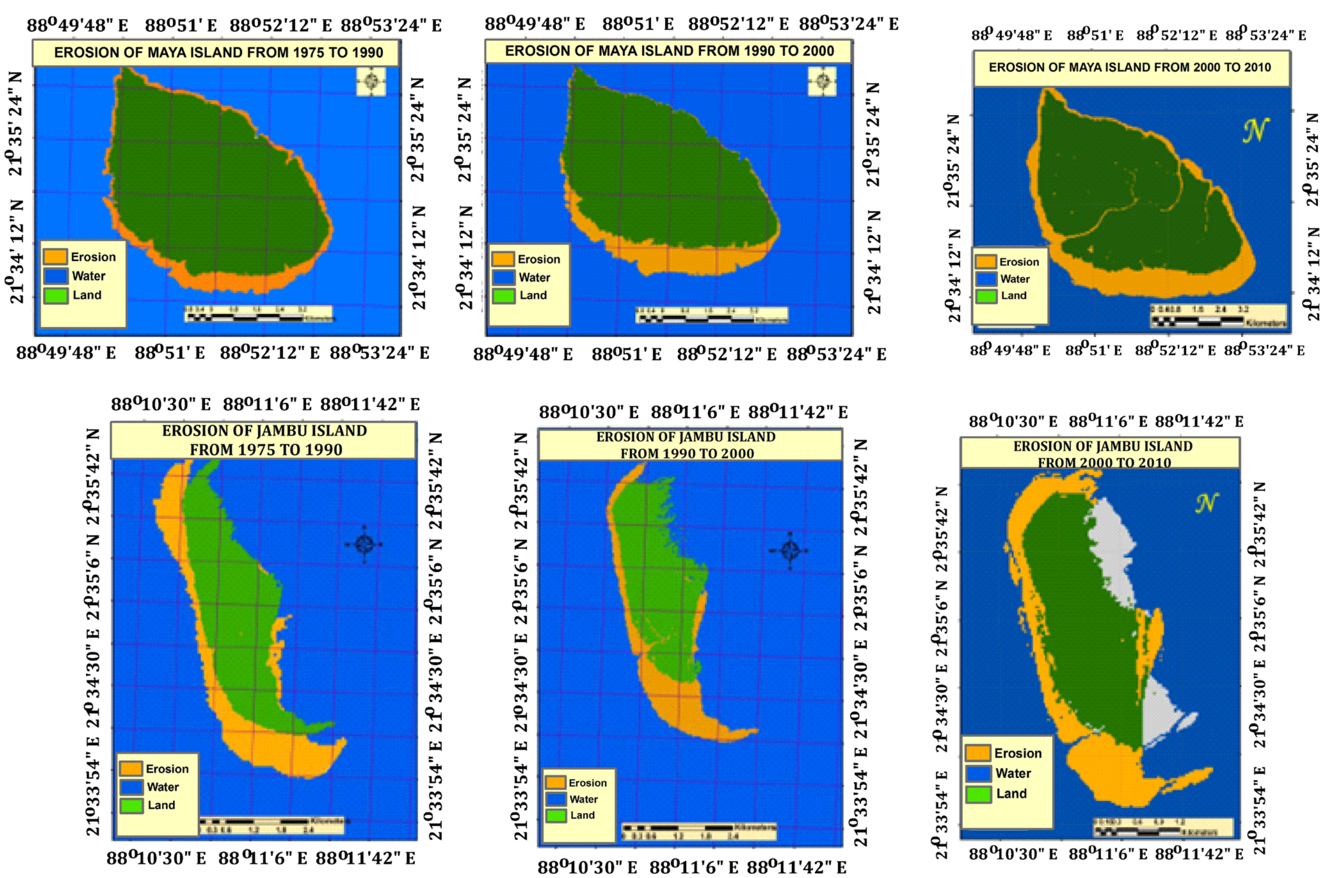

Fig. 3 The erosion taking place in Maya Dwip and Jambu Dwip in the past decades

New Moore lost its existence in this region. The southern fringe of the western lobe of this Ganges-Brahmaputra delta (Maya Dwip, Bhangaduani, Dalhousie, Jambu Dwip islands etc.) is suffering from continued land loss which closely corresponds with the relative sea level rise. Although a significant part of this relative sea level rise is contributed by the subsidence and compaction of the abandoned delta lobe, however, the role of thermal expansion of sea water could also be a major reason, which needs to be investigated further.

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