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Geomorphic signatures of active tectonics on the Padma River, Ganges-Brahmaputra delta, Bangladesh

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ABSTRACT

Recent tectonics on the River Padma is studied with time series Landsat images. The image analysis of those images revealed three extensive erosion zones developed on both banks and are confined to same area over time. A lineament map has been prepared in order to make a correlation with these zones and seismogenetic faults of the region. Result shows two lineament sets (N34^0-65^{0}E and N18^0-60^{0}W) dominating the region. N34^0-65^{0}E and N18^0-60^{0}W lineaments are parallel to the erosion zone directional trend and the main course of Padma respectively. Earthquake data gathered for last 46 years span have also been plotted on the study area, some of the directional trends of earthquake epicenters correlate with the zone and river main course. Elevation difference has been identified from Digital Elevation Model (DEM) and other supporting data, which shows left bank side area more elevated than the right bank side area. Integrating all those evidences and channel dynamics with time it is obvious that Holocene tectonics controls the river main course as well as its major erosion zones.

Keywords: Holocene tectonic, lineament, Remote sensing, Padma River, Bangladesh

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INTRODUCTION

Bangladesh lies on the Indian lithospheric plate, which is pushing against the Asian plate, causing growth of the Himalayas and occasional earthquakes in the region. Earthquakes cause movement of the land, and this can change the topography of the region and alter river courses (Khalequzzaman 1991). The rivers are the most significant features of Bangladesh geomorphology, as they constantly change course, sometimes rapidly, so that topographic features of Bangladesh are ever changing. Neotectonic activities are affecting river courses in the area (Khalequzzaman 1991).

The Padma is a major trans-boundary river in Bangladesh. It is the main distributaries of the Ganges, which originates in the Himalayas. The length of reach is approximately 100 km. The part of the Padma between its confluence with the Jamuna and the Meghna has been undergoing significant physical changes in recent decades (Banglapedia 2006). The rate of widening determined by various authors differs, but not very significantly: 159 m/year (Banglapedia 2006) to 165 m/year (Sarker 2003). Physical characteristics of the Padma and its distributaries are changing due to oscillation of the riverbanks, levee breaching and formation of mid-channel bars.

Satellite remote sensing is effective for investigating river channels over wide area. Although this technology has often used to investigate river channel migration (Throne et al. 1993; Yang et al. 1999 in Takagi et al. 2007) and to identify palaeo-braided channels on terrace surfaces (Leigh et al. 2004 in Takagi et al. 2007), its application to the tectonic behavior of channel over a wide area has been limited to a few studies. Time series satellite images are very helpful to depict the changing behavior of rivers with time reported in earlier studies (Khan and Islam 2003; Das et al. 2007; Sarker 2003). Six different years satellite images were used to reveal the dynamics of the Padma and its erosion vulnerability. These images reveal several extensive erosion zones, which are confined to same area through the time. To understand the nature of confined erosion zones, changes in channel form and tectonic activities on the zones and in Padma itself, this study has been carried out through remote sensing and seismicity analysis of the region.

GEOLOGIC AND TECTONIC SETTINGS

The Bengal basin, a complex foreland basin, south of the eastern Himalayas, exhibits dramatic variability in sediment thickness that reflects a complicated depositional and tectonic history. This basin originally formed as a trailing margin SE

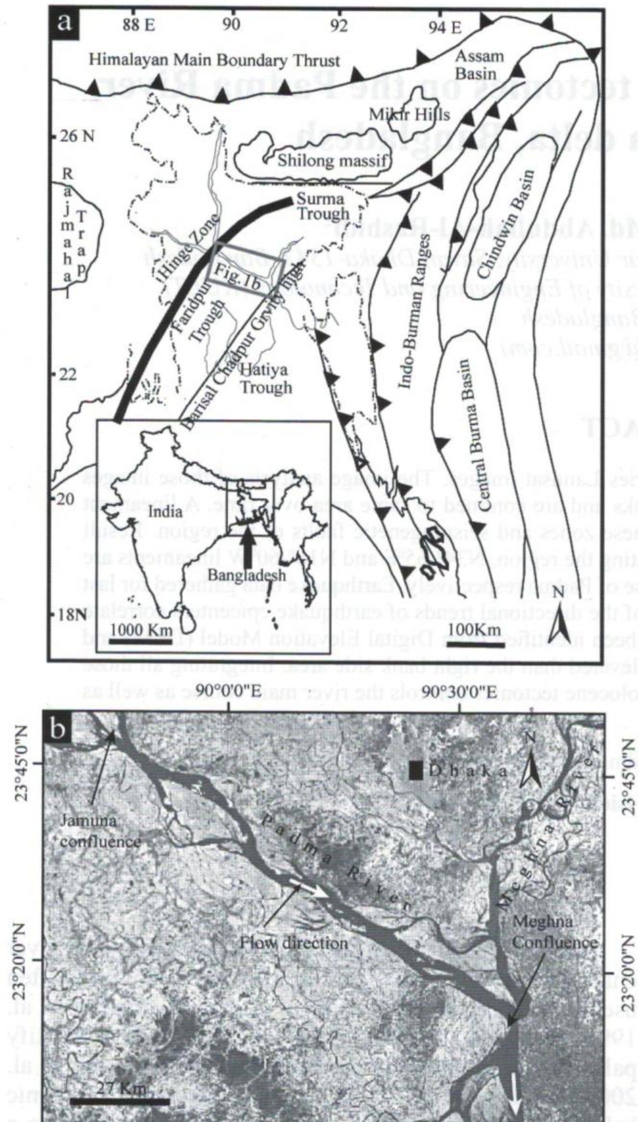

Fig. 1: (a) Regional tectonic map showing various tectonic elements of Bengal Basin and its surrounding areas (Modified after Alam 1972; Guha 1978; Johnson and Alam 1991; Reimann 1993). (b) Geomorphic map of the study area. Background image is the Landsat TM of 2009 of band-4.

of the Indian continental crust, complicated by convergence with Asian plate to the north and oblique convergence with Burma to the east.

The study area lies on the Faridpur trough of Bengal foredeep (Fig.1). Faridpur trough is confined between the paleo continental slope and Barisal gravity high (Alam 1972). The trough is characterized by a general gravity low of northeast trend. Apparently, it relates to general subsidence of the basement.

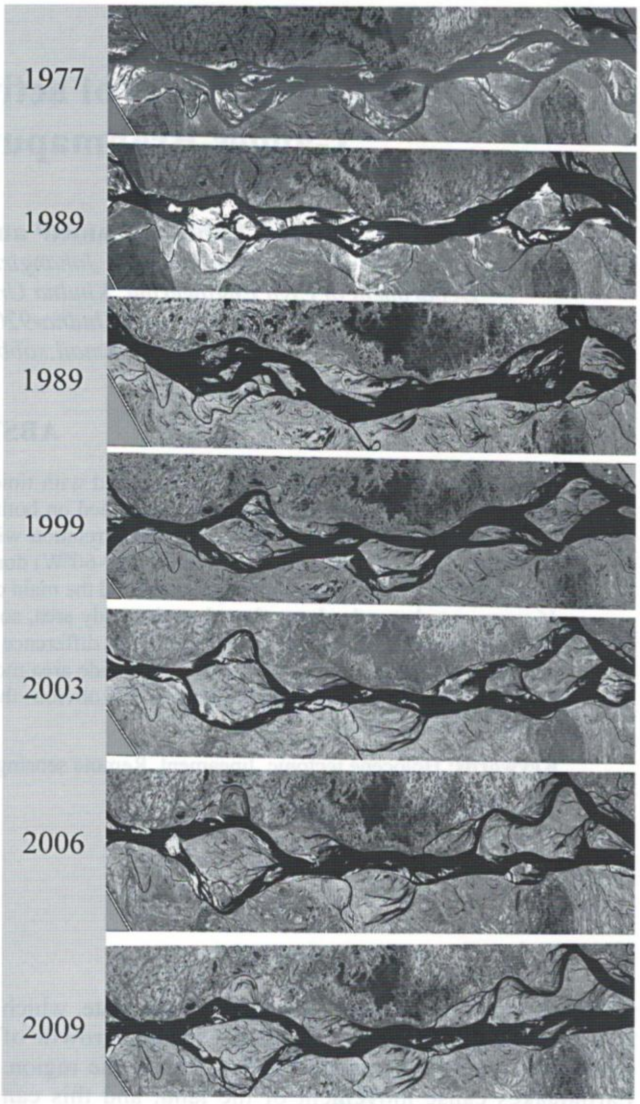

Fig. 2: Time series satellite images (Landsat TM) of the course of Padma

Holocene sediments are exposed (Alam et al. 1990) along both river bank and its surroundings. Alluvial sands and alluvial silts are exposed on left bank and deltaic sand and deltaic silts are exposed on the other bank.

MATERIALS AND METHOD

Time series Landsat images (1977, 1989, 1999, 2003, 2006 and 2009) have been analyzed for river morphological changes. Band-7 of each images were used, as it was very useful for geological features extraction and identification (Ayday and Gümüþlüoðlu 2008; Kunte 1990; Ringrose 1983). Then every band-7 of different years was geometrically corrected and radiometrically calibrated. Finally linear stretching was applied for better visualization. DEM (Digital Elevation Model) of GLS (Global Land Survey) has been constructed to observe the morphology of both banks.

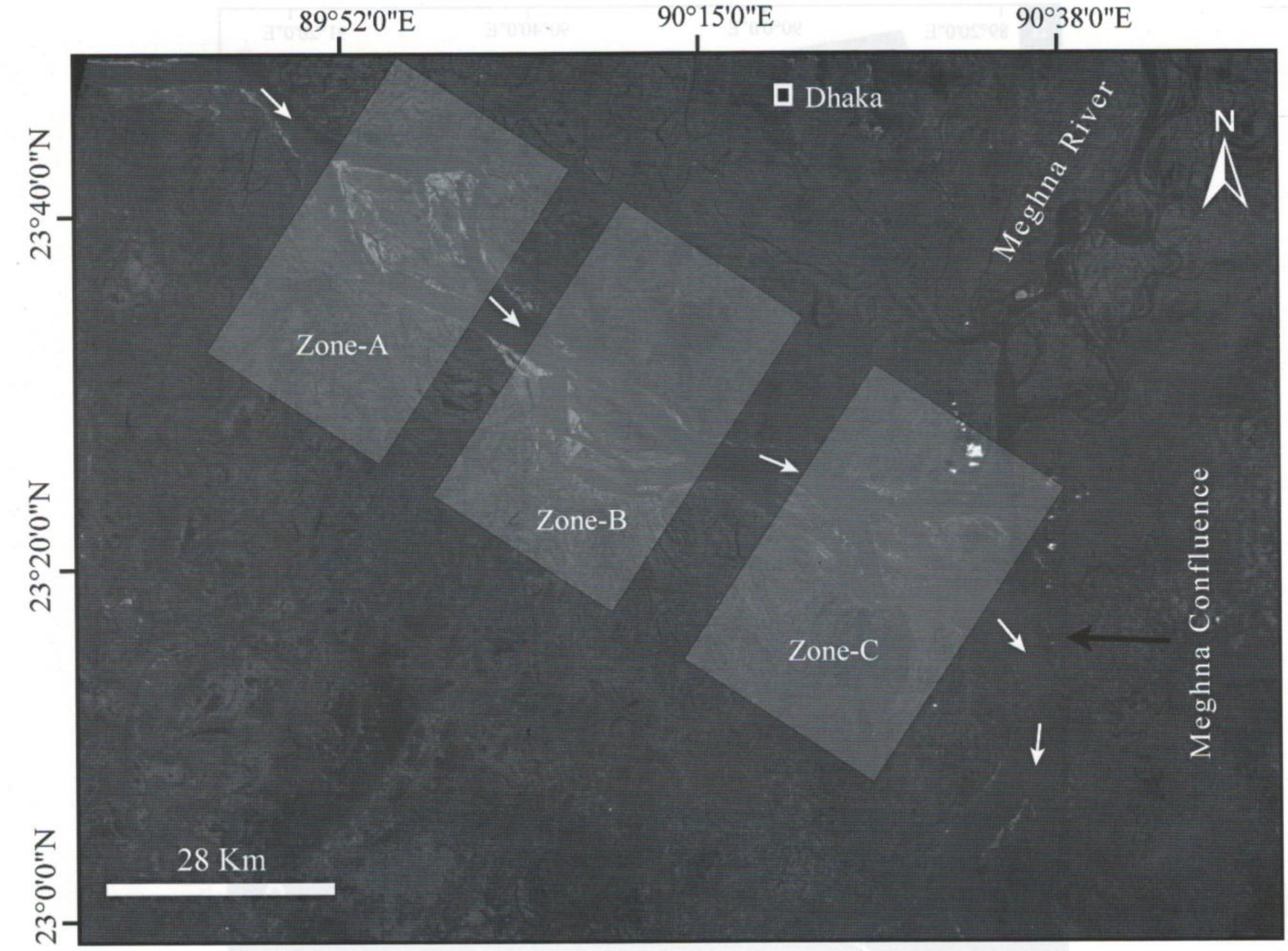

Fig. 3: Different erosion zones of the river, arrow indicates the flow direction from upstream to downstream.

Fig. 4: Digital Elevation Model of the study area showing elevation difference of the both banks of the river

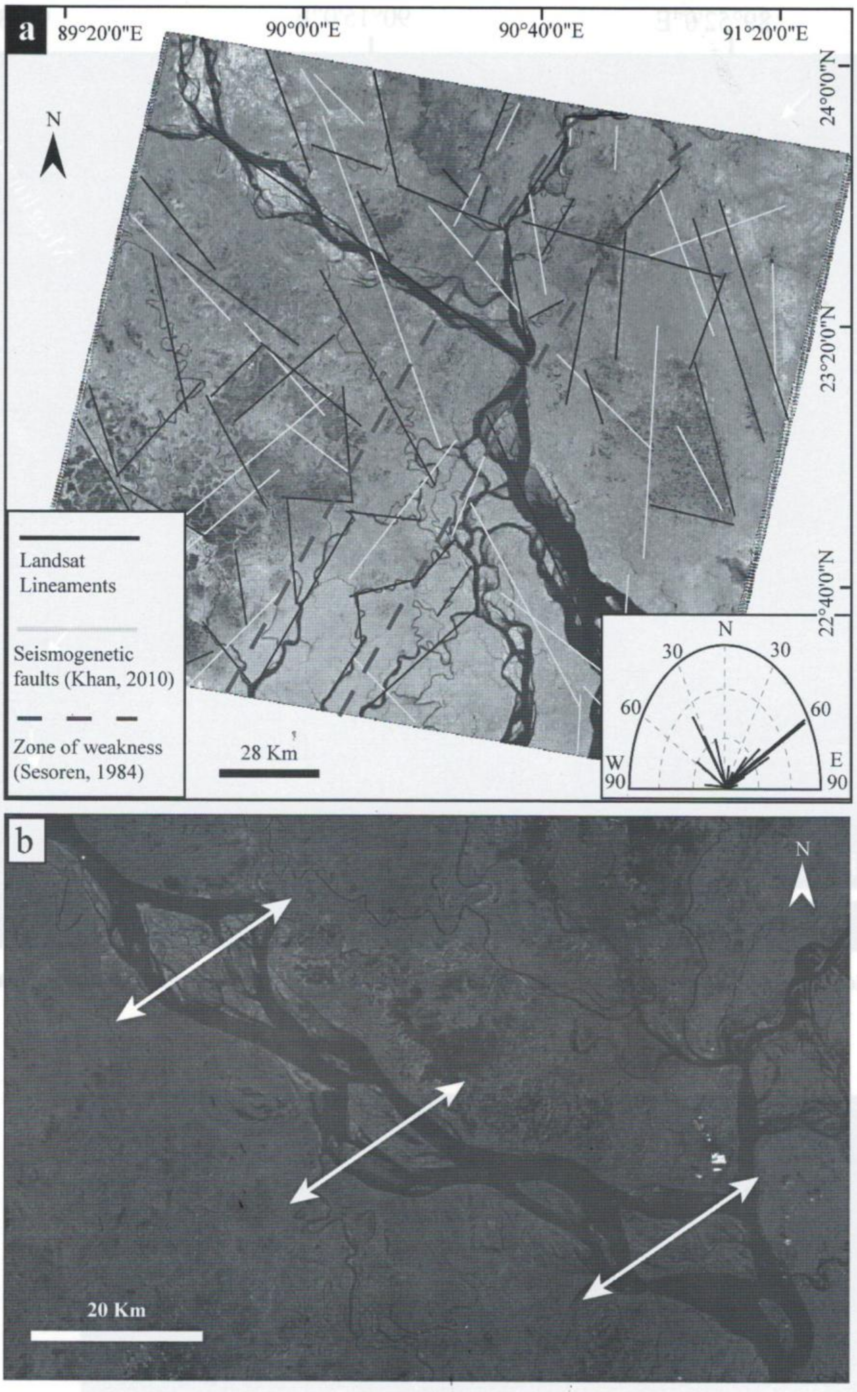

Fig. 5: (a) Map with Landsat image derived lineaments and some seismogenetic faults (Modified after Khan 2010). Rose diagram shows the directions of the lineaments. N, E, W represent north, east, west respectively. (b) Major erosion directional trends of different erosion zones

Methodology proposed by Ayday and Gümüþlüoðlu (2008) have been followed for the recognition of geological linear features (lineaments) using satellite images. For the identification of lineaments, Landsat Thematic Mapper (TM) band-7 of the year 2007 was used. Directional convolution filtering for eight different directions is applied to the image. Eight different bands are obtained from this procedure. Principle Component Analysis (PCA) is applied separately to all of these created eight different layers to obtain the dominant direction in the region. At last, the results were verified and correlated with the original tectonic lineaments and seismogenetic faults of the region.

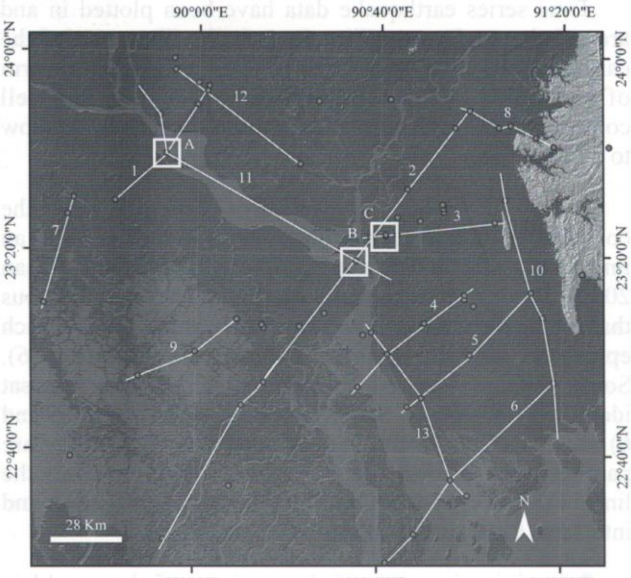

Fig. 6: Spatial distribution of earthquake epicenter (ISC 2006) of the study area. Solid straight lines are hypothetical earthquake trend lines that represent group of epicenters fall on or around the line. Epicenter circumscribed by green boxes marked by A, B and C are described in seismic data analysis section.

Last forty-six years earthquake data have been collected from www.iris.edu (IRIS 2010). Magnitude, epicenter, location and depth of origin of these earthquake data were used to understand the active tectonics of the region.

RESULTS AND DISCUSSIONS

Image analysis

River channel changes, such as bank erosion, down-cutting and bank accretion are natural processes for an alluvial river (Kummu et al. 2008). Remote sensing has emerged as a potentially powerful tool for detailed, quantitative characterization of a fluvial system across broad geographic area with improved temporal coverage (Mertes 2002). Satellite images are especially valuable for study and frequent updating of maps in areas that are poorly accessible or contain rapidly changing landforms (Bolget et al. 1991 in Cu et al. 2006). Time series satellite images have been employed to monitor changes of channel morphology (Peixoto et al. 2009; Bhuiyan et al. 2000; Khan and Islam 2003; Sarker 2003; Das et al. 2007).

Satellite images of six different years (Fig. 2) covering the whole reach of the Padma River have been investigated to verify the nature of changes undergone by the river through times. These time series images depict several erosion zones, accretion zones too. Riverbank erosion is an endemic and recurrent natural hazard in Bangladesh (Banglapedia 2006). The identified zones are very prone to extensive erosion and confined to the same region over time. The part of the Padma between its confluence with the Jamuna and the Meghna (Fig. 2) has been undergoing significant physical changes in recent decades. The Padma has widened between 1973 and 1998 on the order of several kilometers. Bank lines of the river are very unstable (Banglapedia 2006).

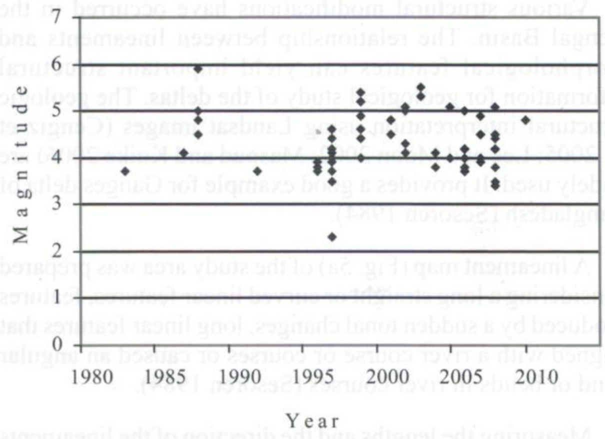

Fig. 7: Time-Magnitude relationship of main shocks and aftershocks in between 89° 42' 0" N to 91° 22' 47.9994" E longitude and 24° 0' 0" N to 22° 58' 48" N latitude

On the basis of severity of erosion the whole reach is divided into three zones (Zone-A, Zone-B and Zone-C) (Fig. 3).

Zone–A is always vulnerable to excessive erosion. Except the image of 1989, all images show high degree of erosion. Left bank erosion gradually becomes reduced from 2006 and on the other hand, erosion in right bank becomes negligible in 2009 (Fig. 2). Zone-B shows its diverse nature. Sometimes it is braided, sometimes meandering and finally it's straight from 2006. After 1989 till 2006 its right bank was severely eroded while erosion of left bank was negligible. The diversity of Zone –C is similar to the zone-A. Extensive erosion is prominent with time in both banks. The difference from zone-A is, its left bank became more vulnerable from 2006, while Zone-A shows vice versa (Fig. 2).

DEM integrated with using remotely sensed data has received considerable attention in recent years for river morphology, changes occurring within time (Kaya et al. 2007 ; Yanites et al. 2010), the extraction of drainage networks and catchments boundaries (Vogt et al. 2003). From DEM (Fig. 4) of the Padma it is obvious that, its right bank is comparatively more elevated than the left bank. Heights from topographic map and elevation details from Google Earth were used to justify this observation.

Lineaments and structural analysis

Lineaments are natural simple or composite-pattern linear or curvilinear features discernible on the earth's surface. Accurate detection of lineaments is indispensable not only to the analysis of the regional and the local tectonics (Masoud and Koike 2006; Solomon and Ghebreab 2006; Cengiz et al. 2005; Jordan and Schott 2005) but also to predict possible earthquake (Joshi and Patel 1997) of a region.

Various structural modifications have occurred in the Bengal Basin. The relationship between lineaments and morphological features can yield important structural information for geological study of the deltas. The geologic structural interpretation using Landsat images (Cengiz et al. 2005; Lee and Moon 2002; Masoud and Koike 2006) are widely used. It provides a good example for Ganges delta of Bangladesh (Sesoren 1984).

A lineament map (Fig. 5a) of the study area was prepared considering a long straight or curved linear features, features produced by a sudden tonal changes, long linear features that aligned with a river course or courses or caused an angular bend or bends in river courses (Sesoren 1984).

Measuring the lengths and the direction of the lineaments shown in figure (Fig. 5a) resulted in rose diagrams showing length in km and frequencies in 30^0 intervals. Two lineament sets ($N34^0$-65^0E and $N18^0$-60^0W) are mainly dominating the region and shown by the rose diagram.

$N34^0$-65^0E lineaments are resulted from mainly tidal rivers in the south. These lineaments zone considered as zone of weakness by various authors (Sesoren 1984; Krishnan 1953) which follows Jamuna-Padma-Meghna river system. Sesoren 1984 later said that this lineament set control the courses of the tidal rivers. Besides these, $N34^0$-65^0E lineaments are almost transverse to the main course of the River Padma and parallel to the major erosion directional trend. There are some seismogenetic faults (Khan 2010) (Fig. 5a) which are also parallel to the $N34^0$-65^0E lineaments and extensive erosion zone trend.

On the other hand $N18^0$-60^0W lineament set is almost parallel to the Padma. The river is also termed as Padma lineament (Khandoker 1987; WARPO 2003). This lineament delineates the southern extremity of the Barind surface and almost straight course of the river through the alluvial plain is probably indicative of being fault-controlled (Nandy 1980). Later Khan (2010) mentioned this lineament as NW-SE trending Padma fault, which is one of the controlling faults of the tectonics of the passive margin of Bangladesh.

From these evidences, it is assumed that these erosion zones are associated with these transverse lineaments and faults

Seismic data analysis

Earthquakes affect not only cities, but they modify landforms by land sliding (Jibsona and Keefer 1989) and they can significantly affect river morphology and hydrology (Schumm et al. 2000). A good background of historical information of earthquake is very important to evaluate the seismicity of a region. A time series occurrence of earthquakes in and around Bangladesh for last 30 years exhibit zones characterizing the propagation of fractures (Khan 2010). The occurrence of these recent earthquakes indicates that the area is tectonically active (Jain and Sinha 2005).

Time series earthquake data have been plotted in and around the study area (Fig. 6). It looks like most of the earthquakes in the study area are part of a small swarm of earthquakes. The depth of earthquakes are not well constrained, so it can be said that the earthquakes are shallow to intermediate.

Precise locations of epicenters of earthquakes and the coincidence of epicenters with faults in an area serve as an important guide for determining zones of active faults (Khan 2010). From this earthquake epicenter map it is obvious that some epicenters follow certain directions. Twelve such epicenters directional lines have been detected (Fig. 6). Some of these detected lines are coincided with Landsat identified lineaments. Six detected lines (1, 2, 3, 4, 5 and 6) are transverse to the Padma main course but they are parallel to the erosion directional trends (Fig. 5b). Only the line-11 follows the direction along the river course itself and intersects three earthquake epicenters (Fig. 6).

Seismicity in most of the regions of the world is intrinsically related to the tectonics of those regions (Khan et al. 2002). Many authors (Krishna and Sanu 2000; Khan 1989; Steckler et al. 2008; Albaric et al. 2009) have studied seismicity in relation to tectonics of the Bangle basin and its adjoining area. The Padma and its surrounding region are becoming seismically active as observed from the distribution of recent main shocks and swarm of earthquakes epicenter (Fig. 5).

A and B indicated earthquakes (circumscribed by green box) (Fig. 6) occurred in 2006 and 2008 respectively. As a result of 'A' earthquake of 4.2 magnitudes, the erosion zone-A have been changing and gradually it's right bank touched the bar, which was almost equally away from both bank. Similarly due to 'B' earthquake of 4.6 magnitudes, left bank of zone-C has touched the bar which was almost equally away from both banks.

From the time-magnitude statistical relationship (Fig. 7), it is obvious that recently seismic activity in the study area is increasing rapidly. The graph also shows that there has been a gradual increase in magnitude of earthquake activity with time and the trend of earthquake magnitude may appear to be beginning to rise at an exponential rate which is an ominous trend. If magnitude increases like this it would be seen much more large-magnitude earthquake activity. For example, recent 4.8 magnitude earthquake ('C' in Fig. 7) caused slightly damages at Narayanganj, was Felt (IV) at Dhaka and Gazipur and also felt (II) at Calcutta, India.

The occurrence of deformation front is marked by the position of focal depths. The data set used in the present study suggests that the neo-deformation front is occurring at earthquake hypocenters depth. However, the reliability of the focal depth is questionable. The neotectonic activities of the study area are being controlled by the ongoing activities along the deformation front.

CONCLUSIONS

The Padma is the combined flow of the Ganges and the Jamuna rivers where erosion is an endemic and recurrent natural hazards similar to those found in other rivers in Bangladesh. But extreme erosions of Padma are confined to the certain regions with time. Time series Landsat satellite images revealed these zones. Two sets of lineaments of the region were obtained from principal component analysis of convolution filtered eight directional images. One is parallel to the erosion zones directional trend and another one is parallel to the main river course. Some of the lineaments also coincide with seismogenetic faults and earthquake epicenters. Recent seismic activities of the area confirm the association among lineaments, neotectonics and erosion zones of the river. The time-magnitude relationship and focal depth analysis of time series earthquake data indicate that the Padma itself and its adjoining are is being controlled by neo-tectonics.

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