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Time Series Landsat Remote Sensing Images and Geographical Information System to Environmental Evaluation of Sites for the Padma River Bridge

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Abstract: Mawa–Janjira at Manikganj–Shariorpur districts in Bangladesh is selected location to construct the planned Padma River Bridge. The aim of this study is to evaluate environmental impact based on riverbank erosion and deposition at proposed sites for the Padma River Bridge. Five scenes of Landsat images are classified applying K-means algorithm using PCI Geomatica. Overall accuracies of 94.67%, 90.27%, 89.93%, 85.80% and 88.40% are achieved from Image-5 TM (2006), Image-4 ETM+ (1999), Image-3 TM (1989), Image-2 MSS (1977) and Image-1 MSS (1977) classification, respectively. A pair of positions at east and west banks for three sites is identified where the Bridge is proposed to construct. The movement of riverbanks at those pair positions based on initial riverbanks in 2006 are estimated using ArcGIS9.3. Based on erosion and deposition of riverbanks, Site A (Paturia–Goalundo) and Site C (Mawa–Janjira) has equal prior to construct. However, considering the migration of the confluence point of the Padma and the Jamuna rivers, geotechnical and socio-economic analysis, Site C (Mawa–Janjira) is identified as the best location. Moreover, application of remote sensing technique and geographic information system has effectively evaluated the sites for the Padma River Bridge.

Key words: Evaluation of sites, Pair position, Erosion and deposition, Padma River Bridge, Landsat images, GIS.

1. Introduction

Southwest zone in Bangladesh is still separated by the Padma River and needs time consuming ferry crossings to major destination such as second seaport and Export Processing Zone located at Mongla, third largest and industrial city located at Khulna and the main land port located at Benapole (Zaman et al., 2006). The Padma River Bridge is a proposed multi-purposes bridge with 25 m width and 5580 m length. It will be located at Mawa–Janjira of Manikganj–Shariorpur districts in Bangladesh which will connect the capital city with the south and southwest parts of Bangladesh. Using Padma River Bridge, growth of Gross Domestic Product in national and regional (southwest) will increase 1.2% and 35%, respectively. It will also generate additional employment opportunities of 743,000 persons per year, which equals to 1.2% of the total labour force of Bangladesh (Asian Development Bank, 2007).

Bangladesh is a floodplain riverine country. Almost every year flooding occurs in the country. During regular flood, about 2600 sq km (18% of Bangladesh) are flooded and during severe flood, the flooded area exceeds 55% of the total area of the country (Islam, 2009, 2010). The Padma is one of the major three rivers in Bangladesh. Flood and flow of the Padma River cause bank erosion and deposition. The average bank erosion of the Padma River since the 1970s is 1400 hectares/year while it increases to 2200 hectares/year in the 1990s (Integrated Regional Information Networks, 2008). Erosion of the banks may impose a lot of cost to construct and further maintain the bridge. However, construction a bridge at naturally hard point (not eroded frequently over time) of the riverbanks may minimize that cost.

Site selection process for a river bridge is influenced by riverbank erosion and deposition, and migration of the river channel which requires spatial information and processing. These spatial data can be obtained using theodolite, global position system (GPS), Remote Sensing (RS) technology and so on. Regular collection of spatial data using GPS and theodolite is costly and time consuming process. Time series RS imagery minimizes these limitations and is now being widely used in identification and quantification of river morphological analysis (Chu et al., 2006; Sarma et al., 2007; Ahmed and Fawzi, 2009; Jian et al., 2009; Islam, 2009, 2010). Geographic Information System (GIS) together with RS provide tools for quantitative and qualitative analysis of spatial analysis and planning for sustainable development (Burrough and McDonnell, 1998; Islam, 2009) and that has been applied in this study to evaluate sites for Padma River Bridge.

2. Study area and data description

2.1 Study area

The study area embraced the confluence points of the Padma–Jamuna at Goalanda, Rajbari and the Padma–Meghna at Matlab, Chandpur (Fig. 1). The difference in height within the study area is ~4.57 m (3.05–7.62 m). The length between these two confluence points is ~110 km. The variation of rainfall is usually ~1500–1750 mm (Haque, 2008). The characteristics of the soil of the northeast bank are flood plain and alkaline, and at the southwest bank, it is peat. The Padma has high water flow in the monsoon and much less in the dry season. Erosion and deposition of the Padma riverbank is influenced by the instable water flow during the monsoon and the dry season, and by the yearly flood (Islam, 2010).

Figure 1: Study area and four potential crossing locations of the Padma River Bridge. (A) A section of the Padma River is marked which indicate inset and is presented at bottom (B). The red double arrows are showed at four potential crossing locations for the Padma River Bridge. The base map is prepared from google earth.

2.2 Data description

This study is carried out using UTM peojected Landsat imagery from the Global Land Cover Facility (GLCF, 2004). All these images are cloud free and acquired from the dry season. The spatial resolution of Landsat images is able to identify of the location of erosion and deposition, and the monitoring of the dynamic river channel (Priestnall and Aplin, 2006; Islam, 2009). Properties of Landsat images used in this study are presented in Table 1.

Table 1: Details of used data sets

Images	Sensor	Id	WRS	Path	Row	Acquisition date
Image-1	MSS	029-176	1	147	044	1977-02-08
Image-2	MSS	020-796	1	148	044	1977-02-09
Image-3	TM	028-758	2	137	044	1989-11-04
Image-4	ETM+	039-253	2	137	044	1999-11-24
Image-5	TM	222-776	2	137	044	2006-12-05

3. Methods and results

There are four locations proposed initially by the feasibility study group of Japan International Cooparation Agency (JICA) to construct the Padma River Bridge (JICA, 2005). These four locations are Site A: Paturia-Goalundo, Site B: Dohar-Charbhadrasan, Site C: Mawa-Janjira and Site D: Chandpur-Bhedarganj (Fig. 1B). Site D: Chandpur-Bhedrganj is eliminated at the preliminary stage in selection process. The reason is one more river bridge across the Meghna River will be necessary to fulfil the purposes of the Padma River Bridge. Therefore, Site A, Site B and Site C are evaluated in this study. A pair of positions i.e. one position at the west and another at the east banks of the Padma River for each site is identified for evaluation. Landsat images are processed to evaluate the pair positions of these three sites.

3.1 Image processing

To avoid a large data set, an area covering approximately a 10 to 12 km distance from the banks of the Padma River is taken as a subset which is large enough as suggested by Campbell (2002) as this type of study. Major urban areas are separated using mask (Fig. 2C). K-means unsupervised classifier is applied to classify images independently. The achieved sixteen clusters from the unsupervised classification are dissolved into six thematic classes. This classification scheme is decided based on the region of interest of this study and on a modification of United Nation Environment Programme (UNEP) (1994) applied in Bangladesh. These six types of land cover are (1) water: contains rivers, estuaries, lakes and water depression; (2) cropland: contains all kinds of crops and agricultural land and dispersed vegetation; (3) wetland: contains marshland indicating waterlogged areas which consists of dense herbaceous and bush growth; (4) fallow land: contains bare and arable land; (5) dry deposit: contains dry sands located at the islands and riverbanks and (6) wet deposit: contains wet sands located at the islands and riverbanks in level I that could be classified without use of ancillary data (Thompson, 1996). However aggregation of clusters is made by using local knowledge and visual interpretation. In this study, 250 pixels for each class are selected independently for accuracy assessment. Results of image classification and accuracy assessment are presented in Table 2.

Table 2: Image classification statistics

Images	Overall accuracy (in %)	Kappa coefficient	Standard deviation
Image-1: MSS (1977)	88.40	0.86080	0.00992
Image-2: MSS (1977)	85.80	0.82960	0.01080
Image-3: TM (1989)	89.93	0.87920	0.00932
Image-4: ETM+ (1999)	90.27	0.88320	0.00919
Image-5: TM (2006)	94.67	0.93600	0.00696

3.2 Movement of riverbank at pair positions

All classified images are transferred to GIS layers using ArcGIS 9.3. Image 1 and Image 2 do not cover the subset area separately as covered by other images like Image 3, Image 4 and Image 5. Both Image 1 and Image 2 are clipped based on Image 5 and then merged together, which represents the major land cover in 1977.

Land covers in 2006 are taken as initial state. Evaluation is performed based on this initial land covers. The pair positions at the east and west banks of the Padma River for each site are identified on the GIS layers in 2006 where the Padma River Bridge is supposed to construct. A standard measurement tool of ArcGIS is applied to measure the distance between the initial location of those pair positions at the riverbank in 2006 and the nearest riverbank in the previous particular year. Thus, it explains the movement of riverbanks at those selected locations based on the initial river channel in 2006. Movements of the riverbank at a certain location indicate either erosion or deposition. This can be called a back casting trend analysis, by which it can be analyzed what was the land cover of a certain position, which is now at the riverbank.

If pair position is located at all other land covers except water/river in previous particular year that is at riverbank in 2006, then the distance between this point position and nearest riverbank indicates vulnerability. This vulnerability is positively proportionate to this distance. It indicates erosion. However, the location of pair point at water/river in a same manner indicates deposition, which is considered more suitable for bridge construction.

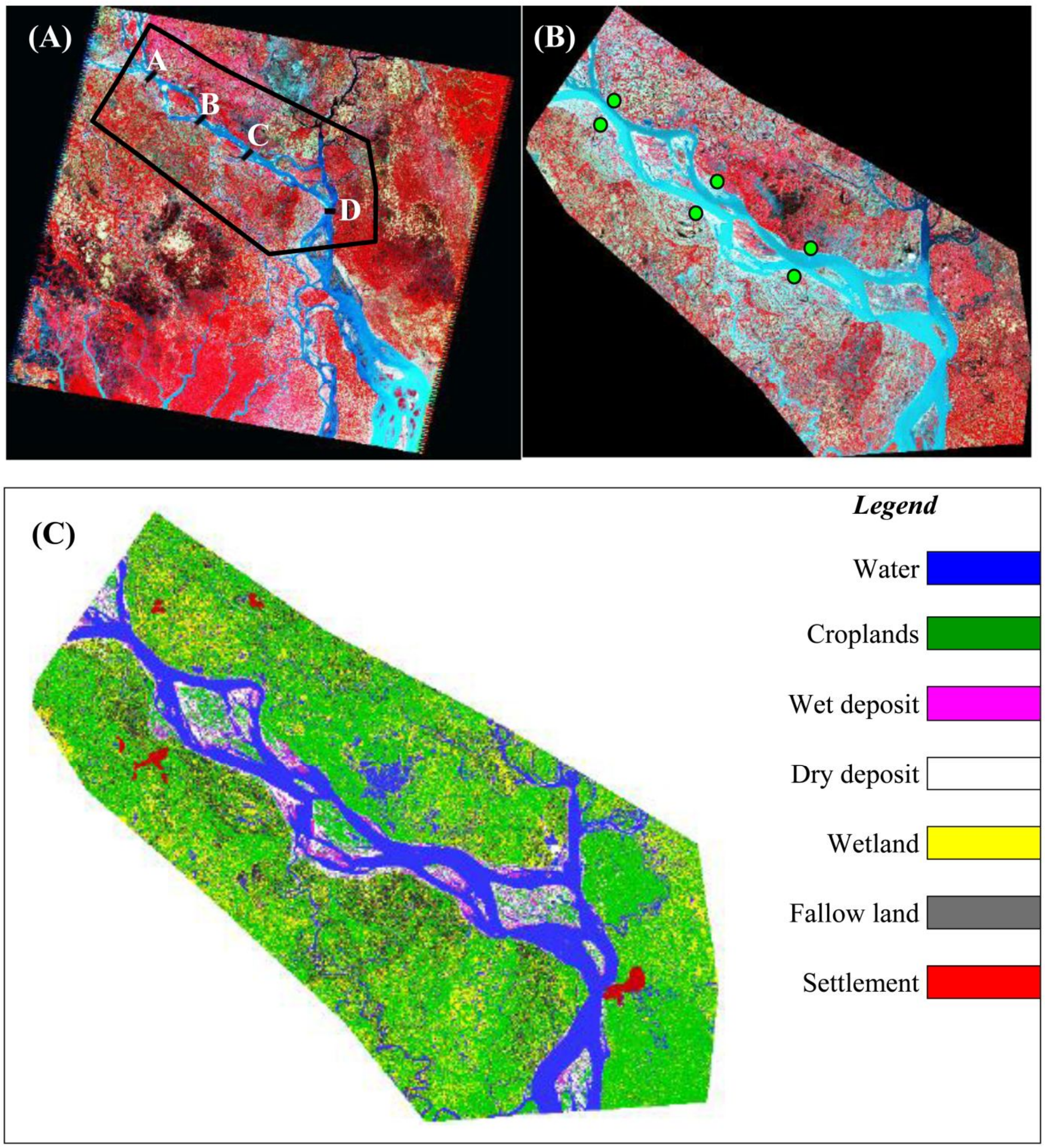

Figure 2: (A) Potential four sites for evaluation in a full data set of Landsat images. The black polygon indicates subset area. (B) Pair point (green marked) positions at Site A, Site B and Site C at this subset area. (C) A classified image of subset area.

At Site A, one of the pair position at the east bank is located at the same land cover and almost stable since 1977 (Tab. 3 and Figs. 3A, 3B, 3C and 3D). In 1977, other of the pair position at the west bank is located at the water/river about 274 m from the nearest riverbank in the east direction. In 1989 it is located at water/river about 600 m from the nearest riverbank at the same direction towards east (Tab. 3 and Fig. 3C). Therefore, during 1977–1989, the west bank is eroded about 326 m towards west. Then during 1989–1999, it is deposited about 1044 m towards east. During 1999–2006, it is eroded again about 444 m.

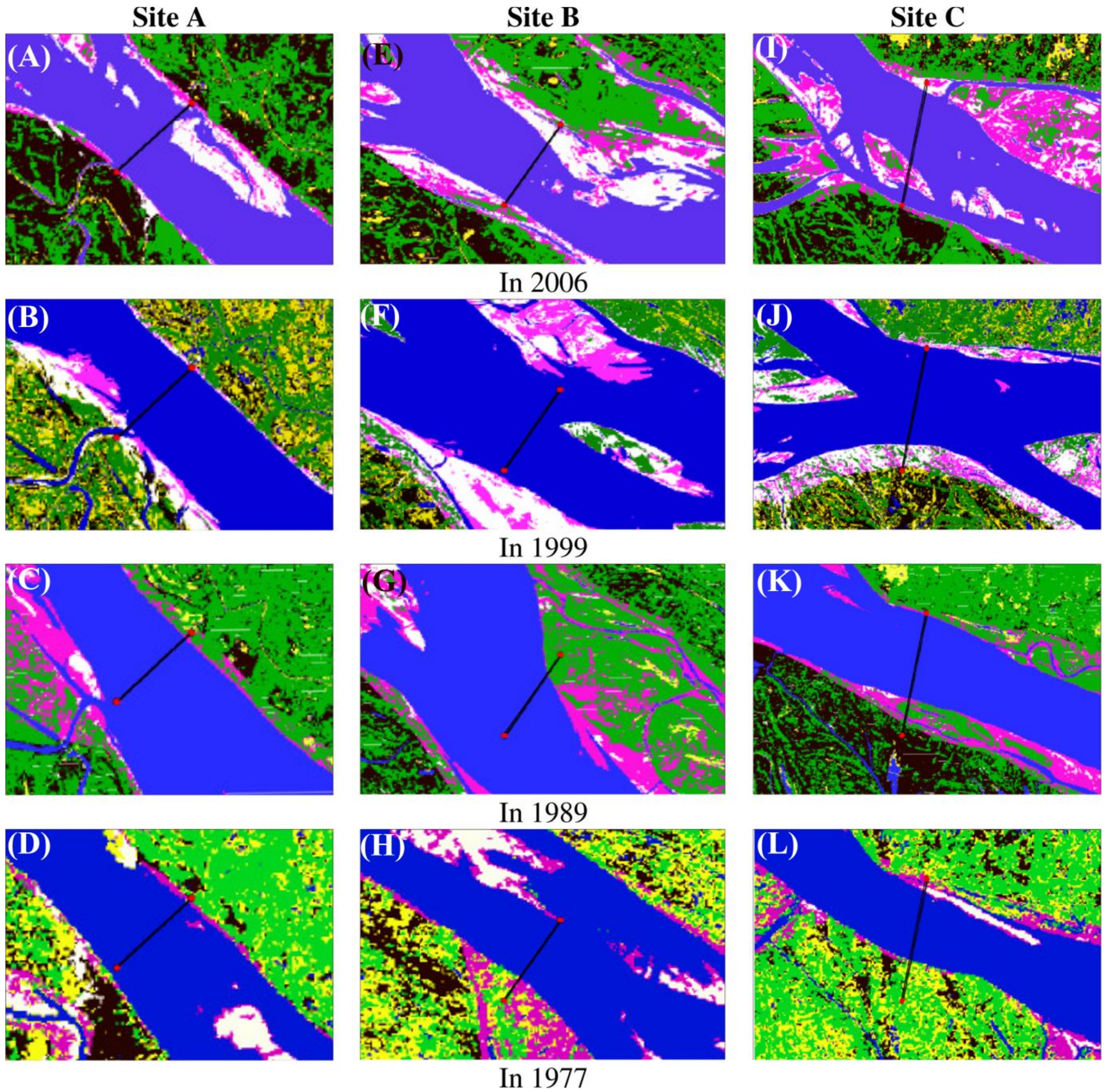

Figure 3: Movement of riverbanks at pair positions. Left, middle and right columns indicate Site A, Site B and Site C, respectively. Year of image acquisition is presented bellow of each row. The pair positions are marked by red points and black lines are indicated to possible crossing location.

At Site B, one of the pair position at the east bank is located at the water/river about 2255 m from the nearest riverbank in west direction in 1997 (Tab. 3 and Fig. 3H). Then it is located at croplands about 580 m from the nearest riverbank in east direction in 1989 (Fig. 3G). It means that during 1977–1989, the east bank is deposited about 2835 m toward west. Then during 1989–1999, it is eroded about 3490 m toward east. However, during 1999–2006, it is deposited again about 2910 m (Tab. 3 and Fig. 3F). In 1977 the other position of the pair at the west bank is located at croplands about 985 m from the nearest riverbank in west direction (Tab. 3 and Fig. 3H). Then in 1989 it is located at the water/river about 2070 m in east direction (Tab. 3 and Fig. 3H). So, during 1977–1989, it is eroded about 3055 m towards west. During 1989–1999, it is deposited about 1870 m. However, during 1999–2006, it is deposited about 200 m (Tab. 3 and Fig. 3F).

At Site C, one position of the pair at the east bank is located at the same land cover during the entire period 1977–2006 (Tab. 3 and Figs. 3I, 3J, 3K and 3L). In 1977, other position of the pair at the west bank is located at croplands about 1890 m from the nearest riverbank in west direction (Tab. 3 and Fig. 3L). Further, it is located at croplands about 1750 m from the nearest riverbank in west direction (Tab. 3 and Fig. 3K). Therefore, during 1977–1989, it is eroded about 140 m towards west. During 1989–1999, it is eroded about 420 m towards west. However, during 1989–2006, it is eroded about 1330 m in the same direction towards west (Tab. 3).

Table 3: Distance from the nearest riverbank and existing land cover in the different years of different sites compare to the initial year 2006.

Year	Banks	Direction			Distance (m)			Land covers		
		Sites			Sites			Sites		
		A	B	C	A	B	C	A	B	C
1999	East	-	West	-	0	2910	0	-	Water	-
	West	West	East	West	444	200	1330	Dry deposit	Water	Fallow land
1989	East	-	East	-	0	250	0	-	Crops-land	-
	West	East	East	West	600	2070	1750	Water	Water	Crops land
1977	East	-	West	-	0	2255	0	-	Water	-
	West	East	West	West	274	985	1890	Water	Crops land	Crops land

4. Discussions and conclusions

The east bank at Site A is considered to more suitable than the west bank for bridge construction. The movement of the east bank is less compared to the west bank. The west bank moves faster than the east due to the erosion and deposition of the riverbank (Tab. 3 and Figs. 3A, 3B, 3C and 3D). However, at Site B, both the east and west bank move quickly over time. The rate of erosion and deposition at both banks at this site is very high. Neither of the banks is stable. Erosion and deposition is happening by turn (Tab. 3 and Figs. 3E, 3F, 3G and 3H). Likewise Site A, the east bank of Site C is stable in the entire period during 1977–2006 whereas, erosion occurs at the west bank. The rate of erosion during 1977–1989, 1989–1999 and 1999–2006 is 11.66, 42 and 190 m/year respectively. Thus, Site A and Site C is more suitable than Site B. Site A and Site C is also connected with existing highway. Therefore, construction of the Padma River Bridge at Site A and/or Site C is better than Site B considering erosion and deposition of riverbank. However, none of these two sites has prior from one over other.

Table 4: Comparison of Site A and Site C from traffic volume, socio-economic, regional, national and international road network aspect as suggested by JICA (2005).

Evaluation criteria		Site A	Site C
Traffic demand (by 2025)		19,850 vehicles/day	41,550 vehicles/day
Economic feasibility	Economic internal rate of return	9.6%	16.9%
	Cost-Benefit ratio	0.71	1.81
Regional development	Increase of GRDP of southwest region	18% up (1.2 %/year)	35% up (2.3 %/ year)
Improvement of accessibility	Dhaka-Mongla	4.5 hours	3.6 hours
	Dhaka-Benapole	4.6 hours	6.6 hours
	Beneficiary population within 3 hours from Dhaka	2,791,000 (9%)	10,417,000 (35%)
	Within 4 hours from Dhaka	12,738,000 (72%)	22,274,000 (74%)
Formation of international road network		-	Asian highway A-1, short distance to Benapole land port and Mongla sea port

Initial Environmental Examination (IEE) is conducted by JICA (2005) for the Site A and Site C to identify the significant environmental impact. Most of the impacts are similar founded for both Site A and Site C. There is no significant prior of one over other.

Estimated amount of land to acquire for the both sites is almost similar (1250 ha) conducted by JICA (2005). The coat of land acquisition and resettlement for Site A and Site C is $24 million and $39 million, respectively. The feasibility study group has strong prior for both Site A and Site C to construct Padma River Bridge.

However, Site A has potential risk since it is located about 4.5 km south–east of the confluence point of the Padma and the Jamuna rivers. The nature of the Jamuna River is high erosion compared to the Padma River. The rate of erosion of the confluence point is very high. During 1977–2004, it moves 9 km towards south–east (Islam, 2010). Controlling the migration of the confluence point of the Padma and the Jamuna towards south-east will impose extra costs in the future to maintain the Padma Bridge if it is constructed at Site A.

Geotechnical report by JICA (2005) suggests that there are also some possible risks of liquefaction at Site A but not for Site C. Coefficients of horizontal ground reaction in the bore holes describe relatively smaller values which would have to be regarded as in the early design of foundations. Blow per Foot (N value) of Standard Penetration Test (SPT) at Site A is smaller than that at Site C. This may be caused of relatively singular particle size distribution of fine sand at Site A.

According to this study concerning erosion and deposition of the riverbanks, Site A and Site B has similar weight to construct the Padma Bridge that is also suggested by the feasibility study group JICA (2005) regarding IEE. However, geotechnical, traffic demand, economic feasibility, regional development, improvement of accessibility and international road network formation investigation by JICA (2005) (Tab. 4) and erosion and their direction study by Islam (2010) suggest that Site C is the best location for the Padma River Bridge construction.

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