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Padma River Bank Erosion in Naria, Shariatpur District, Bangladesh: Geomorphological, Geological, and Geotechnical Aspects

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ABSTRACT *The Naria Upazila of the Shariatpur district is situated on the right bank of the mighty Padma River, where extensive riverbank erosion has been occurring over the past several years. The purpose of the study is to decipher the geomorphological, geological, and engineering geological causes of bank erosion in the area. Conventional fieldwork was carried out in the area and systematic sample collection was done. Standard laboratory processes were followed to analyze the samples. The aerial photographs and Google images study indicate that the Tippera alluvial sediments of the Mid-Holocene age are less eroded than the active bar and floodplain deposits of recent age. This may be owing to the moderately compacted older sediments of the Tippera deposits, whose N values also reflect dense sediment packing. Other geotechnical features like grain size distributions, type, plasticity index, friction angle, and relative shear strength confirm similar results as well. Though the results of the study show that sediment qualities have an impact on erosion the sediment budget, water discharge, river dynamics, etc. might be the core causes of tremendous riverbank erosion in the area. Thus the result of the study could help to a great extent to develop a sustainable river bank protection management program in the area.*
Keywords: *Bank erosion, Geotechnical, N-value, Padma, Tippera.*

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I. INTRODUCTION

River bank erosion is a natural hazard that causes immense suffering for the inhabitants of that region. Alluvial channels adjust themselves to reach regime conditions through degradation and aggradation. With bank erosion and accretion, channels adjust themselves in this system. River erosion affects changing the river channel course and development of the flood plain. These are the most dynamic elements of the landscape and thus an understanding of the processes is fundamental to our explanation of the development of fluvial features. Numerous geomorphological and river management issues depend on the river channel's migration over time and space (Milton et al., 1995; Hickin, 1983). Lateral migration is the positional movement of a river channel as a result of changes in fluid flow and sediment discharges; it is invariably coupled with bank erosion of the stream bed or channel wall under turbulent flow conditions (Yang et al., 1999). Again, the rate of bank erosion may be influenced by several criteria, such as soil qualities, the frequency of freeze-thaw, the stratigraphy of the bank, the type and density of vegetation, and sediment grain size near the base of the bank (Micheli and Kirchner, 2002; Perucca et al., 2007). Many researchers explained that soil detachment at river banks is due to hydraulic erosion imposed by channel flow and subaerial erosion due to the weakening and weathering of bank materials. They created a scale to assess the degree of soil erodibility into five classes for the subareal erosion of banks considering the case that soil composition does indeed affect erosion resistance (Abidin et al., 2017).

However, in recent decades, many reaches are conducted on the Padma river bank erosion, and most identified flood, deforestation, heavy rainfall, and strong current as the causes of river bank erosion. Some detect the changes in the riverbanks and quantification of erosion and deposition of the riverbanks. through remote sensing and GIS tools and analyzes the socio-economic impact of river bank erosion in Bangladesh (Billah, 2018; Islam, 2009).

Bangladesh is a riverine country suffering from riverbank erosion every year, especially along the Padma river. The river has faced tremendous river erosion on the right bank in past recent years. River erosion took a serious turn at Naria Upazila of Shariatpur district where it created havoc. Many buildings, structures, trees, and crops on wide stretches of land have been carried away by floodwaters and strong river currents in several flood-affected regions of the country. Around 5,000 families have become homeless there in the year 2018 due to erosion by the Padma River in Naria. Besides, several thousand acres of croplands have been devoured by the river as the erosion has taken a serious turn in the Upazila. Mokterer char, Kedarpur, Gharshar union of Naria Upazila, and Naria municipality experience deterioration in erosion.

Conventional geological fieldwork was carried out to assess the bank erosion zones and evaluate the scenarios considering the river geomorphology, and geological units and to decipher the influence of the sediment characteristics on the riverbank erosion sediments of the study area at Naria Upazila, Shariatpur District, Bangladesh. The investigated area was about 240 km² (Fig.1).

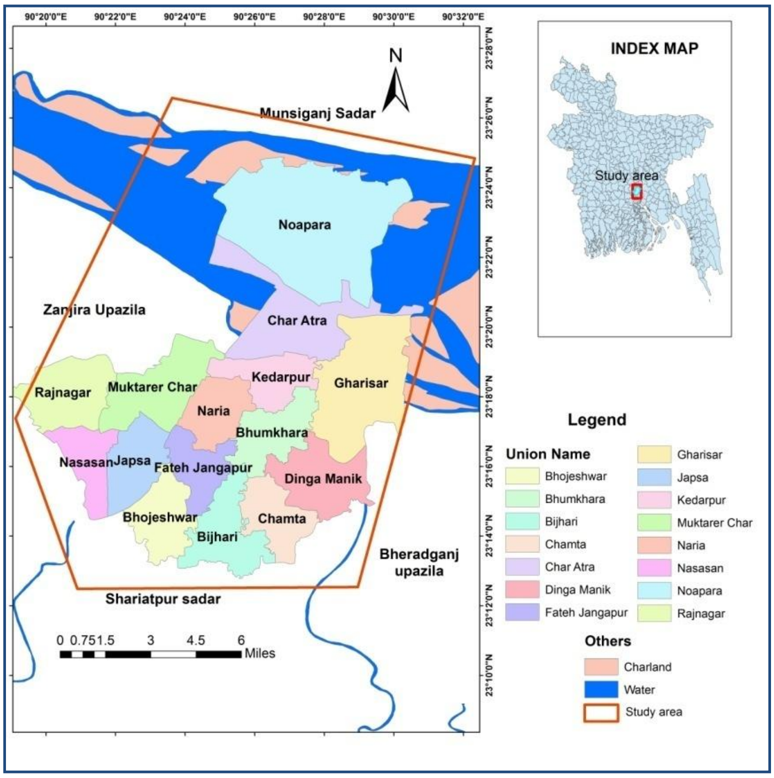

Figure 1. Location Map of Naria Upazila and surroundings

II. MATERIAL AND METHODS

Aerial photographs of 1954 and satellite images were analyzed for identifying different geomorphic units and detecting changes in river morphology. Temporal Google images of 1984, 2018, 2019, and 2020 were studied to detect bank line changes. Fifteen numbers of standard penetration boreholes and 16 auger holes were carried out in Naria Upazilas for sub-surface geological and geotechnical data interpretation. Arc GIS, Starter, and other software were used for different map preparation and analysis. Engineering properties of selective samples were carried out in the Engineering Geological Laboratory of the Geological Survey of Bangladesh and a private laboratory.

III. ANALYSIS AND RESULTS

3.1 Geomorphological Analysis

Bangladesh is part of a complex tectonic setting where three plate boundary collision forces are active in and around the country area. At the confluence of the Indian plate and the Burma platelet, the Cretaceous to Holocene Bengal Basin creates a "remnant ocean basin" (Mitchell and Reading, 1986). This basin is beneath the deltaic portions of Bangladesh and nearby India, as well as the Bay of Bengal (Curray et al., 1982). Physiographically the studied area covers some parts of the Bengal basin of Bangladesh (Alam et al., 2003).

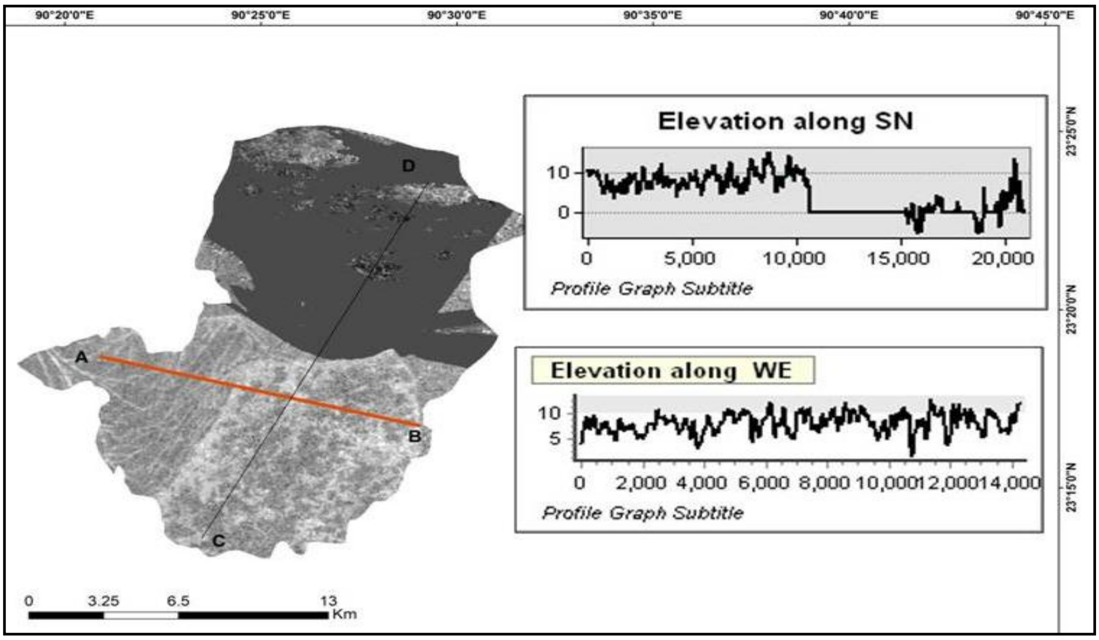

Figure 2. Elevation profile along SN and WE derived from the SRTM (Shuttle radar topographic mission)

By studying the aerial photographs of 1954, four types of geomorphological units are identified which were verified during the fieldwork. The units are-Tippera surface/ Chandina Deltaic plain, Flood Plain, Lateral Bar, and Active Channel. The studied area is situated on the south bank of the Padma River flowing from north to south. Drainage density is low in the mapped area. Palong and Kiritinasha are the small distributaries of the Padma. From the SRTM image and profilings, it is obvious that the western and eastern part of the mapped area is younger than the middle part. The middle part is comprised of the Tippera surface whereas the western part is the floodplain and the eastern part is the bar. Elevation varies with different geomorphic units (Fig.2). Elevation variation (6m -8m) is low and the slope is very gentle.

To assess the bank line movement or change in shifting, four Google images of 1984, 1990, 2000 & 2019 during the dry season are analyzed. As a typical alluvial river, the River experienced frequent morphological changes. The same holds for the Padma river in the research area. With its morphologically dynamic nature, the Padma River near Naria underwent significant alterations in its right banks and the creation of bars in the left banks from 1984 to 2019. The results of the bank line movement of the river indicate that the right banks of the Padma have changed significantly due to varying erosion and accretion. i.e, channel bar and lateral bar formation on other sides. Erosion curvature is higher in flood plain than on the Tippera surface (Fig. 3).

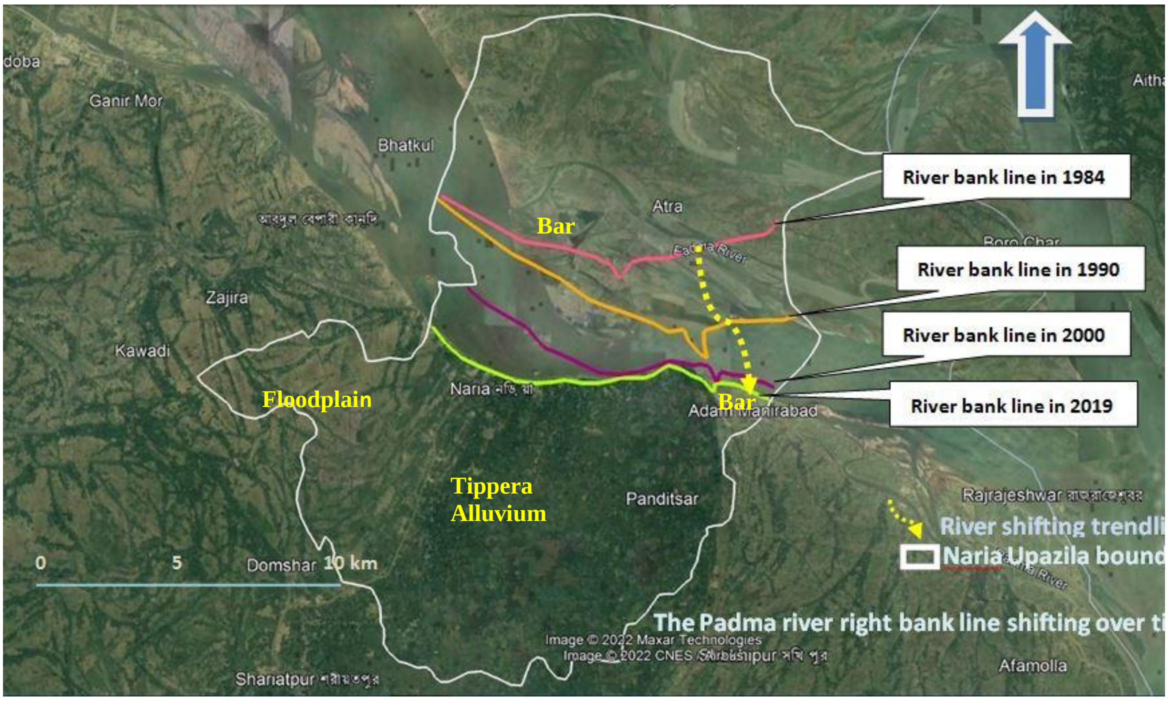

Figure 3. River bank Erosion curvature is higher in the Younger floodplain than in the Mid- Holocene Chandina alluvium. Chanidina Alluvium is about 1m high than the surroundings.

3.2 Surface and Subsurface Geological Analysis

Surface and subsurface geological data were calculated from the Auger and SPT borehole data. Data shows that the study area is mainly composed of Chandina Alluvial/Tippera deposits, Floodplain deposits, and Bar deposits (Fig.4). Sedimentary and lithologic characteristics are discussed below-

Tippera surface/ Chandina Deltaic plain/ Chandina Alluvium

Tippera surface is a distinctive alluvial physiographic unit identified in the Eastern Part of the Bengal Basin flanking the Tripura Hills. It lies between the uplifted Lalmai Deltaic Plain and the Meghna Flood Plain. It is uplifted to the southeast a few feet higher than the adjacent flood plain of the Meghna River (Alam et al., 1990; Bakr, 1977; Morgan and McIntire,1959). Data from Shallow boreholes with hand augers up to 3 m depth shows that the chandina alluvial consists of light olive gray (5 Y 5/2) silty clay, light gray (N6) clayey silt, moderately mottled yellowish brown (10 YR 5/4) silty clay, and from 2.6 to 3 m depth it consists of medium bluish gray (5 B 5/1) silty clay.

The sediment sample collected from the SPT borehole suggests that the upper 5 to 7m consists of mainly yellowish brown and light gray silty clay, medium gray clayey silt, and the lower part mainly consists of light olive gray colored very fine to fine sands and greenish gray colored fine to medium sand. Sands are thinly laminated. The sediments are moderately compacted in hand specimens (Fig.5a, 5b & 6).

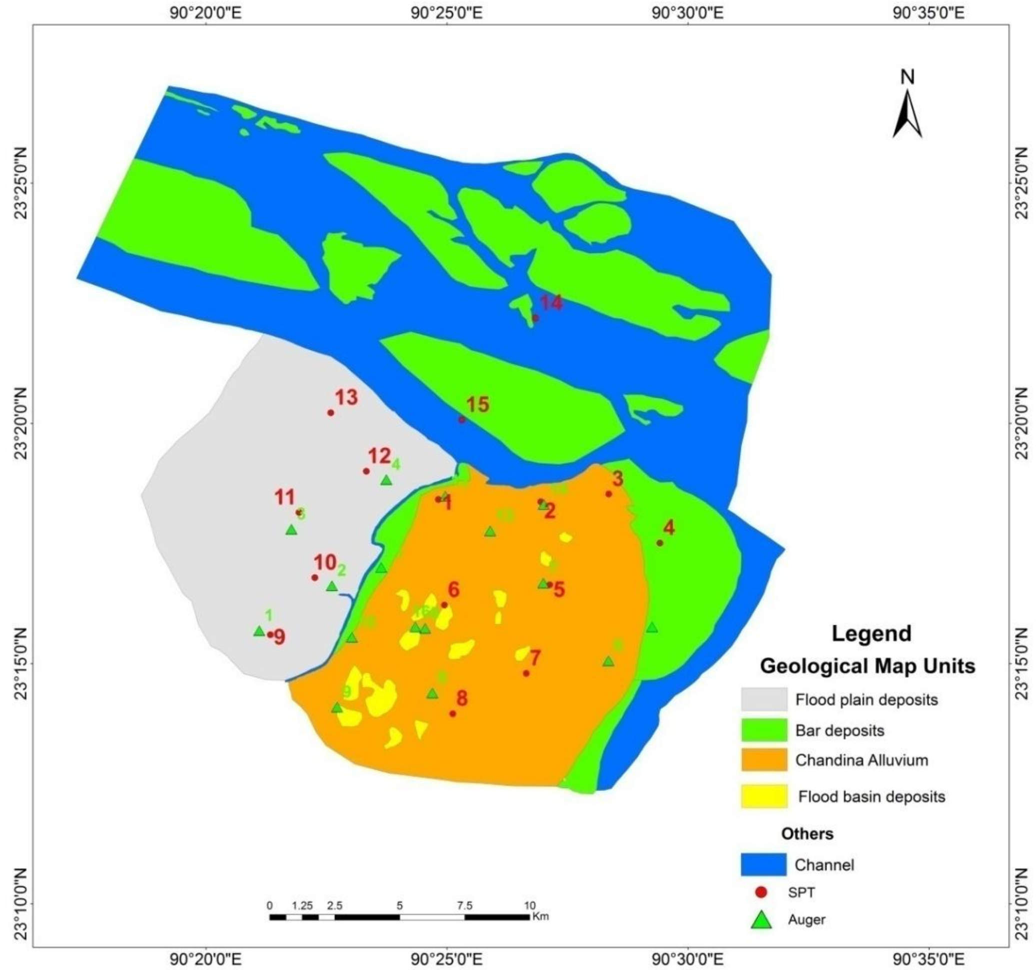

Figure 4. Geological Map of the Naria Upazila and its surroundings

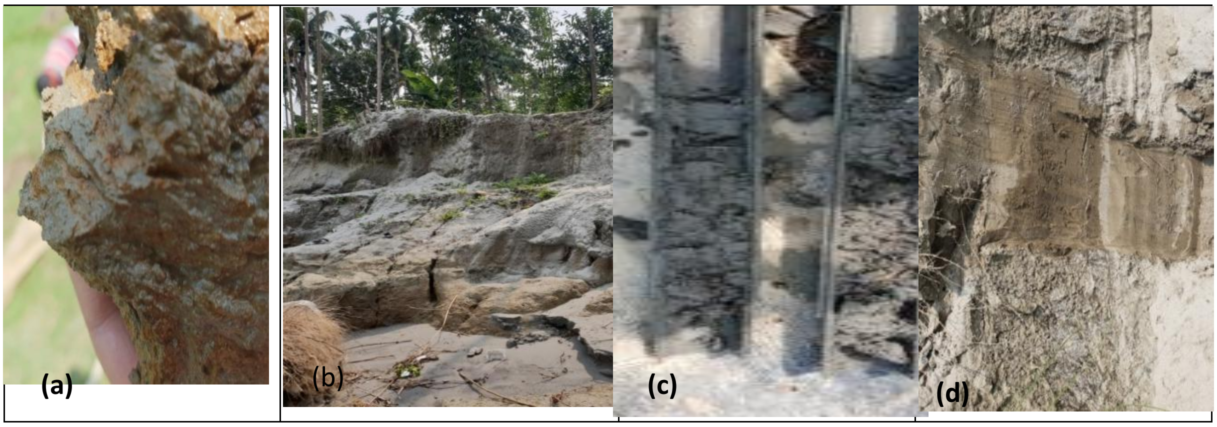

Figure 5. (a) Moderately compacted sediments of the middle part of the chandina alluvium (b) Vertical section of the oxidized surface of Chandina alluvium (c) Flood plain sediments, and (d) Loosely compacted sediments of Channel bar deposits

Flood Plain Deposits

Shallow borehole data from the southern part of the flood plain reveal that the deposits consist of light olive gray and greenish gray silty clay, greenish very fine silty sand. Undisturbed samples from the SPT borehole explicit that the upper 25.5m of the deposits consists of greenish gray colored very fine to fine sand, greenish gray colored fine to medium sand, and medium-grained gray clayey silt (Fig 7).

Flood Basin Deposits shows upper 3m consists of light olive gray (5 Y 5/2) colored clayey silt, light olive gray (5 Y 5/2) silty clay, yellowish gray (5 Y 7/2) clayey silt, and very fine sand. Undisturbed sample from SPT borehole (30m depth) it is evident that upper portions, up to 12 m consist of light gray clayey silt, greenish gray very fine sand with silt and the middle portion consists of laminated very fine sand and clayey silt and the lower portion consists of very fine sand with gray color clayey silt and medium to fine-grained sand.

Bar Deposits

The Channel bar deposit comprises mainly light greenish gray very fine to fine sands, fine sands with some silty clay, and fine to medium sands. Sediments are very loosely consolidated (Fig. 8).

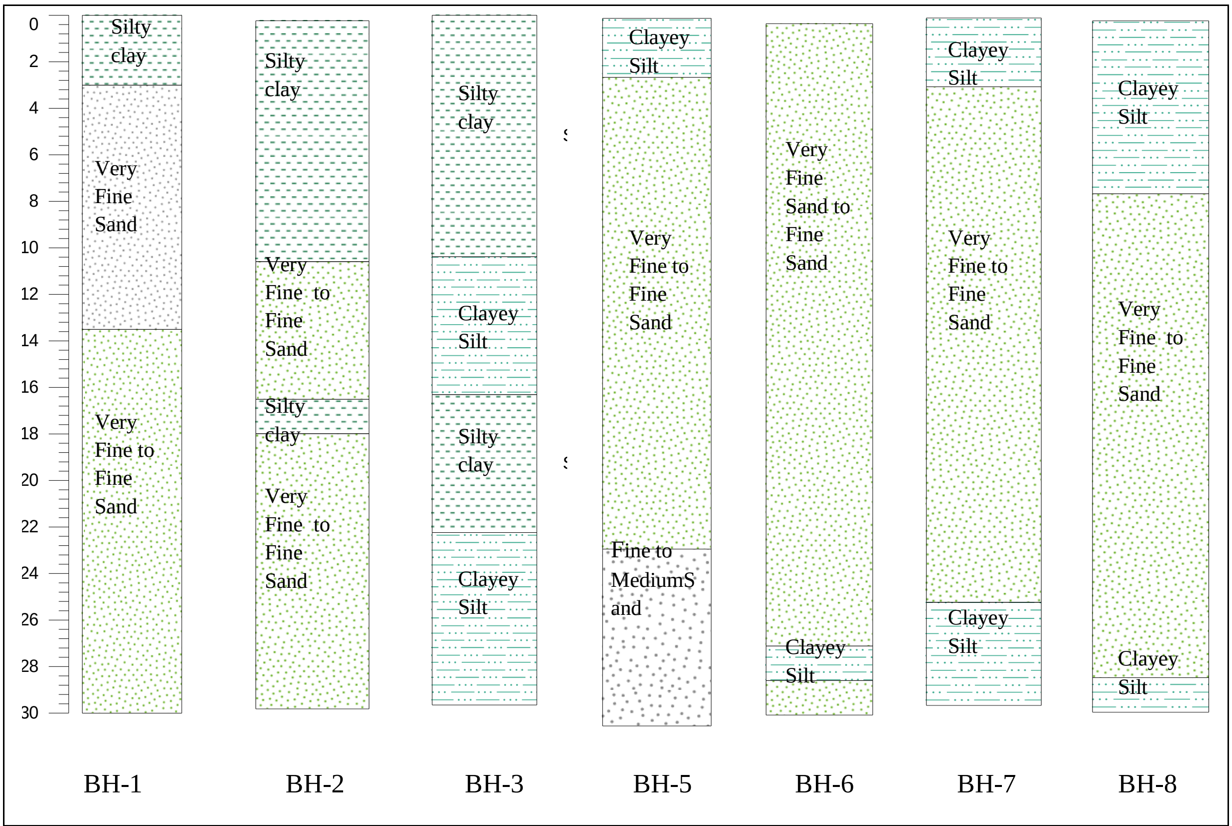

Figure 6. SPT Bore holes data on Tippera / Chandina alluvial deposits,

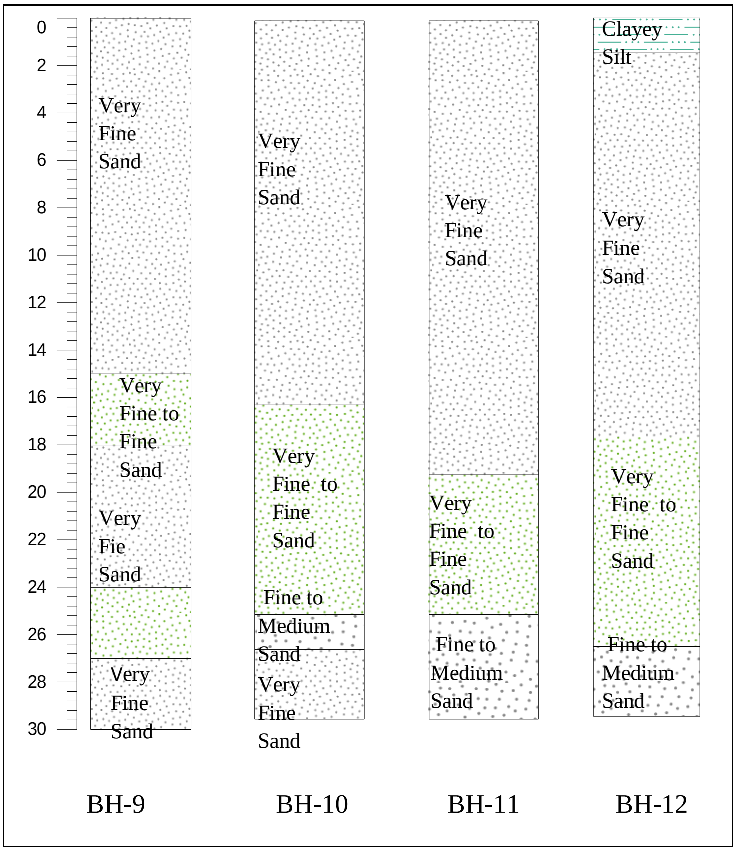

Figure 7. SPT Bore holes data on Flood plain deposits

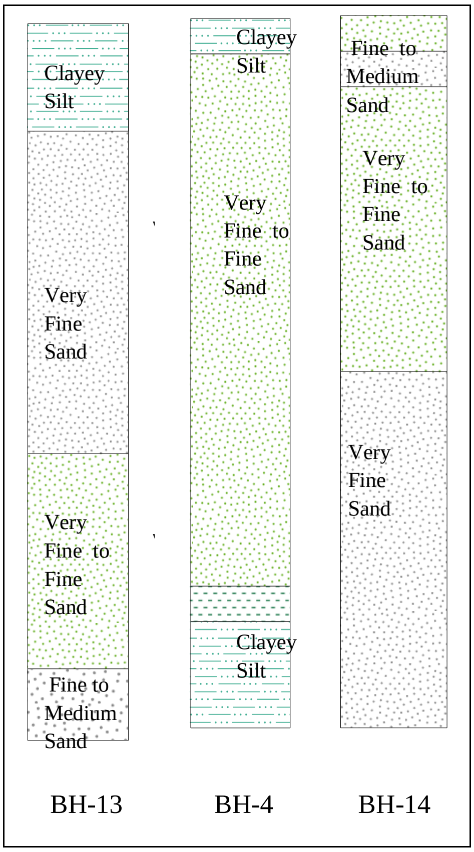

Figure 8. SPT Bore holes data on Bar deposits

3.3 Geotechnical Analysis

To get the N values of the sub-surface three geological units, 15 SPT boring up to 30 meters have been done. Among them, 7 are on Tepera/ Chandina Alluvial deposits, 5 on flood plain deposits, and 3 on Bar deposits. Some geotechnical laboratory tests like grain size analysis, Atterberg limit (liquid limit, plastic limit, and plasticity index), friction angle, and cohesion are determined. The results have been tabulated in Table1, 2, & 3. Samples were collected from different lithological units.

In Chandina alluvium, SPT-N values range from 3 to 30 up to a depth of 20 m depth and increase up to 80 with increasing depth. Whereas in the flood plain deposits N value ranges from 1 to 20 in the upper 20 m depth and increases up to 45 with depth and on bar deposits N values are calculated from 1 to 12 up to the first 20 m depth and increase up to 25. According to Meyerhof, 1956 (Table 1), the sediments of Chandina Alluvial deposits are compact to very dense, floodplain sediments show compact to dense, and bar sediments are very loose to compact soil packing in nature.

Table 1: SPT N-value versus friction angle and relative density (Meyerhoff, 1956)

SPT N Blows /0.3m	Soil packing	Relative Density%	Friction angle
<4	Very loose	<20	<30
04-10	Loose	20-40	30-35
10-30	Compact	40-60	35-40
30-50	Dense	60-80	40-45
>50	Very dense	>80	>45

The grain size analysis study shows that the sediments of Chandina Alluvial deposits mostly comprise silt and sand size particles, Flood plain sediments mostly consist of Silt with some sand, and Bar sediments consist of mostly sand. Laboratorical results are tabulated in table 2.

Table 2: Particle-Size Classification

Tippera/Chandina deposits

Sample ID	Depth	Sand	Silt	Clay
BH-1	1.5	2	93	5
	9	7	89	4
	15	89	11	0
	22.5	84	16	0
	28.5	76	24	0
BH-2	1.5	3	91	6
	9	8	84	8
	15	39	58	3
	28.5	67	32	1
BH-3	1.5	1	67	32
	2.18(UD)	1	88	11
	19.5	3	85	12
	25.5	2	82	16
	30	1	88	11
BH-5	1.5	0	86	14
	2.18(UD)	0	86	14
	6	4	90	6
	10.5	60	38	2
	19.5	78	22	0
	24	90	10	0
	30	90	10	0
BH-6	1.5	5	91	4
	2.2(UD)	1	96	3
	10.5	52	46	2
	15	24	73	3
	22.5	87	13	0
	27	24	73	3
BH-7	1.5	1	89	10
	2.18(UD)	5	90	5
	7.5	83	17	0
	13.5	78	22	0
	18	90	10	0
	22.5	93	7	0
	28.5	1	86	12
BH-8	1.5	1	92	7
	3	3	84	13
	18	87	13	0
	19.5	10	78	12
	30	1	84	15

*Undisturbed samples

Flood plain deposits

Sample ID	Depth	Sand	Silt	Clay
BH-9	1.5	4	90	6
	*2.2	2	90	8
	9	4	88	8
	13.5	6	86	8
	18	66	33	1
	25.5	86	14	0
	30	6	83	2
BH-10	1.5	9	86	5
	2(UD)	2	85	13
	10.5	18	78	14
	18	58	40	2
	27	18	75	7
	30			
BH-11	1.5	5	88	7
	2.2(UD)	1	82	17
	7.5	48	51	1
	13.5	8	84	8
	21	52	48	0
	27	87	13	0
BH-12	2.2(UD)	0	92	8
	3	2	93	5
	10.5	55	44	1
	16.5	92	8	0
	22.5	93	7	0
	25.5	5	85	10
BH-13	1.5	5	89	6
	2.2(UD)	1	91	8
	7.5	12	86	2
	15	51	48	1
	21	93	7	0

Bar Deposits

Sample ID	Depth	Sand	Silt	Clay
BH-4	1.5	45	51	4
	10.5	86	14	0
	15	88	12	0
	22.5	82	18	0
	30	1	83	16
BH-14	1.5	89	11	0
	10.5	83	17	0
	16.5	67	33	0
	22.5	87	13	0
	30	88	12	0
BH-15	19.5	92	8	0
	24	91	9	0
	28.5	85	15	0

Atterberg Limit (Liquid limit, plastic limit, and plasticity index) results of the cohesive soil sample of Tippera sediments and flood plain samples were determined (Table 3). According to Burmister's (1949) soil classification based on the Plasticity index, the values of the Plasticity index of Teppara varies 8 to 26 (average of 15), and floodplain sediments vary from 8 to 31(average of 15.45) which represent low plastic to high plastic.

Table 3: Atterberg Limit analysis result of Borehole & Auger soil samples

Tipera/Chandina Deposits

Sample ID	Depth	Liquid limit	Plastic Limit	Plasticity Index
BH-1	D-1.5m	53	31.03	21.97
BH-02	D-6m	38.1	27.23	10.87
BH-02	D-21m	47.1	28.26	18.84
BH-03	D-3m	39.7	25.42	14.28
BH-03	D-19.5m	41.9	31	10.9
BH-03	D-30m	39.4	28.54	10.86
BH-05	(D-3m)	44.65	33.86	10.79
BH-07	D-30m	40.3	27.73	12.57
Au-08	D-0.4m	54.7	33.61	21.09
Au-8	D-0.9m	38.2	25.58	12.62
Au-11	D-1.6m	32.7	24.48	8.22
Au-11	D-3m	43.6	27.72	15.88
Au-13	D-0.4m	61	34.89	26.11

Flood plain deposit

Sample ID	Liquid Limit	Plastic Limit	Plasticity Index
BH-10	36	26.85	9.15
Au-01	46	26.32	19.68
Au-01	30	21.68	8.32
Ag-02	59.2	27.35	31.85
Ag-03	52.2	43.98	8.22

The direct shear test of sands at different depths was done to determine the shearing strength of the soils (Table 4). The friction angles range from 35.23 to 42.9 in Tippera; from 35.11 to 41.93 in flood plain; from 36.72 to 42.63 in bar deposits and the shear strengths vary from 0.22 to 10.97 kpa, 0.85 to 9.62 kpa, and 1.18 to 5.57 kpa accordingly. The sediments of the study area show nearly close values of friction angles but the shear strength values are a bit higher in Tepepara and very low in bar deposits.

Table 4. Results of direct shear analysis of borehole samples

Sample ID	Depth (m)	Internal Friction Angle (φ)	Cohesion Kpa (c)
Tepera/Chandina Alluvial			
BH-1	15	38.61	0.22
	28.5	38.81	9.62
BH-2	12	38.02^{0}	10.97
	22.5	37.17^{0}	0.85
BH-3	13.5	35.58	1.53
BH-5	16.5	42.9	2.87
	30	35.23	2.13
BH-6	9	42.49	2.87
	22.5	36.27	3.83
BH-7	9	41.78	1.52
	22.5	36.27	1.13

Sample ID	Depth (m)	Internal Friction Angle (φ)	Cohesion Kpa (c)
Flood plain			
BH-9	25.5	36.4	3.66
		38.81	9.62
BH-10	7.5	38.81	9.62
	27	35.11	2.84
BH-11	27	37.17	0.85
BH-12	7.5	41.5	4.22
	22.5	36.27	3.83
BH-13	21	36.27	1.13
	27.5	.41.93	2.87

Sample ID	Depth (m)	Internal Friction Angle (φ)	Cohesion Kpa (c)
Bar deposits			
BH-4	15	36.72	2.34
	24	42.07	2.87
BH-14	1.5	36.72	2.34
	28.5	42.63	1.18
BH-15	1.5	36.72	2.34
	30	40.63	5.57

IV. DISCUSSION AND CONCLUSION

The soil type of the formations has particular relevance to erosion. Physical parameters like grain-size distribution soil type (clay mineral), percentage of clay, liquid and plastic limits and activity, specific gravity, and mechanical properties like shear strength, cohesion, swelling and shrinkage properties, etc. have a great effect on erosion (Paaswell, R. E., Parker, et al., 2008; Pizzuto, 2009).

The study area comprises three geological units- Tippera /chandina alluvial deposits, floodplain deposits, and bar deposits. The mixture of fine size particles like silty clay, clayey silt, and very fine-grained sands of Chandina sediment is less likely to or harder to erode. On the other hand, clayey silt and fine to medium sands of flood plain may have more influence on erosion. Non-cohesive soil of bar deposits consists of larger grains and erodes easily as they do not stick to each other. Moreover, the N-value indicates the relatively dense sediments of Tippera/ Chandina alluvial deposits. **E**mpirical geotechnical correlations to estimate the approximate shear strength properties of the soils represent also the cohesions and higher shear strengths in Tippera sediments.

Moreover, the channel Bars have formed inside the channel, especially on the left bank of the river. The size and shape of the bar are different with time in the surveyed area. The formation of the channel bar is responsible for channel switching on the right bank of the river. River morphology changes with changes in the shape of the river. Mainly shoals are formed in the area which enhances the volume of the channel bar. Thus sediment accumulation or formation of bars on the left bank and higher gradient of Channel bar slope towards the Naria increase the river erosion on the right bank at the study area.

In addition, geologically older sediments of Tippera deposits are more compacted than floodplain and bar sediments that facilitate less erosion than the other two at Naria. Therefore, Physicochemical properties like base exchange capacity, sodium adsorption ratio, pore fluid quality, conditions of the environment, and weathering (wet-dry), freezing, and thawing might have a strong influence on bank erosion. For better understanding and bank management planning it is necessary to study the geologic structure, Sediment Budget, water discharge, and river dynamics also.

However, river bank erosion is a regular phenomenon in Bangladesh every year which make an adverse effect on the local inhabitants. The government is constructing an embankment along with other river bank mitigation work in this area. To develop sustainable structural bank erosion management and land use planning the results of the study could help the policy maker and administrators of the country.

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