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Research Article

VULNERABILITY ANALYSIS OF EMBANKMENT BREACHING – A CASE STUDY OF MOYNA DRAINAGE BASIN IN PURBA MEDINIPUR WEST BENGAL INDIA

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ABSTRACT
The breach of the Moyna drainage basin embankment in Purba Medinipur, West Bengal (India) marked the failure on conventional ways of controlling floods. Present study aimed to investigate the role of geotechnical, geometrical and hydraulic properties on embankment breaching of Moyna drainage basin area. A River Embankment Breaching Vulnerability Index (REBVI) was derived based on weightings of bank material to delineate the risk of vulnerability of the embankment. Amoeba diagram was used to represent the REBVI score. Cluster analysis was performed based on amoeba diagrams and vulnerability index for each indicator. Compaction tests results showed the average bulk densities of the embankment soil are $1.47 g/cm^3$. The average plasticity index (PI) of Moyna drainage basin showed 28.26 per cent. The unconfined compressive strength (CS) of the bank materials varied from $0.43\ kg/cm^3$ – $4.69\ kg/cm^3$, whereas, the mean safety factor (SF) of the drainage basin area was calculated as 0.67. The highest score REBVI values were recorded from Prajabard (Kasai River Right bank) and Gobradan (Keleghai Right bank), and the lowest score calculated at Bakcha (Moyna Drainage Basin Canal) and Dheubhanga (Kasai River Right bank). The result of the amoeba diagram analysis showed Kasai river right bank embankments occupied maximum area than other embankment of this drainage basin. Very high vulnerability points were delineated at Prajabard, Gobradan and Upalda, through cluster analysis, represented less potential to prevent embankment breaching.

Key Words: *Embankment, Bank Material, Geotechnical Analysis, Bank Geometry, Multi-Criteria Analysis*

INTRODUCTION
Embankment breaching, an episodic process in fluvial dynamics, is affecting a wide range of physical, ecological and socio-economic issues in the fluvial environment, especially in developing countries. Because embankments are built of earth, usually that is presented locally, and are predisposed to breaches. These include the establishment and evolution of river and floodplain morphology and their associated habitats (Darby and Thorne, 1996a; Barker *et al.*, 1997; Millar, 2000; Goodson *et al.*, 2002), turbidity problems (Bull, 1997; Eaton *et al.*, 2004), sediment, nutrient and contaminant dynamics (Reneau *et al.*, 2004), loss of riparian lands (Amiri-Tokaldany *et al.*, 2003), and associated threats to flood defense and transportation infrastructure (Simon, 1995). However, it can generate problems when rivers erode lands, wash away crops and demoralize the basis of local livelihoods. Moreover, floods increase the productivity of land, while fine sediment brought by river water; conversely, the deposition of large particles by sand casting harms agriculture.
However, Moyna drainage basin area is located in Purba Medinipur district of West Bengal (India), where agriculture and fishing are the primary source of income of local people through out the historical past. However, earthen embankments in Moyna drainage basin (West Bengal) are beset with multi-facetted problems, such as erosion, breaching in every year. Historical records show that flooding and agricultural

drought in the Moyna river basin has occurred every year in the past (Sahu, 2009). Over the last 70 years, there are records of at least five flood events and 5 agricultural drought events caused considerable damage (Sahu, 2009) due to the breaching of embankment, floods occur and thereafter an imbalance is found in the physical system as well. The major causes of failure identified were breach of the embankment, cutting by the public, overflow, erosion, seepage and sliding. Furthermore, insufficient supervision during construction results in poor-quality earthworks with the use of inappropriate soil materials, insufficient clod breaking, inadequate compaction of topsoil layers, and the use of inferior materials, inadequate maintenance, river migration and cutting by the public (Dixit, 2009; Hoque and Siddique, 1995) are perspective to the problem. Among many reasons, the improper design methodology and construction procedure is prime and one of the most important causes of embankment failure.

Previous study showed that the stability of earthen embankments is influenced by seepage occurred during the increase and decrease of the adjacent water level in the river or reservoir (Morii and Kunio, 1993). Study carried out by Hossain *et al.,* (2010), reported that geotechnical properties of embankment material both decreases rapidly with the increase of water content which associates the bank failure process. However, clear understanding of material behaviour is necessary to interpret the failure phenomenon of a particular problem. To acquire appropriate understanding, earlier researchers documented to characterize geotechnical properties of soil facing mass failure problem like landslides or containing organic matters (Ahmad *et al.,* 2006; Huat *et al.,* 2009). In this study, only bank material has been considered for estimating the embankment breaching. Differential physical properties of cohesive and non-cohesive bank materials result in marked differences in erosion rates, erosion processes and failure modes. Although fine-grained materials are resistant to fluid shear, they tend to have low shear strength and are susceptible to mass failure (Iverson, 2010; Das and Wadadar, 2012). The amount, periodicity and distribution of embankment breaching are highly inconsistent as they are prejudiced by a multitude of aspects (Haque, 1998). In general terms, embankment erosion is accentuated under high discharge conditions (bank full stage), but the efficacy of these flows is dogged by bank condition at the time of the event. The effectiveness of weakening fluvial erosion and mass failure processes tempt considerable variability in the rates of embankment breaching, unsteadiness and retreat.

The present study aimed to investigate the physical, mechanical and geotechnical properties of the embankment material of Moyna drainage basin area, and we also evaluated an existing design methodology for embankment stability analysis through a case study.

MATERIAL AND METHODS

Study area

Moyna drainage basin is situated on north-west part of Purba Medinipur district in West Bengal, India. The basin are is extended from 22° 9' "N to 22° 18' "N latitude and 87° 42' E to 87° 51' E longitude, covered with an area of 154.51 km^2 (Fig. 1). The basin area is bounded by the river Kossai and Chandia from the east and west respectively. River Chandia and Keleghai are on the south and the Baksi canal is located on the north of the basin.

The relief of the Moyna drainage basin is varying from 3 to 6 m. It is a typical trough which is fairly elongated and roughly triangular in shape. The tough deep depressions are found in the village like Baital Chack, Charandas Chak, Lalugeria, Maturichak, etc. Southern part of the basin is deeper rather than the northern part. Settlements area and embankment is representing relief variation at the micro level. The surface soil is sandy loam and clayey. The Moyna drainage basin is characterized by the year wise rainfall variation, showed the vagaries of tropical monsoon climate. The mean annual temperature is around 28.5°C, and the average summer (May) and winter (December) temperatures varying from 45° C and 13 ° C respectively. The mean annual rainfall is about 1850 mm. The seasonal fluctuations of rainfall over the study area have a grate impact on the water discharge with in the Kansai and Chandia river which is directly influenced to the overtopping process of embankment breaching during the rainy season (e.g., July- August).

Collection of bank materials and geotechnical attributes analysis

Field surveys were carried out during the monsoon season. During the field investigation, disturbed and undisturbed samples were collected of the proposed embankment and foundations materials for laboratory testing. In order to know the nature of bank materials, the soil samples were collected directly from the broken parts of the embankment of Moyna drainage basin area in Purba Medinipur district (Figure 1).

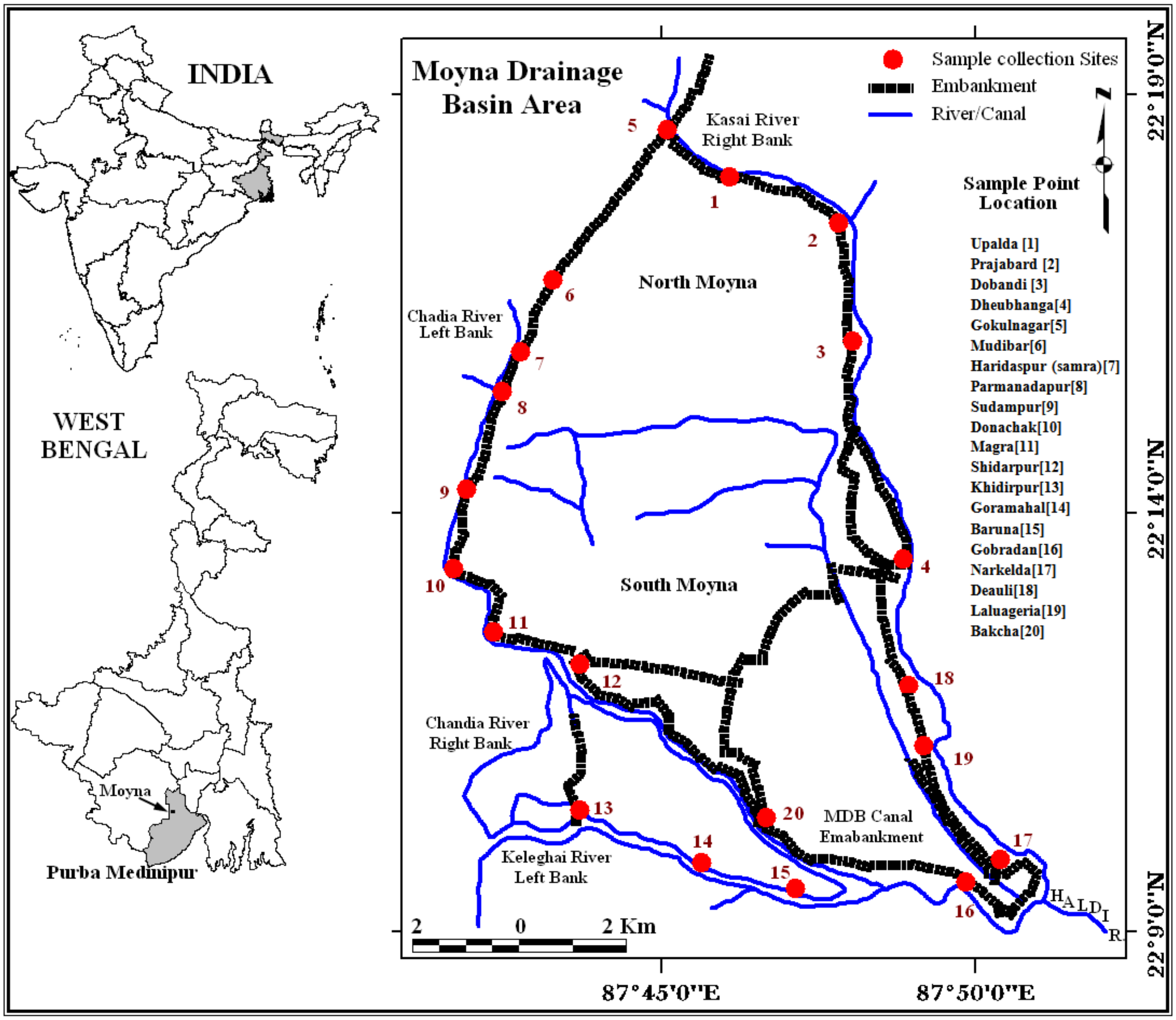

Figure 1: Location map of the study area

A total of twenty soil samples were collected by cylindrical core to investigate the geotechnical attributes of earthen embankment. However, the samples were collected from the bank top, middle and lower part of the bank. Laboratory testing is performed to determine the index properties of the soil samples in order to classify the soil materials, and to estimate the drained and undrained shear strength properties of the fill materials. The laboratory tests were performed in Geography Laboratory of Vidyasagar University, Medinipur (West Bengal, India) and Geotechnical Laboratory, Geological Survey of India (GSI), Kolkata, India. The testing measures were in accordance with American Association of State Highway and Transportation Officials (AASHTO, 1982) and Indian Standard Method of Test for Soil (Part-XV), 1965. The tests include particle size analysed through Sieves, bulk density, liquid limit (ωL, %) and plastic limit (ωP, %) (IS: 2720 Part-V). More detailed investigations were undertaken including plasticity index (PI)

Research Article

followed by Burmister (1972), unconsolidated Shear Strength (λ) and shear stress (τ) by triaxial Compression test (Casagrande, 1936 and Terzaghi, 1936) and unconfined compressive strength test (IS: 2131-1981), (Peck, Hanson and Thornburn, 1976). The collected soil was classified based on United States Department of Agriculture (USDA) classification system. Detailed observations on embankments structure and water level were also measured by appropriate field techniques, since these areas often provided additional information on mechanisms of failure in that embryonic stages of breaching

Geometry of embankment

To investigate the geometry of embankment, a detailed observations of breach parameter included bank top height, base width, and bank slope were investigated. To measure the slope in the field, Clinometer (Geo Surveyor Pocket Transit 002A model) instrument was used for each sampling point. Slope of the target area is measured in degree. The measuring tape was used to estimate the bank top height and base width of each sampling site. We used a measuring stump to estimate the bank top height in the field (Figure 2).

Figure 2: Bank top height measurement at Moyna River bank

Hydraulic pressure

In the Moyna drainage basin area, the water level of the sample sites were measured directly through interview of the local people, and with Gage height data during the peak runoff condition of flood situation.

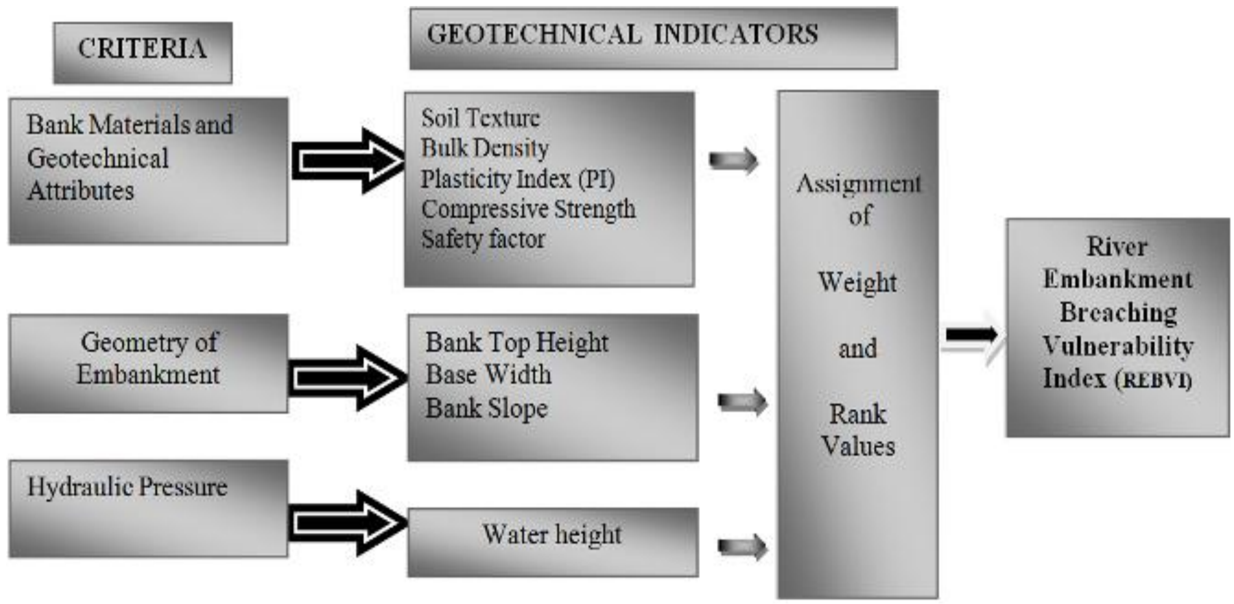

Figure 3: Methodological approach of River Embankment Breaching Vulnerability Index (REBVI)

Table1: Transformation of absolute values into Weighted value (W).

Weight value	**Bank Materials and Geotechnical Analysis**					**Embankments Structure**			**Hydraulic Pressure**
	Soil Texture	**Bulk Density (g/cm^3)**	**Plasticity Index (PI= LL-PL)**	**Compressive strength (kg/cm^2)**	**Safety Factor SF= Shear strength(λ)/ Shear stress (τ)**	**Top height (Bank Height, m)**	**Base Width (m)**	**Bank Slope (outer slope in degree)**	**Water height (m)**
0	Loam	<1.30	>40(Very High)	>4 (Hard)	<0.2	>9	>20	<30	<4
1	Sandy clay	1.30-1.40	20-40 (High)	2-4 (Very Stiff)	0.2-0.4	8-9	15-20	30-35	4-5
2	Clay loam	1.40-1.50	10-20 (Medium)	1-2 (Stiff)	0.4-0.6	7-8	10-15	35-40	5-6
3	Silt loam	1.50-1.60	5-10 (Low)	0.5-1 (medium)	0.6-0.8	6-7	5-10	40-45	6-7
4	Sandy loam	>1.60	<5 (Very low)	<0.5 (soft)	>0.8	<6	>5	>45	>7
Rank value	1	2	3	4	5	1	2	3	1

River Embankment Breaching Vulnerability Index (REBVI)

In this analysis zone of embankment breaching was delineated based on a multi-criteria analysis (Figure 3) using bank materials and geotechnical attributes. Variables such as bank materials, geotechnical attributes, and geometry of embankment either individually or in combination are known to be associated with the embankment breaching. According to their degree of embankments breaching during storms, simple weightings were calculated for all of the input variables leading to a multi-criteria approach. We utilized weighting systems based on the values from 0 – 4, where, '4' means very highly vulnerable, '3' highly vulnerable, '2' moderately vulnerable, '1' less vulnerable, and '0' less very less vulnerable.

Furthermore, based on their importance and stability of materials to potential of embankments breaching each set of continuous data (e.g., for each indicator) were ranked from 1 – 5. The ranked assigned to different features of the individual themes are presented in Table 1.
After deriving the normal weights and ranks of all individual parameters were integrated with one another in a linear model in order to demarcate REBVI in the study area. The equation of REBVI is as follows:
REBVI = $(R_{ST}*W_{ST})+(R_{BD} * W_{BD})+(R_{SF} * W_{SF})+(R_{TH} * W_{TH})+(R_{BW} * W_{BW}) +(R_{BS} * W_{BS}) +(R_{WH} * W_{WH})$ ……………………… (*Equation 1.)*
Where, R= rank value, W= weight value, AV= Absolute value. ST= Soil Texture, BD= Bulk Density, SF= Safety Factor, TH= Top Height, BW = Base Width of Embankment, BS= Bank Slope, WH= Water Height
The result of the REBVI showed that the highest score is less potential for embankment breaching and/or river bank erosion. The score of vulnerability Index for each indicator is plotted by an amoeba diagrams to compare all indicators of REBVI model against each other. The amoeba diagrams is represented the score of vulnerability index with the nine indicators forming the axis.

RESULTS AND DISCUSSION

Geotechnical Properties of Embankment

The soil texture, bulk density, plasticity index, compressive strength and safety factor are most importance geotechnical parameters of an embankment, for its stability, and to potential embankment breaching, which may aids to protect the flood (Pierce *et al.*, 2011). Table 2 shows the geotechnical parameters of embankment. Soil texture of the embankment of Moyna river basin showed most of the soil are sandy loam and sandy clayey in character. In some of the sample sites, silt loam soils were also collected. At Prajabard, Gobradan, Upalda, Gokulnagar and Donachak soils were very fine sandy loam. Very less amount of fine silt loam soil was assembled in the drainage basin area. The very fine sand and coarse silt were of 75% among these grain size. The cohesion (C) was less in the fine sand and very fine sand soils, rather than silt, hence, it offers a less stability of embankment and resulting more breaching during strong hydraulic action. The triaxial compression test on geotechnical attributes of embankment material showed that angle of internal friction (θ) of embankment material are approximate two degree, indicate materials get temporal stability at very low angle. It is reported that the process of slope instability and instantaneous failure occurs during the breaching process (Osman *et al.*, 1988). The riverward slope exceeds the stability angle (>2 degree), indicated intensive geotechnical and internal instability. The slope at Prajabard, Gobradan, and Donachak exceeded the stability angle e.g., 2.5, 3.1 and 2.12 respectively.
The compaction tests results showed the average bulk densities of the embankment soil are 1.47g/cm^3 (standard deviation ± 0.17). The maximum bulk density was recorded in Gobradan village (1.76 g/cm^3), located on the right bank of Keleghai river. Alternatively, the lowest bulk density was recorded from the Shidarpur (located on right bank of Chandia River (1.24 g /cm3). However, in our analysis we found a strong positive correlation between the bulk density and safety factor (r = 0.60, $p<0.03$), and bank slope (r = 0.61, $p<0.05$). Furthermore, a strong negative correlation was calculated between the bulk density and compressive strength (r = 0.59, $p<0.014$).
The moisture content between the plastic and liquid states is known as the liquid limit (LL). The difference between the plastic and liquid limits is called the plasticity index (PI), and indicates the size of the range over which the material acts as a plastic – capable of being deformed under stress, but maintaining its form when unstressed. Highest plasticity index (PI) of the embankment in Moyna drainage basin area was recorded from Khidirpur (48.24 %), situated on the right bank of Keleghai river, while the minimum value was 4.16, recorded from Prajabard (Right bank of Kasai river). However, the average PI of Moyna drainage basin area was 28.26 (%) (Standard deviation ±13.65). The highly plastic materials are more likely to have high levels of saturation after compaction and subsequent low shear strengths by comparison with lower plasticity clays (Skerman et al. 2004). Field moisture control for high

plasticity clays is a very effective means of controlling embankment breaching (White *et al.*, 1999; Hunt *et al.*, 2005; Dyer *et al.*, 2007). A negative correlation was illustrated with the safety factor and plasticity (r = 0.49).

Unconfined compression tests can be used to estimate the undrained shear strength (Su) of saturated, fine-grained foundation materials. The unconfined compressive strength (CS) of the bank materials varied from 0.43 kg/cm^3 – 4.69 kg/cm^3. Highest CS value was recorded from Bakcha (Moyna drainage basin canal); while lowest values was evidenced from Gobradan (Kelaghai right bank). The average CS of the drainage basin was 2.61 kg/cm^3 (standard deviation 1.32). However, in our analysis, a strong positive linear relationship was observed between the plasticity index and compressive strength (R^2 = 0.78; $p<0.001$), of the bank materials.

Geotechnical models of bank stability imply a direct relationship between bank cohesion and the safety factor (SF) that estimates the risk of bank failure (Thorne, 1978). Our results showed the highest SF of the Moyna drainage basin was 0.89, documented at Prajabard (right bank of kasai river). The lowest SF value (0.51) was witnessed from Dheubhanga. The mean SF value of the drainage basin area was calculated as 0.67 (standard deviation ±0.08). It was observed that a strong negative correlation between the safety factor and compressive strength (r = 0.59, $p<0.05$).

Geometrical Properties of Embankment

The important geometrical parameters of an embankment structure are imperative for its stability and potentiality for protecting itself from fluvial hydraulic force (Hunt *et al.*, 2005). Slope played an important role in embankment breaching (Hossain *et al.*, 2010; Hanson *et al.*, 2011). The embankments of Moyna

Table 2 Embankments materials, structure, geotechnical attributes and River Embankment Breaching Vulnerability Index (REBVI) drainage basin areas were consisted with the earthen material, which washed off the fine particles by rainfall as well as run off during monsoon, where the slope is very high. At Prajabard and Gobradan are highly vulnerable areas, where, the inner slope of embankment is varying form 50 – 52 degree. The outer slope of this region is ranging from 53- 56 degree, and the top width of the embankment is diverging from 1.67 – 2 meters. The bank height of the study area varied from 6.4 – 9.5 meters (mean ± SD – 8.25±0.81). However, at the less vulnerable area (Bakcha) shows that the inner slope is 23 degree, while outer slope is 30 degree and the height of embankment is 8.7meter, with 3.5 meter top width. It was reported that steeper slope contribute to sediment transport and to bank erosion and are often associated with coarse heterogeneous materials (Leopold *et al.*, 1964). Bank instability and erosion frequently results in excessive sediment input into the channel and thus affects the channel morphology through increasing width and decreasing depth. Moreover, the base width of the bank areas varied from 10.5 – 16.5 meters (mean ± SD – 13.40±1.55). In our analysis, we observed that there is positive and significant association between the bank height and compressive strength (r = 0.63), and safety factor (r = 0.70) of bank materials. Non-cohesive bank material i.e., sand governs the bank with maximum percentage at 2 - 4 m depth (90%), leads to maximum erosion which ultimately leads to widening of the channel (Das *et al.*, 2012). Pugh (1985) studied the breaching and wash out of specially designed fuse plug embankments for control of emergency spillways. The embankments tested were designed to breach quickly and then erode laterally at controlled rates. Hence, considering the least cost affectivity, the sandbag application could be the practical way of protecting embankment dam in Moyna drainage basin. Besides sandbag; a thin layer of cement composites can be used as a measure of slope protection. The embankment material has got a very low strength and thus, very vulnerable to slope failure and erosion process. Hence, the slope surface needs to be protected from erosion, occurring due to heavy rainfall, run off and the strong wave during high flow of river. On the other hand, the slope of the

Table 2: Embankments materials, structure, geotechnical attributes and River Embankment Breaching Vulnerability Index (REBVI)

Moyna Embankments	**Location/ Sample site**	**Bank Materials and Geotechnical Analysis**					**Embankment Structure**		**Hydraulic Pressure**		**REBVI**
		Soil Texture (ST)	Bulk Density (g/cm^3) (BD)	Plasticity Index (PI= LL-PL)	Compressive Strength (kg/cm^2) (CS)	Safety Factor SF= Shear Strength(λ)/ Shear Stress (τ)	Top Height (Bank Height, m) (TH)	Base Width (m) (BW)	Bank Slope deg (BS)	Water Height (m) (WH)	
Kasai River Right bank	Upalda	Sandy loam	1.67	9.45	0.84	0.64	6.4	15.5	40	6.1	65
	Prajabard	Sandy loam	1.74	4.16	0.46	0.89	7.2	12.4	52	6.5	78
	Dobandi	Silt loam	1.62	18.41	1.34	0.77	8.4	15.2	34	6.1	51
	Dheubhanga	Silt loam	1.39	32.64	3.54	0.51	8.8	16.5	23	5.6	28
Chandia River Left bank	Gokulnagar	Sandy loam	1.64	18.58	1.31	0.67	7.6	12.8	42	6.6	59
	Mudibar	Clay loam	1.31	23.94	2.54	0.62	8.8	13.4	39	7.1	41
	Haridaspur (samra)	Clay loam	1.41	12.47	1.93	0.63	7.5	12.4	36	6.8	48
	Parmanadapur	Sandy clay	1.29	34.71	3.24	0.54	8.9	13.8	38	6.3	32
Chandia River Right bank	Sudampur	Silt loam	1.51	45.12	4.15	0.69	9.1	15.2	43	6.2	38
	Donachak	Sandy loam	1.68	41.38	3.25	0.71	8.9	13.5	46	6.9	51
	Magra	Clay loam	1.34	35.67	3.51	0.68	9	15.4	39	7.1	39
	Shidarpur	Loam	1.24	31.29	2.64	0.65	7.8	14.2	34	6.3	34
Keleghai Right bank	Khidirpur	Sandy clay	1.51	48.24	4.68	0.61	9.5	12.4	36	8.2	36
	Goramahal	Sandy clay	1.46	41.34	3.31	0.64	8.7	13	32	7.4	36
	Baruna	Clay loam	1.54	13.19	1.31	0.76	8.5	10.5	47	7.2	58
	Gobradan	Sandy loam	1.76	8.42	0.43	0.77	7.9	11	50	6.8	73
Moyna Drainage Basin Canal	Narkelda	Loam	1.34	35.61	2.35	0.67	7	12.4	26	6.2	33
	Deauli	Sandy clay	1.54	43.54	3.14	0.66	8.5	13.4	24	5.6	33
	Laluageria	Sandy clay	1.25	37.46	3.62	0.71	7.8	12	32	5.5	34
	Bakcha	Sandy clay	1.32	29.49	4.69	0.61	8.7	13	23	5.4	28

embankment of Kasai river (right bank) is found not well protected. In some places (Parmanadapur, Magra, Donachak, Gokulnagar, Prajabard, Gobradan, Upalda) of the embankment, sandbags have been used during storm; however, these are not well supported due to inefficient placement and lack of maintenance.

Hydraulic Pressure

During flood events, an embankment may need to withstand a rapid rise in water level on the outward face, along with the corresponding changes to internal water pressure (and perhaps seepage) driven by the higher hydraulic gradients across the embankment (Morris *et al.*, 2007). Hydraulic pressure of Moyna drainage basin area is expressed in terms of water height. Water height of the drainage basin area varied from 5.4 – 8.2 meter. The average water height of this drainage basin was 6.50 meter. The maximum water height was recorded from the Keleghai right bank (~7.4 meters), while minimum water height documented on Moyna drainage basin canal (~5.76 meters).

The embankments are relatively old structures that have evolved over decades or even centuries from original constructions. A review of traditional earthwork materials used to construct flood embankments found a wide range of soils and rocks used as fill material depending on the local geology and particularly the superficial deposits (Dyer and Gardener, 1996).

River Embankment Breaching Vulnerability Index (REBVI)

The results of River Embankment Breaching Vulnerability Index (REBVI) are presented in Table 2. The highest score REBVI values were recorded from Prajabard (Kasai River Right bank) and Gobradan (Keleghai Right bank). The Prajabard and Gobradan area were portrayed with sandy loam soil, >50 degree slope, high hydraulic pressure (>6.5 m) and high safety factor. The embankment stability of these areas was also very low that aids to embankment breaching during the rain storm and at high water pressure. The calculated lowest value of REBVI is 28, recorded at Bakcha (Moyna Drainage Basin Canal) and Dheubhanga (Kasai River Right bank). These areas were characterized by silt loam and sandy clay soil, water pressure was low (approximately 5.5 meter), the elevated embankment with less slope (<23 degree). So, this place is more stability and protected for embankment breaching. The REBVI value is ranging from 40 – 55 showed the medium risk for vulnerability. Mudibar and Haridsahpur (Chadia river left bank), Donachak (Chadia river right bank), and Dobandi (Kasai river right bank) dropped in this category. Soils of these regions are characterized by sandy and clayey loam. The average slope of this region is 38.75 degree (SD = ±5.25). However, the hydraulic pressure in this region is similar to high vulnerable zone.

Amoeba Diagrams Analysis

Moyna drainage basin area is bounded by five embankments viz. Kasai river right bank, Chandia river left bank, Chandia river right bank, Keleghai right bank and Moyna drainage basin Canal (Figure 1). The river embankment breaching vulnerability index (REBVI) of these five embankment regions were represented in amoeba diagrams (Figure 4). The result of the amoeba diagram analysis showed Kasai river right bank embankments occupied maximum area than other embankment of this drainage basin. Keleghai right bank embankment is occupied as second position of vulnerable point for embankment breaching. In this embankment region, the calculated value of REBVI at Gobradan and Baruna was maximum, e.g. 73 and 58 respectively.

In general, breaching is observed at the deeper concave bank of the meandering course. The constants need for adjustment of gradient with load necessitates the shift of thalweg point and thus the embankment breaching prone areas are also changing. Overtopping is the most destructive mechanism, observed during rainy monsoon season in the drainage basin area. The river flow becomes supercritical on the opposite side of embankment and thus erosion starts on that side. Additionally, the embankment may obliterate for meters together by this process.

Cluster Analysis

Finally, a cluster analysis was performed based on amoeba diagrams and vulnerability index for each indicator (Table 3) of embankment breach. Fives cluster was delineated of Moyna drainage basin area,

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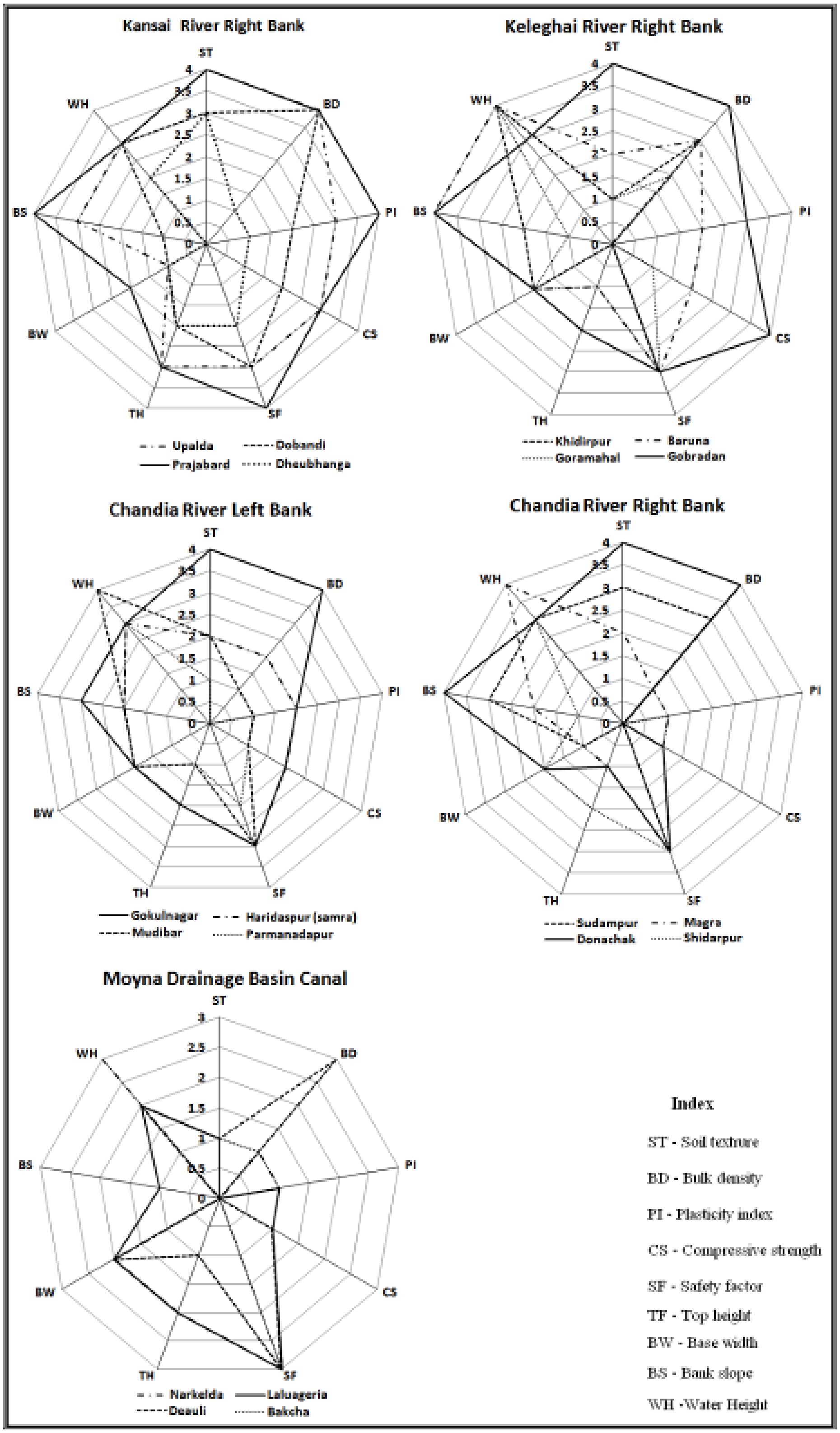

Figure 4: Amoeba Diagrams indicating the River Embankment Breaching Vulnerability Index (REBVI) of Moyna Drainage Basin Area

Table 3: Probability of Embankment Breaching zoned in five clusters according to their River Embankment Breaching Vulnerability Index (REBVI)

Cluster	Range of River Embankment Breaching Vulnerability Index (REBVI)	Location of Vulnerability Zone	Consistency of Embankments	Cluster Description of embankment Breaching
I	<40	Narkelda, Deauli, Khidirpur Laluageria, Bakcha, Magra, Goramahal, Dheubhanga, Shidarpur, Parmanadapur, Sudampur	Very High	High potential to prevent embankment breaching and potential for slope stability.
II	41 – 50	Mudibar, Haridaspur (samra),	High	Low embankment breaching
III	51 – 60	Dobandi, Gokulnagar, Donachak, Baruna,	Medium	Moderate potential of embankment breaching
IV	61 – 70	Upalda	Low	High probability of embankment breaching due to overtopping, and subsidence.
V	>70	Prajabard, Gobradan	Very Low	Very High probability of embankment breaching due to bank failure, piping and overtopping.

according to vulnerability index of embankment breach. Cluster-I (<40 REBVI value) and II (REBVI value of 41 - 50) represents very low vulnerability point at Narkelda, Deauli, Khidirpur Laluageria, Bakcha, Magra, Goramahal, Dheubhanga, Shidarpur, Parmanadapur, Sudampur, Mudibar, and Haridaspur (Samra). In this area the consistence of the embankment is very high. Cluster III (REBVI value of 51 – 60) represents moderate vulnerability point at Dobandi, Gokulnagar, Donachak, Baruna. In Cluster IV (REBVI value of 61 – 70) and V (>70 REBVI value) very high vulnerability points were delineated at Prajabard, Gobradan and Upalda, showed less potential to prevent embankment breaching by the fluvial hydraulic action and rainy storm.

CONCLUSION

The present study in a part of inland river of Moyna drainage Basin area of Purba Medinipur district (West Bengal, India) showed geotechnical and geometrical properties of embankment significantly responsible for embankment breaching. Though the areas are suffering from highly breaching, however, Dheubhanga (Kasai river right bank) and Bakcha (Moyna drainage basin canal) is most vulnerable. Embankment Vulnerability point selection is an important for ensuring the success of any geotechnical solution for better management of embankment breaching and its stability. The river embankment breaching is an episodic process of fluvial dynamic system of the drainage basin area. The soils were used for constructing river embankment in this region, found poorly graded sand with higher silt content. The bulk density of the soil is high with the lower strength properties. Moreover, no protective measure was undertaken on the slope and easy to wash off by rain and fluvial action during the monsoon period. In contrast, the Kasai river right bank and Keleghai right bank soil contains mostly the sand particles with 30% silt content. Excessive pore water pressure affects the shear strength of bank material which leads to

Research Article

the mass failure or piping of the embankments. In the study area, bank failure mechanism is closely associated with the formation of tension crack behind the bank face.

Moreover, human intervention in the form of irrigation system for crop cultivation leads to the break of embankment which is again weakening the embankment. This anthropogenic activity is also responsible for the weakening of the non-cohesive soil at the bottom of the embankment and ultimate breaching of the areas during rainy season. Local people are of the opinion that embankment breaching has increased in recent years due to such activity.

The geotechnical properties of embankment materials need to be improved by using additives or reinforcing materials like soil-cement, natural or geosynthetic fiber. It is also suggested to protect the slope by facing materials using geo-bags, cement composites with reinforcement. We also recommended locating the free surface inside the embankment by conducting seepage analysis prior to conduct slope stability analysis, and to obtain more reliable factor of safety in designing stable embankments.

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