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River bank erosion risk potential estimation through mechanical and erodibility analysis of soil: A study on left bank of Ganga river near Malda district in West Bengal, India

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Abstract

River bank erosion is a risky and common phenomenon in Malda district during monsoon and post monsoon periods of every year. One of the significant causes behind this hazard is the geological nature of the river bank. Geologically river bank of the study area is very weak. The nature of river bank soil textural composition has been measured by basis parameters analysis and mechanical analysis of soil and its erodibility level. Sieve analyses has been done on all collected soil samples and determine uniformity coefficient, coefficient of gradation and sorting coefficient as basic parameters, nature of soil through mechanical analysis of particles after Folk and Worst method and the degree of soil erodibility through Bouyoucos Erodibility Index and ROM scale after ROslan and Mazidah. The results show that the erodibility levels become high to moderate condition along middle to lower extension of left bank line and relatively low along upper extension according to ROM scale. Nature of soil along left bank is dominantly sandy in nature which promotes vulnerable condition of river bank sites. Basic parameters of soil and its mechanical analysis also reveals that unstable condition exist along river bank line but instability condition is increasing from upper to lower segment of bank line. So risk of river bank failure can be measured by determining textural composition of soil.

Keywords: Ganga river, Bank failure, Bouyoucos Erodibility Index, ROM scale, Uniformity coefficient, Coefficient of gradation, Sorting coefficient.

Introduction

The morphological changes of river catchment are controlled by continuous changing of river bank due to erosion[1,2]. So the understanding of bank erosion processes is important to illuminate the issues prevailing river bank erosion. The causes of river bank erosion are being classified into different fluvio-geological factors[3]. Geological factors are associated with size and composition of soil particles which are characterized by the proportion of the alluvial particles in the bank[4]. On the other hand electrochemical bonding is significant controlling factor which influence the erosion behaviour of cohesive bank sediments.

Riverbank erosion is happened both naturally and through human impact[5]. The intensity of land loss depends on amount and intensity of rain and the capability of the river bank soil to survive within such rainy condition. The erodibility of soil is controlled by soil structure; infiltration level and organic matter content[6]. The alluvium network structure generates diversity on surface topography[7-9]. So, interaction between topographical roughness and bank line turbulence has a large significance on shaping river bank erosion behaviour[6]. The near bed turbulence of flow is being increased with increasing roughness of river bed which promotes erosion rate[10]. So the pattern of flow over rough bed is very significant which generates abrasion to the flow hydrodynamics, which also control turbulent configuration[11-15].

The present study has been done to determine degree of erodibility along the left bank line of Ganga near Malda by soil textural analysis. Besides this major objective, others objectives of present study are i. to determine the particle size distribution of soil in left bank sites of the river, ii. to determine basic parameters of soil e.g. Uniformity coefficient, Coefficient of gradation, Sorting coefficient for measurement the strength of river bank soil, iii. to identify the nature of soil in different horizon of given segments along the left bank. Through determine these textural measurement river bank soil, we have tried to measure the magnitude of vulnerability of river bank in respect to erosion and explain the all findings into the concluding part.

Study area: Malda is a central district of the West Bengal which is situated Indo-Bangladesh border with extending an area of about 3733sq. km approximately[16]. The western boundary of the district has bounded by Ganga River where frequent bank erosion is continuously happening form last few decade to till now. Malda district has 15 numbers of blocks, among these block Manikchak, Kaliachak II and Kaliachak III block are located at the western side of the district which are very much affected by bank erosion of Ganga. The geographic extent of the study area is from $24^0 51'$N to $25^0 14'$N and $87^0 46'$ E to $88^0 60'$E, with area of 316.39 square km (Figure-1). Approximately 765 square km area was eroded within the last 30 years along the left bank of river Ganga near Malda district[17]. Average elevation of the Diara region is 30 metre above MSL.

Ganga flows along the western side of the diara region near Malda district which is act as a divider between West Bengal and Jharkhand. The river Ganga first enters into Malda at Rajmahal hills and leaves the region at Khejuria in Farakka. Ganga is flowing along the diara blocks of the district namely Manikchak, Kaliachak-II and Kaliachak-III. Generally, within a year, mainly two times e.g. from the end of June to middle August which indicate monsoon period and second time is from end of September to early November which indicates post monsoon period.

Methodology

Erodibility defines as the resistance capability of the soil in respect to both displacement and transport, Apart from this soil erodibility is also determined by many other factors like topography and management procedure of it. Texture and structure definitely influence the grain size of soil particles which exposed to erosive elements. Therefore, soil texture and structure play an important role to determine intensity of soil erodibility[18]. Silts and sands are relatively large grain size and least resistant particles.

Data collection procedure: The soil samples have been collected form 15 number of sample sites along the left bank line of Ganga river for the present study. We are divided the bank line into three segments, these are upper segment along the Manikchak block, intermediate segment along the Kaliachak II block and lower segment along the upstream part of Kaliachak III block over Farakka barrage. The sieve analysis has been done to analyse proportion of collected soil texture composition within soil laboratory. It was also done to separate soil particles according to their grain size form each collected soil samples and assess the proportion of different grain sizes enclosed within a soil through electronic weight machine. In the present study, the equipment having nominal maximum sieve size 1.7 mm (No. 12), 1mm (No. 18), 710 micron (No. 25), 500 micron (No. 35), 300 micron (No. 50), 180 micron (No. 80) and 150 micron (No. 100) have been considered for sieve analysis. The particles with diameter less than 150 micron were determined by hydrometer method.

Basic parameters of river bank soil: In the present study, Sieve data has been tabulated through the following equations to determine basic parameters of soil,

Percentage retained on any sieve= (Weight of soil retained/ total soil weight) * 100 (1)

Cumulative percentage retained on any sieve = $\sum$ Percentage retained (2)

Percentage finer than an sieve size= 100% - $\sum$ Percentage retained (3)

After these calculations, according to Department of Civil Engineering, University of Memphis, the particle diameters are plotted in log scale, and the corresponding percent finer in arithmetic scale and prepare grain size distribution curves. With the help of these curves for each sample, the following basic three soil parameters have been determined through following equations:

Uniformity coefficient (C_u) = D_{60}/D_{10} (4)

Coefficient of gradation (C_c) = $D_{30}{}^2(D_{10}$ X $D_{60})$ (5)

Sorting Coefficient (C_s) = $(D_{75}/D_{25})^{0.5}$ (6)

Where D_{60} is the diameter corresponding to 60% finer in the particle-size distribution; D_{10} is the diameter in the particle-size distribution curve corresponding to 10% finer; D_{30} is the diameter corresponding to 30% finer in the particle-size distribution; D_{25} and D_{75} are the diameter corresponding to 20% and 75% respectively finer in the particle-size distribution.

Soil type identification through mechanical analysis: The nature of river bank soil in respect to its dominant particle size is very important parameter to determine the erodibility nature of soil which resolves the risk intensity of bank failure as well as erosional vulnerability. So, Folk and Worst's (1988) soil mechanical equation has been applied to determine Mean (Mz) value of soil particles[19] which stated as follows:

Mean (Mz) = (16+50+84)/3 (7)

Where 16, 50 and 84 are the Phi scale sieve diameters corresponding to 16%, 50% and 84% finer in the particle-size distribution respectively. After determine the value of Mean (Mz), the nature of soil of that particular location or sites has identified on the basis of that value through using Wentworth[20].

Basic and mechanical soil parameters calibration and risk factor determination: After individually determine all basic and mechanical soil parameters, river bank failure risk has been measured by calculating gradation mean (mz) value and coefficient of risk factor values after Folk and worst method[19]. To determine these risk factors, following equations have been applied:

Gradation Mean (Mz) = $1/_{n+1}$ {$\sum$ Mean (Mz)} (8)

Coefficient of Risk Factor=$1/_n((R^2{}_1$ X $R^2{}_2$ X $R^2{}_3)^{0.5}$ (9)

Where R^2_1, R^2_2 and R^2_3 are coefficient of determination values for three given segments respectively which are derived by correlating soil basic parameters and n is no of selected segments. Risk intensities are measured on the deriving values. Basically negative coefficient of risk factor values represents stable condition and positive coefficient of risk factor values represents unstable condition and with increasing positive coefficient values, instability condition has been also increased.

Bouyoucos Erodibility Index (BEI) and ROM scale (EI_{ROM}): The present study has been also measured level or degree of erodibility of river bank materials through Bouyoucos Erodibility Index (BEI) and ROM scale (EI_{ROM})[18]. The following equations are applied to determine the above mentioning indices,

Bouyoucos Erodibility Index = {(% sand + % silt)/ % clay} (10)

EI_{ROM} = {(% sand + % silt)/ (2*% clay} (11)

With the above mentioning Bouyoucos Erodibility Index (BEI) and ROM scale (EI_{ROM}), the more realistic and significant soil erodibility value can be measured through which we have also identified the risk categories along the present river bank study sites. The relevant maps have been prepared on the basis of the all determining values through interpolation technique or IDW technique[21].

Results and discussion

Basic soil parameters assessment: Three basic soil parameters namely uniformity coefficient, coefficient of gradation and sorting coefficient have taken into consideration form deriving grain size distribution curves. The relationship between uniformity coefficient and sorting coefficient becomes direct but coefficient of gradation becomes inversely related with uniformity coefficient and sorting coefficient. Besides that higher uniformity coefficient value indicates that maximum degree of uniformity within river bank materials which become risk sign for bank failure. In the present study, the deriving values for uniformity coefficient has been shown in Table-1 which shows that in case of S4, S5 and S13 river bank site, this values are 3.148, 5.006 and 5.7055 respectively which indicates high magnitude of risk in bank failure along adjacent portion of middle segment near Kaliachak II block and middle portion of the Kaliachak III block. Remaining parts of the bank line indicates moderate uniformity coefficient values which shows relatively less instability conditions for these sites. The risk zonation map according to uniformity coefficient values has been shown in Figure-2a.

On the other hand, coefficient of gradation values become less than 1 in maximum river bank sites except site number S4, S8, S9, S11 and S12 (Table-1). Basically lesser coefficient of gradation value indicates higher amount of risk, it means major portion of given left bank line of river is under alarming condition in case of bank failure. On the other in case of sample site number S4, S5 and S13, where uniformity coefficient values become high, there coefficient of gradation values become low, it proves that there is a inverse relationship exist between these two basic parameters of soil but both indicates same results. The risk zonation map in respect to coefficient of gradation has been shown in Figure-2b. The deriving risk zonation map clearly indicates that moderate to high instability condition has been existed all along the bank lie approximately due to majority of less gradation values.

Lastly if sorting coefficient value becomes high, then risk intensity of bank failure along those river bank sites also becomes high. In the present study, the deriving sorting coefficient values indicates that like uniformity coefficient, in case of sample site number S4 and S13 become relatively high than other sites (Table-1). It proves again that there is a positive relationship between uniformity coefficient and sorting coefficient and high sorting coefficient of these two sites indicate probability of bank failure along these sites become also high. On the other hand remaining sites exist with less than 2 sorting coefficient values which also indicate moderate risk intensity of bank failure. The risk zone map in respect to sorting coefficient values has been shown in Figure-2c which reveals that instability conditions exist relatively less in upper segments than lower segments.

The relationship trend between all three given soil basic parameters have been shown in Figure-3 by simple linear regression analysis. In case of upper segment near Manikchak block, coefficient of gradation values negatively correlate with uniformity coefficient and sorting coefficient with coefficient determination value of 0.250 and 0.570 respectively, besides that positive relation has been shown between uniformity coefficient and coefficient of gradation with R^2 value 0.870. In case of lower segment near Kaliachak III block, similar kind of relation between all parameters have been shown with coefficient of determination values of 0.993 (Uniformity coefficient vs Coefficient of gradation), 0.803 (Coefficient of gradation vs Sorting coefficient) and 0.753 (Uniformity coefficient vs Sorting coefficient). So relationships become very significant between all parameters. On the other hand, in case of middle segment near Kaliachak II block, relation between uniformity coefficient and sorting coefficient become positive but less significant with coefficient of determination value 0.002, coefficient of gradation is negatively correlate with sorting coefficient with R^2 value 0.120, but here unfortunately uniformity coefficient positively correlate with sorting coefficient with again less R^2 value 0.030. The causes behind these disparities between parameters are some external influences like surface protection through vegetation covers, cropping patterns etc. So whole analysis clearly indicates that risk magnitude becomes relatively less along upper bank line and it becomes increase towards downward river bank line of Ganga river.

Table-1: Basic parameters values of river bank soil.

Block	Site	Percent Finer (%) in each particle diametre (metre)							Effective Size	Uniformity Coefficient	Coefficient of Gradation	Sorting Coefficient
		1.7	1	0.71	0.5	0.3	0.18	0.15				
Manikchak	S1	98.48	92.42	83.33	81.81	78.78	75.75	0	0.156	1.135	0.881	1.048
	S2	84.28	51.52	8.42	4.97	3.25	1.52	0	0.760	1.536	0.844	1.371
	S3	81.48	48.15	7.41	5.55	3.7	1.85	0	0.750	1.653	0.823	1.369
	S4	79.17	42.71	16.67	11.46	6.25	1.05	0	0.427	3.148	1.334	1.418
	S5	93.33	83.33	56.66	50	43.33	40	0	0.156	5.006	0.229	2.215
Kaliachak II	S6	93.38	90.44	88.97	86.76	83.32	20.59	0	0.174	1.557	0.999	1.201
	S7	92.31	82.05	79.49	76.93	74.36	15.39	0	0.177	1.469	0.940	1.277
	S8	92.17	81.33	80.72	79.52	78.31	15.06	0	0.177	1.469	1.033	1.235
	S9	92.91	90.73	89.64	87.46	85.28	23.99	0	0.172	1.453	1.006	1.260
	S10	95.42	91.6	90.84	90.08	88.55	24.43	0	0.177	1.356	0.980	1.201
Kaliachak III	S11	100	98.44	96.88	95.31	92.19	90.63	0	0.156	1.205	1.068	1.089
	S12	94.87	89.74	78.2	75.64	70.51	69.23	0	0.146	1.288	1.016	1.734
	S13	85.71	69.38	44.89	40.81	32.65	32.65	0	0.146	5.706	0.258	2.713
	S14	94.38	87.64	83.14	80.9	78.65	22.47	0	0.167	1.623	0.956	1.267
	S15	95.15	90.3	86.41	85.44	82.53	24.28	0	0.184	1.497	0.939	1.862

Table-2: Tabulation for determining textural nature of Ganga river bank soil.

Block	Site	Cumulative Percent retained in each Scale sieve diameter							Value of effective sizes after Fork & Worst			Mean (Mz)	Soil Type (After Wentsworth)
		-0.84	-0.14	0.5	1	1.74	2.47	2.74	□16	□50	□84		
Manikchak	S1	6.62	9.56	11.03	13.24	16.18	79.41	100	1.76	2.18	2.57	2.17	Fine Sand
	S2	7.69	17.95	20.51	23.07	25.64	84.61	100	2.16	2.47	0.29	1.446	Medium Sand
	S3	7.83	18.67	19.28	20.48	21.69	84.94	100	2.17	2.49	0.24	1.473	Medium Sand
	S4	7.09	9.27	10.36	12.54	14.72	76.01	100	1.81	2.225	2.56	2.198	Fine Sand
	S5	4.58	8.4	9.16	9.92	11.45	75.57	100	1.83	2.24	2.545	2.205	Fine Sand
Kaliachak II	S6	6.67	16.67	43.34	50	56.67	60	100	-0.205	1.235	2.645	1.225	Medium Sand
	S7	20.83	57.29	83.33	88.54	93.75	98.96	100	0	-0.325	0.605	0.0933	Coarse Sand
	S8	18.52	51.85	92.59	94.45	96.3	98.15	100	0	-0.23	0.315	0.0283	Coarse Sand
	S9	1.52	7.58	16.67	18.19	21.22	24.25	100	0.465	2.615	2.71	1.93	Medium Sand
	S10	2.04	63.26	81.63	85.71	87.75	89.8	100	-0.645	0.295	0.745	-0.065	Very Coarse Sand
Kaliachak III	S11	5.62	12.36	16.86	19.1	21.35	77.53	100	0.355	2.195	2.515	1.688	Medium Sand
	S12	6.59	10.99	14.28	15.38	17.58	72.52	100	1.775	2.215	2.645	2.212	Fine Sand
	S13	4.85	9.7	13.59	14.56	17.47	75.72	100	1.75	2.25	2.685	2.228	Fine Sand
	S14	5.22	8.95	10.44	11.94	14.18	81.34	100	1.825	2.195	2.249	2.089	Fine Sand
	S15	15.72	48.48	91.58	95.03	96.75	98.48	100	0	2.615	2.695	1.77	Medium Sand

Table-3: Mechanical analysis of Ganga river bank soil particles.

Block	Site	Coefficient of Determination (R-square) Value			Mean (Mz)- (After Folk &Worst)	Soil Type (After Wentsworth)	Gradation Mean (Mz)- (After Folk & Worst)	Coefficient of Risk Factor	Risk Intensity
		Uniformity Coefficient vs Coefficient of Gradation	Coefficient of Gradation vs Sorting Coefficient	Uniformity Coefficient vs Sorting Coefficient					
Manikchak	S1	0.250	0.527	0.870	2.17	Fine Sand	4.97	0.125795	Moderately Unstable
	S2				1.446	Medium Sand			
	S3				1.473	Medium Sand			
	S4				2.198	Fine Sand			
	S5				2.205	Fine Sand			
Kaliachak II	S6	0.030	0.120	0.002	1.225	Medium Sand	1.68159	0.00058	Moderately Unstable
	S7				0.0933	Coarse Sand			
	S8				0.0283	Coarse Sand			
	S9				1.93	Medium Sand			
	S10				-0.065	Very Coarse Sand			
Kaliachak III	S11	0.993	0.803	0.753	1.688	Medium Sand	5.22918	0.295322	Highly Unstable
	S12				2.212	Fine Sand			
	S13				2.228	Fine Sand			
	S14				2.089	Fine Sand			
	S15				1.77	Medium Sand			

Table-4: Determination of Bouyoucos Erodibility Index and ROM scale through soil textural composition along left bank line of Ganga river.

Block	Sample	Soil Textural Composition (gm)				Soil Textural Composition (%)			Bouyoucos Erodibility Index	ROM Scale	Soil Erodibility Category
		Sand	Silt	Clay	Total	Sand	Silt	Clay			
Manikchak	S1	260	15	55	330	78.79	4.55	16.67	5.00	2.50	Moderate
	S2	30	15	200	245	12.24	6.12	81.63	0.23	0.11	Low
	S3	65	20	65	150	43.33	13.33	43.33	1.31	0.65	Low
	S4	6	10	80	96	6.25	10.42	83.33	0.20	0.10	Low
	S5	580	15	250	845	68.64	1.78	29.59	2.38	1.19	Low
Kaliachak II	S6	575	25	65	665	86.47	3.76	9.77	9.23	4.62	High
	S7	375	15	70	460	81.52	3.26	15.22	5.57	2.79	Moderate
	S8	570	35	75	680	83.82	5.15	11.03	8.07	4.03	High
	S9	145	10	40	195	74.36	5.13	20.51	3.88	1.94	Moderate
	S10	650	20	160	830	78.31	2.41	19.28	4.19	2.09	Moderate
Kaliachak III	S11	782	40	95	917	85.28	4.36	10.36	8.65	4.33	High
	S12	580	15	60	655	88.55	2.29	9.16	9.92	4.96	High
	S13	575	25	70	670	85.82	3.73	10.45	8.57	4.29	High
	S14	425	15	65	505	84.16	2.97	12.87	6.77	3.38	Moderate
	S15	350	20	70	440	79.55	4.55	15.91	5.29	2.64	Moderate

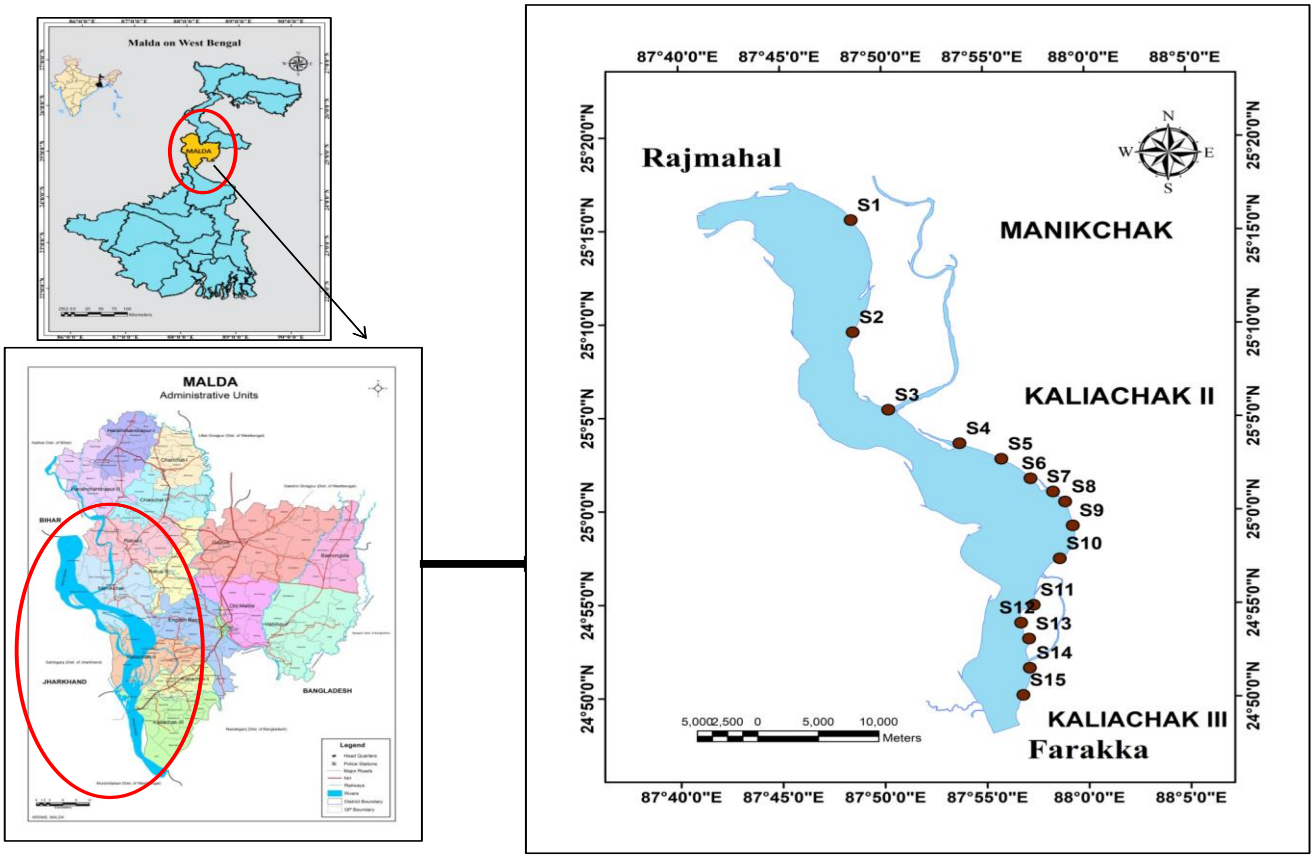

Figure-1: Map of the study area (Source; Majumdar and Mandal 2020).

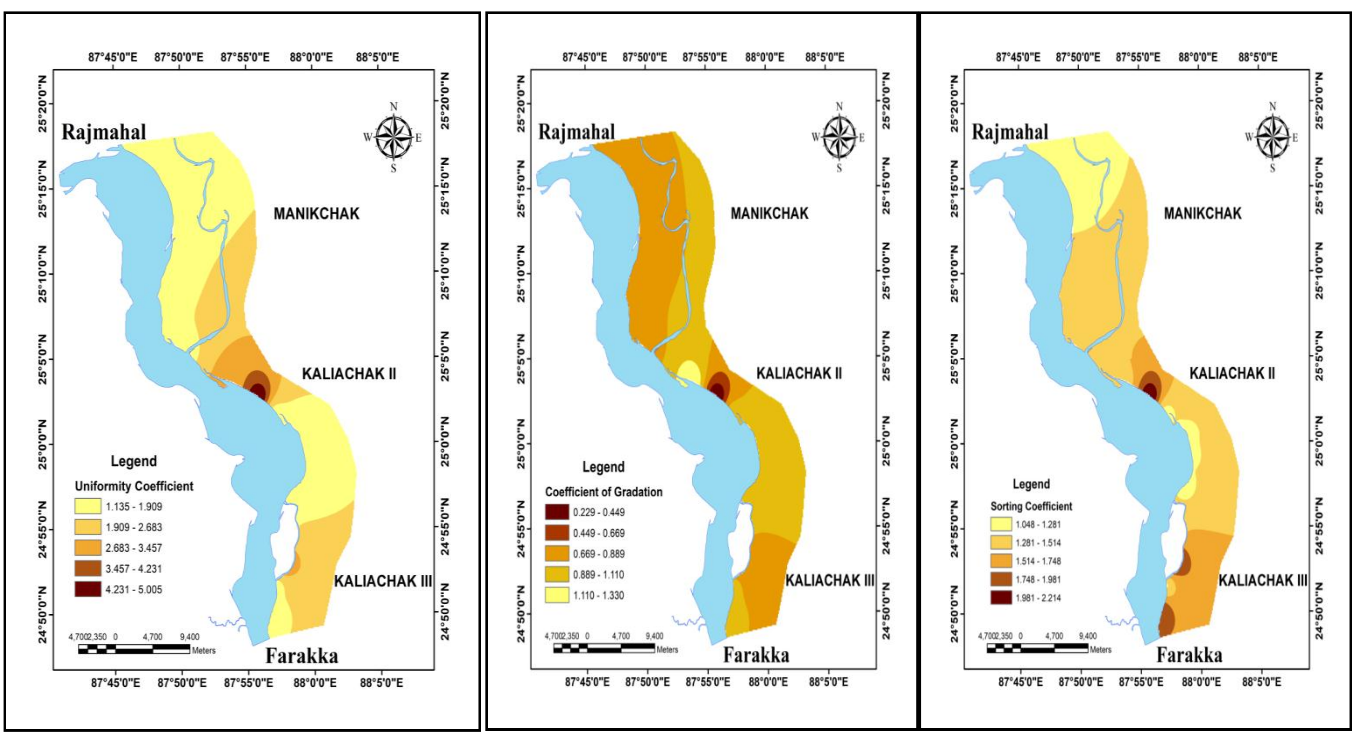

Figure-2: The risk zonation map according to **a** uniformity coefficient, **b** coefficient of gradation, **c** sorting coefficient.

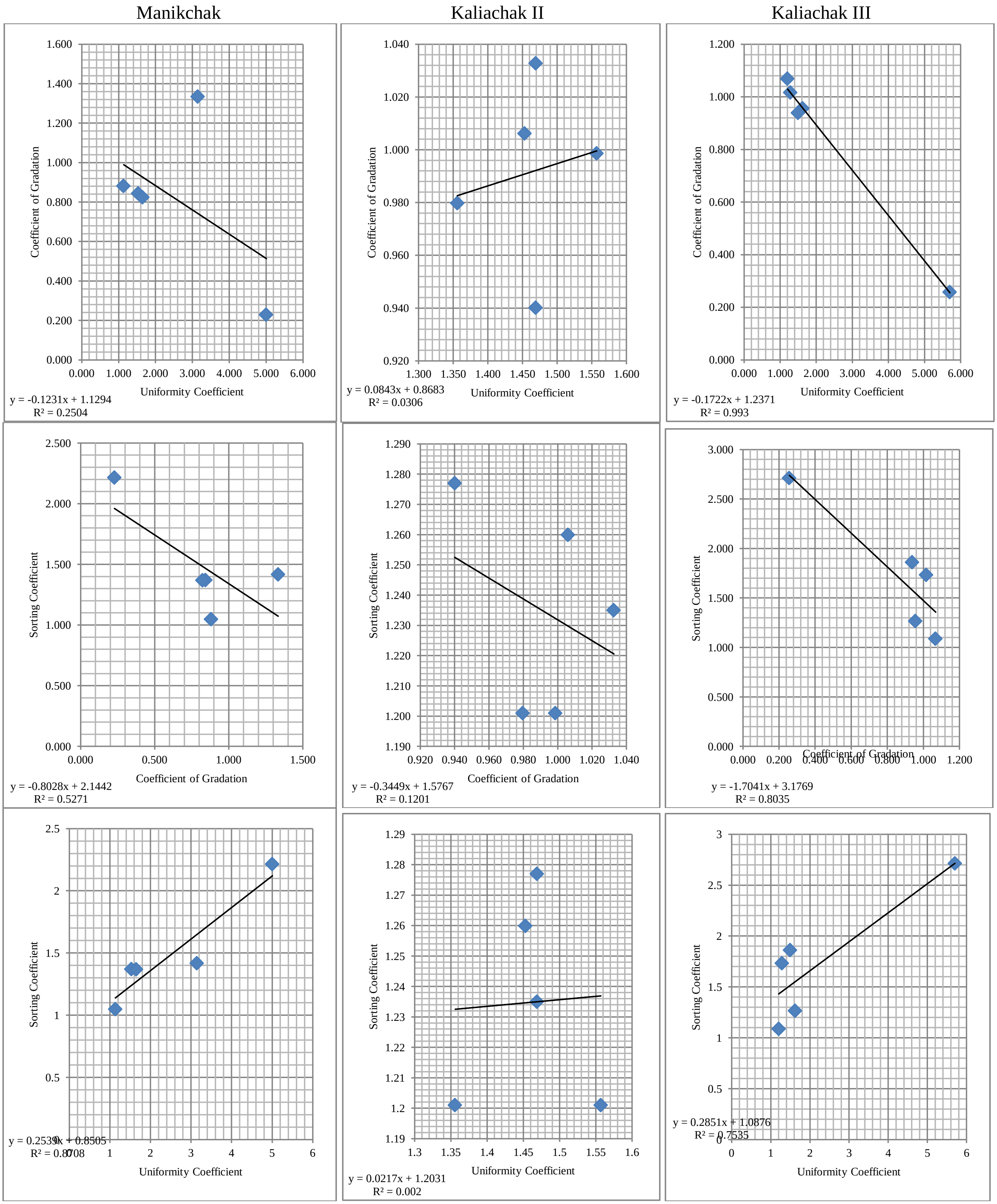

Figure-3: The relationship trend between soil basic parameters (**a, b, c** Manikchak, **d, e, f** Kaliachak II, **g, h, i** Kaliachak III).

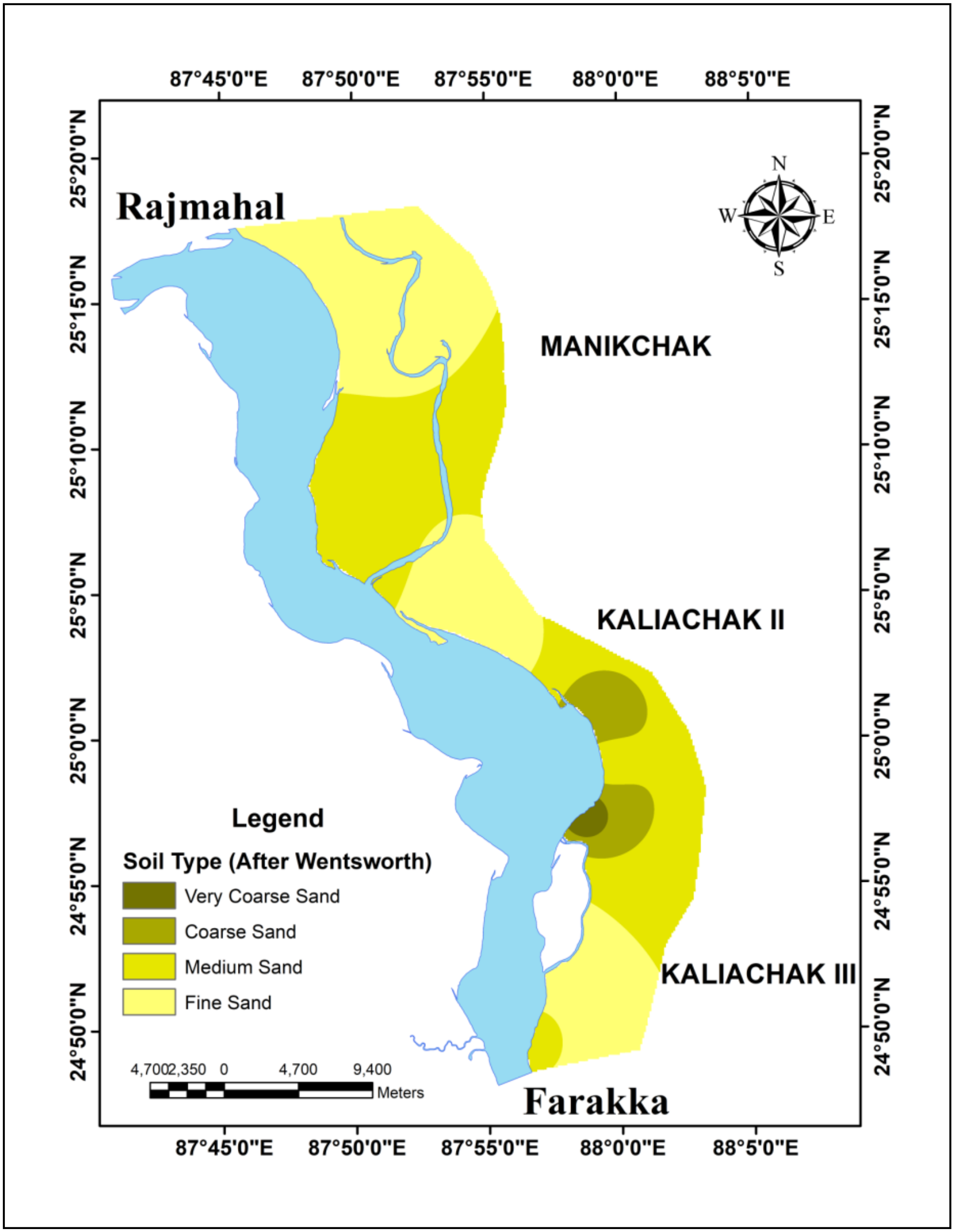

Figure-4: The soil type zonation map.

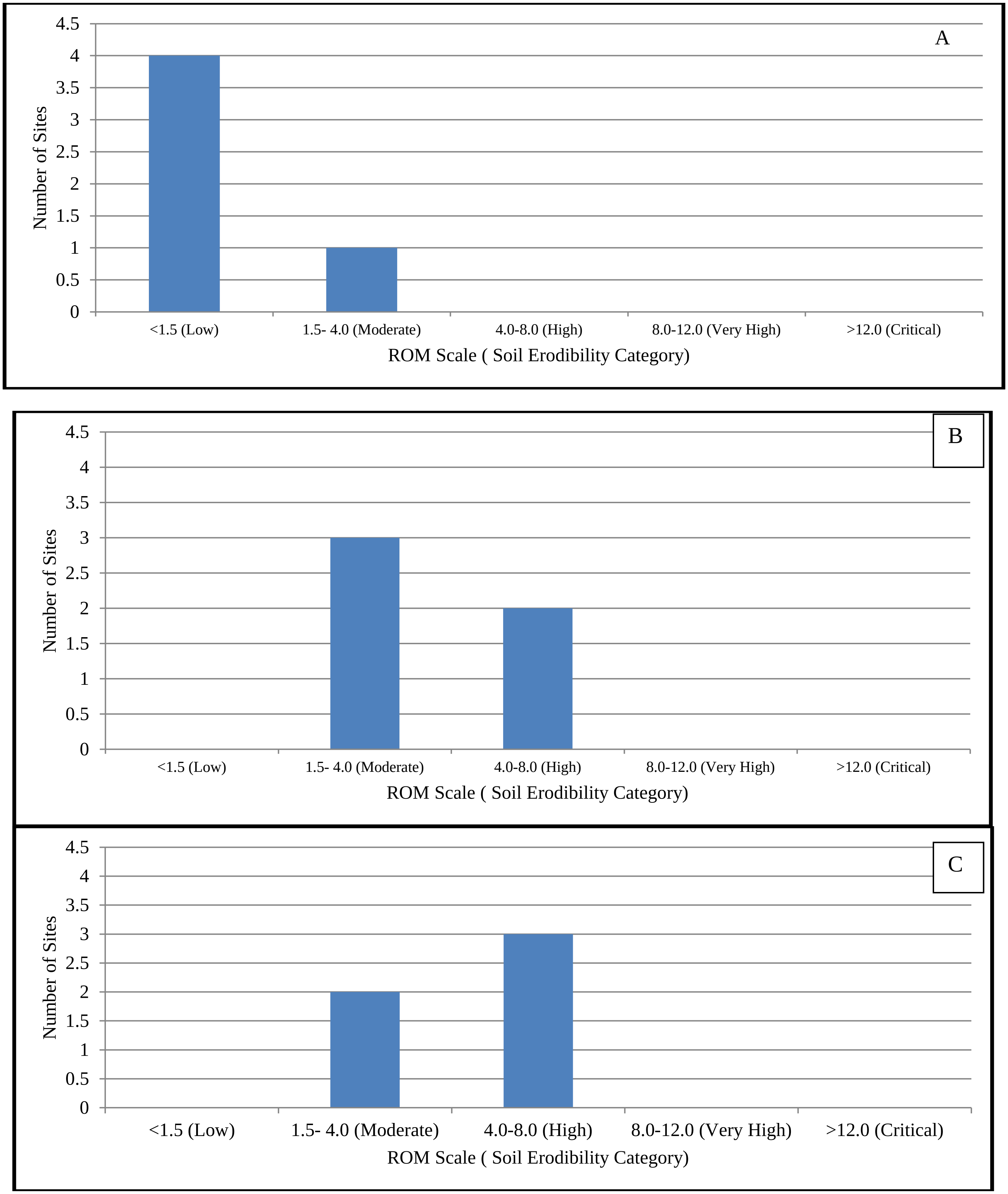

Figure-5: The trend of soil erodibility condition of **a** Manikchak, **b** Kaliachak II, **c** Kaliachak III.

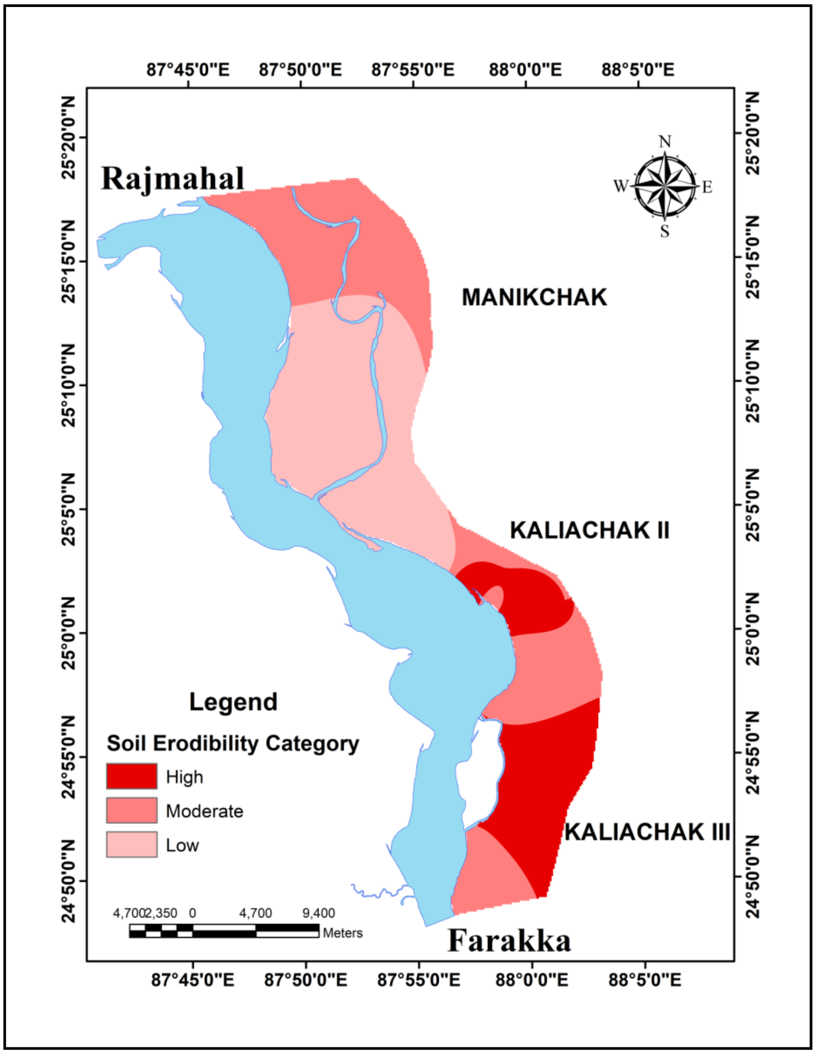

Figure-6: The soil erodibility risk zonation map.

Assessment of river bank line soil types: The textural nature of soil has been done in this segment. On the basis of field observation, it shows that among the textural composition of soil, sand particles are very much dominant along the river bank line. To determine the textural nature of soil according to Fork and Worst method, cumulative percent retention of particles in each Phi (□) scale sieve diameter has taken into consideration. Mean grain size (Mz) of particle for each sample sites has been calculated by equation (7) after Folk and Worst. Here □16, □50 and □84 are taken as standard Phi scale sieve diameter. According to Wentworth (1922), if value of effective size in Phi scale sieve diameter and Mean grain size (Mz) become negative, it means grain size of soil particles must be coarse in nature, basically ranges between very coarse sand to boulder[20]. On the other hand, if these values become positive, then it indicates fine particles and higher the positive values indicate more fine particles.

In the present study, values of effective sizes and mean grain sizes (Mz) for each sample sites have been calculated in Table-2. The deriving results show that values of effective size for each standard Phi scale sieve diameters varied between -0.1 and 3.0, it means textural nature of soil varied from very coarse sand to fine sand along the left bank line according to Wentworth[20]. Here negative effective size values have been found at sample site number S6 and S10 within Phi scale sieve number □16 and at S7 and S8 within □50 which all indicate coarse grain size of soil particles. Besides that Mean grain size (Mz) value becomes negative at site number S10. So on the basis of deriving Mean grain size values, it shows that very coarse sand to coarse sand has been found at sample site number S7, S8 and S10 which all locates at the middle segment near Kaliachak II, it means due to large and coarse grain size, porosity level of water become high along these sites which increase water pressure within soil particles and increase the risk of bank failure. Besides that medium sand to fine grain size particles have been found along the remaining river bank sites which indicates moderate instability of river bank line in context of failure due to moderate porosity level of soil particles. On the basis of nature of soil, Soil zonation map has been shown in Figure-4**.** The deriving map shows that concentration of relatively coarse grain size particles has been shown along middle to lower segments of bank line which promote the high risk of bank erosion. On the other hand, coarseness of grain size becomes relatively low in upper segment which indicates relatively less risk of bank failure.

Prediction of risk intensity by mechanical analysis of soil: Table-3 shows the magnitude of risk along the river bank line near Malda district. These bank failure magnitudes have been measured by gradation mean size (mz) of soil particles which is calculated by Equation-8. The deriving result shows that gradation mean values become relatively high in upper segment near Manikchak and lower portion near Kaliachak III region than middle portion. Basically higher gradation mean sizes of particles indicate high chances of bank failure. After that coefficient of risk factor has been calculated by Equation-9 and deriving result shows that all risk factors values become positive and again relatively greater risk factor values exist along the upper and lower bank line of Ganga river than middle bank line. So after analyzing mechanical and textural composition of river bank line soil particles, it can be concluded that the lower bank line of the study area near Kaliachak III block is highly unstable in the context of bank erosion, besides that upper and middle bank line near Manikchak and Kaliachak II block respectively belong under moderate bank failure risk condition.

Bouyoucos Erodibility Index and ROM scale assessment: The result of sieving test for collected soil samples are recorded and calculated the percentage proportion of each grain size particles for each sample sites in Table-4. At first Bouyoucos Erodibility Index has been tabulated for each sites by equation (10) and result shows that Maximum BEI value has been found in site number S6 (9.23), besides that BEI value having >8 exists along site number S8, S11 and S13 which all belongs under middle and lower river bank line. It means degree of erodibility become high along these sites. After that BEI value between 5 and 8 exists along site number S1, S7, S14 and S15 which are located along all three segments of bank line and lastly BEI value having < 5 exists along remaining portion of the bank line. On the basis of deriving BEI values, it can be concluded that the condition of river bank line in context of erosion become moderate to highly vulnerable.

Besides the Bouyoucos Erodibility Index (BEI), EI_{ROM} or ROM scale is also tabulated by the Equation-11 in Table-4. EI_{ROM} or ROM scale is used to develop an improved soil erodibility index[18]. The deriving EI_{ROM} values show that high erodibility condition exists over sample site number S6, S8, S11, S12 and S13. These all high erodibility prone sample sites belong under middle bank line near Kaliachak II block and lower segment near Kaliachak III block. The EI_{ROM} values exist above 4.0 which categorized as high soil erodibility condition according to Table-2**.** After that in case of sample segment number S1, S7, S9, S10, S14 and S15, EI_{ROM} value ranges from 1.5 to 4.0 which categorized as moderate erodibility condition. These all moderate erodibility prone areas belong under middle and lower bank line except S1. At last low soil erodibility prone zones have been identified along sample segment site number S2 to S5 which are located under upper bank line. Here EI_{ROM} values exist below 1.5. Figure-5 shows the trend of soil erodibility condition of selected three bank line segment on the basis of deriving EI_{ROM} values and its associated soil erodibility categories. So after analysing both indexes, it can be concluded that level of soil erodibility become moderate to high in river bank line along middle and lower segment near Kaliachak II and Kaliachak III respectively and low soil erodibility level exists along upper segment river bank line near Manikchak block. The soil erodibility risk zonation map has been prepared on the basis of soil erodibility categories and shows in Figure-6 and visually shows the soil erodibility condition along the river bank line near Malda district which are already explained.

Conclusion

In the present study, the deriving results reveal that the dominant soil textural composition along whole given bank line is sandy in nature. The diameter in the particle-size distribution curve corresponding to 10% finer is defined as the effective size, or D_{10} which ranges between 0.146 to 0.750 and relatively high values concentrate along upper segment bank line and values become gradually decreases towards downward. Such condition clearly indicates that concentration of fine particle become high along upper segment bank line which increases compactness of bank materials, reduce porosity level and decrease water pressure within bank materials which reduce risk of bank failure. Besides that risk magnitude of bank failure increases towards middle and lower segment of bank line with decreasing effective size values. The all analyzing basic parameters of soil indicates similar situation of left bank line. The mechanical analysis of river bank soil also reveals that risk intensity become relatively low along upper segment of bank line on the basis of its present soil textural arrangement but bank failure risk become gradually increase towards the middle and lower bank line along Kaliachak II and Kaliachak III blocks. To validate these mechanical analyses of soil texture and its results about bank failure risk, two developed soil erodibility measuring index has been applied and both index results highly matched with mechanical analysis of river bank soil texture. Therefore it can be concluded that the mechanical analysis of soil, which are applied in present study to measure risk intensity of bank failure, are highly acceptable for bank line of Ganga river in Diara region of North East India and such kind of mechanical analysis can be further applied for others alluvial channels of the world to predict the magnitude of river bank failure.

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