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A Practical Method of Assessing River Bank Erosion Potential: A Case Study InLower Assam Region of River Brahmaputra

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Abstract: *River bank erosion is an acute and recurrent natural hazard all over the world. The same hazard is also very much common, devastating and frequent in Assam due to river Brahmaputra, Barak and their tributaries. Every year the river Brahmaputra is eroding both banks at alarming rate creating enormous difficulties, havoc and multi-dimensional loss to the affected people. The erosional tendency of river bank of Brahmaputra is not same in its entire reach as the soil characteristics of all locations are not same. It is understood that the extent of erosion depends on many factors. The properties of river bank soil is also one major factor related to erosion. This particular study is carried out to ascertain the role of geotechnical properties of soil in assessing the erosion potential in river bank erosion in lower Assam region of river Brahmaputra of India so that these properties of soil could be used as erosion predictor or assessor to assess the vulnerability of locations in river reach and finally the whole river stream might be categorized locations wise as vulnerable or non-vulnerable to erosion for taking anti erosive measure preference wise.*

Keywords*: Assam, Barak, Brahmaputra, Erosion, River Bank, Vulnerable,*

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I. Introduction

The river Brahmaputra and almost all major tributaries along with river Barak are creating havoc to the people of riverside by regularly eroding their banks. The nature and extent of erosion of river Brahmaputra is tremendous and devastating in comparison to other rivers of India. The extremely braided river Brahmaputra is eroding the banks in its entire course in Assam by increasing its area and forming and destroying sand bars or chars causing huge amount of sediment. The river bank erosion is the burning problem to the riverside people of Assam and it is also the main concern to the Government of Assam. The ill effect of river bank erosion is multi-dimensional- political, economic, demographic, environmental and social. The direct effect of river bank erosion includes- Huge economic loss, Losses of fertile land ,Losses of crops and other resources, displacement of people from one place to other, affect in public health, poverty in the society, unemployment problem increased, increase in landless labor, decrease in agricultural productivity, affect productivity in eroded soil, encroachment of government land, educational structure is negatively changed, effect on environment, effect in individual occupation, effect in transport system, social disorder etc. The Government of Assam is trying to take effective anti-erosional measures to reduce the intensity of erosion. It has been observed that the nature and degree of erosion of river Brahmaputra is more or less area specific. In some location it is very high, in some location it is moderate or low. The degree of erosion of river bank depend on various parameters. The physical properties of soils also play vital role in producing or preventing erosion in river bank. So, in this work it is attempted to ascertain the role of physical properties of bank soil in producing river bank erosion by comparing the soil physical properties of highly eroded locations and non-eroded locations and ultimately use these properties as predictors of erosion to zone the various locations as low, moderate, high etc so that anti erosive measure could be taken on priority basis.

II. Site Selection And Methodology

For the study purpose of assessing the erosion potential of river Brahmaputra on the basis of physical properties of soil, the entire reach of river Brahmaputra in lower Assam region has been visited and roughly observed and finally sixteen locations are chosen for study and collecting soil samples. These locations are tabulated in Table number 1. Out of these sixteen locations, first eight locations are of no or vey less erosion prone and next eight locations are of very high erosion prone.

Table :I (Description of selected locations)

Sl No	Position of locations	Name of locations	Remarks
1	$26^{0}11^{/}13.92^{//};91^{0}44^{/}33.12^{//}$	Joypur(South bank)	No or less erosion
2	$26^{0}12^{/}4.07^{//};91^{0}44^{/}26.95^{//}$	UzanBazarGhat(South bank)	No or less erosion
3	$26^{0}11^{/}9.55^{//}; 91^{0}43^{/}16^{//}$	Ferryghat(North Guwahati)	No or less erosion
4	$26^{0}8^{/}22.6^{//}; 91^{0}34^{/}9.16^{//}$	Majirgaon(South bank)	No or less erosion
5	$26^{0}11^{/}9.71^{//};90^{0}36^{/}43.15^{//}$	Goalpara (South bank)	No or less erosion
6	$26^{0}11^{/}1.7^{//};90^{0}32^{/}57.1^{//}$	Pancharatna(Both bank)	No or less erosion
7	$26^{0}12^{/}1.04^{//};90^{0}33^{/}52.1^{//}$	Jogighopa(Both bank)	No or less erosion
8	$26^{0}0^{/}48.92^{//};89^{0}58^{/}57.5^{//}$	Dhuburi (North bank)	No or less erosion
9	$26^{0}06^{/}58.1^{//};91^{0}25^{/}52.7^{//}$	Dakhala(South bank)	Highly eroded
10	$26^{0}7^{/}34.18^{//};91^{0}32^{/}20.6^{//}$	Palasbari (South bank)	Highly eroded
11	$26^{0}08^{/}44.52^{//};90^{0}14^{/}11.12^{//}$	Nayer Alga char (North bank)	Highly eroded
12	$26^{0}08^{/}13^{//};90^{0}11^{/}52.8^{//}$	Mayer Char (North bank)	Highly eroded
13	$26^{0}08^{/}16.8^{//};90^{0}15^{/}16.1^{//}$	Sonamukhi hills (North bank)	Highly eroded
14	$26^{0}15^{/}26.41^{//};91^{0}06^{/}30.93^{//}$	Bahari(North bank)	Highly eroded
15	$26^{0}06^{/}30.69^{//};91^{0}15^{/}58^{//}$	Garaimari(South bank)	Highly eroded
16	$26^{0}05^{/}52.89^{//};91^{0}17^{/}55.87^{//}$	Saupata Pt-I(North bank)	Highly eroded

All these selected locations are visited and soil samples are collected from the just bank level from the locations having no or very less erosion and same were collected from bank and nearby having very high erosion taking at least five samples from each location covering a length of minimum one km. The laboratory tests were conducted in the Laboratory of Bongaigaon Polytechnic and Assam Engineering college of Assam as per the Indian Standard. The physical test conducted mainly include particle density (IS 2720 , Pt XXIX,1975), particle size analysis (IS2720, Pt-IV, 1985), compaction characteristics (IS 2720, Pt VIII, 1985), specific gravity (IS 2720, Part III, Sec 1, 1980), liquid limit and plastic limit (IS2720, Pt-V,1985), permeability (IS 2720, Pt XVII,1985), direct shear test (IS 2720, Pt XIII,1985) and relative density (IS 2720, Part 14. 1983). The average laboratory test results of basic physical properties of five samples collected from each 16 locations under consideration are tabulated in Table number 2 and 3.

Table :2(Results of particle size analysis)

Location	Cu	Cc	% of Sand	% of Clay	% of Silt	% of Clay and Silt
1	12.3	2.6	80.4	14.6	5.0	19.6
2	9.4	1.82	82.6	15.5	1.9	17.4
3	8.6	1.26	89.2	8.6	2.2	10.8
4	6.2	2.24	80.8	13.6	5.6	19.2
5	7.2	1.96	78.6	18.2	3.2	21.4
6	11.3	1.7	81.4	16.5	2.1	18.6
7	9.1	1.5	89.2	9.4	1.4	11.8
8	11.6	1.9	87.0	8.6	4.4	13.0
9	4.5	1.08	94.6	2.7	2.7	5.4
10	3.0	0.86	95.2	2.4	2.4	4.8
11	6.2	0.98	91.9	4.05	4.05	8.1
12	3.8	1.85	88.8	3.2	8.0	11.2
13	4.6	1.26	97.5	1.25	1.25	2.5
14	3.6	1.71	94.9	2.55	2.55	5.1
15	3.4	1.23	98.6	2.2	8.2	1.4
16	3.1	1.31	94.4	2.8	2.8	5.6

(In case of particle size analysis, the hydrometer analysis is not done if the percent of silt and clay is less than 10% and for calculation purpose the clay and silt content are assumed to be equal of the finer amount)

Table:3(Results of other physical properties)

Location	Sp gravity	Particle density (kg/m^3)	Liquid limit (%)	Permeability (cm/sec)	Bulk density(kg/cum)	Relative density (%)	Cohesion (Kg/sqcm)	Angle of shearing resistance (degree)
1	2.71	2710	38.60	2.6x10^{-5}	2130	69.56	0.18	28.61
2	2.69	2690	36.40	8.3x10^{-5}	1956	73.24	0.13	22.45
3	2.77	2770	40.52	5.6x10^{-5}	2036	59.10	0.15	26.10
4	2.67	2670	39.60	2.1x10^{-5}	1987	62.35	0.13	28.00
5	2.69	2690	37.82	9.2x10^{-5}	1991	66.32	0.11	26.54
6	2.70	2700	38.62	2.6x10^{-5}	2054	61.56	0.16	23.51
7	2.70	2700	38.00	8.3x10^{-5}	2006	58.30	0.21	30.26
8	2.71	2660	40.20	1.26x10^{-5}	1897	58.64	0.15	22.69
9	2.66	2610	31.85	8.2x10^{-4}	1789	41.65	0.06	32.45
10	**2.61**	**2610**	**30.61**	3.1x10^{-4}	1765	**31.25**	**0.05**	**38.62**
11	2.56	2560	34.45	4.6x10^{-4}	1896	36.54	0.08	33.58
12	2.62	2620	34.78	7.9x10^{-4}	1881	26.41	0.03	42.56
13	2.61	2610	30.12	8.0x10^{-4}	1821	28.96	0.04	41.50
15	2.62	2620	29.88	8.2x10^{-4}	1794	36.41	0.07	39.68
15	2.60	2600	30.26	3.5x10^{-4}	2136	41.57	0.06	36.25
16	2.56	252 0	31.89	4.1x10^{-4}	1842	30.89	0.06	37.56

III. Result Analysis

All low or non -eroded locations contain some higher percentage of clay which clearly indicates that the clay content plays vital role in resisting erosion in lower Assam region of river Brahmaputra. The average particle density of soil particles in erosion free areas are found to be 2698.75 Kg/m^3 and the average of same for highly eroded locations are 2593.75 Kg/m^3 which signifies that the lighter soil particles are more susceptible to erosion. In case of liquid limit also, it is observed that the liquid limit value of safe areas is higher than the unsafe or risky areas. The average value of liquid limit of all eight less eroded areas are found to be 38.72 % whereas the same for highly eroded locations are found to be 31.73 %. The values of permeabilities of all non or less eroded locations are less and in the range of 10^{-5} cm/sec whereas the values of permeabilities of all eroded locations are high and all are in the range of 10^{-4} cm/sec. The values of relative densities of all non-eroded locations are comparatively very high than the values of highly eroded locations with average of 63.63 % and 31.74 % respectively. From gradation point of view, it is found that the soil of non- eroded locations is more or less well graded in comparison to the soils of other locations. Considering all these, finally six physical properties are taken as erosion predictors to assess the erosion vulnerability of river bank. They are be permeability, liquid limit, clay content, particle density, relative density and gradation of soil.

IV. Development Of Model

Results analysis of soils of eroded and non-eroded locations clearly reveal that the values of some physical properties of soil of eroded and non-eroded locations are widely varied which means that these properties have either negative or positive contribution in erosion. So, these particular properties can be taken as erosion hazard assessor to assess the extent of erosion in a particular location. For this a model is proposed in the line of Rosgen's modified method of bank erosion hazard index (BEHI). In Rosgen's modified method, the stream bank erosion predictors are related to field observation and they include -root depth, root density, surface protection and bank angle. These four matrices or stream bank predictors are used in modified method (Rosgen,2001) to develop bank erosion hazard index (BEHI) as given in table 4.

Like Rosgen, in this new model the consideredstream bank erosion predictors or parameters are related to soil physical properties and they are mainly relative density, permeability, clay content, liquid limit, particle density, and gradation of soil and these are used to calculate the hazard scores in the observed locations. The index for various category of risk rating in new model is kept same as in Rosgen's modified method and value for different risk category are assigned logically after comparing the minimum and maximum observed value of all parameters under consideration and a table for bank erosion hazard index (BEHI) is prepared which is shown in table 5.

Table:4(Bank erosion hazard index as per Rosgen's modified method)

Risk rating category		Root depth/Bank ht	Root density in %	Bank angle (degrees)	Surface protection in %	Total
Very low	Value	1.0-0.9	100-80	0-20	100-80	
	Index	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	4-7.6
Low	Value	0.89-0.5	79-55	21-60	79-55	
	Index	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	8-15.6
Moderate	Value	0.49-0.3	54-30	61-80	54-30	
	Index	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	16-23.6
High	Value	0.29-0.15	29-15	81-90	29-15	
	Index	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	24-31.6
Very high	Value	0.14-0.05	14-5.0	91-119	14-10	
	Index	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	32-36
Extreme	Value	<0.05	<5	>119	<10	
	Index	10	10	10	10	37-40

Table:5(Assignment of bank erosion hazard index in new model)

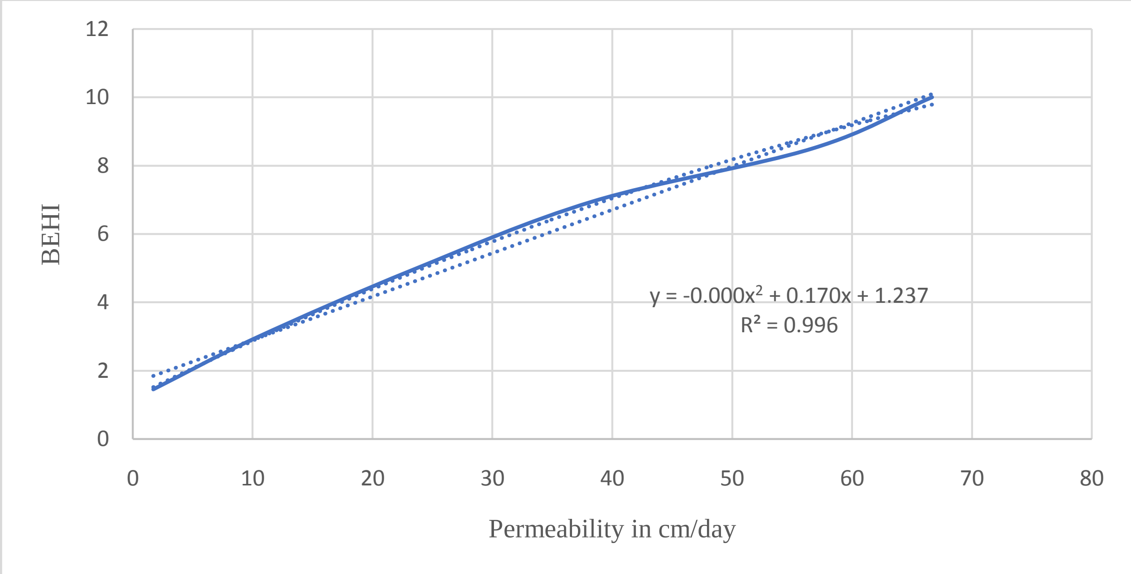
Adjective Hazard or risk rating category		Permeability(cm/month)	Liquid limit(%)	Clay content(%)	Particle density (kg/m^{3})	Relative density (%)	Gradation of soil	Total
Very low	Value	1-100	>44	90-100	>2800	>80	*(1)	
	Index	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9	1.0-1.9(1.45)	6-11.4
Low	Value	101-500	44-40	60-89	2800-2700	80-65	**(2)	
	Index	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9	2.0-3.9(2.95)	12-23.6
Moderate	Value	501-900	39-35	20-59	2699-2650	64-50	***(3)	
	Index	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9	4.0-5.9(4.95)	24-35.4
High	Value	901-1400	34-30	10-19	2649-2600	49-35	****(4)	
	Index	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9	6.0-7.9(6.95)	36-47.4
Very High	Value	1401-2000	29-25	5-9	2599-2500	34-25	*****(5)	
	Index	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0	8.0-9.0(8.5)	48-54
Extreme	Value	>2000	<25	<5	<2500	<25	******(6)	
	Index	10	10	10	10	10	10	55-60

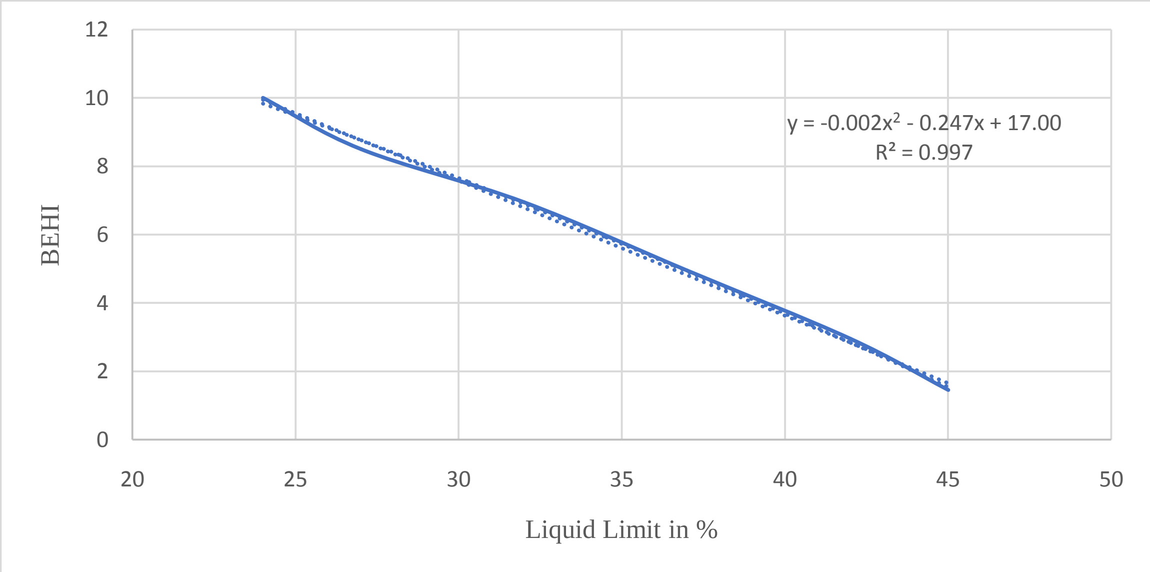
V. Development Of Hazard Graph And Equations

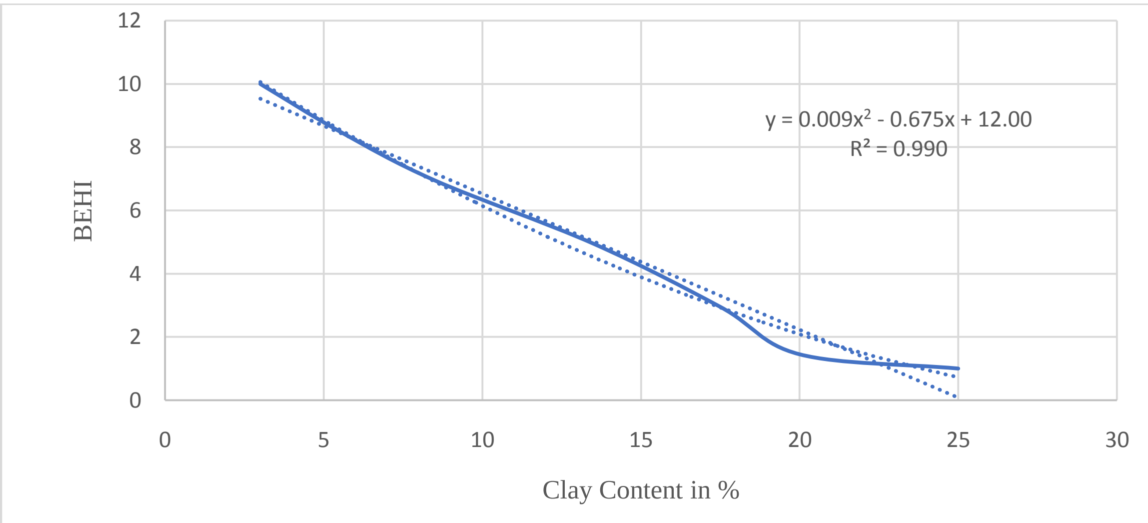
Using the values and indices of Table 5, the graph for determining the hazard index for any observed value of hazard parameters are developed by using excel spreadsheet and shown in Fig1, putting bank erosion hazard index (BEHI) in Y- axis and hazard parameters in X-axis. From the generated graphs, polynomial relations between hazard parameters and bank erosion hazard index (BEHI) are developed to calculate the hazard scores. For gradation of soil the graph is prepared by slightly different way as per the following Table number 6. In this case the clay is considered strongest against erosion and hence given least minimum score 1.45 and uniformly graded soil is considered as weakest against erosion and given highest score 10.

Table:6 (Guidelines for preparing graph for gradation)

Gradation of soil	Symbol used	Value assigned (Y- axis)	Score assigned (X-axis)
Only clay	*	1	1.45
Well graded sandy clay	**	2	2.95
Medium graded Clayey sand	***	3	4.95
Medium graded sand	****	4	6.95
Poorly graded sand	*****	5	8.50
Uniformly graded sand	******	6	10


BEHI
Permeability in cm/day
y = -0.000x² + 0.170x + 1.237
R² = 0.996
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80


BEHI
Liquid Limit in %
y = -0.002x² - 0.247x + 17.00
R² = 0.997
12
10
8
6
4
2
0
20
25
30
35
40
45
50


BEHI
Clay Content in %
y = 0.009x² - 0.675x + 12.00
R² = 0.990
12
10
8
6
4
2
0
0
5
10
15
20
25
30

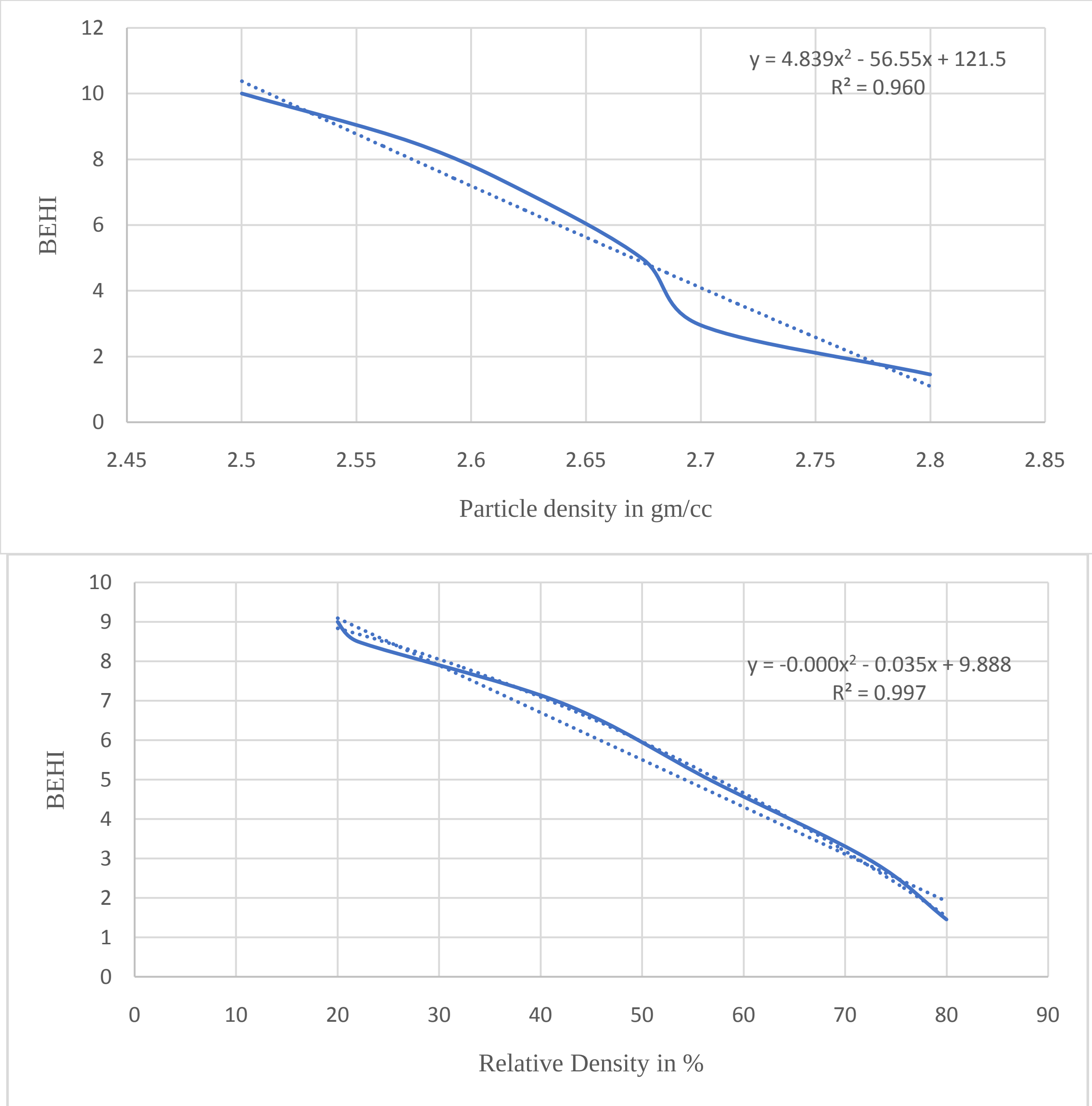


Fig: 1 (Developed graphs and equations of hazard parameters)

From the developed graphs, the following hazard- parameters relations are obtained.

$BEHI = -0.0006K^2 +0.1706K+1.2377$ (1)

$BEHI= -0.0021(LL)^2 -0.2475(LL)+17.002$ (2)

$BEHI= 0.009(CC)^2 -0.6754(CC) +12.005$ (3)

$BEHI= 4.839(PD)^2-56.55(PD)+121.5$ (4)

$BEHI= -0.0009 (RD)^2 -0.0355(RD) +9.8889$ (5)

Where BEHI = Bank Erosion Hazard Index
K = Permeability in cm/day
LL = Liquid Limit in %
CC = Clay Content in %
PD = Particle density in gm/cc
RD = Relative density in %

VI. Application of The Model

The developed hazard equations are applied to calculate the total score obtained on the basis of considered six parameters to assign the adjective hazard or risk rating category as very low, low, medium, high, very high or extreme as per table 5 in all selected sixteen locations with specimen calculation in location number 2 and location number 10. For gradation of soil no equation is developed and average score is assigned as per table number 6.

Table : 7 (Specimen calculation of hazard scores)

1. Location details :- Uzan Bazar Ghat Location No:- 2
2. Latitude: - $26^0 12^/ 4.07^{//}$
3. Longitude: - $91^0 44^/ 26.95^{//}$
4. Present Status: Very less erosion

BEHI Category	Symbol used	Observed value/ details	Score obtained	Total Score	Remarks
Permeability (cm/day)	E	7.17	2.43	20.98	Rate of erosion is expected to be low as per table 5
Liquid limit (%)	F	36.40	5.34		
Clay content (%)	G	15.5	3.70		
Particle density (gm/cc)	H	2.69	2.10		
Relative density (%)	I	73.24	2.46		
Gradation of soil	J	Medium graded Clayey sand(***)	4.95		

Table: 8 (Specimen calculation of hazard scores)

1. Location details :- Palashbari Location No:- 10
2. Latitude: - $26^0 7^/ 34.18^{//}$;
3. Longitude: -$91^0 32^/ 20.6^{//}$
4. Present Status: Very highly eroded

BEHI Category	Symbol used	Observed value/ details	Score obtained	Total Score	Remarks
Permeability (cm/day)	E	26.85	5.34	46.17	Rate of erosion is expected to be high as per table 5
Liquid limit (%)	F	30.61	7.56		
Clay content (%)	G	2.4	10		
Particle density (gm/cc)	H	2.61	6.87		
Relative density (%)	I	31.25	7.90		
Gradation of soil	J	Poorly graded sand (*****)	8.50		

Table:9(Calculation of total scores using developed graphs)

Location	Score(E)	Score(F)	Score(G)	Score(H)	Score(I)	Score(J)	Total score	Expected erosion hazard
1	1.61	4.47	4.06	1.17	3.06	4.95	19.32	low
2	2.43	5.34	3.70	2.10	2.46	4.95	20.98	low
3	2.06	3.69	6.86	1.98	4.64	4.95	24.18	moderate
4	1.54	4.06	4.48	5.00	4.17	4.95	24.2	moderate
5	2.55	4.78	2.69	4.39	3.58	4.95	22.94	low
6	1.62	4.46	3.31	4.09	4.29	4.95	22.7	low
7	2.43	4.71	6.45	4.09	4.76	4.95	27.39	moderate
8	1.42	3.82	6.86	1.17	4.72	4.95	22.94	low
9	10	7.09	10	5.31	6.85	8.50	51.49	very high
10	5.34	7.56	10	6.87	7.90	8.50	46.17	high
11	7.10	6.10	9.18	8.44	7.39	4.95	43.16	high
12	10	6.09	10	6.84	8.32	8.50	49.75	very high
13	10	7.64	10	6.87	8.10	8.50	51.11	very high
14	10	7.73	10	6.84	7.42	8.50	50.49	very high
15	5.85	7.12	10	6.82	6.86	8.50	45.15	high
16	6.50	6.97	10	8.44	7.93	8.50	48.38	very high

Table- 10 (Average assignment of bank erosion hazard index in new model)

Adjective Hazard or risk rating category		Permeability (cm/month)	Liquid limit(%)	Clay content(%)	Particle density (kg/m^3)	Relative density (%)	Gradation of soil	Total
Very low	Value	1-100	>44	90-100	>2800	>80	*(1)	
	Av Index	1.45	1.45	1.45	1.45	1.45	1.45	6-11.4
Low	Value	101-500	44-40	60-89	2800-2700	80-65	**(2)	
	Av Index	2.95	2.95	2.95	2.95	2.95	2.95	12-23.6
Moderate	Value	501-900	39-35	20-59	2699-2650	64-50	***(3)	
	Av Index	4.95	4.95	4.95	4.95	4.95	4.95	24-35.4
High	Value	901-1400	34-30	10-19	2649-2600	49-35	****(4)	
	Av Index	6.95	6.95	6.95	6.95	6.95	6.95	36-47.4
Very	Value	1401-2000	29-25	5-9	2599-2500	34-25	*****(5)	

High	Av Index	8.50	8.50	8.50	8.50	8.50	8.50	48-54
Extrem	Value	>2000	<25	<5	<2500	<25	******(6)	
e	Av Index	10	10	10	10	10	10	55-60

The total hazard score can also be calculated taking the average indices as shown in table 10 without reading the value from the graphs or equations. The total scores so calculated are show in table 11

Table:11(Calculation of total scores using average indices as per Table 10)

Location	Score(E)	Score(F)	Score(G)	Score(H)	Score(I)	Score(J)	Total score	Expected erosion hazard
1	1.45	4.95	6.95	2.95	2.95	4.95	24.20	Moderate
2	2.95	4.95	6.95	4.95	2.95	4.95	27.70	Moderate
3	2.95	2.95	8.50	2.95	4.95	4.95	27.25	Moderate
4	1.45	4.95	6.95	4.95	4.95	4.95	26.20	Moderate
5	2.95	4.95	6.95	4.95	2.95	4.95	27.70	Moderate
6	1.45	4.95	6.95	2.95	4.95	4.95	26.20	Moderate
7	2.95	4.95	6.95	2.95	4.95	4.95	27.70	Moderate
8	1.45	4.95	8.50	4.95	4.95	4.95	29.75	Moderate
9	10	2.95	10.00	6.95	6.95	8.50	45.35	High
10	4.95	6.95	10.00	6.95	8.50	8.50	45.85	High
11	6.95	6.95	10.00	8.50	6.95	4.95	44.30	High
12	10	6.95	10.00	6.95	8.50	8.50	50.90	Very high
13	10	6.95	10.00	6.95	8.50	8.50	50.90	Very high
14	10	6.95	10.00	6.95	6.95	8.50	50.90	Very high
15	6.95	6.95	10.00	6.95	10.00	8.50	49.35	Very high
16	6.95	6.95	10.00	8.50	8.50	8.50	49.40	Very high

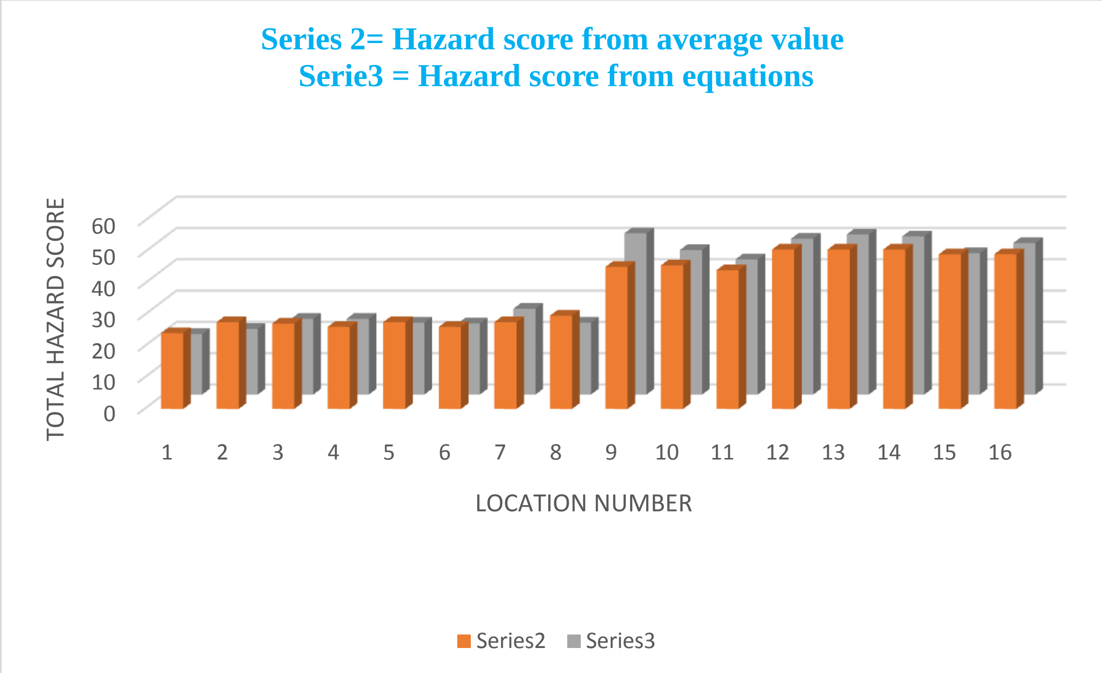


Fig :2 (Total hazard scores of all locations)

VII. Conclusion

The river Brahmaputra of Assam creating tremendous ill effects to its river side people by severe erosion in many locations in its entire reach. Every year the poor state suffers many folded losses due to river bank erosion. This particular natural hazard is accepted as burning and recurrent problem all over the world and full swing researches are going on for the solution of the problem. But till date no any full proof scientific or engineering solutions are obtained. Experts opine that this particular river related natural hazard is most common in the globe and not possible to completely eradicate but it can be controlled or minimized to great extent by using appropriate anti erosive measures or by proper site-specific river training works. For effective and proper adoption of erosion control measures or river training works, it is very much important to locate or identify the vulnerable locations so that anti erosive measures could be taken in advance on priority basis. Keeping all these in mind an attempt has been made to find to a practical method to assess the degree of vulnerability of all locations on the basis of physical properties of soils as some physical properties of soil play vital role in producing or retarding the erosion. To fulfill this idea, all together sixteen locations in lower Assam region of river Brahmaputra is selected out of which half number of locations are of very less erosion prone and next half numbers are of very high or high erosion prone. From all these sixteen locations soils samples are collected to find the value of some important physical properties related to erosion. From the comparative study of the obtained results, it is clear that the that the average values of the considered soil parameters widely differ for erosion free and erosion prone locations. So, finally six soil physical properties- permeability, liquid limit, clay content, particle density, relative density and gradation of soil are taken to develop a practical method to compute the erosion hazard vulnerability of river bank in lower Assam region of river Brahmaputra in particular and to apply the same in general for all rivers in the line of Rosgen's modified method of bank erosion hazard index (BEHI). After applying the method in computing BEHI in all selected locations, it is found that it gives satisfactory results in identifying the degree of erosion vulnerabilities of locations by giving expected erosion hazard vulnerabilities as low or moderate in all less or non-eroded locations and it gives very much satisfactory results in identifying locations of high risk by giving the risk category as high or very high (table 9) in all eight erosion prone areas. So, finally it may be concluded that this practical and simple method can effectively be used to identify or assess the vulnerable locations, if the calculated scores indicate the hazard expectation as high, very high or extreme. If the calculated scores indicate the hazard expectation as moderate or below then the observed location may be marked as erosion free from geotechnical properties point of view.

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