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Role of Critical Shear Stress and Erodibility of Soil in Stream Bank Erosion in Lower Assam Region of River Brahmaputra.

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ABSTRACT
River and streams are the vessels of this globe through which the blood of earth (water) flows to keep living the planet like human being and plant kingdom. The beauty of this planet in comparison to other planets of this universe is due to existence of life in the globe which is possible only due to presence of sufficient water in the earth. History reveals that most of the world civilization has been formed on the bank of some big river that is civilization and rivers are closely related to each other. So many big cities are also situated in the bank of rivers. Due to its unconsolidated or loose banks and floodplains the alluvial rivers have a regular tendency to erode their banks and deposit eroded soils on bars and their floodplains causing tremendous ill effects to the human being and the environment. The Brahmaputra is one of the major and mightiest and braided river of the world which flows through three different sovereign countries like China, India and Bangladesh. The river Brahmaputra is known by different name in different region. In India it is known as Brahmaputra, in China it is known as YarlungZangbo, in Tibet it is commonly known as Tsangpo and in Bangladesh it is famous as Jamuna. The origin of the river Brahmaputra is in the Angsi glacier located on the northern side of the Himalayas in Burang country of Tibet. The length of the river from its origin to the final entry into Bay of Bengal is about 3848 km and in Assam it is about 700 km. The depth of the river varies from just few metres to 120 m in certain locations with average depth of about 38 m in rainy season. The river Brahmaputra is a very good example of braided river with the area of river basin is about 651334 square km along with the formation of huge temporary sand bars during the winter. The width of the river is also varies just more than 1 km to about 10 km. The nature of the river Brahmaputra is enormous and unpredictable in terms of migration and channel cutting and creating tremendous havoc by eroding its banks to the people living neighboring its sides.
Key Words: Assam, Brahmaputra, Critical Shear Stress, Empirical, Erodibility, Erosion, River Bank

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I. INTRODUCTION

River bank erosion in fluvial process generally occur due to three main reasons (Fischenich 1989): The flowing water exert hydraulic forces on erodible bed and bank materials, geotechnical instabilities occur in bank soil, combination of hydraulic forces and geotechnical instability causes bank failure. As per the opinion of Fischenich (1989) the hydraulic failure of bank occurs when the flowing water exerts tractive force on the bed or bank materials that exceeds the critical shear stress of that particular stream bank materials. Hydraulic failure of river bank is generally influenced or accelerated due to lack of vegetation or vegetative cover, high boundary velocities and slope of the bank.

about 39.58 % of the total land area of Assam is vulnerable for flood and erosion hazard which is about 9.40% of total flood prone area of the country. As per the records the national average

Assam is a land of river. Assam with its vast network of rivers under the leadership of mighty Brahmaputra and Barak is prone to natural disasters like flood and erosion which has a very negative and adverse impact on overall development of the state. Every year during the monsoon period he Brahmaputra and Barak river with more than 50 numbers of tributaries joining them, causes the flood and erosion devastation. The flood and erosion hazard of Assam is quite different as compared to the other state of India so far as the magnitude of erosion, extent and duration of flooding. As per the assessment of RastriyaBarhAyog (RBA) the flood prone area of the state is 31.05 Lakh Hectares against the total area of state 78.523 Lakh Hectares. It means that annual area affected by flood is 9.31 Lakh Hectares which is about 10.2 % of the total area of the country. It signifies that the flood prone area of Assam is four times the national mark of the flood prone area of the country. Assam is one of the poorest state of India with approximately 36% people are living below poverty line. The state Assam faces flood along with river bank erosion more or less in every year. After independence Assam faced major floods accompanied by erosion in 1954, 1962, 1972, 1977, 1984, 1988, 1998, 2002, 2004, 2012. As per the report of Water Resource Department, Assam, the average annual loss due to flood and erosion is about Rs. 200.00 crores. (source nrsc). The mighty river Brahmaputra is flowing through the middle of entire state from east to west dividing the whole state into two distinct part northern part and southern part. During its journey so many major tributaries are combining with Brahmaputra to meet their final destination at Bay of Bengal. The river bank erosion is a very common and major hazard in Assam. Almost all tributaries erode its bank regularly. The extent of erosion of river Brahmaputra is tremendous, devastating and unpredictable in terms of its intensity and locations. Keeping all these in mind and understanding the depth of the problem, an attempt has been made to identify and select such vulnerable positions by measuring the critical shear stress and soil erodibility of some selected locations of river Brahmaputra and to ascertain the role of critical shear stress and soil erodibility of bank soil in assessing the vulnerability of erosion.

Study area and methodology: For this all together sixteen locations have been selected in lower Assam region of river Brahmaputra. Out of these sixteen locations eight locations are of low erosion prone and another eight locations are of very high erosion prone. From all locations disturbed soil samples are collected and tested in the laboratory as per IS system. The selected locations are shown below in fig.1

Fig :1 (Selected location)

Critical shear stress and Erodibility of soil:

Shear strength of a soil may be defined as the maximum internal resistance the soil can withstand against the possible sliding or shearing along the plane. The shear strength of a soil on any plane is primarily the function of soil characteristics and the normal stress acting on the plane. As per Coulomb (1776) the shear strength of soil can be expressed as $S= C+\sigma\tan\phi$; where S= shear strength of soil in a plane; C= unit cohesion; σ = normal stress acting on the plane; ϕ = angle of internal friction of the soil. Shear strength of soil is one of the most important properties of soil from engineering point of view. The knowledge of shear strength of soil is important for the following purposes-

1. It determines the settlement of soil.
2. The load bearing capacity of soil depends on the shear strength of soil.
3. Earth pressure on any structure is governed by shear strength.
4. Sensitivity of soil is a function of shear strength of soil.
5. Shear strength controls the stability of earth slopes.
6. Shear strength of soil decreases the erodibility of river bank.

The shear strength of soil can be determined in laboratory by direct shear test, by triaxial compression test, by unconfined compression test and in field by vane shear test.

The soil particles of river bed or banks experience stress due to flowing water. This stress always try to detach soil particles from its original position and carry away these detach particles along with the flow. Whether the soil particle will detach or move forward that depends on its strength of stability and the stress exerted by the flowing water current. If the stability strength is more than the applied shear stress than the particle will not move or detach otherwise the case will be opposite. The maximum amount of shear stress that a soil particle can bear without detachment is known as the critical shear stress (τ_c)of soil and hence more the value of critical shear stress more will be the stability against erosion.Critical shear stress (τ_c) and erodibility coefficient (k_d) are two very important parameters related to river bank erosion. So many factors influence the erodibility parameters but Jet Erosion Test (JET) is an effective technique for site measurement of these parameters. This JET was developed for measuring erodibility parameters in situ as well as in the laboratory (Hanson 1990b; Hanson and Cook 1997;Hanson and Simon 2001).So many empirical relations have been developed to determine the erodibility parameters on the basis of physical properties of soil. E.R. Daly' G.A. Fox and A.K.Fox (2016) conducted 74 JETs at three sites at Oklahoma to study the variability of erodibility parameters of field test and empirical relation and they observed a large amount of variability between the two.

Predicting stream bank erosion is remaining as a very difficult issue though multi-

Critical shear stress of soil can be determined by using several approaches. This can be determined in situ by submerged jet devices; it can be estimated from soil specific gravity and particle size; it can be determined in flume studies. For non-cohesive or sandy soil the shield diagram is used to estimate the critical shear stress of soil on the basis of particle size. Open channel flow test is also mostly adopted for measuring erosion particularly in cohesive soil and then graphically or visually the critical shear stress is estimated.

So many relations are suggested by experts in their literature between soil texture and erodibility parameters. Generally critical shear stress (τ_c) is estimated from soil texture parameters and erodibility coefficient (k_d)is estimated from τ_c. Torres and Julian (2006) suggested a relation between critical shear stress with clay and silt content of soil. The developed relationship is given by

$\tau_c= 0.1+0.1779(CS\%)+0.0028(CS\%)^2 -2.34x10^{-5} (CS\%)^3$ (2)

Where CS = Clay and Silt content.

Beasley and Smerdon (1961) performed eleven number of flume study on Missouri soils to relate the critical shear stress (τ_c) with some basic soil properties which are shown below

$\tau_c=0.16 (I_w)^{0.84}$ (3)

$\tau_c=10.2 (D_r)^{-0.63}$ (4)

$\tau_c= 3.54x10^{-28.1D}{}_{50}$ (5)

dimensional research are going in this field. Generally stream bank erosion mechanism are of three types: fluvial erosion, mass failure and sub aerial processes. Fluvial erosion in river bank is a continuous process when the applied shear stress on soil particle by flowing water exceeds the critical shear stress of soil. Fluvial erosion generally undercut the bank toe making the soil layer overhanging and ultimately tension cracks developed and mass failure occur (Fox and Wilson,2010; Midgley et al ,2012).

Erosion prediction model or particle detachment model are commonly employed for prediction of river bank erosion rate. The erosion rate of cohesive bank material can be assessed using excess shear stress equation (Partheniades,1965; Hanson, 1990a, 1990b) which is expressed as

$\varepsilon_{r=} k_d(\tau -\tau_c)^a$ (1)

Where $\varepsilon_r$is the rate of erosion (in cm s^{-1}); $k_d$is the erodibility coefficient (in $cm^3 N^{-1} S^{-1)}$;

τ is the average hydraulic boundary shear stress (N m^{-2}); $\tau_c$is the critical shear stress (N m^{-2}); 'a' is an empirical exponent assumed to unity (Hanson, 1990a,1990b; Hanson and Cook, 1997,2004). As per this empirical model the erosion or detachment of soil particle will start if the value of τ exceeds τ_c.

$\tau_c=0.493x10^{0.0182P}c$ (6)

Where

τ_c= Critical shear stress in Pa or N m^{-2}

I_w= Plasticity index

D_r= Dispersion ratio

D_{50}= Mean particle size in metre

P_c= Percent clay by weight in %

The relation established in terms of I_w, D_r, P_c with critical shear stress is found to be most reliable as all these soil properties are directly related to the cohesion of soil.

Neil (1967) presented an equation relating mean velocity to grain size, specific gravity and flow depth after performing an experiment on incipient motion of two sizes of uniform glass balls, six sizes of graded balls and cellulose acetate balls ranging in diameter from 6 to 30 mm for wide channel with flatbed as

$\rho V^2mc/ \gamma'_s Dg=2.50(Dg/d)^{-0.20}$(7)

Where

Vmc= Competent mean velocity for first displacement of bed materials

Dg= Effective diameter of bed grains

d = depth of flow

$\gamma'_s= (\rho_s- \rho) g$

g=acceleration due to gravity

ρ_s = bed material mass density

ρ = fluid mass density

Neill (1973), Fairfax Country (2004) established a relation between specific gravity, median particle diameter and water depth with incipient shear stress as

τ_c= 0.76090 γ (G-1)D $^{2/3}{}_{50}$ d$^{1/3}$ (8)

Where

τ_c= incipient or critical shear stress in Pa

γ = specific weight of water (N m^{-3})

G= specific gravity of soil

D_{50}= mean particle diameter (m)

d = depth of flow (m)

Therese is no simple relationships between soil erodibility (k_d) and soil properties but some empirical relations are suggested by different experts.Hanson and Simon (2001) established an inverse relationship to determine $k_d$from $\tau_c$for cohesive soil as

for estimating k_d andτ_c. Subsequently this relation has been updated by Simon et al (2011) on the basis of some other Jet Erosion Test as

k_d= 1.62(τ_c)$^{-0.838}$ (10)

On the basis of flume experiments performed on undisturbed cohesive soil samples collected from 42 streams of US and conducted at the Waterways Experiment Station in Vicksburg, Mississippi, Osman and Thorne (1988) suggested an equation to determine the lateral erosion rate for soils having $\tau_c$greater than 0.6 Pa as

dB = (223x10^{-4}τ_c e$^{-0.13\tau_c}$) / γ (11)

where

dB = initial lateral bank erosion rate (m/min/unit area)

τ_c = critical shear stress (dyne/cm^2)

γ = Soil unit weight (KN/m^3)

Using this relation the actual erosion rate is calculated by the following equation

dW = dB x (τ-τ_c)/ τ_c (12)

Where

k_d= 0.2(τ_c)$^{-0.5}$ (9)

Where k_d= Erodibility coefficient in cm^3/ N.s

This relationship has been derived by Hanson and Simon (2001) after conducting 83 in situ Jet Erosion Tests in cohesive streambeds in the Midwestern United State of America. The results found in these tests showed a wide range of variations with τ_c spanning six order of magnitude and$k_d$spanning four order of magnitude. Of course a general inverse relation has been clearly noticed between $k_d$and τ_c , suggesting that soils with high value of $\tau_c$have a low value of k_d and vice versa.This relationship can be incorporated in stream bank erosion and stability model like Bank Stability and Toe Erosion Model (BSTE

dW= actual erosion rate (m/min)

dB = initial lateral bank erosion rate (m/min/unit area)

τ = flow shear stress (dyne/cm^2)

τ_c = critical shear stress (dyne/cm^2)

As per the opinion of authors (Osman and Throne,1988) the result of erosion as calculated above may give some unrealistic result. If so then calibration factor is suggested by the authors.

Calculation of Critical Shear Stress of Selected Location

In this work all together sixteen locations have been selected and physical properties of soil samples of all locations have been determined in the laboratory. On the basis of properties of soil and using the relation (2) as suggested by Torres andJulian (2006) ieτ_c= 0.1+0.1779(CS%)+0.0028(CS%)^2-2.34x10^{-5} (CS%)^3 the critical shear stress of bank soil is calculated and tabulated below

Table:1 Critical shear stress by relation no 2

Location no	% of clay and silt	Value of calculated τ_c in Pa	Average value of τ_c in Pa	Remarks
1	19.6	4.49	3.72	Location number 1 to 8 are of very less erosion prone area where the average value of critical shear stress is found to be much more than the other highly eroded areas
2	17.4	3.92		
3	10.8	2.32		
4	18.8	4.28		
5	21.4	4.96		
6	18.6	4.23		
7	10.8	2.32		
8	13.0	2.83		
9	5.4	1.14	1.47	Location number 9 to 16 are of highly erosion prone area where the average value of critical shear stress is found to be much less than the other low eroded areas.
10	4.8	1.02		
11	9.9	2.11		
12	11.2	2.41		
13	2.5	0.56		
14	5.1	1.08		
15	10.4	2.23		
16	5.6	1.18		

As per Smerdon and Beasley(1961) the critical shear stress of soil can also be calculated by equation no (6) ie$\tau_c=0.493x10^{0.0182P}c$, on the basis of percent clay which is an important properties from erosion point of view. This relation has been used to determine the critical shear stress of soil in all locations and results are as follows

Table:2 (Critical shear stress by relation no 6)

Location no	% Clay	τ_c(Critical Shear stress) in Pa	Average value of τ_c in Pa	Remarks
1	14.6	0.91	0.86	Location number 1 to 8 are of very less erosion prone area where the average value of critical shear stress is found to be much more than the other highly eroded areas
2	15.5	0.94		
3	8.6	0.71		
4	13.6	0.87		
5	18.2	1.06		
6	16.5	0.98		
7	9.4	0.73		
8	8.6	0.71		
9	2.7	0.55	0.55	Location number 9 to 16 are of highly erosion prone area where the average value of critical shear stress is found to be much less than the other low eroded areas.
10	2.4	0.54		
11	4.45	0.59		
12	3.2	0.56		
13	1.25	0.52		
14	2.25	0.54		
15	2.2	0.54		
16	2.8	0.55		

Fig:1(Comparison of critical shear stress of all locations obtained by relation no 2)

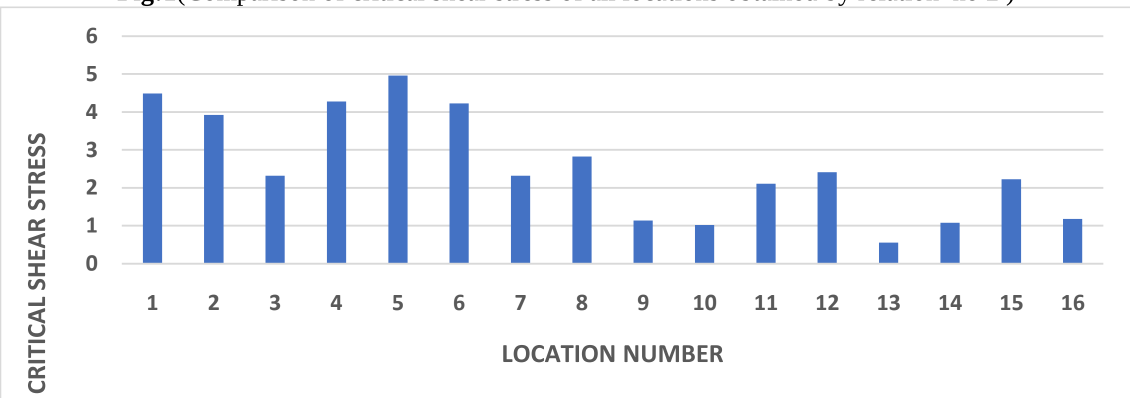
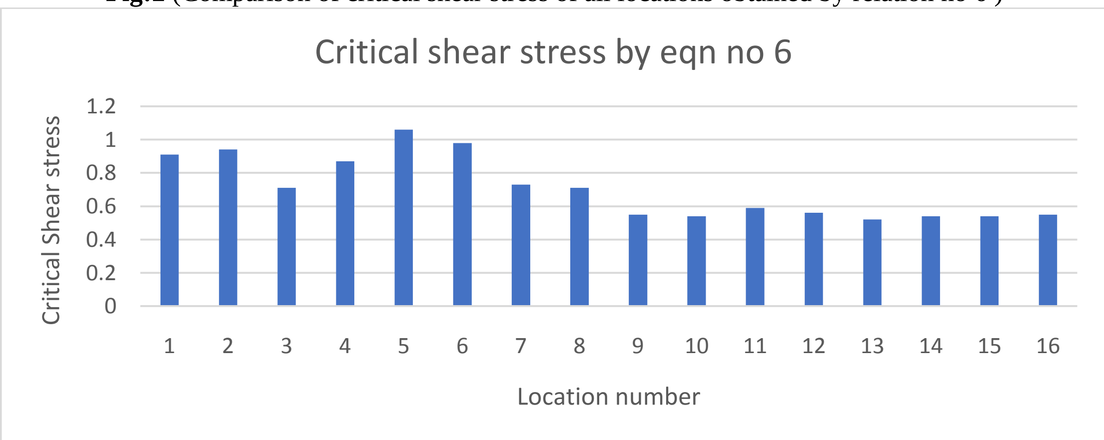


Fig:2 (Comparison of critical shear stress of all locations obtained by relation no 6)



It has been clearly observed that whatever may be the method ,the value of critical shear stress of non-eroded or less eroded locations are almost two times higher than the eroded locations. As the percentage of clay is increased the value of critical shear stress also increased. Therefore, the clay content and critical shear stress play vital role in the stability of bank soil.

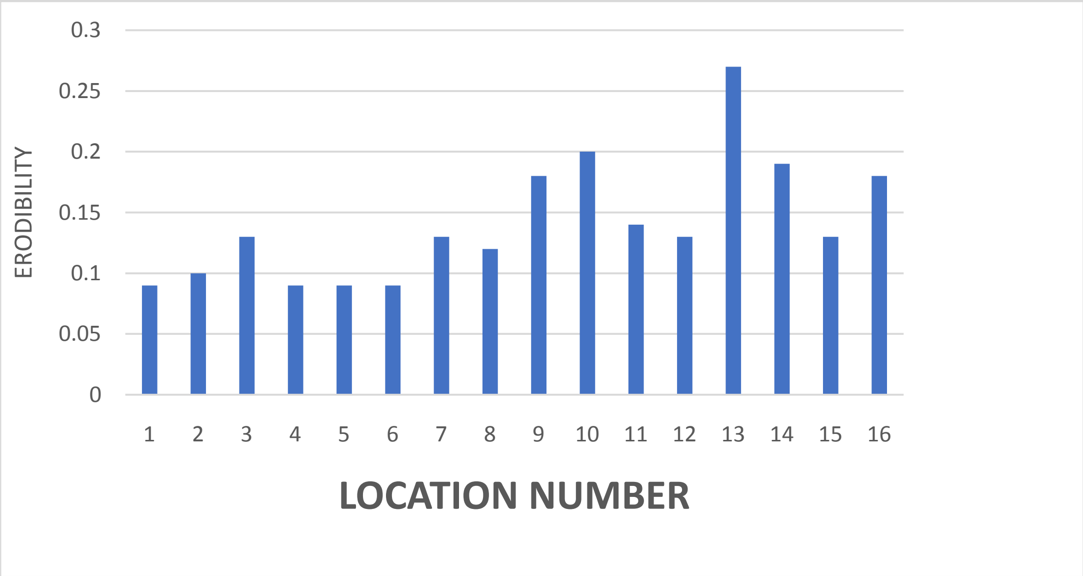
Calculation of Soil Erodibility of Selected Location

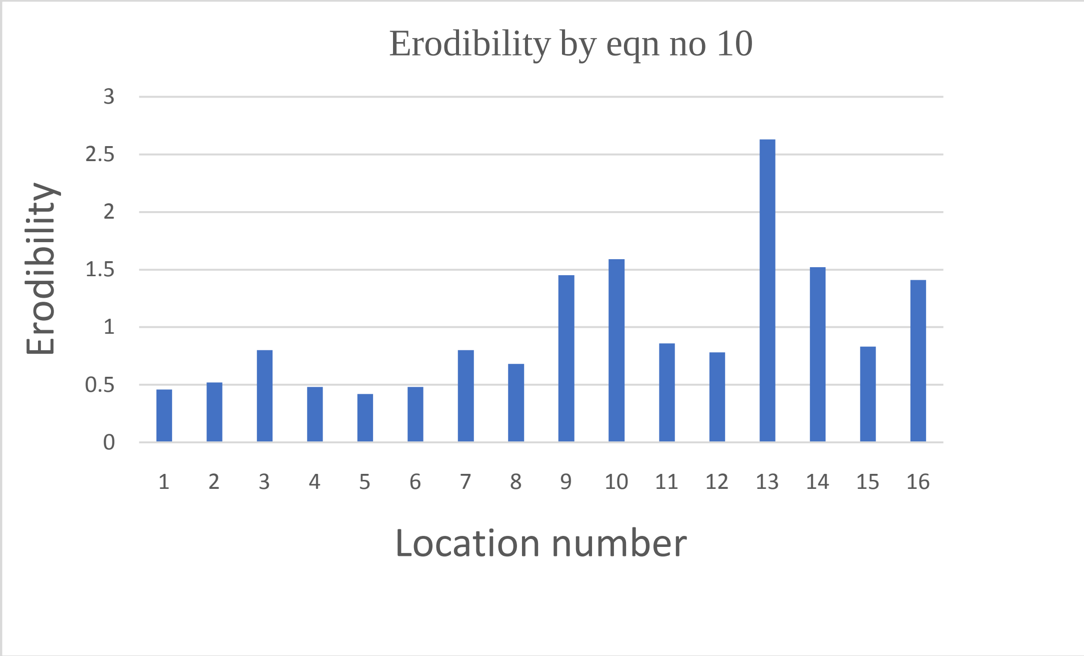
The erodibility of all selected locations are calculated on the basis of Critical Shear Stress (as obtained by relation number 2) by using the two relations (9) and (10) and tabulated in table no 3

Table:3 (Erodibility by relation 9 and 10)

Location no	Value of τ_c in Pa	Erodibilityby relation no 9 in cm^3/ N.s	Erodibility by relation no 10 in cm^3/ N.s	Average of Erodibility	Remarks
1	4.49	0.09	0.46	0.11 cm^3/ N.s by relation no 9 0.58 cm^3/ N.s by relation no 10	Location number 1 to 8 are of very less erosion prone area
2	3.92	0.10	0.52		
3	2.32	0.13	0.80		
4	4.28	0.09	0.48		
5	4.96	0.09	0.42		
6	4.23	0.09	0.48		
7	2.32	0.13	0.80		
8	2.83	0.12	0.68		
9	1.14	0.18	1.45	0.18 cm^3/ N.s by relation no 9 1.38 cm^3/ N.s by relation no 10	Location number 9 to 16 are of highly erosion prone area
10	1.02	0.20	1.59		
11	2.11	0.14	0.86		
12	2.41	0.13	0.78		
13	0.56	0.27	2.63		
14	1.08	0.19	1.52		
15	2.23	0.13	0.83		
16	1.18	0.18	1.41		

Fig:4 (Comparison of erodibility of all locations by relation no 9 and 10)
(Table : Erodibility by equation no 9)





The critical shear stress and erodibility of soil is inversely related to each other. The average value of erodibility is almost double in eroded locations as compared to the non-eroded locations.

New empirical relation for erodibility:The erodibility of different locations (as shown in table) determined by the relation $k_d=0.2\ (\tau_c)^{-0.5}$ as suggested by Hanson and Simmon (2001) and the relation $k_d= 1.62(\tau_c)^{-0.838}$ as suggested by Simon et al (2011) give results of wide variations. It has been observed that the results of erodibility (k_d) as determined by the relation

$k_d=0.2\ (\tau_c)^{-0.5}$ give very low value as compared to the results obtained by the relation $k_d= 1.62(\tau_c)^{-0.838}$ .The average value as obtained by the later relation is almost 427 % more than the previous relation in case of soils of less eroded locations. On the other hand the same is almost more by 666 % in case of highly eroded locations. This shows that there is huge difference in results between the two relations. So an attempt has been made to get an average result by developing an empirical relation on trial and error basis and accordingly the following empirical relation is proposed by changing the coefficient of the relation $k_d= 1.62(\tau_c)^{-0.838}$ as suggested by Simon et al (2011) from 1.62 to 0.967 and expressed as

$k_d= 0.967\ (\tau_c)^{-0.838}$ (13)

Now the erodibility of different locations are calculated on the basis of critical shear stress using this new empirical relation and results are tabulated below

Table (Erodibility of all locations by the new relation 13 and comparison with average of two already developed relations)

Location no	Value of τ_c	Average Erodibility by relation no 9 and 10	Erodibility by New proposed relation no 13	Average of Erodibility in cm^3/ N.s	Remarks
1	4.49	0.275	0.275	Average value of all non eroded location by existing two relations is $0.343 cm^3$/ N.s Average value by proposed relation is $0.346 cm^3$/ N.s	Location number 1 to 8 are of very less erosion prone area
2	3.92	0.31	0.31		
3	2.32	0.465	0.477		
4	4.28	0.285	0.285		
5	4.96	0.255	0.252		
6	4.23	0.285	0.288		
7	2.32	0.465	0.477		
8	2.83	0.40	0.404		
9	1.14	0.815	0.866	Average value of all non-eroded location by	Location number 9
10	1.02	0.895	0.951		

11	2.11	0.50	0.517	existing two relations is $0.764 cm^3/N.s$ Average value by proposed relation is $0.825 cm^3/N.s$	to 16 are of highly erosion prone area
12	2.41	0.455	0.462		
13	0.56	1.45	1.571		
14	1.08	0.855	0.906		
15	2.23	0.48	0.493		
16	1.18	0.66	0.841		

The proposed new empirical relation to determine the soil erodibility(k_d) on the basis of Critical shear stress of soil (τ_c) is found to be quite satisfactory in giving the average of the already developed relations. The average value obtained by this newly proposed relation is almost same as the average of Hanson and Simmon (2001) and Simon et al (2011).

Fig: 5 (Comparison of erodibility of all locations obtained by new relation)

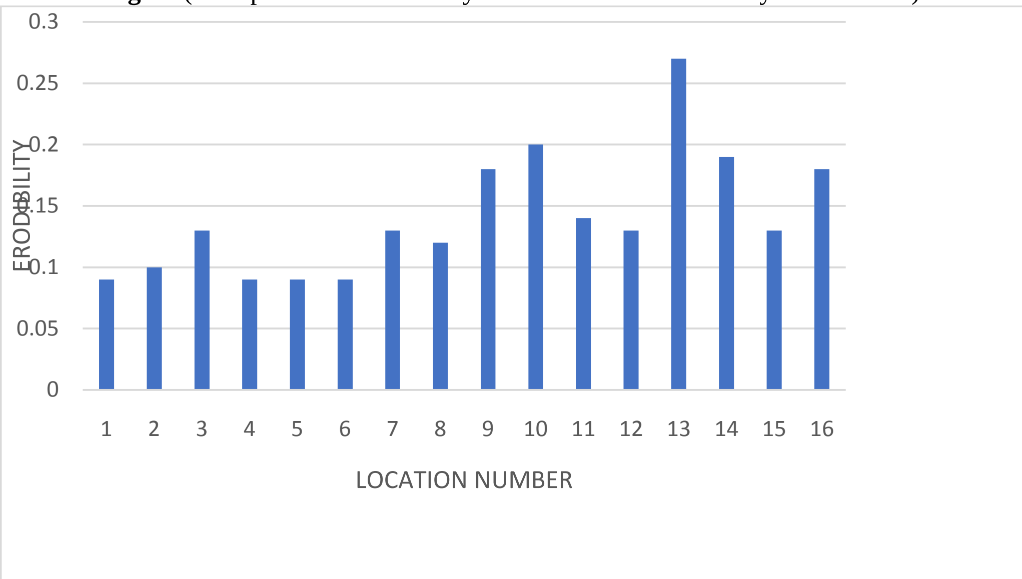
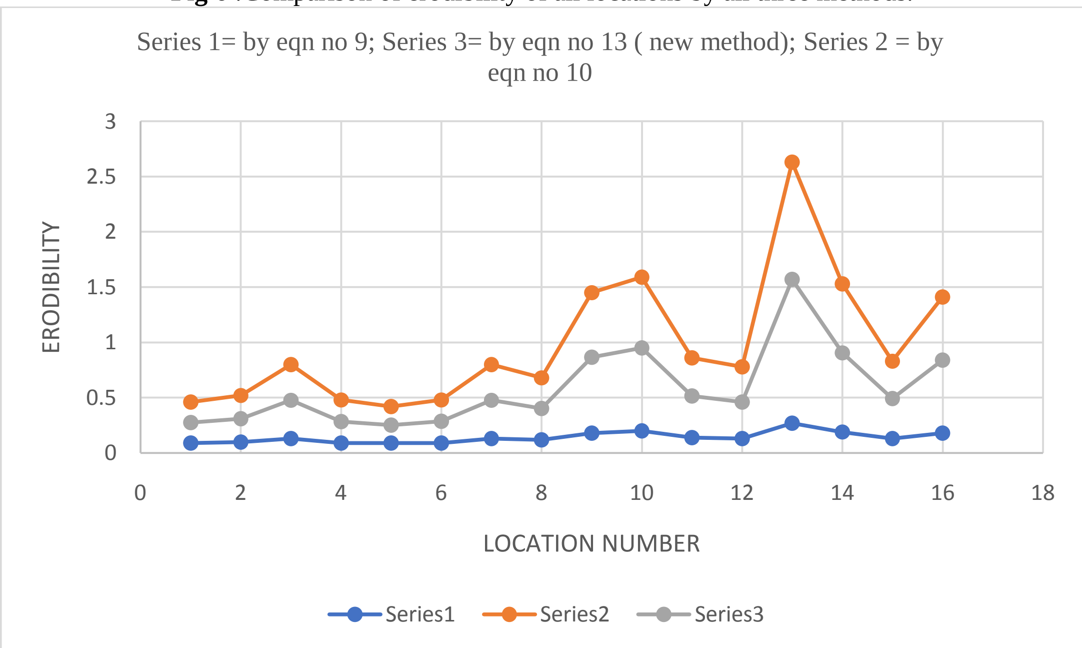


Fig 6 :Comparison of erodibility of all locations by all three methods.



II. CONCLUSION

The critical shear stress (τ_c) and soil erodibility (k_d) play vital role in determination of probability of stream bank erosion in a certain location of river bank. Any soil particle on the surface of river bank under water is subjected to shear stress due to flowing water. This shear stress has a tendency to destabilized and erode away the soil particles from its original position. There are several approaches to determine the critical shear stress of soil on the river bank. In our case the critical shear stress is determined on the basis of clay and silt content as proposed by Torres and Julian (2006) and on the basis of clay content only as proposed by Beasly and Smerdon (1961). In both methods the value of critical shear stress were found much higher in all safe and erosion free areas than all other vulnerable areas without any exception. The value of erodibility of soils are calculated by the relation number 9 as proposed by Hanson and Simon (2001) and by the relation number 10 as proposed by Simon et al (2011) on the basis of critical shear stress as obtained by the relation number 2. Both the relations suggest comparatively high value of erodibility for areas susceptible to erosion than the erosion less areas. Of course the magnitude of erodibility obtained by the two methods differ a lot in terms of maximum, minimum and average. This could be overcome by using the relation as proposed by the author as shown in relation number 13. From the analysis of results of critical shear stress of all locations, it is clear that the average value of non-eroded locations and highly eroded locations are 3.72 N/m^2 and 1.47 N/m^2respectively as calculated by the relation number 2. So, a bench mark could be adopted to assess the possibility of erosion in a certain location on the basis of the value of critical shear stress in stream bank by categorizing the location as low possibility if the calculated value of critical shear stress is mor than 3.0 N/m^2 and the same may be categorized as location of high possibility of erosion if the value of critical shear stress is found to be less than 2. 0 N/m^2 . Also, the erodibility of soil can be used as a parameter for predicting the strength or weakness of river bank against erosion. If the value of coefficient of erodibility is found to be less than 0.35 $cm^3\ N^{-1}\ S^{-1}$ as calculated by the new relation 13, the location may be considered as safe against erosion and if the same is found to be more than 0.8 $cm^3\ N^{-1}\ S^{-1}$, the location may be identified as high risk of erosion. Finally it could be concluded that the value of critical shear stress and coefficient of erodibility of soil are two important parameters to assess the vulnerability of erosion in lower Assam region of Brahmaputra. The extent of vulnerability of whole region of river Brahmaputra or any other river may be pin pointed by calculating the value of critical shear stress and soil erodibility at the entire reach and accordingly the whole river bank may be marked location wise as safe or vulnerable for easy identification and subsequent implementation of effective anti-erosional measures on priority basis.

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