EMBANKMENT STABILISATION IN SOUTH EASTERN NIGERIA USING VETIVER GRASS (*Chysopogon zizanioides*);

Case Study of NEWMAP Project Site in Umuda - Isingwu, Umuahia North L.G.A. Abia State.

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ABSTRACT

Soil erosion and embankment failures are serious challenges confronting our environment. Hence, this work studied embankment stabilization using Vetiver grass (Chrysopogon zizanioides) in Umuda - Isingwu community. The principal objective of this study was to determine the stability of an engineered slope by computing the factor of safety (FS) of the samples collected from the embankment. To ascertain the factor of saety, the soil samples collected from the study area were analyzed by mechanical sieving and hydrometer method, the specific gravity of the soil was determined as 2.61 and 2.46 for bare sample and Vetiver rooted sample using Pycnometer. The following soil parameters were also determined: unit weight for bare and Vetiver rooted samples as 17.40KN/m^3 and 16.62KN/m^3 respectively. The result obtained from the study showed that the soil samples are coarse sand and loamy sand, with average shear strength of the control (bare) soil samples and Vetiver rooted soil samples as 68.52KN/m^2 and 132.32KN/m^2 respectively. The factor of safety of the samples; bare and Vetiver rooted soils were computed to be 1.72 and 2.98 respectively. These computed factors of safety showed that Vetiver rooted samples are 1.73 times stable more than the bare soils. Hence it can be deduced that Vetiver grass can be put to effective use in the area slope management and stabilization in Nigeria.

Keywords: Soil erosion, embankment stability, Vetiver grass and factor of safety

1.0 INTRODUCTION

In Nigeria, “over 6,000km^2 of land are affected by erosion and about 3,400km^2 are highly exposed, in some areas of southern Nigeria farmland degradation has caused yield reductions between 30% and 90%, and as much as a 5% drag on agricultural GDP (ABIA-NEWMAP, 2017).

The quest to curb and provide lasting solutions to these degradation problems caused by erosive rainfall intensities has remained a crucial issue under debate among environmentalist and soil and water conservation engineers. This is validated in Ke, Feng and Wu (2003) affirmation that due to the rate of land degradation caused by erosion, efforts has been made among scholars to unmask the best minimum cost effective measure for slope stabilization.

In order to effectively control soil erosion cum embankment failures, there is need to identify the root causes. Okorafor, Akinbile & Adayemo (2017) confirmed that the major causes of soil erosion within south eastern Nigeria are human interference, climatic factors (rainfall), poor geology of the region, undulating topography, soil nature. In a similar research, Islam (2000) identified devastating flood, excessive rainfall and tidal surge as the dominating factors contributing to embankment failure processes which results to immense damage to agriculture and infrastructures every year. Nasrin (2013) revealed that countries of sub-Saharan are besieged by serious environmental degradation resulting in desert encroachment, draught and soil erosion due to either wind impact or very high intensive rainfall resulting in heavy runoff and soil loss.

NEWMAP (2017) reported that in Umuda - Isingwu community, high torrential rainfall created catastrophic soil erosion in the area which culminated to gully formation, surficial slope failures and second degree problems including huge capital expenditure in curtailing the menace.

Having identified some the possible factors facilitating embankment failures, the best possible mitigation or control measures to these factors greatly depend on cost of its implementation. Cost implications of conservation measures are important indicators of how these measures are accepted by stakeholders. In a bid to remediate, reclaim and protect embankments, an optimal cost benefit ratio is usually targeted. The importance of cost consideration was made paramount in Arifuzzaman, Anisuzzaman, Rahman and Akhte (2013) where traditional practices for

protecting embankments were identified as being expensive and sometimes not effective due to improper design and construction fault(s) for the designed life of such structures.
Current researches have shown that Biotechnology is an effective alternative solution for embankment protection. In the same vein, much emphasis have been made on the use of Vetiver grass which proved to be a successful biotechnical method to protect slopes in most case histories studied and reported in literature.

Vetiver according to Likitlersuang *et al*. (2009) is a perennial grass that had been promoted to help conserve the soil and runoff by the World Bank in the 1980s and since then has developed to become an important soil bioengineering method.

Vetiver grass botanically known as *Chrysopogon zizanioides*, is a fast growing perennial plant with an extensive, dense and deep root system and strong stems, resulting in a versatile noninvasive plant now widely used to address a myriad of environmental and soil and water related problems (Jotisankasa *et al*.,2015). Grimshaw and Heifer (1995) stated that Vetiver covers an exceptionally wide range of soils and climates.

The Vetiver grass has been used as a structural component of soil bioengineering techniques as root-based reinforcement in the stabilization of slopes on the right bank of the São Francisco River (Machado, Holanda, Silva, Maranduba & Lino, 2015).

Due to the aggregating potential of its root system, Vetiver grass has been widely used to contain erosion, providing a physical mechanical consolidation of soil and increasing the shear resistance due to soil-root interactions, thus preventing shallow landslides (Machado et al., 2015).

Jotisankasa *et al*. (2015) reported that the Vetiver system (VS) has proven to be very effective in mitigating erosion and shallow slope instability, provided it is applied correctly. This report went further to state that the mechanical effects of Vetiver system on slope are mainly beneficial, normally through reinforcement.

Verhagen et al. (2008) conducted different laboratory and model tests on Vetiver grass which revealed its use in coastal engineering because of its ability to establish a full-stop to bank erosion caused by rapid draw down.

Nasrin (2013) analyzed the stability of embankment slopes and found out that Vetiver grass plantation was able to increase the factor of safety of embankment slope by 1.50 times, reduces erosion by 71%. So, it can be said that Vetiver grass plantation can protect the embankment from rain-cut erosion and shallow depth slope failure.

Arifuzzaman et al. (2013) studied Vetiver as a green and economical technology to protect river bank. They found that;

i. The cohesion and angle of internal friction of Vetiver rooted soil matrix is significantly higher than those of the bared soil.
ii. The factor of safety of the embankment protected by Vetiver grass is 1.76 to 2.06 times higher than that of embankment without any protection.
iii. The cost of slope protection by Vetiver grass is significantly lower than the cost of other available slope protection measures. Also, it generates zero carbon-di-oxide.

Mahannopkul and Jotisankasa (2019) established that root tensile strength is an important factor controlling the performance of bio-slope stabilization works while stating that the critical condition of slope with the lowest factor of safety would happen when the soil suction is zero and the root suction is high.

In this study, the following specific objectives form the basic research variables to be determined; the soil gradation of study area, the shear strength of bare soil (control) and that of soil with Vetiver root and the stability of the embankment expressed in terms of the soils' factor of safety (FS) due to Vetiver roots.

2.1 MATERIALS AND METHODS

2.1.1 Description of Study Area.

The Nigeria Erosion and Watershed Management Project; (World Bank assisted) in Umuda/Isingwu communities, located in Umuahia North local government area of Abia State was used as the study area.

The area lies between longitude 05^{o} 32’ and 05^{o} 34’ North, and latitude 07^{o} 28’ and 07^{o} 30’ East. There are two principal geological formations in the state namely Bende - Ameki and the Coastal Plain Sands otherwise known as Benin Formation.

The climate is characteristically of the Equatorial type found in South-Eastern Nigeria, essentially warm and humid. This is a resultant effect of its prevailing seasonal wind, nearness to the sea coast and the relatively flat topography of the environment. Air temperature has seasonal and diurnal variations. On the average, the ambient maximum air temperature in the area varies from 28.0^{0}C to 37.5^{0}C while the minimum temperature varies from about 22^{0}C to 27^{0}C (NEWMAP, 2017).

The soil formation as observed is predominantly sandy soil and easily erodible.

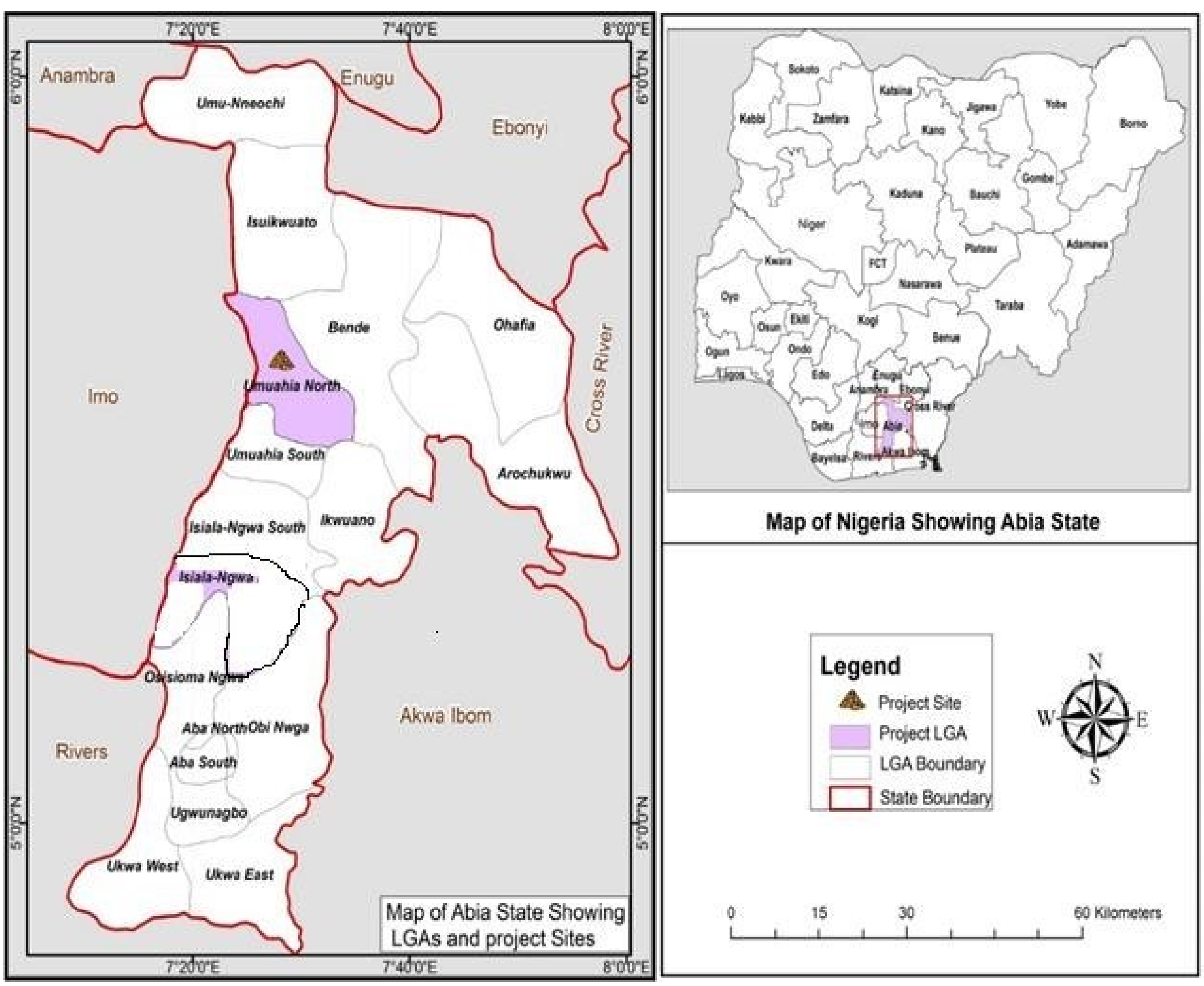

Figure. 2.1: Map of Abia State showing the Project site (NEWMAP ESMP, 2017).

2.1.2 Soil Sampling and Testing.

The soil samples collected using auger and sampling core from the engineered slope under study area were used for the laboratory tests and analysis. The samples are of two categories; control sample (soil without Vetiver roots) and Vetiver rooted soil sample.

Figure. 2.2: Vetiver rooted soil sample **Figure 2.3: Bare soil sample (control)**

Figure 2.4: Collection of vegetated sample and Vetiver grass in Umuda/Isingwu

The mechanical or sieve analysis was performed to determine the distribution of the coarse, larger-sized particles, and the hydrometer method was used to determine the distribution of the finer particles. A graph of percentage passing against sieve size was also plotted to know the gradation of the soil samples using USDA textural triangle. This test was conducted as described in section 9 page 32 BS 1377 part 2, 2001. (It is also important to note that the particle that passed through the 75µ were subjected to wet sieving by hydrometer).

The specific gravity of both the control sample and Vetiver rooted samples were determine us Pycnometer in the laboratory. Similarly, the In-situ bulk density of the Vetiver rooted soils were determined using a core sampler of known volume of 139.18cm^3. The result was used to estimate the unit weight of the soil since it is the product of bulk density and acceleration due to gravity.

Direct shear box test was used to determine the shear strength of the disturbed shear strength in the laboratory using a normal load of between 0.24KN - 0.64KN. It was conducted as standard test and was carried out according to section 3 page 3 of BS 1377 part 8, 2001.

2.1.3 Method of Analyzing Results

The soil samples were texturally classified using the USDA classification system.

Results of the bare soil sample (control) were compared to Vetiver rooted soil samples in terms of their factor of safety. This was geared towards determining the stability of the slope resulting from the use of Vetiver grass as the stabilizing material.

2.1.4 Factor of Safety (FS) computation

The factor of safety equation provided by Nasrin (2013), using effective stress analysis without vegetation as shown in equations 3.1 was used to compute the FS for the bare soil (control sample).

$$FS = \frac{\acute{c} + (\gamma z - \gamma_w h_w)\cos^2 b \tan\phi}{\gamma z \sin b \cos b} \quad (3.1)$$

Where, c′ = effective soil cohesion (KN/m^3) γ = unit weight of soil (KN/m^3) z = vertical height of soil above slip plane (m) β = slope angle (degrees) γ_w = unit weight of water (KN/m^3) hw = vertical height of ground water table above slip plane (m) and ϕ= effective angle of internal friction of the soil (degrees)

Furthermore, the main influences of vegetation on the stability of slope segment given by Nasrin (2013) as shown in equation 3.2 was used to compute FS due to vegetation

$$Fs = \frac{(\acute{C} + C'_R) + [\{(\gamma z - \gamma_w h_v) + W\}\cos^2 b + T\sin q]\tan\phi + T\cos q}{\{(\gamma z + W)\sin b + D\}\cos b} \quad (3.2)$$

Where, c'_R = enhanced effective soil cohesion due to soil reinforcement by roots (KN/m3) W = surcharge due to weight of vegetation (KN/m2) hv = vertical height of groundwater table above the slip plane with the vegetation (m) T = tensile root force acting at the base of the slip plane (KN/m) θ = angle between roots and slip plane (degrees)

D = wind loading force parallel to the slope (KN/m)

3.1 PRESENTATION OF RESULTS.

3.1.1 Grain Size Distribution Analysis.

Table 3.1 Particle size distribution for bare soil (1) (500g)

Sieve size(mm)	Sieve Mass(g)	Sieve Mass + Soil (g)	Mass of Retained (g) passing	% Retained	Cumulative % Retained	% Soil
4.75	374.95	374.95	0	0.00	0.00	100.00
2.36	358.44	358.7	0.26	0.05	0.05	99.95
1.18	306.88	330.45	23.57	4.72	4.77	95.23
0.85	377.95	517.41	139.46	27.91	32.68	67.32
0.425	328.03	543.07	215.04	43.04	75.73	24.27
0.3	318.05	368.28	50.23	10.05	85.78	14.22
0.15	396.26	434.99	38.73	7.75	93.53	6.47
0.075	312.84	323.45	10.61	2.12	95.66	4.34
Pan	271.92	293.61	21.69	4.34	100.00	0.00
Total			499.59			

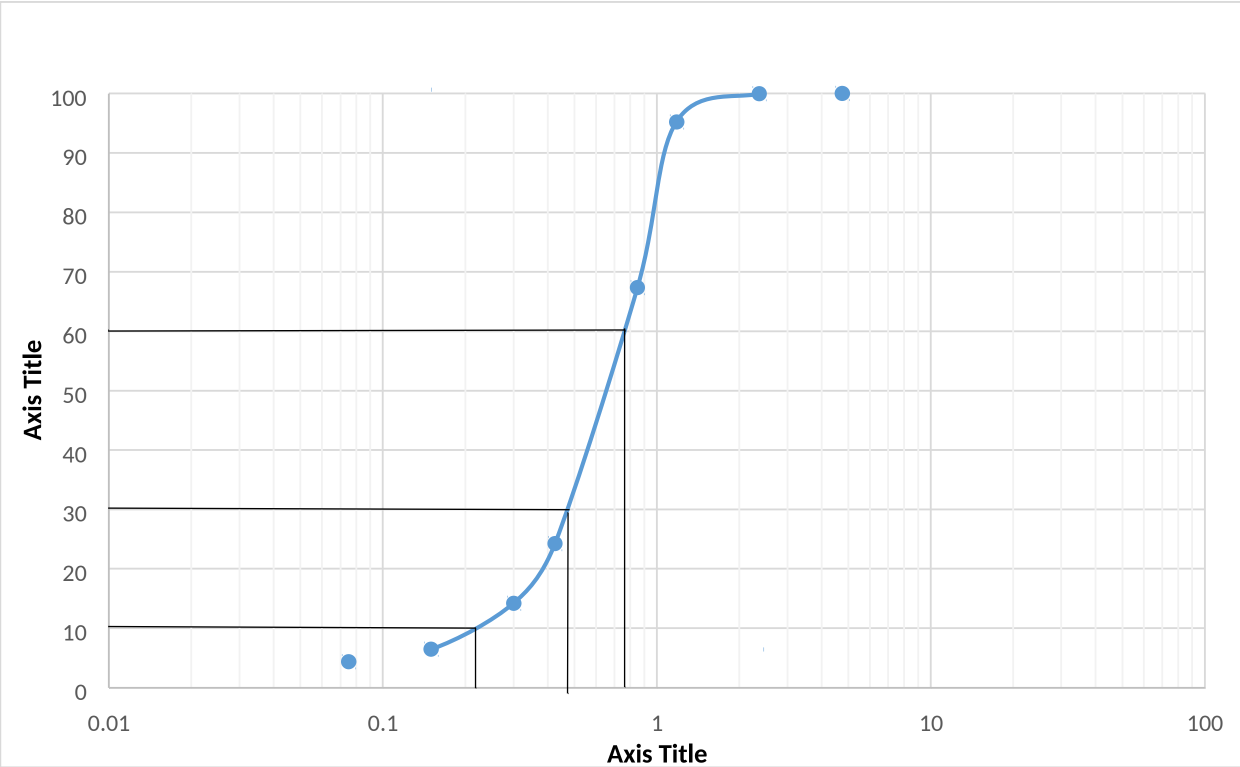

Figure. 3.1: Particle Size Distribution Curve for the Soil bare Sample (1) in the Study Area.

D_{10}= 0.23mm, D_{30} = 0.5mm and D_{60} =0.8mm

Table 3.2: Particle Size Distribution Data for the Bare Soil Sample (2) in the Study Area for Dry Sieving.

Sieve Size (mm)	Mass Retained (g)	% Mass Passing (g)	% Passing
2	0.6	59.4	99
1.18	1	58.4	97.3
0.85	4.5	53.9	89.8
0.6	16.2	37.7	62.8
0.425	12.8	24.9	41.5
0.3	5.5	19.4	32.3
0.15	2.1	17.3	28.8
0.075	3.5	13.8	23
Pan	0.3	13.5	

Table 3.3: Particle Size Distribution data for the Soil control Sample (2) in the Study Area from hydrometer analysis of fines.

Date	Time	Hydrometer reading (Rh1)	True reading g(Rh)	Effective depth H_R (mm)	Fully corrected readings®	Particle Diameter D (mmµ)	% finer than D K (%)
12/10/2019	1	5	5.5	191.45	4.8	0.056	12.96
	10	4.6	5.1	193.1	4.4	0.018	11.88
	30	4.4	4.9	193.9	4.2	0.01	11.34
	60	4.1	4.6	195.14	3.9	0.007	10.53
13/10/19	1440	3	3.5	199.65	2.8	0.0015	7.56

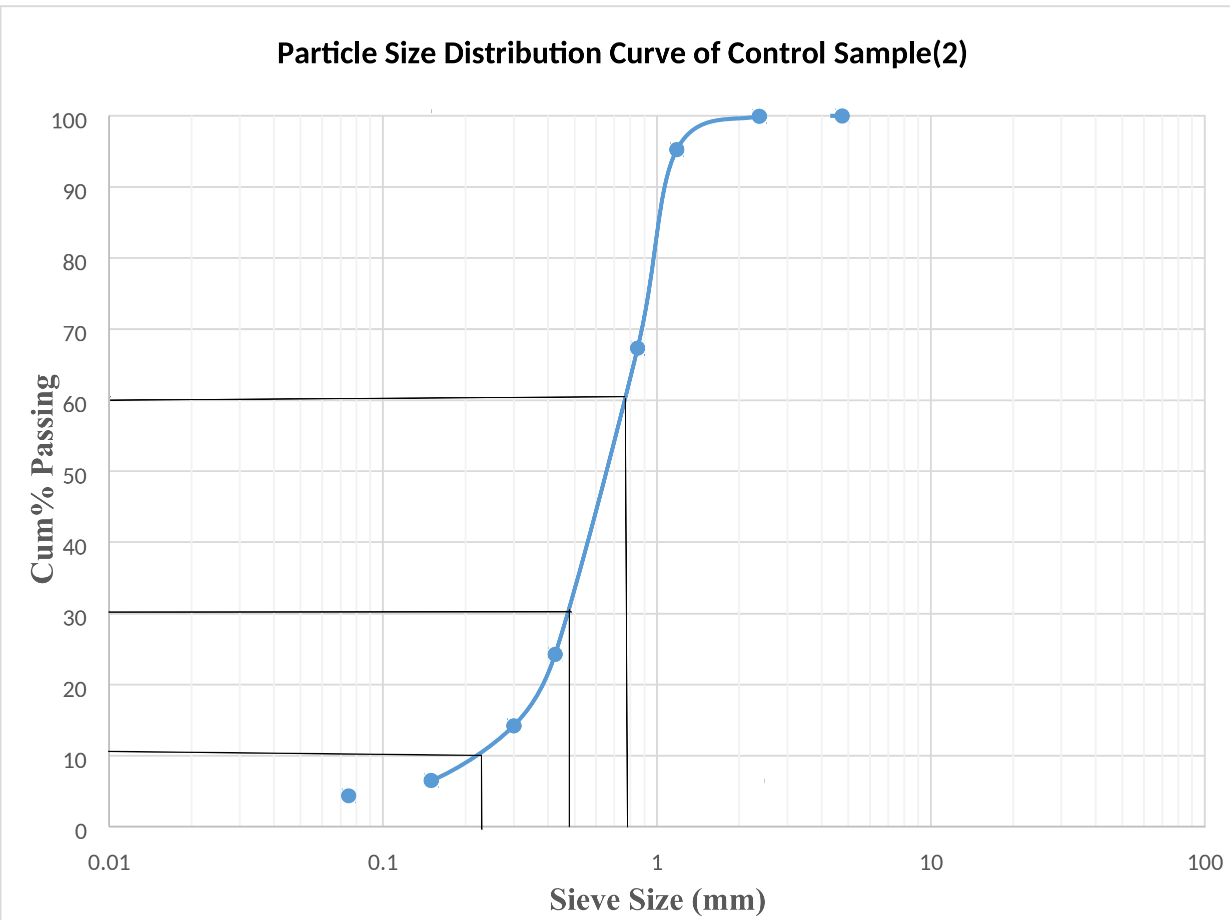

Figure. 3.2: Particle Size Distribution Curve for the Soil control Sample (2) in the Study Area.

D_{10}= 0.005mm, D_{30} = 0.15mm and D_{60} =0.5mm

Table 3.4: Bulk density and unit weight of bare soil.

Bulk De nsity	
Bare soil (contr ol sample)	
Length of soil sample	90.50mm
Diameter of sample	44.25mm
Weight of soil + cylinder(g),M_1	391.82
Weight of cylinder(g), M_2	145
Volume of soil(cm^3),V	139.18
Mass of soil(g) M_3	246.82
Bulk density of soil(g/cm^3)	1.77
Bulk density(kg/m^3) (1)	1774.02
Acceleration due to gravity, g (m/s^2) (2)	9.81
Unit weight, $^{\gamma}g(KN/m^3)$ = (1)x(2)	17.40314

Table 3.5: Bulk density and unit weight of soil samples with Vetiver roots soil.

No of trials	1	2	3	Average
Length of soil sample	90.50mm	90.50mm	90.50mm	
Diameter of sample	44.25mm	44.25mm	44.25mm	
Weight of soil + cylinder(g)	370.76	367.43	353.94	
Weight of cylinder(g)	145	145	145	
Volume of soil(cm^3)	139.18	139.18	139.18	
Mass of soil(g)	225.76	222.43	208.94	
Bulk density of soil(g/cm^3)	1.62	1.60	1.50	
Bulk density(kg/m^3)	1622.072	1598.15	1501.22	
Unit weight(N/m^3)	15912.53	17099.5	16841.5	16617.9
Unit weight(KN/m^3)	15.91	17.10	16.84	16.62

Table 3.6: Specific gravity for bare sample

Materials	Mass (g)		Specific Gravity $(M_2-M_1)/[(m_4-m_1)-(m_3-m_2)]$		
No of Trial	1	2	1	2	Average
Empty bottle (M_1)	114.81	113.85			
Bottle + soil (M_2)	216.67	193.14			
Bottle+ water + soil (M_3)	435.02	421.38			
Bottle + water (M_4)	372.52	372.28	2.59	2.63	2.61

Table 3.7: Specific gravity for soil with Vetiver root matrix sample

Materials	Mass(g)		Specific Gravity $(M_2-M_1)/[(m_4-m_1)-(m_3-m_2)]$		
	1	2			
Empty bottle(M_1)	114.81	113.85			
Bottle + soil (M_2)	203.84	199.97			
Bottle+ water + soil(M_3)	427.2	423.2			
Bottle + water(M_4)	372.99	373.57	2.56	2.36	2.46

Table 3.8: Sample dimension for shear box test

Length of sample (L)	60mm
Width of Sample (w)	60mm
Height of the sample (H)	20mm
Area of sample A, (Lx w)	3600 mm^2
Volume of sample,	7200mm^3

Table 3.9: Normal Stress (?$_n$)

(1) Load (kg)	(2) Load (KN) /100	(3) Area (m^2)	(4) (2)/(3) (KN/m^2)
24	0.24	0.0036	66.7
44	0.44	0.0036	122.2
64	0.64	0.0036	177.8

Table 3.10: Computed shear box test results

(1)	(2)	(3)	(4)	(5)	(6)
Sample	Load (kg)	Max. H.R	(3)x0.002 (mm)	(4)x0.88 (KN)	(5)/A (KN/m^2)
Bare Soil/ Control Sample (1)	24	72	0.144	0.12672	35.2
	44	136	0.278	0.24464	67.467
	64	200	0.406	0.35728	98.756
Bare Soil Control/ Sample (2)	24	82	0.164	0.14432	40.089
	44	142	0.284	0.24992	69.442
	64	200	0.4	0.352	97.778
Sample With Vetiver Roots (1)	24	92	0.184	0.16192	44.978
	44	142	0.284	0.24992	69.422
	64	203	0.406	0.35728	99.244
Sample With Vetiver Roots(2)	24	86	0.172	0.15136	42.044
	44	147	0.294	0.25872	71.867
	64	210	0.42	0.3696	102.667
Sample With Vetiver Roots(3)	24	65	0.13	0.1144	31.778
	44	128	0.256	0.22528	62.578
	64	191	0.382	0.33616	93.378

Table 3.11: Shear Strength Computation

Sample	(1) Cohesion C	(2) Normal stress, σ_n	(3) Angle of internal friction, ϕ	(4) Tan ϕ	(5) Shear strength (1)+(2)x(4) (KN/m^2)
Bare/control(1)	0	177.8	22.57	0.47	83.566
Bare/control(2)	25	177.8	9.1	0.16	53.448
Soil with Vetiver roots(1)	20	177.8	25.67	0.48	105.344
Soil with Vetiver roots(2)	28	177.8	35.78	0.72	156.016

Soil with Vetiver roots(3)	20	177.8	33.15	0.65	135.57

3.1.2 Shear Strength Graphs

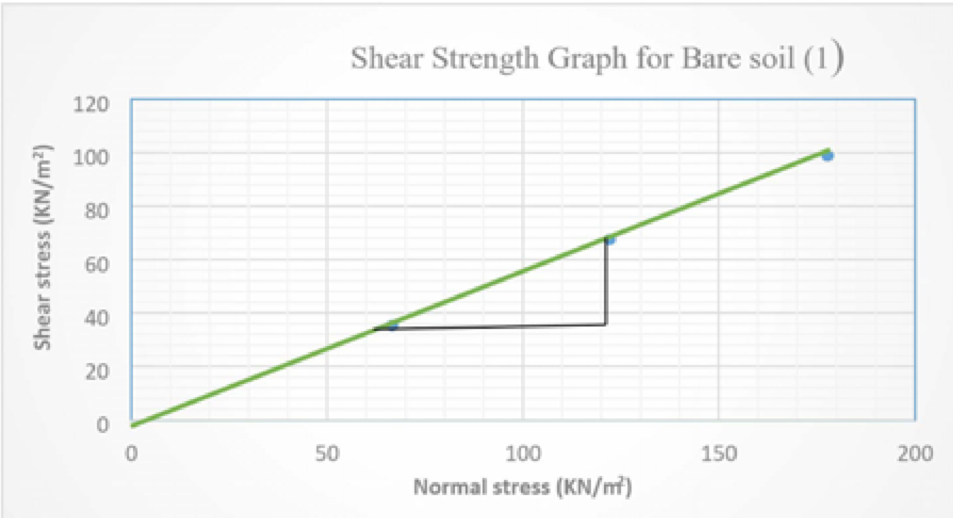

Figure 3.3: Shear strength graph of bare soil sample (1)

Cohesion, C = 0 Angle of internal friction, ϕ = 22.57°

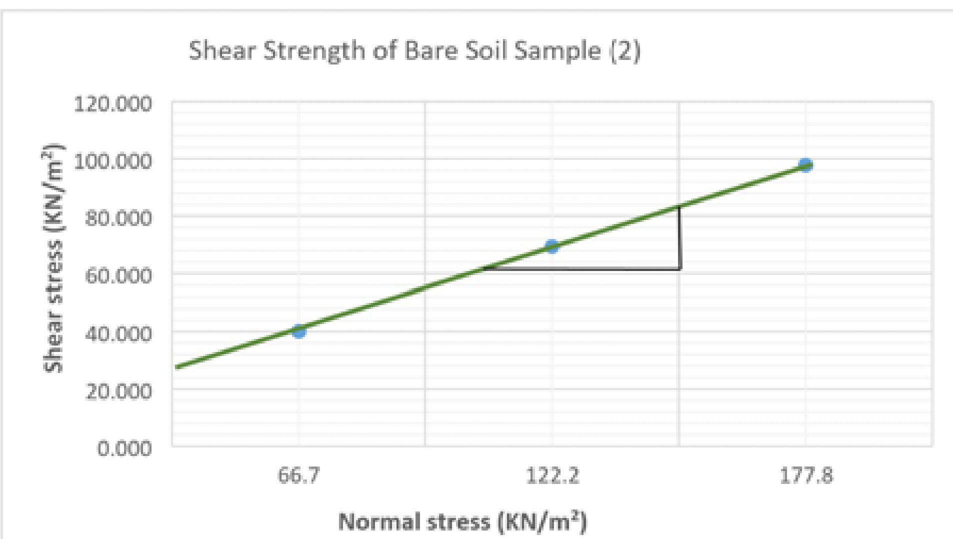

Figure 3.4: Shear strength graph of bare soil sample (2)

Cohesion, C =25 KN/m^2 Angle of internal friction, ϕ =9.1 °

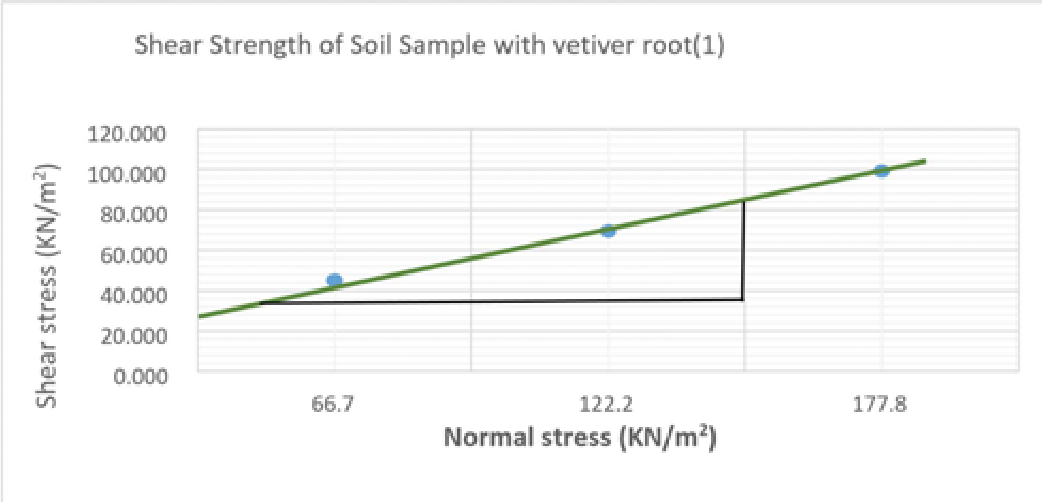

Figure 3.5: Shear strength graph of soil matrix with Vetiver roots (1)

Cohesion, C =20KN/m^2 Angle of internal friction, ϕ =25.67 °

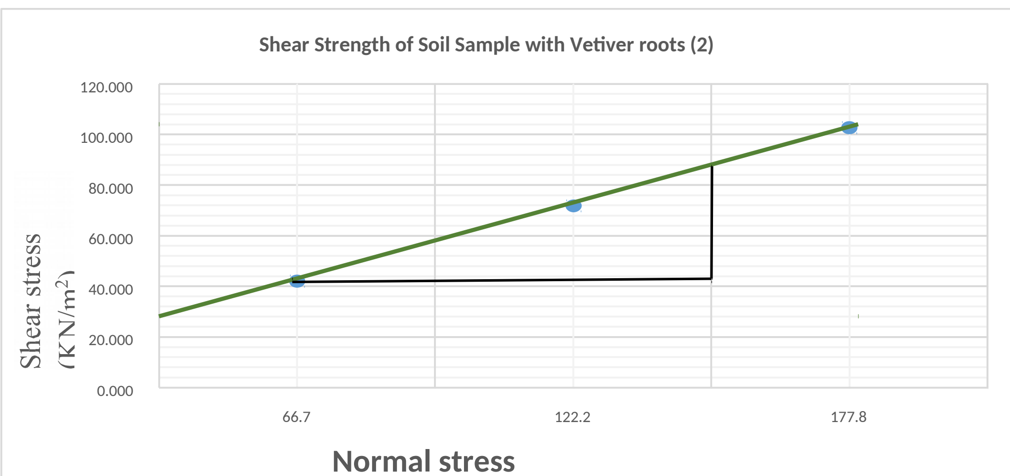

Figure 3.6: Shear strength graph of soil matrix with Vetiver roots (2)

Cohesion, C =28KN/m^2 Angle of internal friction, ϕ =35.78°

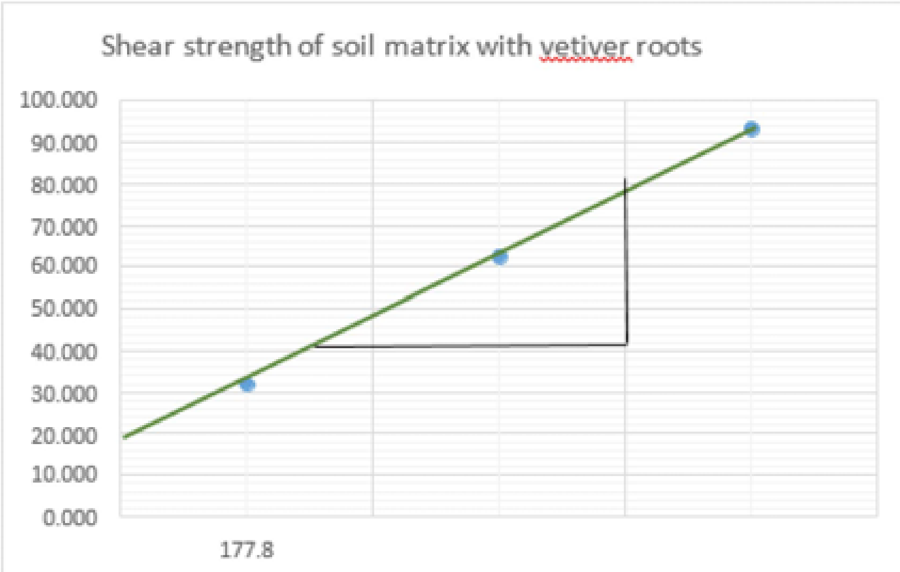

Figure 3.7: Shear strength graph of soil matrix with Vetiver roots (3)

Cohesion, C =20KN/m^2 Angle of internal friction, ϕ =33.15°

Table 3.12: Summary of shear strength of sample

Samples	Bare (1)	Bare (2)	Rooted (1)	Rooted (2)	Rooted (3)
Shear strength (KN/m^2)	83.566	53.448	105.33	156.02	135.57
Average (KN/m^2)	68.507		132.307		

3.1.3 Factor of Safety (FS) Computation.

Table 3.12: Parameters used for stability analyses

Parameters	Bared Soil	Vetiver Rooted Soil
Unit weight of soil, γ (KN/m3)	17.4	16.62
Vertical height of soil above slip plane (m)	1	1
Slope angle, β (deg.)(*ABIA NEWMAP ESMP,2017*)	45	45
Unit weight of water, γ_w (KN/m^3)	9.81	9.81
Vertical height of ground water table above slip plane, h_w (m)	0	0
Surcharge due to weight of vegetation, W (KN/m^2)	1.57	1.44
Vertical height of groundwater table above the slip plane with the vegetation, h_v (m) (*Nasrin,2013*)	0	0
Tensile root force acting at the base of the slip plane, T (KN/m) (*Nasrin,2013*)	0.4	0.4
Angle between roots and slip plane, q (deg.)	0	0
Wind loading force parallel to the slope, D (KN/m)((*Nasrin,2013*)	0.1	0.1

Formula for Factor of Safety Calculation (Nasrin, 2013) Bare Samples:

For bare; Ć = [C (1) + C (2)]/2 = (0+25)/2 =12.5KN/m^2

Effective soil cohesion of bared soil, c' = 12.5KN/m^2

Effective angle of internal friction of bared soil, ϕ' = 15.835 (average value).

$FS = \frac{\acute{c} + (gz - g_w h_w) \cos^2 b \tan \phi}{gz \sin b \cos b} =$

$= \frac{12.5 + (17.4*1 - 9.81*0) \cos^2 (45) \tan (15.835)}{(17.4x\ 1) \sin 45 \cos 45} =$ **1.72**

Vetiver Rooted Samples

Effective soil cohesion of bared soil, c' = 12.5 KN/m^2

Effective soil cohesion of rooted soil = 22.67 KN/m^2

Enhanced effective soil cohesion due to soil reinforcement by roots, c'_R = (22.67-12.5) =10.17KN/m^2

Effective angle of internal friction of bared soil, ϕ' = 12.5°

$FS = \frac{(\acute{C} + C'_R) + [\{(\gamma z - \gamma_w h_v) + W\}\cos^2 b + T \sin q] \tan \phi + T \cos q}{\{(\gamma z + W) \sin b + D\} \cos b}$

$= \frac{(12.5 + 10.17) + [\{(16.62x1 - 0) + 1.44\} + 0.4\sin 0] \tan 12.5 + 0.4\cos 0}{\{(16.62x1) + 1.44) \sin 45 + 0.1\} \cos 45} =$ **2.98**

3.2 Discussion of Results.

3.2.1 Grain Size Analysis and soil classification.

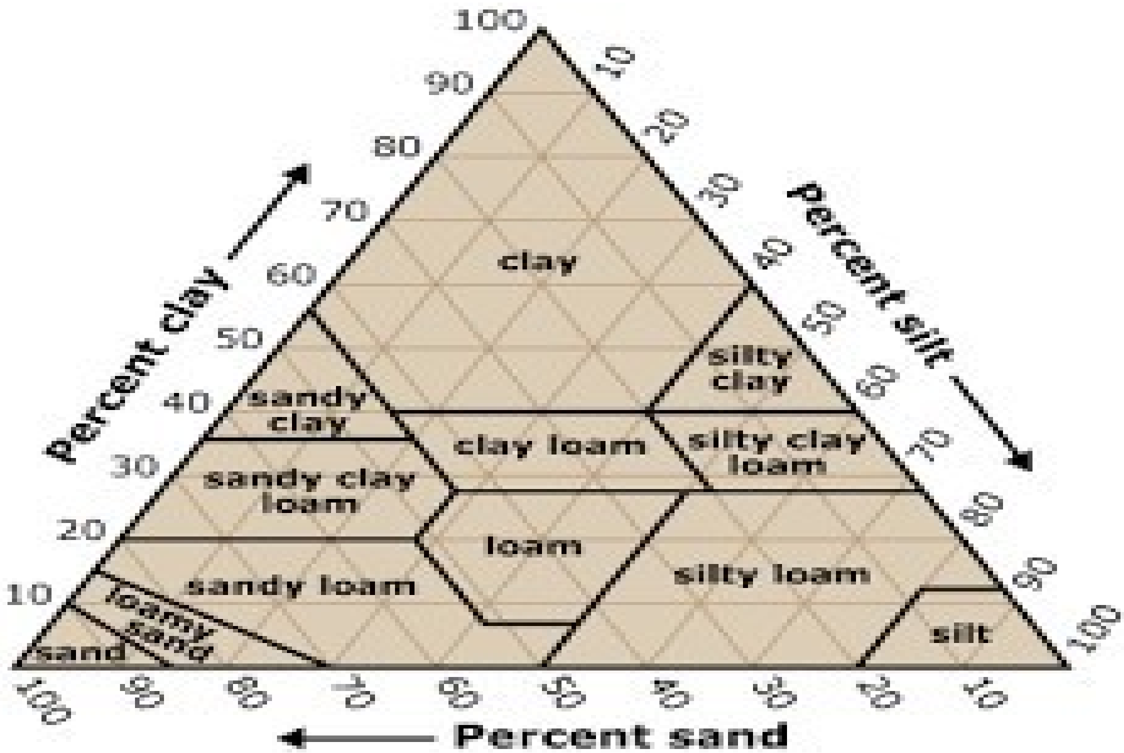

Figure 3.8: USDA Textural Soil Classification Triangle

The curve of particle size distribution of the sample in figure 3.1 shows that the soil is a cohesionless soil with over 90% of its particles within the particle range of 0.1mm-1mm which is sand range. Having a coefficient of uniformity which is slightly above 3.0 is an indication that the soil is uniformly grade. Given that none of its particles are retained in 4.75mm BS sieve is an indication that percentage coarse gravel is immaterial. Considering the provision of the USDA textural classification triangle of fig.3.3, the soil is sand and since most of its particle sizes are within 0.5-1mm range, it is a **coarse sand.**

The second control sample whose particle size distribution curve as shown in figure 3.2 shows that the soil sample has a gradation of 5% clay particles, 80% sand particle sizes and 15% silt particles which according to USDA textural classification triangle belongs to a textural class of loamy sand with specific gravity of 2.69.

3.2.2 Direct Shear Box Test Results (shear strength of soil samples).

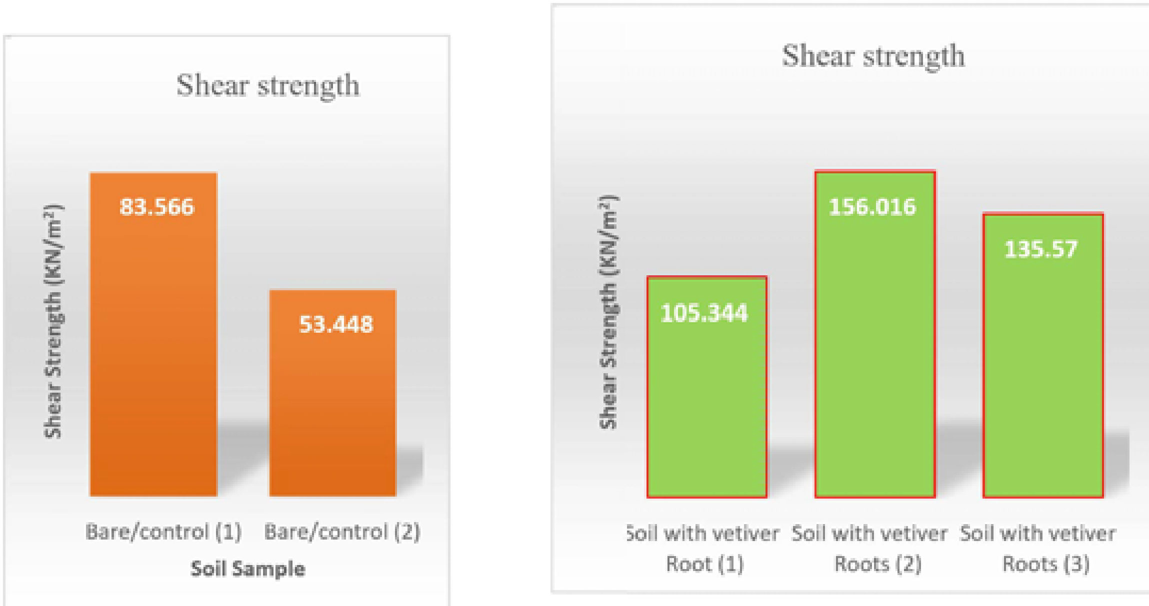

Figure.3.9: Comparison of shear strength result between bare soil and Vetiver grassed soils.

Figure 3.9 above shows the variation in shear strength of bare soil samples (1 and 2) is approximately 30KN/m^2 which is about 21% variation in their contributing total shear strength. The bare soil (1) with the highest shear strength is cohesionless but the significant high shear strength can be traced to its significant high angle of internal friction (ϕ) of 22.57°.

The second control sample has an angle of internal friction of 9.1° and Cohesion of 25KN/m^2 under the same normal stress of 177.8KN/m^2 which shows that second control sample [bare soil (2)] has significant quantity of clay particles in it which raise its cohesion with little contribution to its angle of internal friction hence the reduced shear strength when compare with the first control sample.

Conversely, the variation of shear strength of samples with Vetiver roots is relatively less between 26.5% - 34.2% of the cumulative shear strength of the three rooted samples studied. The average shear strength is 132.31 KN/m^2. The average shear strength of the Vetiver rooted soils is seen to be approximately 2 times greater than that of bare soils. The soils with Vetiver roots according to Nasrin

(2013) have average shear strength 85.10 MPa hence given ratio of sample studied in this work and the load range of 0.24 –

0.64KN, the claim is valid.

3.2.3 Computed Factor of Safety (FS).

The computed factors of safety using equations 3.1 and 3.2 for bare and Vetiver rooted soil samples respectively show that the Vetiver grass planted in an engineered slope in the study area contributed to the stability of that embankment by approximately 1.73 times its original shear strength before grassing with Vetiver grass. Hence, this study has revealed that the embankment stability is approximately 2.98 as against that of bare soil with factor safety of 1.7.This result is in agreement with Arifuzzaman *et al*. (2013) finding that Vetiver increases slope stability by more than 1.5 times the natural shear strength of its hosting soil.

4.1 CONCLUSION

The following conclusions are drawn from the summary of findings from the study:

From particle size distribution analysis and classification according to USDA textural classification standard, the two control samples; Bare Soil (1) and Bare soil(2) were found to be Coarse sand and loamy sand respectively. The average shear strengths of control soil samples(bare soils) are about two times lesser than those of Vetiver rooted samples. Hence the average shear strength of control and Vetiver rooted samples were found to be 68.50KN/m^2 and 132.31 KN/m^2 respectively.

In analyzing the slope stability as a result of contributions of Vetiver root system, it was found that the Vetiver stabilized soil samples had an average factor of safety; 1.73 times that of bare samples. The FS of Vetiver rooted samples and bare samples are 2.98 and 1.72 respectively. This is an indication that Vetiver grass is a good embankment stabilizer against shallow or surficial failures.

From the above stated findings; soil type, shear strength and factor of safety as a result of Vetiver rooting architecture and its soil reinforcing ability, it can be deduced that Vetiver is resilient in it adaptability in tropical and semi-arid regions with south eastern Nigeria inclusive. It is a good embankment stabilizer against surficial erosion and failures. Plantation of Vetiver is cost-effective, sustainable and eco-friendly method for the erosion control and mitigation of slope failure in South Eastern Nigeria.

4.2 Recommendations

The determination of in situ shear strength of samples for stability analysis are pertinent, hence subsequent work(s) should be directed to developing apparatus that will help in determining such in Nigeria context.

Cost-benefit analysis is needed to compare the benefits of Vetiver grass plantation over other conventional methods of slope protection in Nigeria.

The adaptability of Vetiver to different soil types within Nigeria territorial boundaries is also an important area of research.

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