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Agronomical Stabilization of Umuda-Isingwu Erosion Site Using Vetiver Grass

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Abstract

Soil erosion and embankment failures are serious challenges confronting our environment. In the face of these challenges, different possible solutions are been studied at different levels with special consideration on the implementation cost of such solutions. Hence, this work studied agronomical stabilization of Umuda- Isingwu erosion site using vetiver grass. 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 on the erosion site. To ascertain the factor of safety, the soil samples collected from the study area were analyzed to determine its gradation by mechanical sieving and hydrometer method, while the density bottle was used to estimate the density of the samples which when multiplied by acceleration due to gravity of 9.81m/s^2 gave the unit weight of samples. The results showed that the soil samples are coarse sand and loamy sand, unit weight of bare and Vetiver rooted samples as 17.40KN/m^3 and 16.62KN/m^3 respectively, average shear strength of the bare soil samples and Vetiver rooted soil samples as 68.52KN/m^2 and 132.32KN/m^2 respectively and 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 about 1.73 times more stable than the bare soil. Hence, Vetiver grass is a good embankment and erosion site stabilizer and should be put to effective use in the area erosion control and slope stabilization in Nigeria.

Keywords: Soil erosion; embankment stability; Vetiver grass; factor of safety.

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1. Introduction

In Nigeria over 6,00km^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 [1]. 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 [2] affirmation that due to the rate of land degradation caused by erosion, efforts have been made among scholars to unmask the best minimum cost effective measure for slope stabilization. In order to effectively control soil erosion and embankment failures, there is need to identify the root causes. The major causes of soil erosion within south eastern Nigeria are human interference, climatic factors (rainfall), poor geology of the region, undulating topography and soil nature [3]. In a similar research, [4] 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. Further studies also revealed that countries within the sub - Saharan region 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 [5]. According to Nigeria erosion and watershed management project (NEWMAP), Umuda - Isingwu community has over the years experienced high torrential rainfall which created catastrophic soil erosion in the area [1]. The most significant effects of the erosive activities of rainfall in the area include gully formation, surficial slope failures and huge capital expenditure in curtailing the menace. Cost implications of conservation measures are important indicators which provide useful insights on how these measures will be accepted by stakeholders. In a bid to remediate, reclaim and protect erosion sites and embankments especially as seen in the study area, an optimal cost to benefit ratio is usually targeted. The place of cost consideration in developing a sustainable plan for environmental stabilization project is very important. Hence, Arifuzzaman, Anisuzzaman, Rahman and Akhte advocated for substitution of traditional practices (civil constructions) for protecting embankments which was identified as being expensive and sometimes not effective due to improper design and construction fault(s) [6]. Current researches have shown that bioengineering is an effective alternative solution for erosion site stabilization. In the same vein, much emphasis have been made on the use of Vetiver grass which proved to be a successful bioengineering method to protect slopes in most case histories studied and reported in literature. In describing the vetiver grass, Likitlersuang, Lohwongwatana, Vanno and Boonyananta explained that vetiver 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 [7]. 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 [8]. Vetiver covers an exceptionally wide range of soils and climates [9]. 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. Due to the aggregating potential of its root system, Vetiver grass has been widely used for erosion control, provision of physical and mechanical consolidation of soil and increasing the shear resistance of soil due to soil-root interactions, thus preventing shallow landslides [10]. Vetiver system (VS) has proven to be very effective in mitigating erosion and shallow slope instability, provided it is applied correctly [8]. This report went further to state that the mechanical effects of Vetiver system on slope are mainly beneficial, normally through soil reinforcement. The use of vetiver grass in coastal engineering because of its ability to establish a full-stop to bank erosion caused by rapid draw down has also been noticed [11]. Its ability to increase stability of an embankment was revealed in [5] as increasing embankment factor of safety by 1.50 times it original stability factor while also reducing erosion by 71%. The authors in [6] studied vetiver as a green and economical technology to protect river bank. They found that; the cohesion and angle of internal friction of Vetiver rooted soil matrix is significantly higher than those of the bared soil and 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. It is an established fact that root tensile strength is an important factor controlling the performance of bio-slope stabilization works [12].In addition, the critical condition of slope with the lowest factor of safety mostly sets in when the soil suction is zero and the root suction is high. This work is in furtherance of scholarly study in the area of biotechnical slope stabilization.

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 sample) and that of soil with Vetiver root; and
- The stability of the embankment expressed in terms of the FS due to Vetiver roots.

2. Materials and Methods

2.1 Materials

The materials used in this study were soil samples (vetiver rooted and bare soil) from the engineered slope under study. These materials are as shown in figure 1 below.

Figure 1: Materials used for the study.

2.1.1 Description of Study Area

The Nigeria Erosion and Watershed Management Project site 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 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 [1]. The soil formation as observed is predominantly sandy soil and easily erodible.

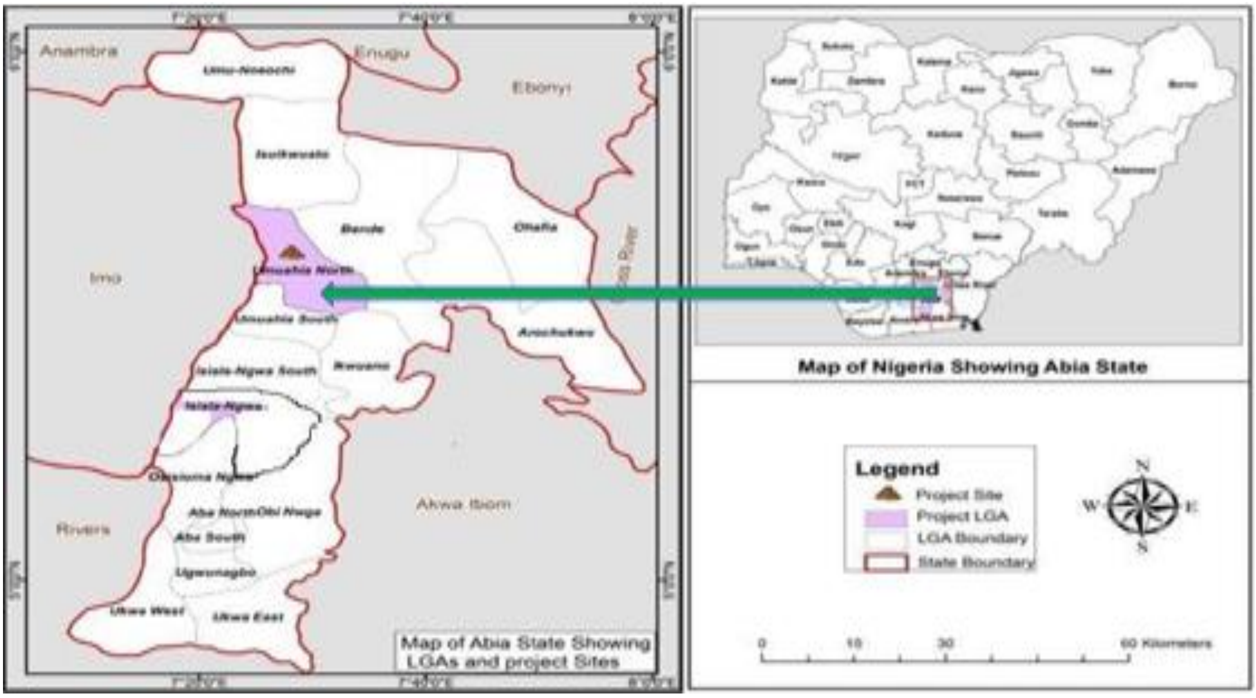

Figure 2: Map of Abia State showing the study area (NEWMAP ESMP, 2017)

2.2 Methods

2.2.1 Soil Sampling and Testing

The soil samples were collected using auger and sampling core from the engineered slope under study before being subjected to laboratory tests and analysis. The samples are of two categories; control sample (soil samples without vetiver grass roots) and vetiver grass rooted soil samples. The 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 plotted to know the gradation of the soil samples. Using USDA textural triangle, the soil samples were classified. This test was conducted as described in section 9 page 32 BS 1377 part 2, 2001 [13]. 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 apparatus was used to determine the 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 [14].

2.2.2 Method of Results Analysis

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 aimed at determining the stability of the slope resulting from the use of Vetiver grass as the stabilizing material. The factor of safety equation provided by Nasrin (2013), using effective stress analysis without vegetation as shown in equations (1) was used to compute the FS for the bare soil (control sample).

$$FS = \frac{c' + (\gamma z - \gamma_w h_w) \cos^2 b \tan\varphi}{\gamma z \sin b \cos b} \qquad (1)$$

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)

φ = effective angle of internal friction of the soil (degrees)

Furthermore, the main influences of vegetation on the stability of slope segment given in [5] as shown in equation (2) below was used to compute FS due to vegetation

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

Where,

c'_R = enhanced effective soil cohesion due to soil reinforcement by roots (KN/m^3)

W = surcharge due to weight of vegetation (KN/m^2)

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. Result Presentation and Discussion

3.1 Grain Size Distribution Analysis

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

Sieve Size (mm)	Sieve Mass (g)	Sieve Mass + Soil (g)	Mass of Retained (g)	% Retained	Cumulative % Retained	% Soil passing
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			

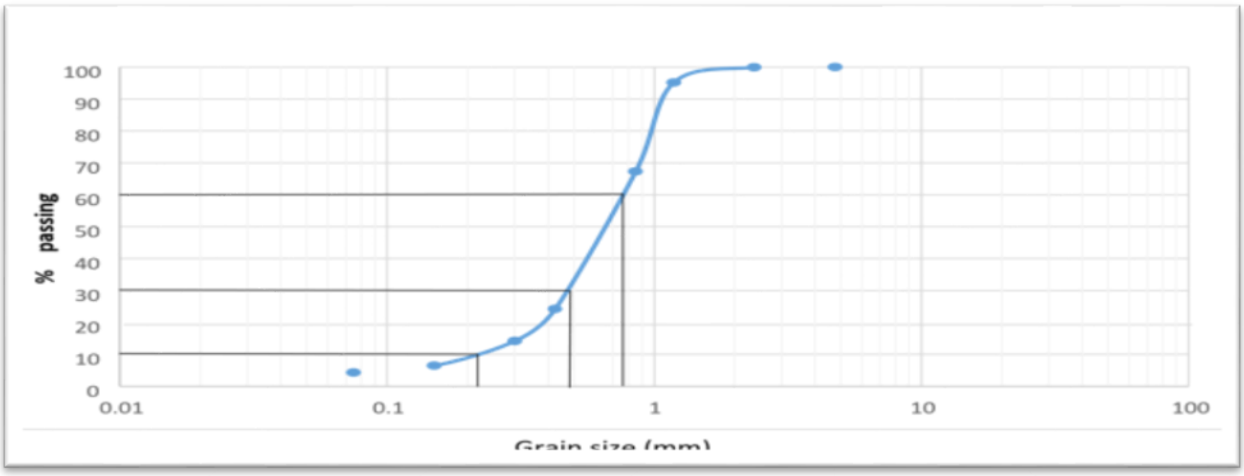

Figure 3: Particle soil distribution of bare soil sample (1)

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

Table 2: Particle Size Distribution Data for the Bare Soil Sample (2) 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: 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 (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

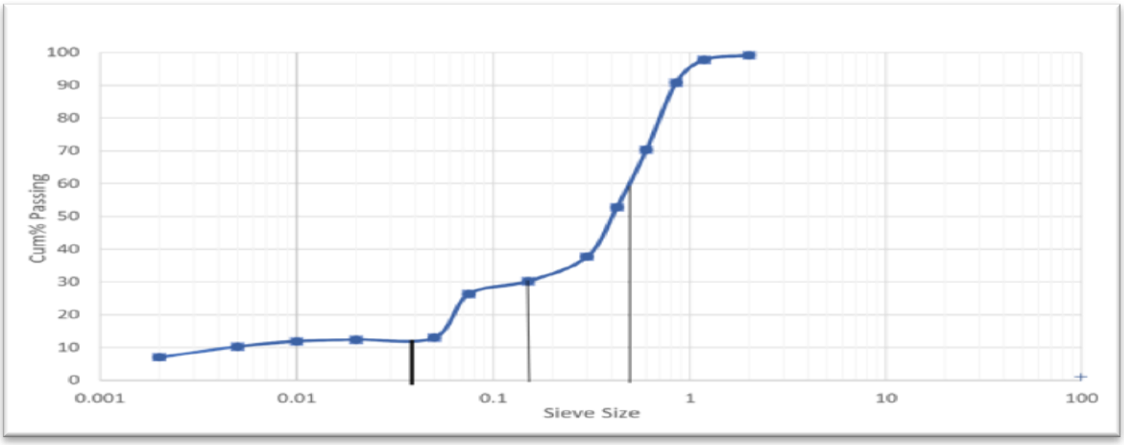

Figure 4: Particle soil distribution of bare soil sample (2)

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

3.1.2 Bulk density and Unit weight of soil samples

Table 4: Bulk density and unit weight of bare soil

Length of soil sample(mm)	**90.50**
Diameter of sample(mm)	44.25
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, γg(KN/m^3) = (1)x(2)	17.40314

Table 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

3.1.3 Strength Results of samples

Table 6: 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 7: Normal Stress (σ_n)

(1)	(2)	(3)	(4)
Load (kg)	**Load (KN)**	**Area (m^2)**	**(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 8: Computed Shear Stress Results

(1)	(2)	(3)	(4)	(5)	(6)
Sample	**Load (kg)**	**Max. H.R**	**(3)x0.002**	**(4)x0.88**	**(5)/A**
			(mm)	**(KN)**	**(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	24	92	0.184	0.16192	44.978
	44	142	0.284	0.24992	69.422
Vetiver Roots(1)	64	203	0.406	0.35728	99.244
Sample with	24	86	0.172	0.15136	42.044
Vetiver Roots (2)	44	147	0.294	0.25872	71.867
	64	210	0.42	0.3696	102.667
Sample with	24	65	0.13	0.1144	31.778
	44	128	0.256	0.22528	62.578
Vetiver Roots(3)	64	191	0.382	0.33616	93.378

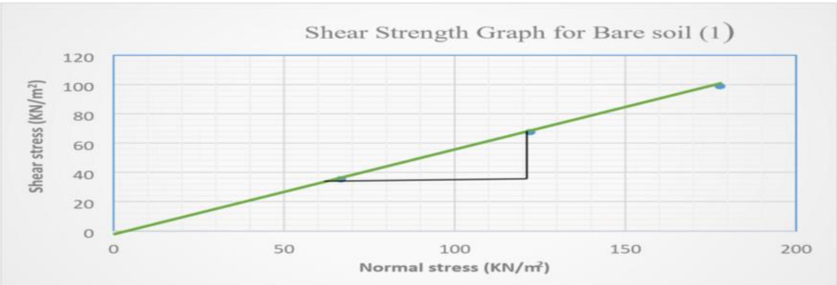

Figure 5: Shear strength graph of bare soil sample (1)

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

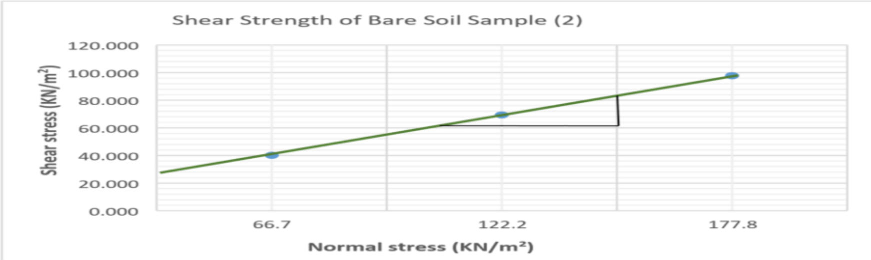

Figure 5: Shear strength graph of bare soil sample (2)

Cohesion, C =25 KN/m² Angle of internal friction, φ =9.1 °

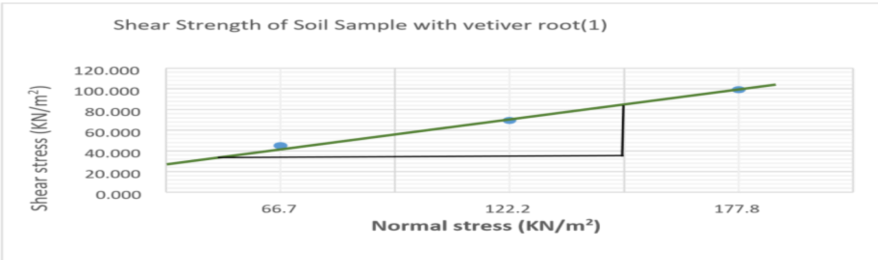

Figure 6: Shear strength graph of soil matrix with Vetiver roots (1)

Cohesion, C =20KN/m² Angle of internal friction, φ =25.67 °

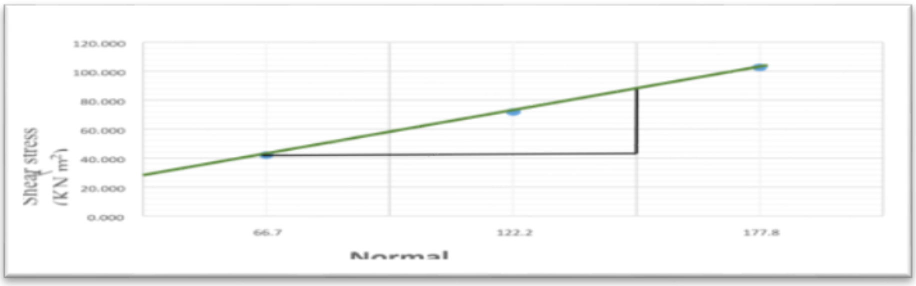

Figure 7: Shear strength graph of soil matrix with Vetiver roots (2)

Cohesion, C =28KN/m² Angle of internal friction, φ =35.78°

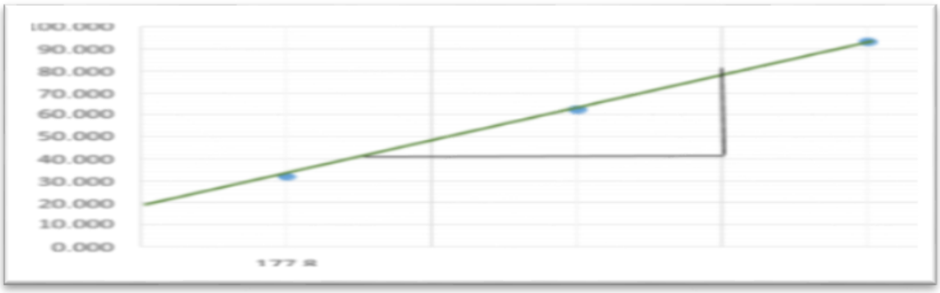

Figure 8: Shear strength graph of soil matrix with Vetiver roots (3)

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

Table 9: 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

Table 10: Summary of shear strength of sample

Samples	**Bare (1)**	**Bare (2)**	**Vetiver Rooted (1)**	**Vetiver Rooted (2)**	**Vetiver 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	

3.1.4 Factor of Safety (FS) Computation

Table 11: 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.) [1]	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) [5]	0	0
Tensile root force acting at the base of the slip plane, T (KN/m) [5]	0.4	0.4
Angle between roots and slip plane, q (deg.)	0	0
Wind loading force parallel to the slope, D (KN/m) [5]	0.1	0.1

3.2 Discussion of Results

3.2.1 Grain size Analysis and Soil Classification

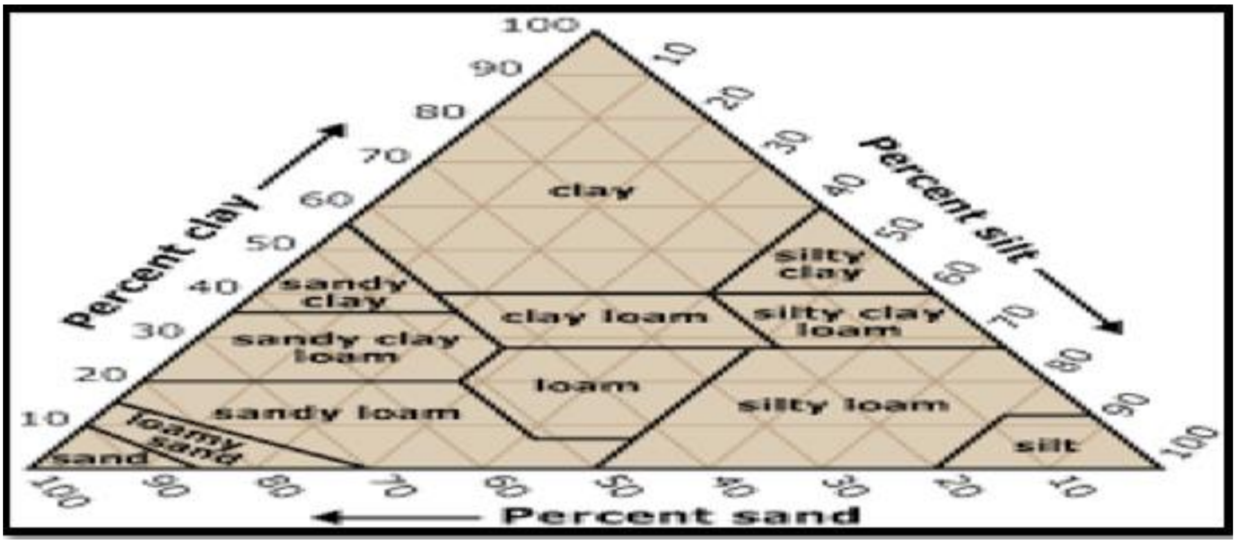

Figure 9: USDA Soil classification Triangle

The particle size distribution curve of the samples in figure 4 shows that the soil is a cohesion less soil with over 90% of its particles within the particle range of 0.1mm1mm 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 figure 11, 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 5 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

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

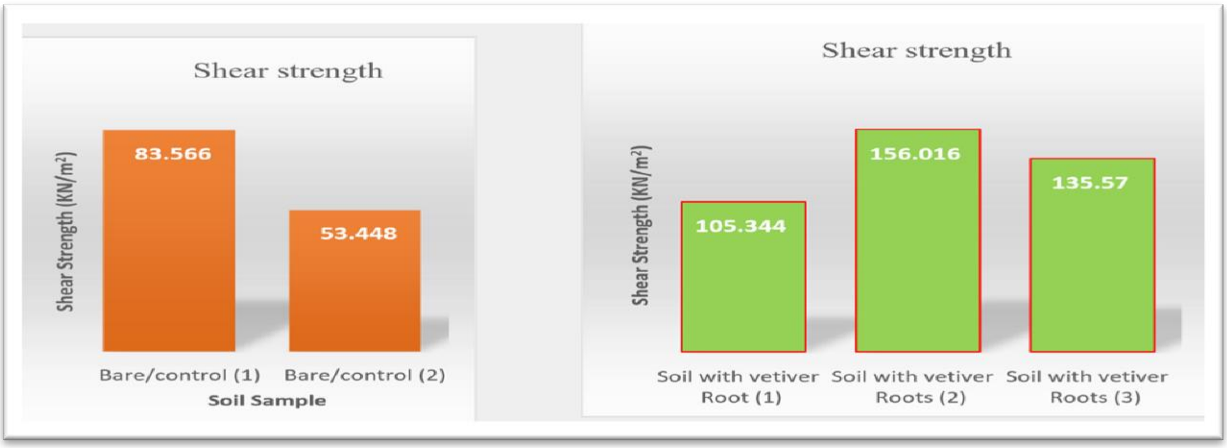

Figure 10: Comparison of shear strength result between bare soil and Vetiver grassed soils

Figure 10 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 cohesion less but the significant high shear strength can be traced to its high angle of internal friction (φ) of 22.57^o. The second control sample has an angle of internal friction of 9.1^o 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 raised 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 approximately 2 times greater than that of bare soils. The soils with Vetiver roots according to Nasrin in [5] have average shear strength 85.10 MPa hence, given the 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) of the soil samples

Bare Samples (equation 1):

Formula for Factor of Safety Calculation [5]

For bare; C′ = [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).

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

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

Vetiver Rooted Samples (equation 2)

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°

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

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

The computed factors of safety using equations 1 and 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 the 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 [6] finding that Vetiver increases slope stability by more than 1.5 times the natural shear strength of its base soil.

4. 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 grass stabilized soil samples had an average factor of safety of about 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 erosion site stabilizer and 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 its adaptability to different soil types in tropical regions with south eastern Nigeria inclusive. Plantation of Vetiver is cost-effective, sustainable and eco-friendly method for the erosion control and mitigation of slope failures in South Eastern Nigeria.

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