

Geological and Geotechnical Investigation of Gully Erosion along River Bosso, Minna, North Central Nigeria

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Received March 31, 2014; Revised April 14, 2014; Accepted April 15, 2014

Abstract Geological and geotechnical investigation along River Bosso, Minna to determine the soil characteristics contributing to gully erosion in the area was done. Field mapping showed that granite, granite-gneiss and schist of Basement complex suite underlie the area and granite is more prominent than granite-gneiss and schist. The index test results for the natural moisture content ranges from 11.19 – 24.08%; the plasticity index ranges from 0 – 5.21%; the sieve analysis result shows that coefficient of uniformity, C_u ranges from 3.37 and 29.00 while coefficient of curvature, C_c ranges from 0.17 – 0.89; the undisturbed bulk density is between 0.87 – 1.11kg/m³ and the compacted bulk density is between 1.25 – 1.49kg/m³; the specific gravity ranges from 2.16 - 2.67. For the performance test; the compaction result shows that the optimum moisture content (OMC) ranges from 8.90 – 14.85% while the maximum dry density (MDD) ranges from 1.880 - 2.09mg/m³; the triaxial shear test result shows that the angle of internal friction is between 6⁰ - 9⁰ and the cohesion ranges from 28 – 42kg/m²; the permeability is between 1.42×10^{-3} and 1.93×10^{-3} cm/sec. The relatively high sand content and low plasticity of the soil is susceptible to erosion which is attributed to the dominant granitic rock of the study area with high affinity for gully erosion. The anthropogenic factors found to have contributed to gully growth are farm practice, mining activities and residential buildings on the flood plain.

Keywords: geology, geotechnical properties, subsoil, gully erosion, anthropogenic factors

Cite This Article: I. A. Okunlola, I. A. Abdulfatai, Kolawole L. L., and Amadi A. N., “Geological and Geotechnical Investigation of Gully Erosion along River Bosso, Minna, North Central Nigeria.” *Journal of Geosciences and Geomatics*, vol. 2, no. 2 (2014): 50-56. doi: 10.12691/jgg-2-2-2.

1. Introduction

River Bosso is the major channel that drains Bosso town in Bosso Local Government Area of Niger State, Nigeria which passes through the Federal University of Technology, Bosso campus, Minna, to Dutsen-Kura Hausawa to Dutsen-Kura Gwari and Kpakungu area of Minna. The river is trained within the Bosso campus of Federal University of Technology, Bosso but is discontinued somewhere within the campus. The river is again trained from Dutsen-Kura Hausawa and terminated at Dutsen-Kura Gwari. The untrained area has been seriously affected by gully erosion activities which are adversely affecting lives of people along the river bank. The area investigated is located on latitude N9°35'00" to N9°39'00" and longitude 006°31'00" to 006°34'00" (Figure 1). Minna is underlain by the Basement complex suite which comprises mainly of Migmatite-gneiss complex, older granite and schist belt while the Migmatite-gneiss complex accounts for about 30% of the outcrops. They are composed of migmatite of various structures and composition but predominantly with

tonolitic or amphibolitic paleozoic and granitic leucozones having N-S structural grade. The older granite is composed of rocks of predominantly granodiorites composition which form rugged topography and inselbergs that is exemplified by Minna batholiths around Bosso area (Ajibade, A. C. 1980).

2. Materials and Methods

Geological field mapping was carried out to determine rock types in the area investigated as the residual soils along the river channels are weathered products of the rocks in the area studied. Sampling was done between 06m – 1m from the surface of the gully sites identified along the river bank. The research also utilized personal observation methods and took pictures of the menace.

Geotechnical investigation were carried out which include both field and laboratory studies. Seven distributed samples were taken for laboratory analysis. The laboratory procedure included both index and performance test. Five index properties (moisture content, specific gravity, Atterberg limit, bulk density and sieve analysis) were determined. The results of index properties

guided the selection of three samples for performance test such as compaction, permeability and triaxial test. The laboratory tests were conducted at the Civil Engineering Department Laboratory of Federal University of

Technology, Minna and were all performed in accordance with the specified standard procedures (BS, 1975; ASTM 1979).

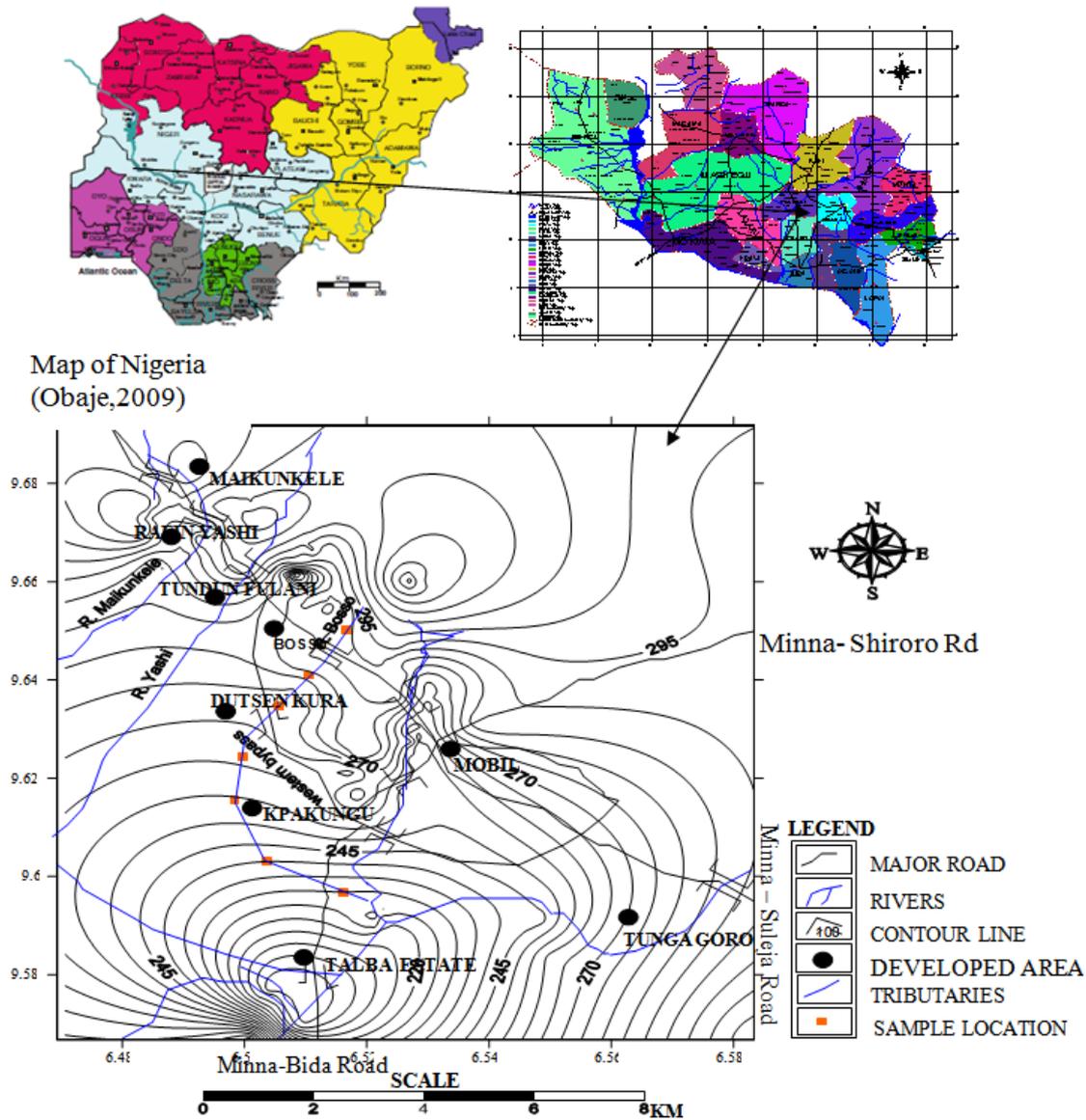


Figure 1. Location map of the study area

Sieve or gradation analysis: Gradation is a descriptive term that refers to distribution and size of grains in a soil. The apparatus used for this test included B.S Test Sieves, Mechanical Shaker, Weighing Balance and Sieve brush. A known weight of samples were placed on carefully selected sieves. The sieves were placed on the mechanical shaker. Sieving was done by means of internal and vertical movement of the sieve accompanied by a jarring action. The cumulative percentage retained and cumulative percentage passing were calculated. The coefficient of uniformity (C_u) and coefficient of curvature (C_c) were calculated to determine the grading of soil. For a material to be well graded it must fulfil one or all of the following: that C_c is between 1.0 and 3.0; and or C_u must be greater than 4.0 for gravels and greater than 6.0 for sands. Otherwise it is poorly graded (P). D_{10} = grain size value at 10% passing, D_{30} = grain size value at 30% passing, D_{60} = grain size value at 60% passing has been used to calculate C_c and C_u . 200g of prepared samples were sieve washed

and dried. The sample were sieved and the amount retained on each sieve were collected and weighed to determined the percentage of material passing each sieve size. The following formulae were used to calculate C_u and C_c respectively.

$$C_u = \frac{D_{60}}{D_{10}}; C_c = \frac{(D_{30})^2}{(D_{10})(D_{60})}$$

Bulk density test: This test was carried out to determine weight per unit volume of loose dry material such as powder and sand. The unit of its measurement is kg/m^3 . The values of bulk density of soil is typically between 1 – 2 kg/m^3 (Grossman and Reinsch, 2002). It is inversely proportional to porosity and directly proportional to compaction and runoff. The apparatus used include a cylinder of known weight and volume, flat –bladed knife, 1kg metal rod (18 inch) and weighing balance were the apparatus used for this test. The cylinder was filled with sand and levelled with flat – bladed knife and weighed

without compaction. The cylinder was emptied after the weighing. Five layered compaction with 1kg metal rammer was carried out on the sample in the cylinder. The sample was weighed and was used to calculate the bulk density. These procedures were repeated three times for each sample and the following formula was used to determine the bulk density for each sample:

$$\text{Bulk density, } \rho = \frac{W_2 - W_1}{V}$$

W_1 = weight of cylinder, W_2 = weight of cylinder and sample, V = volume of cylinder.

Atterberg limit test: This is used to determine the effect of moisture content on fine grained soil especially soil passing through Sieve No. 40. It defined the boundaries of several state of consistency of plastic soil. It is used to determine the plasticity of soil. Liquid limit, plastic limit, plasticity index, liquidity index and relative consistency are some parameters determined through Atterberg limit test. These parameters help to determine the plasticity and clay content of a soil sample. Surfer 8 software was used to plot the graph of plasticity index and liquidity limit. The graph was used to classify the soil.

Liquid limit: It is the moisture content at which the soil begins to behave like fluid under the influence of a standard blows. This was determined with the aid of cone penetrometer. Samples were dried and were carefully broken down to prevent the destruction of individual particles. The soils used were those passed through 425 μ m Sieve BS for the experiment. The dried soils were thoroughly mixed with water on a flat glass plate. A palette knife was used for mixing the soil and water into a paste. The paste was then carefully pushed with a palette knife into a cylindrical metal cup. Care was taken to prevent the entrapment of air. The cup was levelled and was placed under the cone penetrometer after it has been adjusted to point zero. The cone was then released to penetrate the soil and the reading was recorded. This was repeated till the soil failed or after five trials.

Plastic limit: It is the moisture content at which the soil begins to behave like plastic. A representative sample of air - dried soil passing the 425 μ m BS test Sieve was thoroughly mixed with water on a glass plate until it is sufficiently plastic to be moulded into a ball.

A piece of soil was taken and rolled into a ball between the hands until it developed a hairline crack on the surface. The sample was then divided into two and each of these two divided into four and tested as follows:

The soil is rolled into 6mm diameter thread between the thumb and index finger. This was further rolled into 3mm with some pressure between the finger – tips and a cleaned flat glass plate. The sample was remoulded into 6mm diameter thread and again rolled into 3mm. This procedure was repeated until longitudinal and transverse crack appear at a rolled diameter of 3mm. The moisture content was determined after these cracks appeared. This procedure was carried out two times for each sample.

Plasticity index, PI: It is the difference between liquid limit, LL and plastic limit, PL ($PI = LL - PL$). It represents the range of soil moisture content over which soil is plastic.

Liquidity index, LI: It is the ratio of the differences between the natural moisture content and plastic limit, $W_n - PL$, to the plasticity index, PI. Mathematically:

$$\text{Liquidity Index, LI} = \frac{W_n - PL}{PI}$$

Relative consistency, C_r : It is the ratio of the differences between liquid limit and natural moisture content, $LL - W_n$, to the plasticity index, PI. This help to determine whether a soil sample can be remoulded or not. If the C_r is less zero, any process of remoulding will transform the soil into thick, viscous slurry. If it is greater than zero, it means that the soil cannot be remoulded. Mathematically;

$$\text{Relative Consistency, } Cr = \frac{LL - W_n}{PI}$$

Moisture content test: This test was used to determine the water content of the soil. It is expressed as a percentage of the weight of water to the dry weight of the soil. A known weight of samples were taken out of the preserved samples from the field and weighed. The sample was oven dried at a temperature of about 110 $^{\circ}$ C for about 24 hours. The weight of the sample was taken again and was used to calculate the moisture content with the following formula:

$$\text{Moisture content, } w = \frac{M_2 - M_3}{M_3 - M_1} \times 100 \text{ (Mg / m}^3\text{)}$$

M_1 = mass of container, M_2 = mass of wet soil + container, M_3 = mass of dry soil + container. It is expressed in percentages. This procedure was carried out for each sample three times.

Specific gravity test: Specific gravity is the ratio between the density of a substance and the density of water at 4 $^{\circ}$ C. The specific gravity is dimensionless. The specific gravity for water is 1. The specific gravity of soil is generally between 2.50 and 2.90 for sand is 2.63; silt is 2.70 and 2.90. The following formula was used to calculate the specific gravity after necessary measurement were taken:

$$\text{Specific gravity, } G_s = \frac{M_2 - M_1}{(M_4 - M_3)(M - M_1)}$$

M_1 = mass of conical flask, M_2 = mass of conical and soil, M_3 = mass of conical flask, soil and water, M_4 = mass of conical flask and water.

Compaction test: Compaction is the processes by which the moisture content change in soil is controlled, increase unit weight, shear strength, reducing permeability. This make the soil less susceptible to settlement under load, especially repeated loading. This is usually done by mechanical means (Brian, 1978). 2.5kg method of compaction was used for this test. The apparatus consist of 2.5kg rammer, a known volume of mould with removable base and a detachable collar. Three kilogram of air dried soil was used for the test and the test was repeated five times for each sample. The moisture content used was between 4% - 20% of the weight of the sample, and samples were mixed thoroughly before compaction. Three layers of compaction were done for each trial and 27 blows were used to compact each layer. Graphs of dry density, ρ_d against moisture content were plotted using rock work software to determine the optimum moisture content. Bulk density and dry density were calculated using the following formula:

$$\text{Bulk density} = \frac{M_1 - M_2}{1000} \text{ (Mg / m}^3\text{)}$$

$$\text{Dry density, } \rho_d = \frac{M_2 - M_1}{1000(1 + m)}$$

M_1 = mass of mould (g), M_2 = mass of mould and compacted sample (g), 1000 = volume of mould (cm^3), m = moisture content used.

Triaxial shear test: Triaxial test was used to determine the shear strength properties of soil samples. The type of the triaxial test conducted was *consolidated undrained test*. Test sampler of 50mm in diameter with a height to length ratio between 2 and 3 using the optimum moisture content obtained from compaction test were prepared. The sample were encased by a thin membrane and placed inside a plastic cylindrical chamber that was filled with water. Each sample was subjected to a normal stress or confining pressure (δ_3) by compression of the fluid in the chamber. Axial stress (load, $\delta_1 - \delta_3$) also called deviator stress was applied constantly through a vertical loading ram. Rock work software and suffer 8 software were used to plot the graph of normal stress to determined angle of internal frictional and cohesion.

Permeability test: Permeability also called the hydraulic conductivity is a measure of the ability of water to flow through the soil. It expressed in units of velocity which is meter per second (m/s). Falling head permeameter apparatus was used for this test. This method was chosen because all the samples were almost fine grained. The

apparatus used consisted of burette, porous cover, screen soil sample tube, constant head chamber. Disturbed samples were compacted using the optimum moisture content determined from compaction test carried out earlier. Four compacted samples were used for this test and their average were determined and recorded. The samples were soaked in water for 48 hours and were removed from water thereafter. The base of the mould was connected to the water reservoir and top connected to a calibrated glass stand pipe of known cross section area. The pipe was then filled with water. Water level in the stand pipe was allowed to fall continuously as water flows through the soil specimen. Observations were made until a steady state of flow was attained. The time it took the water to flow from one height to another was noted. The following formula was used to calculate the permeability:

$$K = \frac{2.303aL}{A(t_1 - t_0)} \cdot \log_{10} \left(\frac{h_0}{h_1} \right)$$

K = permeability, a = cross section of stand pipe, L and A = length and area of cross section of the soil sample or mould, t_0 = initial time, t_1 = final time, h_0 = initial height of water, h_1 = final height of water.

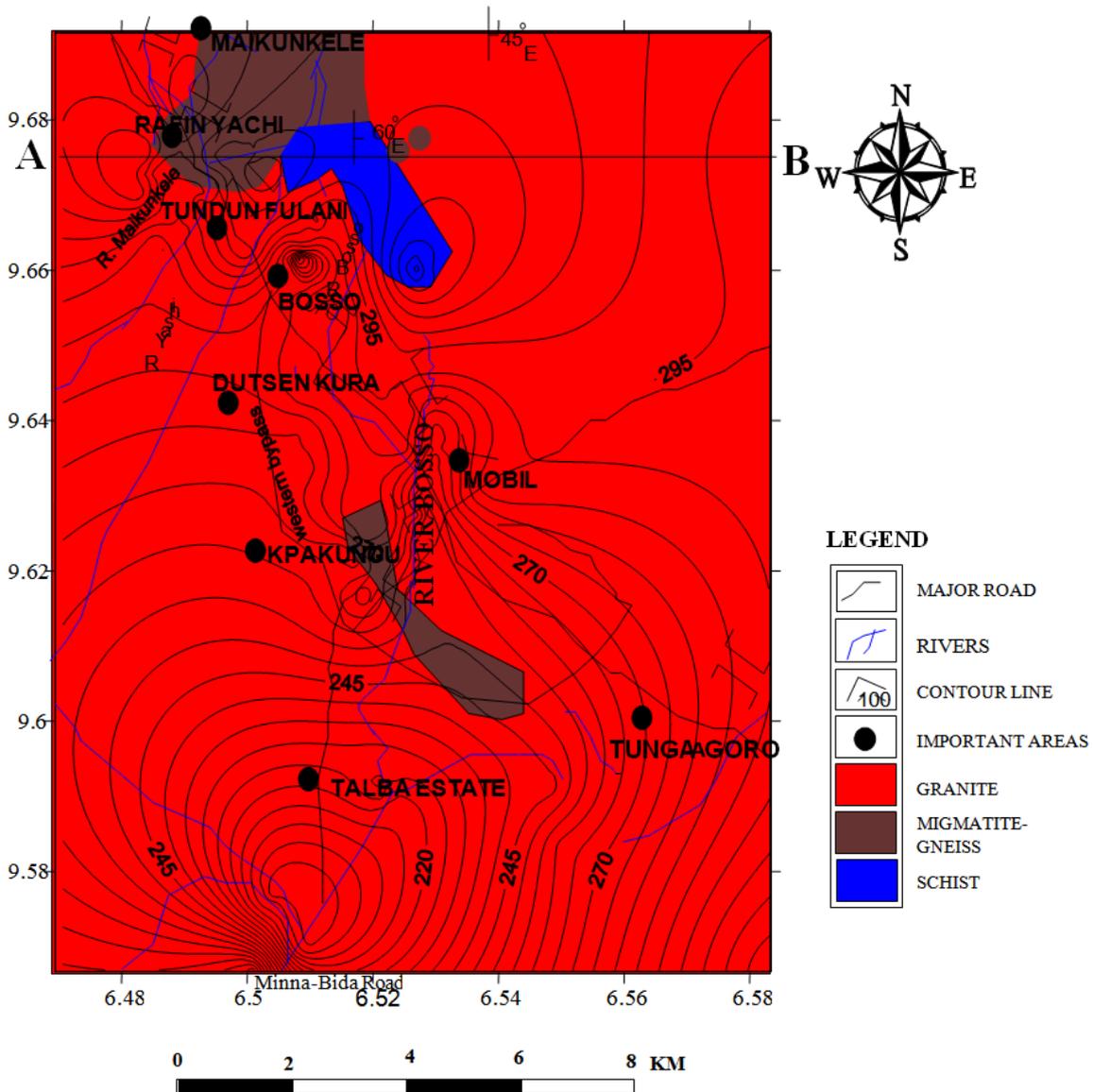


Figure 2. Geological map of the study area

3. Discussion of Results

The result of geological field mapping shows that there are three major rock units in the area which are granite, migmatite - gneiss and schist (Figure 2). Granite rock (about 85%) is the dominant rock in the area followed by migmatite – gneiss (about 11%) and then schist (about 4%).

The geotechnical laboratory results show that the natural moisture content for soil along River Bosso (RB) ranges from 11.19 – 29.31% (Table 1); while none of the natural moisture content approached the Liquid limit

(20.67 - 29.97%) and this is an indication that these soils are susceptible to large consolidation settlement (Ara, *et al.*, 1997). The Atterberg limit result shows that the plastic limit is between 17.05 -24.65%, liquid limit is between 20.67 - 29.97% and plasticity index ranges from 0 – 5.63%, which indicates that, the soil at depth between 0.6 – 1 meter exhibit low plasticity. The result also show that the liquid limit for samples RB2, RB3, RB5 and RB7 were not attained after five trials and they all have zero plasticity. The relative consistency ranges between 0 – 4.79 which signified that the soil cannot be remoulded which is also an indication of low plasticity.

Table 1. Summary of laboratory results for soil along River Bosso

Gully Location	RB1	RB2	RB3	RB4	RB5	RB6	RB7
Depth (m)	0.8	3	6	5	5	6	3
Width (m)	8	21	41	29	24	31	19
Natural Moisture content	24.08	13.59	21.17	17.46	29.31	11.19	18.37
Uncompacted, BD (kg/m ³)	0.87	1.07	1.15	0.97	0.94	0.95	1.11
Compacted, BK (kg/m ³)	1.25	1.42	1.49	1.3	1.32	1.33	1.4
Specific Gravity	2.16	2.83	2.66	2.37	2.32	2.67	2.66
Plastic Limit (%)	24.89	-	-	23.01	-	25.12	-
Liquid Limit (%)	29.91	-	-	28.22	-	28.91	-
Plasticity Index (%)	5.02	-	-	5.21	-	3.79	-
C_r	1.16	0	0	2.06	0	4.79	0
C_u	3.37	7.03	4.00	3.56	29.00	5.62	8.00
C_c	0.65	0.59	0.61	0.68	0.17	0.73	0.89
Soil Classification	Sandy – Silt	Sandy – Silt	Silty – Sand	Sandy – Silt	Silty – Sand	Silty – Sand	Silty – Sand
Optimum Moisture Content, OMC (%)	13.98	Not Determined	Not Determined	14.85	Not Determined	8.9	Not Determined
Maximum Dry Density, MDD (mg/m ³)	1.88	Not Determined	Not Determined	1.951	Not Determined	2.09	Not Determined
Angle of Friction, ASR (°)	6	Not Determined	Not Determined	7	Not Determined	9	Not Determined
Cohesion, C (kg/ m ³)	28	Not Determined	Not Determined	42	Not Determined	40	Not Determined
Permeability (cm/sec)	1.50×10^{-3}	Not Determined	Not Determined	1.42×10^{-3}	Not Determined	1.93×10^{-3}	Not Determined

The plasticity index ranges from 0 – 5.21. The graph of Plasticity Index (PI) against Liquid Limit (LL) shows that the soils plot below A–line for RB1, RB4 and RB6 and their values are below 4 and 50% respectively which are typical of silt.

The sieve analysis result (Table 1) shows that C_u ranges from 3.37 and 29 while C_c ranges between 0.17 and 0.89 which are values associated with uniform soil (Das, 2006) that are poorly graded and are therefore likely to erode easily. The sieve analysis results combined with Atterberg limit results aided the classification of the soils as sandy – silt for samples RB1, RB2 and RB4 and silty – sand for RB3, RB5, RB6, and RB7.

These materials are highly susceptible to gully erosion. This agrees with Obiefuna *et al.*, 1999 who concluded that high sand and low silty/clay content in the soil contribute to gully growth.

The uncompacted bulk density (UBD) is between 0.87 – 1.15kg/m³ and the compacted bulk density (CBD) is between 1.25 – 1.49kg/m³. This shows that the bulk density of soil is relatively low, poorly consolidated and therefore prone to short dispersion times (Hudec *et al.*, 2006). The specific gravity ranges from 2.16 - 2.83. The specific gravity for RM 1, 4 and 5 are particularly low and are attributed to some reasonable percentage of organic matter presence in these samples. The compaction result shows that the optimum moisture content (OMC) is from 8.90 – 13.98% while the maximum dry density (MDD) is

from 1.880 – 2.090mg/m³. These values are within the range classified as sandy clay by O'Flaherty (1988). Also, similar values gotten by Ishaku *et al.*, 2002 was classified as low and that such soil are considered loose with little amount of clay as binding material. The triaxial shear test result shows that the angle of friction is between 6° - 9° while the cohesion, C is between 28 – 42kg/m². These values are low when compared with 65Kpa cohesion and 26° angle of friction classified as average by Alao and Opaleye (2011) and thus, can only offer little resistance to the effect of both surface water and subsurface flow. The Coefficient of permeability, k is between 1.42×10^{-3} – 1.93×10^{-3} cm/sec which is classified as low to medium (Carter and Bentley, 1991), an indication that there are low to medium base flows which could result in the collapse of river bank and consequently advance the growth of gully erosion (Nwajide and Hague, 1979; Egboka and Nwankwor, 1986; Onwumesi and Egboka, 1991).

Other factors found to be contributing to gully erosion growth in the area include:

- Dumping of refuse in the river channel (Figure 3) which results in the flooding and increase in runoff down the river channel.
- Sand mining/excavation (Figure 4) is common practice along the river channel. This practice help in the increment of river channel as excavation is not only done on the river bed.

- Farm practice was also recorded as a contributory factor as some ridges were cultivated perpendicular the slope (Figure 5). This encourages runoff and erosion.



Figure 3. Refuse dump along River Bosso



Figure 4. Sand excavation along River Bosso



Figure 5. Farm ridges placed perpendicular to River Bosso Channel

- Building on the flood plain (Figure 6) of river Bosso was also observed as a contributory factor to gully erosion growth in the area as any construction on flood is inimical to the river system.

- The gully poses danger not only to human being and their properties but also to vegetation (Figure 7) as more trees are being consumed as a result of the expansion of the river channel.



Figure 6. Building on flood Plain along River Bosso



Figure 7. Gully effect on vegetation along River Bosso

4. Conclusion and Recommendations

The geotechnical properties of the residual soils from the predominantly granitic rock of the study area inherently make the study area susceptible to gully erosion as it is also aided by anthropogenic activities and the following conclusions and recommendations can be drawn:

- The textural properties of the residual soils is sandy – silt and silty – sand.
- The natural moisture content did not approach the Liquid limit.
- The Plasticity index ranges from 0 – 5.63%.
- C_u ranges from 0.03 and 0.14 which are values associated with uniform soil.
- k is between 1.42×10^{-3} – 1.93×10^{-3} cm/sec which is classified as low to medium and an indication of high base flow.
- The results of all geotechnical parameters test shows that the soil along the along the bank of River Bosso favours gully erosion growth.
- The interrupted mitigation measure should be completed for river Bosso especially within the residential areas.
- Mining activities (especially sand mining/excavation) taking place along the rivers should be regulated.

- Improved farming practices should be introduced such that practices that encourage gully erosion e.g. ridging perpendicular to river bank are reduced.
- Dumping of refuse on the river channels and flood plain should be prohibited.
- Discourage construction of houses along the immediate flood plain.

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