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Assessment of Geotechnical Properties of Soil in Capitol Gully Erosion Site, University of Benin, Benin City, Edo state

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A geotechnical assessment of soils in Capitol gully erosion site in University of Benin was carried out in order to evaluate the susceptibility of the soil to erosion. Soil samples were collected with a hand auger from nine(9) sampling points in the study area at a depth of 1m. The geotechnical properties of the soil samples analyzed in the laboratory were Sieve analysis, Atterberg Limits, Compaction, Moisture content and Shear strength. This work was carried out to evaluate the effect

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of dumping of metal scraps, used batteries, packaging materials, spent lubricants and worn-out parts, which contain contaminates, such as heavy metals which is highly toxic and hazardous to soil, fauna, and man. Uwelu auto-shops and mechanic workshops lies within the Drift/Top soil in the Benin Formation. Nine (9) samples points including control were profiled at 0-5 cm, 5-10 cm, 10-15cm and 15-30cm. Using auger from nine different point at the automobile mechanic workshop in order to get a representative sample (composite sample). The physiochemical analysis of the soil was carried out using standard method (pH, EC, TDS) and heavy metals(Ni, Cr, V, Pb, Cd, Zn). At profile depth 5-10 cm and 10-15 cm, there was significant difference between control and Cr, V, Pb, Cd, Zn and EC. Cd, V, Pb, Zn and Cr and the Contamination Factor value was greater than 1.5 in all the profile samples which translates to Contamination from anthropogenic sources. Plastic Limit Index (PLI) of the profiles revealed that the sub soil at 10-15 cm and 15-30 cm where the most contaminated with the highest PLI values. Futhermore, it was observed that the soil sample comprised mainly of sands and more fines with low and high plasticity. Monitoring and further studies on the level of these heavy metals should be carried out in the near future and at intervals to ascertain long-term effects of this anthropogenic impact.

Keywords: Geotechnical properties; contamination factor; heavy metals; anthropogenic.

1. INTRODUCTION

"Soil is formed as a result of weathering of rocks. It is a product of the interference of man on rocks through human activities. Soil erosion therefore is the process by which soil particles are detached from rock materials and transported from one place to another through an agent such as wind, water, and landslide wearing away and moving the surface constituents of the earth". "Soil erosion may be a slow process that continues relatively unnoticed or it may occur at an alarming rate causing serious loss of topsoil. This loss of topsoil from farm land may be reflected in reducing crop yield potential, lowering of surface water quality and drainage network. Hence a good study of soil erodibility will enhance optimum agricultural yield and provide insightful measures that can effectively mitigate geo environmental hazards such as gully erosion".

"Although erosion is a natural phenomenon, human interference on natural systems have created erosion that is much higher than the average geological erosion rate. Humans have often caused accelerated erosion by our manipulation of the soil for agriculture, construction, overgrazing by animals and through combustion of land. This combustion also releases Volatile Organic Compounds which could cause hazardous health effects that may build up in the body (eye, nose and throat irritations, headaches, loss of coordination and nausea, damage to liver, kidney and central nervous system) [1].

"Gully erosion can be defined as the displacement of soil or soft rock by a flow of water whose velocity is sufficient enough to detach and transport soil particles. Gullies develop due to a decrease in soil surface resistant to erosion or an increase in the erosive forces acting on the land surface. The causes of gullies may be naturally or artificially induced, or a combination of both factors, but the underlying geology and the severity of accompany surface processes play a key role in its formation. It is a highly visible form of soil erosion that affects soil productivity, restrict land use and can threaten road, fences and buildings. Environmental hazards associated with abandoned gullies in Nigeria are on the rise and a major concern to citizens, government and the environmental geologist" [1].

"One practical definition of gullies is that there are incised channels that cannot be filled by normal tillage operations. Other studies uses a depth of 0.3m as the threshold between rills and gullies" [2]. "Dry lands are particularly susceptible to gully formation because of sparse vegetation and a precipitation period that favours short and high intensity rainfall events" (Sidle *et al.,* 2018).

Research has unequivocally demonstrated that gully erosion is more common in sedimentary terrain than in Nigeria's basement complex. Nearly every year, lives and property have been lost as a result of this erosion activity on varying scales. A public awareness campaign, improved farming methods, a cultural approach to gully control, the passage of legislation prohibiting any actions that encourage gully growth, and the full execution of suggested solutions are among the alternatives that have been put up.

The purpose of this research is to evaluate the geotechnical parameters of soil at the Capitol Gully erosion site at the University of Benin in Benin City, Edo State. The need to understand the soil properties in a region prone to erosion, with possible consequences to infrastructure and communities, motivates this research. The study will provide insights into the soil's behavior and susceptibility to erosion using a systematic technique that includes field surveys, laboratory testing, and data analysis. The findings will be critical in developing effective erosion control techniques and protecting the University's assets and the environment.

1.1 Description of Study Area

The study area is at Capitol Gully, in Benin, University of Benin, Ugbowo Campus which extends from Benin Lagos road in the West to the Benin Auchi road in the North East Egor Local Government Area of Edo State. The study area lies between latitude N06˚25’16.8” to N06˚25’16.9”and longitude E05˚28’17.8’’ to E05˚38’20.9’’. The western sector slopes at between 3-8% (average slope of 4%) into Ikpoba River which receives sediments from the gully area. On this same sector (western), the slope breaks just behind the Capitol. From this point, runoff due to change in gradient accelerates into Ikpoba River, [3].

The elevation of the study area ranges from 40m to 57.3m above mean sea level. According to a similar research carried out by [4], the average temperature in this area is approximately 27℃ and annual rainfall is between 1,500mm/yr to 3,000mm/yr. The wet season spans from March to November with break in the month of August otherwise known as August Break The major soil type in the area ranges from clayey soil in the upper reach of the catchment to sandy soil towards the river bank. The land use types mainly include grassland, shrubs and bare soil. Humidity is about 85% most of the time and the area lies in the tropic al rain forest zone.

1.2 Geology of the Study Area

The study area lies within the Benin formation which consist of 99.8% thick accumulation of massive, loose and friable sandstone with 0.2% mud rock. Petrographic studies have revealed that quartz is the dominant mineral present in this formation. Other minerals include feldspar, limonite, zircon, opague and minor clay matrix. Geochemical results shows high concentration of Silica (SiO_2) and Aluminum (Al_2O_3) in the sandstone which makes it mineralogical matured Heavy minerals include Hematite (Fe_2O_3) and Zircon (Zr) while rare earth elements include La, Ce, Nd, Gd and Tb. Trace elements are Cu, Pb, Zn, Ag, Sr, V and Nb which has pronounced enrichment in clay than the sandstones. The color variation of white, yellow and pink are indicative of fully aerated environment and has no effect on the geochemistry of the sandstones.

2. MATERIALS AND METHODS

2.1 Compass Survey and GPS Reading

A compass survey of the area was carried out to determine the direction of drainage and to produce a base map. Field coordinates and elevation data collected were placed in decimal formats and digitized in a surfer software, a powerful contouring and surface mapping package to produce a contour and drainage maps.

2.2 Collection of Samples

Three (3) soil samples were collected at depths of 1m each which is disturbed samples. Disturbed sample is a sample in which the natural structure of the soil is modified partly or fully during sampling. The following procedures was employed for the collection of disturbed sample that was used for this project.

i. Drilling with the aid of continuous flight hand auger;
ii. At a depth of 1.0m each, samples were collected.

The samples collected were taken to the laboratory for index properties analysis.

2.3 Laboratory Tests

In general, sample preparation and testing methodology was carry out according to British standard specification BS EN 1997-1-2004 and BS EN 1997-2-2007, Geotechnics Designs (General Rules and Ground Investigation and testing respectively).

The tests carried out include the following:

1. Particle size analysis
2. Consistency test such as: Liquid limit, (b)Plastic limit
3. Standard compaction tests
4. Moisture content tests
5. Specific gravity tests
6. Triaxial compression test

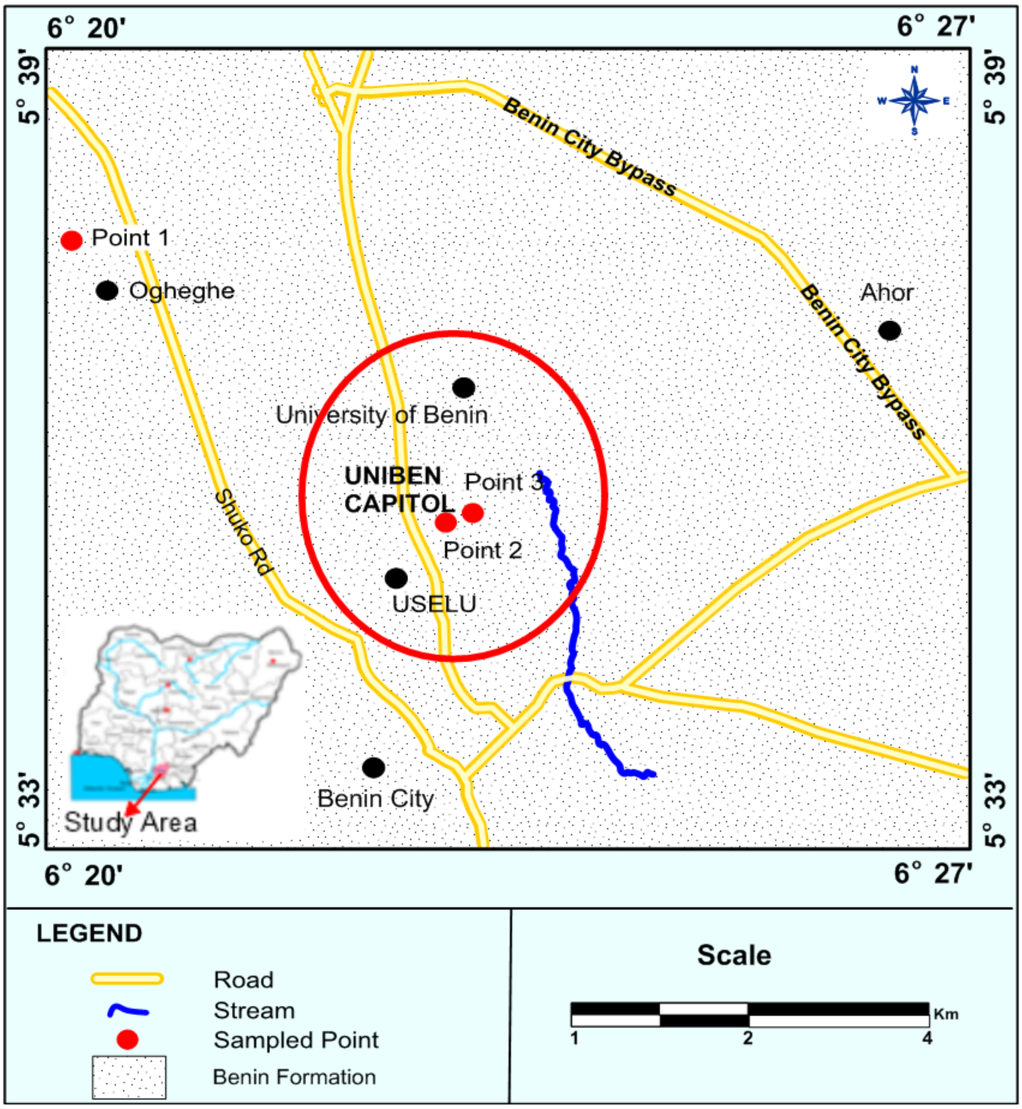

Diagram 1. Map of the study area (Capitol gully)

Diagram 2a. Capitol gully erosion site

Diagram 2b. Collection of samples at the site
Photo Credit: Austin

2.3.1 Particle size analysis

This test is to determine the percentage quantity of individual grain sizes as they occur in a particular soil layer. British Standard Sieves (BS-Sieves) were used onthe mechanical sieve shaker to separate these grains into various sizes. The samples were then weighed and their percentage weights calculated. The result of this test is of value when used for classification purposes. It enables soil groupings to be delineated, and their properties inferred. These were carried out in accordance with the AASHTO T27-70 (BS EN 1997-2-2007), ASTM D7328, and D6913. Also, the distribution of different soil particles passing the 0.075mm sieve size was determined by a sedimentation process using hydrometer analysis.

The relationship is presented in equation 3.1 representing the formula for calculation.

Percentages retained on any sieve= $\frac{wt.of\ soil\ retained}{Total\ soil\ wt} * 100$ (3.1)

2.3.2 Consistency test

This is a measure of the index properties of soils. It also involves the plasticity of the soil, which is a measure of its resistance to flow. The consistency tests carried out include: Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) tests all of which make up the Atterberg Limits Tests. These were determined in accordance with BS EN 1997-1-2004 and BS EN 1997-2-2007, ASTM D4318-05.

Liquid limit: The liquid limit (LL) is the water content, expressed in percent, at which the soil changes from a liquid state to a plastic state and principally it is defined as the water content at which the soil pat cut using standard groove closes for about a distance of 13cm (1/2 in.) at 25 blows of the liquid limit machine (Casagrande Apparatus). The liquid limit of a soil highly depends upon the clay mineral present. The conventional liquid limit test is carried out in accordance of the procedures of AASHTO T 89 or ASTM D 4318. A soil containing high water is in the liquid state and it offers no shearing resistance. The liquid limit can also be determined in the laboratory by the cone penetration method.

Plastic limit: “The plastic limit (PL) is the water content, expressed in percent, below which the soil stops behaving as a plastic material and it begin to crumble when rolled into a thread of soil of 3.0mm diameter” (Arora, 2004). The conventional plastic limit test is carried out as per the procedure of AASHTO T90 or ASTM D4318. The soil in the plastic state can be remoulded into different shapes. When the water content is reduced the plasticity of the soil decreases changing into semisolid state and it cracks when remoulded. The fine-grained fractions of construction materials are characterized by the liquid limit, plastic limit, and plasticity index characteristics, which are all fundamental components of various engineering qualities. A fine-grained soil's shear strength is primarily influenced by its consistency.

2.3.3 Standard compaction tests

The moisture content test was carried out using the oven and appropriate sensitive weight measuring equipment as specified in BS 1377 - 1975 (Methods of Testing soil for Civil Engineering Purposes) and ASTM D698 (The Standard Proctor Compaction Test).The test was carried out to determine the amount of moisture in the soil. This is usually a function of the level of saturation of the soil.

The relationship is presented in equation 3.2 representing the formula for calculation.

The dry density ρd used was computed as follows

$$\rho d = \frac{\delta}{1 + \frac{Avg.mc}{100}} \quad (3.2)$$

2.3.4 Shear strength (triaxial compression test)

UndrainedTriaxial Tests were carried out to determine the shear strength parameters of soil as specified in BS 1377-1975 (Methods of testing soil for Civil Engineering Purposes) and ASTM D2850, D4767 (Standard test method for unconsolidated undrainedtriaxial compression test on cohesive soils).The shear strength parameters include the angle of internal friction (ϕ) the cohesion (C) of the soil. The cohesion and internal friction were obtained from intercept and slope of the straight line graph respectively.

2.3.5 Moisture content test

Change in moisture content is the most influential parameter that affects the property of soils. Moisture content is defined as the ratio of the mass of water to the total mass (Arora, 2004).It is expressed as a percentage, but used as a decimal computation.

The moisture content of fine-grained soils such as gravels and clays is generally more than that of the coarse grained soils such gravels and sands. The characteristics of a soil, especially a fine-grained soil, change to a marked degree with a variation of its water content. The moisture content test is carried out in the laboratory according to the procedures of AASHTO T265 or ASTM D2216.

2.3.6 Specific gravity tests

Specific gravity is the ratio of unit weight of soil solids to that of water. The tests were performed as per procedures laid out in BS EN 1997-1-2004, BS EN 1997-2-2007, ASTM C127, D854, and D792.

Specific gravity calculation is presented in equation 3.3

$$Gs = \frac{(M_2 - M_1)}{(M_4 - M_1) - (M_3 - M_2)} \quad (3.3)$$

Where G_s = specific gravity of the liquid used

M_1 = mass of bottle

M_2 = mass of bottle +dry soil M_3 = mass of bottle +soil+liquid

M_4 = mass of bottle +liquid Calculate the average of the 2 values obtained.

3. RESULTS

3.1 Particle Size Distribution

The results of sieve analysis, reveals that the percentage passing sieve 75micron ranges from 9.4 to 55 percent, with the highest value being at sampling point 3 as shown in Table 1. 9.4 at sampling point one(1), 35 at sampling point 2 and 55 at sampling point 3.

Table 1. Summary of Result of particle size distribution

Sampling Points	Site	Depth (m)	Percentage Passing Sieve No			
			1.18mm	0.425mm	0.212mm	0.075mm
1	Capitol	1.0m	96.1	73.4	26.7	9.4
2	Gully	1.0m	95.8	75	49	35
3		1.0m	98	92	73	55

3.2 Atterberg/Consistency Determination

The result of Atterberg limits presented in Table 2 revealed that the liquid limit of soil samples varied from 33.27 to 42.42% across sampling point with no value recorded in sampling point1.plastic limit ranged from 13.29 and 17.03. Soils from sampling point 1 was considered non plastic. Plasticity index across sampling locations ranged from 19.98 to 25.44%.

3.3 Compaction Tests

Maximum dry density and Optimum moisture content.

The maximum dry density as indicated below ranges from 1.75 to 1.64, with sample one having the highest value, while the optimum moisture content ranges from 11.20 to 16.5 with sample three having the highest value.

3.4 Shear Strength Determination

The triaxial tests results revealed that the degree of cohesion varied from 8.07 to 20.93kN/m2. The highest value was recorded at sampling point 2. The degree of friction ranged from 13.0 to 23.81 with the highest value recorded at sampling point 3 as indicated in Table 4.

4. DISCUSSION

4.1 Particle Size Distribution

The results of sieve analysis, reveals that percentage passing sieve 75micron ranges from 9.4 to 55 percent, with the highest value being at sampling point 3 as shown in Table 1. This implies that the predominant aggregate is sand with obvious presence of fine material such as silt and clay. The low amount of fine in sampling point 1 is indicates the lack of clay size materials which would have cemented the sand particles. Hence the study area contains insufficient binding materials and therefore suggests high susceptibility of the soil material to erosion.

The high amount of fines in sampling point 2 and 3 could be attributed to intense weathering of the underlying geology of the area. Such Areas having weak unconsolidated sandy formations are also usually very susceptible to erosion [5].

Table 2. Summary of Results of Atterberg limit determination

Sampling Points	Site	Depth (m)	LL (%)	PL(%)	PI (%)
1	Capitol Gully	1.0	0.00	Non-Plastic	0.00
2		1.0	42.42	17.03	25.44
3		1.0	33.27	13.29	19.98

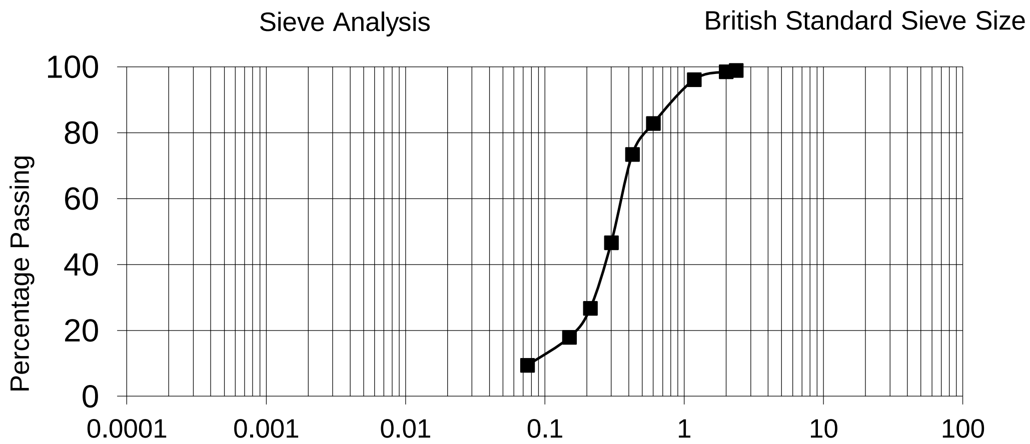

Fig. 1. Graph of particle sizes against percentage passing for sample 1

Table 3. Summary of compaction test results

Sampling Points	Site	Depth (m)	MDD (g/ cm^3)	OMC (%)
1	Capitol Gully	1.0m	1.75	11.20
2		1.0m	1.72	16.1
3		1.0m	1.64	16.5

Table 4. Results of shear strength determination

Sampling Poin ts	Site	Depth (m)	Cohesion (KN/m^2)	ϕ(deg)
1	Capitol Gully	1m	8.07	13.0
2		1m	20.93	22.00
3		1m	10.00	23.81

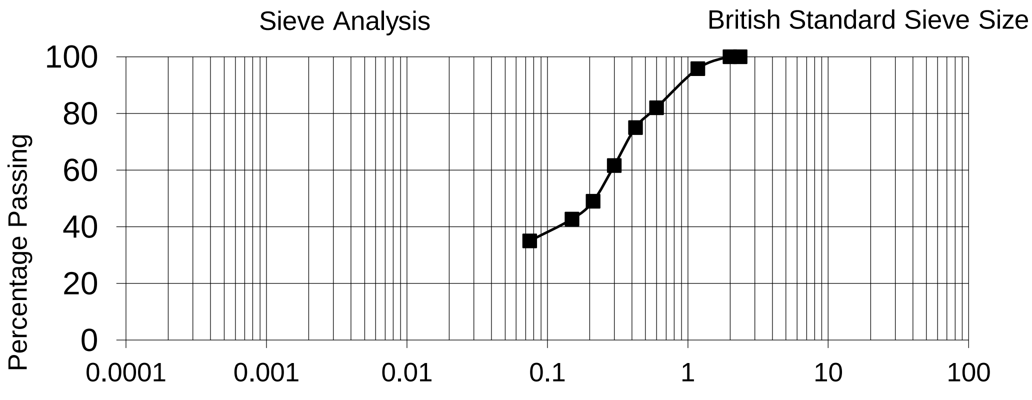

Fig. 2.Graph of particle sizes against percentage passing for sample 2

4.2 Atterberg/Consistency Determination

The values of the liquid limit and plastic limit ranges from 42.42% to 17.03% for sampling point 2, and 33.27% to 13.29% for point 3, while sampling point1 recorded no values. The plasticity index for sampling points 2 and 3 were 25.39% and 19.98% respectively as indicated in Table 2. Sampling Point 1 has zero plasticity index, indicating that the soil was non plastic. The value of plasticity index at sampling point 1 indicates that the soil is relatively unstable over a wide range of moisture content. This low value could also be attributed to low amount of fine fractions in the samples and indicates that the soil may change from one state of consistency to another with minimum change in water content [6].

(Prakash *et al.,*2012), stated that a soil is non plastic(sand) if it has a plasticity index of zero, moderately plastic (silty clay) if it has a plasticity index between 7-17, and highly plastic if its plasticity index is greater than 17. Hence sampling points 2 and 3 are highly plastic. FMWH [7] have specified Liquid limit of ≤ 30% and Plasticity index of ≤ 13% as soils suitable for construction of civil engineering structures. Therefore, soils from sampling locations 2 and 3 are unsuitable as construction materials and are therefore prone to gully erosion which may bring about changes in land use.

4.3 Specific Gravity

The study area comprises a mixture of sand and clayey mineral aggregates with specific gravity ranging from 2.48 to 2.52. According to a research work carried out by [8], the specific gravity of lateritic soil should be within the range of 2.60 to 3.40 and the specific gravity of clay should range from 2.2 to 2.6. The result however depicts that the study area falls within the clay range and were poorly laterized. Laterites in soils are usually very valuable for construction and building of engineering structures as they become hard when exposed to air [9]. The study area which contains no laterite would consists of weak, unconsolidated formations that are easily erodible.

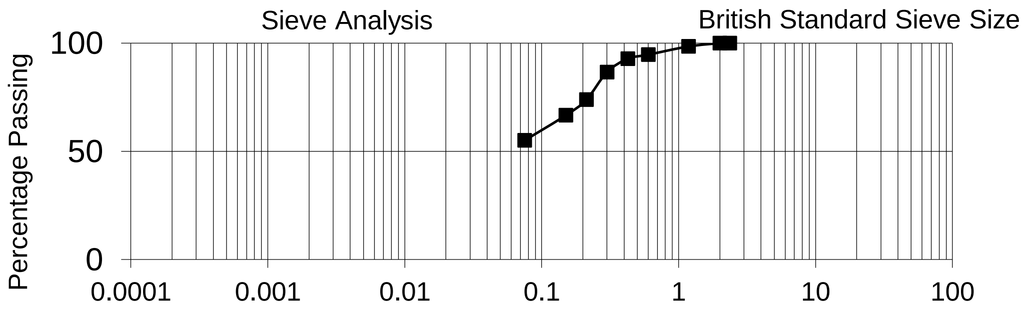

Fig. 3. Graph of particle sizes against percentage passing for sample 3

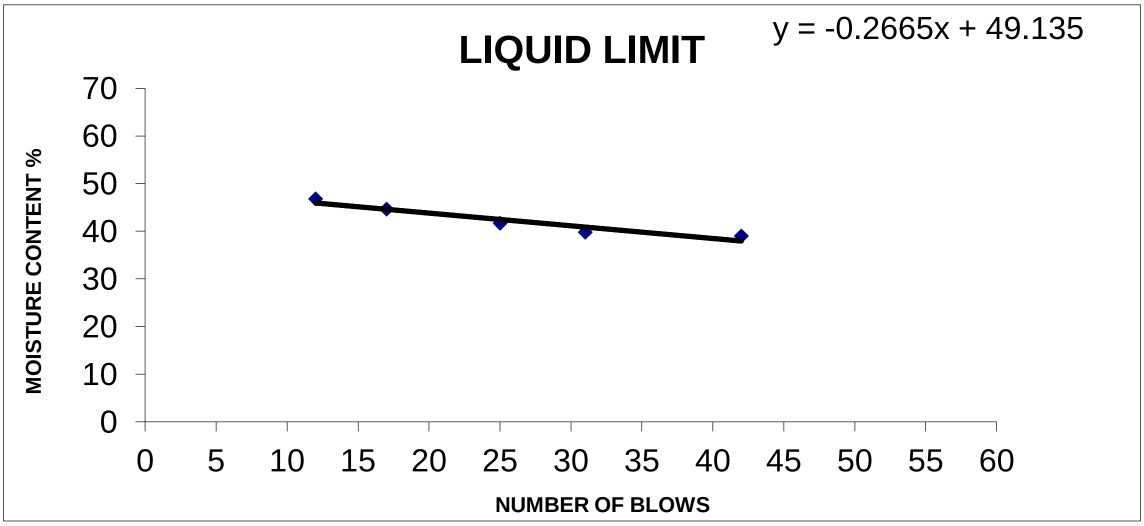

Fig. 4. Graph of no of blows against moisture content for sample 2

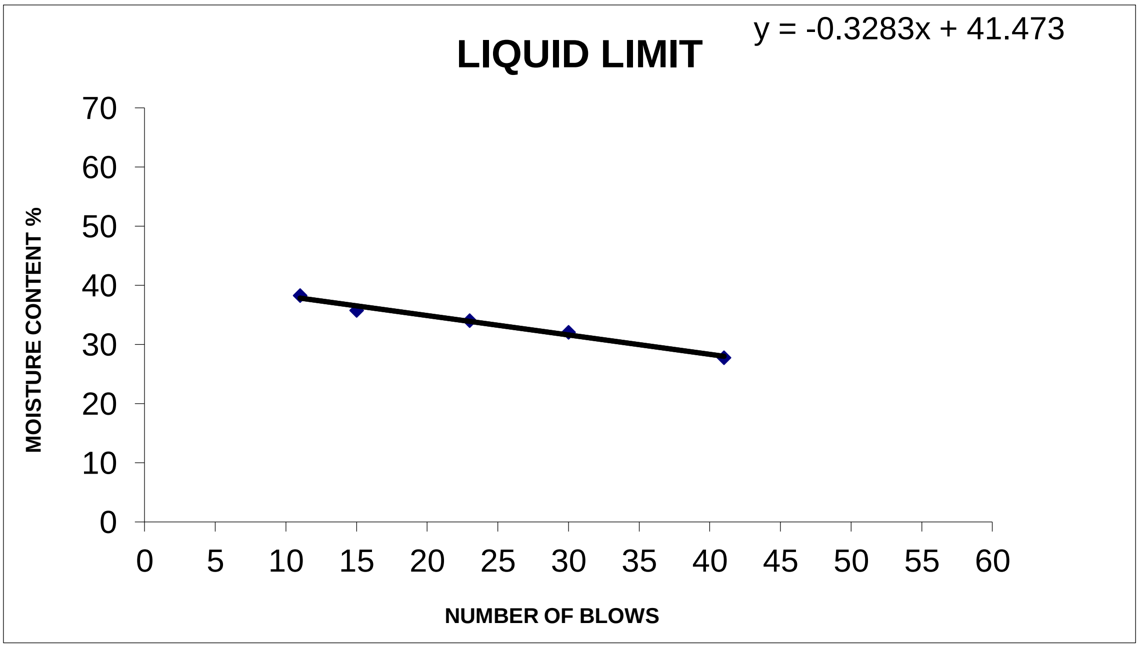

Fig. 5. Graph of no of blows against moisture content for sample 3

4.4 Compaction Tests

The maximum dry density as indicated below ranges from 1.75 to 1.64, with sample one having the highest value, while the optimum moisture content ranges from 11.20 to 16.5 with sample three having the highest value. The low values of MDD imply that the soils are generally not compacted and are loosely bound. These values are within the range classified as low by [10]. Loose soils are generally more easily erodible than compacted soils, hence the study area is highly prone to soil erosion.

The result of the moisture content test also shows low values of moisture content for the sampling points evaluated. This low moisture content of the subsurface soil leads to high capacity for water retention during rainfall. It eventually causes breakdown of the grain to grain forces that existed in the soil [11].

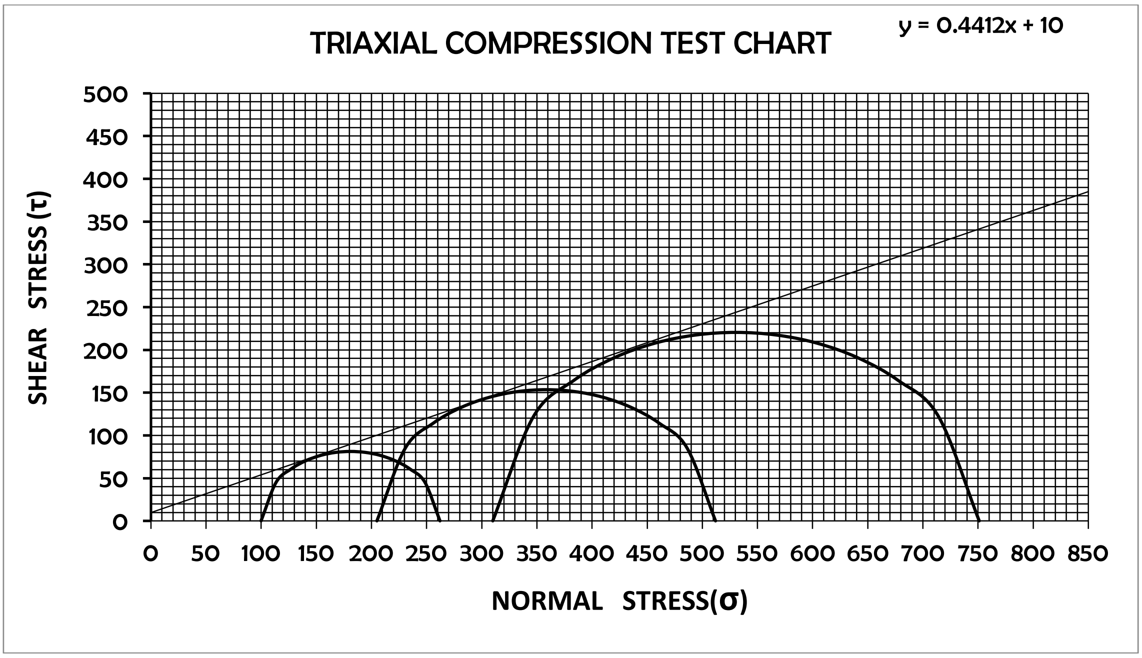

Fig. 6. Graph of normal stress against shear stress for sample 2

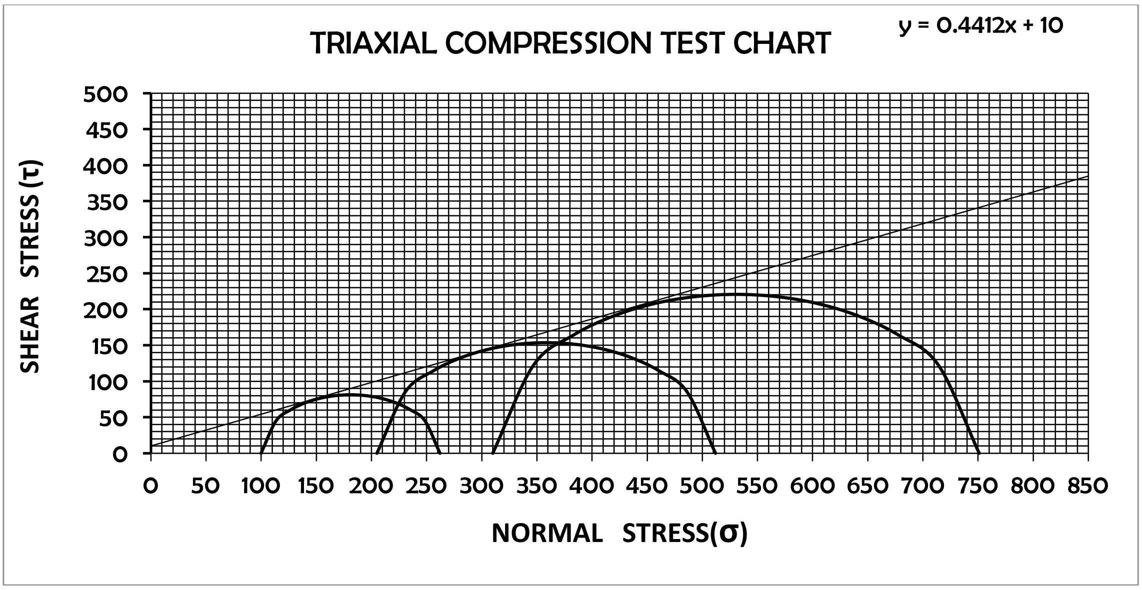

Fig. 7. Graph of normal stress against shear stress for sample 3

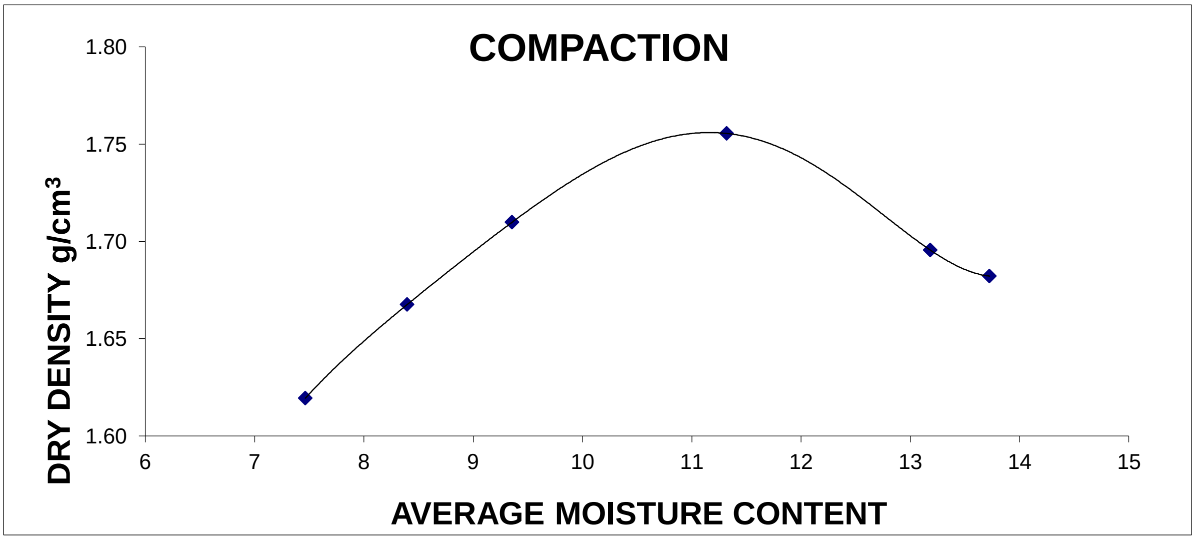

Fig. 8. Graph of average moisture content against dry density for sample 1

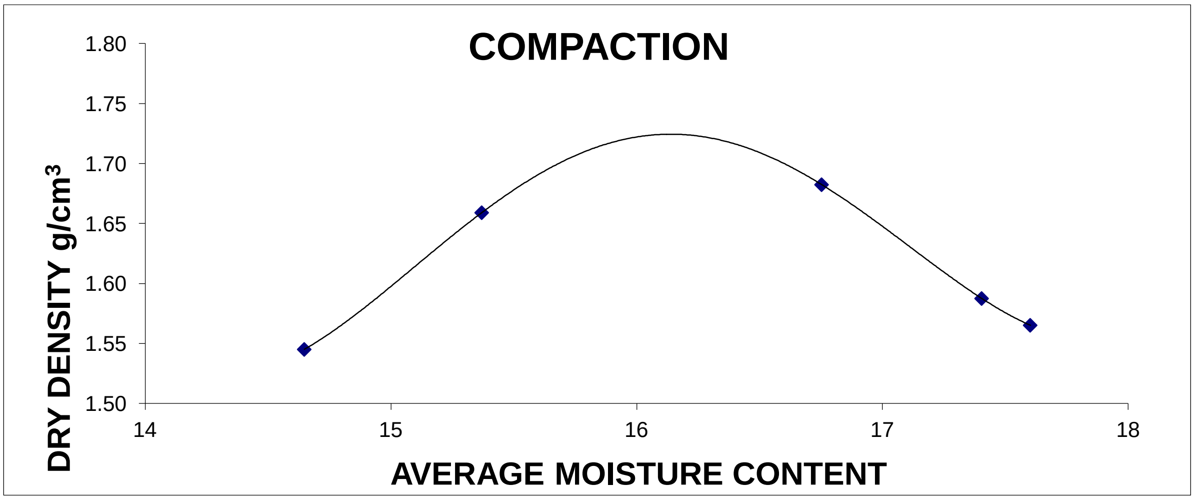

Fig. 9. Graph of average moisture content against dry density for sample 2

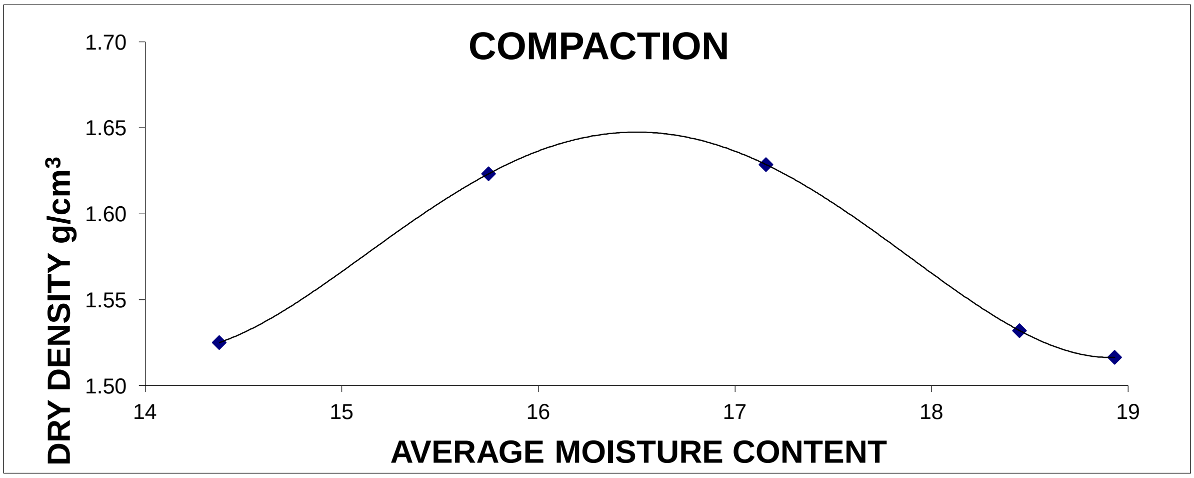

Fig. 10. Graph of average moisture content against dry density for sample 2

4.5 Shear Strength Determination

The triaxial tests results revealed that the soil contains both cohesive and cohesionless component.the values of cohesion (C) range from from 8.07 to 20.93kN/m². The degree of friction varied from 13.0 to 23.81 across the sampling points. 65Kpa Cohesion (C) and 26° angle of friction, has been classified as the average values that would offer resistance to surface run off [12]. It can be deduced therefore that the soils would offer little or no resistance to both surface water and ground water. Thus, could be the reason for gully development in the area [13,14].

5. CONCLUSION

From the results and analysis, it was observed that the soil sample comprised mainly of sands and more fines with low and high plasticity. According to AASHTO soil classification system, the soil can be classified as A-7-5 soil.

From the results and analysis, it was observed that the location comprised mainly of silty clay material. According to AASHTO and USSC soil classification systems, the soil was classed as A-7-5. This shows that the soil is predominantly silty clay to fines and with low plasticity.

In terms of strength, the allowable bearing capacity calculated using shear parameters obtained from laboratory Shear box tests and Triaxial compression test revealed that the soil does not possesses reasonable potential for an economic foundation.

Findings also revealed that the soils were poorly laterized and could offer minimal resistance to flowing water. Hence in conclusion, the gully in the University of Benin capitol is probably due to the poorly laterized nature of the soils and the low amount of the degree of friction of the soils.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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