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Geotechnical Characterization and Stabilization of Gully Erosion Soils at Auchi, Anambra Basin Southeastern Nigeria

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ABSTRACT

Gully erosion is a severe ecological concern in Auchi and its environs, which has led to destruction of lives and properties. Termite reworked soils have been observed to possess improved engineering properties and have over the years been used to improve soil properties. This research therefore seeks to mitigate the effects of the erosion by stabilizing the gully soils using termite-reworked soils of different genetically diverse origins. Soils from gully walls and beds from two gully erosion sites in the Auchi area and termite-reworked soils from different geological terrains were sampled. All the soils were analyzed for the determination of natural moisture content, grain size analyses, and Atterberg limits. The gully soil samples were thereafter compacted with termite-reworked soils at optimum blending ratio ranging between 27 to 50% by weight gotten through an arithmetic method by adopting grading limits for soil-aggregate mixtures. Shear strength parameters were determined on the compacted soils at OMC. The results revealed that the gully soil is non-plastic unconsolidated poorly graded sand with uniformity coefficient between (1.70-2.50), coefficient of curvature (0.77-1.15), natural moisture content between (4.00-9.00), while the termite reworked soils of both terrains are fairly graded inorganic soil of low to medium plasticity composed of kaolinite as the dominant clay mineral, indicating non-swelling and shrinkage potentials. Both termite-reworked soils are classified as lean clay soils, indicative of their suitable binding properties. The gully soils possess low maximum dry density showing the soils are unconsolidated and friable while the effect of the stabilization increases the MDD and reduces the OMC. Pre-stabilized gully soils have an average cohesion value of 15.5 KN/m^2 indicating a very loose soil while the SBT (Sedimentary base termitarium) stabilized gully soil and the BCT (Basement complex termitarium) stabilized gully soil have an average cohesion value of 51.3 KN/m^2 and 57.3 KN/m^2 indicating the presence of binding material. Conclusively, blending of gully soil with termite-reworked soils significantly enhanced the cohesion between the grain particles of the gully soils, improved its strength and can thus help prevent gully.

1. INTRODUCTION

Soil is perhaps the most important natural resource (possibly after water) on the planet because it provides a haven for the most valuable earth resources, allowing plants and animals to grow and develop. As a result, dangers to the soil endanger both human and animal life. One of the most dangerous threats to the environment is erosion. It is an obvious example of environmental degradation and damage. It occurs when surface water flow is caught in a small concentrated stream and begins to erode ground surface channels, widening and deepening them [1]. Soil erosion is stated to be a single significant process that is responsible for the loss of many soils around the world [2]. Noted that one kilometer of gully produces 10,000 cubic meters of sediments every square kilometer of land [3]. Therefore, if this happened to a 100-year-old gully, the average yearly rate of erosion will be 1.5 Tons per hectare each year. In addition, Jeje [4] calculated that 531,417.6 and 329,436.5 Tons of sediments were removed from gullies in Auchi and Ikpoba slopes, respectively, in Benin City.

The term "soil stabilization" refers to the process of changing the qualities of an existing soil by blending (mixing) two or more materials and improving particle size distribution, or by adding stabilizing additives to satisfy the engineering specifications required. As a result, mechanical and chemical stabilization can be distinguished. Many researchers have worked on mechanical soil stability, but few, if any, have focused on gully erosion prevention.

Sandy soils are non-cohesive and may lack the binding force required for effective compaction, making them very porous to moisture infiltration. The cohesiveness of soil is critical for its compactability and, as a result, densification, which improves its load behavior. Minke [5] adding clayey elements in powder form to improve the cohesion or binding force of such soils could be considered. Furthermore, despite prior efforts to stabilize earth materials, the focus has always been on improving the carrying capacity of foundation soils or altering construction materials, and the trial-and-error approach of stabilization is always used. Unfortunately, these procedures may not always have a fundamental basis and are time-consuming, necessitating the use of a different strategy.

This entails considering the aggregate's and binder's index qualities before stabilizing with the mathematical proportioning method.

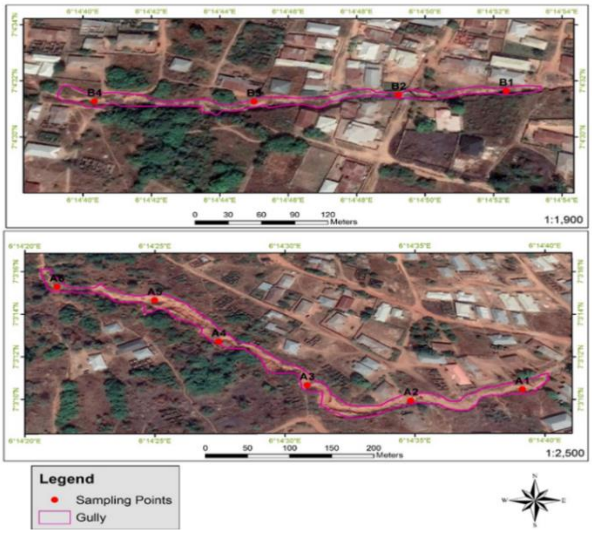

Figure 1. Satellite imager showing the gullies in 2020 (Source: Google Earth)

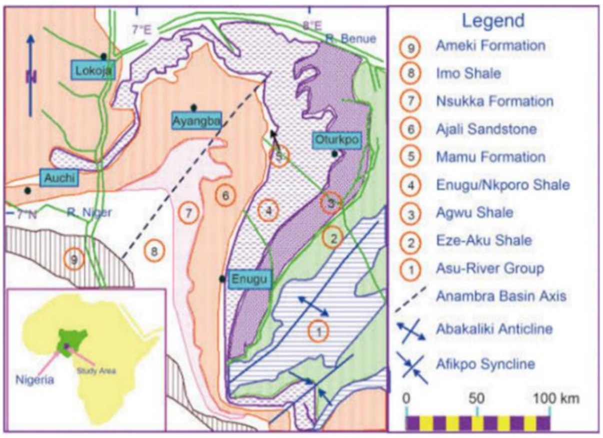

Figure 2. Geological map of Anambra Basin showing the study area (Nton and Bankole, 2013)

Gully erosion in human residential areas requires special attention due to the danger it poses to homes and other structures, essentially putting inhabitant's lives in jeopardy. The residents of Auchi have faced several dangers because of the gully (Figure 1 Shown the studied gullies within the residential area). It has caused the collapse of many residential buildings and worship centers, destruction of road networks and other infrastructure, as well as the degradation of land for commercial and agricultural purposes [6]. Auchi is underlain by Ajali sandstone, which is a quartz arenite and is part of Anambra Sedimentary basin (Figure 2), with quartz accounting for about 95% of the framework elements. As a result of the lack of cement support, the Ajali sandstone is exceedingly friable, with most grains being sub angular to angular, favoring high porosity and hence, enhancing gully erosion.

Because of the devastation caused by the gully, immediate assistance and provision of a long lasting solution is required. However, recent study on the soils has revealed that the principal reasons of the gully erosion are related to the hydrogeological and geotechnical qualities of the soils in the area. Several workers including [7-9], worked on the sandy soils in Southeastern Nigeria. Previous soil research works agrees that soil/gully erosion is more severe in areas of difficult terrain with friable sandy soils with low fines concentration and unconsolidated sandy bedrock. While these studies are valuable, they were however conducted to learn about the gully's origins. Not much, work in terms of characterization of the gully soils and the search for ways to improve and stabilize the soils. Therefore, this work is an attempt to improve and or stabilize gully soils by blending it with termite-reworked soils from genetically diverse origins, to reduce gully spread and the problems caused by its activities.

2. MATERIALS AND METHODS

Ten soil samples were obtained from two different gully locations in Auchi, Southeastern Nigeria (Figure 1), while six bulk samples of termites reworked soils from Basement Complex and Sedimentary terrains were also collected. The gully soil samples, as well as the gully floors and walls, were taken at regular intervals. Before the samples were obtained, the exposed surface of the gully and the termite soils were scraped off, and the samples were packed and labelled properly. Samples were subsequently air dried for 3 weeks. All the samples were subjected to index tests (moisture content, Atterberg limits and grain size analyses) prior to stabilization following the [10] standards test procedure.

For the gully soil samples, particle size analysis was done using dry sieving because it is mainly sandy while the reworked soil samples went through a mix of wet sieving and hydrometer methods, as well as dry sieving. After sample preparation and index tests on both samples prior to stabilization, the optimum blending limits for soil-aggregate mixtures specification [11] served as a guide (Table 1). The samples were blended, and design tests including compaction and shear strength test were conducted.

Table 1. Typical grading limits for soil-aggregate mixtures specifications (IRC: 63-1976)

Sieve Designation	Nominal Maximum Size Material % by Weight Passing the Sieve				
(IS: 460-1962)	80mm	40mm	20mm	10mm	5mm
80mm	100	-	-	-	-
40mm	80-100	100	-	-	-
20mm	60-80	80-100	100	-	-
10mm	45-65	55-80	80-100	100	-
4.75mm	30-50	40-60	50-75	80-100	100
2.36mm	-	30-50	35-60	50-80	80-100
1.18mm	-	-	-	40-65	50-80
600µm	10-30	15-30	15-35	-	30-60
300µm	-	-	-	40-40	20-45
75µm	5-15	5-15	5-15	10-25	10-25

2.1 Arithmetic proportioning method

The actual gradation of each gully soil samples and that of the termite-reworked soils from genetically diverse origins were considered in order to determine the optimum blending ratio. For each gully soil sample with the respective termite soil from Basement and Sedimentary terrains. Prior to the calculation, SBTL1 (Sedimentary Based termitarium, L1) and

BCTW1 (Basement complex termitarium, W1) were selected for the blending considering their index properties. Therefore, optimum blending ratio were determined for each gully soil samples (GSA1 – GSA6) and (GSB1 – GSB2) with SBTL1 and BCT W1 respectively as shown in Table 2. Eqns. (1) and (2) below were used to calculate the amount of gully soil and the respective termite reworked soil in the blend (Table 3).

$$\text{Percent of Gully soil} = \frac{\sum B}{\sum A + \sum B} \quad (1)$$

$$\text{Percent of Reworked soil} = \frac{\sum A}{\sum A + \sum B} \quad (2)$$

where, A=Respective Gully soil sample; B=Respective termite reworked soils; GSA=Gully soil samples at location A; GSB=Gully soil samples at location B.

2.2 Stabilization

The gully soil samples were stabilized at different calculated blending ratio ranging from 27% to 50% as shown in Table 3, with the two termite reworked soils (SBTL1 and BCTW1) differently and subjected to Compaction test using the modified AASTHO energy level and the shear strength test (undrained) at the optimum moisture content (OMC) as detailed in the study [10].

Table 2. Sample of Arithmetic method of proportioning soils to meet gradation requirements

		Percentage Passing							
Sieve Size	GSA1 A	SBTL1 B	Specs S	S^1	S^1-A	S^1-B	0.73A	0.27B	Blend
4	100.00	100.00	100.00	100.00	0.0	0.0	73.0	27.0	100.0
10	99.30	99.80	80.00-100.00	90.00	9.3	9.8	72.5	26.9	99.4
20	95.6	93.7	65.0-85.0	75.0	5.6	18.7	69.8	25.3	95.1
40	81.3	83.7	50.0-70.0	60.0	21.3	23.7	61.1	22.6	83.1
70	35.4	70.1	45.0-55.0	50.0	14.6	20.1	25.8	18.9	44.7
140	2.5	60.2	5.0-15.0	10.0	7.5	50.2	1.8	16.3	18.1
200	0.6	57.4	1.0-10.0	5.5	4.9	51.9	0.4	15.5	15.9
					∑A=63.2	∑B=174.4			

Table 3. Summary of the optimum blending ratio for each gully soil sample

Sample Name	GSA1	GSA2	GSA3	GSA4	GSA5	GSA6	GSB1	GSB2	GSB3	GSB4
BCTW1(%)	36.0	40.0	44.0	50.0	41.0	40.0	49.0	46.0	49.0	49.0
SBTL1(%)	27.0	34.0	37.0	42.0	46.0	43.0	43.0	42.0	43.0	44.0

3. RESULTS AND DISCUSSIONS

3.1 Field observations

The gully soils are dry reddish fine silty sand underlain by whitish fine sand, observed from a V-shaped cross-section of the gully (Figure 3). The fine silty sand thickness varies from gully to gully and it is assumed that the soil profile is loose and so erodible; this assertion is corroborated by the topography, as illustrated by the slope map (Figure 4).

Figure 3. The cross-section of the studied gully

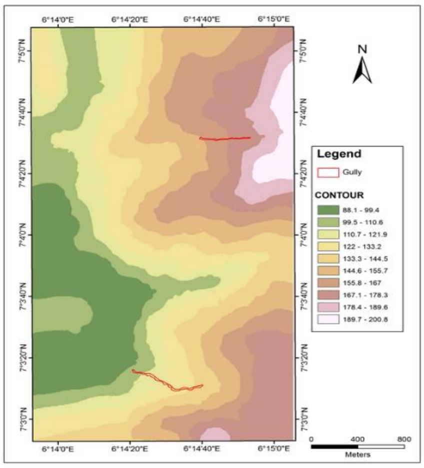

Figure 4. Slope map of the study area

However, the generated slope map reveal an increase in speed and volume of the overland flow, rate of particle detachment as well as transportation of soil particles as Auchi town is located in a rolling hill area and part of the town especially where gully erosion is more pronounced in areas with high steepness. This finding agrees with the findings of Igwe [12]. They found that gullies with steeper slopes have higher erodibility potentials than the flat ones. The depth of the gullies varies from 1.0 m to 22.0 m, with an average of 8.5 m, while the breadth of the gullies varies from 4.0 m to 25.0 m, with an average of 12.5 m. The main direction of these gully systems is E-W; this suggests that Auchi gullies are still in the preliminary stages of development as it is not totally conform to the drainage pattern of the area. Hence, the topography of the area, lack of well-connected drainage system, the nature of the Ajali Sandstone, high rainfall and human interferences contributed to the gully spread.

3.2 Preliminary classification tests

The specific gravity result of all the studied gully soil samples (Table 4) ranges from 2.58 and 2.66, with an average of 2.65 and termite reworked soil samples (Table 5) ranges from 2.62 and 2.66, with an average of 2.64. All the soil samples fall within (2.50 – 2.80) [13]. This confirms the fact that the soils occur within similar climatic environment and the slight difference in specific gravity can be linked to variation in texture of the parent rocks. Because of the narrow range of specific gravity, it is not particularly useful for this evaluation.

The grain size analyses result (Table 4, Figure 5) show that the gully soil samples are predominantly medium to fine grained sand, with an average of 97.69%. They are classified as poorly graded, non-plastic soils (SP) based on the unified soil classification system (USCS). Consequently, due to the low amount of fines (Figure 6), which would have cemented the sand particles; and thereby suggests high susceptibility of the soils to erosion. In addition, Coefficient of Uniformity (Cu) ranges from 1.70 and 2.50 while Coefficient of Curvature (Cc), ranges between 0.77 and 1.15 which are values associated with uniform soil that are poorly graded [14] and are therefore likely to erode easily. Furthermore, the gully soils are all poorly graded because their uniformity coefficient, Cu, are all less than five, the sieve analysis results combined with Cu and Cc results aided the classification of the soils as poorly graded sand. These materials are highly susceptible to gully erosion as opined by Obiefuna et al. [15] who concluded that high sand and low silty/clay content in the soil contribute to gully growth. The Basement and Sedimentary terrain termite-reworked soil samples on the average contain 46.40% sand-size grains, 34.45% silt-size grains, 19.16 clay-size grain and 42.30% sand-size grain, 13.68 silt-size grain, 44.03% clay-size grain respectively (Table 5), the termite reworked soils on the other hand are fairly graded (Figures 7 and 8) with no gravel size fractions. Generally, Sedimentary terrain termite reworked soil samples show a higher amount of clay size fraction and this may be as a result of higher degree of weathering and laterization process which may have affected its deposition, hence thy are classified as silty sandy clay based on the unified soil classification system (USCS). SBTS1 and SBTS2 contain more clay-size fraction than the surrounding soil. Hence, the grain size characteristics of derived soils are because of the parent materials [16, 17] and the degree and or extent of the external process that acted on it.

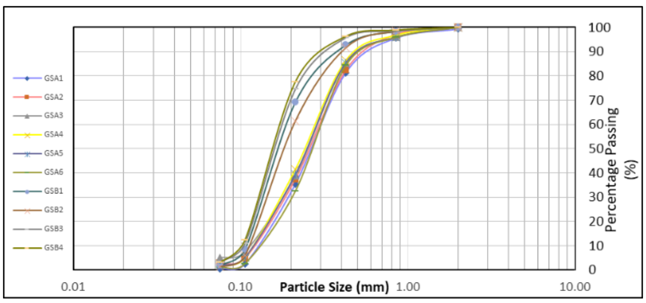

Figure 5. Gradation curves of the gully soils

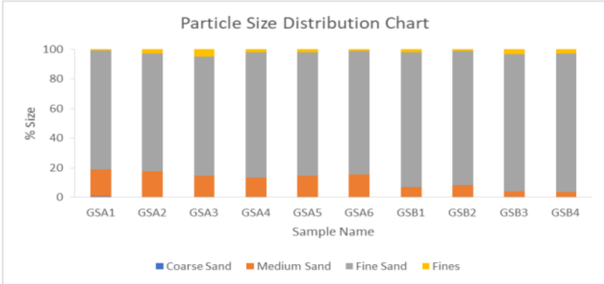

Figure 6. Visual representation of the particle size distribution of gully soil

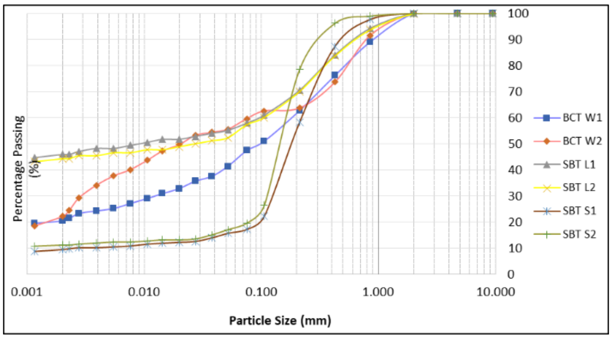

Figure 7. Gradation curves of the termite reworked soil samples

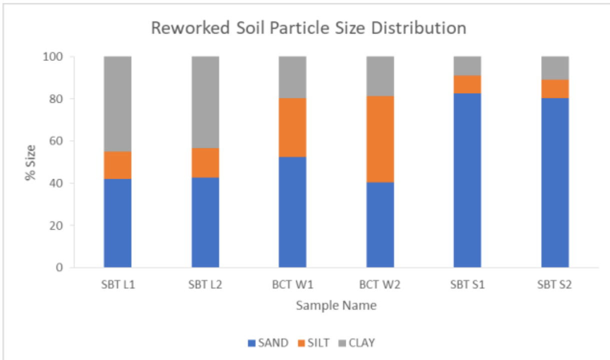

Figure 8. Visual representation of reworked soil particle size distribution

The uniformity coefficient of the soil was not determined because none of the grading curves crosses the D_{10} line. All the soil samples have a proportion of clay content and fines are more than 10% (Figure 9), except for the termite reworked soils within the vicinity of gully SBTS1 and SBTS2 which has amount of clay less than 10%, hence they cannot serve as a blend.

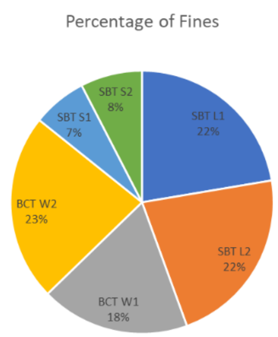

Figure 9. Visual representation of the percentage fines

Table 4. The result of the index tests of the gully soil samples

Sample Name	NMC	S_G	Grain Size Distribution (%) Coarse Sand	Medium Sand	Fine Sand	Fines	Soil Grading Cu	Cc
GSA 1	5.00	2.58	0.70	18.00	80.70	0.60	2.38	0.90
GSA 2	5.00	2.65	0.00	17.60	79.60	2.80	2.31	0.83
GSA 3	5.00	2.66	0.00	14.70	80.20	5.10	2.50	0.80
GSA 4	6.00	2.66	0.00	13.60	84.50	1.90	2.23	0.77
GSA 5	6.00	2.64	0.00	14.60	83.50	1.90	2.23	0.86
GSA 6	9.00	2.65	0.00	15.70	83.10	1.20	2.14	0.95
GSB 1	4.00	2.64	0.00	7.30	90.70	2.00	1.73	1.08
GSB 2	5.00	2.66	0.00	8.40	90.30	1.30	1.75	0.89
GSB 3	6.00	2.66	0.00	4.30	92.40	3.30	1.80	1.09
GSB 4	6.00	2.66	0.00	3.70	93.70	3.00	1.70	1.15

Cu: Uniformity Coefficient, Cc: Coefficient of Curvature. NMC: Natural Moisture Content. SG: Specific Gravity. GSA: Gully Soil A. GSB: Gully Soil B, SG: Specific Gravity

Table 5. The results of the index tests of the termite reworked soil samples

Sample Name	NMC	S_G	Sand (%)	Silt (%)	Clay (%)	USCS
BCTW1	17.00	2.65	52.50	27.88	19.62	CSS'
BCTW2	23.00	2.62	40.30	41.01	18.69	CSS
SBTL1	11.00	2.66	42.00	13.17	44.83	SSC
SBTL2	3.00	2.63	42.60	14.18	43.22	SSC
SBTS1	4.00	2.62	82.70	8.43	8.87	SCS
SBTS2	1.00	2.66	80.30	8.81	10.89	SCS

BCT: Basement Complex Termitarium. SBT: Sedimentary Base Termitarium. SCS: Silty Clayey Sand, SSC: Silty Sandy Clay. CSS: Clayey Sandy Silt, CSS': Clayey Silty Sand.

3.3 Consistency limits

Sample BCT W1 and 2, SBT L1 and 2 have a high plastic limit and liquid limit (Table 6 and Figure 10), though they all display intermediate plasticity (Figure 11). The large values of their plasticity index indicate that they are stable over or a wider range of moisture content compared to those of samples SBT S1 and S2 that are non-plastic. However, the trend of the consistency limits did not show a clear-cut difference between SBT and BCT (Figure 10). The shrinkage limit increases as the natural water content of the samples increases, which is a result of an increase in the clay content of the samples, therefore the entire examined reworked soil samples have low shrinkage potential. Except for BCTW2, the results show that the soil activity ranges from 0.36 to 1.20, indicating that kaolinite is the major clay mineral in the soils, also the same results were obtained using the inferred clay mineral classifications of Mitchell et al. [18, 19]. The reworked soils are safe to employ as a binder because Kaolinite has a limited swelling and shrinking capability, and they are inorganic clays of intermediate plasticity (Figure 11). Furthermore, the calculated value of the Skempton activity of the reworked soil implies that they are inactive to normal soil [20], except for BCTW2 (Table 6).

Table 6. Plasticity characteristics and inferred clay mineral in the reworked soils

Sample Name	LL (%)	PL (%)	PI (%)	LS	SA	ICM
BCTW1	32.70	16.00	16.70	7.90	0.85	Kaolinite
BCTW2	45.50	23.00	22.50	10.70	1.20	Illite
SBTL1	46.10	17.00	29.10	10.00	0.65	Kaolinite
SBTL2	34.60	19.00	15.60	4.30	0.36	Kaolinite
SBTS1	-	-	-	0.70	-	-
SBTS2	-	-	-	0.70	-	-

LL: Liquid Limit, PL: Plastic Limit, PI: Plasticity Index, LS: Linear Shrinkage, SA: Skempton Activity, ICM: Inferred Clay Mineral

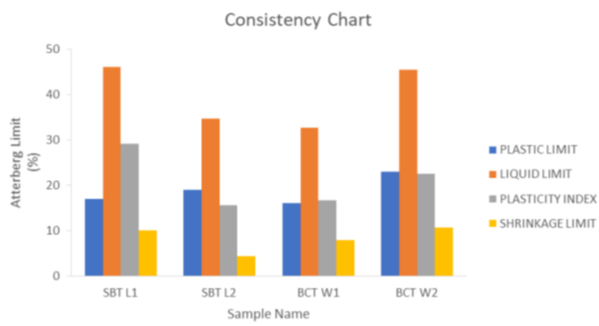

Figure 10. Visual representation of the reworked soils consistency limits

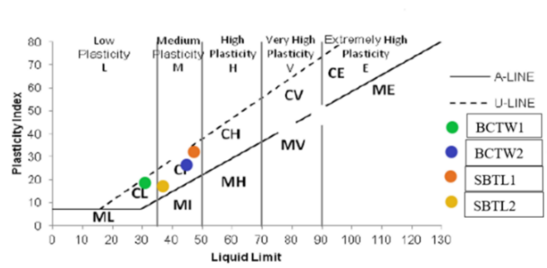

Figure 11. Casagrande plasticity chart for samples termite reworked soil samples

3.4 Compaction properties

Results of the optimum moisture content (OMC) and maximum dry density (MDD) of compacted stabilized and unstabilized gully soil samples (Figure 12-17). The compacted gully soil maximum dry density (MDD) ranges from 997 to 1113 kg/m^3 with a mean value of 1048.5 kg/m^3 and the optimum moisture content (OMC) ranges from 8.2 to 12.3% with a mean value of 10.6%. There is no consistent trend in the value of OMC and MDD of the unstabilized gully soil samples but there is a fair relationship between the amount of fine sand-size grain and the OMC values, (Figure 15). The OMC value increases with an increase in the amount of fine sand; this may be because of high size to volume ratio, which increases the adsorption capacity of the soil. The maximum dry density (MDD) for Sedimentary and Basement terrain reworked soils stabilized gully soil samples range from 1149 to 1217 kg/m^3 with a mean value of 1174.4 kg/m^3, and 1115 to 1240 kg/m^3 with a mean value of 1062.6 kg/m^3. The optimum moisture content (OMC) ranges from 6.6 to 10.7% with a mean value of 9.44%, and 8.5 to 10.6% with a mean value of 9.83% respectively. The highest MDD and the Lowest OMC was observed at 42% and 36% optimum blending ratio for Sedimentary terrain termite reworked soil and Basement terrain termite reworked soil respectively.

When compared to the unstabilized gully soil samples, the result demonstrated a considerable drop in the OMC (Figure 12), resulting in the greatest dry density obtained for all the stabilization levels studied (Figure 13). For each of the reworked soil components, the highest MDD occurred at the lowest OMC. In addition, the reworked soil increased the maximum dry density in variable percentages at all stabilization levels. Increased cohesiveness of the soil compaction was achieved with the addition of reworked soils with improved compactability of the gully soils. It was also discovered that the reworked soil flexibility affects the moisture-density behavior of stabilized samples, for example. This is consistent with the idea that soil compaction and density are influenced by moisture and clay content. In addition, the soil produces a grain-to-grain contact, lowering permeability and porosity, which is a sign of suitability for preventing gully growth because it would exhibit limited failures and erosion susceptibility.

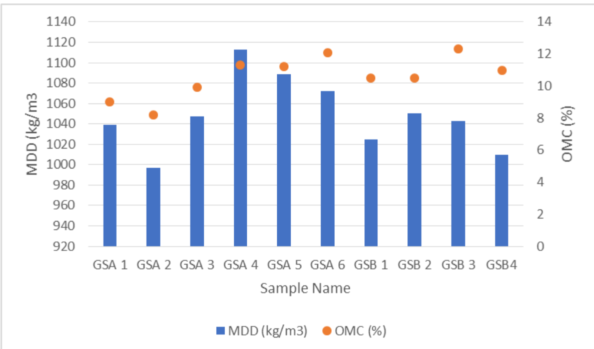

Figure 12. Compaction parameters obtained at modified AASHTO level prior to stabilization

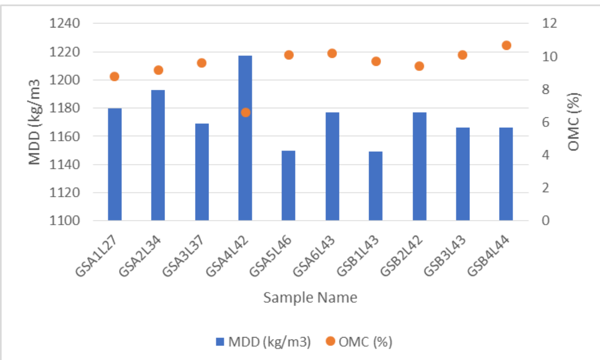

Figure 13. Compaction parameters obtained at modified AASHTO level after stabilized with sedimentary base termitarium

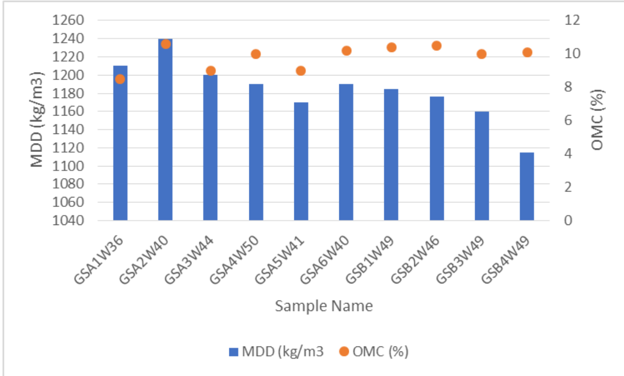

Figure 14. Compaction parameters obtained at modified AASHTO level after stabilized with basement complex Termitarium

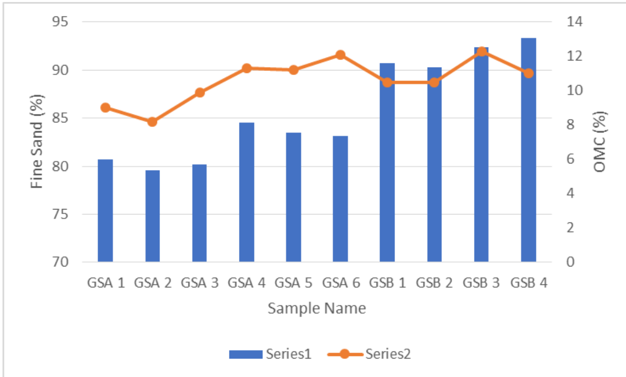

Figure 15. Relationship between fine sand grain and optimum moisture content of unstabilized gully soil

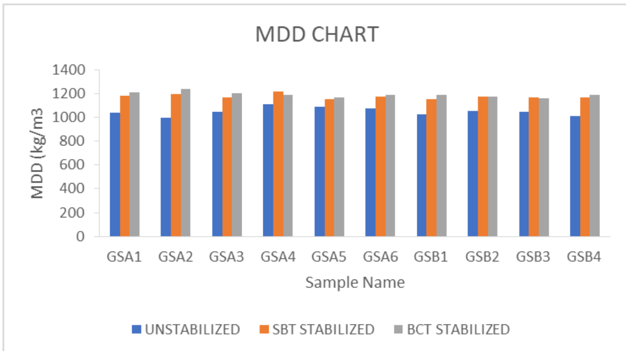

Figure 16. Variation in the maximum dry density

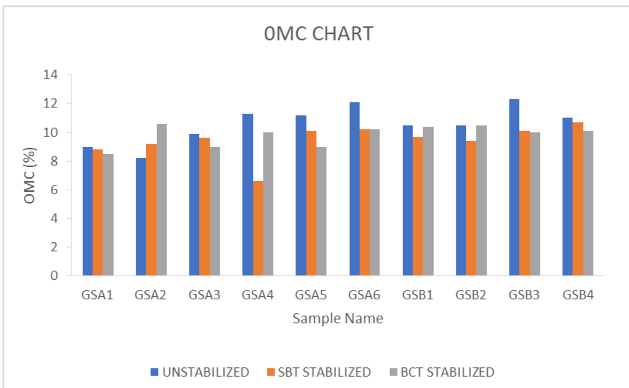

Figure 17. Variation in the optimum moisture content

3.5 Shear strength parameters

Table 7A shows the cohesion value obtained for the unstabilized gully samples varies from 0-32 KN/m^2 with a mean value of 15.5 KN/m^2 and the shear angle of internal friction ranges from 23˚ to 40˚ with an average value of 34.2˚. The shear strength enhances the initiation of gully erosion by encouraging overland flows. According to Surendra and Sajeev [21]. While the cohesion value obtained over the stabilized gully soil samples with sedimentary base termitarium varies from 29.3-65.2 KN/m^2 with an average value of 51.3 KN/m^2 (Table 7B). the shear angle of internal friction ranges from 19.3˚-39.4˚, with an average value of 30.7˚. The cohesion value obtained over the stabilized gully soil sample with basement complex reworked soil ranges from 43.5-79.0 KN/m^2 with an average value of 57.5 KN/m^2. The shear angle of the internal friction ranges from 18.4˚-35.5˚ with an average value of 62.7˚. The improved cohesion values are because of the addition of stabilizer which in-turn enhanced the cohesive force between the grain-grain boundaries, and this indicates very dense compaction [21]. Therefore, gully spread can be prevented.

More important in this discussion are the results of the regression analysis (Figure 18). The coefficient of correlation value (R^2) showed a positive relationship between cohesion and the stabilizer, with R^2 values of 0.922 and 0.5334 being obtained from the regression analyses between cohesion values and SBT and BCT percent stabilizers respectively for the gully soil samples. This implies that cohesion of the stabilized gully samples is more strongly improved across all the percentages of the stabilizers.

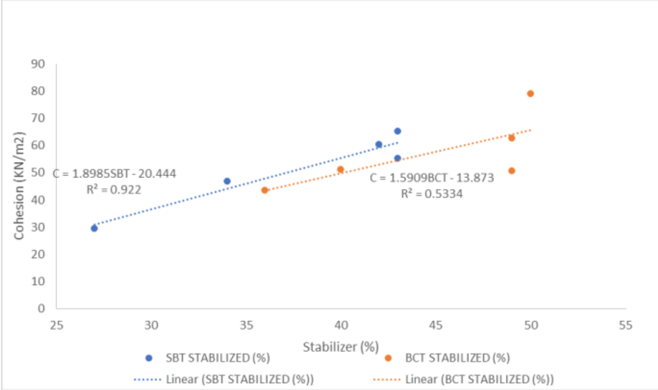

Figure 18. Correlation of percentage stabilizers and cohesion

Table 7. A & B. Shear strength parameters

A

	Unstabilized		
Sample Name	S (KN/m^2)	C (KN/m^2)	φ°
GSA1	17.84	10.00	33.00
GSA2	37.86	32.00	23.00
GSA4	21.65	0.00	40.00
GSB1	19.80	7.50	40.00
GSB3	48.03	28.00	35.00

B

	Stabilized with SBT				Stabilized with BCT		
Sample Name	S (KN/m^2)	C (KN/m^2)	φ°	Sample Name	S (KN/m^2)	C (KN/m^2)	φ°
GSA_1L_{27}	187.90	29.30	27.90	GSA_1W_{36}	459.10	43.50	35.60
GSA_2L_{34}	367.30	46.70	34.80	GSA_2W_{40}	373.30	51.10	34.20
GSA_4L_{42}	539.40	60.20	39.40	GSA_4W_{50}	488.50	79.00	34.20
GSB_1L_{43}	325.10	55.20	32.10	GSB_1W_{49}	242.50	62.70	25.40
GSB_3L_{43}	174.80	65.20	19.30	GSB_3W_{49}	138.20	50.70	18.40

4. CONCLUSIONS

According to the results of the geotechnical investigations, the selected study locations had all the characteristics of an erosion-prone environment, including steep slopes resulting in large runoff and low shear strength.

In the studied area, the underlying soil strata consist of cohesion less sand with a small number of fines, which would have cemented the sand particles, indicating a lack of binding elements and consequently a high vulnerability to erosion. As a result, termite reworked soils of genetically diverse origins are required for stabilization.

The properties studied revealed that termite reworked earth improved the gully soil's dry density, which improved the strength properties of stabilized soils. As a result, it could act as a stabilizing agent, with stabilizing amounts ranging from 27% to 50% by weight. Termite rebuilt earth enhances the gully soil's cohesiveness, which has an impact on its moisture density qualities, plasticity, and compactability. For all the stabilization levels tested, termite reworked earth stabilised samples showed a rise in the maximum dry density of stabilised samples, though the rate of the increment varied.

When compared to the initial unstabilized gully sand sample, the reworked earth elements reduced the optimum moisture content of the stabilized samples. It could reduce porosity and increase densification in granular soils. Finally, the two termites reworked earth components tested demonstrated good additive potential for the gully soil samples and can thus be used as stabilizing agents for the gully soil to prevent or reduce gully spread.

The qualities of both basement and sedimentary termitaria reworked soils are a function of the underlying geology of the area, according to the findings of this study.

REFERENCES

[1] Chikwelu, E.E., Ogbuagu, F.U. (2014). Geotechnical investigation of soil around Mbaukwu gully erosion sites, Southeastern part of Nigeria. IOSR Journal of Applied

Geology and Geophysics (IOSR-JAGG), 2: 6-17. https://doi.org/10.9790/0990-0240617
[2] Murck, B.W., Skinner, B.J., Porter, S.C. (1996). Environmental Geology. New York.
[3] Hughes, A.O., Prosser, I.P., Stevenson, J., Scott, A., Lu, H., Gallant, J., Moran, C.J. (2001). Gully erosion mapping for the national land and water resources audit. CSIRO Land and Water, Canberra, Technical Report, 26: 1-20.
[4] Jeje, L.K. (2005). Urbanization and accelerated erosion: The case of Effon-Alaye in Southwestern Nigeria. Seminar Paper, Department of Geography, Obafemi Awolowo University, Ile-Ife, Nigeria.
[5] Minke, G. (2000). Earth Construction Handbook: Advances in Architecture. Volume 10. WIT Press ISBN 185312-805-8.
[6] Dalil, M., Ilegieuno, A.A., Babangida, M.U., Husain, A. (2016). Assessment of the impacts of gully erosion on Auchi settlement, Southern Nigeria. Journal of Geography and Regional Planning, 9(7): 128-138, https://doi.org/10.5897/JGRP2016.0558
[7] Amagu, A.C., Eze, S.N., Jun-Ichi, K., Nweke, M.O. (2018). Geological and geotechnical evaluation of gully erosion at Nguza Edda, Afikpo Sub-basin, Southeastern Nigeria. Journal of Environment and Earth Science, 8(12): 148-158.
[8] Kayode-Ojo, N., Ikhide, A.O., Ehiorobo, J.O. (2019). Gully erosion problems in selected areas of Edo State: factors and control. Nigerian Journal of Environmental Sciences and Technology (NIJEST), 3(1): 161-173. https://doi.org/10.36263/nijest.2019.01.0104
[9] Ocheli, A., Ogbe, O.B., Aigbadon, G.O. (2021). Geology and geotechnical investigations of part of the Anambra Basin, Southeastern Nigeria: Implication for gully erosion hazards. Environmental Systems Research, 10(1): 1-16. https://doi.org/10.1186/s40068-021-00228-2
[10] British Standard Institution (BS) 1377. (1990). Methods for testing soils for civil engineering purposes. British Standard Institution, London, pp. 232.
[11] IRC: 63-1976. Tentative guidelines for grade aggregates and soil aggregate mixture in road pavement construction. Published by Indian Road Congress, Jamnagar House, and Shahjahan Road, New Delhi-110011.
[12] Igwe, O. (2016). Predisposing factors and the mechanisms of rainfall-induced slope movements in Ugwueme, South-East Nigeria. Bulletin of Engineering Geology and the Environment, 75(2): 623-636. https://doi.org/10.1007/s10064-015-0767-0
[13] Wright, P.H. (1986). Highway Engineering, Sixth Edition. John Willey and Sons: New York, NY.
[14] Das, B.M. (2006). Principles of Geotechnical Engineering. Fifth edition.
[15] Obiefuna, G.I., Nur, A., Baba, A.U., Bassey, N.E. (1999). Geological and geotechnical assessment of selected gully sites, Yola Area, North-East Nigeria. Journal of Environment Hydrology, 7: 11-12.
[16] Adeyemi, G.O. (1995). The influence of parent rock factor on some engineering index properties of three residual lateritic soils in southwestern Nigeria. Bulletin of the International Association of Engineering Geology-Bulletin de l'Association Internationale de Géologie de l'Ingénieur, 52(1): 3-8. https://doi.org/10.1007/BF02602677
[17] Oyediran, I.A., Adeyemi, O.G., Oguntuase, E.O. (2008). Influence of termite activities on the geotechnical properties of some lateritic soils in parts of akungbaakoko southwestern Nigeria. Ορυκτός Πλούτος, 2008(148): 17-24.
[18] Mitchell, J.K., Soga, K. (1993). Fundamentals of Soil Behavior (3rd Ed.). John Wiley and Sons, Inc.
[19] Bell, F.G. (2007). Engineering Geology 2nd Edition, Butterworth-Heinemann Publishers, Oxford, pp. 581.
[20] Skempton, A. (1953). The colloidal activity of clays. Proceedings, 3rd International Conference on Soil Mechanics and Foundation Engineering, Zurich, pp. 57-61.
[21] Surendra, R., Sajeev, K.B. (2017). Roles of geotechnical properties of soils on civil engineering structures. Resources and Environment, 7(4): 103-109. https://doi.org/10.5923/j.re.20170704.03