Geotechnical Assessment of Umuezealaibe, Isu-Njaba Gully Erosion Site in Isu Local Government Area, Imo State of Nigeria

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Abstract
The geotechnical assessment of the Umuezealaibe, Isu-Njaba gully erosion site represents a comprehensive investigation into the factors contributing to the instability of this critical geological feature. Through a combination of rigorous field surveys, extensive laboratory analyses, and advanced stability assessments, this study aimed to unravel the underlying causes of the erosion phenomenon. Representative soil samples were collected using soil auger and subjected to a battery of tests, including index property analyses, sieve analyses for grain size distribution, and shear strength tests. The result of the study revealed the following: topography of the land shows a high sloppiness which makes it highly susceptible to erosion, predominantly that of weak clay and loose sandy clays, specific gravity of the collected samples ranges from 2.59 to 2.68, averaging at 2.65. The soil exhibited average natural moisture content and bulk unit weight, measuring 15.0% and 1.93 mg/m^3, respectively. Furthermore, the average plastic limit and plasticity index for the identified gully system stood at 19.0% and 14.2%, respectively. These tests provided crucial data for designing effective rehabilitation measures. The results of the laboratory analyses indicated that the soil in the study area is characterized by medium-plasticity, low shear strength, and a unique composition classified as silty sand within the Unified Soil Classification System (USCS). Furthermore, geotechnical software, Slide was employed to conduct stability analyses, pinpointing critical areas susceptible to instability. Multiple methods were applied, including Bishop's method and Janbu's method, to determine the most suitable factor of safety and predict potential failure modes. The result of the slope stability analysis gave a factor 0.757 and 0.916 for left hand side (LHS) and right hand side (RHS) respectively on the most critical slope identified from field survey cross-sectional data. These factors of safety were determined and compared to a reference value of 1.5, which indicates instability. In conclusion, the geotechnical assessment underscores the urgency of addressing the gully erosion site's instability to ensure the safety of both the surrounding environment and human infrastructure. The findings highlight the need for immediate measures to mitigate further degradation and potential disasters. Recommendations encompass a holistic approach, integrating agronomic and engineering practices, such as afforestation, drainage systems, and the use of geosynthetic materials, to promote long-term stability and environmental preservation. Additionally, continuous monitoring and community awareness initiatives are imperative for sustained erosion control and hazard mitigation.

Keywords: *Gully erosion, Geotechnical, Exogenic, Endogenic and Erodibility.*

1. INTRODUCTION

It is important to note that the removal of top soil has caused several environmental degradations. Simply put, environmental degradation is a decline in the quality of our environment. This can be a result of pollutants that spoil the air, water or food supply, the over-extraction of resources so that little remains for future use, or the destruction of habitats so that the resources they once contained are no longer available.

Erosion is one of the major environmental degradations affecting life this is because it leads to loss of soil nutrients needed for plant growth, hence the term soil erosion. Soil erosion can be described as the detachment, transportation and deposition of soil particles from one place to another under the influence of wind, water or gravitational force. The main factors influencing soil erosion include precipitation, wind, landscape relief, soil properties, vegetation cover and human activity (Tsue *et al*., 2014).

Soil erosion is a serious environmental, economic and social problem; it causes not only land degradation and soil productivity loss, but it also threatens the stability and health of society and sustainable development of rural areas (Jing *et al.*, 2005). Thus, timely and accurate estimation of soil erosion with respect to geotechnical properties of soil has become imperative for many developing countries. On the other hand, gully erosion is an advanced stage of rill erosion. Soil erosion grows from surface erosion to rill erosion then to gully erosion. As a matter of fact, preventing formation of gully is much easier than controlling them once it has formed (Nwankwoala and Igbokwe, 2019).

It becomes pertinent to note that if incipient gullies are not stabilized they tend to become longer, larger and deeper. Nwankwoala and Igbokwe (2020) stated that under certain climatic and geologic, vertical gully banks can easily become as high as 20-30m or above, this type of gully can engulf hill side farming areas, grass lands and even forest land.

The formation of gullies is usually influenced by increase in surface runoff which acts as cutting agent of the soil. The very great depth of these gullies and the failure of control almost all control measures suggest that they may result as interplay of exogenic and endogenic forces. Erosivity and erodibility are factors that contribute to soil erosion and formation of gullies. Erosivity is determined by the rainfall, a natural phenomenon which is not under human control. It is important to note that rainfall intensities can usually be high in Southeast Nigeria. On the other hand, erodibility depends on soil practice, topography and land management. Rainfall seasonality and fragile soils makes an area vulnerable to induced erosion posing threat to the watershed. A significant change in land use can increase the rate at which the soil eroded. Due the nature of the erosion process, erosion control requires a quantifiable and qualitative evaluation of potential soil erosion on a specific site. The potential risks differ spatially because of heterogenous topography, geology, soil types, land cover and land use. Therefore, gully erosion problems have become a subject of discussion among soil scientists, geographers, geologists, engineers and social scientists. Ofomata (1970) indicated that gully erosion types are the most visible forms of erosion in Nigeria mainly because of the remarkable impression they leave on the surface of the earth. Again, Ofomata (1970) remarked that more than 1.6% of the entire land area of eastern Nigeria is occupied by gullies. This is very significant for an area that has the highest population density 500 persons per km^2 in Nigeria. Before the 1980's the classical gully sites in the southeast region were the Agulu, Nanka, Ozuitem, Oko in Aguata area, Isuikwuato and Orlu. With the increased development activities, the number and magnitude escalated thus making many government administrations within the region to set up soil erosion control with different names in different states (Ofomata, 1970). In summary Erosion gullies from high rainfall intensity, wind action, slope instability, poor engineering and agricultural practices and other exogenic processes are common features both in the sedimentary formations and the basement areas of Nigeria (Onu & Opara, 2012). One thing common to the known erosion sites in the country is that most of them begin as rills along slopes and develop gradually with time into gullies. The most active forms of erosions are generally found along slopes which represent the flanks of paleo-depressions resulting from endogenic processes. Most of the time the erosions get accelerated through human and other cultural activities which appear to interfere negatively with natural processes and degrade landforms (Onu & Opara, 2012).

The spread of gully is therefore seen as a cancer affecting many communal grazing spots, foot paths, cattle trafficking lines, roads, etc. Gully erosion prevents field operations and movement in Isu-Njaba local government area of Imo State. The subsoil and gravel mined by erosion is a major threat on lower lying fertile agricultural fields by burying them under. It is important to note that a lot of farmers in Isu-Njaba are currently affected by gully erosion and complaining that their lands have been taken away by the debris which they couldn't remove. Also, in Isu-Njaba many low-lying areas and public infrastructure facilities have been overburdened and overlaid by subsoil which is not fertile. The subsoil which is noted to be composed of sand, gravel, cobbles and boulders. Although there are many ongoing efforts being executed by the government in an attempt to curb the gully erosion menace at Isu-Njaba and enhance land use but the extent at which the gully is expanding has not been adequately reduced by the existing level of treatment. Lastly the unresolved problem of gully erosion and the application of in adequate measures to tackling gully erosion gave rise to this study "Geotechnical Assessment of Isu-Njaba, Imo State Gully Erosion Site". Therefore, in this study, an attempt would be made to employ applicable laboratory tests to evaluate geotechnical properties of the soil within the gully site. The assessment mainly intends to provide insight on the geotechnical parameters that contribute immensely to gully development in that area. This knowledge would be useful in controlling gully erosion and landslides in the area.

2. STUDY AREA

The study area is the gully erosion site at Umuezealaibe, Isu-Njaba in Isu L.G.A, Imo State within the UTM WGS84 coordinate system 628120.0^{0}N and 310855.0^{0}E. The community is an ancient community with rich human and natural endowment. The community has large population with large hectares of farm lands of which major of the dwellers are farmers with yield agricultural products such as cassava, yam, cocoyam, palm produce as well as other food/cash crops. The area has the characteristic features of the humid tropical wet and dry climate governed primarily by the rainfall.

The area has the characteristic features of the humid tropical wet and dry climate governed primarily by the rainfall. There are two distinct seasons, rainy season which begins from March to October and the dry season which begins in November and terminates in February. The mean annual rainfall of the area is about 2, 270mm. The region is rural consisting mainly of farmlands and few built-up areas.

The topography of Umuezealaibe, Isu-Njaba gully erosion site in Isu L.G.A according to an in-depth site appraisal and spot height acquisition is a steep slope. From the slope analysis and the 3D wire frame analysis, the orientation of the site is steep towards the westward end. The slope ends in a wide valley dominated by a local river flow (Njaba River).

The land use of the study area is focused on mixed-use development, with a mix of residential, vegetation and water body. From the land use map thus generated, the project area consists basically of few built up areas as well as vegetative areas (farm lands).

The geology of the study area is composed of Benin formation, which is comprised of loose lateritic material under a superficial layer of fine-grained sand. The geologic formation is consists completely of alluvial sediments, mainly sand. The region falls into the Niger Delta sedimentation cycle, more specifically into the Benin Formation which is a shallow massive sand sequence that is characterized by high sand percentage (70 – 100%) and forms the top layer of Niger Delta depositional sequence. This formation, which is of late tertiary age, is rather deep, porous, infertile and highly leached. The soil consists

The geotechnical investigation methodology of the study area involves a comprehensive study and analysis of the soil. This section provides an in-depth analysis of the methodologies used to conduct the geotechnical testing to determine the physical properties of the soil at the gully erosion site. The various testing procedures and the apparatus used to carry out the tests are covered here.

To determine the properties of the soil of the gully areas, representative samples were collected for laboratory analysis. All laboratory investigations and analyses were carried out in accordance with the British Standards (BS) 1377.

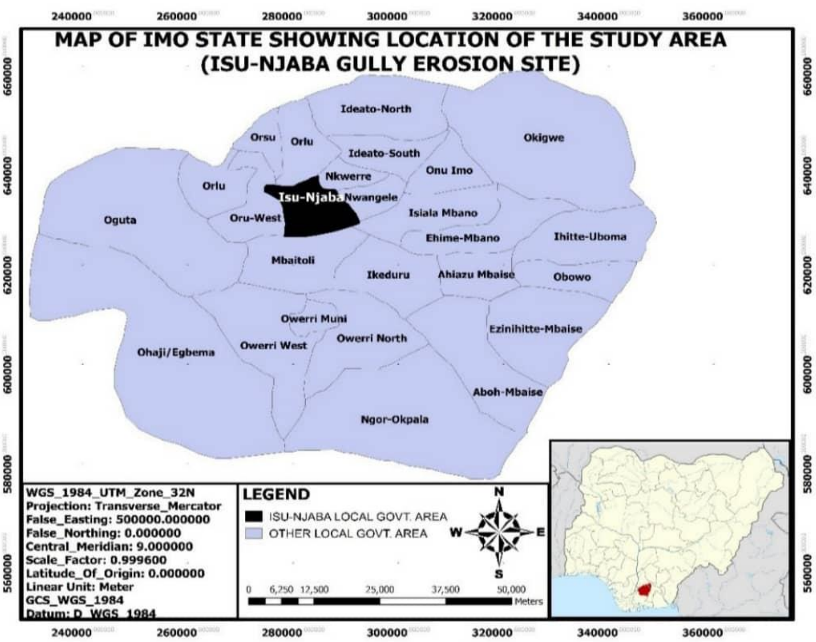

Figure 1: Map of Imo State showing Isu-Njaba, the LGA of study area.

3. METHODOLOGY

Data Collection

Five undisturbed soil samples were collected using auger for geotechnical investigations on 31st May, 2023. Each of the soil sample collected was observed in hand specimen and later stored in separate polythene bags and labelled accordingly (P1 – P5) for easy identification and to conserve the moisture contents. The samples were taken to Soil laboratory of Federal University of Technology, Owerri and the geotechnical analysis were carried out to determine the index and engineering properties of the soils within the project area of interest. Table 1 shows the coordinates, and elevation of the sampling points respectively for the gullies while Figure 2 is satellite imagery showing the locations of the sampling points for both gullies.

Table 1: Gully Point Sampling Locations

Sampling Points	Easting	Northing	Elevation (m)
P1	285329	633270	162.0
P2	285684	633448	102.9
P3	285729	633527	105.4
P4	285207	633597	103.0
P5	285443	633481	117.0

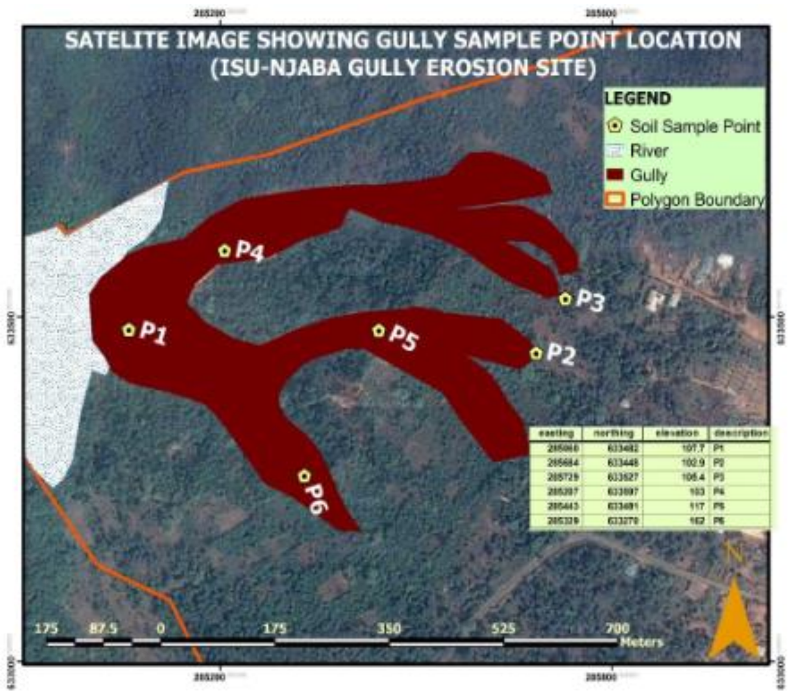

Figure 2: Satellite imagery of gully sampling point location

Laboratory Testing
Different tests were carried out to assess the geotechnical properties of Umuezealaibe, Isu-Njaba gully erosion site in Isu L.G.A. These tests include:

Grain Size Distribution Analysis
This experiment was used to determine the grading of the geological materials in the soil and identification of the clay mineralogy and relative proportions of different sizes of particles. Wet sieving method was used.

Apparatus:

i. British standard test sieve: 2.0 mm, 1.18 mm, 0.85mm, 0.60 mm, 0.425 mm, 0.30mm, 0.15mm, 0.075mm and pan.
ii. Sieve brushes
iii. A metal glass tray

Procedures:
A 60.0g sample was obtained and immersed in an evaporating dish containing some quantity of water and a dispersing agent (Sodium hexametaphosphate); for dispersing clay and other soil types. The content was left for 24 hours to soften the clay particles. Washing was done to ensure complete separation of fines. Clay fines were washed off with more water. This process continued until sample left was free from fines. The free fine material inside the evaporating dish was carefully placed inside a container and put in an oven to dry at temperature of 105^{o}C -110^{o}C overnight. The sample was brought out of the oven; and the dry soil was passed through a nest of the complete range of sieves to cover the sizes of particles present down to the 0.075mm. This operation was carried out by a mechanical sieve shaker.

Criteria for Grading Soils

The following criteria are in accordance with the unified soil classification system: For a gravel to be classified as well graded, the following criteria must be met:

$\mathrm{Cu} > 4 \ \& \ 1 < Cc < 3$

If both of these criteria are not met, the gravel is classified as poorly graded or GP, If both of these criteria are met, the gravel is classified as well graded GW.

For a sand to be classified as well graded, the following criteria must be met:

$\mathrm{Cu} \geq 6 \ \& \ 1 < Cc < 3$

If both of these criteria are not met, the sand is classified as poorly graded or SP but if both of these criteria are met, the sand is classified as well graded or SW.

Atterberg Limits
Atterberg limits are basic measure of the critical water contents of a fine – grained soil such as its shrinkage limit, plastic limit and liquid limit. Shrinkage limit is the water content where further loss of moisture will not result in any more volume reduction. Shrinkage limit is much less commonly used than the liquid and plastic limit. The test to determine shrinkage limit is

ASTM international D4943. Plastic limit (PL) is moisture content at which the soil is non plastic, is determined by rolling out a thread of the fine portion of a soil on a flat, non-porous surface.

Determination of Liquid Limit (LL)

Liquid limit (LL) is the water content at which the behavior of a clayey soil changes from plastic to liquid. However, the transition from plastic to liquid behavior is gradual over a range of water contents, and the shear strength of the soil is not actually zero at the liquid limit. The precise definition of the liquid limit is based on standard test procedures described below.

Apparatus:

Moisture content container, Oven (100^0C-105^0C), Cassagrande grooving tool, Distilled water, Spatula for soil mixing, #40 sieve, Plastic squeeze bottle (for dispensing minute quantities of water, Weighing balance, Glass plate.

Procedures:

A sample of about 250g of soil passing the #40 sieve was used the soil sample was placed on a glass plate and mixed with distilled water using spatula. The paste was place into an airtight container and sealed with adhesive tape. The paste was left for 24hrs on a dry surface to allow water permeate through the soil mass. The paste was removed from the container after maturing. Then, the soil was remixed with spatula for about 10mins; the paste was pressed against the side of the cup of cassagrande device, to avoid trapping air.

A groove was cut through the sample using grooving tool. Below were applied to the paste by turning the crank handle of the machine at a steady rate of two revolutions per second; so that blows required closing the groove was noted. The process was repeated on the paste at three different moisture contents respectively and the corresponding number of blows noted. The moisture content of the paste in each case was also determined using standard methods.

Determination of Plastic Limit (PL)

A quantity of the soil paste (after remixing above) was placed in the glass plate; the paste was kneaded and then shaped into a ball. The ball was moulded between the fingers and rolled between the palms of the hands so that the warmth of the hand slowing dries it. When slight cracks appeared on the surface, the balls were divided and rolled further, until each approach a diameter of about 3mm, the moisture content of the balls were determined. The average moisture content of the balls were computed and recorded as plastic limit (PL).

Moisture Content, Bulk and Dry Unit Weight Determination

Moisture contents of the soil samples were determined using the drying method. It is the ratio of the weight of water present to the weight of dry soil in a given soil mass. This test covers the determination of MC of soil as a % of its dry unit weight.

Apparatus:

Moisture content container, Electric oven (Temperature 105^0C - 110^0C) and Weighing balance.

Procedures:

The moisture container was washed with clean water, dried and weight recorded as W1. The weighing balance was adjusted and cleaned and different soil specimen was taken each from the samples, placed in the container, weighed and their respective weighs recorded as W2. The moisture content container and its contents were oven dried. Respective weighs of container + dry soil sample taken after 24hrs were recorded as W3. The results obtained are presented in the Table 2 and 3 below.

Table 2: Natural Moisture Content

ContainerNumber	PT1	PT2	PT3	PT4	PT5
Weight of wetsoil + can (g) (M_2)	35.6	32.66	34.72	35.15	33.22
Weight of dry soil + can (g)(M_3)	33.46	30.46	32.18	32.58	30.49
Weight of can (g)(M_1)	17.23	15.27	16.15	16.22	15.38
Weight of dry soil (g)$(M_3 - M_1)$	16.23	15.19	16.03	16.36	15.11
Weight of water (g)$(M_2 - M_3)$	2.14	2.2	2.54	2.57	2.73
Water content, $w = \frac{(M_2 - M_3)}{(M_3 - M_1)} \times 100\ \%$	13.19	14.48	15.85	15.71	18.07

Table 3: Bulk and Dry Unit Weight (γ_b and γ_d)

Container Number	PT1	PT2	PT3	PT4	PT5
Weight of Cutter + sample (g) (W_2)4	295.14	301.13	299.15	297.15	301
Weight of Cutter (g) (W_1)	107.14	108.15	107.34	108.12	109.21
Weight of sample (g) $(W_2 - W_1)$	188	192.98	191.81	189.03	191.79
Volume of sample, V (m^3)	98.20	98.20	98.20	98.20	98.20
Bulk unit weight, $\gamma_b = \frac{(W_2 - W_1)}{V}\ (mg/m^3)$	**1.91**	**1.97**	**1.95**	**1.92**	**1.95**
Dry unit weight, $\gamma_d = \frac{\gamma}{1 + \frac{w}{100}} \times 10\ (kN/m^3)$	**16.91**	**17.17**	**16.86**	**16.64**	**16.54**

CALCULATION: % Moisture Content

$$W(\%) = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

Where, W1 - Weight of container (g), W2 - Weight of container + Wet soil (g)

W3 - Weight of container - dry soil (g), W - Moisture content in %.

Shear Strength Test

This determines the shearing strength of the soil sample in order to determine the relative effect of movement due to load that will be imposed on the soil. It aids in the determination of cohesion and angle of internal friction of the material.

Apparatus:

Direct shear machine, Vernier calipers, Timer (stop watch), Small level.

Procedures:

Soil samples were carefully hemmed to the size of the shear box ring; the dimensions of the sample (length, width and height) were measured with venier calipers. The sample was placed in the cell of the shear box and a load was hung on it. The machine was adjusted properly and readings were taken from the dial gauge at intervals of 30secs; this reading was taken until the sample fails; the process was repeated twice with heavier loads.

From the data generated, the normal stress and the shear stress against normal stress was plotted on a graph sheet; a line of best fit was drawn from the plots. The intercept of the line on the ordinate and the angle it makes with the abscissa (slope) were determined. The intercept represents the cohesion (c) while the slope represents the angle of internal friction (φ).

Data Analysis Techniques

The results of the geotechnical analysis were analyzed using conventional statistical tools. Statistical analysis can be used to identify patterns and relation between the data, to determine the degree of significance of the findings, and to support the development of recommendations for remediation and prevention of gully erosion in the study area.

The descriptive statistics such as mean was used to analyze the results of the geotechnical analysis and were carried by using Microsoft Office Excel 2010.

4. RESULT PRESENTATION AND DISCUSSION

Index and Engineering Properties of Explored Soil Samples

Index and engineering properties of explored soil samples provide crucial insights for construction and geotechnical projects. These properties include moisture content, density, grain size distribution, plasticity, and shear strength. Understanding these factors aids in designing stable foundations, slope stability analysis, and efficient earthwork planning, ensuring project success and safety. The summary results of laboratory tests for the index and engineering properties of gully samples investigated are respectively presented in Tables 4 and 5.

Based on the findings in Figures 3 and 4, the global minimum factor of safety was determined and compared to a reference value of 1.5. The gully slopes on both the left-hand side (LHS) and right-hand side (RHS), analyzed for the specific chainage, exhibited instability. This evaluation focused on the most critical slope identified from field survey cross-sectional data, using parameter values derived from disturbed samples.

In technical terms, the current gully slopes lack stability, rendering them unsuitable for supporting structures that could lead to eventual failure under structural loading. Moreover, the risk of failure could arise from continuous sheet flow causing undercutting or incremental rainfall-induced triggers. To ensure the sustained durability of the gully slopes from a design perspective, it is recommended to implement an appropriate design slope.

Gully Samples Results

Table 4 below presents the outcomes of soil index property analysis. The specific gravity of the collected samples ranged from 2.59 to 2.68, averaging at 2.65. The soil exhibited average natural moisture content and bulk unit weight, measuring 15.0% and 1.93mg/m^3, respectively. Furthermore, the average plastic limit and plasticity index for the identified gully system stood at 19.0% and 14.2%, respectively.

Referencing Table 5 which summarizes the engineering characteristics of gully samples, the average dry unit weight of the sampled soils spanned from 16.62kN/m^3 to 17.17kN/m^3. Cohesion averaged at 5.9kN/m^2, while the internal angle of friction ranged between 24.2° and 26.6°, with an average of 25.0°. The soil exhibited an average shear strength of 88.53kN/m^2. Allowable bearing capacities fell within the range of 243.63kN/m^2 to 270.06kN/m^2, with an average of 255.82kN/m^2. Additionally, the soil displayed an average effective diameter D_{50} of 0.32 mm.

Based on the Unified Soil Classification System (USCS), the soil qualifies as silty sand, constituting a slightly plastic silty mixture belonging to the SM group.

Table 4: Summary Result of the Index Properties of Gully Samples

Points	Sampling Depth (m)	Specific gravity, G_S	Natural moisture content (%)	Atterberg Limit			γ_b(mg /m^3)	D_{50} (mm)	USCS
				LL (%)	PL (%)	PI (%)			
P1	3.5	2.65	13.19	35.00	19.80	15.20	1.91	0.35	SM
P2	2.0	2.59	14.48	29.00	17.80	11.20	1.97	0.25	SM
P3	4.0	2.63	15.85	33.00	22.40	10.60	1.95	0.28	SM
P4	3.1	2.68	15.71	33.00	16.10	16.90	1.92	0.25	SM
P5	2.4	2.68	15.67	36.00	18.90	17.10	1.92	0.45	SM
Average		**2.65**	**15.0**	**33.2**	**19.0**	**14.2**	**1.93**	**0.32**	SM

LL – Liquid Limit; PL – Plastic Limit; PI – Plasticity Index; γ_b– Bulk unit weight; NP – Non-plastic
Source: Researchers' Fieldwork, 2023

Table 5: Summary Result of the Engineering Properties of Gully Samples

Points	Sampling Depth (m)	Compaction		l_d	y_d (kN/m^3)	Angle of internal friction ø (°)	Cohesion, C (kN/m^2)	Shear Strength, $\tau(kN/m^2)$	Bearing capacity	
		Optimum Moisture Content (%)	Max. dry density, MDD (kN/m^2)						Q_{ult}	Q_a
P1	3.5	17.48	1.92	1.72	16.91	24.2	7.8	87.18	749.74	249.91
P2	2.0	19.05	1.73	1.65	17.17	24.4	8.7	89.21	810.18	270.06
P3	4.0	18.31	1.90	1.72	16.86	25.4	4.9	88.96	749.4	249.80
P4	3.1	17.82	1.81	1.67	16.64	25.0	7.52	90.43	797.16	265.72
P5	2.4	17.69	1.76	1.65	16.62	26.6	0.58	86.86	730.89	243.63
Average		**18.07**	**1.82**	**1.68**	**16.84**	**25.0**	**5.90**	**88.53**	**767.47**	**255.82**

Source: Researchers' Fieldwork, 2023

Slope Stability

Slope stability is crucial in preventing disastrous landslides and erosion. It involves assessing the balance between gravitational forces and the strength of soils or rocks in a slope. Factors like water infiltration, geological conditions, and human activities impact stability. Proper analysis and engineering solutions ensure safe construction and environmental preservation.

From the site survey it was noted that the site terrain is generally unstable. This was necessitated primarily due to soil movement, resulting in both landslides and the formation of gullies. This instability is most apparent on the gully slopes, which typically exhibit inclinations ranging from 65° to 90° and are marked by hairline cracks on the walls.

To validate these observations from fieldwork, a stability analysis of the existing gully slopes was conducted using Slide 6.0 software. This analysis encompassed both the left-hand side (LHS) and right-hand side (RHS) of the gully. The software employed three distinct methods: the Ordinary/Fellenius (Swedish slice) method, Bishop's simplified method, and Janbu simplified method. These methods were compared to select the most appropriate factor of safety in alignment with engineering standards and practices.

Figures 3 and 4, show the detailed stability analysis for existing main gully slope at CH1+275 using average values of: cohesion, C = 5.9kPa, unit weight, γ = 16.79kN/m^3 and angle of internal friction, ∅ = 24.96°, obtained from laboratory analysis.

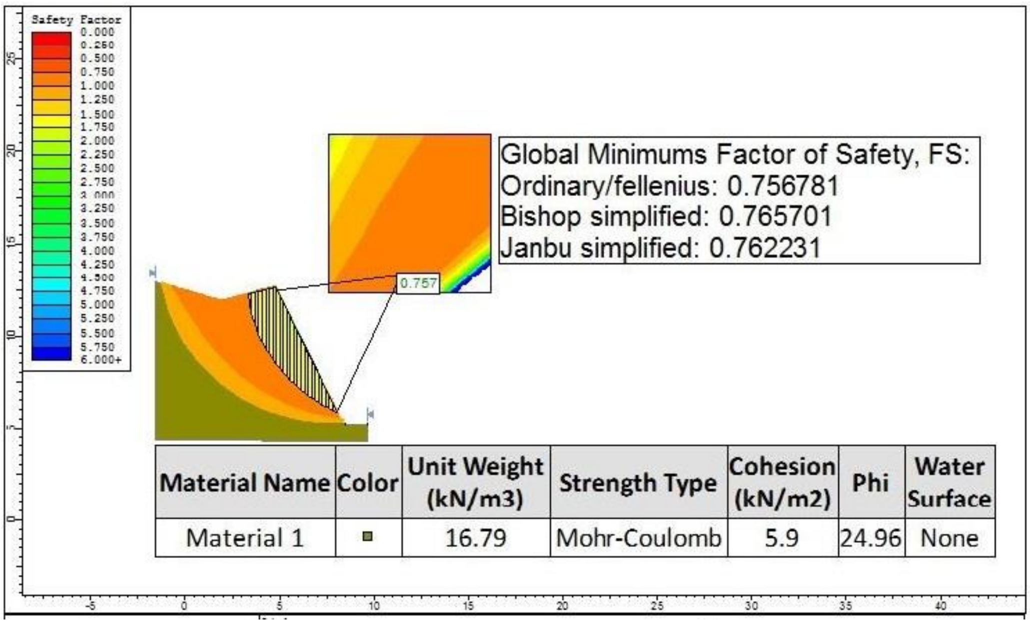

Figure 3: CH1+275 LHS stability analysis respectively for existing main gully slope using parameters values obtained from disturbed soil samples

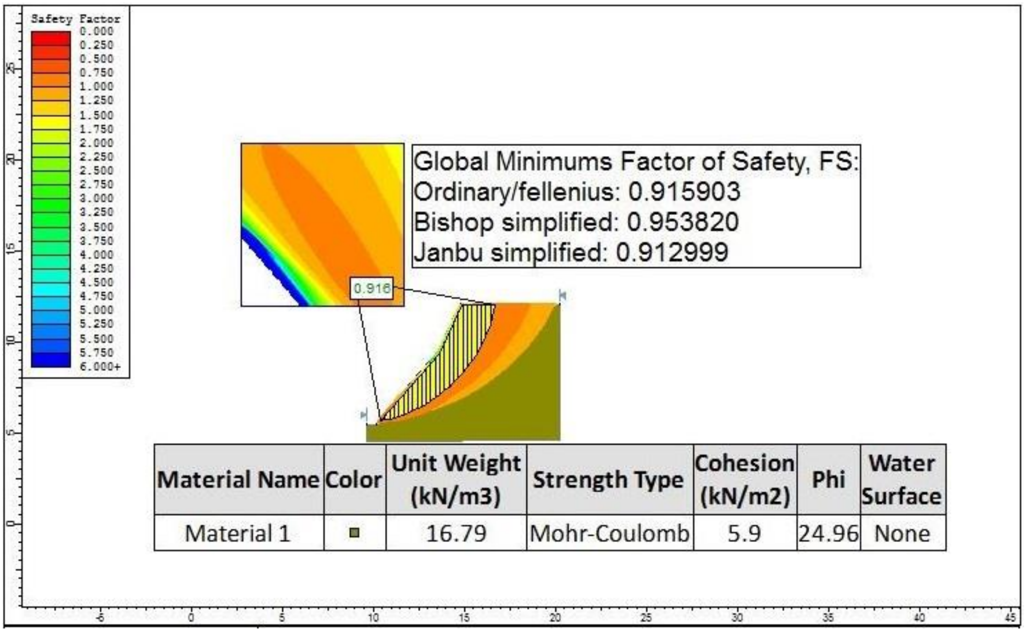

Figure 4: CH1+275 RHS stability analysis respectively for existing main gully slope using parameters values obtained from disturbed soil samples

5. SUMMARY OF RESEARCH FINDINGS

The geotechnical assessment of the Umuezealaibe, Isu-Njaba gully erosion site in Isu L.G.A aimed to comprehensively understand the soil and geological characteristics influencing the gully's instability. Through field investigations, laboratory analyses, and stability assessments, a thorough evaluation was conducted to unveil the underlying factors contributing to the erosion phenomenon. Representative samples (disturbed) were collected and laboratory tests undertaken to determine both the index and engineering properties of the soil so as to provide required parameters for the design of rehabilitation measures. The laboratory analyses include determining index properties such as specific gravity, moisture content, and plasticity. Grain size distribution using the sieve analysis method revealed the soil's particle distribution, influencing permeability and compaction properties. Moreover, shear strength tests were conducted to gauge the soil's resistance to shear stresses under different conditions.

The results of the Atterberg, sieve and compaction tests showed that the soil in the study area are cohesionless, not compact, and medium-plastic, hence the menace of gully erosion has a geopedologic and hydrologic influence. From the Unified Soil Classification System (USCS), the soil material identified within the project area is the soil is silty sand, silty mixture with slight plasticity and belongs to SM group.

Applying geotechnical software, stability analysis was performed to evaluate the gully slopes' safety against potential failures. By considering factors like slope inclination, soil properties, and external forces, the analysis pinpointed critical areas prone to instability. Multiple methods were employed, such as Bishop's method and Janbu's method, to ascertain the most suitable factor of safety and predict potential failure modes.

6. CONCLUSIONS

The geotechnical assessment highlighted significant insights into the Isu-Njaba gully erosion site's instability. The soil's high plasticity, low shear strength, and steep slope angles were identified as key contributors to the erosion problem. The instability poses risks to nearby structures and the environment. Thus, urgent measures are needed to prevent further degradation and potential disasters.

In conclusion, the geotechnical assessment of the Isu-Njaba gully erosion site underscores the urgency of addressing the instability to ensure the safety of both the surrounding environment and human infrastructure. By implementing recommended measures and fostering interdisciplinary collaboration, sustainable solutions can be devised to combat the erosion challenge and promote long-term stability.

7. RECOMMENDATION

An integrated use of agronomic and engineering practices that will protect the soil and reduce runoff is required. This will involve afforestation and tillage practice that will ensure optimum absorption of rainfall.

A proper and concrete drainage, retaining walls, or other engineered structures to mitigate further erosion and provide long-term stability should be constructed along the roads and areas suffering the menace of erosion.

The use of geosynthetic materials, such as geotextiles and geogrids, to reinforce the soil and enhance its shear strength, preventing further erosion should be considered.

Implementing immediate erosion control measures, such as installing erosion control blankets, terracing, and planting vegetation to stabilize the slopes and reduce surface runoff. This will reduce widening of incipient gullies.

Erodibility potential maps need to be prepared, using geological and geotechnical properties of the soil zones. Areas with high potentials for gully erosion hazards should be delineated for closer monitoring on regular basis.

There is need to raise awareness among the local community about the dangers of erosion and the importance of adopting sustainable land-use practices. More so, establish a monitoring system to continuously assess slope stability and erosion progression. This will aid in identifying potential issues and implementing timely interventions.

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