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Geological and geotechnical assessment of gully erosion sites in parts of Uturu, Southeastern Nigeria

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ABSTRACT

This study aims to assess the hydrogeological and geotechnical characteristics of gully erosion sites in Uturu and its environs. Standard hydrogeological and geotechnical investigation methods were adopted in this study. A field geological study of the area revealed that it is covered by sedimentary rocks. The soils are lateritic and are the product of intensive weathering that occurs under tropical and subtropical climatic conditions resulting in the accumulation of hydrated iron and aluminum oxides. Results of sieve analyses show that the soils at the gully sites have sorting values ranging between 0.42 and 2.3 coefficient of uniformity values ranging between 3.0 and 10, and coefficient of curvature values ranging between 0.2 and 1.3. These indicate that the soils are fair to well-sorted in those places. The plasticity index values ranging between 11.0 and 29 with a mean value of about 20 indicate soils of moderate to high plasticity, slight dry strength and easily friable. Values of maximum dry density range between 1.83 and 2.12 g/cm^3 at optimum moisture contents of between 7.4 and 11.3% revealing that the soils were generally loose. The hydraulic conductivity and transmissivity values as determined from the statistical grain size method range between 3.8×10^{-4} to 6.4×10^{2} cm/s and 3.8×10^{-2} to 9.6×10^{4} cm^2 respectively. These indicate moderate seepage fluxes and adverse pore pressures and are thus easily erodible. From the geotechnical analysis results, recommendations for erosion control such as aforestation and construction of drainages were suggested.

Keywords: Hydraulic conductivity, geotechnical, erosion, gullies, plasticity, Uturu.

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INTRODUCTION

Gully erosion is the state in which soil particles are transported through large channels. In some places, gullies carry water for brief periods of time during rainfall but appear as small valleys or crevasses during the dry seasons. It is an environmental hazard that is ravaging the landscape of parts of Uturu and its environs as well as other parts of the country especially Southeastern Nigeria (UNDP, 1995). Research on gully erosion emphasized the role played by rainfall intensity and runoff models with a passive reference to geology, hydrogeology and geotechnical characteristics of gully sites (Wishchmeier and Smith, 1978; Effiong-Fuller, 2000; Usoro, 1989; Fornis et al., 2005; Van Dijk et al., 2005).

The devastating effects of gullying destruction of the environment in various parts of Eastern Nigeria have also been variously discussed (Grove, 1951; Floyd, 1965; Ofomata, 1965; Ogbukagu, 1976; Nwajide and Hogue, 1979; Nwankwoala and Igbokwe, 2019; Igbokwe et al., 2022). They attributed the causes, origin and growth of the gullies to the effects of agriculture, human activities and geology.

Soil erosion is one of the prominent geological and environmental hazards currently ravaging the land surface of the Southeastern part of the country, especially Abia State. It generally degrades land and affects not just plants and animals but is capable of taking away human life and destruction of properties. The loss of these resources or functions, through erosion, is a serious environmental problem. Apart from natural processes, soil erosion is greatly accelerated by anthropogenic activities such as the construction of roads and buildings, logging, mining and agricultural production.

Investigations carried out by Nwankwo and Nwankwoala (2018), Egboka et al. (2019) and Obiefuna et al. (1999), have shown that the primary causes of gully genesis and expansion lie in the hydrogeological and geotechnical properties or characteristics of complex aquifer systems. The high hydrostatic pressure in the aquifers produces a reduction in the effective strength of the unconsolidated coarse sands in the walls of gullies leading to intense erosion (Egboka and Okpoko, 1984; Obiefuna and Nur, 2003). Hence, the development of gullies has caused extensive damage to the environment and has driven many away from their homes and farmlands.

The underlying geology of Uturu and environs, Southeastern Nigeria consists of heterogeneous materials namely basement complex, beach sands, coastal plain sands, mangrove swamp deposits, sandstones, shale, Sambreiro Warri – deltaic deposits, recent and sub-recent alluvian (FDLAR, 1990). According to Egede (2013), the soils of southeastern Nigeria are heterogeneous in nature comprising loose red-earth with sands, sandstones, and clayey-loam with or without ferric properties underlain by shale formation. Also reported by Ezemonye and Emeribe (2012), the soils are derived from shale and sandstone parent materials which are deep, porous and acidic with low organic content as a result of leaching from rainfall activity. According to Ufot et al. (2016), southeastern soils are low in organic matter content, base status and water storage capacity with high susceptibility to accelerated erosion and land degradation. Ezezika and Adetona (2011) further states that the soils have low silt/clay content thus resulting in sandy soil which is cohesionless, very permeable and has very high infiltration rates.

With the above points and facts, it is observed that soil erosion is very common in the Uturu area of Abia State. The cumulative impact leaves the inhabitants homeless, jobless and miserable. Consequently, the threats posed by gaping and daunting large gullies to farmlands, roads and human settlements are so numerous. Several areas in Abia State as well as Uturu have been devastated by different types of soil erosion ranging from rill erosion to gully erosion. The incidence of gully erosion is a common phenomenon in Uturu and its environs which has several negative effects on the physical environment, biodiversity, and psychological and economic development of the inhabitants. Therefore, there is an urgent need to conserve the environment for sustainable development that hydrogeological and soil test analysis will be carried out in the Uturu area of Abia State to provide hydrogeological and geotechnical information on the genesis and expansion of gullies. The information from the study will help suggest appropriate measures to control gully development.

Study area

The study area is Uturu in Abia State, Nigeria. Uturu is a town located in Abia State, Nigeria (Figure 1). It is in the transition from rural to urban status, so it is witnessing many development activities. The population of Uturu has been growing at a high rate over decades, until the last decade. It has archaeological importance – in 1977, a team of archaeologists discovered signs of the habitation of the early, middle, and late stone Age (Homo erectus).

Uturu is divided into two regions, Ihite and Ikeagha. Ihite comprises Achara and Mba Ugwu (Ugwu – Ogu, Ugwu – Ele, Ngodo, Amegu, Obi – Agu, Nnembi and Aro). Ikeagha comprises Isunabo, Akpukpa, Umu-mara, Nvurunvu, and Ndundu. The area is located at a low relief and valley-like area with a maximum elevation of about 156m. As a result, runoff is relatively moderate and the infiltration rate is high. Groundwater storage has also been in abundance due to adverse climatic conditions. Soil erosion has become a prominent phenomenon and is ravaging the landscape of the study area. The prevalent vegetation is rainforest and mangrove swamps with two distinct seasons: the dry season which last from November to March, and a wet season which lasts from April to October (NIMET) 2000 – 2015. The mean annual rainfall is about 2145.90 mm most of which falls between June and September.

The study area is geologically situated in the Eastern Niger Delta. It geologically falls within two out of eleven geologic units in the area (Amos–Uhegbu et al., 2013). These are Bende – Ameki Formation and the Benin Formation.

METHODS OF STUDY

The soil investigation, which comprised field study and laboratory analysis was carried out. The field investigation for the soil data collection includes sampling and measurement in seven different gully erosion sites, with the aid of geologic equipment and the Global Positioning System (GPS). Seven true soil representative samples were randomly collected from active erosion sites for laboratory analysis. The soil samples were subjected to laboratory test to determine the hydrogeological and geotechnical properties or characteristics of the soil that facilitates its prone to gully erosion in accordance with standardized methods specified by the American Society for Testing and Materials (ASTM) and the British Standard (BS).

The laboratory tests carried out on the soil samples

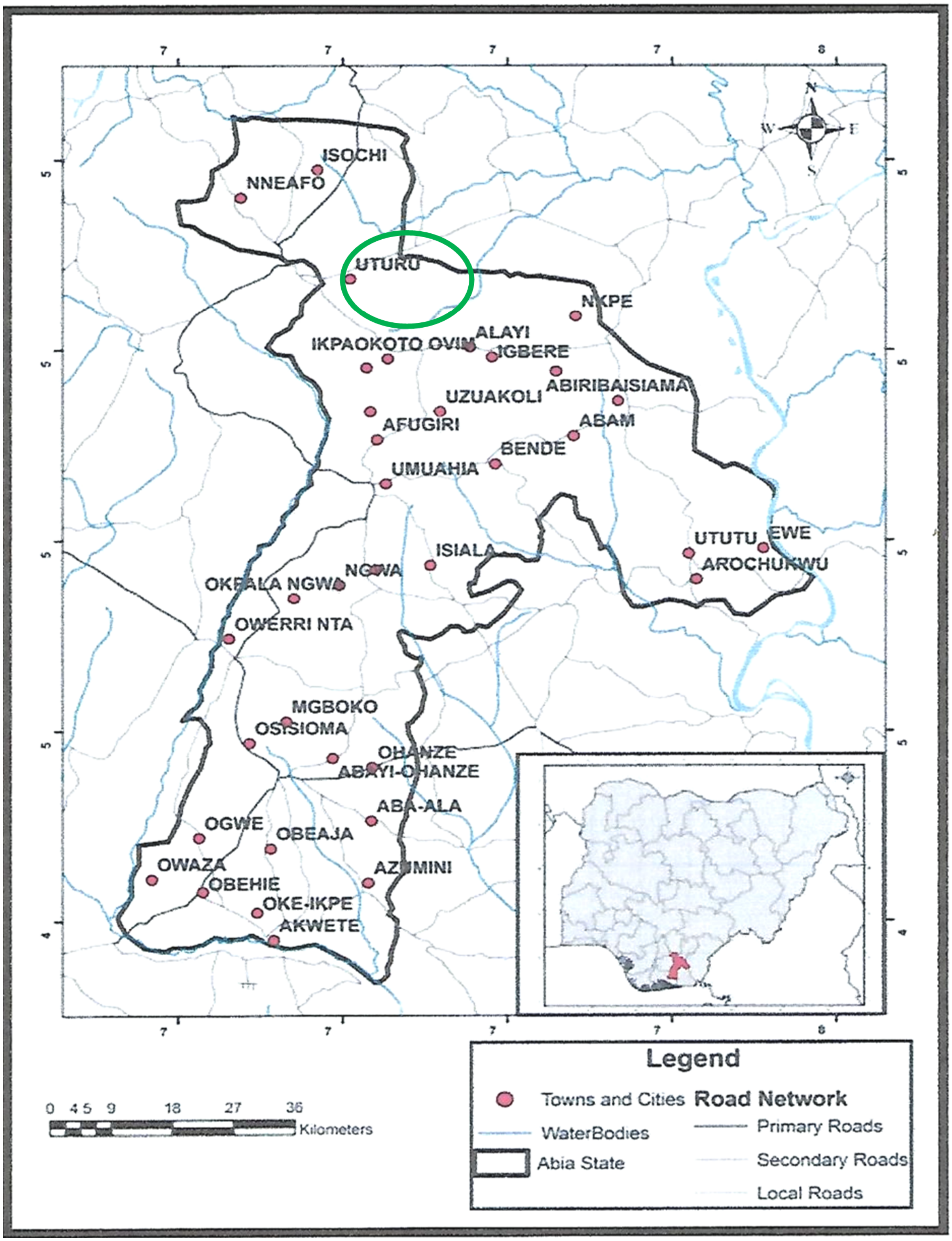

Figure 1. Map of Abia State showing the location of the study area in the green circle.

include Atterberg Limit, California Bearing Ratio (CBR), compaction and Particle Size Distribution (PSD) tests at the Engineering Geology Laboratory, Department of Geology, University of Port Harcourt, Nigeria. Sampling was done between 1 and 1.5 m from the surface of the gully erosion sites and also utilizes personal observation made during the field mapping of the affected areas of gully erosion. Data were presented using various graphical tools and results were recorded as measured by the various instruments.

RESULTS AND DISCUSSION

Field results revealed that the Uturu area is covered by sedimentary rocks. The sedimentary rocks of the area have undergone considerable weathering leading to about 50 to 150 m thick unconsolidated weathered overburden layers consisting of loose sands, gravels, silts and clays.

- The plasticity index ranges from 19.00 to 27.00 indicating medium to slightly high plasticity.
- Optimum Moisture Content (OMC) ranges from 7.40 to 11.30%.
- Maximum Dry Density (MDD) ranges from 1.83 to 2.12 g/cm^3.
- The grain size distributions range from 5.02 to 8.43
- Coefficient of uniformity ranges from 1.00 to 2.00
- Coefficient of curvature ranges from -1.00 to 0.30
- The study area records 85% of the atmospheric precipitation (Obiefuna and Nur, 2003).
- A mean hydraulic conductivity, k is 5.02 m/s
- A mean transmissivity, T is 6.35 m^2/s

The incipient gullies were observed in different parts of Uturu and its environs, which are covered by sedimentary rocks. The menace of devastation was found in four (4) locations. The sedimentary rocks of the area have undergone considerable weathering leading to about 50 to 150 m thick unconsolidated weathered overburden layer consisting of loose sands, gravels, silts and clays.

The range of the depth of incision of the gullies observed is about 1.50 to 5.10 m with widths ranging from 2.50 to 6.00 m (Table 1). The geotechnics of these areas determines the susceptibility to gully erosion or their erodibility. To determine the causes and to suggest solutions to the problems, the geotechnical parameters or characteristics of the soils at the seven (7) locations using soil mechanics laboratory tests such as liquid limit and plastic limit, the grain size analysis, moisture content, specific gravity and shear strength test were carried out. Table 2 summarizes the results of the test conducted. The liquid limit and plastic limits were used to obtain the plasticity index, which is a measure of the plasticity of the soil. The values obtained ranged from 19.00 to 27.00 indicating medium to slightly high plasticity according to Annon (1979). The samples are soft and could be crushed by fingers and hence erodible.

The compaction test indicates that the Optimum Moisture Content (OMC) ranges from 7.40 to 11.30% whereas the Maximum Dry Density (MDD) ranges from 1.83 to 2.12 g/cm^3 indicating that the soils are slightly compacted and not loosed. The grain size distributions analysis indicates sorting values to range from 5.02 to 8.43 and coefficient of uniformity and coefficient of curvature values of 1.00 to 2.00 and -1.00 to 0.30 respectively indicating that the soils are fair to well sorted implying high content of the fine-grained materials such as clays and silts that provide cohesion. As the soil compacts, the voids are reduced and this causes the dry unit weight (or dry density) to increase. Initially then, as the moisture content increases so does the dry unit weight. If water is added beyond the optimum moisture content, the water will occupy the extra space since there is no air volume and dry density will reduce.

There are two marked seasons in the year: rainy (March to October) and dry (November to February) seasons. The hottest months are January – March with a mean monthly temperature of 27°C. The relative humidity is usually high throughout the year, reaching a maximum of 90% during the rainy season.

Benin Formation consists of thick unconsolidated sands with lignite streaks and wood fragments. The sands are sub-angular to well–rounded, most medium to coarse-grained, pebbly, and moderately sorted with inter-finger of local lenses of poorly cemented sands and clay, thus giving rise to multi-aquifer systems separated by aquitards.

Table 1. Gully parameters and coordinates as obtained from the field.

Gully site	Depth (m)	Width (m)	Latitude (N°)	Longitude (E°)
Isunabo	5.10	2.60	5.8290707	7.4305303
Umumara	4.00	2.50	5.8305397	7.4183638
Akpukpa	1.50	4.00	5.8304567	7.3997804
Nvurunvu	1.50	3.00	5.8304668	7.3997905
Ndundu	2.30	3.50	5.9385823	7.4255769
Achara	3.30	5.60	5.9351299	7.5550222
Mba-Ugwu	3.50	6.00	5.8295592	7.3933618
Mean value	3.02	3.88		

The meteorological data from the Nigeria institute of Meteorological, Umudike shown in Table 3 include the rainfall data for the study area. The average annual precipitation occurring almost entirely as rainfall over a sixteen water year period (April to March) amounted to 95,971,200 m^3 volume of water. The value of actual

Table 2. Consistency values, optimum moisture content and maximum dry density of the samples.

Sample location	Sieve Analysis of grains (%)	Liquid Limit (LL)	Plastic Limit (PL, %)	Plasticity Index (PI)	Consistency Index (CI)	California Bearing Ratio (%)	Optimum Moisture Content (OMC, %)	Maximum Dry Density (MDD, g/cm^3)
Isunabo	41.81	46.00	27.00	19.00	2.40	21.00	9.60	1.96
Umumara	33.10	47.00	22.50	24.50	1.80	18.00	7.40	2.09
Akpukpa	38.04	33.00	20.00	12.70	2.40	16.00	11.30	1.97
Nvurunvu	20.92	33.00	22.00	11.00	2.70	24.00	10.10	1.83
Ndundu	29.44	48.00	19.00	29.00	1.60	16.00	10.20	1.96
Achara	39.02	45.00	23.00	22.00	1.90	14.00	9.30	2.02
Mba-Ugwu	36.70	48.00	27.00	21.00	2.20	8.00	7.40	2.12

Table 3. Meteorological data for Uturu and Environs monthly rainfall (mm) from 2000/2001 to 2014/2015 water year.

Year	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb	Mar.	Total
2000/01	164.50	153.60	265.50	265.20	216.90	277.50	228.40	75.90	3.80	0.00	7.80	175.90	1835.00
2001/02	224.10	194.30	522.70	273.50	179.00	317.20	277.10	18.60	0.00	3.10	107.10	68.50	2185.20
2002/03	259.00	436.30	240.10	359.80	333.70	238.50	247.50	57.00	0.00	0.00	37.90	119.50	2329.30
2003/04	159.80	231.40	282.40	447.50	372.60	340.80	180.20	69.20	0.00	0.20	11.90	22.40	2118.40
2004/05	134.50	217.60	279.40	309.50	304.30	324.90	249.10	52.50	5.10	17.30	126.70	64.00	2084.90
2005/06	141.30	222.40	264.40	277.00	225.00	336.70	323.00	45.40	8.60	76.60	81.90	131.90	2134.20
2006/07	136.00	202.80	237.30	303.40	133.70	483.10	237.40	14.20	0.00	0.00	62.90	35.50	1846.30
2007/08	219.80	373.50	352.30	187.60	327.40	404.00	211.00	6.70	8.90	62.80	62.80	47.80	2387.20
2008/09	219.80	373.50	352.30	310.20	327.40	404.00	211.00	6.70	8.90	62.80	62.80	47.80	2387.20
2009/10	100.50	416.20	236.00	306.30	287.40	205.50	311.10	23.70	0.00	0.00	78.20	34.70	1999.60
2010/11	126.00	213.50	459.00	276.90	420.70	309.30	349.20	78.20	4.60	0.00	60.80	111.40	2409.60
2011/12	105.80	347.70	239.50	236.50	345.10	424.70	242.80	12.00	9.60	0.00	88.20	57.00	2108.90
2012/13	142.00	233.70	213.00	363.00	161.80	349.00	244.60	58.50	0.00	75.40	36.50	40.80	1917.30
2013/14	92.80	466.10	239.10	280.90	237.10	218.00	184.80	99.50	90.90	0.00	43.70	138.80	2191.60
2014/15	78.70	249.20	281.80	144.40	444.20	405.30	165.10	147.40	0.00	8.40	81.70	130.50	2136.70
Mean value	144.21	293.55	297.77	289.38	296.91	336.96	252.46	58.06	10.43	17.15	59.21	89.81	2145.89

evapotranspiration estimated from the Turc model based on the mean annual rainfall is about 83,726,749 m^3 or 85% of the atmospheric precipitation (Obiefuna and Nur, 2003). An estimate of the surface runoff of 18,545,899 m^3 or 19% of the atmospheric precipitation was achieved employing the Veisman (1972) rational formula. Thus based on Bell (1983), the infiltration was estimated by subtracting the sum of actual evapotranspiration and the surface runoff from the total precipitation. Accordingly when this is done for the study area an average infiltration value of 65,180,850 m^3 was obtained.

The thick unconsolidated sand with lignite streaks and wood fragments gives rise to multi-aquifer systems. The unconsolidated weathered overburden aquifer is derived from the weathering of the underlying sedimentary rocks and consists of residual soils such as gravels, sands, silts and clays. The sediment aquifer directly underlies the unconsolidated weathered overburdened aquifer and consists of sediments that have been subjected to weathering due to surface processes. Furthermore while the hand-dug wells are tapping the unconsolidated weathered overburdened aquifer, the boreholes are tapping the thicker and deeper part of the sedimentary aquifer unit.

The hydraulic properties as determined from statistical methods (Hazen, 1893; Harleman et al., 1963; Uma et al., 1989) indicate a mean hydraulic conductivity K, value of 5.02 m/s and a mean transmissivity, T, value of 6.35 m^2/s. Comparisons were made for K to the Todd (1995) and T to the Gheorghe (1978) classification and were found to be relatively high (Table 4).

Table 4. Hydraulic conductivity and transmissivity values estimated from statistical grain size methods.

Sample location	Hydraulic conductivity, cm/s			Transmissivity, cm^2/s			Thickness (cm)
	Hazen (1893)	Harleman et al. (1963)	Uma et al. (1989)	Hazen (1983)	Harleman et al. (1963)	Uma et al. (1989)	
Isunabo	3.6×10^2	2.3×10^2	1.3×10^1	7.6×10^4	4.8×10^4	2.7×10^3	210.00
Umumara	3.6×10^2	2.3×10^2	1.3×10^1	7.2×10^4	4.6×10^4	2.6×10^3	200.00
Akpukpa	1.0×10^{-1}	6.4×10^{-2}	3.8×10^{-4}	1.0×10^1	6.4×10^0	3.8×10^{-2}	150.00
Nvurunvu	8.1×10^0	5.2×10^0	3.1×10^{-1}	8.9×10^2	5.7×10^2	3.4×10^1	200.00
Ndundu	4.0×10^2	2.5×10^1	1.5×10^0	5.2×10^3	3.3×10^3	2.0×10^2	130.00
Achara	6.4×10^2	4.1×10^2	2.4×10^1	1.5×10^5	9.4×10^4	5.5×10^3	230.00
Mba-Ugwu	1.0×10^3	6.4×10^2	3.8×10^1	1.5×10^5	9.6×10^4	5.7×10^3	150.00

CONCLUSION

The study has focused on the hydrogeological and geotechnical investigation of gully erosion sites in Uturu and its environs, Abia State, Nigeria. The study set out to answer a few objectives which were: provide hydrogeological parameters and data of the area available in Uturu, Abia State; provide geotechnical parameters and data of the soils available in Uturu, Abia State; identified problems and features making the area susceptible to gully erosion; and proffer sustainable solutions to problems of gully erosion in the affected area of Uturu, Abia State.

Hydrogeological and geotechnical investigations of the sediments of Uturu and its environs were made to infer the surface and subsurface processes that contribute to the formation of gullies in the area. A mean hydraulic conductivity K and a mean transmissivity T values of 2.09 and 3.79 m^2/s recorded indicate an aquifer unit of relatively high performance. The result of the geotechnical investigation indicate values obtained from sorting, which range from 0.42 to 2.3 and coefficient of uniformity and coefficient of curvature values of 3 to 10 and 0.2 to 1.3, respectively. Thus the soil is largely well sorted with high content of fine grain material such as silt and clays that provide cohesion. These made the soil loose and susceptible to gully erosion. The following are recommended control of gullies in the area:

- An integrated approach involving agronomic practices or massive afforestation efforts aimed at protecting the soil from the direct impact of rain drops.
- Some engineering methods can modify the slope characteristics in an attempt to check the amount and velocity of runoff (Obiefuna and Nur, 2003).
- Draining the soil using appropriate methods will help the shear strength and reduce the susceptibility of the soil to erosion.
- Continuous geotechnical evaluation should be carried out on the soil to assess changes in the soil and the environment.
- Reclamation by backfilling of existing gullies with laterite and other good filling materials accompanied by adequate compaction and drainage.
- The state government should enact an edict or law to prevent human activities such as burning, digging of sand and indiscriminate dumping of waste at erosion sites.

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