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Research paper

Evaluation of geotechnical properties of gully erosion materials in ORLU and its environs, IMO state, Nigeria

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Abstract

The evaluation of geotechnical properties of rock materials is used to ascertain the environmental factor that necessitated gully erosion in Orlu and its environs, Imo State, Nigeria. The study is aimed at geotechnically defining the characteristics, causes and formation of the gully erosion with particular emphasis on the current land degradation in the study area. Data used in the study were derived from field measurements, and laboratory analysis. Gully variables such as length, depth and widths were also determined. The result of the geological mapping revealed that there are three geologic formations encountered in the study area namely; Ameki, Ogwashi Asaba, and Benin Formations. The result of the field studies shows that 27% of the gullies observed occur in Ameki Formation while no gully was discovered in Ogwashi Asaba formation. The grain size distribution curves interpretation revealed that 80% (by weight) of the soils are medium to coarse grained sand and fine gravels, while the remaining 18% and 2% are for fine grained sand and coarse grained silt. The Atterberg Limit Test interpretation shows that the plasticity index of the formations ranges from 24.83% to 48.42%. Based on the results of the geotechnical properties of rock materials in the study area, the factors responsible for gullies occurrence in the study area were identified as topography, rainfall, geology, and anthropogenic factors. The devastating effects of gully erosion in the study area were observed to include loss of about 22km2 of arable lands; 2 major and 6 minor road failures; loss of many houses and other infrastructures; pollution of surface and underground water. Finally, it is recommended that the appropriate authorities, individuals and all stakeholders in the environmental protection agency should develop ideas in environment watch towards gully erosion control.

Keywords: *Gully Erosion; Gully Variables; Grain Size; Plasticity and ORLU.*

1. Introduction

Geologic environment of Orlu and environs has undergone destruction due to natural phenomena and man-made activities. Most common natural disasters of different magnitudes affecting the area include landslides and gully erosion (Okagbue and Uma 1987). The formation of gullies has become one of the greatest environmental disasters facing many towns and villages in South-eastern Nigeria (Adekalu et al., 2007). This region is fast becoming hazardous for human habitation with resultant problems of destruction of roads, economic trees, houses, and loss of arable land. Hundreds of people are being directly affected every year and needs to be re-located. Large areas of agricultural lands are becoming unsuitable for cultivation as erosion destroys farmlands and lowers agricultural productivity (Egboka et al., 1990). Therefore, the objective of this study is to investigate the occurrence, source and possible solutions to the gully erosion in Orlu and environs.

2. Location and accessibility

The area of study comprises Orlu town, Amucha, Nkwerre, Amigbo, Umuaka, Nduche and many others which are all located in Imo State, South-eastern, Nigeria (Fig. 1).

It lies between latitudes $5^o 39^I$ N - $5^o 50^I$ N and longitudes $7^o 09^I$ E - $8^o 20^I$ E. It is bounded on the North by Urualla, on the East by Okigwe towns, on the South by Ogwa, and on the West by Mgbidi, and covers about 268km^2 in area. The study area is accessible from numerous neighbouring towns and villages through state and local government roads (Fig 1). Earth roads and footpaths equally abound, both of which facilitated access to gullies located away from the major roads.
Rainy and dry seasons are the two main climatic conditions existing in the study area. The dry season runs through the months of November to March while the rainy season begins in April and ends in October but may also extend to November.

3. Methods of investigation

Data used in this study were derived from field measurements. Satellite imageries were used to prepare the maps and soil samples were subjected to laboratory analysis. Profiles were taken at 100m sample points intervals to delineate gully morphological variables, while soil samples were taking along the gully wall layers (top, middle and bottom) and a representative sample picked from this composite sample in order to analyse the geotechnical properties of the soil. A 30m tape, cone penetrometer and soil sampler were used. Data collected were analysed using a descriptive statistic. Sieve analysis for grain distribution, and Atterberg limits tests

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were conducted on the samples. The grain size distribution analysis was carried out using mechanical shaker,

A detailed geologic field mapping exercise was conducted and the result used to prepare the detailed gully site and geologic map of the study area (Fig. 2). Gully characteristics like length, breadth, depth and orientation were taken. Soil samples were taken from the gullies and used to determine the geotechnical properties of the samples. Parameters determined include plastic limits, liquid limits and plasticity index.

3.1. Geology and hydrogeology of the area

The study area falls between two of the Nigeria sedimentary basins namely; Niger Delta Basin and Anambra Basin (Table 2). Cenozoic Niger Delta complex was developed as a regressive offlap sequences. Three major lithostratigraphic units recognized in the Niger Delta are the Akata, Agbada and Benin Formations (from the oldest to the youngest).

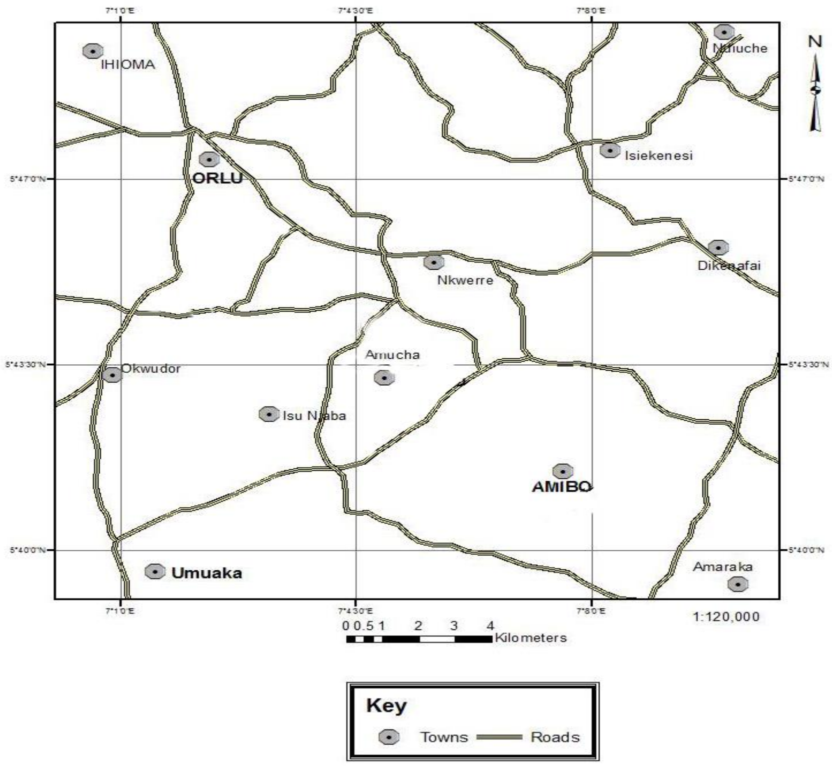

Fig. 1: Accessibility Map of the Study Area.

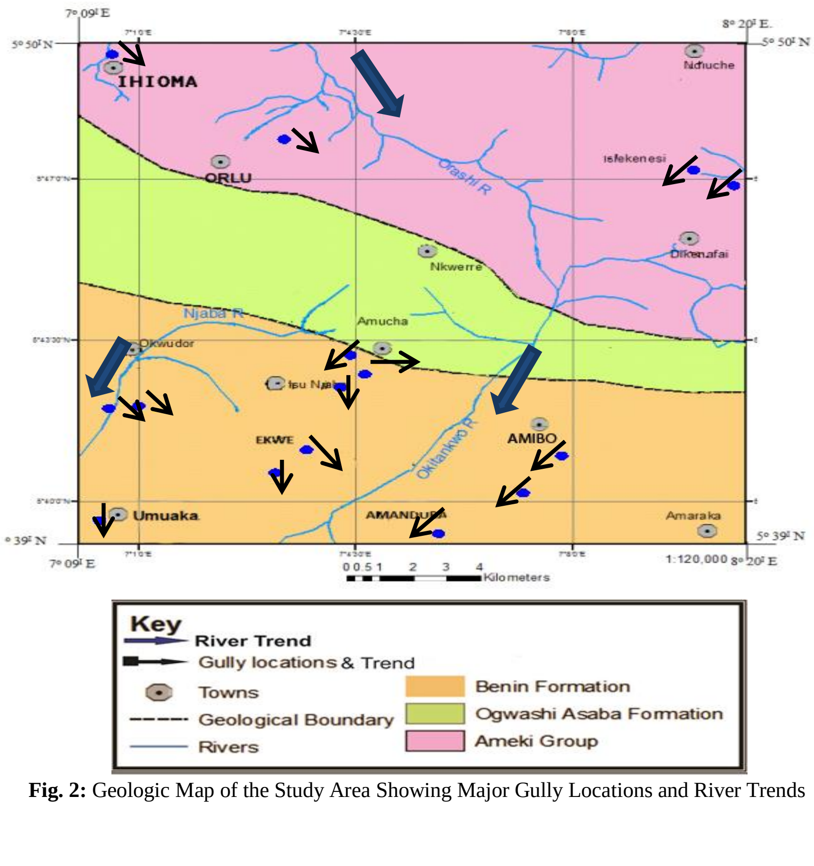

Fig. 2: Geologic Map of the Study Area Showing Major Gully Locations and River Trends

The Akata Formation is composed of continuous shale and about 10% sandstone. Its age ranges from Eocene to Recent. The Agbada Formation conformably overlies the Akata Formation in the subsurface. It is a parallic sequence of alternating shale and sandstone with a variable age ranging from Eocene in the north to Pliocene/Pleistocene in the south and Recent in the Delta surface. The Agbada Formation is thickest at the center of the Delta with a thickness of up to 457.2 m. The continental Miocene-Recent Benin Formation conformably overlies the Agbada Formation. It is composed of loose fresh water bearing sand with occasional lignite and clay and going up to 2,286 m deep with no over pressures. It is made of more than 90% sands and about 10% shale/clays. (Burke, 1996).

On the other hand, the Anambra Basin is the most prominent basin formed during the Abakaliki tectonic episode (Igbokwe, et al. 2008). The Anambra Basin is dominantly filled with clastic sediments constituting several distinct lithostratigraphic units ranging from Upper Campanian to Recent in age. The lithostratigraphic units have a thickness of up to 2500m (Reyment, 1965), and includes Nkporo Shale, Mamu Formation, Ajali Sandstone, Nsukka Formation, Imo Shale, Ameki Formation, Nanka Sands. The area is underlain by Ameki Formation, Ogwashi-Asaba Formation and Benin Formation (Fig.2).

The climate and the hydro-geologic conditions of the region control the surface and groundwater in the area. The surface water is a major factor in the formation of gullies in the study area as the gullies are closely linked to the drainage (Egboka 1983) (Fig. 3). The study area is drained by two major river systems: Njaba River in the south west and Orashi River system extending from the north to the south of the study area.

3.2. Assessment of gully sites

Gully geometry, coordinates, location, dimensions, and inferred causes were determined and in the study area. The results are tabulated in table 1

3.4. Distribution of gullies

The gully erosion distribution in the formations of the study area is illustrated below (Fig. 5). No gully was discovered in Ogwashi Asaba Formation.

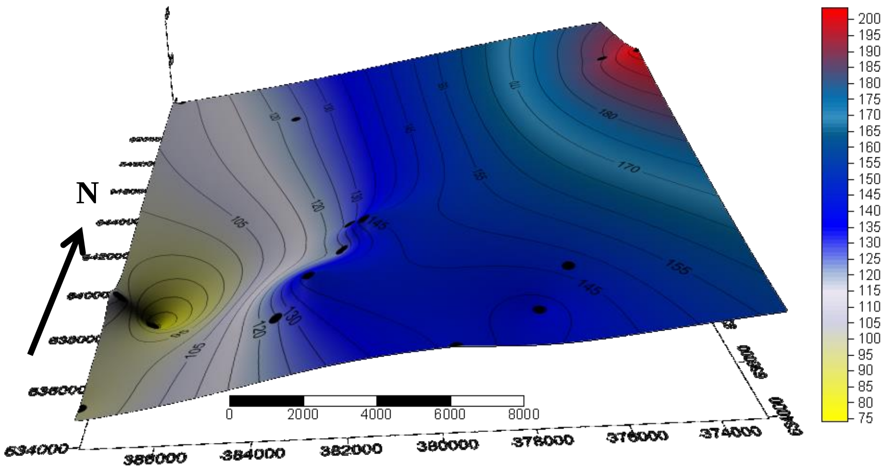

Fig. 3: Current Topographic Outlook of the Study Area Showing Locations of the Gully Sites Plotted with GPS Readings.

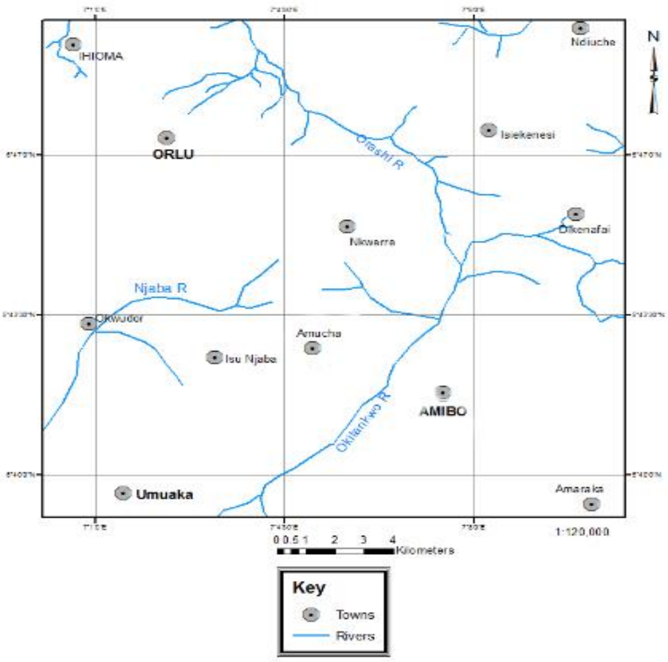

Fig. 4: Drainage Map of the Study Area.

Table 1: Inventory of Gully Sites at the Study Area

S/N	Location	Coordinate And Elevation	Dimension Length (m), Depth(m), Width(m)	Gully Trend	Inferred Causes
1	Orlu(Mgbee)	05⁰ 48′ 08” N 007⁰ 02′ 46”E 123m	Length=1500 Depth=150 Width=100	Nw – Se	Concentrated flow due to topography, poor civil work construction
2	Affor Ukwu Isiekenesi	05⁰ 47′ 36” N 007⁰ 07′ 55” E 189m	Length=1050 Depth=8 Width=9	Ne – Sw	Concentrated flow due to abrupt termination of storm drain.
3	Affor Nta Isiekenesi	05⁰ 47′ 19” N 007⁰ 08′ 25” E 204m	Length=950 Depth=9 Width=10.5	Ne – Sw	Concentrated flow due to topography, geology of the area, high rainfall, poor engineering work
4	Okwudor	05⁰ 43′ 04” N 007⁰ 00′ 46” E 109m	Length=500 Depth=10 Width=40	Ne – Sw	Anthropogenic/ natural factor.
5	Umuseke Okwudor	05⁰ 43′ 07” N 007⁰ 01′ 08” E 72m	Length=50 Depth=7 Width=9	Ne – Sw	Concentrated flow due to topography, poor engineering works; geology.
6	Amucha	05⁰ 44′ 06” N 07⁰ 03′ 44” E 127m	Length=250 Depth=14 Width=12	W – E	Concentrated flow due to topography, poor farming method, poor engineering work
7	Obiato Umuaka	05⁰ 40′ 59” N 007⁰ 00′ 41” E 95m	Length=750 Depth=12 Width=11	N – S	Concentrated flow and incomplete storm drain
8	Obara Ekwe	05⁰ 41′ 54” N 007⁰ 02′ 50” E 124m	Length=80 Depth=6.3 Width=5.5	Nw – Se	Concentrated flow due to topography of the area
9	Obamara Ekwe	05⁰ 42′ 20” N 007⁰ 03′ 13” E 145m	Length=10 Depth=3.9 Width=5.4	N – S	Geology, concentrated flow, topography
10	Amandugba	05⁰ 40′ 48” N 007⁰ 04′ 52” E 141m	Length=9.6 Depth=2 Width=1.5	Ne – Sw	Concentrated flow, geology, and anthropogenic factors
11	Isunjaba	05⁰ 43′ 45” N 007⁰ 03′ 55” E 146m	Length=100 Depth=60 Width=80	Ne – Sw	Concentrated flow due to topography, geology
12	Abah Isunjaba	05⁰ 43′ 30” N 007⁰ 03′ 37” E 122m	Length=80 Depth=18 Width=25	N – S	Topography and anthropogenic factors
13	Amauju Amaigbo	05⁰ 41′ 34” N 007⁰ 05′ 54” E 137m	Length=80 Depth=1.8 Width=3.5	Ne – Sw	Concentrated flow due to poor engineering works and geology of the area
14	Umuokwaraoha Amaigbo	05⁰ 42′ 16” N 007⁰ 06′ 22” E 147m	Length=600 Depth=8 Width=5	Ne – Sw	Topography and concentrated flow of water, geology of area
15	Ihioma	05⁰ 49′ 39” N 07⁰ 00′ 43” E 108m	Length=400 Depth=10 Width=12	Nw – Se	Geology of the area, poor farming method, topography of the area

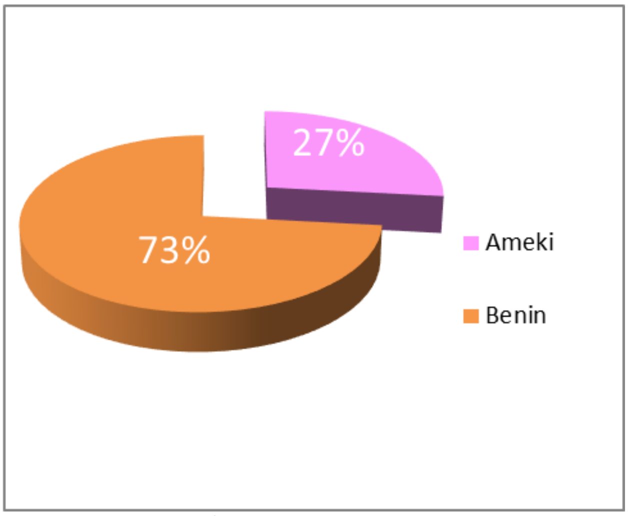

Fig. 5: Distribution of Gullies in the Formations in the Study Area.

Results and Interpretation (Geotechnical Analysis Results)

Table 2: Grain Size Parameters for Soil Samples

Sample No:	Location	Mean	Median	Sorting Value Remark	Skewness Value Remark	Kurtosis Value Remark	Coeff. Of Uniformity Value Remark
1	Orlu (Mgbee)	0.87	0.90	1.2614 Poorly Sorted	-0.0294 Strongly Coarse Skewed	1.0125 Mesokurtic	3.4118 Uniformly Graded
2	Affor Ukwu Isiekenesi	0.97	0.90	1.2515 Poorly Sorted	0.0998 Near Symmetrical	1.1091 Leptokurtic	3.7500 Uniformly Graded
3	Affor-Nta Isiekenesi	2.00	1.90	2.6735 Very Poorly Sorted	0.0958 Near Symmetrical	0.9751 Mesokurtic	11.0000 Well Graded
4	Okwudor	1.00	1.10	1.4229 Poorly Sorted	0.1754 Coarse Skewed	3.5519 Extremely leptokurtic	5.0000 Uniformly
5	Umuseke Okwudor	1.10	0.80	1.2720 Poorly Sorted	0.0870 Near Symmetrical	1.2568 Leptokurtic	3.5294 Uniform Graded
6	Amucha	0.97	0.90	1.4076 Poorly Sorted	0.7901 Strongly Fine Skewed	1.2054 Leptokurtic	3.8000 Uniformly Graded
7	Obiato Umuakah	1.10	1.00	1.4129 Poorly Sorted	-0.0169 Coarse Skewed	1.1217 Leptokurtic	4.4167 Uniformly Graded
8	Obara Ekwe	1.03	0.90	1.3273 Poorly Sorted	0.1667 Fine Skewed	1.3115 Leptokurtic	4.1538 Uniformly Graded
9	Obamara Ekwe	1.77	1.50	0.6390 Moderately well Sorted	0.4828 Strongly Fine Skewed	0.9904 Mesokurtic	2.3529 Uniformly Graded
10	Amandugba	1.47	1.60	0.5242 Moderately well Sorted	-0.2321 Coarse Skewed	1.0432 Mesokurtic	2.1053 Uniformly Graded
11	Isunjaba	0.80	0.70	0.7179 Moderately well Sorted	0.3324 Fine Skewed	1.3320 Leptokurtic	2.2222 Uniformly Grade
12	Abah Isunjaba	0.93	0.80	0.8848 Moderately well Sorted	0.3125 Fine Skewed	1.3115 Very Platykurtic	2.4737 Uniform graded
13	Amauju Amaigbo	0.87	0.80	0.8500 Moderately well Sorted	0.7591 Strongly Fine Skewed	0.6510 Platykurtic	2.3810 Uniformly Graded
14	Umuokwaraoha Amaigbo	1.87	1.00	1.0455 Poorly Sorted	0.2667 Strongly Fine Skewed	1.5574 Very Leptokurtic	2.6667 Uniformly Graded
15	Ihioma	1.00	0.90	0.8947 Moderately well Sorted	0.2657 Strongly Fine Skewed	1.1550 Leptokurtic	2.5263 Uniformly Graded

Table 3: Atterberg Limit Test within the Study Area

Sample No	Location Name	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
1	Orlu (Mgbee)	60	22.48	37.52
2	Afor-Ukwu, Isiekenesi	54.2	20.36	33.84
3	Afor-Nta, Isiekenesi	61	20.75	40.25
4	Okwudor	Non Plastic	Non Plastic	Non Plastic
5	Umuseke, Okwudor	Non Plastic	Non Plastic	Non Plastic
6	Amucha	64.4	18.65	45.75
7	Obiato-Umuakah	Non Plastic	Non Plastic	Non Plastic
8	Obara-Ekwe	Non Plastic	Non Plastic	Non Plastic
9	Obamara-Ekwe	Non Plastic	Non Plastic	Non Plastic
10	Amandugba	Non Plastic	Non Plastic	Non Plastic
11	Isunjaba	Non Plastic	Non Plastic	Non Plastic
12	Abah, Isunjaba	Non Plastic	Non Plastic	Non Plastic
13	Amauju, Amaibo	44.75	19.92	24.83
14	Umuokwaraoha, Amaigbo	62.5	19.6	42.9
15	Ihioma	65	16.08	48.92

Table 4: Effective Size (D10), (D60) and Phi (Φ) Values for Soil Samples

Soil Sample No:	Location	Effective Size (D10) (mm)	D60 Size (mm)	φ5	φ16	φ 25	φ 50	φ 75	φ 84	φ 95
1	Orlu(Mgbee)	0.17	0.58	-1.20	-0.40	0.10	0.90	1.80	2.10	3.00
2	Affor Ukwu Isiekenesi	0.16	0.60	-1.00	-0.20	0.20	0.90	1.80	2.20	3.30
3	Afor Nta Isiekenesi	0.03	0.33	-1.10	-0.40	0.50	1.90	3.40	4.50	5.8
4	Okwudor	0.10	0.55	-1.00	-0.10	1.30	1.00	1.90	2.40	4.20
5	Umuseke Okwudor	0.17	0.60	-1.20	-0.30	0.10	0.80	1.60	2.00	3.40
6	Amucha	0.15	0.57	-1.30	-0.30	0.10	0.90	1.80	2.30	3.70
7	Obiato Umuaka	0.12	0.53	-1.20	-0.10	0.10	1.00	2.00	2.40	4.00
8	Obara Ekwe	0.13	0.54	-1.10	-0.10	0.30	0.90	1.80	2.30	3.70
9	Obamar Ekwe	0.17	0.40	0.00	1.50	0.80	1.50	2.00	2.30	2.90
10	Amandugba	0.19	0.40	-0.10	0.60	1.00	1.60	2.10	2.20	2.70
11	Isunjaba	0.18	0.40	-0.10	0.20	0.40	0.70	1.20	1.50	2.50
12	Abah Isunjaba	0.19	0.47	-0.20	0.20	0.40	0.80	1.40	1.80	3.00
13	Amauju Amaigbo	0.21	0.50	-0.10	0.20	0.40	0.80	1.30	1.60	2.60
14	Umuokwaraoha Amaigbo	0.15	0.40	-0.20	0.20	0.40	1.00	1.80	2.20	3.40
15	Ihioma	0.19	0.48	-0.10	0.20	0.40	0.90	1.50	1.90	3.00

4. Discussion of results

The lengths of the gullies within the study area range from 9.6m at Amandugba, to 1500m at Orlu-Mgbee. Their width ranges from 1.5m at Amandugba to 100m at Orlu-Mgbee and their depths from 2m at Amandugba to 60m at Isunjaba. The gullies were found to have predominately V-shaped structures indicating that they are active, and the major trends of the gully are NW-SE, NE-SW and N-S (Table 1). The coordinates and dimension of the gullies as show in Table 1 help in predicting gully heads.

Results from the grain size distribution curves indicate that about 80% (by weight) of the soils are medium to coarse grained sand and fine gravels which are easily eroded by runoff water, while the remaining 18% and 2% are fine grained sand and coarse grained silt (Fig. 6) which are easily erodible soil materials. The various effective grain sizes and Phi values for soil samples collected and analysed indicates that the samples range from very poorly sorted (at Afor-nta, Isiekenesi) to moderately sorted (at Ihioma). The analysis also shows that the samples ranges from strongly fine skewed to strongly coarse skewed. In addition, the result shows that the kurtosis of the samples ranges from very platykurtic (very flat) to extreme leptokurtic (very peak) and the coefficient of uniformity obtained from the samples indicates that the soil samples are uniformly graded within the study area except Afor-nta Isiekenesi that has well graded soil (Table 4).

Based on the grain size analysis of the soil samples, removal and transport of the soil grains by runoff water is easier. Smaller particles are easily carried away by water since the transporting medium requires relatively small amount of energy. This is why erodibility potential of the soil units is high within the study area.

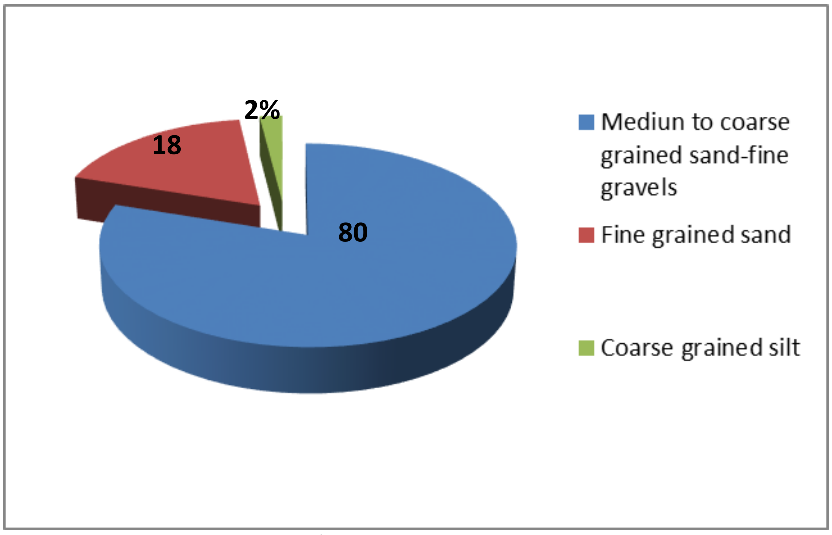

Fig. 6: Distribution of Grain Size in the Gullies in the Study Area.

The results from the Atterberg Limit Tests (Table 5) indicate the existence of two classes of soil materials namely - plastic material and non-plastic material. About 53% of the samples collected are non-plastic while 47% are plastic. The areas that have plastic materials are Orlu-Mgbee, Afor-Ukwu Isiekenesi, Afor-Nta Isekenesi, Amucha, Amauju-Amaibo, Umuokwaraoha-Amaigbo and Ihioma. The moderate clay content of the soil materials within some part of the study area was found to reduce the devastation caused by gullies in the area. The liquid limit ranges from 44.75% to 65% while the plastic limit ranges from 16.08% to 22.48% and plasticity index ranges from 48.92% to 24.83%. The areas without plastic soil material are highly affected by the gullies since low plasticity of the soil units indicates low cohesive force between grains. They include Okwudor, Umuseke-Okwudor, Obiato-Umuaka, Obara-Ekwe, Obamara-Ekwe, Amandugba, Isunjaba, and Abah-Isunjaba.

5. Conclusion and recommendations

5. 1. Conclusion

The conditions that favour gully erosion in the Ameki and the Benin Formations are complete within the study area. These include high rainfall, steep slope, friable substratum and intense human activities. Field studies show that the environmental hazard posed by gullying has continued to defy control measure put in place to checkmate it, as a result of the peculiar geological, hydrogeological, geotechnical, climate and anthropogenic factors at play in the area. It is calculated from the gully dimensions that $22km^2$ out of the $268km^2$ total land mass in Orlu and its environs has been lost to gully erosion. Since gullying is progressive, the dimension and features of individual gullies, as well as the numbers of gullies in Orlu and its environs will continue to change. In addition, the study has shown that the soils in this area have a high percentage of sand and high sand to clay ratio. This type of soil belongs to 'irrigable' class of the Modified US Bureau of Reclamation Land Suitability Class specifications (Usman et al., 2014), are highly erodible.

The gullies in the study area are genetically related to the three major drainage systems whose sources are from the northern upland (Awka - Orlu cuesta) and the east central plateau, namely: Orasi River system, Njaba River systems and Okitankwo River systems. It was observed that among the three river systems in the study area, the most active gullies are concentrated in the Orashi - Njaba system (Fig 3) with over 80% of gullies in the study area.

There is the consensus among Geoscientist and other Earth scientists working on the gullies in South Eastern Nigeria that the control of the disaster should be scientifically and systematically implemented rather than the common and general practice of channelization and embankment construction (Ezechi and Okagbue 1989, Egboka and Okpoko,1984).

5.2. Recommendations

It is recommended that the appropriate authorities, individuals and all stakeholders in environmental protection shall constitute the major factors in environment watch towards gully erosion control-

- Agricultural practices like bush burning which is prevalent in Umuakah, Njaba, should be discouraged.
- Incipient control measures like use of sandbags, fence filter mechanism, and use of catch-pits should be encouraged.

This control measure is already in use in places like Isiekenesi.

- Slope stabilization by reducing the slope angle during road construction should be encouraged.
- Afforestation should be practiced to provide vegetative cover that will reduce the impact of raindrop energy at Amandugba.
- Multi-channelling should be a popular practice to help reduce the flow velocity of runoff in Orlu Mgbee.
- Proper assessment and treatment of water in the study area before human consumption should always be undertaken to avoid diseases associated with water contamination by runoff.
- Monitoring of the unaffected areas to ensure the practice of prevention and compliance with anti-erosion statutes should be enforced by the relevant authorities.

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