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Research Paper

Environmental and geotechnical assessment of an aggressive gully erosion site in Nigeria

*Nwachukwu M. A., Owette I.
Department of Environmental Technology, Federal University of Technology Owerri Nigeria
E-mail: futo.essg@hotmail.com

Abstract: This study was carried out to assess the surface processes and subsurface characteristics that contribute to the formation and expansion of gully erosion in Akpulu - Ideato north county, Imo state Nigeria. Part of Akpulu community close to the gully head may submerge in the next few years if control measures are not intensified. A gully measuring 15-18m deep, 9-12 m wide to 6.5 km long is advancing aggressively, threatening life, property, food production, and security of ecosystem in Akpulu and environs. Analysis of soil samples collected from accessible portion of the gully to depths of 3 m show peculiar geotechnical characteristics; Liquid limits 20 – 70%, Plastic limits 17.35 – 22.75%, and Plasticity index 7.65-13.70%. The soil has high clay/silt content, with ranges of maximum dry density (1.7- 2.1g/m^3), Optimum moisture content (9- 24%), and average shear strength of 27.5 KN/m^2. It is easily erodible, as the silt gets dissolved by high velocity flood on 0.02 flow gradient. Expansion and maintenance of the main drainage channel from Umuchu to Akpakporo River in Apkulu is recommended. Secondary drainage channels to join the main channel, and increased trees planting from the gully head are recommended.

Keywords: Silty soil; Slope; Shear strength; Landslides; Deep gully; Hazards; South-east Nigeria

Introduction

Over many years ago channels in some part of South East Nigeria (Figure 1a) especially Akpulu in Ideato North Local Government Area of Imo State (Figure 1b) were noticed to have entrenched their valley.

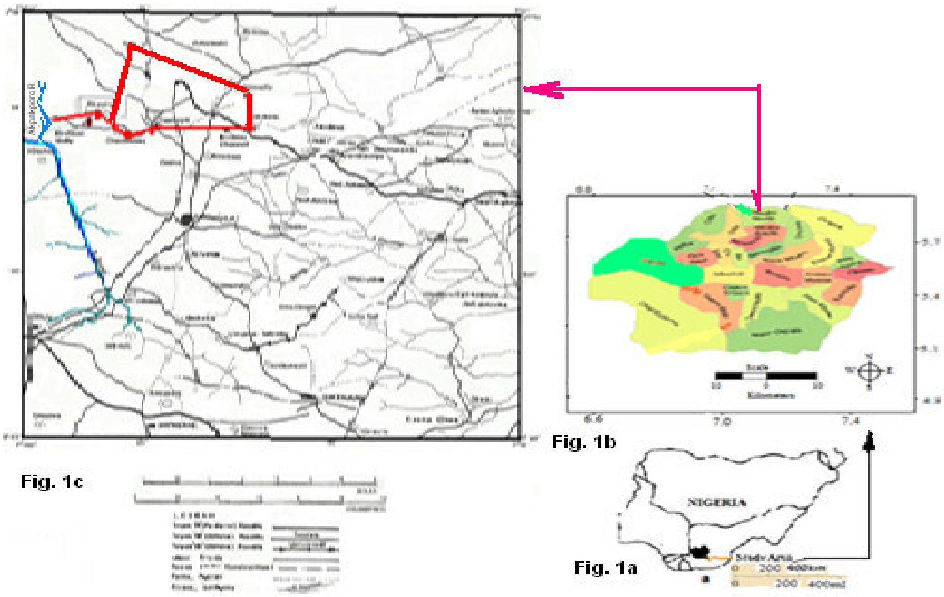

Figure 1. a: Map of Nigeria showing Imo state; b: Map of Imo state showing Ideato north local government area; c: Map of Ideato North/South showing Akpulu, and the erosion channel.

These channels generally eroded in red earth and unconsolidated geologic materials establishing prominent gully with near vertical slope. This channel which caused this erosion, was as a result of road construction in which there drainage were channeled from Achina-Umuchu-Uga down to Akpulu and another road construction whose drainage were also directed to the same study area. Increased erosion activities in the vicinity of the early gully of the study area have continued to expand this gully into a complex system. This gully is advancing aggressively into residential area, constituting the most threatening environmental hazard in the area. Lithostratigraphy of the gully site comprises thick cohesionless sand stratum, overlain by a red silty sand layer and then silty topsoil. This intense gulling involved sudden and often catastrophic movement of large earth masses (landslides) causing sudden death of human beings and other animals. Properties worth millions of naira have been destroyed, wrecked homes, pollution of Akpakporo River and washed road away.

Incident of gully erosion has caused much concern to the people of Akpulu, Ideato north local government authority, Imo state government, the south-east, and Nigeria. It has generated much attention among private and institutional researchers but with limited output. Studies have been conducted, seminars and workshop also held on the immediate and remote causes of this gully. Effort was made in the past to control the erosion menace, which resulted in the design and construction of concrete channel to conduct the erosion flood into Akpakporo River. This channelization from Umuchu through Akokwa to Akpulu (Figure 1c) is about a distance of 24.5 km. Later development of gully erosion from Uga linked the Umuchu-Akokwa-Akpulu channelization, and resulted in the channel overflow. This overflow created an uncontrolled secondary drainage channel aggravating the present headward movement of the gully south of Akpulu residential area. This has made the present channelization program under completion and repairs inadequate.

This erosion has degraded arable land, to reduce food production in the area. It has reduced infrastructural development, and socio-economic aspect of the Akpulu community. It has necessitated an urgent administrative policy with new approach to land conservation and management in the area. The gully has caused the death of many people in the community particularly children. About four school children were killed and six others seriously injured at a time in 2001 when they fell into this gully. The children were all playing near the sites of the erosion when suddenly the ground caved-in and caused them to plunge head first into the over 50 feet deep gully. They lamented that help was late in coming as the depth of the gullies scared those who had come on rescue mission. "It took about two hours before people managed to bring them out and before then four of them had died and six in serious conditions." Beside Akpulu, a number of other communities in Ideato area sharing similar erosion threat include Umuago, Obodoukwu, Osina, Urualla, Isiokpo, Uzii, Ndiejezie in Arondizuogu, and Akokwa, to mention but a few. A major cause of the many erosion problems is linked to the abandoned federal government road project which culverts and drainages were not in place.

Study Area

Okwu Akpulu is bounded in the East by Uga, in the north by Isiokpo, in the West by Obodoukwu and in the South by Akwa ihedi in the south eastern Nigeria (Figure 1a). Okwu Akpulu lies between latitude 4^0 45'N and 7^0 15'N and Longitude 6^0 05'E and 7^0 25'E in Ideato North (Figure 1b). Erosion channel to Akpulu is from Umuchu-Akokwa-Isiokpo-Akpulu; Umuchu-Uga-Akpulu with estimated distance of channelization = 1.5+8.5+5+7.5+2 = 24.5 km. Okwu Akpulu is located North-West of Ideato North Local Government Area of Imo State with landmass of about 5 km. It has a population density of about 1100 person/km^2 (Figure 1c). The soil of the study area is silty, well graded to poor graded sands and containing low to medium plasticity clay.

Climate

The local climate of the study area is the same with the general climate of Imo State. The elements of the climate of the study area are as follows; rainfall season usually starts from March to October. This average yearly rainfall is about 2200mm with a monthly peak of 450mm in August. Its runoff from a distance of over 6km enters into Okwu Akpulu gully enroute to the Akpakporo River. Temperature of the study area is similar to the rest of other communities in Ideato north county area. The mean annual temperature ranges in the other of 20^0c and 30^0c respectively. The relative humidity of the study area varies normally within the period of the year. It ranges from 70% - 80% within April to other (wet season) and from 60% during the dry period (November - February).

Vegetation

The study area falls within the high rain forest belt of West Africa. Its vegetative cover consists of the canopies of economic trees such as Palm tree, Melina and Oil bean tree. Other intermediate canopies consist of moderately populated trees such as Pears, Mangoes, and Bamboos etc. The under growth canopy is composed of shrubs, herbs and grasses. As a result of interplay between man and climate this original vegetation has been seriously altered. Deforestation, lumbering, bush burning and over farming activities by man has reduced the original forest to successive or secondary vegetation with patches of grasses shrubs and few economics trees
(Figure 2a).

Literature Review

Gully Characteristics

Over 65 percent of the soil on earth is said to have displayed degradation phenomena as a result of soil erosion, salinity and desertification (Okin, 2002). Although the impact of rain drops on the shallow streams result to splash soil, it does increase turbulence, thus providing greater sediment carrying capacity (Collinet and Valentine 1985) and if these, minor channels are neglected or under estimated, with subsequent rainfall and run-off, it will develop to gully erosion (Duley 2008). The average size of Okwu Akpulu gully is more than 50m deep by visual assessment at the head cut. The Akpulu gully width is about 40m, and over 6.5 km long. Bottom of the gully rests on undulated sandstone overlain by a sequence of brownish to reddish sands, with interlayer of silt and clay. The gully sides fail by slumping while its head falls mainly by toppling and sliding (Figure 2). The discharge velocity into the gully at peak flow is estimated at 108m/sec and this may continue for over two hours after a heavy down pour (Owuama, 2001). The topography of Okwu Akpulu is undulated but generally dips southwards with a 3% slope on the average. Thus the undulating nature of Okwu Apkulu contributed to the problem of the gully in the area.

Based on interactions and informal interviews with community members during this research field work, it is estimated that about 85% of Okwu Akpulu people are peasant farmers. They derive their main income from sales of agricultural produces like cassava, melon, yam, cocoyam, maize, palm oil, vegetable and fruit others depends in hunting and other agro forestry by-product for their little income. It is important to assess the negative impact of gully erosion to household economy and that of Ideato north communities affected. According to Burrow (1980) soil erosion has critical effects on urban and rural development. At present, it is the single most important environmental degradation problem in the developing world (Ananda and Herath 2003).

Troeh *et al* (1980) indicated that gullies are described as small, medium and large, according to dept and width9 medium sized gullies are between 1m to 5m deep. They further stated that gullies are considered to be active as long as erosion keeps the side bare of vegetation and inactive when they have been stabilized by vegetation. Gully erosion is an advanced stage of rill erosion much as rill erosion is an advanced stage of sheet erosion. A gully develops by processes that may take place either simultaneously or during different period of its growth. In engineering terms, the cause of gully erosion is the breakdown of a state of meta-stable equilibrium in the stream of water course (Hudison 1971). He maintained that running water in many form is the greatest agent causing erosion. That gully erosion occurs when the geological formation of an area has been affected by the seasonal variation. FDALR (1980) stated that gully result because the soil has failed, and concentrated run off has flowed on the failed soil, the phenomenon called gully resulted. He opined that man is a major factor in the creation of gully due to deforestation. The action of man on land degradation; according to Taniya (1988) the world has lost an estimated 200 million hectares of cropland due to erosion since farming began.

The reward of the natural vegetation cover for the various activities of farmers exposes the land to direct impact of the rain drop. Since impact of rain is responsible for detachment of soil particle which can then be transported by runoff water and for the breakdown surface to form a seal caused vastly increase in runoff. According to Lai and Russel (1981), the farmer is to be blamed for contributing to erosion. When wrong technique or wrong crops are input to a soil, a chain reaction of dividing productivity and erosion sets-in as soon as natural vegetation on the land is removed. It is continued that land-use or vegetation type conservation carelessly designed, and poorly built manmade structures also help to accelerate erosion. Hudec et al. (2006) observed that the most affected gully erosion areas are underlain by unconsolidated to poorly consolidated sandy materials. The cleaner, more porous and weakly cemented sands are the most prone to gully advance, which increases directly with an increase in the proportion of grains, more than 1 mm. in diameter. Ezezika and Adetona (2011) concluded that community-based, low-technology land management practices and public awareness programs through workshops could halt the development of many gullies in the Southeastern region of Nigeria. In this case, universities need intensify effort towards sustainability studies on erosion, and report findings in the form of public sustainability seminars.

Factors affecting formation and rate of gully erosion

A review of the opinion of selected scholars on the causes of gully erosion mainly in south-eastern Nigeria is hereby presented. *Floyd (1965)* attributed gully erosion to Soil characteristics and human activities. *Ofomata (1965)* saw gully erosion as mainly due to soil characteristics, but less human activities. *Ogbukagu (1976)* maintained that gully erosion is mostly due to geologic set- up and soil characteristics. *Egboka & Nwankwo (1985)* uphold hydrogeological and geotechnical parameters as causative agent in the generation of erosion in the rain forest belt of Nigeria. *Nwajide & Hogue (1979)* identified topography, climate, and soil characteristics as major causes. *Smith (1995)* agreed that increasing population pressure is a major accelerator of gully erosion. *Abegunde (2003)* observed that deep gullies (>15m) and shallow gullies (<15 m) are developed by run-off water. *Ellison (2007)* holds on amount of raindrops, the intensity, and diameter of the drop as key factors. *Obiefuna and Adamu (2011)* recognized geological and geotechnical parameters as main causative agents in the formation of gullies. The varying opinions of these researchers become significant from one location to another. Thus what might be the cause(s) of erosion in a locality may not apply in another locality. Causative agent(s) of gully erosion may reduce or increase, thereby mitigating or aggravating erosion respectively.

Man made factors: Poor land use, poor road construction and design, Mining, include inappropriate location and abandoned borrow pits. Vehicle trails and cases of overgrazing. ***Physical factors:*** Precipitation; Energy of rainfall (E) = 0, 199 + 0, 0873 log I) which depends on duration, size and erosivity of precipitation (*Ellison, (2007).*

E = kinetic energy of the rainfall per mm of rain amount (MJ/ha mm), and

I = rainfall intensity (mm/h).

Total kinetic energy of the rainfall $E_t = P.E$ and hence erosivity (Troeh *et al* 1980) With P = quantity of precipitation (mm)

Topography: Elevation, size and shape of a drainage area, as well as the length and gradient of its slopes. The slopes of the land surface over which water flow influences runoff velocity and volume

Materials and method

Field Techniques

The field techniques bordered on two stages of mapping; the first stage was identification of the gully erosion channels, while the second stage involved measurements with GPS and collection of soil samples into brown polyethylene. GPS was used to measure elevation along the erosion channel and coordinate of the gully erosion site. Oral interview was also conducted with selected members of the community. Gully sites and drainage channels including the natural erosion channels and the concrete control channels were traced by foot. Three soil samples were collected from the accessible gully face at 1 m interval. Usually the weathered gully face was cut off, in order to obtain samples from fresh surface. Sample were serially numbered at the point of collection, and followed by laboratory analysis as samples were subjected to a number of laboratory tests including grain size distribution (Sieve analysis), direct shear test, compaction test and Atterberg limit tests. Depth of incision and width of the gully were measured with tape. The depth of incision measured 50 m, and width was 40 m. The gully head estimated incision point has a distance of about 200 m to nearest residential area.

Laboratory Techniques

The following geotechnical parameters were determined as follows: *Atterberg Limit Test;* The Atterberg or consistency limit tests include liquid limit and plastic limit tests.

Compaction Test (Proctor); Determine optimum moisture and the maximum dry density relationships of the soils to erosion. *Grain Size Distribution;* Measured clay-silt content of the soil, and detail particle size analysis. *Direct shear test:* One of the most important engineering properties of a soil measured the soil's erosion shearing resistance.

Statistical Analysis

Data obtained were subjected to statistical analysis to produce the following curves:

- Liquid limit flow curves as number of blows against percentage moisture
- Dry density against percentage moisture to obtain optimum moisture content (OMC) and maximum dry density (MDD) mg/m^3
- Percent passing sieve vs. sieve size and
- Shear stress (KN/m^2) vs. Normal stress (KN/m^2)

Results

Gully site has thick vegetation cover to have aided erosion control, but the prevailing natural trees and plants, and nature of soil are not supportive (Figure 2a). A secondary erosion channel to the active gully head is developed off the concrete control channel following frequent overflow or the inadequate size, and alignment of the concrete channel at spill points. At some locations, palm tree trunks are used by villagers for improvised pedestrian bridge (Figure 2b).

2a **2b**

Figure 2; a. Trees slumped and grow in the gully b. Secondary drainage channel to the gully

3a **3b**

Figure 3; a. Inprovised wooden bridge carried away by flood b. A recent gully slide surface, gully face, slope and deep consists of sluped trees or vegetation cover, prevents complete view. Gully vegetation predominantly consist of indian bamboo (Bambus Vulgaris) planted originally to check advancement of the gully.

Different waste and valuable materials, including shoes, clothing, and household items can be found along the erosion channel. Villagers testified horrible cases of buried corps exhumed from another community and transported to Akpulu by erosion. Full length wood planks previously used for improvised bridge can be found in the drainage channels (Figure 3a). Figure 3b is a section of the Akpulu gully showing width of recent slide surface; Slope (α) of gully wall varies from 55o around gully deep (15-18 m) to 75o around gully top.

Natural slope of erosion drainage channel

Five elevation points were measured at 200 m interval from the gully head, and along the natural drainage channel (Figure 4) . A gradual increase in elevation was observed from the gully head to 1.0 km upland. By direct reading using a GPS, the following data were collected (Table 1).

Table 1: GPS field measurements

Number	GPS Elevation	Distance (m)	GPS Coord. N	GPS Coord. E
1	443	0	05.55’286”	07 08’ 541”
2	467	200	05. 55’ 286”	07. 08’ 543”
3	487	400	05. 55’ 308”	07. 03’ 556”
4	492	600	05. 55’ 321”	07. 03’ 601”
5	505	800	05. 55’ 338”	07. 03’ 613”
6	518	1000	05. 55’ 339”	07. 08’ 618”

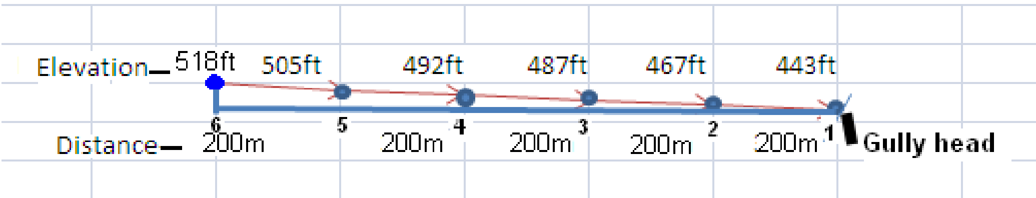

Figure 4 Natural slope of erosion channel

Figure 4 is based on the GPS data of Table 4 giving a total vertical distance of 75 ft (22.9 m) to a total horizontal distance of 1000 m. This represents a drainage slope of **0.02** across Akpulu area, along the natural erosion channel. According to Obiefuna and Adamu (2011), the engineering aspects of soil erosion control should be geared towards changing the slope characteristics of the area so that the amount and velocity of run-off are decreased.

4.2 Result of grain size analysis

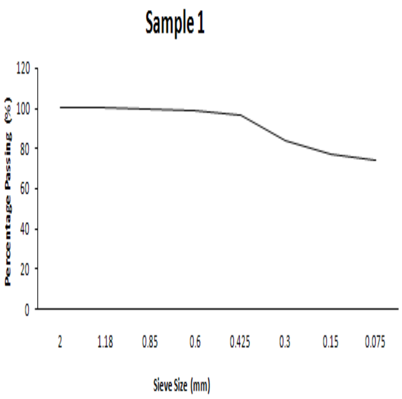

Fig 5a

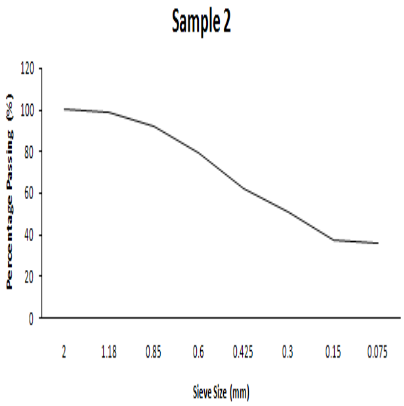

Fig. 5b

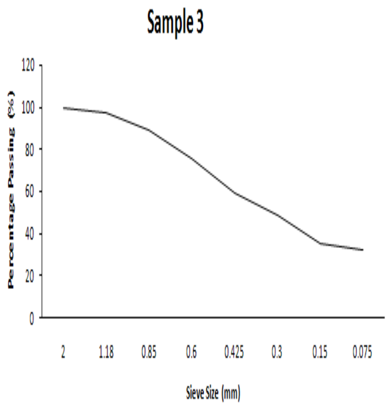

Fig. 5c

Figure 5 and 6 shows graph of percent grain passing sieve against sieve size, and weight retained against sieve size respectively of the three samples.

Sample 1, collected 1 m from surface has 74.7% fines. This is the highest percentage of fines less 0.075mm or clay/silt content of the three sample depths. Sample 2, collected 2 m depth from surface contains 37.8% fines, about half the clay/silt content of sample 1. Sample 3, collected 3 m from surface has 31.5% of fines. The three samples consist of red earth cohesionless soil. This result confirms that the Akpulu soil has increasing downward coarse sequence. The topsoil is predominantly silty, making the soil easily erodible. Presently a gully measuring 15-18m deep, 9-12 m wide to hundreds of meter long is observed.

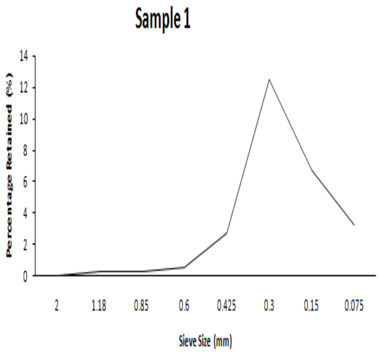

Fig. 6a

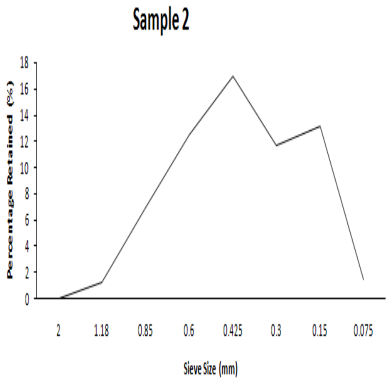

Fig. 6b

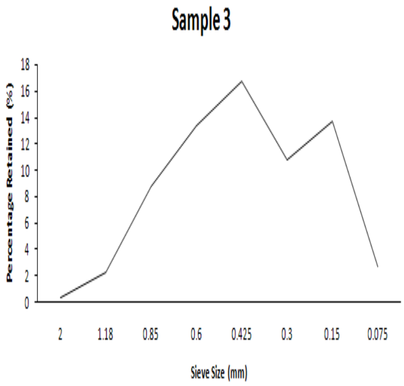

Fig. 6c

The basic principle of Akpulu gully erosion is the fast dissolution of the prevailing high silt content of the topsoil. The silt easily dissolve and transported as wash load carried within the water column as part of the flow.

Shear test analysis

Because of the low sand grain content, high flow velocities, the significant channel slope, greater of the grains will become suspended load, compelling low shear strength to the soil. Figure 7 illustrates the result of direct shear test for samples 1-3. Result show average shear stress of
27.5 KN/m^2. This is naturally low to resist erosion even under reserved vegetation canopy.

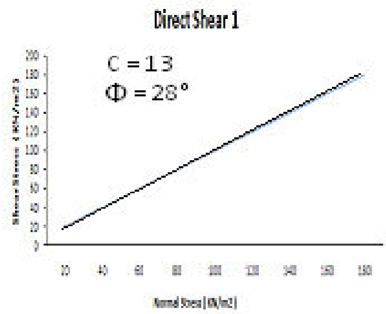

Fig. 7a

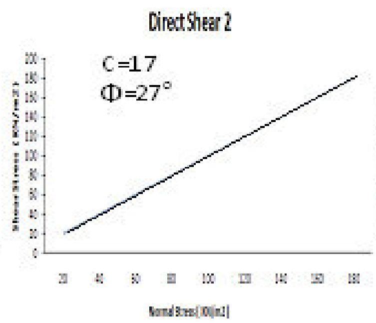

Fig. 7b

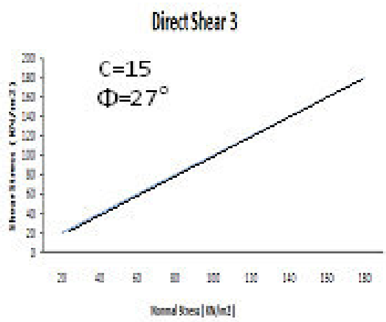

Fig. 7c

Optimum Moisture Content (OMC): The moisture content at which the maximum possible dry density is achieved *for a particular compaction energy or compaction method.* Figure 8 show dry densities in mg/m^3 corresponding to the maximum point on the moisture content/dry density curve reported as the maximum dry density (MDD) to the nearest 0.01. The percentage moisture content corresponding to the maximum dry density on the moisture content/dry density curve is reported as the optimum moisture content (OMC) and quoted to the nearest 0.2. Result show plasticity index 10.15-13.7%, average OMC of 12.7%, and average MDD of 2.01Mg/m^3 for the erosive top layer of Akpulu soil.

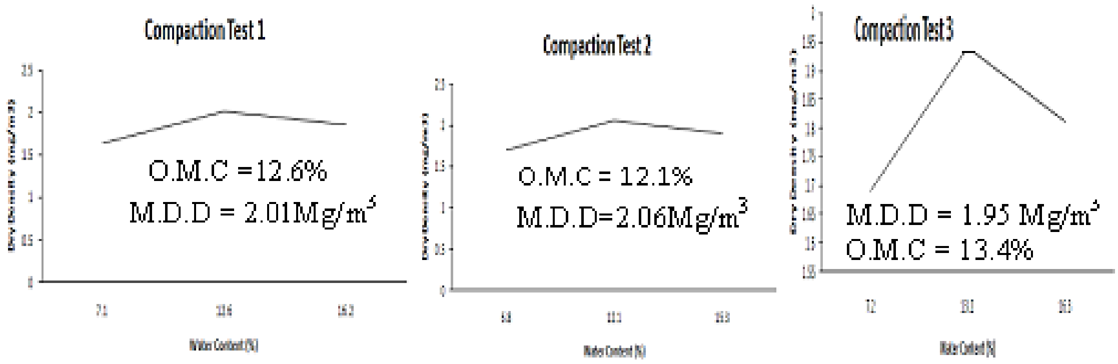

Figure 8. Graph of compaction test for the three soil samples

Okunade 2007a, working on the geotechnical properties of major problem soils of parts of Imo state, including around the study area, reported the following properties; liquid limits 20 – 70%, plasticity indices (5 – 55) %, plastic limits 10 – 50) %. He found MDD between 1.7- 2.1g/m^3 and OMC between 9- 24%. Okunade's work justifies our findings with respect to liquid limit, OMC, plasticity index, and MDD. It is imperative therefore to conclude that Akpulu soil on its own is a major problem soil; highly susceptible to gully erosion.

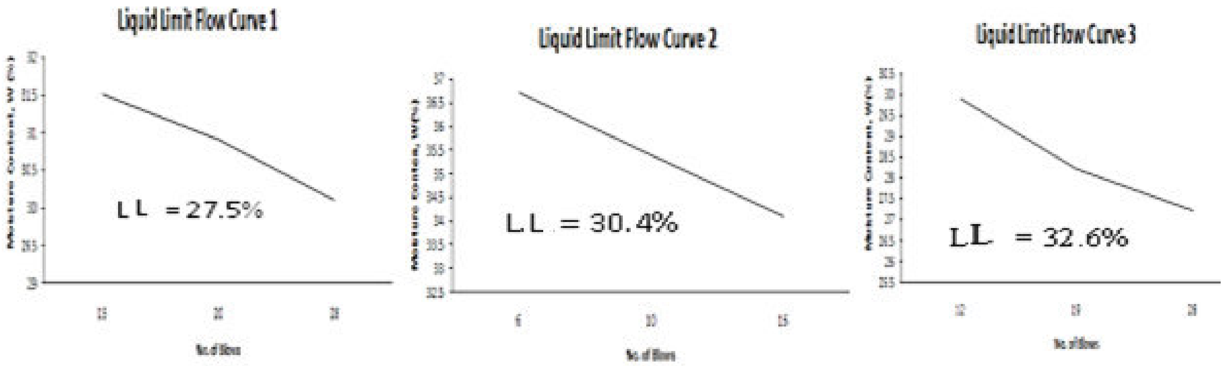

Figure 9. Graph of compaction test for the three soil samples

Figure 9 illustrates the result of liquid limit test on the three samples with average liquid limit of 30.16%. Two plastic limit (PL) tests for each of the samples gave average of 17.35%, and plasticity index (PI) = LL-PL gave average of 10.15% for sample one. Sample 2 has average PL of 22.75%, and a PI of 7.65%, while sample 3 has average PL of 18.9, and a PI of 13.7%. Onweremadu et al. (2007) related pedality and soil moisture retention characteristics to erodibility of selected soils. They observed that liquid limit of 10-62%, plastic limit of 10-45%, and plasticity index of 0.0-17.8% ranges, show high variation that increases erodibility of soil. Comparing these values with our findings confirms Akpulu soil as naturally highly erosive.

Geometry of Akpulu gully

Figure 9 illustrates the type geometry of Akpulu gully. The fine texture of Akpulu intact soil with high silt content and fines supports gully erosion. This is particularly effective with the silt content increasing upwards (fining upward sequence). A situation of this nature reduces soil strength and cohesion, thereby enhances soil erosivity to a critical depth. The critical depth is the depth where erosion has stabilized due to increased slide embankment. Slide embankment consist soil dislodged by sliding, partially washed, with greater percent of the silt dissolved, thereby increasing cohesion. In Akpulu gully, a critical depth of 15-18 m was estimated, as provided by the amount of sliding and grain retention supporting stabilization. Gully width varies from 9 to 12 m, which combines with the gully depth to make the gully area terrible, impassable, and a living environmental hazard to the immediate affected area of Akpulu community.

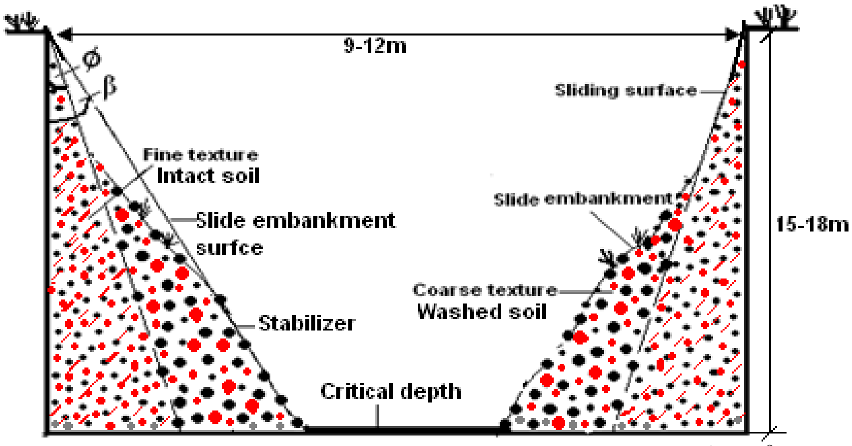

Figure 9. Typical geometry of Akpulu erosion gully; Sliding angle ($\phi = 75^o$), Slide embankment angle ($\beta = 60^o$)

Summary and conclusion

To check erosion, efforts should be directed towards identifying, removing or correcting the causative agent(s). This study has confirmed that roads and building constructions are the major activators of erosion problems in Akpulu while soil characteristics such as high silt content are the support factors. The erosion has affected the value of lands negatively in the affected communities. It has reduced the rate of physical development in the area. Natural environmental conditions such as gradient of topography and climatic conditions of the rain forest belt are contributing factors responsible for soil erosion in Akpulu. Inadequacy of the existing engineered concrete drainage channel conducting flood from Umuchu to Akokwa, through Isiokpo, and from Uga to Akpakporo River in Akpulu contributes to the soil erosion problem in Akpulu. Soil erosion has resulted in the loss of lives and properties in the community. It causes siltation and contamination of rivers and streams in the area. Soil erosion has reduced the agricultural output of the community thereby increasing poverty and hunger in the area**.** The erosion menace has drastic effects on ecosystem of plants and several organisms inhabiting the affected area.

The relevant authorities have not made much effort towards combating the menace of erosion in the study area, whereas gully erosion is the greatest environmental hazard threatening the part of Nigeria. The present situation calls for emergency response to save a large segment of the community residential area from being submerged in the next few years. Recommended emergency response operations may include the following control measures:

(a) *Engineering:* Engineering structure such as dam, dikes, concrete drainage channel, spill ways, retaining walls, etc. may be designed and constructed wherever suitable to divert or channel flood to nearby streams. This will slow down flow rate of flood, and reduce its erosive energy.

(b) *Biotechnology:* Identification and planting of local plants and tree that can help in controlling the erosion in Akpulu is urgent. In south-east Nigeria, the following plant species could be used for gully stabilization, Anacardium Occidentalis, Acioa barteri, Pentaclethra Macrophylla, Bambus Vulgaris, Gmelina Araborea, Centrosema Pubescens, Pinus Caribeam, Eupatorium Voge iii, Baphia Nitida, Elaesis Guinesis Panicum Maximum and Pennisetum Purpureum. Tree planting can be either through;

- Forest tree planting that could regenerate the soil by its leaf falls, which in turn decomposes and encourages under growths to cover the soil. The leaf litters also makes the soil absorb more water and thus reduces runoff.

- Establishment of orchards of fast-maturing fruit trees or multipurpose trees that could also help to rejuvenate the soil and produce food.

The following recommendations are therefore made

- *Environmental impact assessment:* Road contractors will present environmental impact assessment (EIA) of their road project for approval by the government authority prior to commencement of the project. The EIA must contain a proper drainage design at both sides of the road channeled to the nearest water way.

- *EIA implementation:* Government regulation through a special trained environmentalist should monitor the EIA implementation during execution of the road project.

- *Community efforts:* The affected communities will help in conserving their natural environment through monitoring their activities to avoid initiating erosion.

- *Road drainage maintenance workers:* Establish local road drainage maintenance workers (RDMW) as downstream staff of the ministry of works and housing to regularly clean drainages, and allow free flow.

- *Public enlightenment;* Government and public officials must know about erosion problems.

There must be a regular environmental education program to educate civil servants, teachers and the rural masses. This environmental education program may hold in market squares, and in churches, courtesy of institutional linkage with the ministry of environment. Farmers will be informed about the best farming method so that their farm practice will not have negative impact on the environment. This program will help to enlightened the public on environment best manage practice (EBMP).

- *Sustainability studies:* There is urgent need for sustainability studies by universities, polytechnics, and the colleges of education in Nigeria. For example, a sustainability study could imply yearly monitoring and assessment of Akpulu gully erosion site, and reporting every two years. Studies of this nature will enable close monitoring and assessment of control measures put in-place, ecosystem management, and early warning or environmental alert. Sustainability studies are recommended for hundreds of other similar and greater erosion sites in the south-eastern Nigeria.

REFERENCES

Abegunde, A.A., Adeyinka S. A., Olawuni P. O., Oluodo A. O (2003):"The impact of Erosion on Rural Economy: The Case of Nanka in Anambra State of Nigeria". In Urban Finance and Infrastructure Development in Nigeria. Yomi Fawehinmi (ed.) Atlantis Books. PP227-243.

Ananda J. and Herath S. (2003) – "soil erosion in Developing countries:Ps 343 – 53

Burrow R. L (1980). Cross-section, velocity, and bedload data at two erosion sites on the Tanana River near Fairbank, Alaska; USDI Geological Survey Open File Report 80-699

Collinet, J. and Valentin, C, (1985). Evaluation of factors influencing water erosion in West Africa using rainfall simulation. Challenges in African hydrology and water resources IAHS Publ, 144: 451-461.

Ezezika O. C., and Adetona O (2011) Resolving the gully erosion problem in Southeastern Nigeria: Innovation through public awareness and community-based approaches; J. of Soil Science and Environmental Management Vol. 2(10), pp. 286-291

Egboka B.C.E and Nwankwo, G.I (1985) – The hydrogeological and geotechnical parameter as causative agent in the generation of erosion in the rain forest belt of Nigeria. J.AFR Barth Sci 3(4), pp 417 – 425.

Federal Department of Agriculture and Land Resources (1980) Technical Report on erosion and wetland of south-eastern Nigeria

Floyd, B. (1965) – Soil erosion and deterioration in eastern Nigeria. The Nigeria geography journal 8(1) pp 33-44

Hudec P.P, Simpson W.F, Akpokodje, E.G, Umenweke, M.O (2006). PROCEEDINGS of the Eighth Federal Interagency Sedimentation Conference (8thFISC), April2-6, 2006, Reno,

Hudson, N. (1971). Soil conservation; Cornell University Press New York p. 35

Nwajide, C.S. and Hogue (1979). Gullying processes in south eastern Nigeria. The Nigeria Field 44/2 p.61-74.

Obiefuna G. I., and Adamu J. (2011). Geological and Geotechnical Assessment of Selected Gully Sites in Wuro Bayare Area NE Nigeria; Research Journal of Environmental and Earth Sciences 4(3): 282-302,

Ofomata, G.E. (1984). The management of soil erosion in Nigeria; Paper presented at the 24th Annual Conference of the Nigeria Geographical Association Kano, April 6-10.

Ogbukagu, H.N. (1976). Soil erosion in the Northern part of the Awka – Orlu uplands, Nigeria Nigeria Journal on Mining and geology 13, pp 6-13

Okin, G.S. (2002). Towards a unified view of biophysical land degradation processes in Arid and semi arid lands pp. 95-97

Okunade, E.A. (2007). Engineering properties of lateritic Adobe bricks for local building construction and recommendations for practice. Medwell journal of engineering and applied sciences 2 Vol. 9 Pp. 1455-1459

Onweremadu E. U., Akamigbo F.O.R., Igwe C. A. (2007) Pedality and soil moisture retention characteristics in relation to erodibility of selected soils; Nature and Science, 5(1), 2007,

Owuama, C.O. (2001). Gully head stabilization measure at an Erosion site in south eastern Nigeria. Journal of the Environmental Studies vol.2, p.48

Russel P. E (1993). Mechanisms for beach erosion during storms; Elsevier; Continental Shelf Research Vol. 13, issue 11 p 1243-1265

Smith, P. (1993). Soil water conservation in Rowland J.P.T (ed) Dry land farming in Africa. C.T.A Macmillan, London and Basingtone p.142

Taniya, (1988). Geography of Nigeria development Ibadan- Heinemann Educational Books Nigeria Limited

Troeh, F.R. and Donahue, D.L. (1980). Soil and water conservation for productivity and environmental protection; Prentice hall Inc. Englewood Cliff p. 83-110