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Geotechnical Assessment for Gully Erosion Control and Management in Agulu-Nanka, Southeastern Nigeria

[1]H.O. Nwankwoala and [2]T. Igbokwe

[1]Department of Geology, University of Port Harcourt, Nigeria
[2]Institute of Natural Resources, Environment and Sustainable Development (INRES), University of Port Harcourt, Nigeria

Abstract: This study is aimed at providing geotechnical parameters and data of the soils, identify problems and features making the area susceptible to gully erosion and proffering sustainable solutions to problems of gully erosion in the affected areas of AguluNanka, Anambra State, Southeastern Nigeria.Standard methods were used in the geotechnical assessment. 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, natural moisture content ranges from 1.71% –12.53% - this is because the soilshave low retentive capacity, hence cannot hold much water. Compaction test shows the maximum dry density (MMD) and the optimum moisture content (OMC) of the soil to be very low; plasticity index ranges from 0–33.283; compacted bulk density between 1.55- 1.76 kg/m^3; the specific gravity ranges 1.68 – 2.06, with permeability ranging between 1.32×10^{-3} and 1.63×10^{-3}cm/sec. This indicates that the area is highly prone to gully erosion which has proven to be detrimental to both agricultural activities and community development programs. The result also shows that there have been some anthropogenic activities increasing the susceptibility of the area to erosion.Results obtained revealed that the soils in the study area are cohensionless, not compact and non-plastic, hence the menace of gully erosion. A highly exaggerated emphasis and predominance on engineering control measures involving construction of check-dams, bulldozing of earth materials, backfilling with soils and compacting, or construction of drainage or cut-off flood channels do not seem to be successful in checking gully incipient and extension or expansion in Nankaand its environs. This study will helpin the implementation of better environmental policies that are geared towards effective harnessing and beneficial use of the environment for agricultural and community development use.

Key words: Gully erosion · Soils · Permeability · Geotechnics · Agulu-Nanka

INTRODUCTION

The removal of top soil has caused several environmental degradations, which in turns makes life difficult in terms of agricultural participation because of loss of soil nutrient from the top soil as well as reduction of the surface area for agricultural activities, transportation, housing and desertification. The fact that erosion is a natural occurrence is not in doubt, but human activities have aided the rate at which erosion occurs globally.

Traditional owners, cattle glaziers and other local residents in the catchment are usually concerned about the economic, cultural and environmental impacts of local gully erosion and downstream sedimentation. As a matter of fact, preventing the formation of a gully is much easier than controlling it once it has formed. If incipient gullies are not stabilized, they become longer, larger and deeper [1]. Under certain climatic and geological conditions, vertical gully banks can easily become as high as 20-30 meters or more. This type of gully can engulf hillside farming areas, grass lands and even forest lands. In most cases, it is not possible to stabilize those gullies because of the huge landslides which occur on vertical (20-30m) gully banks after heavy rains and alternate freezing and thawing [2].

Corresponding Author: Dr. H.O. Nwankwoala, Department of Geology, University of Port Harcourt, Nigeria.

Gullies greatly interfere with normal farming operations such as cultivation, mustering stock, general access and water supply. They present many problems to landholders as they are a continuing source of soil loss. Sediment transported from gullies may be deposited in dams leading to a reduction in capacity and often has additional detrimental effect on other man-made drainage infrastructure such as the blocking of pipes and culverts. Sediment mobilized in drinking water catchments by erosion can reduce water quality for downstream users. Water quality is affected by the increased turbidity and the nutrients adsorbed on the sediments can pollute the water potentially leading to algal blooms. In-stream habitat for aquatic plants and animals may also be degraded by the smothering of the river bed with silt and sand. Sediment covers vegetation and inhibits growth.

Due to high rate of rainfall in South-eastern part of Nigeria, most erosion gullies seen within the area has been attributed to high rainfall intensity, with topography, poor engineering and agricultural practices contributing immensely to the rate of soil degradation [3, 4, 5]. Irrespective of these human activities that tend to accelerate erosion processes, some geological influences and soil properties within the area also make it prone to erosion [6]. Natural causes of gully erosion and landslides are high rainfall intensity, low vegetation cover, high altitude, strength of soils and surficial sediments and groundwater/soil interactions [7, 8, 9].

Ofomata [10] 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. As it is known by many, gully erosion is the worst form of erosion that apart from snatching fertile lands is the main source of sediment load arriving at reservoirs. The spread of gully is seen as a cancer affecting many communal grazing spots, foot paths, cattle trafficking lines, roads, etc. It also obstructs field operations and movement. The subsoil and gravel mined by erosion is a major threat on lower lying fertile agricultural fields by burying them under. A lot of farmers' fields are presently affected and complaining that their lands have been taken away by debris which they cannot remove. Many low-lying areas and public infrastructure facilities have been overburdened / overlaid by subsoil which is not fertile. The subsoil is composed of course sand, gravel, cobbles and boulders. Although there are many on-going efforts carryon by the various supporting projects and the regular government's land management program to rehabilitate gullies, the scale at which it is expanding has not been adequately coped up with the existing level of treatment (Nile Basin Initiative, 2012). It is this unresolved problem of gully erosion and the application of inadequate measures to tackling the problem that poses the major problem in his study. Akunobi [11]; Chikweluand Ogbuagu [12]; Obi and Okekeogbu [13] conducted several studies on gully erosion menace in many parts of southeastern Nigeria. The purpose of this study was to investigate: Geotechnical analysis and geographic information system (GIS) application for sustainable catchment management and gully erosion control in AguluNanka, Anambra State. Specifically, the study will seeks to: (i) provide geotechnical parameters and data (permeability, liquidity, plasticity, consistency, moisture content and compaction) of the soils available in the area (ii) Identify problems and features making the area susceptible to gully erosion, (iii) Proffering sustainable solutions to problems of gully erosion in the affected areas of AguluNanka, Anambra State, Southeastern Nigeria.

The Study Area: The area of the study, AguluNanka in Anambra Statefalls within the Nigerian meteorological zone characterized by warm temperature days and moderately cool nights. Two distinct climatic divisions are demarcated. These are the dry and rainy seasons, representing two broad periods of significant but contrasting variations in weather parameters and hence geopedologic stability [14]. Figure 1 is the landuse/landcover map of Nanka. The rainy season extends between April and October (though it extends between March-and November when prolonged), with a short period of momentary dryness known as August break (since it usually occurs in August). Annual rainfall averages about 1800 millimeter with prominent peak period in September [15].

The precipitation varies 303 mm between the driest month and the wettest month. The variation in temperatures throughout the year is 3.5°C.

Methods of Study: Coordinates taken for the Gully Sites in Nanka

- N 6236.7872; E7453.9832
- N 6220.9364; E7458.5948
- N 6232.064; E754.2252
- N 6228.7196; E7455.6032
- N 6220.7816; E 7451.2292
- N 6232. 4132; E7449.0548
- N 6234. 3932; E759.51
- N6227.1176; E 7453.0308
- N 6311.6208; E7433.6612
- N 6314.6208; E7445.282

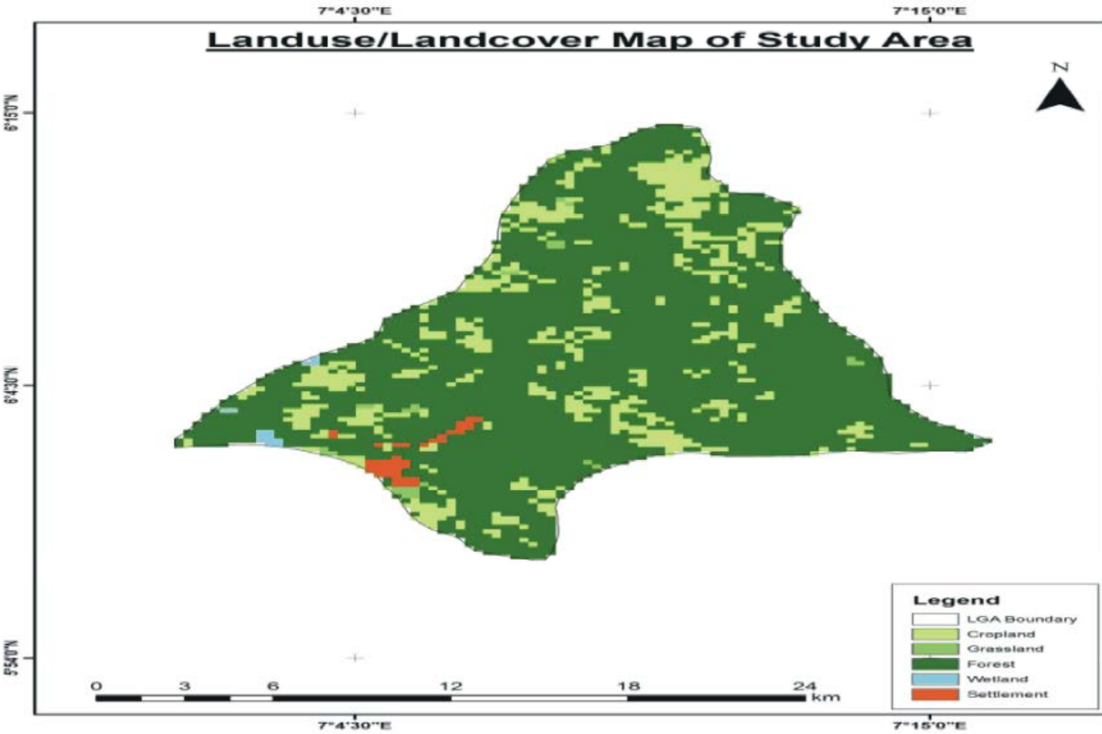

Fig 1: Satellite view of a landuse/landcover map of Nanka

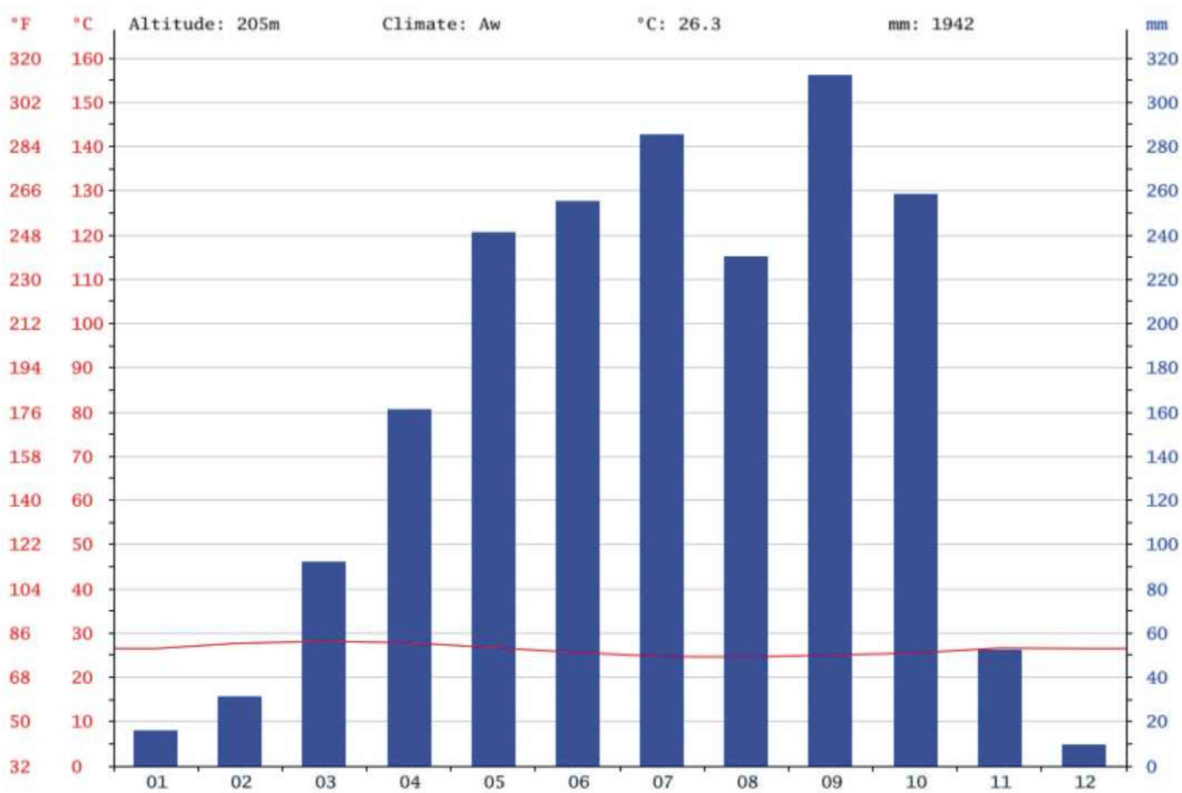

Fig. 2: Climate Graph / Weather By Month inNanka

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature (°C)	26.5	27.7	28.1	27.8	26.7	25.6	24.7	24.6	25	25.5	26.6	26.5
Min. Temperature (°C)	21.5	22.5	23.4	23.2	22.3	21.6	21.3	21.7	21.2	21.3	22	21.3
Max. Temperature (°C)	31.6	32.9	32.9	32.5	31.1	29.6	28.2	27.6	28.9	29.8	31.3	31.8
Avg. Temperature (°F)	79.7	81.9	82.6	82.0	80.1	78.1	76.5	76.3	77.0	77.9	79.9	79.7
Min. Temperature (°F)	70.7	72.5	74.1	73.8	72.1	70.9	70.3	71.1	70.2	70.3	71.6	70.3
Max. Temperature (°F)	88.9	91.2	91.2	90.5	88.0	85.3	82.8	81.7	84.0	85.6	88.3	89.2
Precipitation / Rainfall (mm)	16	31	92	161	241	255	285	230	312	258	52	9

Fig. 3: Weather by Month/Weather Averages in Nanka

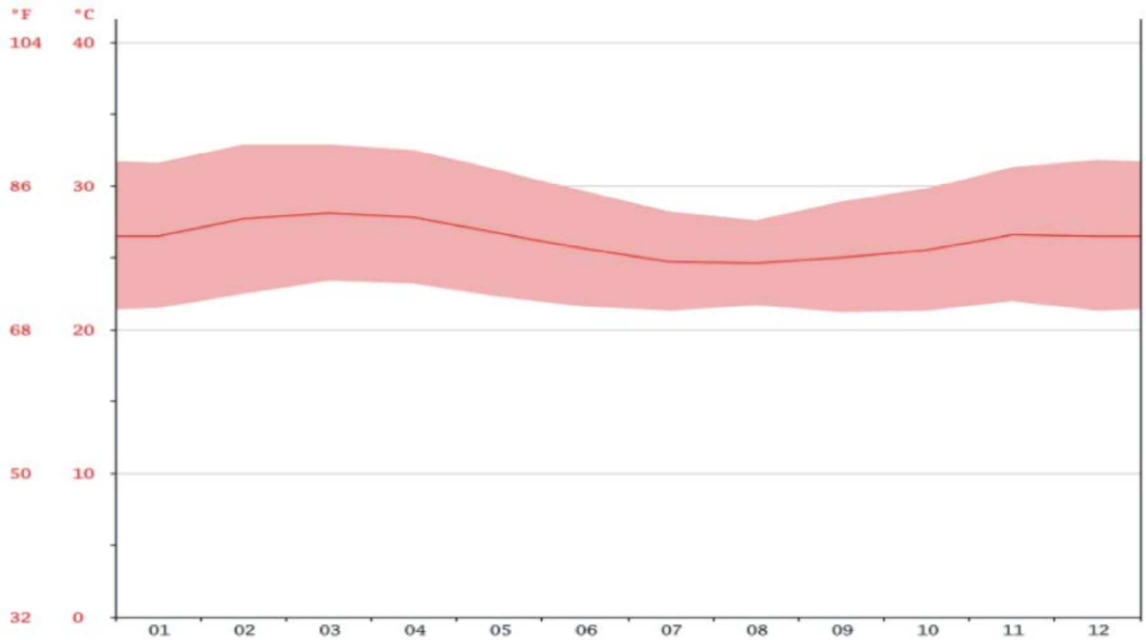

Fig. 4: Average Temperature of Nanka

Gully Characteristics:

- Gully Width = Range is between 0.13m-397.20m
- Gully length = Range is between 10m- 4, 369.20m
- Gully Height = Range is between 2m-52.96 m
- No. of gullies sited = 12 gullies (some were concentrated)

Soil Parameters

Permeability Test: The soil permeability is a very important factor to study the behavior of soil in its natural condition with respect to water flow. The constant head method is particularly suitable for relatively coarse grained soil such as sands and gravel.

$$V = q/A = Ki. \quad (1)$$

where:
V = velocity of flow or average discharge velocity
q = discharge per unit time;
A = total cross-sectional area of soil mass, perpendicular to the direction of flow;
i = hydraulic gradient;
k = Darcy's coefficient of permeability

If a soil sample of length L and cross-sectional area A, is subjected to differential head of water $h_1 - h_2$, the hydraulic gradient i will be equal to $[(h_1 - h_2)/L]$ and we have:

$$q = k.\ [(h_1 - h_2)/L]\ A \quad (2)$$

where hydraulic gradient is unity, k is equal to V. Thus, the coefficient of permeability, or simply permeability is defined as the average velocity of flow that will occur through the total cross-sectional area of soil under unit hydraulic gradient. Dimensions are same as of velocity, cm/sec.

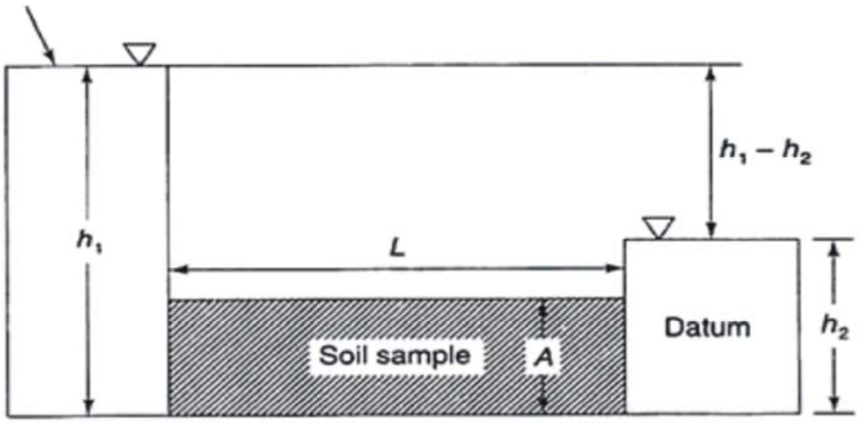

Fig. 5: Hydraulic gradient determination

Determination of Moisture Content: The moisture content of a soil sample is defined as the mass of water in the sample expressed as a percentage of the dry mass, usually heating at 1050C, i.e.

Moisture content, w = W D M M x 100 (%) (3)

where, MW = mass of water MD = dry mass of sample

Sample Requirements

Sample Mass: The mass required for the test depends on the grading of the soil, such as:

- Fine-grained soils, not less than 30 grams
- Medium-grained soils, not less than 300 grams
- Coarse-grained soils, not less than 3 kg

Soils group (i) Fine-grained soils: Soils containing not more than 10% retained on a 2 mm test sieve(ii) Medium-grained soils: Soils containing more than 10% retained on a 2 mm test sieve but not more than 10% retained on a 20 mm test sieve (iii) Coarse-grained soils: Soils containing more than 10% retained on a 20 mm test sieve but not more than 10% retained on a 37.5 mm test sieve.

Accuracy of Weighing: The accuracy of weighing required for test sample is as follows; (a) Fine-grained soils: within 0.01 g. (b) Medium-grained soils: within 0.1 g. c) Coarse-grained soils: within 1g.

Safety Aspects:

- Heat-resistant gloves and / or suitable tongs should be used to avoid personal injury and possible damage to samples.

Determination of Consistency or Liquidity Index of Soil (LI): The liquidity index (LI) is used for scaling the natural water content of a soil sample to the limits. It can be calculated as a ratio of difference between natural water content, plastic limit and liquid limit:

LI=(W-PL)/(LL-PL) (4)

where W is the natural water content

Determination of Plasticity of the Soil: The Plastic Limit (PL) is determined by rolling out a thread of the fine portion of a soil on a flat, non-porous surface. The procedure is defined in ASTM Standard D 4318. If the soil is at moisture content, where its behavior is plastic, this thread will retain its shape down to a very narrow diameter. The sample can then be remolded and the test repeated. As the moisture content falls due to evaporation, the thread will begin to break apart at larger diameters. The plastic limit is defined as the moisture content where the thread breaks apart at a diameter of 3.2 mm (about 1/8 inch). A soil is considered non-plastic if a thread cannot be rolled out down to 3.2 mm at any moisture possible.

Determination of Consistency of the Soil

Determination of Wet-Soil Consistency: Testing is done when the soil is saturated with water, as, for example, immediately after a good rainfall. First, determine stickiness, that is, the ability of soil materials to adhere to other objects. Then, determine plasticity, that is, the ability of soil materials to change shape, but not volume, continuously under the influence of a constant pressure and to retain the impressed shape when the pressure is removed.

RESULTS AND DISCUSSION

Results of Geotechnical Analysis

Soil Compaction Test: Soil compaction was carried out with the aim of determining the moisture density relationships of soils.

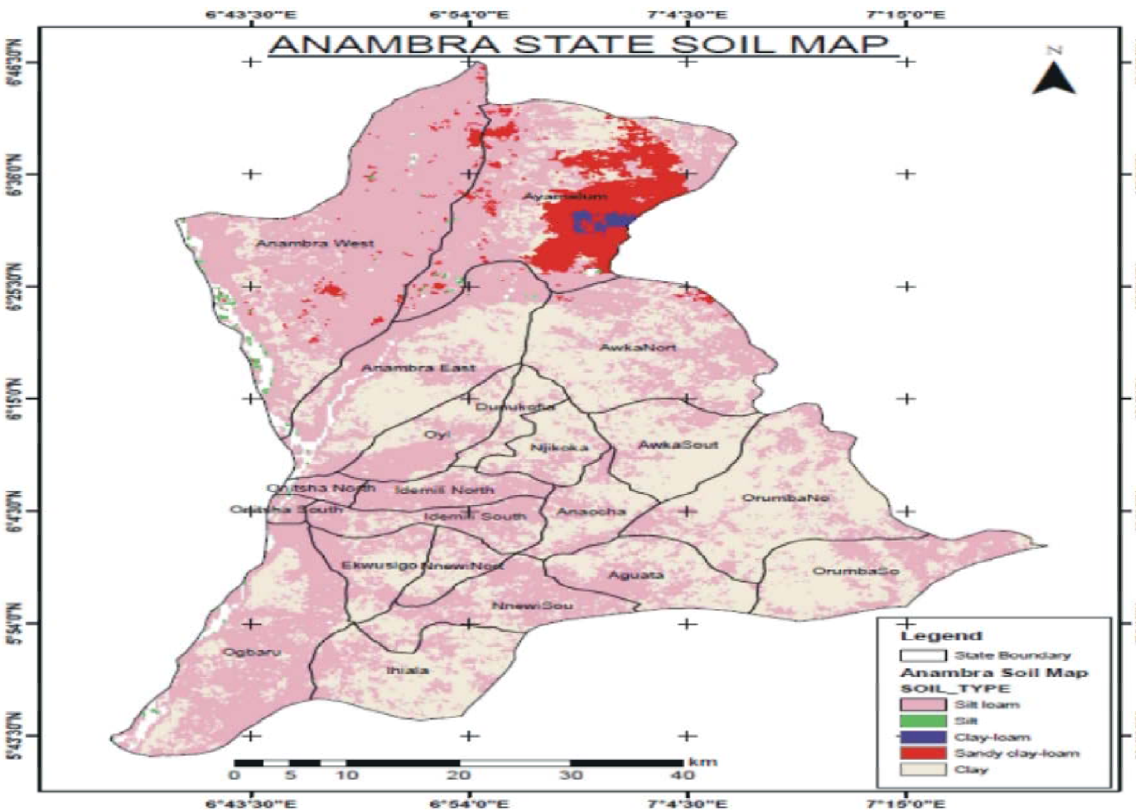

Fig. 6: Map of Study Area Showing Soil Distribution in the State (Source:ASTER Image (DEM) - Advanced Spaceborne Thermal Emission and Reflection Radiometer) (2019)

Fig. 7: Satellite image (Digitized Map of Agulu-Nanka as Study Area)

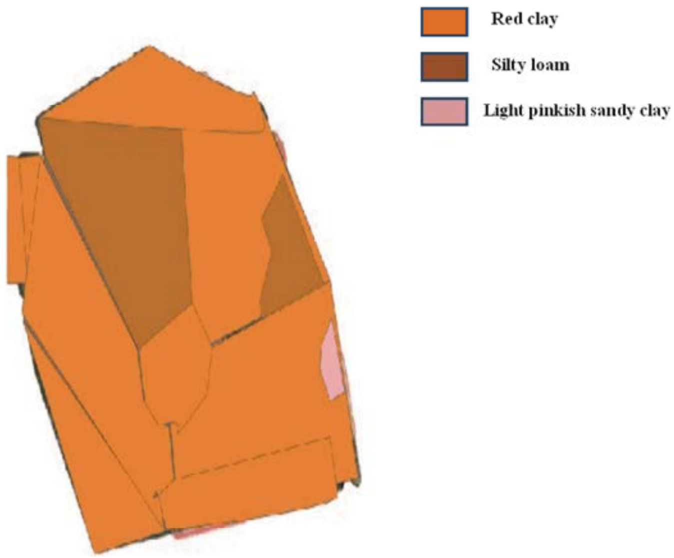

Fig. 8: Map of Study Area Showing Soil Distribution

Fig. 9: Measuring of Gully Size

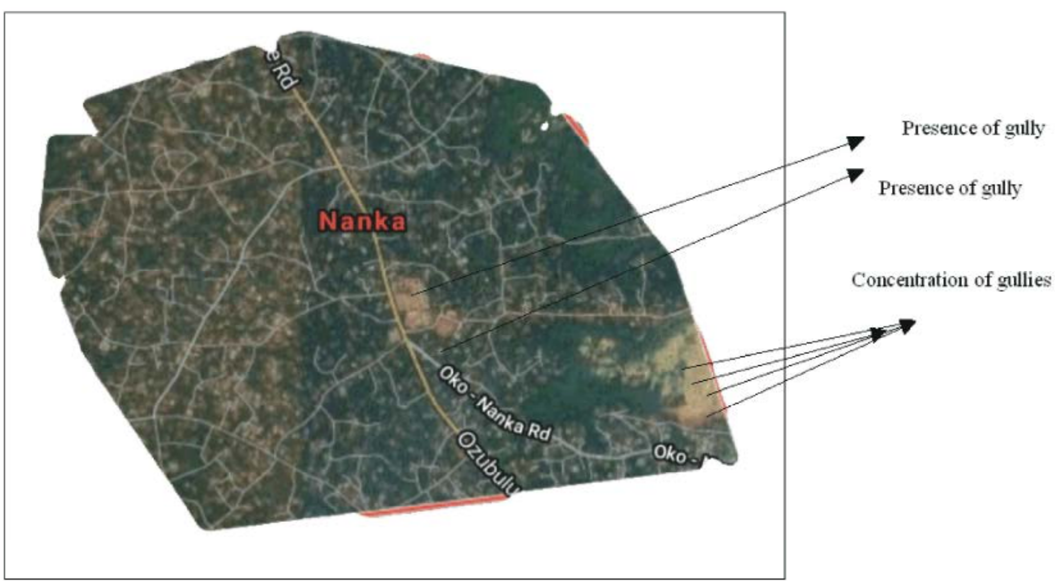

Fig. 10: Map of Gully Sites within Study Area

Table 1: Soil Compaction and Moisture Content Test Results for Sample A

S/N	No of Procedures	1	2	3	4	5
1	Moisture can No	SCM1	SCM 2	SCM 3	SC4	SC5
2	Mass of cup + wet soil	150	150	150	150	150
3	Mass of cup + dry soil	147.37	147.85	147.56	147.22	147.20
4	Mass of water	2. 63	2.15	2.44	2.78	2.80
5	Mass of cup, g	14.0	14.50	14.70	15.20	14.50
6	Mass of Dry soil	133.37g	133.35g	132.86 g	132. 02g	132.70g
7	Mass of wet soil, g	136	135.50	135.30	134.80	135.50
8	Water content, w%	1.75	1.43	1.63	1.85	1.87

Mean Water Content, w% = 1.71

Table 2: Soil Compaction and Moisture Content Test Results for Sample B

S/N	No of Procedures	1	2	3	4	5
1	Moisture can No	SCM6	SCM7	SCM 8	SCM9	SCM10
2	Mass of cup + wet soil, g	150	150	150	150	150
3	Mass of cup + dry soil, g	124	136	138	126	131
4	Mass of water, g	26	14g	12g	24g	19g
5	Mass of cup, g	14.0	14.50	14.70	15.20	14.50
6	Mass of Dry soil, g	110g	121.50g	123.3 0g	110.80g	116.50g
7	Mass of wet soil, g	136	135.50	135.30	134.80	135.50
8	Water content, w%	19.11	10.70	10.86	11.28	10.70

Mean Water Content, w% = 12.53

Table 3: Soil Compaction and Moisture Content Test Results for Sample C

S/N	No of Procedures	1	2	3	4	5
1	Moisture can No	SCM11	SCM12	SCM 13	SCM15	SCM16
2	Mass of cup + wet soil, g	136	81.5	102.70	90.20	85.50
3	Mass of cup + dry soil, g	124	136	138	126	131
4	Mass of water, g	2.21	1.78	2.22	1.71	1.67
5	Mass of cup, g	14.0	14.50	14.70	15.20	14.50
6	Mass of Dry soil, g	110g	121.50g	123.3 0g	110.80g	116.50g
7	Mass of wet soil, g	78	67	88	75	71
8	Water content, w%	2.83	2.66	2.52	2.28	2.35

Mean Water Content, w% = 2.53

Table 4: Soil Plasticity and Liquidity TestResults for Sample A

S/N	Test	Plastic Limit		Liquid Limit	
1	Container /No of Blows	118	101	112/12	73/32
2	Wt of cont + wet soil g	18.20	17.9	30.5	26.4
3	Wt of cont + dry soil g	18.0	17.70	27.7	24.60
4	Wt of Moisture g	0. 05	0.08	0.05	0.08
5	Wt of Container	16.60	16.20	16.1	16.40
6	Wt of dry soil g	1.52	1.50	1.56	1.61
7	Moisture Content %	3.29	5.33	3.20	4.97

Table 5: Soil Plasticity and Liquidity TestResults for Sample B

S/N	Test	Plastic Limit		Liquid Limit	
1	Container /No of Blows	108	88	112/12	73/32
2	Wt of cont + wet soil g	18.20	17.9	30.5	26.4
3	Wt of cont + dry soil g	18.0	17.70	27.7	24.60
4	Wt of Moisture g	0.20	0.20	2.8	1.80
5	Wt of Container	16.60	16.20	16.1	16.40
6	Wt of dry soil g	1.40	1.50	11.6	8.0
7	Moisture Content %	14.30	13.30	24.10	22.5

Table 6: Soil Plasticity and Liquidity Test Results for Sample C

S/N	Test	Plastic Limit		Liquid Limit	
1	Container /No of Blows	112	99	102/12	54/24
2	Wt of cont + wet soil g	18.20	17.9	30.5	26.4
3	Wt of cont + dry soil g	18.0	17.70	27.7	24.60
4	Wt of Moisture g	0.20	0.20	2.8	1.80
5	Wt of Container	16.60	16.20	16.1	16.40
6	Wt of dry soil g	1.40	1.50	11.6	8.0
7	Moisture Content %	14.30	13.30	24.10	22.5

Summary of Findings and Discussions:

- The topography of the land shows a high sloppiness which makes it highly susceptible to erosion.
- The type of soil found in the study area is predominantly that of weak clay and loose sandy clays.
- The index test results for the natural moisture content ranges from 1.71% –12.53 %;
- The plasticity index ranges from 0–33.283.
- The compacted bulk density is between 1.55-1.76 kg/m^3; the specific gravity ranges from 1.68-2.06.
- The permeability is l between 1.32×10^{-3} and 1.63×10^{-3} cm/sec. The result shows that the area is highly prone to gully erosion which has proven to be detrimental to both agricultural activities and community development programs.
- The result also shows that there have been some anthropogenic activities increasing the susceptibility of the area to erosion.

Discussion of Findings: The findings revealed that thetopography of the land shows a high sloppiness which makesNanka highly susceptible to erosion. The types of soil found is predominantly clayey and sandy clay which were found not to be strongly compacted. The index test results for the natural moisture content ranges from 2.30% - 15.20 %; the mean plasticity index range is low. The compacted bulk density is also low between 1.55- 1.76 kg/m^3; the specific gravity ranges from 1.68 - 2.06. For the performance test; the compaction result shows that the average moisture content (OMC) ranges from 1.71 -12.53 %. The permeability is between 1.32×10^{-3} & 1.63×10^{-3}cm/sec which is not good enough to hold off erosion in the area. The results show that gully erosion caused terrible damages to both agricultural activities and Community Development Programmes in the area. In collaboration with the findings of the study, Ama, *et al*. [17] revealed that gully erosion is partly enhanced by the low shear strength and plasticity index soils. The result also shows that there have been some anthropogenic activities increasing the susceptibility of the area to erosion like excavation and deforestation.

Unfortunately, the majority of gullies in Nanka are very large, the widths ranged between 0.13m-397.20m, the gully height ranged between 2m-52.96m , while the lengths ranged between 10m- 4, 369.20mand this has contributed to loss of large expanse of useful lands which has become unsuitable for settlement and cultivation in Nanka and other parts of Southeastern Nigeria. There have been numerous attempts to curb gully erosion in these regions; especially through large-scale engineering projects, however, little has been discussed about the real causes of this menace (geotechnical and geologically) and ways to prevent their onset or the use of community-based low technology approaches to mitigate their development. The features responsible for gully erosion in Nankadepend on several factors like: highamount of land exposed, the high sloppiness of the land, the nature of the soil, poor method of land management, the intensity and duration of rainfall [18, 19, 20, 21]. The findings of the study is also in line with the findings of Hudson [22], who stressed that soil erosion has damaging effects on land and agricultural production. Akpata and Atanu [23]; Salako *et al.* [24] also added that the increasingly deforestation which affects environmental conditions results from low level of education among the people in the area, this generally causes human activities contributing to soil erosion.

The results of the moisture content presented in Tables 1, 2 and 3 indicates that the soil samples show relatively low moisture content value ranging from 1.71 to 12.53 %, this is because the soil have low retentive capacity and hence cannot hold much water. Compaction test shows the maximum dry density (MMD) and the optimum moisture content (OMC) of the soil to be very low. One of the major reasons for carrying out compaction test on soil is to increase the soil strength and to prevent seepage of water through the soil. Hence both soil water content and the bulk density (dry density) affect soil strength, which will increase when the soil is compacted to a higher density and when the soil loose water, it dries and hardens. The geographic and geotechnical data analysis shows that Nanka and its environs have relatively weak clays and sandy clays. Though compaction test indicates the maximum dry density to which the soil may be compacted by a given force and it indicates when the soil is either drier or wetter than its optimum moisture content while compacting will be more difficult.

CONCLUSION

Results obtained revealed that the soils in the study area are cohensionless, not compact and non-plastic, hence the menace of gully erosion. A highly exaggerated emphasis and predominance on engineering control measures involving construction of check-dams, bulldozing of earth materials, backfilling with soils and compacting, or construction of drainage or cut-off flood channels do not seem to be successful in checking gully incipient and extension or expansion in Nankaand its environs. To this end, the following are recommended:

- 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 drastically by adding considerable quantity of cementing materials like highly compacted clays to the soil.
- Other soil stabilization techniques such as grouting, dewatering, construction of concrete ripraps and horizontal concrete terracing should be applied where pore pressures and seepage forces are high.
- The use of an integrated agronomic and engineering practice that will protect the soil and reduce run-off is also required. This will involve afforestation and tillage practices that lead to the use of agro-forestry practices which are based upon the development of the interface between the agricultural and forestry use of land.
- Discourage construction of houses along the immediate flood plain.
- Construct formidable and strategic river channels or dams to help reduce or control incidence of flooding and erosion in the area.
- Avoid human caused erosion susceptibility, such as unauthorized and indiscriminate removal of topsoil, overgrazing, continuous cropping, dumping of wastes and blocking of drains.
- Consult erosion control experts to help the communities tackle the problem of erosion.
- Educate the people on the dangers of uncontrolled human activities causing or contributing to erosion and flooding in the area.
- Effective intervention and collaboration between local and State government to tackle erosion in the area.
- Government need to map out the entire area and prepare gully erosion hazard/risk maps to guide property developers and builders in order to build anti-erosion structures.

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