ASSESSMENT OF GEOTECHNICAL AND HYDROGEOLOGICAL PROPERTIES OF SELECTED GULLY EROSION SITES IN IKWUANO AREA, SOUTHEASTERN NIGERIA.

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ABSTRACT
An assessment of the geotechnical and hydrogeological properties as agents in the formation and expansion of gullies in Ikwuano area is presented. 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 accumulation of hydrated iron and aluminium oxides. Results of sieves analysis 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 the coefficient of curvature values ranging between 0.2 and 1.3. These indicate that the soils are fair to well sorted in places. The plasticity indices values ranging between 11.0 and 29 with mean value of about 20 indicate soils of moderate to high plasticity, slight dry strength and easily friable. Value of maximum dry density ranges between 1.83g/cm^3 and 2.12g/cm^3 at optimum moisture contents of between 7.4% and 11.3% reveals that the soils were generally loose. The hydraulic conductivity and transmissivity values as determined from statistical grain size method range between 3.8 $\times 10^{-4}$cm/s to 6.4 $\times 10^{2}$cm/s and 3.8 $\times 10^{-2}$cm^2/s to 9.6 $\times 10^{4}$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 aforestration, construction of drainages and concrete rip-raps were suggested.

KEYWORDS: Hydrogeological, geotechnical, transmissivity, plasticity, Ikwuano area, Nigeria.

INTRODUCTION

The study area lies between latitude 5^{O}19' to 5^{O}29'N and longitude 7^{O}32' to 7^{O}40'E (Fig. 1). It has a total landmass of approximately 281km^2 and population of about 137, 993 (2006 Census). The area has 4 clans namely Ariam, Ibere, Oboro and Oloko with 44 autonomous communities and 52 villages. It is bounded by Bende in the north, Umuahia in the northwest, Isialangwa in the southwest Obioma Ngwa in the south and Akwa Ibom in the southeast. The area is located in a low relief area with a maximum elevation of about 150m. As a result, run-off is relatively low and infiltration rate is high. Groundwater storage has also been abundance due to adverse

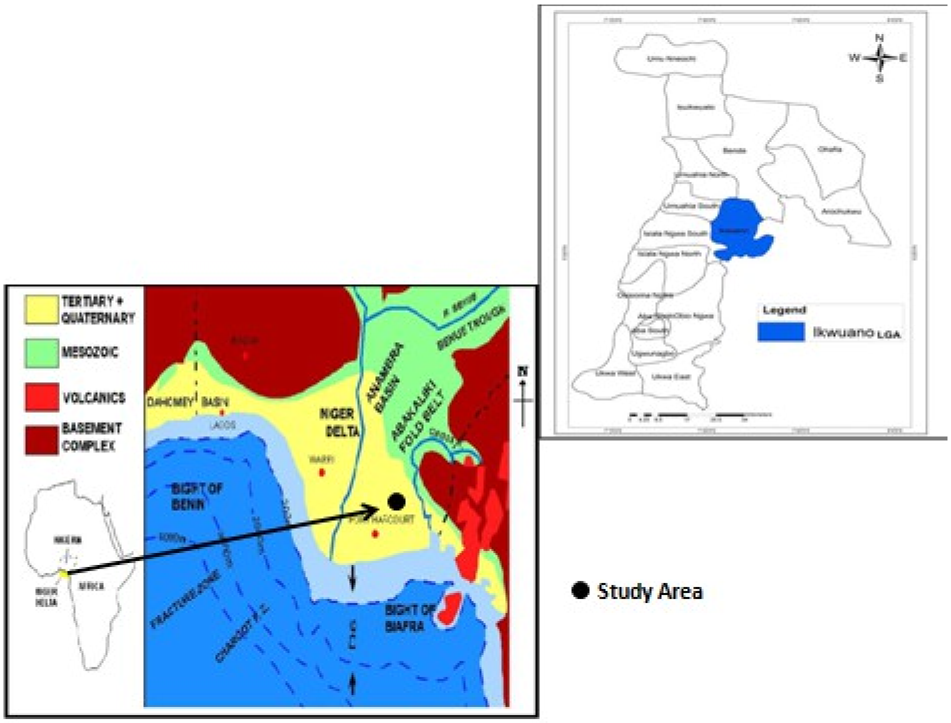

Fig. 1: Map showing location of study area modified (in set: map of Abia State with Ikwuano LGA).

climatic conditions. Soil erosion has become prominent phenomenon and is ravaging the landscape of the study area.

The area is endowed with natural spring and streams including Onu-Inyang River which flows from Bende (the north boundary) through the study area in a south-westerly direction; while Iyinta-Ocha River flows from the central part (Isiala) through south-western part (Ogbuebule) into Akwa Ibom State on the western flank. Akoo River and Iyi-Oba River flow southerly from the eastern part of the study area. On the hand, Anya River traverses the entire western flank of

Ikwuano and joins with Ahi (the westernmost counterpart). This formed a confluence with other rivers and tributaries to the Qua Ibo River of Akwa Ibom and Cross River States of Nigeria.

Earlier studies have attributed their genesis and growth to the influence of human activities on geomorphological processes and qualitative and semi-quantitative methods were employed to produce suggestions for solving the problems (Grove, 1951). However investigations carried out by Egboka and Nwankwo (1985) and Obiefuna et al., (1999) have shown that the primary causes of gully genesis and growth lie in the hydrogeological and geotechnical properties of complex aquifer systems. The high hydrostatic pressure in the aquifers produce a reduction in the effective strength of the unconsolidated coarse sands in the walls of gullies leading to intense erosion (Egboka and Okpoko, 1984 and Obiefuna and Nur, 2003).

The development of gullies has caused extensive damage to the environment and has driven many away from their homes and farmlands. Recently, the State Government was on his address soliciting for the State Environmental Protection Agency intervention to curb the menace of gully erosion. These exigencies prompted this assessment of geotechnical and hydrogeological of the area to proffer solutions to the devastating effects of gullies to agricultural, infrastructural and socio-economic lives of the people in the area.

It is easily accessible by the Umuahia-Ikot Ekpene, Amawom-Bende, Ndoro-Ibere, Ogbuebule-Oloko and Amaoba-Nnono-Ahuwo-Umuigwu link roads. There are numerous footpaths and tracks that provide access to the villages in the study area. The prevalent vegetation is the rain forest and mangrove swarms with two distinct seasons: the dry season which last from November to March; and a wet season which last from April to October (NIMET) 2000-2015. The mean annual rainfall is about 2145.89mm most of which falls between the months of June to September (Table 3).

Previous works on the area are generally on a regional scale which includes the works of Offodile (1992), Igboekwe et al. (2006), Ebilah-Salmon and Partners (1994), Ijeh and Udoinyang (2013) and Ukandu et al. (2011). These workers gave details on the geology, geological structure, hydrogeology and water quality of old southeastern Nigeria. Subsequent surface and groundwater quality assessment was carried out by Ijeh and Udoinyang (2013). Geoelectric Sounding for the Determination of Aquifer Characteristics in Parts of Umuahia Area of Nigeria was carried out by Mbonu et al. (1991). The objective of this study is to assess the results of geotechnical and hydrogeological analysis obtained from field measurements and soil test to infer the formation and expansion of gullies in the area.

GEOLOGIC SETTING

The study area is geologically situated in the Eastern Niger Delta. Its geologically fall within two out of eleven geologic units in the area (Amos-Uhegbu et al., 2013). These are Bende-Ameki Formation and the Benin Formation (Fig. 2).

The Bende-Ameki Formation was classified by Simpson (1955) into two lithological groups, namely; the lower part which consists of fine to coarse grain sandstones and intercalations of calcareous shales and thin shelly limestone and upper part which comprise coarse, cross-bedded

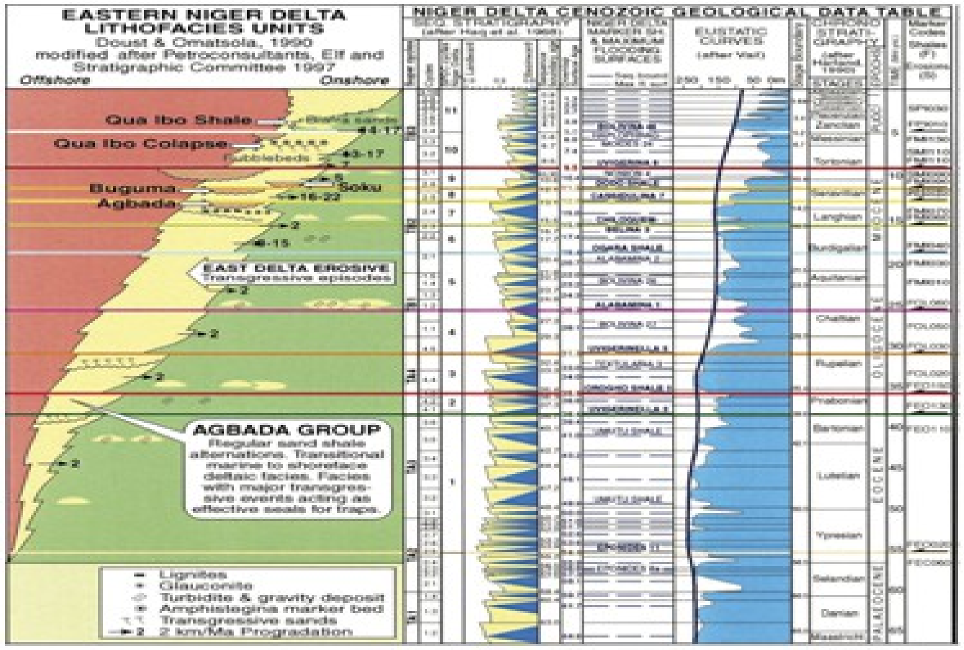

Fig. 2: Stratigraphic Column showing Eastern Niger Delta lithofacies units and Cenozoic Geological Data (Reijers, 1996).

sandstone with bands of fine, grey-green sandstone and sandy fossiliferous clays. The age of the formation has been given as Early to Middle Eocene (Reyment, 1965; Adegoke, 1969; Amos-Uhegbu et al., 2013; Obasi et al., 2015) respectively. The depositional environment of the Ameki Formation has been interpreted based on the faunal assemblage by various authors such as Adegoke (1969) in Amos-Uhegbu et al. (2013), Nwajide (1979) Obasi et al. (2015), White (1926) in Amos-Uhegbu et al. 2013. Adegoke (1969) interpreted it to be an open marine depositional system suggesting that the fish may probably have been washed into the Ameki Sea from inland waters whereas Nwajide (1979) in Obasi et al. (2015) is of the opinion that its near-shore to intertidal/sub-tidal zones of the shelf environment. White (1926) in Amos-Uhegbu et al. (2013) on the other hand, interpreted as an estuarine environment because of the presence of the fish species of known estuarine affinity. The sandstones of the study area belong to the Ameki Formation (Eocene) which underlies the Imo Shale (Paleocene) which conformably overlies the

Nsukka Formation. The Ameki Formation consists predominantly of alternating shales, clayey sandstone and fine-grained fossiliferous sandstone with thin limestone bands.

Benin Formation is one of the lithostratigraphic units in the modern Cenozoic Niger Delta (Fig. 2). Short and Stauble (1967) described the continental Benin Formation as a probable product of upper deltaic depositional environment with identifiable structural units such as point bars, channel fills, natural levees, back swamp deposits and ox-bow fills.

The age of the Benin Formation is Oligocene to Recent in the subsurface and also as surface outcrop in the northern parts western Niger Delta basin and also in some parts of Umuahia area of the Eastern Niger Delta. This upper part of the Benin Formation is known as the Ogwashi-Asaba Formation; while the younger southern part which is Miocene to Recent is known as Coastal Plain Sands.

The petrographic analysis by Onyeagocha (1980) shows that the rock composition is about 95-99% 0f quartz grains; 1-2.5% of Na + K mica; 0.5-1.0% of feldspar, and 2.3% of dark-coloured mineral.

MATERIALS METHODS

This research work started with a field reconnaissance survey at point where road failures were noticed. This was achieved with the aid of a topographic map of the area. Pictures of the failure portion or point were taken. Soil samples were collected at grade, sub base and base levels, with the use of geologic equipments such as geologic hammer, measuring tape, chisel and sample bags for carrying the samples. Seven (7) samples were collected at 7 different pits at sub-surface levels. Before taking the samples, the faces of the soil were scrapped to remove long exposed Oxidized materials to enable the collection of fairly fresh samples. Soil samples were collected at base, sub base and grade levels, which were taken to the laboratory for geotechnical analysis.

These include the Atterberg limit test, California Bearing Ratio test, compaction test and particle size distribution test. All samples were air dried and lumps broken using a rubbered pistle. This was done to stimulate as much as possible the field condition especially as it affects the use of soil in road construction. Table 2 indicates (a) Sieve analysis test result for Ikwuano and its environs (b) Atterberg limit test result, (c) California bearing ratio test result and (d) Compaction test, for the various places in Ikwuano area where the samples were collected.

GEOTECHNICAL PROPERTIES

Incipient gullies were observed in different parts of Ikwuano and environs, which are covered by the sedimentary rocks. The menace of devastation was found at Ikwuano; Ariam, Iberenta, Ndoro, Okwe-Obuohia Road, Ogbuebule, Amawom and Iyalu. The sedimentary rocks of the area have undergone considerable weathering leading to about 50-150meters 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 1.50m to 8.30m with width ranging from 2.50m to 7.6m (Table 1). The geotechnics of these areas determine 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 locations using soil mechanic laboratory test 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 Anon (1979). The samples are soft and could be crushed by fingers and hence erodible.

Compaction test indicates that the optimum moisture content (OMC) ranges from 7.40% to 11.30% whereas the maximum dry density (MDD) ranges from 1.83g/cm3 to 2.12g/cm3 indicating that the soils are slightly compact and not loosed.

Table 1: Gully parameters as obtained from the field.

Gully site	Depth (m)	Width (m)
Ariam	3.50	6.00
Iberenta	8.30	7.60
Ndoro	2.30	3.50
Okwe-Obuohia Road	1.50	3.00
Ogbuebule	1.50	4.00
Amawom	4.00	2.50
Iyalu	5.10	2.60
Mean value	3.74	4.17

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

Sample location	Sieve Analysis by passing BS 200 (%)	Liquid limit (LL)	Plastic Limit (PL)	Plasticity index (PI)	Consistency index (IC)	Califonia bearing ratio (%)	OMC	MDD
Ariam	36.70	48.00	27.00	21.00	2.20	8.00	7.40	2.12
Iberenta	39.02	45.00	23.00	22.00	1.90	14.00	9.30	2.02
Ndoro	29.44	48.00	19.00	29.00	1.60	16.00	10.20	1.96
Okwe-Obuohia Road	20.92	33.00	22.00	11.00	2.70	24.00	10.10	1.83
Ogbuebule	38.04	33.00	20.00	12.70	2.40	16.00	11.30	1.97
Amawom	33.10	47.00	22.50	24.50	1.80	18.00	7.40	2.09
Iyalu	41.81	46.00	27.00	19.00	2.40	21.00	9.60	1.96

The grain size distributions analysis indicate 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.

HYDROGEOLOGICAL PROPERTIES

Coastal Plain Sands (Benin Formation) dips southward (Igboekwe et al., 2006) and is shallow in Umudike where the expected thickness is about 200m (Ebillah-Salmon & Partners, 1994) There are two marked seasons in the year: rainy (March-October) and dry (November- February) seasons The hottest months are January - March with mean monthly temperature of 27°C. 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 separately by aquitards.

Table 3: Meteorological data for Ikwuano and environs monthly rainfall (mm) from 2000/2001-2014/2015 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	78.40	444.90	354.00	187.60	464.80	319.90	335.60	112.10	25.00	13.40	0.00	168.40	2504.10
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	362.00	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	318.00	184.80	99.50	90.80	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

The meteorological data from the Nigeria Institute of Meterology, Umudike shown on 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 95,971,200m3 volume of water. The value of actual evapotranspiration estimated from Turc model based on the mean annual rainfall is about 83,726,749m^3 or 85% of the atmospheric precipitation (Obiefuna and Nur, 2003). An estimate of the surface runoff of 18,545,899m^3 or 19% of the atmospheric 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 65,180,850m3 was obtained. Potential sources of surface water supply are streams and rivers Onu-Inyang, Iyinta-Ocha, Akoo, Iyi-Oba and Ahi which are largely perennial located to the south and east of the study area (Fig. 1). They have their peak discharges between the months of August and September and the minimum discharges in the months of April and May.

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 overburden 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 overburden 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 and Uma et al*.,* 1989) indicate a mean hydraulic conductivity K, value of 5.02m/s and a mean transmissivity,T, value of 6.35m^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.

	Hydraulic conductivity cm/s			Transmissivity cm^2/s			Thickness
Sample location	Hazen 1893	Harleman et al. (1963)	Uma et al. 1989	Hazen 1893	Harleman et al. (1963)	Uma et al. 1989	(cm)
Ariam	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
Iberenta	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
Ndoro	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
Okwe-Obuohia Road	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
Ogbuebule	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
Amawom	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
Iyalu	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

Reconnaissance and observation survey

For the purpose of handling, the identified causes of gully erosion in Abia State were labeled GE-Cause A: lack of drain facilities, GE-Cause B: badly constructed road pavements, GE-Cause C: negligence to rainfall and runoff volume during the design stage of drains, GE-Cause D: dumping of municipal solid waste on drain channels and GE-Cause E: wrongly located building structures as a result of wrong planning, (where GE is Gully Erosion) and the responses from the affected local governments in Abia state were evaluated in percentage (Onyelowe, 2017).

Fig. 3 also showed the gully erosion diagrammatical effects of the different identified causes A to E in Ikwuano Local Government Area of Abia State. It could be deduced that again GE-Cause D; dumping of municipal solid waste on drain facilities was predominant in effects. This also goes to show that this does not only deface the environment, but poses lots of geoenvironmental hazards ranging from pollution and emission of poisonous metal gases to the decay it causes on the transportation facilities on a daily basis. And this adversely affects the lives of the people (Onyelowe, 2017).

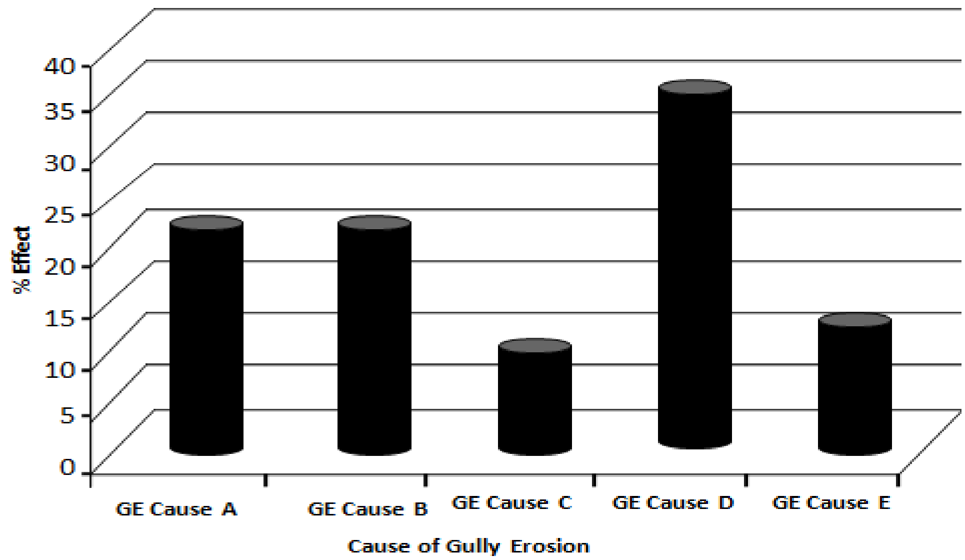

Fig. 3: Percentage effect of the causes of Gully erosion in Ikwuano LGA (After Onyelowe, 2017).

During the survey, the following causes of the gullies were identified (An-Bin et al., 2012); (i)lack of drainage facilities, (ii) badly constructed road pavements, (iii) negligence to rainfall and runoff volume during the design stage of drains, (iv) dumping of solid waste on drain channels and (v) wrongly located building structures as a result of wrong planning.

CONCLUSION

Geotechnical and hydrogeological investigations of the sediments of Ikwuano area were made for the purpose of inferring 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 2.09m/s and 3.79m2/s recorded indicate an aquifer unit of relatively high performance. The result of the geotechnical investigation indicate sorting values ranging from 0.42 to 2.3 and coefficient of uniformity and coefficient of curvature values of 3 to 10 and .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 hence made the soil loose and susceptible to gully erosion. The above result have shown that control of gullies in the area requires an integrated approach involving agronomic practices or massive aforestation efforts aimed at protecting the soil from direct impact of rain drops as a first step. The second step requires some engineering methods which can modify the slope characteristics in an attempt to check the amount and velocity of runoff (Obiefuna and Nur, 2003). Finally, draining the soil using appropriate methods will help the shear strength and reduce the susceptibility of the soil to erosion.

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