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HYDROGEOLOGICAL AND GEOTECHNICAL INVESTIGATIONS OF GULLY EROSION SITES IN CALABAR AREA, SOUTHEASTERN NIGERIA

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ABSTRACT

For many years, gully erosion and landslides are posing a serious threat to human existence, agricultural land, infrastructure and socio-economic activities in Calabar and its environs. Consequently, hydrogeological and geotechnical studies of gully erosion sites were carried out in order to provide information on the genesis and continual expansion of gullies in the area. The results indicate that gullies are located in the upper aquifer of the Benin Formation (Coastal Plain Sands). The estimated hydraulic parameters of the sand obtained from granulometric analysis give hydraulic conductivity K ranging from 3.6 X 10^{-5} to 2,25 X 10^{-2} cms^{-1}, with a mean of 2 4 X 10^{-3} cms^{-1}. specific discharge V_d varies from 1.8 X 10^{-7} to 1.13 X 10^{-4} cms^{-1} and average linear groundwater velocity V_a ranging from 6.0 X 10^{-7} to 3.75 X 10^{-4} cms^{-1}. The geotechnical results further indicate that the liquid limit LL ranges from 24.0 to 54.0%. The plasticity index PI varies from 10.1 to 29.0% with a mean of 16.9%. The optimum moisture content OMC ranges from 8,3 to 14.3% while the silt- clay fraction ranges from 4.0 t0 34.0 with mean of 26.2%. The maximum dry density MDD of the soil ranges from 1810kgm^{-3} to 2050kgm^{-3} while the shear strength test show values of cohesion C in the range 13kgm^{-2} to 32kgm^{-2} in an angle of internal friction, Φ ranging from 12^0 to 17^0. The implication of these data is that gully erosion is partly enhanced by the low shear strength and plasticity index of the soils In addition, the values of hydraulic parameters suggest high seepage forces and pore pressure. These will tend to reduce the shear strength of the soil and enhance its erodibility. Recommendations were also made on how to control erosion in the area

KEW WORDS: Gully erosion, upper aquifer, hydraulic parameters, geotechnical, Calabar.

INTRODUCTION

The Federal and State Governments of Nigeria, over the years have been spending huge sums of money to control gully erosion and other forms of land degradation across the country with little or no success recorded. Gully erosion is an environmental hazard that is ravaging the landscape of parts of Calabar as well as other parts of the country especially southeastern Nigeria (UNDP 1995). Recognizing the severity and magnitude of this problem, the Federal Government of Nigeria, for and on behalf of the states affected (namely: Abia, Akwa Ibom, Cross River and Imo) requested assistance from the United Nations Development Programme (UNDP) to carry out baseline studies and design a programme to combat erosion, landslide and other forms of land degradation (Effiong-Fuller, 2000). Previous workers on gully eroison emphasized the role played by rainfall intensity and run-off models with a passive reference to geology. hydrogeology and geotechnical characteristics of gully sites (Wishchmeier and Smith, 1978; Effiong-Fuller, 2000; Usoro, 1989; Fornis et, al., 2005; Van Dijk et. al., 2005). Nachtergaele et. al. (2001) investigated and tested the ephemeral gully erosion model (EGEM) in Mediterranean environment while Kaminsky and Geffenbaum (2000) assessed the relevant factors that influence coastal changes such as sediment budget, regional tectonics, climatic forces and human intervention on the Southwest Washington coastal region.

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

It was in the light of the above considerations that hydrogeological and soil test analyses were done in the Calabar area with a view of providing hydogeological and geotechnical information on the genesis and expansison of gullies. The infomation from the study will help suggest appropriate measures to control gully development.

LOCATION AND GEOLOGY OF THE STUDY AREA

The study area lies between latitudes 4^050'N and 5^006'N and longitude 8^015'E and 8^025'E in the southeastern part of Nigeria (Fig. 1.) It covers an approximate area of 200km^2 of which 35% is inhabited. It is presently, consist of two local government areas (viz: Calabar Municipality and Calabar South) It lies in a humid tropical climate with frequent alternation of wet and dry seasons The meteorological data for the period (1980-2000) show that the mean monthly temperature varies between 23 7^0C and 28.7^0C for the wet and dry seasons respectively (Table 1) The amount of rainfall (Table 1) varies between 0 and 286.3mm and 5 4 to 796.6mm for the dry and wet seasons respectively The mean monthly relative humidity for the period varied between a minimum of 82 4% and a maximum of 86.8% (CRBDA, 1982; Edet and Okereke, 2002) There are two main rivers in the area namely, the Calabar River in the west and the Great Kwa River in the east (Fig. 1).

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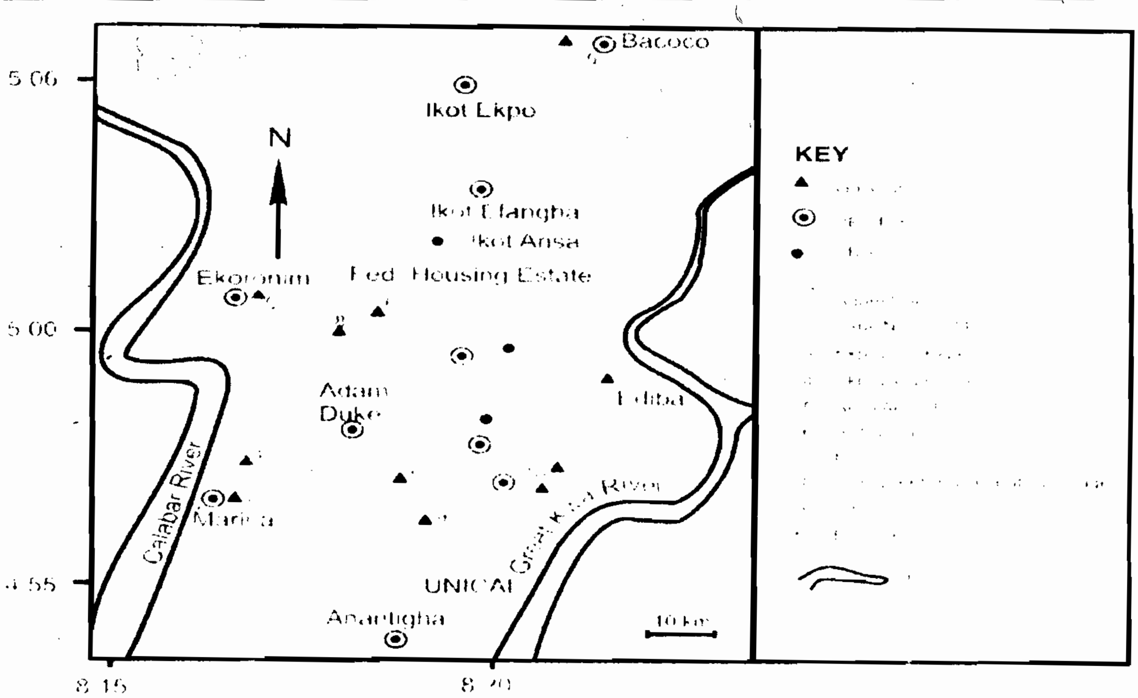

Fig.1: Sketch map of Calabar showing sample locations and gully erosion sites

The study area is underlain by Tertiary and Quarternary to Recent sediments known as the Benin Formation (Coastal Plain Sands), (Fig. 2.). The formation consists of alternating sequences of gravel and sand of various grain sizes, silt, clay and alluvium. This alternating sequence built up a multi-aquifer system in the area. The materials of this formation are derived from the adjoining Precambrain Basement and Cretaceous sediments (Fig. 2). The Cretaceous sediments include mostly, conglomerate, sandstone, limestone, shale, mudstone and marl of the Calabar Flank (Ekwueme et. al., 1995). The rocks of the Precambrian basement complex are migmatite, gneisses, schists, phyllite, granodiorite, granite, pegmatite, tonalite, charnokite, etc, (Rahman et al 1981, Ekwueme et. al., 1995).

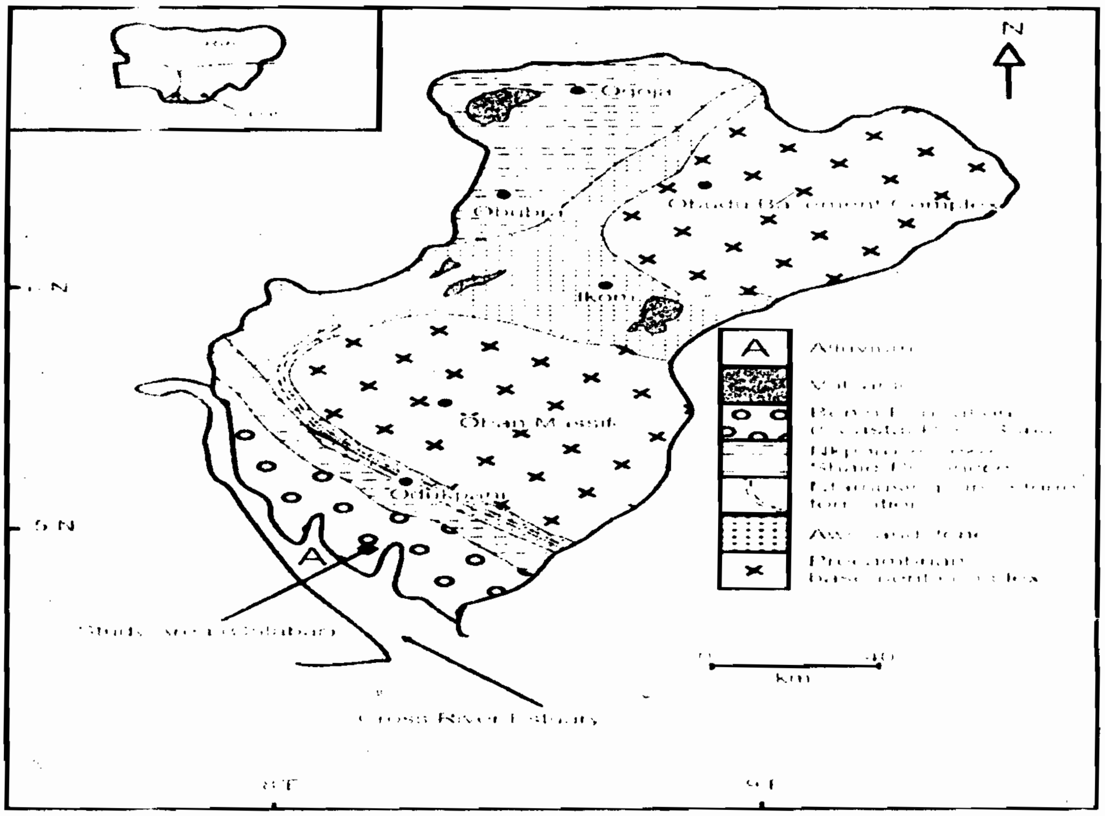

Fig. 2: Generalised geologic map of Cross River State including study area (after Ekwueme et. al., 1995)

Table 1: Meteorological and discharge data[a]

Month	Temperature (^{0}C)	Precipitation (mm)	Discharge (10^6m^3)
January	23.70	32.30	350.00
February	28.70	26.70	200.00
March	28.40	165.80	250.00
April	27.90	199.10	460.00
May	27.30	287.60	1100.00
June	26.30	404.40	1900.00
July	25.40	459.10	2420.00
August	25.20	407.20	5170.00
September	25.80	404.60	8000.00
October	26.10	343.30	6500.00
November	26.90	145.50	1960.00
December	27.10	28.10	760.00
Maximum	28.70	459.10	8000.00
Minimum	23.70	26.70	200.00
Mean	26.60	242.00	2423.00

[a]Compiled from CRBDA (1982)

MATERIALS AND METHODS

Field measurements of goetechnical parameters on different gully erosion sites were conducted between April 6th and September 11th 2006 within the Calabar area. Soil samples were collected from the following erosion sites: Adam Duke, Marina, Edim Otop, Ekpeyong Ekpe, Ekpeyong Bassey, Ikot Uduak, Ekorinim, Ibok street, Uwanse, and Bacoco (Fig. 1 and Table 2). The depths of incision and widths of gullies were noted using metre rule. The coordinates of the gully locations were determined in the field with the aid of Global Positioning System (GPS).

The soil samples were subjected to a number of geotechnical tests including; consistency limits, compaction, California Bearing Ratio (CBR), sieve analysis and shear strength tests in accordance with relevant ASTM methods. The sieve analysis was based on ASTM D423-63 of 1958, while Atterberg limits were based on ASTM D 423-66 and D424-57 of 1958. The compaction and CBR tests were done accordingly and the maximum dry density (MDD), optimum moisture contents (OMC) and the California bearing Ratio (CBR) were deduced graphically. For shear strength tests Mohr-Coulomb failure envelope were constructed to compute cohesion and angle of internal friction. From the granulometric (grain size) analysis, hydrogeologic parameters were estimated viz; hydraulic conductivity K, and specific discharge V_d and average linear ground water velocity V_a. The static water level (SWL) of some boreholes in the study area was measured and lithologs of existing boreholes were obtained from the Federal Department of Water Resources, Calabar.

RESULTS

Results of tests on the hydrogeological and geotechical parameters of the gully sites are indicated on Tables 2 and 3. The study sites include Marina, Adam Duke, Edim Otop, Ibok Street (near parliamentary village), Ekorinim, Murtala Mohammed Highway and Esuk Nsidung (Fig. 1)

Table 2: Gully locations and hydrogeological parameters

S/ No	Name/Number	Latitude N	Longitude E	Width m	Depth m	Ranking*	D10 Mm	Hydrualic conductivity K cm/s	Specific discahrge V_d cm/s	Average linear groundwater velocity Va cm/s
1.	Adam Duke (G1)	4^{0}56.602	80^{0}19.951	7.2	2.0	9	0.006	3.6x10^{-5}	1.8x10^{-7}	6.0X10^{-7}
2.	Esuk Nsidung (G2)	4^{0}57.147	8^{0}21.262	10.0	8.0	4	0.01	1.0x10^{-4}	5.0X10^{-7}	1.67X10^{-6}
3.	Ekpenyong Ekpenyong (G3)	4^{0}56.008	8^{0}18.873	7.4	2.1	10	0.015	2.25x10^{-4}	1.13X10^{-6}	3.75X10^{-6}
4.	Ekpenyong Bassey (Nyagasang (G4)	4^{0}58.597	8^{0}21.76	7.0	3.4	7	0.02	4.0x10^{-4}	2.0X10^{-6}	6.67X10^{-6}
5.	Bacoco (G5)			15.0	6.3	5	0.012	1.44x10^{-4}	7.2X10^{-7}	2.4X10^{-6}
6.	Ikot Uduak (G6)	5^{0}00.174	8^{0}21.129	15.0	4.2	6	0.010	1.0x10^{-4}	5.0X10^{-7}	1.67X10^{-6}
7.	Ekorinim (G7)	5^{0}00.197	8^{0}19.934	200	14.5	3	0.15	2.25x10^{-2}	1.13X10^{-4}	3.75X10^{-6}
8.	Ibok Street (G8) off Parliamentary Village	4^{0}59.976	8^{0}20.856	300	16.0	2	0.015	2.25x10^{-4}	1.13X10^{-6}	3.75X10^{-6}
9.	Uwanse/Otomo (G9)	4^{0}56.658	8^{0}20.076	5.0	2.0	8	0.016	2.26x10^{-4}	1.28X10^{-6}	4.27X10^{-6}
10.	Edim Otop (G10)	4^{0}57.147	8^{0}18.626	1000	20.0	1	0.015	2.25x10^{-4}	1.13X10^{-5}	3.75X10^{-6}
	Mean			**165.60**	**7.85**		**0.027**	**2.41x10^{-3}**	**1.13X10^{-5}**	**4.04X10^{-6}**
	Minimum			**5.0**	**2.0**		**0.006**	**3.6x10^{-5}**	**1.8X10^{-7}**	**6.0X10^{-7}**
	Maximum			**1000**	**20.0**		**0.15**	**2.25x10^{-2}**	**1.13X10^{-4}**	**3.75X10^{-4}**

* Based on the width and depth of individual gully sites.

Hydrogeological Characteristics

On the basis of stratigraphic relation, lithology, geoelectrical and hydrogeological data, two main aquifers have been delineated from the study area (Edet and Okereke, 2002; Amah and Esu 2007). These are the upper gravelly sandy aquifer UGSA (or Type 1) and lower fine sandy aquifer LFSA (or Type II) (Fig. 3). All the gullies identified are located within the upper gravelly sand aquifer (Type I). The Type I aquifer varies in thickness from 0-100m and static water level (SWL) (1.0-48.0m) respectively. A potentiometric map of the upper aquifer in the area is shown in Fig. 4 with the hydraulic heads varying from less than 5m near the coast to over 40m near the northern margin. The water level contours illustrate direction of groundwater flow to be southward towards the Cross River, southeast to the Great Kwa River and northward to the Bacoco-Akim Akim area

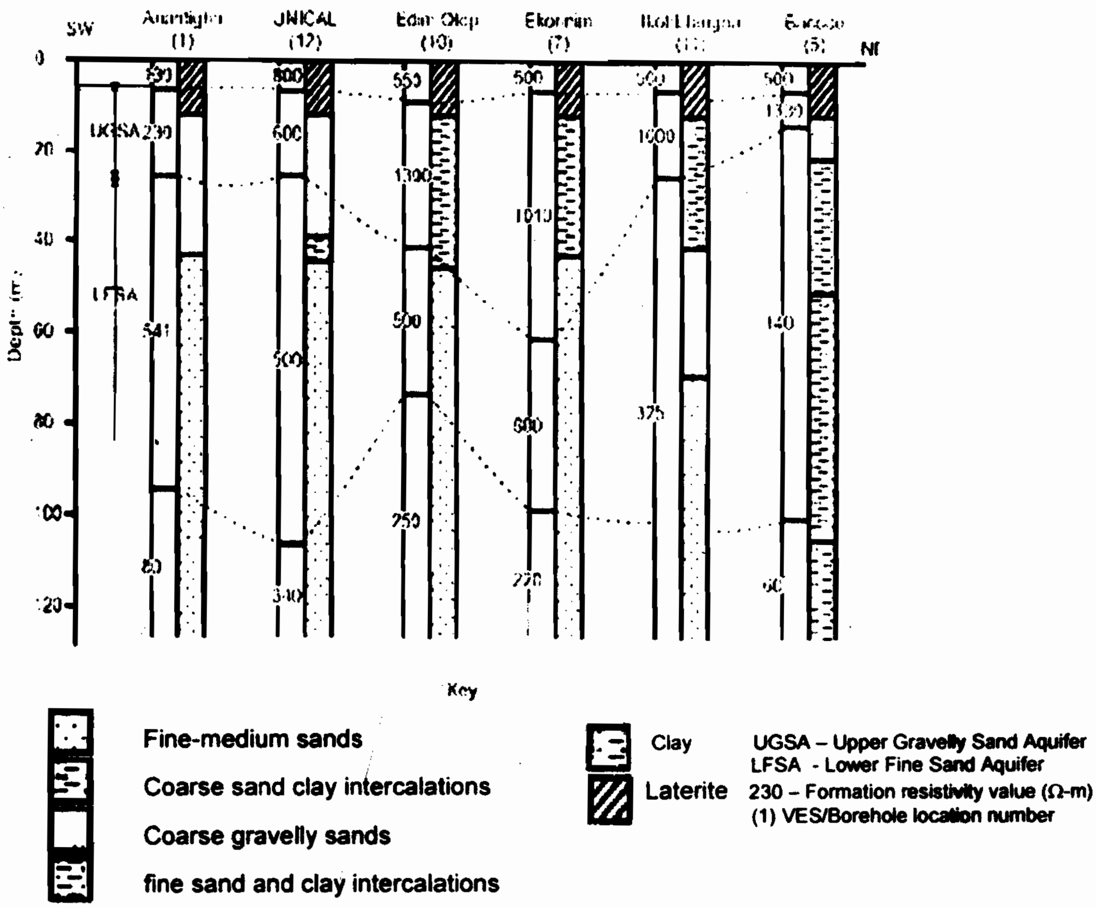

Fig. 3: Geo-electric and lithologs section SW-NE of Calabar area.

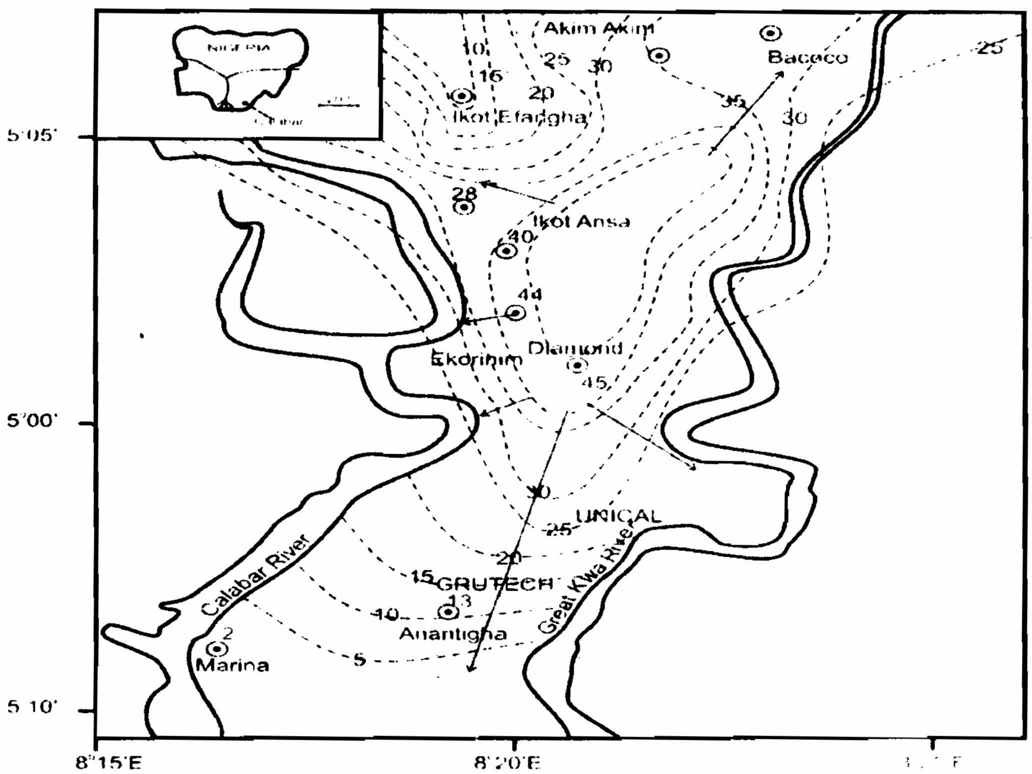

Fig. 4: Potentiometric map of Calabar area, showing groundwater flow directions

The results of hydraulic properties obtained from grain size analysis using Hazen (1893) method (Fig. 5) show an average hydraulic conductivity (K) of 2.41 X 10^{-3} cms^{-1}. The specific discharge also called Darcy's velocity or Darcean flux (V_d) is developed in overcoming friction in pore spaces. It is the product of hydraulic conductivity (K) and hydraulic gradient (i)

$$V_d = Ki$$

Where

V_d = specific discharge
i = hydraulic gradient
K = hydraulic conductivity

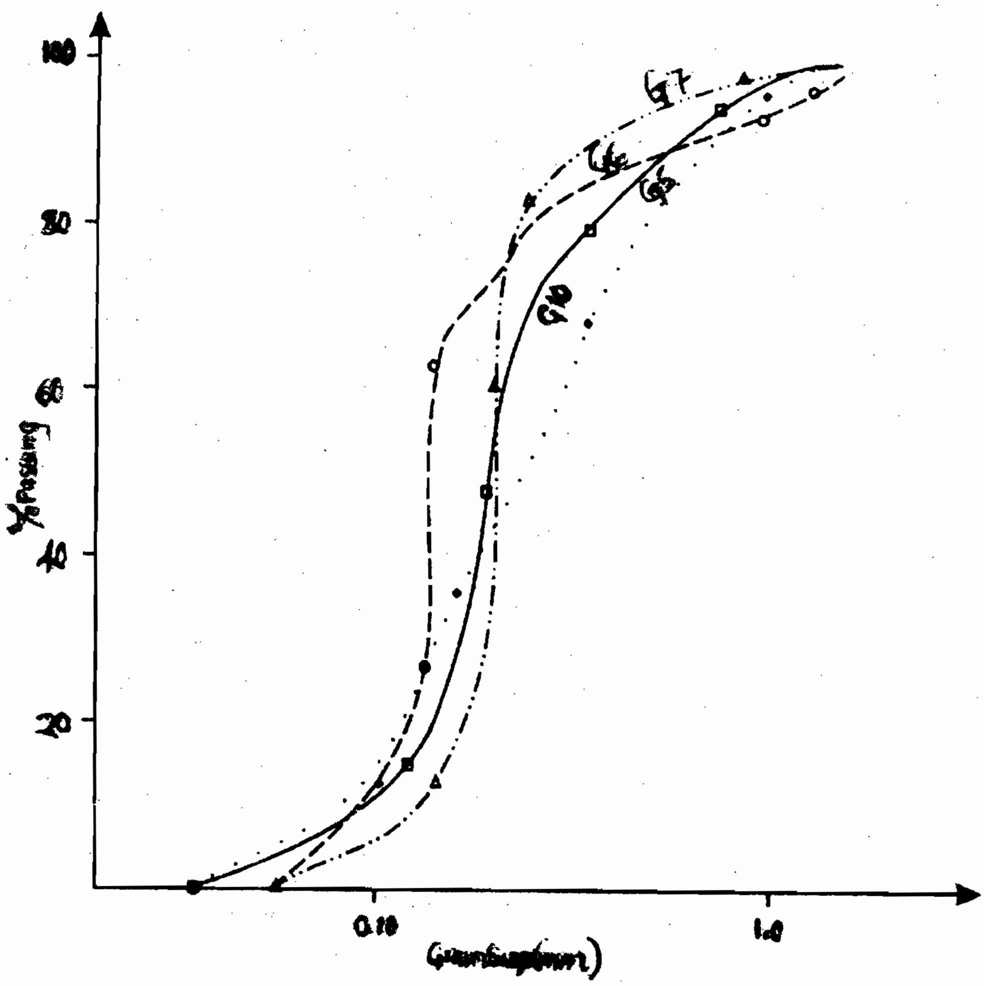

Fig. 5: Grainsize distribution curves for Bacoco (G5), Edim Etop (E10), Ekorinim (G7), and Ikot Uduak (G6)

The mean hydraulic gradient for the upper aquifer (Amah and Esu 2007) is 0.0052 when multiplied by the hydraulic conductivity gives a specific discharge of 1.13 x 10^{-6} cms^{-1}. The average linear groundwater velocity V_a is a measure of the speed with which water moves through the pores, and is obtained by dividing specific discharge by the real or volumetric average porosity. It is computed as

$$V_a = \frac{V_d}{n}$$

Where

V_d = specific discharge
n = porosity of the aquifer
V_a = average linear groundwater velocity

The porosity of the upper aquifer is assumed to be approximately 30% for Coastal Plan Sand (Freeze and Cherry, 1979). The average linear groundwater velocity V_a ranges from 6.0 x 10^{-7} to 3.75 x 10^{-4} cms^{-1}, with a mean of 4.04 X 10^{-5} cms^{-1} (Table 2). This indicates high seepage fluxes and pore pressure.

Geotechnical Characteristics

The liquid limit (LL) ranges from 24% to 53.6% with a mean of 37.3% while the plastic limit (PL) varies from 13.9 to 31.1% with a mean of 20 43%. The plasticity index (PI) which is calculated by subtracting plastic limit from Liquid limit ranges from 10.1% to 29% with a mean of 16.9% (Table 3). This indicates that the soils are moderately to highly plastic (Ranyan and Rao, 2000), (Table 4). The silt-clay fraction has a mean values of 26.2% with a range of 4 to 34% (Table 3). The compaction test reveals that the optimum moisture content OMC ranged 8.3 to 14.3 % with a mean of 11.8%; maximum dry density MDD of 1810 to 2050kgm^{-3} and the soaked Californian Bearing Ratio (CBR) of 17 to 90% (Table 3). The shear strength test reveals a mean of angle of internal friction Φ of 15^0 with a range of 12 to 17%. The cohesion C ranges from 13 to 32kg/m^2 with a mean of 21. 6kg/m^2. The soil, in the study area is classified as sandy clay (Table 3) under the unified soil classification system (USCS) and as A -2-7 in the American Association of State Highway and Transportation Officials (AASHTO). The geotechnical results show that the sand in the study area has a slight to medium plasticity, low angle of internal friction or shear strength, and could easily be crushed with fingers.

The most devastating of all the gully erosion sites is the one at Edim Otop with the average depth of incision and width of gully being approximately 20.0m and 1000m respectively. It is already posing a serious threat to the environment and is at the stage of engulfing many houses, farmlands and human lives in the area (Fig. 6).

(A)

(B)

Fig. 6: Devastating effects of gully erosion on the: (A) Landscape (B) Infrastructure at Edim Otop, Calabar Municipality

Table 3: Summary of geotechnical tests

S/N	Gully locations	Liquid limit LL%	Plastic limit PL%	Plastic index PI%	Optimum moisture content OMC%	Maximum dry density MDD kg/m³	CBR %	Angle of internal friction (θ)°	Cohesion kg/m²	Silt/clay ratio %	Soil classification
1	G1	35.0	18.6	16.4	13.5	1818	25	11	19	34.0	SC
2	G2	35.0	17.9	17.1	4.3	1810	17	15	25	34.0	SC
3	G3	29.0	18.2	10.8	10.4	2000	90	17	19	20.0	SC
4	G4	51.0	28.0	23.0	12.4	1925	40	12	32	32.0	SC-SM
5	G5	28.0	15.0	13.0	13.4	1835	22	16	20	31.0	SC
6	G6	28.0	17.7	10.3	9.3	1875	42	15	19	33.0	SC
7	G7	51.0	22.4	29.0	14.1	1875	39	16	13	4.0	SM
8	G8	53.6	31.1	25.2	11.3	1910	30	14	29	23.0	SM
9	G9	24.0	13.9	10.1	8.3	2050	53	15	20	23.0	SC
10	G10	36.0	21.9	14.1	10.4	1950	34	16	20	28.0	SC
	Mean	**37.31**	**20.4**	**16.9**	**11.75**	**1915**	**39.2**	**15**	**21.6**	**26.2**	**SC**
	Minimum	**24.0**	**13.9**	**10.1**	**8.3**	**1810**	**17**	**12**	**13**	**4.0**	**SM**
	Maximum	**54.0**	**31.1**	**29.0**	**14.3**	**2050**	**90**	**17**	**32**	**34.0**	**SC**

Table 4: Soil classification on the basis of plasticity Index PI (after Ranjan and Rao 2003)

Plasticity Index, P I	Soil Description
0	Non plastic
<7	Low plastic
7-17	Medium plastics
>17	High plastics

DISCUSSION

Some gully erosion sites have been identified in the Calabar area. Soil samples for laboratory tests were collected from these sites: Marina, Adam Duke, Edim Otop, Ibok Street near parliamentary Village, Ekorinim, Akim Akim along Murtala Muhammed Highway, Uwanse, Oyo Ita street, Nyanasang and Esuk Nsidung (Fig. 1). In these places, the hazards caused by erosion is overwhelming have resulted in land degradation, landslides, loss of lives and infrastructures, destruction of ecosystem and loss of fertile agricultural land (Fig 6). These places require urgent attention by the State and Federal Governments in order to combat the menace of erosion.

The results of the tests show that the Benin Formation (Coastal Plain Sands) have some clay intercalations in the sands. The average cohension of these clay fractions is 21.6kg/m² and the angle of internal friction of the sands is low, ranging from 12° to 17°. These clay layers are saturated during groundwater flow. They subsequently expand and loose their cohesion because of excessive pore water pressure. This implies that when water is added to the soil through rain-strom and groundwater, the fines easily loose their cohesion, while the sands and gravels are gradually disintegrated and eroded away. In addition, there is high pore water pressure build up and seepage flux. The high pore water pressure consequently reduces the effective stress of the sands in the aquifer and along the gully walls as shown by the effective stress equation 1.

$$\delta^1 = \delta - \mu \quad \ldots \quad (1)$$

Where δ^1 = effective stress of soil skeleton
δ = total stress of soil skeleton + water.
μ = pore water pressure (or neutral stress).

The decrease in the effective stress will lead to a reduction in the shear strength of the soil as explained by Coulombs law in equation 2 below

$$s = c + \delta^1 \tan\theta \quad \ldots \quad (2)$$

where s = shear strength
c = cohesion
δ^1 = effective stress
θ = angle of internal friction
$\tan\theta$ = coefficient of internal friction.

The erodibility of the soil is thus enhanced.
Moreover, the value of plasticity index (10. 1 to 29.6%) with a mean of 16.9% and maximum dry density (MDD) (mean of 1920 kg/m³) are low, indicating that the soil has slight dry strength, loose, and can easily be crushed with fingers (Obiefuna and Nur, 2003). It will therefore offer little resistance to gully erosion. There is a good agreement for the range of PI recorded in this work with those of Esu and Ilori (2003) who put their plasticity index PI of some samples obtained from the Coastal Plain Sands at 20-27% while Akpan and Edet (2005) recorded a PI value of 10-11% for different localities in the study area. The lithologic logs and geoelectric sections (Fig 3) show that the Coastal Plain Sands are dominantly sandy Their percentage of fines varies both laterally and vertically from one locality to another and as such their engineering properties are expected to differ accordingly. The high -risk erosion areas coincided with the discahrge areas of groundwater flow direction (Fig. 4) such as the Bacoco area, Ekorinim and Edim Otop. The variability in the hydraulic and geotechnical properties of the gully sites is due to the heterogenous nature of its sediments.

CONCLUSION

The study has shown that the genesis of many gullies is not only related to rainfall intensity and runoff, but also to the hydrogeological and geotechnical characteristics of the Coastal Plain Sands of Calabar area The relatively high values of hydraulic conductivity, specific discharge and the average linear groundwater velocity recorded in all the erosion sites suggest high seepage forces and pore pressures During the rainy season, fast percolation of recharge water and increased pore water pressure build up occur in the sands of the Benin Formation These will tend to reduce the shear strength of the soil and enhance its erodibility.

The sands of the study area have increasing clay intercalations. The clay layers are easily satured during groundwater flow. They subsequently expand and loose their shear strength due to excessive pore water pressure, thereby resulting in erosion and gullying. The plasticity index and the maximum dry density are low indicating that the soil has slight dry strength, loose and easily be crushed with fingers. Therefore it offers little resistance to gully erosioin.

The results of the investigations have further shown that the following erosion control practices be adopted for the gullies in Calabar area viz:

i. Construction of concrete structures to protect the river banks against the force of flowing water.

ii. Reclamation by back filling of existing gullies with laterite and other good filling materials accompanied by adequate compaction and drainage

iii. Draining the soil to reduce the associated pore water pressure build up will help to increase the shear strength of the soil

iv. Planting trees and grassses are also necessary to protect the soils from direct impact of raindrops

v. The State government should enact an edict to prevent human activities such as farming, bush burning, digging of sand and indiscriminate dumping of wasted at erosion sites.

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