Gully Category, Slope Position and Soil Depth Studies of 'Acid Sand': Effects on Soil Physical Properties in Akwa Ibom State, Southeastern Nigeria

Abstract

The menace of gully erosion is quite alarming on soils of coastal plain sands of southeastern Nigeria. Consequent upon this, a study was conducted to determine effect of Gully Categories, gully slope position and soil depth affect soil properties on coastal plain sand, Akwa Ibom State, Southeastern Nigeria.

The study was conducted in nine (9) gully erosion sites. The gullies were grouped into three broad categories based on their dynamics namely, Active gullies (ACG), Meta stable gullies (MSG) and Stabilized/old gullies (SOG) at three Gully slope positions of upper slope (US), middle slope (MS) and Lower Slope (LS) with a control site (CT).

The gully face/side was reconditioned and soil samples were collected based on these categories of gullies. Samples were collected with a spade at 0-20cm and 20-50cm depths. Data generated were fitted into a 3 x 3 x 2 factorial designed and the data generated were assessed with the used of analysis of variance.

The result revealed that under gully category, there was no significant effect of gully category on content of Fs, Cs, Ts, Silt and Clay, but fraction dominated other soil particle fractions also, SOG > MsG >AcG soil in saturated hydraulic conductivity, and was affected by gully category. Particle size distribution was significantly affected by gully slope position course sand, total sand, silt and clay contents (3.9, 2.25, 0.91 and 1.9 respectively) at P< 001.

Result of bulk density affected by gully slope position obtained shows the lowest bulk density in CT soil (1.38 mgm^{-3}), followed by LS soil (1.39 Mgm^{-3}) and US (1.44 Mgm^{-3}) soils, which were statistically equal. Effect of depth shows that 0.20cm depth, Fs, Cs, Ts, silt and clay had mean values of 256, 525, 780, 50 and 169 gkg^{-1}, respectively, while 20-50cm depth, Fs Cs, Ts, Silt and Clay recorded mean values of 262, 523, 784, 52 and 164 gkg^{-1}, respectively.

PWP was also significantly affected by the interaction of Gully Category, Gully Slope position and soil depth. The combination of SOG and subsoil showed high PWP at the CT, US and Ms. When compared to other combinations (ACG and MSG) with exceptions in ACG x US x Subsoil and MSG x US x Topsoil and MSG x US x topsoil and Subsoil, which were at the same level with the earlier mentioned combinations involving SOG. The topsoil had higher sand content, lower clay and silt content, higher bulk density and lower total porosity, higher saturated hydraulic conductivity, higher SWC, FWC and PWP, higher organic matter and nutrient potentials with less stability of aggregations.

Keywords: Gully Category: gully slope position; soil depth; soil physical properties; acid sand.

INTRODUCTION

The greatest threat to environmental settings of South-eastern Nigeria is the gradual dissection of the landscape by soil erosion. These soils are highly eroded and structurally unstable (Idowu and Oluwatosin, 2008). Erosion forms a major type of soil degradation that adversely affect agricultural productivity and thus casting doubt on food security.

Erosion is natural process, where energy provided by water, wind and gravity drives the detachment, transport and deposition of soil particles. Soil erosion is a systematic removal of soil from the land surface by various agents of denudation under different geotogic, climatic and soil conditions (Babayi *et al.*, 2012). It is a complex interaction with many factors the most basic being edaphic and rainfall. These factors can be categorized into two major type, i.e geologic and accelerated erosion. Geologic are caused by the forces of nature, while the accelerated are caused by man's activities on the environment and the two main agents of soil erosion are water and wind.

Water erosion is divided into splash, rill sheet and gully erosion. Rain drop erosion is soil detachment and transport resulting from the impact of water drops directly on soil particles. The idealized concept of sheet erosion was the uniform removal of soil in thin layers from sloping land, resulting from sheet or over land flow (Glenn *et al.*, 1993). Rill erosion produces channels just like gully erosion but the channels are much smaller than that of gully erosion. Bradferd *et al.* (1973) stated that the rate of gully erosion dependes primarily on the runoff producing characteristics of the watershed, Gully erosion produces water worn channel (Monkhouse and Small, 1978), it is a steep side channel with a cross sectional area larger than one square root that is formed due to intermittent flow or runoff after snow melt (Poesen *et al.*, 2003).

Gully is a recently extended drainage channel that transmits ephemeral flow, steep side, steeply sloping or vertical head scarf with a width greater than 0.3m and a depth greater than 0.6m and cannot be obliterated by normal tillage operation (Soil science society of America, 2001). It is a V or U – shaped trench in unconsolidated materials with minor channel in the bottom, but not necessarily linked to a major stream (Graf, 1983). Gullies can be active (actively eroching) or inactive (stabilized).

Ogban and Edoho (2011) viewed active gully as a young and head ward erosion with incision, actively occurring at the rate of 3.30 meter per year. Gully erosion was triggered by human exploitation of natural ecosystems in different form such as forest clear cutting, rangeland change to rain fed farm, urban development, road construction in recent century in different parts of the world (Croke and Mocker, 2001; Nachtergaele, 2001) This phenomenon is critical in the South-eastern part of Nigeria.

Bettis III (1983) pointed out factors involved in it's growth and degradation, thus the phenomenon is either natural or artificial, gully erosion is one of the major environmental challenges facing Southeastern zone of Nigeria. Soil properties, rainfall and runoff intensity, wind action, geological, hydrogeochemical and geotechnical characteristics and anthropogenic activities are factors generating soil and gully erosion processes. (Egboka and Orajaika, 1987). Igwe, (1994) noted that the anthropogenic factors are mainly technical fact comprising mainly of land use and tillage methods. Giordano *et al.* (1991) showed that among the factors that encourage soil erosion are vegetations clearance, intensive harvesting. and over grazing leaving the soil bare.

Other factors include soil compaction caused by heavy machinery that reduces the infiltration capacity of the soil, thus promoting excessive water runoff and soil erosion (Igwe, 2012). In classical modeling, works on soil erosion prediction and estimation, works by Renard *et al.* (1997) and Igwe et al. (1999) recognized topography/relief, rainfall and soil factors as being the main agents that determine the extent of soil erosion hazard.

Nowadays, gully erosion is a major process of land degradation in arid and semi arid areas of the world. Researchers have showed that causes of gully erosion initiation in different climates can be different. Poesen et al. (2003) reported that in many landscapes, under different land use, the presence and dynamics of various Gully categories such as ephemeral gullies, permanent and bank gullies were observed. Gully formation and morphology are frequently correlated with physiographic, climate and anthropogenic factors such as topography, precipitation, vegetation and land use (Lal, 2001; Cerda, 2002). Also, correlation of gully erosion severty with soil intrinsic physio-chemical factors is asserted in the literature (Battaglia *et al.,* 2002; Piccarreta *et al.,* 2006).

Gully erosion is the worst stage of all types of soil erosion which affects several soil functions and one of the most challenging environmental problems in the globe. Efforts made in the past to combat the problem and proffer solutions to the factors affecting gully erosion in our soils which is fragile and structurally unstable in nature did not make much meaning. The gully erosion sites are still on the increase affecting soils that would have been used for agricultural purposes. Therefore, the study was aimed at investigating the effect of gully categories, gully slope and soil depth on soil physical properties of the soil in the coastal plain sand parent material in Southeastern, Nigeria.

MATERIALS AND METHODS

Environment of the Study area

The study was conducted on soils of coastal plain sands in Akwa Ibom State, South-eastern Nigeria. Akwa Ibom State is situated between latitudes 4^{0} 30^{1} and 5^{0} 30^{1} N and longitudes 7^{0} 30^{1} and 8^{0} 20^{1} E. The state has a total area of 8, 412 km^{2} and a shoreline of 129 km long (Petters *et al.* 1989).

The climate of Akwa Ibom State is characterized by two seasons namely, the dry and wet seasons. The dry seasons lasts from November to March, while the rainy season occurs between the months of April and October. Rainfall is heavy ranging from over 3,000mm along the coast to 2,000mm on the northern fringes. Temperatures are uniformly high throughout the year with slight variation between 26^{0} and 28^{0}C. High relative humidity's are common, with a mean of 75 percent while solar radiation ranges from 6-15 KJ per day (Petters et al. 1989).

The soils are derived from sandy parent materials and are highly weathered and dominated by low activity clays. Sands and clays from river deposition cover a greater part of the state and institute the Benin formation, also, known as the coastal plain sands. They originated from the tertiary sandstones with the low shale and Ameki formation (Petter et al. 1989). Akwa Ibom State is situated in the humid region of the Southern-eastern Nigeria. The natural vegetation is mainly savannah with some redict of rainforest distributed in patches (Jungerius 1964). The nature vegetation has been almost completely replaced by secondary forest of predominantly wild, oil palm, wood shrubs such as chromolaenacdarata and various grass under growth (Petters, et al. 1989).

The predominant land use practice in the area as in most of the south-east includes among others arable crop production, cash crop production and non-agricultural uses. The major crops grown are cassava, yam, maize, cocoyam and vegetables.

Field Methods

The study was conducted in nine gullies erosion site on the coastal plain sands in Akwa Ibom State, Southeastern Nigeria. The gullies were grouped into three broad categories based on their dynamics, namely active gullies (AcG), Meta-stable gullies (MsG) and stabilized/old gullies (SoG). The longitudinal section of each gully was partitioned into upper (US), middle (Ms) and lower (LS) gully slope positions for this study. The gully face was reconditioned and soil samples collected. Soil samples were collected at 0-20cm and 20-50cm depths and at a control site of 50cm away from the gully area. The study was therefore a 3 x 3 x 2 factorial experiment in randomized complete block (RCB) design, with gully category in main plot, gully slope position in subplot and soil depth in sub-subplot.

A set of undisturbed samples were collected with metal cylinders measuring 7.2cm long and 6.8cm internal diameter at the same depths and at the control sites for moisture content determination, saturated hydraulic conductivity and bulk density in the field Geographic positioning system (GPS) was used to obtain the co-ordinates of the sampling points (Table 1).

Gully Volume/size was calculated as follows: GV = GL x GW x GH (m)

Where;

GV = gully volume (m^3), GL = gully length (m), GW = gully width, GH = gully height (m)

Laboratory Analysis

The bulk soil samples were air-dried and sieved through a 2mm mesh to obtain the fine earth to be used for physical and chemical analysis.

Physical Analysis

Particle size distribution:

Particle size distribution was determines using the Bouyoucos hydrometer method as described by Udo et al. (2009), after dispersing the soil particle calgon (sodium hexa metaphosphate and sodium carbonate).

Saturated hydraulic conductivity was determined on the intact core soil samples and computed from Reynolds and Elrick (2002), as follows:

$$Ksat = \frac{QL}{\Delta h\ At} \quad \text{(cm/hr)}$$

Where

Ksat = hydraulic conductivity (cm/h)

Q = discharge rate (cm^3), L = Length of soil column (cm), h = height of water above soil column (cm) Δh = change in hydraulic head, cm = L + h (L = length of soil – containing cylinder, h = height of water above soil containing cylinder), A = Cross sectional area of the cylinder (cm^3), t = Time, (min).

Bulk density

The core samples were oven-dried at temperature of 105^0C to a constant weight. The bulk density was calculated using the mass volume relationship as follows:

$$\ell b = \frac{Ms}{Vt}$$

Where,

ℓb = bulk density (g/cm^3), Ms = Mass of oven dry soil (g), Vt = total volume of soil (cm^3). The total volume of the soil was calculated from the internal dimension of the cylinders.

Total porosity was calculated from particle and bulk density as stated below:

$$f = \left[1- \{ \frac{\ell b}{\ell s} \right]$$

Where, f = total porosity (m^3/m^3), ℓb = bulk density, Mg/m^3 assumed to be $2.65 g/m^3$, ℓs = particle density Mg/m^3.

Macroporosity: This was computed from the following relationship $f a = f - \Theta v$

Where,

$f a$ = macro porosity (m^3/m^3), f = total porosity (m^3/m^3), Θv = volumetric water content (m^3/m^3).

Statistical Analysis

The data generated were fitted into a 3 x 3 x 2 factorial in randomized complete block (RCB) design and subjected to analysis of variance, correlation matrix and multiple regression analyses. Significant differences were tested at probability level of 5%.

Table 1: Coordinates of Sampling Points of Active Gullies

S/N	**LOCATION**	**L.G.A**	**CO-ORDINATES**				
			Upper Slope (US)	**Middle Slope (MS)**	**Lower Slope (LS)**	**Control (CT)**	**At the stream Area**

1	Ikot Nya	Nsit Ibom	04^0 50.867’N 007^0 54.108’E	04^0 50.819’N 007^0 54.135’E	04^0 50.755’N 007^0 54.136’E	04^0 50. 852’N 007^0 54.133’E	04^0 50.753’N 007^0 54.172’E
2	Ikot Ebo	Etinan	04^{0}49.429’N 007^0 52.291’E	04^0 49.460'N 0070 52.250’E	04^0 49.490’N 007^0 52.205’E	04^0 49.432’N 007^0 52.291’E	04^0 49.491’N 007^0 52.201’E
3	Ikot Udo Ekop	Ibesikpo/ Asutan	04^0 56.685’N 007^0 54.861’E	040 56.685’N 0070 54.924’E	04^0 56.721’N 007^0 54.921’E	04^0 56.721’N 007^0 52.291’E	04^0 56.695’N 007^0 54.988’E

Table 2: Coordinates of Sampling Points of Meta-Stable Gullies

S/N	LOCATION	L.G.A	CO-ORDINATES				
			Upper Slope (US)	**Middle Slope (MS)**	**Lower Slope (LS)**	**Control (CT)**	**At the stream Area**
4	Ibiaku Ikot Amba	Ibiono Ibom	05^0 07.641’N 007^0 52.607’E	05^0 07.661’N 007^0 52.625’E	05^0 07.693’N 007^0 52.640’E	05^0 07.668’N 007^0 52.635’E	05^0 07.532’N 007^0 52.593’E
5	Ediene Ikot Obio Imoh	Uyo	05^0 00.830’N 007^0 51.510’E	05^0 00.770’N 007^0 51.499’E	05^0 00.733’N 007^0 51.477’E	05^0 00.759’N 007^0 51.438’E	05^0 00.675’N 007^0 51.326’E
6	Odot I	Nsit Atai	04^0 49.043’N 008^0 02.785’E	04^0 49.056’N 008^0 02.755’E	04^0 49.071’N 008^0 02.765’E	04^0 49.072’N 008^0 02.772’E	04^0 49.093’N 008^0 02.736’E

Table.3: Coordinates of Sampling Points of Stabilized Gullies

S/N	LOCATION	L.G.A	CO-ORDINATES				
			Upper Slope (US)	**Middle Slope (MS)**	**Lower Slope (LS)**	**Control (CT)**	**At the stream Area**

7	Ediene Abak	Abak	04^0 58.842'N 007^0 47.683'E	04^0 58.848'N 007^0 47.731'E	04^0 58.841'N 007^0 47.767'E	04^0 58. 827'N 007^0 47.687'E	04^0 58.821'N 007^0 47.812'E
8	Ntak Inyang	Itu	05^0 17.270'N 007^0 13.623'E	05^0 17.270'N 007^0 13.623'E	04^0 17.200'N 007^0 13.623'E	05^0 17.270'N 007^0 13.623'E	05^0 17.270'N 007^0 13.623'E
9	Ikot Akan	Nsit Ubium	04^0 46.556'N 007^0 53.832'E	04^0 46.564'N 007^0 53.827'E	04^0 46.578'N 007^0 53.800'E	04^0 46.549'N 007^0 53.843'E	04^0 46.677'N 007^0 53.710'E

Results

Effect of Gully Erosion (category) on some soil physical properties mean values of particle size distribution as affected by soil gully category are presented in Table 2. Soil of AcG had fine sand, coarse sand, total sand, silt and clay content of 274, 516, 790, 52 and 158 gkg^{-1}, respectively. Soil of MsG had Fs, Cs, Ts, Silt and clay contents of 242, 538, 780, 47 and 173 gkg^{-1}. There was no significant effect of gully category on the contents of Fs, Cs, Ts, Silt and clay. Generally, the sand fraction dominated soils of the different gully categories, followed by clay and silt.

Bulk density was significantly affected by Gully category. Bulk density of MsG soil (1.44 Mgm^{-3}) was the highest, but statistically equal with that of AcG soil (1.44 Mgm^{-3}) and significantly higher than that of SoG soil (1.38 Mgm^{-3}).

Total porosity was significantly affected by Gully category with the highest total porosity of 0.48 m^3 m^{-3} obtained in SoG soil, this was significantly higher those of AcG soil (0.46 m^3 m^{-3}) and MsG soil (0.4533 m^3 m^{-3}), which were similar.

Macroporosity of AcG, MsG and SoG soils were 0.28, 0.27 and 0.28 m^3 m^{-3} , respectively, while microporosity were 0.17, 0.18, and 0.20 m^3 m^{-3}, respectively. Macroporosity was not significantly affected by Gully category. There were significantly differences of microporosity among Gully categories in the following order:

Table 4: Mean Value Soil physical properties affected by Gully category in the study area

	Particle Size Distribution												Water Retention Characteristics		
	Fs	**Cs**	**Ts**	**Silt**	**Clay**	**BD**	**Tp**	**Ma**	**Mi**	**Ksat**	**SWC**	**FWC**	**PWP**	**AWC**	**OM**
			gkg^{-1}			**Mgm^{-3}**		**$m^3\ m^{-3}$**		**$cm\ hr^{-1}$**		**$m^3\ m^{-3}$**			**gkg^{-1}**
AcG	274	516	790	52	158	1.44	0.46	0.28	0.17	4.96	0.38	0.17	0.1	0.07	25.11
MsG	260	517	777	55	168	1.46	0.45	0.27	0.18	5.55	0.39	0.18	0.11	0.07	25.13
SoG	242	538	780	47	173	1.38	0.48	0.28	0.2	6.14	0.42	0.2	0.13	0.08	32.07
Sig	0.13	0.34	0.37	0.11	0.19	<.001	<.001	0.16	<.001	0.01	<.001	<.001	<.001	0.76	<0.001
LSD	3.1	3.37	1.95	0.79	1.65	0.04	0.01	0.02	0.01	0.69	0.02	0.01	0.01	0.02	2.75

Fs – Fine sand, Cs – Coarse Sand, Ts – Total sand, Bd – bulk density, Tp – total porosity, Ma – macroporosity, Mi – microporosity, Ksat – saturated hydraulic conductivity, SWC – saturation water content, FC – field capacity, PWP – permanent wilting point, AWC – available water capacity. AcG – active gullies, MsG – meta-stable gullies, SoG – stabilized/old gullies, OM – organic matter.

SOG soil >MsG soil > AcG soil

Saturated hydraulic conductivity (Ksat) was significantly affected bu Gully category with the highest Ksatg of 6.14 cm hr^{-1} obtained in SoG soil, this was statistically equal with the of MsG soil (5.55 cm hr^{-1}), but significantly higher than that of AcG soil (4.96 cm hr^{-1}). Saturation water content (SWC) were significantly affected by Gully category. The SWC obtained in SoG (0.42 $m^3\ m^{-3}$) was significantly higher than those of MsG and AcG (0.39 and 0.38 $m^3\ m^{-3}$) and these obtained in MsG and AcG were not significantly different. FC and PWP were significantly higher in SoG, followed by MsG and AcG in that order. There was no significant effect of Gully category on available water capacity (AWC). The highest organic matter content (32.07 gkg^{-1}) in SoG, which was significantly higher than that of MsG (25.13 gkg^{-1}) and AcG (25.11 gkg^{-1}).

EFFECT OF GULLY SLOPE POSITION ON SOME SOIL PHYSICAL PROPERTIES

The mean values of some soil physical properties as affected by Gully slope position are presented in Table 5.

Particle size distribution affected by Gully slope position shows that Gully slope position had no significant effects on fine sand content, (3.58) but coarse sand, total, silt and clay contents were significantly affected by Gully slope position (3.9, 2.25, 0.91 and 1.9), respectively at <.001. Coarse sand, and total sand contents were significantly higher in Ms soil, followed in the order, US, CT, and Lastly LS soil. Higher significantly silt content was obtained in LS (595 gkg^{-1}), followed by CT (585 gkg^{-1}), MS (435 gkg^{-1}) and US (425 gkg^{-1}), in that order, while clay content decreased in the order: LS (193 gkg^{-1}), > CT (185 gkg^{-1}), > US (150 gkg^{-1}) > Ms (138 gkg^{-1}).

Effect of Gully slope position on Bulk Density

Bulk density was significantly affected by Gully slope position with the lowest bulk density obtained in CT soil (1.38 Mgm^{-3}), followed by LS soil (1.39 Mgm^{-3}) and then US (1.44 Mgm^{-3}) and MS (1.50 Mgm^{-3}) soil, which were statistically equal.

Table 5: Mean Value Soil physical properties affected by Gully slope position in the study area

	Particle Size Distribution										Water Retention Characteristics				
	Fs	**Cs**	**Ts**	**Silt**	**Clay**	**BD**	**Tp**	**Ma**	**Mi**	**Ksat**	**SWC**	**FWC**	**PWP**	**AWC**	**OM**
	←		**gkg^{-1}**	→		**Mgm^{-3}**	←	**$m^3\ m^{-3}$**	→	**$cm\ hr^{-1}$**	←	**$m^3\ m^{-3}$**		→	**gkg^{-1}**
CT	266	490	756	59	185	1.38	0.48	0.29	0.19	5.1	0.38	0.18	0.11	0.07	29.33
US	250	557	807	43	150	1.44	0.46	0.27	0.19	5.71	0.41	0.18	0.12	0.07	27.20
MS	251	568	819	43	138	1.50	0.43	0.25	0.18	5.92	0.41	0.19	0.11	0.09	25.95
LS	267	480	747	60	193	1.39	0.47	0.29	0.18	5.46	0.40	0.19	0.12	0.07	28.61
Sig	066	<.001	<.001	<.001	<.001	<.001	<.001	0.00	0.36	0.21	0.01	0.36	0.25	0.11	0.158
LSD	3.58	3.9	2.25	0.91	1.9	0.05	0.02	0.02	0.02	0.8	0.02	0.02	0.01	0.02	3.18

Fs – Fine sand, Cs – Coarse Sand, Ts – Total sand, Bd – bulk density, Tp – total porosity, Ma – macroporosity, Mi – microporosity, Ksat – saturated hydraulic conductivity, SWC – saturation water content, FWC – field water capacity, PWP – permanent wilting point, AWC – available water capacity. CT – Control, US – Upper slope, MS – middle slope, LS – lower slope, OM – organic matter.

Total porosity and macroporosity were significantly affected by Gully slope position. The highest significant total porosity and ,macroporosity of 0.48 and 0.29 $m^3\ m^{-3}$, respectively, were obtained in CT soil, followed by LS soil with total porosity of 0.47 $m^3\ m^{-3}$ and macroporosity of 0.29 $m^3\ m^{-3}$ and lastly, US soil with total porosity of 0.46 $m^3\ m^{-3}$ and macroporosity of 0.27 $m^3\ m^{-3}$ and lastly, Ms soil with total porosity of o.43 $m^3\ m^{-3}$ and macroporosity of 0.25 $m^3\ m^{-3}$. There was no significant effect of Gully slope position on Microporosity.

The saturated hydraulic conductivity of US, MS, LS and CT soils were 5.71, 5.92, 5.46 and 5.10 cm hr^{-1}, respectively. There was no significant effect of Gully slope position on saturated hydraulic conductivity. Saturated water capacity (SWC) content was significantly affected by Gully slope position with the SWC obtained in US (0.41 $m^3\ m^{-3}$), MS (0.41 $m^3\ m^{-3}$) and LS (0.40 $m^3\ m^{-3}$) being equal but significantly higher than that of control (0.38 $m^3\ m^{-3}$) (Table 6). Field water capacity (FWC), PWP and AWC were not significantly affected by Gully slope position. Organic matter values of 29, 32, 27.19, 25.92 and 28.61 gkg^{-1} obtained in US, Ms, LS and CT, respectively were not significantly affected by Gully slope position.

Effect of soil Depth on some physical properties of the soil in the study area

Effect of soil depth on some physical properties of the soil depth on particle size distribution showed that in 0-20cm depth, Fs, CS, TS Silt and Clay had mean values of 256, 525, 780, 50 and 169 gkg^{-1} respectively, while 20-50cm depth recorded Fs, Cs, Ts, Silt and clay with 262, 523, 784, 52 and 164 gkg^{-1}, respectively. Bulk density was significantly affected by soil depth with subsoil (20-50cm) and had a significantly higher bulk density of 1.48 Mgm^{-3} than that of topsoil (0-20cm) with bulk density of 1.38 Mgm^{-3} (Table 6).

The result shows that Bulk density was significantly affected by soil depth with subsoil (20-50cm) having a significantly higher bulk density of 1.48 Mgm^{-3} than that of topsoil (0-20cm) with bulk density of 1.38 Mgm^{-3}.

Total porosity and macroporosity were significantly affected by soil depth and both were higher in top soil than in the subsoil. There was no significant effect of soil depth on microporosity.

Table 6: Mean Value Soil physical properties affected by soil Depth

	Particle Size Distribution												Water Retention Characteristics		
	Fs	**Cs**	**Ts**	**Silt**	**Clay**	**BD**	**Tp**	**Ma**	**Mi**	**Ksat**	**SWC**	**FWC**	**PWP**	**AWC**	**OM**
			gkg^{-1}			**Mgm^{-3}**		**m^3 m^{-3}**		**cm hr^{-1}**		**m^3 m^{-3}**			**gkg^{-1}**
0-20	255	525	780	51	169	1.38	0.48	0.29	0.19	6.26	0.41	0.19	0.11	0.08	29.50
20-50	261	523	784	52	164	1.48	0.44	0.26	0.18	4.32	0.38	0.18	0.11	0.07	26.04
Sig	0.64	0.89	0.62	0.68	0.43	<.001	<.001	<.001	0.07	<.001	<.001	0.07	0.69	0.07	0.003
LSD	2.53	2.76	1.59	0.64	1.34	0.03	0.01	0.02	0.01	0.57	0.01	0.01	0.01	0.01	2.25

Fs – Fine sand, Cs – Coarse Sand, Ts – Total sand, Bd – bulk density, Tp – total porosity, Ma – macroporosity, Mi – microporosity, Ksat – saturated hydraulic conductivity, SWC – saturation water content, FWC – field water capacity, PWP – permanent wilting point, AWC – available water capacity, OM – Organic Matter

Saturated hydraulic conductivity was significantly affected by soil depth with Ksat at the topsoil (6.26 cm hr^{-1}) being significantly higher than that pf the subsoil (4.83 cm hr^{-1}). Saturation water content (SWC) was significantly affected by soil depth with the topsoil (0-20cm), recorded higher SWC than the subsoil (20-50cm). Field water capacity (FWC), PWP and AWC were not significantly affected by soil depth. Organic matter concentration was obtained in the topsoil (29.50 gkg^{-1}) was significantly higher than that of the subsoil (26.04 gkg^{-1}).

Interactive effect of Gully category

Gully slope position and soil depth on soil physical properties. The interactive effects of Gully category, Gully slope position and soil depth on some soil physical properties are presented in Table 7. Soil physical properties that are significantly affected by any combination of these three factors were further shown by means of bar chart.

Coarse sand was significantly affected by the interaction of Gully category and Gully Slope position, coarse sand of US under AcG was significantly higher than those of CT and LS, irrespective of the Gully category. MS under SOG and MsG had coarse sand content that was significantly higher than those of CT and LS, irrespective of the gully category, under all the gully categories, CT and LS gave the least significant coarse sand content.

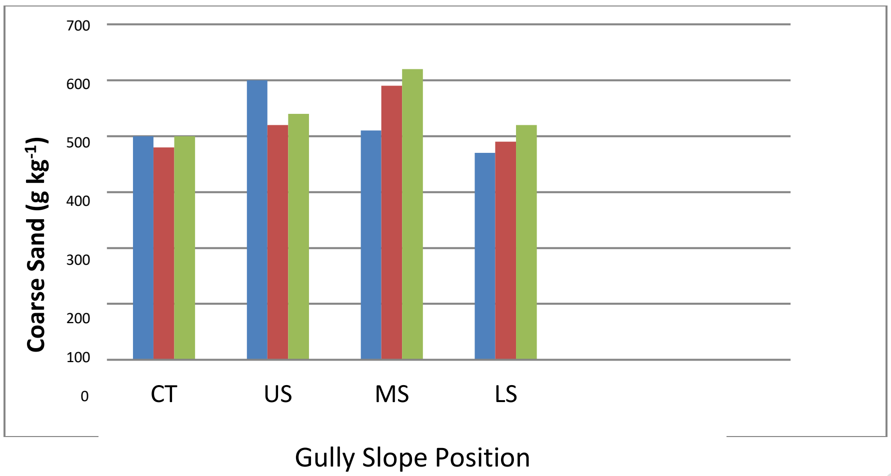
Bulk density of CT and LS under AcG and MsG were the highest and significantly different from those of SoG. Bulk density of MS under MsG was significantly higher than those of AcG and SoG while in the US, bulk density was not significantly different among the three gully categories.

Total porosity was inversely related with bulk density, as such, results obtained bulk density were opposite for total porosity. Macroporosity of US and Ms under AcG were the highest significant compared with those of MsG and SoG soils. There was no significant differences in macroporosity under CT and LS for the three Gully categories. Soil of the control, irrespective of the gully category had the least significant macroporosity compared to other combinations of Gully category and Gully slope position. Saturated hydraulic conductivity was highest at US and LS under SoG than under AcG and MsG. Under CT, the MsG and Sog had Ksat that were equal but significantly higher than that of AcG. There was no significant differences in PWP between the topsoil and subsoil in each of the gully categories, but the subsoil of SoG had significantly higher PWP than those of AcG and MsG.

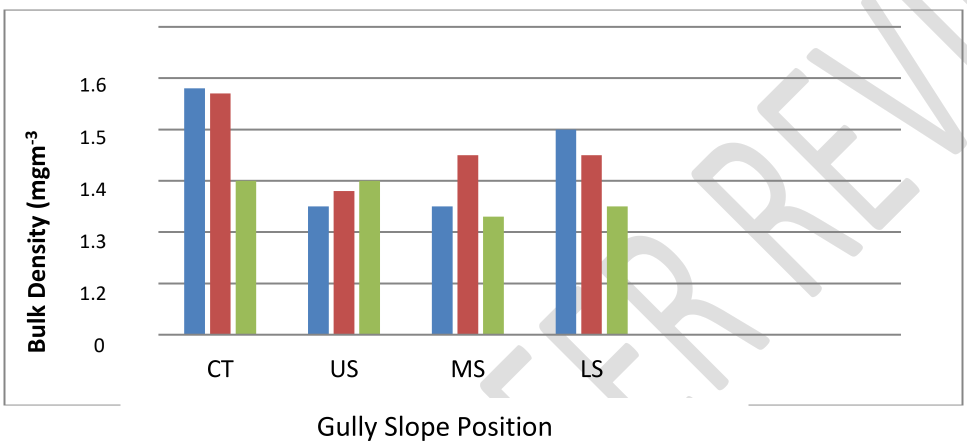
Table 7: Some soil physical properties as affected by the interactions of Gully category, Gully slope position and soil depth

	Fs	Cs	Ts	Silt	Clay	BD	Tp	Ma	Mi	Ksat	SWC	FWC	PWP	AWC	OM
	←		gkg^{-1}	→		Mgm^{-3}	←	$m^3\ m^{-3}$	→	$cm\ hr^{-1}$	←	$m^3\ m^{-3}$	→		gkg^{-1}
						Gully Category x Gully Slope Position									
Sig	0.14	0.03	0.5	0.92	0.25	0.00	<.001	0.00	0.85	0.02	0.1	0.85	0.14	0.78	0.05
LSD(0.05)	6.2	6.75	3.89	1.58	3.29	0.08	0.03	0.04	0.03	1.39	0.03	0.03	0.02	0.03	4.27
						Gully Category x Soil Depth									
Sig	0.74	0.71	0.74	0.48	0.61	0.67	0.36	0.24	0.45	0.09	0.16	0.45	0.01	0.06	0.47
LSD(0.05)	4.34	4.77	2.75	1.12	2.33	0.06	0.02	0.03	0.02	0.98	0.02	0.02	0.02	0.02	3.02
						Gully slope position x Soil Depth									
Sig	0.22	0.16	0.74	0.95	0.6	0.2	0.87	0.74	0.46	0.73	0.67	0.46	0.32	0.19	0.65
LSD(0.05)	5.06	5.51	3.18	1.29	2.69	0.07	0.02	0.03	0.02	1.13	0.03	0.02	0.02	0.03	3.48
						Gully Category x Gully Slope position x Soil Depth									
Sig	0.97	0.87	0.28	0.51	0.44	0.59	0.78	0.31	0.37	0.35	0.66	0.37	0.03	0.16	0.67
LSD(0.05)	8.77	9.54	5.5	2.23	4.65	0.11	0.04	0.05	0.04	1.96	0.05	0.04	0.03	0.05	6.04

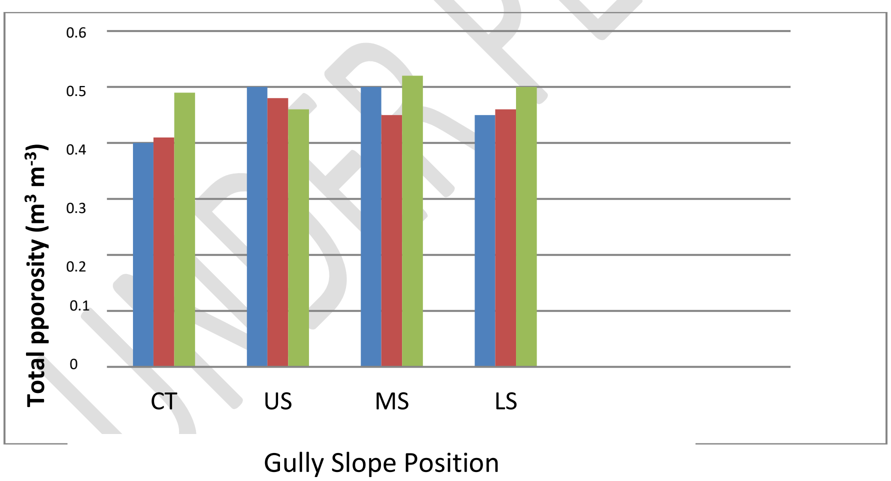
Fs – Fine sand, Cs – Coarse Sand, Ts – Total sand, Bd – bulk density, Tp – total porosity, Ma – macroporosity, Mi – microporosity, Ksat – saturated hydraulic conductivity, SWC – saturation water content, FWC – field water capacity, PWP – permanent wilting point, AWC – available water capacity, OM – Organic Matter a


700
600
500
400
300
200
100
0
Coarse Sand (g kg-1)
CT
US
MS
LS
Gully Slope Position

b


1.6
1.5
1.4
1.3
1.2
0
Bulk Density (mgm-3
CT
US
MS
LS
Gully Slope Position

c


0.6
0.5
0.4
0.3
0.2
0.1
0
Total pporosity (m3 m-3)
CT
US
MS
LS
Gully Slope Position

d

e

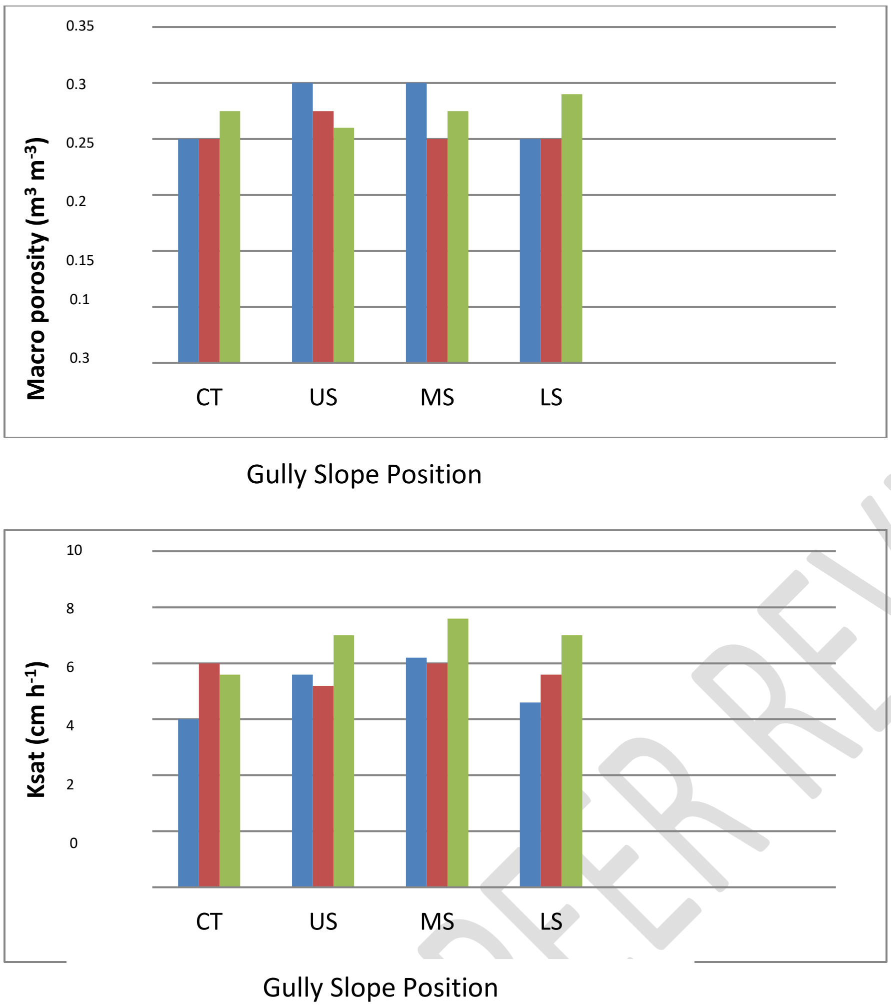


Figure 1 Means of Significant Soil Physical properties as affected by the interactions of Gully Category and Gully Slope position: (a) Coarse Sand, (b) bulk density (c) Total porosity (d) Macro porosity (e) Saturated hydraulic conductivity.

Permanent wilting point was significantly affected by the interaction of Gully Category and soil depth (Table 8). There were no significant differences in PWP between the topsoil and subsoil in each of the Gully categories but the subsoil of SoG had significantly higher PWP than those of AcG and MsG (Figure 2).

PWP was also significantly affected by the interaction of Gully category, Gully slope position and soil depth (Table 8). From figure.3, the combination of SoG and subsoil showed high PWP at the CT, US and MS when compared to other combinations involving AcG and MsG, with exceptions in AcG x US x Subsoil and MsG x US x topsoil and MsG x US x topsoil and subsoil, which were at the same level with the earlier mentioned combinations involving SoG.

Discussion

The dominance of sand in soils of the study area is attributed to the sandy parent material which is dominated by weathering – resistant quartz, as is the case with many tropical soils (Igwe and Obalum, 2013). It has been reported that textures of soils are influenced by the type of parent materials from which they were derived (Dewit and Bekker, 1990; Essien and Ogban, 2018, Ogban and Essien, 2016). The insignificant difference in soil separates among the three gully categories are attributed to be fact that particle sizes are inherent properties of the soil and are little affected by changes in land use and management.

The significantly higher coarse and total sand content in MS, followed by US is attributed to the washing of fine particles down slope (Duiker, 2003; and Ogban *et al.*, 2022), at the expense of the larger sand particles that cannot easily be transported. Consequently, the content of silt and clay in soils of US and MS were reduced. The LS soils had comparatively lower content of coarse and total sand, because most of the silt and clay transported from upslope were deposited in down slope and the original topsoil may have been buried.

There was no significant effect of soil depth on particle size distribution, because the degradation of the soil by erosion may have buried the topsoil or mixed it with the subsoil (Duiker, 2003), thereby disrupting the arrangement of particles in the soil. The reason for the higher bulk density of MsG and AcG than the SoG can be linked to the fact that the growth of vegetation ehich characterizes stable gully increased the organic matter content of SoG soil as observed in this study compared with those of MsG and AcG. Bot and Benites (2005), reported that soils that have high organic matter contents normally have lower bulk density compared to those with low organic matter (Essien *et al.,* 2023 and Simon *et al.,* 2023).

Soils of US and Ms had bulk density values that were higher than those of control of LS because of the significantly higher sand compared with those of control and LS (Essien et al. 2019). Brown and Wherett (2018) reported that sandy soils usually have higher bulk densities than soils that are high in fine silts and clays because they have larger but fewer pore spaces. On the other, Mondel et al. (2018) reported that soils with higher clay contents compact and significantly less and have lower bulk density. The result shows that subsoil had a significantly higher bulk density than the top soil. This can be attributed to the lower organic matter content in the subsoil, compacted due to the weight of the overburden materials.

Control and LS soils had significantly higher total porosity and macroporosity than those of US and MS as a result of the significantly higher clay and lower sand content in the former than the latter. Soil of SoG had a significantly high total porosity and microporosity because of the high organic matter content, Bot and Benites (2005) maintained that increased organic matter contributes indirectly to soil porosity (Via increased soil faunal activity). Fresh organic matter stimulates the activity of macrofauna such as earthworms, which creates burrows lined with the glue-like secretion from their bodies and are intermitted filled with worm cast materials.

Total porosity and microporosity were significantly higher in the topsoil than the subsoil because organic matter and activities of micro organism are dominant in the topsoil than the subsoil. Essien and Ogban (2018) mentions that organic matter o n the surface lead to improved soil aggregation and porosity, also increase the number of macropores, the reason for insignificant difference of macroposity among the three Gully categories under control could be linked to the near similarity of the influence of vegetation and root activities which improved soil structure and increased macropores of the soil. Doherty (2016) commented that treatments have insignificantly results when close enough that one cannot be certain that they are actually different. The significantly lower macroporosity in the soils of control, irrespective of the Gully categories means that micropores dominated and thus, have the ability to hold more water.

Ksat was significantly higher in soil of SoG and MsG than AcG because of the significantly higher organic matter contents, which also resulted in the significantly higher total porosity and significantly lower bulk density recorded in SoG soil.

On the other hand, the significantly lower organic matter contents and the apparently lower clay content in AcG may have predisposed the particles of AcG soil to ease of disintegration and subsequent sealing of the soil pores, thereby impeding infiltration. Lado *et al* (2004), had reported that the disintegration of soil macroaggregate into microaggregates following rainfall, slaking dispersion and sealing can decrease infiltration and saturated hydraulic conductivity of the soils.

Soils of SoG has a significantly higher SWC, FC and PWP, because it had the highest organic matter content, resulting in lowest bulk density, highest total porosity compared with soils of MsG and AcG.

Bot and Benites (2005); Essien *et al.* (2019); Essien and Umoh (2020) had reported that organic matter contributes to the stability of soil aggregates and pores through adhesion properties of organic materials, such as bacterial waste products, organic gel, fungal hyphae and worm secretions and casts.

Furthermore, organic matter intimately mixed with mineral soil materials has a considerable, influence in increasing moisture holding capacity.

Conclusion

The poor structure of soil particles leads to instability of coastal plain sands, which resulted from the predominance of sand particles, with little proportion of silt and clay that bind soil particle more. This is the major predisposing factor of coastal plain sands to erosion menace that is ravaging of soils of Akwa Ibom State. Stabilized gullies had dominance of vegetation growth, resulting in higher content of organic matter, increased stability of soil aggregates, lower bulk density, higher total porosity, increased saturated hydraulic conductivity, SWC, FWC and PWP, increased soil nutrients compared with soils of active and meta stable gullies. AcG and MsG had little or no vegetation, lower organic matter and clay content, and therefore low structural abilities and soil nutrient potentials compared with SoG.

The washing of fine particles down slope caused the lower Gully slope position to be dominated by silt and clay while the upper and middle Gully slope positions dominated by sand. Consequently, the lower gully slope position became higher in bulk density with lower total porosity and lower saturated hydraulic conductivity. The top soil had higher sand content, lower clay and silt content higher bulk density and lower total porosity, higher saturated hydraulic conductivity, higher SWC, FWC and PWP, higher organic matter and nutrient potentials with less stability of aggregates.

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