DOI: https://doi.org/10.67042/njss.2011.0wssitwd

Nigerian Journal of Soil Science

Journal homepage:www.soilsjournalnigeria.com

ERODIBILITY AND GULLY EROSION IN RELATION TO SOIL PROPERTIES IN AKWA IBOM STATE, SOUTH EASTERN, NIGERIA.

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ABSTRACT

This study was conducted to evaluate soil physical and chemical properties in relation to erodibility and gully erosion in Akwa Ibom State, South eastern Nigeria. The locations of study were three gully erosion sites/ types, namely, active and meta-stable (ms-1 and ms-2) gullies. Results of the study showed that coarse sand (CS) particles averaged 863, 710 and 800 gkg^{-1} in the active and ms-1 and ms-2 respectively, and were several orders of magnitude greater than the fine sand particle. The silt particle averaged 20, 94 and 41g kg^{-1}, while the clay fraction averaged 66,139 and 86 g kg^{-1} in the respective locations. Clay ratio (CR) averaged 12.14, 3.59 and 9.18, while silt/clay ratio averaged 0.32, 0.76 and 0.46, in the respective sites. Soil texture was either sandy loam (sl) or loamy sand (ls) generally. Wet aggregate stability (WAS) >2-mm averaged 15.8, 19.8 and 21.6%, while >0.5–mm averaged 34.2, 26.8 and 27.1% in the respective locations. Values of erodibility (K) were generally low, averaging 0.045, 0.065, and 0.053 ha^{-1} $MJ^{-1}mm^{-1}$ respectively. Soil organic C (org C) averaged 0.87, 1.22 and 1.72 gk g^{-1}, respectively. Sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) respectively averaged 0.04, 0.04 and 0.04, and 1.20, 1.79 and 1.56% in the active and ms-1 and ms-2. Oxides of iron averaged 2181.9, 1851.0 and 2891.4 mg kg^{-1} (crystalline) and 1047.7, 1923.4 and 1978.2 mg kg^{-1} (amorphous), respectively. The index of susceptibility, K, correlated positively with silt (si) ($r=0.877^{**}$) and clay (cl) ($r=0.795^{**}$), and negatively with CS ($r=-0.902^{**}$) and CR ($r=-0.694^{*}$). The values of the silt and clay fractions indicate low content of inorganic colloids, while the CR indicates high soil dispersion potential irrespective of the moderately high values of soil organic C or organic matter and macro-aggregation. Consequently, the soils could be easily eroded, the low values of K notwithstanding.

Keywords: soil properties, erodibility, gully erosion, acid sands, Southeastern, Nigeria.

INTRODUCTION

Rainfall energy and intensity, soil properties, and land use and management are principal factors influencing the occurrence and severity of soil erosion problem in South eastern, Nigeria. Gully erosion is a characteristic feature on the landscape of the area, and is attributed to land use and management, especially continuous cropping with the associated shortened or lack of natural fallow and loss of the protective vegetal cover (Ukpong, 1997; Abubakar *et al.*, 1998), lithology, soil texture and infiltration potential, as well as the total annual rainfall and intensity common in the sub-region (Ofomata, 1981, 1988; Ijeoma, 1988).

The inherent susceptibility of a soil to water erosion expressed as soil erodibility factor (K) in the Universal Soil Loss Equation (Wischmeier and Smith, 1965), can be determined (i) directly by field measurements under natural rainfall using the "unit plot" technique (Wischmeier and Smith, 1961) (ii) by rainfall simulator (Meyer and McCune 1958) or (iii) by estimation from easily measured soil properties using the nomograph of Wischmeier *et al.* (1971). Several and variable results have been reported with these methods (Bruce-Okine and Lal, 1975).

The objective of the study was to assess the physical and chemical properties of the soils in relation to gully erosion, and to provide the tools for soil conservation and management in the area.

MATERIALS AND METHODS

The study area: The study was conducted in three gully erosion sites located at Etim Ekpo, Oron, and Uyo in Akwa Ibom State, situated between latitudes 4^0 30^1 and 5^0 30^1 N and longitudes 7^0 30^1 and 8^0 30^1 E. A combination of study tour and literature review was used to select the sites. The gullies in Akwa Ibom State were grouped into two broad categories based on their dynamics, namely, active and meta-stable (ms-1) and (ms-2), the latter referring to stabilized, old gullies. Whereas headward erosion (incision) and soil mass movement are common in the active gullies, especially during storms, slope processes appear to have ceased or become restricted to ordinary sheet wash in meta-stable gullies. There are over 200 gully erosion sites in the state, about 70% are active while about 30% are meta-stable. Three gullies, one active and two meta-stable (ms-1 and ms-2) were studied.

The active gully was young and headward erosion, incision actively occurring at the rate of 3.30 myr. The ms-1 gully was mature, widening, and flattening while ms-2 was an old gully, stabilized by vegetation. The gullies measured 729, 920, and 630 m^2, within 18.0, 24.2 and 12.6 ha catchment basins, respectively.

Akwa Ibom State has a uniform hot humid tropical climate, characterized by two distinct dry and wet seasons. The wet or rain season lasts from March to November and produces a *udic* soil moisture regime. The mean annual rainfall is about 3000 mm, decreasing from the coast to the hinterland, and occurring mostly as erosive storms. Temperatures are uniformly high throughout the year, varying from 26 to 28^0C, producing a *hyperthermic* soil temperature regime. High relative humidities varying from 75 to 95 % are common.

River-deposited sands and clays cover over 80 percent of the state and constitute the Benin formation, otherwise known as the Quaternary coastal plain sands. This parent material covers approximately 75 % of the state. A belt of shales associated with sandstones and limestones, the tertiary Imo shale and the phosphatic Ameke formation, stretches along the northeast of the State. The sites studied were located in the coastal plain sand area, and therefore, of fairly uniform lithological characteristics. The soils developed from this parent material generally have loamy sand and sandy loam surface layer over sandy clay loam to sandy clay sub-soils, and are deeply permeable. They have low organic matter content and resilience, and structurally unstable. The soils are mostly *Arenic* or *Aquantic Kandiudults*.

The vegetation is mostly secondary forest of predominantly wild oil palms, woody shrubs such as *Chromolaena odorota*, and various grass undergrowth. Land use is mostly the traditional shifting cultivation with the associated bush fallow system. The bush fallow period has however, been shortened to an average 4 years (Ogban *et al.*, 2004, 2005), and the vegetal cover largely immature and unable to restore soil productivity or quality (Areola, 1990).

Field Methods

Composite soil samples were collected at depth intervals of 0-15 and 15-30-cm at the

upper, middle, and lower gully positions, and one control sample 100-m away from the gully edge at the middle gully position for laboratory mechanical and chemical analyses. Another set of disturbed samples was collected at the same gully positions for wet aggregate stability analysis. A set of undisturbed core samples was collected with metal cylinders 7.2-cm long and 6.8-cm internal diameter for the determination of hydraulic conductivity and bulk density.

Laboratory Methods

Hydraulic conductivity (Ksat) was determined on the intact core soil samples, and Ksat computed from the equation (Reynolds and Elrick, 2002):

$$Ksat = QL/At\Delta H \quad (1)$$

where

Ksat = hydraulic conductivity, cm/h
Q = volume of water, cm^3
A = cross-sectional area of sample, cm^3
L = length of soil column, cm
h = height of water above soil column, cm
ΔH = hydraulic head difference (L+h), cm
t = time, min

The values of Ksat were used to compute the values of permeability as follows:

$$kp = ksat\eta/\rho g \quad (2)$$

kp = permeability, cm^2
Ksat = see equation (I)
η = viscosity $gcm^{-1}s^{-1}$
ρ = density of water, gcm^{-3}
g = acceleration due to gravity, cms^{-2}

Bulk density was determined as described by Grossman and Reinsch (2002), and non-capillary porosity determined after equilibrating the intact cores at a tension of 50-cm.

Non-sand free wet aggregate stability was determined with sieve sizes 2-mm and 0.5-mm as described by Nimmo and Pekkins (2002). The composite samples were air-dried and sieved through a 2-mm mesh and the fine-earth used for mechanical or particle-size distribution analysis using the Bouyoucos hydrometer method (Gee and Or, 2002). Clay ratio (CR) was computed as described by Bouyoucos (1935).

Soil pH was determined in 1:2.5 soil/water volume ratio with a glass electrode pH meter. Organic C was determined by the modified Walkley-Black wet oxidation method (Nelson and Sommers, 1996). Total exchangeable bases, Ca, Mg, K and Na, exchangeable acidity and CEC were determined as described by (Sumner and Miller 1996; Loeppert and Inskeep, 1986). Finally, the soil-erodibility factor K was derived from the nomograph of Wischmeier *et al.* (1971).

The data were subjected to Pearson's correlation analysis for relationships among the parameters, in particular those that have interacted to produce the predicted values of K.

RESULTS AND DISCUSSION

Physical and analytical chemical data generated from the control and main sampling points along the gullies appear similar. Therefore, the results and discussion are presented as comparative analysis among the gully types.

Soil physical properties

Data in Table 1 show that the mean values of coarse sand (CS) were 863, 710, and 800 g kg^{-1}, in active, ms-1, and ms-2, respectively, and were generally high, compared to 51, 58,

and 73 g kg^{-1} fine sand content in the respective gully sites. This implied that the soils irrespective of gully type, whether active or stable, comprised largely particle fractions that required a large threshold force for detachment and transport. Equally, the low proportion of the fine sand fraction indicated that soil sealing may not be a problem in the soils. However, the large proportion of coarse sand or total sand (TS) indicated soil fragility and low content of colloidal materials, mainly clay, and therefore low resistance to erosion by splash and shear stress. The ease of splash and dispersion in the soils is thus, indicated by the low contents of the silt and clay fractions in all sites. The low contents of the silt and clay particles may be due to prolonged cycles of weathering and erosion, and may indicate that the clay separate may not be an important inorganic aggregation material in the soils.

The soils of the gully sites were similar in texture, being either sandy loam or loamy sand in the surface (0-15 cm) or subsurface (below 15 cm). Because of the sandy texture, only a small proportion of rainwater may escape as unconcentrated surface wash. However, Hortonian overland flow, where the rain intensity is larger than the rain infiltration into the soil, does occur, ranging from slight (where the surface is covered with grasses/weeds) to severe, common in the bare cultivation systems in the area, with high shear stress and low shear strength.

The low potential for surface-sealing due to the low content of fine sand implies that the soil remained permeable, and that much of rainwater infiltrates the soil profile to deeper layers, saturating these layers causing chemical dispersion, and because the soil at lower depth has low strength, enhancing gully advance and gully bank erosion. These processes may have combined to sustain the erosion process in the active gully, and rapid gully development in the state and or other areas on similar lithology/parent material in Southeastern, Nigeria.

The clay ratio (CR) and silt/clay ratio (Table 1) reflect the contents of sand, silt and clay fractions in the soils and age of the parent material, respectively. The CR averaged 12.14, 3.59 and 9.18 in the three respective gully sites. That is, higher in the active gully and lower in ms-1, ms-2 being intermediate. Again, CR reflects the dispersibility of soil, indicating that the soils in all three locations are highly dispersible but highest in the active gully and may explain why it was still eroding, and lowest in ms-1.

The low silt/clay ratio on the other hand, indicated the prevalence of parent material that may have been exposed to prolonged weathering processes The soils are derived from Quaternary coastal plain sands parent material. Consequently, processes of overland flow, leaching losses and deep percolation may have combined to deplete the soils of most order but the coarse particle-size fractions.

The soils of the gully erosion sites were generally characterized by moderately high values of bulk density, averaging 1.50, 1.45 and 1.26 Mgm^{-3} in the active, ms-1 and ms-2, respectively. Although the soils comprise predominantly quartz mineral particles, as shown by the high total sand content, reflecting the nature of the parent material, they may be structurally loose, friable in consistence and less cohesive, and therefore, explain their permeable nature. This may also be explained by the moderately high values of macropores in the soils. In other words, the soils may have low hydraulic resistance and root activity may not be impeded by soil density within the range observed.

Percent wet macro-aggregate stability >2.0-mm averaged 15.8, 19.8 and 21.6%, and >0.5-mm averaged 34.2, 26.8 and 27.1%, respectively in the active, ms-1 and ms-2 gullies (Table 1). Macro-aggregate stability in all sites was ≤50.0%, indicating that a greater proportion of the stable aggregates was <0.5-mm. This reflected poor macro-aggregation which may be due to the low content of clay and other colloidal materials in the soil, as

well as the ease of slaking, physical dispersion and structural disintegration, or low resistance to erosion under the high intensity rainfall in the area.

Hydraulic conductivity, Ksat, averaged 31.26, 22.57 and 33.42 cmh^{-1} in the active, ms-1 and ms-2 gullies, respectively, and was generally very rapid. The trend in Ksat follows that of the mechanical properties and wet macro-aggregate stability in all three gullies. The pattern of similarity in the physical properties among the gullies is also demonstrated by the observed values of intrinsic permeability, which averaged $5.71x10^{-6}$, $6.08x10^{-6}$ and $8.53x10^{-6}$ cm^2, and moderately slow, generally. The pattern of differences in the physical properties indicated that the gullies were similar in terms of the underlying lithological material irrespective of whether active or stable.

The implication of the observed values of Ksat is that fine sand and particle fractions <0.02-mm could easily be translocated below the surface soil. Further, the soil erosion problem could not be due to soil water flux density, which is rapid (Ksat) within the profile, but the flux density of storm rain-water with the potential for Hortonian flow in excess of the shear strength of the soil. However, the surface-free water vanishes from the surfaces of agricultural soils following the cessation of rainfall, indicating the drainage effectiveness of the macropore system. Consequently, the erosion problem could not necessarily be due to the characteristics of the soils but the overwhelming effect of the high energy and intensity rainstorms in the area.

The erodibility factor, K, or susceptibility of a soil to erosion, was generally low, whether active or stable gully (Table 1). This may be either because of high rainwater acceptance and transmission, or the nomograph underestimated the erodibility of the soils. However, the low content of some of the parameters, such as clay fraction and micro-aggregate stability, indicated poor structural stability and that the physical conditions which favour (gully) erosion exist.

Soil chemical properties

Soil pH in water averaged 4.9, 4.9 and 5.0 in the active, ms-1 and ms-2 gullies, respectively and was strongly acidic (Table 2). Soil organic C level varied from an average value of 0.87 g kg^{-1} in the active, 1.22 g kg^{-1} in ms-1, to 1.72 g kg^{-1} in ms-2, ranging from moderately low to moderately high (FMANR,1990). This implied that the soil in the active gully area could be even more fragile than in ms-1 and ms-2. Soil organic C or organic matter is reputed to be the main binding and stabilizing agent for micro-aggregates and hence macro-aggregates, affecting soil structure and stability. In other words, the disruptive effect of raindrop is reduced, and there is improvement in soil water transmission properties (e.g., saturated hydraulic conductivity, relatively larger percentage of transmission pores, high soil-water sorptivity and transmissivity, etc.). However, considering the moderate levels of soil organic C (<2%), the synergistic effect of soil physical, hydraulic, and chemical properties may be more important than differences in organic C levels in relation to soil erosion in the study area.

Generally, the levels of soil organic C obtained were attributed to the ground cover of immature vegetation, due to shortened natural fallow period and a highly oxidizing environment (*isohyperthermic* temperature and *udic* soil moisture regimes). This latter notwithstanding, soil organic matter management or consciously improving soil organic C content appears the only alternative to improving soil quality attributes including soil structural stability and resilience and controlling soil erosion, in view of the low inorganic colloid content of soils in the area.

The content of the bivalent cations (Ca^{2+}, Mg^{2+}) is higher than the monovalent (Na^{+}, K^{+}) and points to soil structural stability in the area. Reports have shown that soil erosion is negatively correlated with the bivalent cations. The susceptibility to water erosion increased

linearly with an increase in the monovalent cations, especially sodium adsorption ratio (SAR), consequently, while the bivalent cations may have contributed to the stability of the measured aggregates as an index of soil structural stability, the low content of the monovalent cations may not have posed a problem such as clay dispersion, structure collapse, or reduction in hydraulic conductivity.

The Ca/Mg ratio was generally low in the soils (Table 2). As an index of soil structural stability and weathering status, the observed values indicated that the soils were highly weathered and leached or have lost much of colloidal materials needed in the formation of soil aggregates, realization of soil structural stability and minimization of soil degradation through soil erosion. Equally, the ESP values are generally low (Table 2). The ESP index issued to establish the dispersion potential of a soil, and high values indicated ease of soil dispersion and gullying. As already stated, the soils are poorly aggregated, easily dispersible and splashed. Therefore, the ESP index may not be important in characterizing the soils in relation to soil or gully erosion.

The hydrous oxides of iron and aluminium were relatively high compared to the total clay content (Table 2). Hydrous oxides are known to create cement between domains and micro-aggregates and add stability to aggregates (micro-aggregates and macro-aggregates) in humid tropical soils low in organic matter and clay. Perhaps, the observed values of macro-aggregates may be attributed to the hydrous oxides. However, aggregates stabilized by the oxides are not strongly cemented. Deshpande *et al.* (1968) had observed that the oxides influence aggregation or aggregate stability very little, because the oxides are structurally inactive and are easily deactivated by anion adsorption. The latter renders the oxide surfaces negatively charged and promote dispersion of the aggregates (Bowden *et al*., 1980). Consequently, the only feasible and indeed sustainable means of improving the soil quality attributes, in particular the structural attributes (aggregate stability) to enable soil resist erosion, is soil organic matter management.

Pearson correlation matrix of all soil parameters (Table 3) showed 36 pairs of significant values, out of which 19 pairs were positive and 17 negative. The important relationships however are those with soil erodibility, K. Among these, coarse sand (CS) was negatively significantly correlated with K ($r=-0.902^{**}$) indicating the resistance that the former offers to shear stress or the higher fluid drag (water) required by coarse particles. The silt (Si) and clay fractions were positively significantly ($r=0.877^{**}$,$r=0.795^{**}$) respectively correlated with K, indicating the indirect influence of the silt and clay size particles on the formation of large heavy aggregates and resistance to erosion. However, since the content of the silt and clay size fractions is very low and macro-aggregate stability is moderate, the contribution of these particle-size fractions may have been low, equally. Clay ratio (CR) is negatively significantly ($r=-0.694^{*}$) correlated with K, and indicates that the susceptibility of the soils to erosion may be due to the low content of the silt and clay fractions, which can adhere and form large aggregates than the sand fraction which may not easily be entrained but can easily be physically and chemically dispersed and detached.

CONCLUSION

The soils of three gully erosion sites in Akwa Ibom State were studied in terms of their physical and chemical properties and susceptibility to erosion generally and gully erosion in particular. The results showed that the soils have high total sand content and low content of silt and clay. Although the soil particles may not easily be transported because of the higher fluid drag required, they can be easily dispersed and detached than the silt and clay particles which can adhere to form large, heavy aggregates that can resist erosion. The

sandy texture therefore predisposed the soils to erosion. The clay ratio was generally high, and as an index of soil dispersibility indicated high dispersion potential of the soils.

The soils are porous and permeable as shown by the moderately high values of bulk density and macroporosity. Wet macro-aggregate stability was moderately high. Values of saturated hydraulic conductivity were high and ksat was very rapid. The soils have moderately high soil organic C content and high content of the hydrous oxides. But, both, needed in the formation and stabilization of aggregates, to resist erosion, are however easily degraded. Soil erodibility K was low, and did not adequately reflect the generally poor soil erosion quality attributes. Although the soils have good water absorption and transmission properties, storm-water flux density occasionally may exceed the soil infiltrability resulting in runoff or overland flow with high shear stress that can incise the land surface and develop rapidly into gullies.

In view of the poor soil quality attributes, soil conservation and management must emphasize improving the soil organic matter content with its potential to improve soil structural stability, soil water infiltrability and soil chemical quality and thus, reduce soil erosion and gullying in the area.

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Table 1: Physical properties of soils of gully erosion sites in Akwa Ibom State

	Depth cm	**CS**	**FS** ← gkg^{-1}	**Silt**	**Clay** →	**CR**	**si/cl** ratio	**Texture**	**K t.ha.h haMJmm**	**Bd** mgm^{-3}	**Mp** m^{3}m^{-3}	**WAS%** >2-mm	> 0.5-mm	**Ksat** cmh^{-1}	**Ksat class**	**kp** cm^2	**kp class**
Ac (k)	0-15	895	57	0	48	19.83	0	s	0.042	1.22	0.328	21.2	38.8	24.88	v.rapid	6.35x10^{-6}	mod slow^4
	15-30	867	85	0	48	19.83	0	s	0.052	1.43	0.268	12.6	37.4	39.45	rapid	1.01x10^{-6}	mod slow^4
Ac (m)	0-15	844	48	60	48	8.26	1.25	ls	0.060	1.58	0.228	19.1	30.9	9.71	rapid	2.48.10^{-6}	mod slow^4
	15-30	826	56	30	88	7.47	0.34	ls	0.045	1.46	0.262	11.2	48.8	26.70	v. rapid	6.81x10^{-6}	mod slow^4
Ac (l)	0-15	877	41	20	62	11.20	0.32	s	0.042	1.85	0.137	18.1	21.9	44.30	rapid	1.13 x10^{-5}	mod ^{3}
	15-30	829	48	20	102	7.19	0.20	ls	0.043	1.78	0.154	10.6	29.4	40.66	rapid	1.04x10^{-5}	mod slow^4
Ac (c)	0-15	879	35	20	66	10.63	0.30	s	0.040	1.22	0.328	21.2	38.8	24.90	rapid	6.35x10^{-6}	mod slow^4
	15-30	886	41	7	66	12.70	0.11	s	0.038	1.43	0.268	12.6	27.4	39.50	rapid	1.01x10^{-6}	mod slow^4
	$\overline{x}$	863	51	20	66	12.14	0.32		0.045	1.50	0.247	15.8	34.2	31.26	v.rapid	5.71x10^{-6}	
ms-1 (h)	0-15	790	68	80	62	6.04	1.29	ls	0.060	1.34	0.290	20.8	34.2	15.78	rapid	4.03x10^{-6}	mod slow^4
	15-30	717	81	100	102	3.95	0.98	sl	0.069	1.36	0.291	25.4	30.6	27.92	rapid	7.12x10^{-6}	mod slow^4
ms-1 (m)	0-15	623	75	100	202	2.31	0.50	scl	0.076	1.42	0.262	16.8	28.9	29.42	rapid	6.74x10^{-6}	mod slow^4
	15-30	706	32	120	142	2.82	0.85	sl	0.072	1.48	0.240	14.2	22.2	16.92	rapid	4.31x10^{-6}	mod slow^4
ms-1 (l)	0-15	793	39	60	108	4.95	0.56	sl	0.051	1.43	0.258	17.5	32.1	36.48	rapid	9.31x10^{-6}	mod slow^4
	15-30	751	56	75	148	3.48	0.51	sl	0.060	1.51	0.228	13.3	26.4	30.62	rapid	7.81x10^{-6}	mod slow^4
ms-1(c)	0-15	623	75	96	202	2.31	0.50	scl	0.062	1.58	0.228	29.1	30.9	9.71	v.rapid	2.48x10^{-6}	mod slow^4
	15-30	708	38	120	140	2.82	0.85	sl	0.066	1.46	0.262	21.2	28.8	16.70	rapid	6.8x10^{-6}	mod slow^4
	$\overline{x}$	710	58	94	139	3.59	0.76		0.065	1.45	0.257	19.8	26.8	22.57	v.rapid	6.08x10^{-6}	
ms-2(h)	0-15	794	64	60	82	6.04	0.73	ls	0.052	1.45	0.272	35.5	44.5	10.92	rapid	2.79x10^{-6}	mod slow^4
	15-30	743	55	60	142	3.95	0.42	sl	0.049	1.43	0.267	33.4	26.6	24.28	rapid	6.19x10^{-6}	mod slow^4
ms-2(m)	0-15	834	62	42	62	8.62	0.68	ls	0.053	1.32	0.300	20.1	32.8	40.41	rapid	1.03x10^{-5}	mod slow^4
	15-30	758	58	56	128	4.43	0.44	sl	0.054	1.38	0.277	15.4	22.4	33.64	rapid	8.58 x10^{-6}	mod slow^4
ms-2 (l)	0-15	848	84	10	58	13.71	0.17	ls	0.050	1.41	0.266	17.8	28.6	38.92	rapid	9.93x10^{-6}	mod slow^4
	15-30	740	98	60	102	5.17	0.59	sl	0.068	1.48	0.240	11.7	20.4	34.20	rapid	8.72x10^{-6}	mod slow^4
ms-2 (c)	0-15	872	86	0	42	22.81	0	s	0.044	1.45	0.278	28.1	21.9	44.30	rapid	1.13x10^{-5}	mod ^{3}
	15-30	808	80	40	62	8.71	0.65	ls	0.053	1.43	0.284	10.6	19.4	40.66	rapid	1.04x10^{-5}	mod slow^4
	$\overline{x}$	800	73	41	86	9.18	0.46		0.053	1.26	0.274	21.6	27.1	33.42		8.53x10^{-6}	

Table 2: Chemical properties of soils of gully erosion sites in Akwa Ibom State

Sample	Depth	pH	Orgc	Exchbases									Cryst oxide		Amorph oxide	
No	**cm**	**H_2O**	**gkg^{-1}**	**Ca**	**Mg**	**Ca/Mg**	**Na**	**K**	**ECEC**	**SAR**	**ESP**	**Bsat**	**Fe**	**Al**	**Fe**	**Al**
				←		**$cmol\ kg^{-1}$**			→			**%**	←	**$mgkg^{-1}$**	→	
Ac (k)	0-15	4.1	0.19	2.88	1.10	2.62	0.09	0.18	6.17	0.05	1.46	68.9	834.0	113.2	500.4	79.9
	15-30	5.1	0.19	2.56	1.20	2.13	0.09	0.21	5.82	0.05	1.55	69.8	1084.2	126.5	917.4	118.9
Ac (m)	0-15	4.9	2.02	3.20	1.40	2.29	0.05	0.05	5.94	0.02	0.84	75.8	6672.0	106.6	917.4	166.5
	15-30	5.0	1.80	3.20	1.20	2.67	0.07	0.08	6.47	0.03	1.08	70.3	1668.0	176.2	1584.6	99.9
Ac (l)	0-15	5.1	0.74	2.56	1.00	2.56	0.05	0.06	5.43	0.03	0.92	67.6	2251.8	159.8	1084.2	79.9
	15-30	5.1	0.62	1.60	1.80	0.89	0.05	0.05	3.94	0.03	1.27	63.5	834.0	139.9	1334.4	126.5
Ac (c)	0-15	4.8	0.77	2.35	1.27	1.97	0.08	0.08	5.49	0.04	1.46	68.9	2415.9	104.4	1237.1	104.3
	15-30	4.8	0.64	2.85	1.37	2.18	0.06	0.05	5.90	0.03	1.02	73.4	1695.4	104.4	806.2	88.8
	$\overline{x}$	4.9	0.87	2.65	1.29	2.16	0.07	0.10	5.65	0.04	1.20	69.8	2181.9	128.9	1047.7	108.2
ms-1 (h)	0-15	4.5	2.13	1.60	0.90	1.78	0.05	0.08	4.23	0.03	1.18	62.2	2085.0	193.1	2418.6	93.2
	15-30	4.9	2.11	2.88	1.12	2.57	0.07	0.06	5.89	0.04	1.19	70.1	1334.4	266.4	1668.0	93.2
ms-1 (m)	0-15	5.2	0.18	2.27	0.90	2.52	0.09	0.15	4.98	0.05	1.81	68.5	1167.6	119.9	1000.8	99.9
	15-30	5.3	0.13	2.56	1.20	2.13	0.08	0.14	5.46	0.04	1.47	72.9	1292.7	96.6	834.0	113.3
ms-1 (l)	0-15	4.6	1.10	2.72	1.92	1.42	0.06	0.06	5.62	0.03	1.06	84.7	3966.2	103.3	1292.7	149.9
	15-30	4.7	1.00	3.20	1.50	2.13	0.05	0.06	4.98	0.02	1.00	96.6	1542.9	151.4	1125.9	66.6
ms-1(c)	0-15	5.1	2.06	2.24	1.40	1.60	0.06	0.06	1.60	0.03	3.75	72.4	1417.8	99.9	6505.2	139.9
	15-30	4.9	1.04	1.92	0.80	2.40	0.06	0.08	2.10	0.04	2.86	60.4	2001.6	99.9	542.1	119.9
	$\overline{x}$	4.9	1.22	2.42	1.22	2.07	0.07	0.09	4.36	0.04	1.79	73.5	1851.0	141.9	1923.4	109.5
ms-2(h)	0-15	4.8	2.32	2.56	1.20	2.13	0.07	0.03	5.78	0.04	1.21	66.8	1334.4	253.1	1417.8	99.8
	15-30	5.4	2.28	1.92	0.80	2.40	0.06	0.04	4.58	0.04	1.31	61.6	7506.0	346.3	1417.8	99.9
ms-2(m)	0-15	4.4	1.15	2.40	1.15	2.09	0.07	0.08	5.30	0.04	1.32	69.8	1751.4	146.6	2043.3	113.2
	15-30	4.6	1.14	2.88	1.11	2.59	0.07	0.06	5.96	0.04	1.17	69.1	1749.4	196.5	1417.8	63.3
ms-2 (l)	0-15	4.9	1.25	2.08	1.25	1.66	0.07	0.05	5.53	0.04	1.27	62.4	2460.3	169.9	980.0	79.9
	15-30	5.1	1.24	2.88	1.50	1.92	0.07	0.04	6.17	0.03	1.13	72.8	4837.2	233.1	959.1	113.2
ms-2 (c)	0-15	5.2	2.19	2.56	1.30	1.97	0.06	0.07	5.58	0.03	2.53	71.3	1334.4	159.8	6672.0	99.9
	15-30	5.2	2.15	2.88	1.00	2.88	0.05	0.03	4.92	0.03	2.54	80.5	2160.4	106.6	917.4	133.2
	$\overline{x}$	5.0	1.72	2.52	1.16	2.21	0.07	0.05	5.48	0.04	1.56	69.3	28.91	201.5	1978.2	100.3

Table 3: Pearson correlation matrix of some physical an chemical properties of soils

	Cs	Fs	Si	Cl	CR	Si/Cl	Bd	Mp	WAS_2	WAS_5	Ksat	SOC	Ca	Mg	Ca/Mg	Na	K	ECEC	SAR	ESP	B_{sat}	Fe_c	Al_b	Fe_a	Al_a	K
CS	1.00																									
Fs	-0.41	1.00																								
Si	-0.92**	0.25	1.00																							
Cl	-0.96**	0.26	0.82**	1.00																						
CR	0.75*	0.15	-0.85**	-0.69*	1.00																					
Si/Cl	-0.51	0.40	0.49	0.38	-0.47	1.00																				
Bd	-0.15	-0.08	0.12	0.17	-0.19	0.09	1.00																			
Mp	0.17	0.14	-0.16	-0.19	0.26	0.12	-0.99**	1.00																		
WAS_2	-0.13	0.30	0.08	0.07	0.04	0.27	0.02	0.12	1.00																	
WAS_5	0.02	-0.22	0.08	-0.04	-0.23	0.00	-0.60*	0.60*	0.37	1.00																
K_{sat}	0.42	-0.01	-0.48	-0.31	0.50	-0.21	0.10	-0.12	-0.41	-0.60*	1.00															
SOC	-0.21	-0.09	0.19	0.21	-0.37	0.63*	0.46	-0.43	0.14	-0.33	0.24	1.00														
Ca	0.33	-0.46	-0.43	-0.23	0.27	-0.36	0.18	-0.15	0.01	0.03	-0.02	-0.05	1.00													
Mg	-0.04	-0.32	-0.04	0.04	-0.08	0.32	0.02	-0.02	0.05	0.02	0.04	0.34	0.44	1.00												
Ca/Mg	-0.19	-0.16	-0.27	-0.14	0.25	-0.68*	0.13	-0.14	-0.14	-0.02	0.02	-0.27	0.40	-0.63*	1.00											
Na	-0.18	0.01	-0.18	-0.16	0.22	-0.42	-0.30	0.34	0.50	0.69*	-0.37	-0.51	0.30	-0.15	0.39	1.00										
K	-0.09	0.06	0.02	0.17	0.22	-0.52	-0.46	0.41	-0.34	0.09	0.06	-0.71*	0.05	-0.41	0.55	0.29	1.00									
ECEC	0.72*	-0.35	-0.68*	-0.68*	0.50	-0.38	-0.22	0.21	-0.27	0.12	0.38	-0.11	0.49	0.01	0.42	0.32	0.13	1.00								
SAR	-0.10	0.22	-0.03	0.20	0.11	-0.26	-0.55	0.52	-0.06	0.38	0.13	-0.41	-0.17	-0.42	0.38	0.51	0.69*	0.21	1.00							
ESP	-0.57	0.52	0.35	0.59*	-0.04	0.32	0.05	0.03	0.47	-0.19	-0.17	0.05	-0.21	0.08	-0.28	-0.13	0.06	-0.78**	-0.00	1.00						
B_{sat}	-0.09	-0.47	0.11	0.19	-0.18	0.15	0.13	-0.13	-0.11	-0.09	0.03	0.30	0.62*	0.84**	-0.26	-0.18	-0.12	0.05	-0.39	-0.05	1.00					
Fe_c	0.21	-0.48	-0.22	-0.19	-0.12	0.11	0.29	-0.32	-0.32	-0.13	-0.10	0.29	0.66*	0.58	-0.07	-0.30	-0.40	0.30	-0.57	-0.37	0.60*	1.00				
Al_c	0.15	0.33	-0.03	-0.31	0.05	0.13	0.09	-0.03	0.51	0.22	-0.03	0.15	-0.34	-0.38	0.02	0.39	-0.39	0.18	0.05	-0.26	-0.57	-0.39	1.00			
Fe_a	-0.64*	0.24	0.62*	0.606*	-0.52	0.36	0.20	-0.17	0.36	0.03	-0.44	0.11	-0.37	0.12	-0.46	-0.21	-0.23	-0.96**	-0.25	0.73*	0.05	-0.21	-0.16	1.00		
Al_a	-0.34	-0.05	0.34	0.262	-0.38	0.59*	-0.23	0.24	0.10	0.24	-0.48	0.16	0.29	0.65*	-0.46	-0.17	-0.20	-0.21	-0.36	0.21	0.65	0.54	-0.41	0.31	1.00	
K	-0.90**	0.49	0.88**	0.78**	-0.69*	0.49	0.02	-0.06	-0.08	-0.04	-0.33	0.12	-0.41	-0.26	-0.05	-0.20	0.21	-0.48	0.21	0.29	-0.07	-0.22	-0.02	0.37	0.256	1.00