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Physico-Chemical Characteristics and Dispersion Related Properties of Colluvial Sediments Exposed in Afikpo Gully Erosion Southeastern Nigeria

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Abstract
Gully erosions had continued to pose serious ecological challenges to countries like Nigeria. The gullies had led to the development of badlands and water loss due to low water holding capacity of soil. The soil erodibility factor has since been recognized as a contributing factor to soil erosion hazard and this had not been applied in study of geo-environmental degradations in southeastern Nigeria. The study uses the physicochemical properties of colluvial soils and erodibility indices derived from dispersion related properties in evaluating gullies. From the results, the sediments were dominated by majorly dispersive soil such as sands with low percentage of silt fractions, hence low cohesion and low plasticity indices, which are vulnerable to gullies. The pattern of dispersion of the studied soils followed the Hofmeister's isotropic series with decreasing order of cations enhancing dispersion of $Ca^{2+} < Mg^{2+} < K^{+} < Na^{+}$. The hydraulic conductively which ranged from 4.87×10^{-4} to 7.34×10^{-4} were considered low implying that less water will move underground and more runoff would be generated to cause erosion. The ESP of these soils indicates that the soils are likely dispersive as a result of CEC with values slightly above 15 meq/100 g of clay and with the predominance of non expansive clay mineral. An application of certain civil engineering, hydrological or bioenvironmental processes so as to control the overland flow and excessive runoff are highly recommended. Holistic rehabilitation development programs of monitoring the earth surface to reclaim devastated land to ensure a safe environment should be encouraged.

Keywords: *Erodibility indices, Dispersivity, Geo-environmental degradation, hydraulic conductivity, Southeastern Nigeria*

Introduction

Gullies are form of soil degradations which consist of an open incised and unstable channel generally more than 30 centimeters deep. Gullies occur when a geomorphologic threshold is exceeded due to an increase in water flow erosivity and/or sediment erodibility (Igwe (2012; Conoscenti et al., 2014; Asghari Saraskanroud et al. 2017). Geo-environmental degradations resulting from gully developments have been intensively discussed during the past 40 years. Gully formation, growth and shape according to Rydgren (1993) are usually correlated with different landscape parameters such as relief, climate, vegetation, and anthropogenic factors. Uncontrolled progress of gullies had resulted in geo-environmental degradation in form of development of badlands; loss of crop productivity and water loss due to low water holding capacity of soil. These negative effects had destroyed the ecology affecting the economy of the affected areas. Menace of soil erosion especially gullies in no doubt represented major ecological challenge facing most states in Nigeria. The correlation of gully erosion severity with soil intrinsic physico-chemical factors had been asserted in the literature (Lal, 2001). A number of studies (Obi and Asiegbu, 1980; Okagbue 1988, Uma and Onuoha 1986; Igwe, 2012) revealed that gully erosion hazards had remained active over the years now, devastating the physical ecology of large part of southeastern Nigeria.

Researchers (Okagbue and Ezechi, 1988; Igwe, 2012; Ume et al., 2014) showed that gully incidences generate between 4.2 and 10 m 3/ha/year of sediments, which constitute about 45–90 % of total sediment production on agricultural lands. The erodibility of the soil, according to Igwe (2012) is the vulnerability or susceptibility of the soil to erosion as erosivity of rainfall is significantly higher than in moderate and cold climates. For the soil degradation by gully erosion, most previous studies (Obi and Asiegbu, 1980; Okagbue 1988; Igwe, 2012) were focused on the degradation characteristics by ephemeral gully erosion in terms of its in-situ effects on soil physical and chemical properties, key soil factors and soil quality degradation process. The soil factors however represent the soil erodibility which is also a product of underlying geology and soil characteristics. The influence of lithology on soil erosion processes according to Igwe (2012), is manifest directly by the resistance of the denuded bed rocks exposed to the flow of water and affected by the character of parent materials whose properties are given by the bed rock. In southeastern Nigeria, catastrophic gullies had severally impacted negatively on the agricultural, infrastructural, and socio-economic aspects. This has been very common all over geographical region of southeastern Nigeria. The erodibility of the soil is the measure of a soils susceptibility to particle detachment and transport by agents of erosion. The state of erodibility in erosion prone areas as in the case of Afikpo Southeastern Nigeria where vast areas were recently abandoned to gullies (Fig. 1) had not been related to the exchangeable sodium percentage (ESP), the sodium adsorption ratio (SAR) and the total amount of dissolved salts (TDS) of the surface soils. This study will provide an insight on the erodibility of the soils and the contributions of erodibility indices derived from dispersion related properties in the gullies in the tropics.

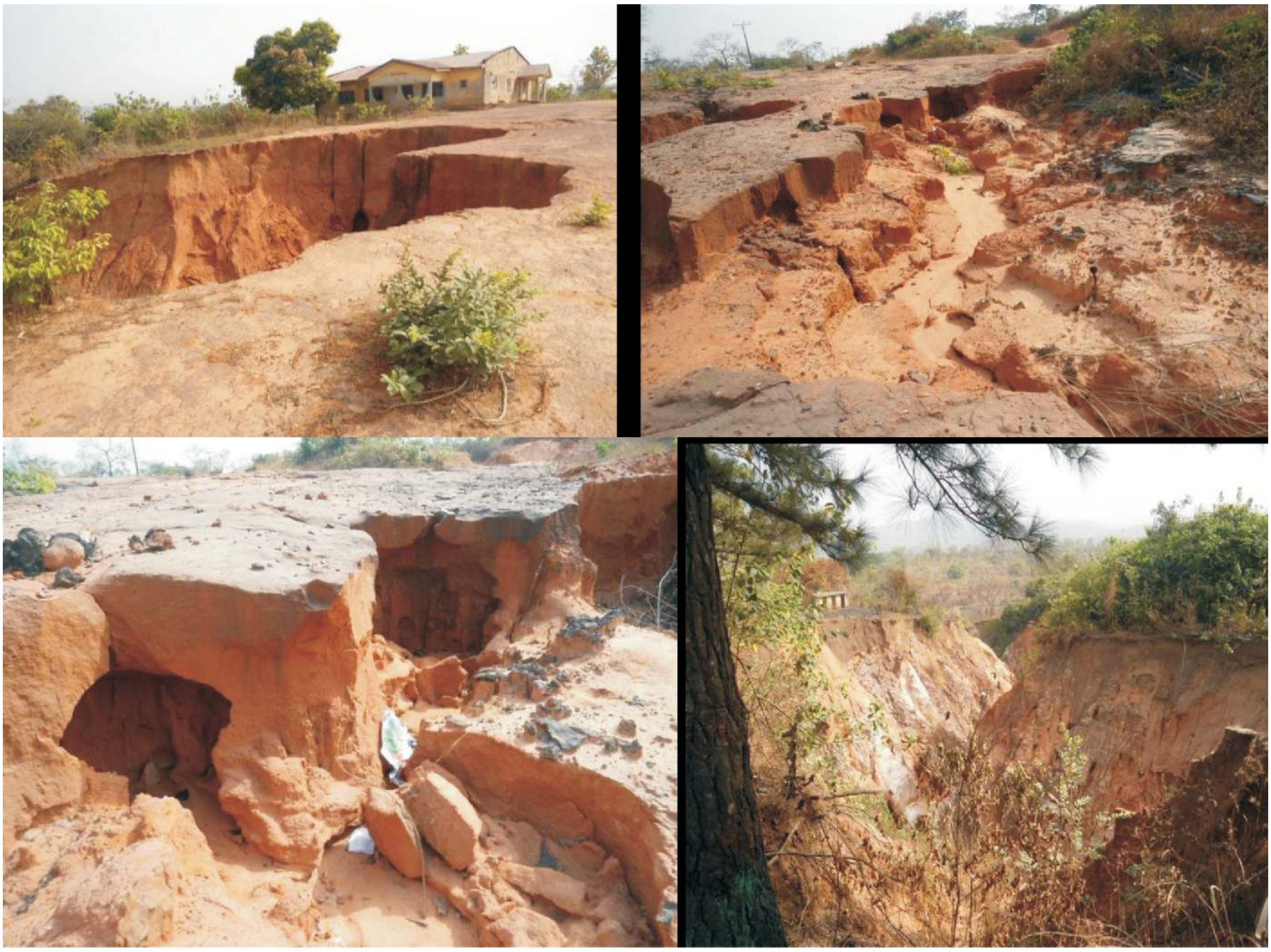

Fig.1: Deep gullies in Afikpo, Southeastern Nigeria: (a). Gullies at the Afikpo South Local Government Heaquarters where offices as at January 2019 had been abandoned to gullies. (b.) Gullies at Nguzu Edda roads. (c.) Gullies at Ekoli Edda where the road was cut into two truncating free movement. (d.) Gully erosion at Amoso Edda

Geomorphology of Gullies in Southeastern Nigeria

The greatest threat to the environmental settings of southeastern Nigeria is the gradual but constant dissection of the landscape by soil erosion by water. The geomorphology of gully erosion has been relatively well studied in Nigeria (Ofomata 1981; Okagbue and Uma, 1987; Nwajide and Hoque, 1979; Ogbukagu 1976). Researches on gullies had long scientific history and the underlying fundamentals of gully processes had been investigated for many decades though research is still ongoing and increasingly focuses on very detailed topics of erosion. Various authors such as Nwajide and Hoque (1979), Akpokodje et al. (1986), Okagbue and Uma (1987), Ofomata (1981) and Uma and Onuoha (1988) have carried out extensive study on gullies and good number of studies mostly in southeastern region of Nigeria had shown that susceptibility to geo-environmental degradation was due to some parameters such as the nature of soil, topography and geology. These parameters include measures (Ofomata 1981; Okagbue and Uma, 1987), geomorphology (Nwajide and Hoque, 1979), geology (Ogbukagu 1976), hydrogeology (Uma and Onuoha 1986) and engineering- geological properties of the soils (Obi and Asiegbu, 1980; Okagbue and Ezechi, 1987; Okagbue 1988).

Nwajide and Hoque (1979) in their studies on some gullies in southeastern Nigeria attributed their major causes to the combination action of physical, biotic, anthropogenic factors and engineering properties of the soil materials. However, erodibility of soils in tropics are highly dependent on the combination of soil properties such as grain size distribution, clay content, plasticity, exchangeable capacity and organic matter content, the amount of free Fe and Al present in the soil, the relative ratio of basic cations on the exchange sites, the dormant clay minerals and the pH of the soil solution. Erosion reduces soil stability and nutrient efficiency by altering the soil's physical, chemical, and biological properties (Lal, 2001; Lobo et al., 2005; Asghari Saraskanroud et al. 2017). The soil erodibility factor according to Igwe (2012) has since been recognized as a contributing factor to soil erosion hazard. The erodibility indices of the soils which have been related to the ESP, SAR and the TDS predict or promote soil erosion. Relating the erodibility in erosion prone areas to the ESP, SAR and TDS of the surface soils had been absence in the earlier studies in Southeastern Nigeria (e.g., Okagbue and Ezechi, 1988; Onwuemesi and Egboka, 1991; Ezemonye and Emeribe, 2012; Igwe, 2012) where geo-environmental degradation severally affected the area. In the light of the above observations and in an effort to under study the major causes of these gullies, this research used the combinations of physico-chemical characteristics and erodibility indices derived from dispersion related properties to analyze colluvial sediments exposed in gullies in Afikpo, southeastern Nigeria.

Geomorphology, Hydrogeology and Geological Setting

Geographically, the study area comprised of various sites where the effect of these gully erosions are severe in Afikpo (longitudes $7^0$49' E to $7^0$54' E and latitudes $5^0$45' N to $5^0$50' N, see Fig. 2). The other areas affected severally by gullies include Owutu-Edda, Ebonwana-Edda, Ekoli-Edda, Ekeje and Amaiyi Edda. The study area can be accessed by major roads and footpaths that exist within the area. Afikpo lies on the Cross River Basin with an irregular and uneven topography. Hydro-geologically, the drainage pattern can be said to be a plain metric arrangement of several streams which are usually adjusted to certain topographic, structural or lithology controls. The pattern of the draining streams are mainly complex, composing of dendritic and parallel pattern. The drainage pattern of the study area is dendritic. The major river is the Cross River and its tributaries which include: Obumkpuma, Ugwuakalilu, Amoba, Wowo, and Ipoko streams. The hills in the area are very steep and rocky, making soils there very susceptible to erosion irrespective of its nature. Afikpo is characterized by an undulating relief. The undulating relief is due to the alternation of sandstone and shale and differential weathering and erosion which give rise to the undulating land form. The sandstone constitute of the ridges due to its high resistance to erosion while the low land constitute the shale due to its low resistance to erosion and weathering, the contact between the sandstone and shale is located at the base. The south westerly winds bring the rain from April to October while the north east trade winds are responsible for the harmattan with low humidity from December to February. During the rainy season the temperature ranges from 16° to 28° C. The predominant vegetation visible along these zones is the grasslands, with scattered forests and woodland areas as well as tropical rainforest which comprise tall trees with thick undergrowth with fewer branches. However, these zones have been seriously affected by natural and human influences.

Geologically, Afikpo of Eze Aku Formation (Fig. 3) lies within Anambra Basin whose genesis has been linked with the development of the Niger Delta mio-geosyncline and the opening of the Benue Trough Nigeria. The geology plays direct and indirect influence on the gully formation. The indirect effect is on the soil formation and the nature of soil which contribute significantly to erosion processes. The opening of the South Atlantic Ocean initiated tectonism in the region of Southern Nigeria and led to the development of the Benue Trough (Wright, 1968). The development of the Benue Trough (Murat, 1972) provided the main structural control and framework for subsequent geologic evolution in Southeastern Nigeria with three major tectonic cycles identified. Each tectonic phase was terminated by folding and uplift. The first major tectonic phase (Aptian-early Santonian) directly followed, and was related to, the initial rifting of the Southern Nigeria continental margin and the opening of the Benue Trough. This phase produced two principal sets of faults, trending NE-SW and NW-SE.

The NE-SW set of faults bound the Benue Trough; while the NW-SE sets defined the Calabar flank. The second tectonic phase (Turonian -Santonian) was characterized by compressional movements resulting in the folding of

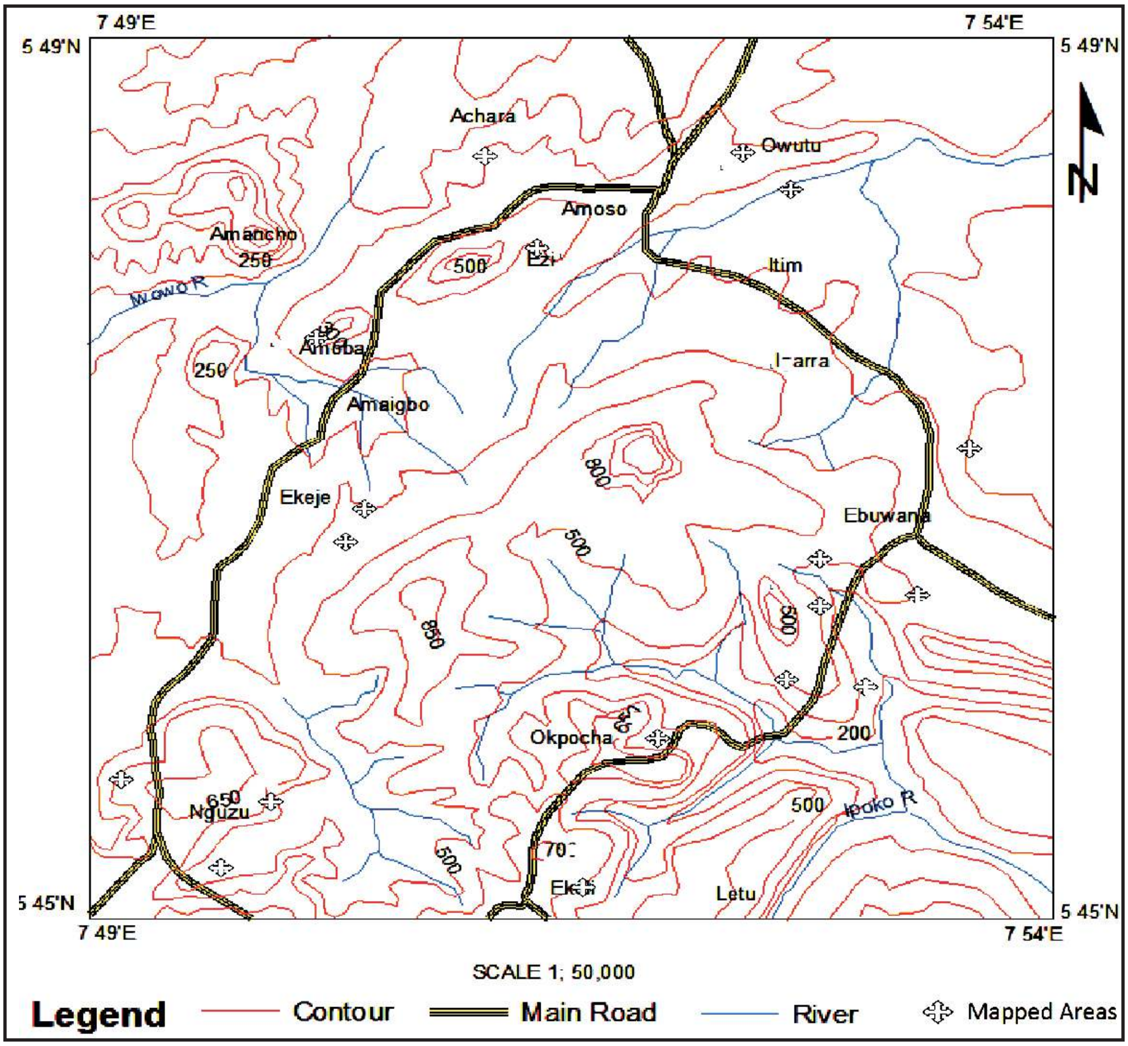

Fig. 2: Accessibility map of Afikpo where the study was carried out

the Abakaliki Anticlinorium and the complementary Afikpo Syncline (Nwajide, 2013). The third phase (Late Campanian - Middle Eocene) involved rapid subsidence and uplift in alternation, with subsequent progradation of the Niger delta. The stratigraphy comprises of cyclic sedimentary sequence that started in the early Cretaceous time (Reyment, 1965). The marine and fluviatile sediments comprised of friable to poorly cemented sands, shales, clays and limestone were deposited, with occasional coal, peat and thin discontinuous seams of lignite. The sediments have been affected by the major Santonian folding and a minor Cenomanian folding and uplift, Murat (1972). The major Formations encountered within gully sites included Afikpo Formation, Nkporo Shales and Mamu Formation (Fig. 3). The Afikpo Formation comprises of sandstones and shales while that of Nkporo Shales consists of soft shales grey to dark grey in colour with intercalations of sandstone and ironstone.

Material and Methods

Sampling and Testing

Sites that were severally gullied were identified and 12 colluvial soil samples collected from these sites with sample bag and tube samples at considerable depth for laboratory tests. All the gullies in the area were formed and developed in loose formation of fine and alluvium terraces containing predominantly sand and silts. The cross section of the exposed sites in most locations (Fig. 1a) displayed similar pattern of local stratigraphy which showing where grayish whitish sand units were overlain by reddish lateritic soils (Fig. 1b). The extent of geo-environmental degradation within the study sites were previously shown in Figure 1. Much care was taken to ensure that the samples collected for analysis were true representatives of the in situ materials in the field. Sampling equipments such as shovel, compass,

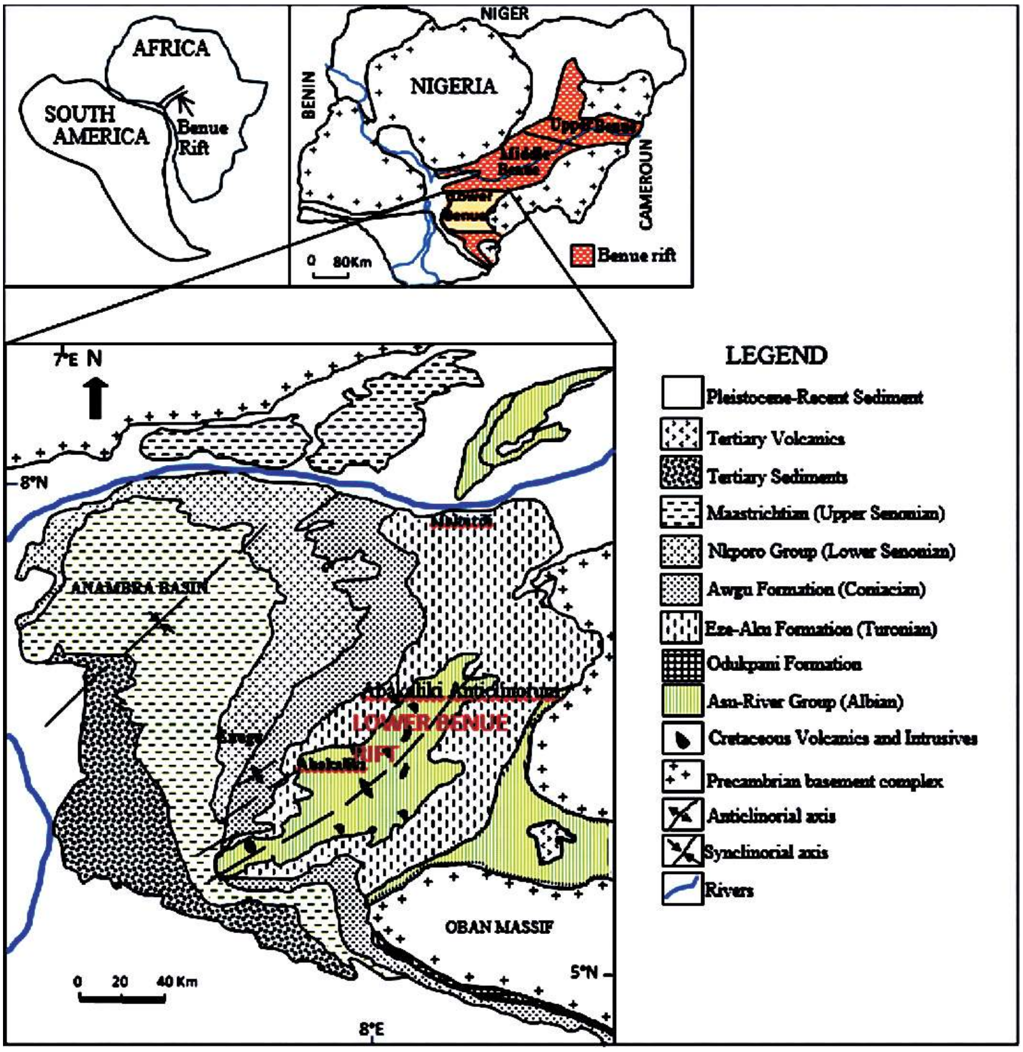

Fig. 3: Geological map of Afikpo, Southeastern Nigeria (Modified from Nwajide, 2013)

polythene and digital camera were also used for the mapping. The samples were packaged and sent to the laboratory at National Steel Raw Materials Exploration, Kaduna Nigeria for analysis.

The Atterberg limits test was conducted in accordance with American Society for Testing and Material ASTM method D423 and BS 1377 (1975). The particle size distribution test was determined using the hydrometer analysis in accordance with BS 1377 (1975). The results of grain-size distribution and Atterberg limits tests were used to classify the colluvial soils. Natural moisture content test was conducted in accordance with BS 1377 (1975). Coefficient of hydraulic conductivity test was conducted in accordance with BS 137 (1975) and expressed in meter per second (m/s). Organic content test was determined using Walkley and Black's method (Nelson and Summers, 1982). The pH test followed the procedure of BS 1377: Part 3 (1990) standard. The exchangeable basic cations Ca^{2+}, Mg^{2+}, K^{+} and Na^{+} were determined by first extracting ions from a 2g aliquot of the samples with 20ml of a pH 7-buffered ammonium acetate solution. The exchangeable cation of each of the samples was measured by titrating the leachate of a 2g aliquot of the samples by barium acetate with NaOH of known molarity and according to the methods given in ASTM (1979). This test was conducted to determine the total amount of exchangeable cations that the soil can absorb.

Dispersion Related Properties

Total content of dissolved solute, in the pore water is a property used to govern the susceptibility of clayey soils to dispersion. Where TDS is given as

$$\mathbf{TDS = Na^{+} + K^{+} + Ca^{2+} + Mg^{2+}} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Dispersive erosion depends on the mineralogy and chemistry of soil on the one hand, and the dissolved salts in the pore and eroding water on the other. The presence of ESP is the main chemical factor contributing towards dispersive clay behaviour. This is expressed in terms of ESP as,

ESP= $[Na^{+}]/[Ca^{2+}] \times 100$ …....……...……………… (2)

It is expressed in meq/100g.

The SAR is used to quantify the role of sodium where free salts are present in the pore water and is defined as

$$SAR = \frac{Na}{\sqrt{0.5(Ca + Mg)}} \quad \text{.......................................(3)}$$

It is expressed as milli-equivalent per litre.

For statistical analysis of dispersion related properties data of the selected colluvial sediments, Pearson correlation in the confidence level of 95% was used.

Results and Discussion

Physical Properties of Colluvial Sediments

The inherent susceptibility of soils to detachment and transport by various erosive agents, according to Asghari Saraskanroud et al. (2017) is a function of the physical and chemical properties of soil. The results of grain size distribution tests as shown in Figure 5 indicates that the studied colluvial soils have high percentage of sand with very low clay fractions in the order of sand>silt>clay indicating the sediments from the gullies in Afikpo southeastern Nigeria are highly susceptible to erosion. Considering that the soils are poorly graded, they are likely to erode easily. Furthermore, high sandy soil content encourages high rate of hydraulic conductivity of water into the soil, which would induces landslide and erosion.

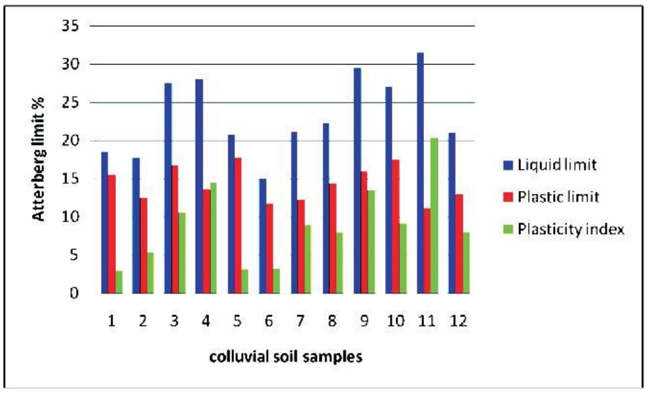

Fig. 4: Results of the Aterberg limit conducted on the sampled soils

The more dispersed the soil system is, the greater is the swelling caused by the concentration gradients at the clay particle-water interface. According to Obiefuna et al. (1999) soil with high sand and low fines contribute to gully growth. Soils with less than 10% clay particles may not have enough colloids to support dispersive piping (Bell and Maud, 1994). According to Chikwelu et al. (2014), soil made up of sands with low clays, are generally not well sorted, thus do not behave well as drained material. This character usually makes the hydraulic conductivity of the material not well improved and in turn can hardly increased incidence of water logging, surface run-off and erosion. The clays are well-graded soils of low plasticity containing adequate percentage clay size fractions and amount of fines showing soils with high specific surface which allow low migration of leachate. The results of the Atterberg limits as shown in Figure 5 indicates that the colluvial sediments have low plasticity index (an indicator of plasticity), an indication that the soils are friable which may resulted in ease of water flow thereby moving the soil particles down slope with increased in velocity of motion of the water. The variation in amount of clay as shown in the results obtained which were gegerally low may have contributed significantly to the variation produced in Atterberg limits. Although the Atterberg limits do not provide a means of identifying a potentially dispersive soil (Donaldson 1975), the higher the values of PI, according to (Bell and Maud, 1994) the higher are the resistance to dispersion. The rates of geo-environmental degradation in the area were largely attributed to the amount of sand fraction which were generally high. The plasticity index showed that the soil cannot be remoulded which is also an indication of low plasticity as a result of low percentage of fines to bind the material thereby caused the area to be susceptible to erosion.

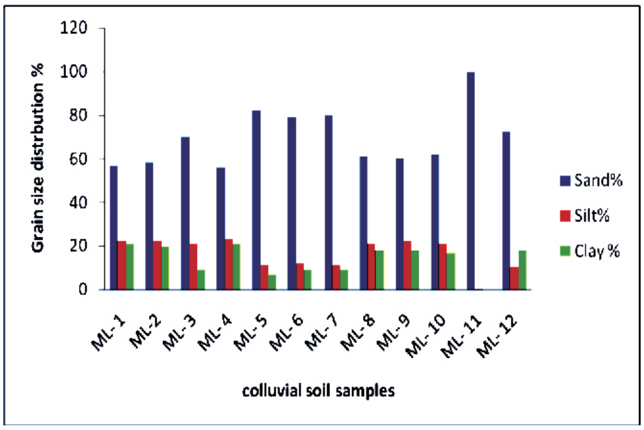

Fig. 5: Graphical representation of the grain size distribution results from the colluvial sediments

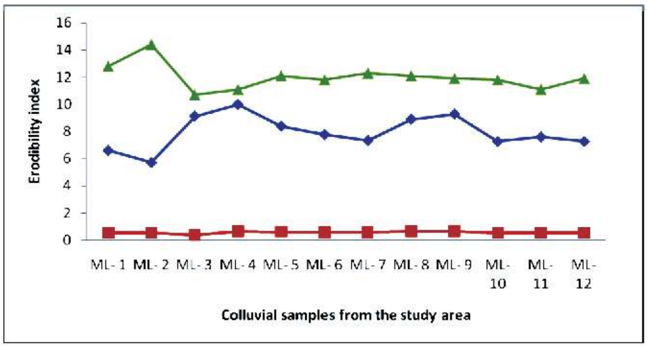

Fig. 6: Relationship between the erodibility indices as derived from the dispersion related properties

The results of the natural moisture content (W_n) are presented in Table 1 which ranged from 17.1 to 33.4% with average value of 25.3%. The results of the W_n indicate poor structural stability which cannot retain water as a result of fewer fines to bind these soils together. Gullies are consequences of severe water erosion, and as a result, soil moisture content is an important parameter to consider in sites where erosion is present as moisture content governs surface runoff. The variation in water content which is very significant can be due to local factors such as surface drainage and possibly presence of clay seams. Low moisture content in the tested sediments can be linked to the low clay and organic content of the soils, because the presence of clays and organic material tends to increase soil moisture content. The porosity results as presented in Table 1 ranged from 37.0 to 44.7% with average value of 40.3%. Nevertheless, the water content of a soil or rock is related to its porosity. Other factors that affect the porosity of soil included particle size distribution, sorting, solution effects mineralogical composition and the particularly the presence of clay particles. The poor porosity associated with the studied colluvial sediments may be attributed to densification of the soils with depth of the Afikpo gullies. This would help in reducing the infiltration rate which may lead to water logging and run off and thereby making these soils to have low structural stability and less resistance to erosion. The results of the bulk density tests as shown in Table 2 ranged from 1.44 - 1.62 kg/m^3 with a mean value of 1.55kg/m^3. The low density of the soil could be responsible to the erosion severity when the area especially when high rainfall witnessed resulting in leaching problem that made the area to be left with a very little binding material.

Table 1: Results of some physical properties of colluvial soil samples.

Sample ID	pH (%)	Organic Matter (%)	Moisture content (%)	Porosity (%)	Bulk density (Kg/m^3)	hydraulic conductivity (cm/sec)
ML- 1	5.50	1.83	24.44	37.00	1.54	7.34×10^{-4}
ML- 2	5.30	2.08	33.42	40.21	1.53	6.42×10^{-4}
ML- 3	5.30	1.37	27.11	41.50	1.62	6.44×10^{-4}
ML- 4	5.80	1.46	28.95	37.30	1.59	4.87×10^{-4}
ML- 5	4.50	0.38	17.19	44.71	1.59	4.94×10^{-4}
ML- 6	4.40	0.37	20.92	44.50	1.44	5.55×10^{-4}
ML- 7	5.80	0.71	23.18	37.80	1.61	4.99×10^{-4}
ML- 8	4.90	1.18	21.79	43.00	1.58	6.34×10^{-4}
ML- 9	4.80	1.15	23.94	41.61	1.45	6.25×10^{-4}
ML- 10	5.40	1.39	28.02	41.66	1.52	6.62×10^{-4}
ML- 11	4.80	1.84	28.49	39.61	1.53	6.42×10^{-4}
ML- 12	4.80	1.37	26.25	41.50	1.59	6.28×10^{-4}
Min	4.40	0.37	17.19	37.00	1.40	4.87×10^{-4}
Max	5.80	1.84	33.42	44.71	1.62	7.34×10^{-4}
Mean	5.12	1.26	25.31	40.46	1.55	6.04×10^{-4}

Table 2: Some chemical analyses of sampled soils

Sample ID	Na^+	K^+	Ca^{2+}	Mg^{2+}	Fe^{2+}	CEC meq/ 100g	TDS meq/ 100g	SAR meq/ liter	ESP meq/ 100g
ML- 1	0.85	1.15	3.46	1.15	1.70	15.3	6.61	0.56	12.8
ML- 2	0.83	1.48	3.42	1.15	1.69	15.4	5.73	0.55	14.4
ML- 3	0.98	2.91	3.97	1.28	1.64	14.3	9.14	0.37	10.7
ML- 4	1.11	3.01	4.41	1.47	2.41	15.1	10.0	0.65	11.1
ML- 5	1.02	2.03	4.01	1.34	1.87	16.2	8.40	0.62	12.1
ML- 6	0.92	1.63	3.97	1.26	1.59	14.3	7.78	0.57	11.8
ML- 7	0.91	1.49	3.70	1.25	1.40	15.2	7.35	0.58	12.3
ML- 8	1.08	2.23	4.20	1.40	1.10	17.2	8.91	0.65	12.1
ML- 9	1.11	2.24	4.51	1.43	1.12	24.2	9.29	0.65	11.9
ML- 10	0.86	1.59	3.65	1.17	1.80	14.3	7.27	0.55	11.8
ML- 11	0.85	1.55	3.62	1.58	1.27	15.4	7.60	0.53	11.1
ML- 12	0.87	1.61	3.60	1.19	1.72	25.6	7.27	0.56	11.9
Min	0.83	1.48	3.42	1.15	1.10	14.3	5.73	0.37	10.7
Max	1.11	3.01	4.51	1.80	2.40	25.6	10.0	0.65	12.8
Mean	1.09	1.92	3.88	1.31	2.61		7.94	0.57	12.0

Table 3: Pearson Correlation between the physical and chemical properties of the sampled soils.

	Sand	Silt	Clay	LL	PL	PI	NMC	Porosity	OMC	TDS	SAR	ESP
Sand	1											
Silt	-0.39	1										
Clay	-0.36	0.86**	1									
LL	0.39	0.26	0.16	1								
PL	0.03	0.61*	0.41	0.43	1							
PI	0.44	0.03	0.02	0.91**	0.02	1						
NMC	0.16	0.47	0.53*	0.54*	0.13	0.56*	1					
porosity	0.45	0.17	0.08	0.15	0.47	-0.02	-0.01	1				
OMC	0.02	0.45	0.54*	0.48	0.14	0.49	0.87**	-0.16	1			
TDS	0.26	0.44	0.29	0.69**	0.51*	.55*	0.18	0.42	0.05	1		
SAR	0.13	0.42	0.59*	0.27	0.25	0.22	0.17	0.33	0.14	0.49	1	
ESP	-0.04	0.42	0.56*	-0.23	0.10	-0.27	0.40	0.15	0.41	-0.27	0.43	1

NMC- natural moisture content, OMC- organic matter

****.** Correlation is significant at the 0.01 level (2-tailed); ***.** Correlation is significant at the 0.05 level (2-tailed).

The results of hydraulic conductivity (*K*) analysis of the colluvial sediments as summarized in Table 1 and ranged from 4.87×10^{-4} to 7.34×10^{-4} cm/sec. Based on the classification by Lambe (1954), a permeability of 10^{-5} to less than 10^{-7} cm/s indicates a very low to practically impermeable soil, a requirement for barrier soils. The *K* values obtained classified as low to medium, an indication that there are low to medium base flows which could result in the collapse of river bank and consequently advance the growth of gully erosion. All the soil samples analyzed exhibited low permeability as a result of the high silt and clay content. The hydraulic conductivity results which ranged from 4.87×10^{-4} to 7.34×10^{-4} are considered low which implied that less water will move underground and more runoff will be generated to cause erosion. The porosity and hydraulic conductivity of any soil affect the speed at which water can percolate or infiltrate into the ground. With increased rainfall flooding on a flat plain will be readily promoted considering the low hydraulic conductivity.

Chemical Properties of Colluvial Sediments

Cation exchange capacity (CEC) is a measure of the soil capacity to absorb and release cations (Jordán et al., 2009 Khaledian et al., 2016). Each clay mineral type is characterized by a range of CEC values but the environmental condition, mainly the pH and the presence of soluble salts, may influence this property. A high CEC contributes to erodibility since it is an indicative of certain dispersive clay minerals. The results of the CEC as shown in Table 2 reflecting the type of predominant clay minerals present. The typical CEC ranges of pure illite and pure smectite are 10 to 40 meq/100g and 80 to 150 meq/100g respectively (Grim, 1968). Monovalent exchangeable cation, Na, according to Bell and Maud (1994), can cause more swelling with water addition than divalent exchangeable cations, Ca and Mg Soils with high CEC values and PI greater than 35% swell to such an extent that dispersion is not significant. According to Grim (1968), the Ca:Mg ratio could be an indicator of erodibility, with low Ca:Mg values corresponding to higher erodibility, whereas a Ca:Mg ratio of less than one was one of the probable causal properties of dispersive soils. An increase in soil dispersivity when the soil was leached with decreasing Ca:Mg ratio water.

According to Hofmeister's lsotropic series the decreasing order of cations enhancing dispersion is $Ca^{2+} < Mg^{2+} < K^{+} < Na^{+}$ (Van Olphen, 1977). Ca^{2+} is regarded as a stable cation and adds to aggregate stability when added to a soil by replacing Na and Mg on exchange sites. The higher Ca^{2+} content in the study area (see Fig. 7) might be due to its strong adsorption to the soil colloids, higher charge and small hydrated radius as compared to other cations, particularly Na^{+}. Therefore, any sediment that has more calcium and especially sodium ions are more at the risk of dissolution and create deeper tunnel. The low CEC can be attributed to low organic matter, pH and non active clay minerals. From this result, these soils are likely non dispersive. The results of the acidity of the soil pH tests are presented in Table 1. According to Bell and Maud (1994), the pH value of dispersive soils generally ranges between 6 and 8. However highly dispersive soils often have pH above 8. Soils with a pH value lower than 7.8 can become dispersive on leaching if they contain free salts. From the result, these soils are not dispersive rather they medium to slightly strong acidic and are likely very prone to erosion.

Soil organic matter often plays an important role in soil nutrient availability, and its increase may decrease the potential of soil erosion (Oliveira et al., 2015). From the results, the organic matter content ranged from 0.37 to 1.84% with an average value of 1.26%. According to Lal et al. (1998), soil organic matter increases soil porosity, thereby increasing infiltration and water-holding capacity of the soil, providing more water availability for plants and less potentially erosive runoff and agro-chemical contamination. The organic carbon content within the erodible fine surface fraction is usually between 1.0 and 2.0% (Boyle, 2002). Soil erosion and runoff are greater when the organic matter is low as that result in low porosity. Erosion caused by low content of organic matter may have a long lasting secondary consequence. Results of the organic matter content appear to be low as a result of high rate of erosion that have washed away the organic matter that acts as a binding agent in other words, making these soils to be less porous as a result of low activity of organisms.

Dispersion Related Properties

The summarized results from the analysis of dispersion related properties are presented in Table 2. If the ESP exceeds 5%, the soil is probably dispersive, if the ESP is above 15% the soil is dispersive, if the ESP falls between 5% and 15% and the combined exchangeable Na^{+} and Mg^{2+} percent is greater than 15%, then the soil is generally dispersive. With a threshold value of ESP of 10 meq/100g, soils have their free salt leached by seepage of relatively pure water and are prone to dispersion. Soils with ESP values above 15% are highly dispersive, according to Gerber and Harmse (1987). On the other hand, those soils with low cation exchange values (15 meq/100 g of clay) are non-dispersive at ESP values of 6% or below. Soils with high CEC values and a PI greater than 35%, according to Bell (2007), swell to such an extent that dispersion is not significant. Those with low CEC values have been found to be completely non-dispersive at ESP values of 6% or below. The ESP of these soils indicates that the soils are dispersive as a result of low CEC and largely composed of dominantly of illite clay mineral. According to Bell and Maud (1994), for an eroding fluid, the boundary between the flocculated and deflocculated states depends on the value of the SAR.

The SAR values derived from the dispersion related properties for the studied soils are generally less than ranged 1.0 Meq/liter. SAR value greater than 10 Meq/liter is considered dispersive soil, between 6 and 10 was considered as intermediate dispersive soil while less than 6 Meq/litre was classified as non-dispersive. High accumulation of soluble salts especially high values of SAR according to Asghari Saraskanroud et al. (2017) have led to dissolution erosion that provides the conditions for creating tunnel erosion. The samples with high ESP and SAR have low clay content promotes the erodibility potential. The colluvial sediments from the Afikpo gullies are likely dispersive considering the facts that the CEC and ESP values obtained from the study were slightly above 15 meq/100 g of clay and 10%, respectively.

Relationship Among the Tested Dispersion Related Properties

The physical and chemical properties of the studied soils showed that soil erodibility indices did not show significant differences probably as the soil tested were obtained from the same locality their properties are highly related. The colluvial sediments were predominated with sands as well as low silt and clay contents and low dry density which may have resulted in their susceptible to piping erosion. The fine particle contents in the soil establish the presence of silts and clay sediments. It is easily eroded sand and is known to be very unstable. This is the case with Afikpo gullies in Southeastern Nigeria. Sediments with high sand or silt contents with less clay particle erode easily under a flat terrain. The erodibility of these soils may then be attributed as a result of the grain size distribution which is predominantly sand; that are loosely bonded or loosely held together. The soils have low silt/clay content making the sands cohesionless, very permeable with high infiltration rates, thus making control of gullies difficult after soils have been cut through by climatic factors. Generally, soils that are high in silt, low in organic matter are the most erodible. Therefore, once there is any runoff on the surface, there would be less resistance by the sand resulting in the intensity of the gully erosion in the area and can be attributed to high annual rainfall amounting to 2000 mm (Ofomata, 1964).

The gully development increases once the underlying cohesionless soil with high void ratio and low porosity is penetrated. This is because of the loose nature of the soils and the inability of the plant roots to bind the soil particles together. The chemical analyses showed that soils are non dispersive as a result of low CEC and hence, less expandable. The high hydraulic conductivity of the study soils combined with the high porosity lead to high infiltration rates. Statistically, the correlation matrix as shown in Table 2 indicates strong and positive correlation exist between LL and PI ($r^2 = 0.91$, $p<0.001$), silt and clay ($r^2 = 0.86$, $p<0.001$), organic matter and moisture content ($r^2 = 0.87$, $p<0.001$), LL and TDS ($r^2 = 0.69$, $p<0.001$), clay and SAR ($r^2 = 0.59$, $p<0.001$), and clay and organic matter ($r^2 = 0.54$, $p<0.001$). From the research, the higher the clay, the higher the content of organic matter is and the stronger the anti-erodibility of the soil will be. Soil pH, organic matter and CEC were all found to be low indicating that the soils are quite below their potential productivity level and hence less dispersive. The correlations between porosity and SAR (0.33, $p<0.001$), porosity and ESP (0.15, $p<0.001$) and ESP and PI (-0.27, $p<0.001$) were very weak and hence no significant exist.

Conclusions

Physicochemical characteristics and dispersion related properties of colluvial sediments exposed in gullies of Afikpo Southeastern Nigeria were evaluated and the effect on the geo-environmental degradation deduced. The study indicate that the underlying soil strata in the study area consist of sandy silt soil that is cohesionless, friable, unstable soil and easily eroded even under a flat terrain as a result of low clay content. The inherent characteristics of the local soils to a large extent promote the spread of soil erosion especially the gully type in the region. Soil pH, organic matter and effective exchangeable cation were all found to be low indicating that the soils are quite below their potential productivity level. There was apparently low amount of cation as a result of low level of organic matter in the soil. Conclusively, the above study shows that the relationship observed among the soils characteristics and soil erodibility could not have occurred by chance. Thus erodibility of soils is therefore significantly influenced by soil characteristics. These results indicate that the study area is dominated by majorly non dispersive soil, loose sands with low percentage of silt/clay fractions, and hence low cohesion, which are vulnerable to factors of gully erosion such as rainfall slope of land-surface and human activities. Susceptibility of a soil to severe gullies are function of, among other things, of soil geotechnical properties and erodibility indices.

Considering that the colluvial sediments around Afikpo gullies are predominantly sandy, the soils also have low hydraulic conductivity, making the soils susceptible to severe gullies. Addition of chemical ameliorants such as lime or gypsum could be recommended to help change the cation composition on the exchange sites of clay minerals as Na^{+} could be leached out and replaced by cations such as Ca^{2+}. Organic manure instead of fertilizer should be used during agronomic practices as this helps to stabilize the structure by improving the binding characteristics and compensating for soil nutrient loss, causes by high intensive rain and leaching. This practice is very important because of its high sand fraction which indicates low aggregate stability, as it will reduce the direct current and impact of heavy rains with the soil surface. Mechanical structures can also be put in place to help silt trapping and vegetation establishment properly constructed drainage facilities should be built in the study area.

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References

Akpokodje, E.G., Olorunfemi, B.N. and Etu-Efeotor, J.O. (1986). Geotechnical Properties of Soils Susceptible To Erosion in Southeastern Nigeria. Nig. Journal App. Sci. 3 (1). pp. 81-95.

ASTM American Society for Testing and Material (1979). Annual Book. ASTM Standard, Part 19, Philadelphia.

ASTM: Annual book of ASTM Standards, ASTM Publication, Philadelphia, USA, 1994

Asghari-Saraskanrouda, S., Zeinalia, B. and Mohammadnejad, V. (2017). Analysis Physical and Chemical Properties of Soil and Morphometric Impacts on Gully Erosion, Desert, 22-2, 157- 166

Bell, F.G. and Maud, R.R. (1994). Dispersive Soils in South Africa and Earth Dams. Proceedings 13th International Conference on Soil Mechanics and Foundation Engineering, New Delhi. Oxford and IBH Publishing Co., New Delhi, 3, 1003-1008.

Bell, F.G. (2007). Engineering Geology. Butterwotth-Heinemann, Oxford, UK, p. 581.

Bocco, G, Blanco J.L. and Morale, L.M. (1990). Computer-Assisted Mapping of Gullies: A Spatial Database for a Gully Information System. Int. J. Appl. Earth Observ. Geoinform. **1:** 45-50.

Boyle, M. (2002). Erosion's Contribution to Greenhouse Gases. Erosion Control. Features. January/February. P. 21 – 29.

Cavey, B. (2006). Gully erosion, Department of Natural Resources and Water Fact Sheets L 81 P. 1-4.

Chikwelu, E.E. and Ogbuagu F.U. (2014). Geotechnical Investigation of Soils Around Mbaukwu Gully Erosion Sites South – Eastern part of Nigeria. Journal of Applied Geology and Geophysics v. 2. Pp. 6 – 17.

Conoscenti, C., Agnesi, V., Angileri, S., Cappadonia, C., Rotigliano, E. and Märker, M. (2014). A GIS-Based Approach for Gully Erosion Susceptibility Modelling: A Test in Sicily, Italy. Environmental Earth Sciences, 70; 1179-1195.

Donaldson, G.W. (1975). The Occurrence of Dispersive Soil Piping in Central South Africa. Proceedings 6th Regional Conference for Africa on Soil Mechanics and Foundation Engineering Division, Durban, 229-235.

Egboka, B.C.E. and Nwankwor, E.I. (1986). The Hydrogeological and Geotechnical Parameters as Causative Agents in the Generation of Erosion in the Rain Forest Belt of Nigerian. Journal of Africa Earth Science, **3**(4), 417-425.

Ezemonye, M.N. and Emeribe, C.N. (2012). Rainfall Erosivity in Southeastern Nigeria. Ethiopian Journal of Environmental Studies and Management (EJESM), 5 (2), 112-122.

Gerber, A. and Harmse, H.J. (1987). Proposed procedure for identification of dispersive soils by chemical testing. *The Civil Engineer in South Africa*, **29**, 397–399.

Grim R.E. (1968). Clay Mineralogy. 2nd Edition,McGarw- Hill, New York, 596pp..

Idowu, O.J. and Oluwatosin, G.A. (2008). Hydraulic Properties in Relation to Morphology of a Tropical Soil with Hardened Plinthite under Three Land Use Types. Tropical and Subtropical Agro Ecosystems, **8:** 145-155.

Igwe, C.A., (2012), Gully Erosion in Southeastern Nigeria: Role of Soil Properties and Environmental Factors; In Tech Open Science Publishers, Pp.157-171.

Herdershot, W. H. and Duquette, M. (1986). A simple barium chloride method for determining cation exchange capacity and exchangeable cations. Soil Science Society of America Journal, **50**, 605-608.

Jenny, H. (1989). Soil Resources: Origin and Behavior. New York: Springer-Verlag. 377 p.

Kabir, M. H. and Taha, M. R. 2004. Assessment of Physical Properties of a Granite Residual Soil as an Isolation Barrier, Electronic *Journal of Geotechnical Engineering* Vol. 92c, 13pp.

Khaledian, Y., Kiani, F., Ebrahimi, S., Brevik, E.C., and Aitkenhead-Peterson, J. (2016). Assessment and Monitoring of Soil Degradation During Land Use Change Using Multivariate Analysis, Land Degrad. Dev., 128–141, doi:10.1002/ldr.2541.

Lal, R., Kimble J.M., Follett R.F. and Stewart, B.A. (1998). Soil Processes and the Carbon Cycle. Boca Raton, Florida:CRC Press. 609 p.

Lal, R., 2001. Soil Degradation by erosion. Land degradation and development, 12; 519-539.

Lambe. T.W. (1954). The permeability of Fine Grained Soils: Symposium on Permeability of Soils. A.S.T.M. Special Technical Publication No. 163.

Lobo, D., Lozano, Z. and Delgado, F. (2005). Water Erosion Risk Assessment and Impact on Productivity of a Venezuelan Soil. Catena, 64; 297-306.

Jordán, A., Zavala, L.M., Nava, A.L. and Alanís, N. (2009). Occurrence and Hydrological Effects of Water Repellency in Different Soil and Land Use Types in Mexican volcanic highlands, Catena, 79, 60–71.

Murat, R.C. (1972). Stratigraphy and Palaeogeography of the Cretaceous and Lower Tertiary in Southern Nigeria". In: African Geology. Dessauvagie, F.J. and Whiteman, A.J. (eds). University of Ibadan Press: Ibadan, Nigeria. Pp. 251 –266.

Nelson, D. W. and Sommers, L. E. (1982). Total carbon, organic carbon and organic matter. Methods of Soils Analysis – Part 2 Chemical and Microbiological Properties, Agronomy Monograph No. 9, Second edition. ASA-SSSA, 539-578.

Nwajide, C.S. and Hoque, H. (1979). Gullying processes in South Eastern Nigeria. The Nigerian Field **44**(2): 64-74.

Nwajide, C.S. (2013). Geology of Nigeria's Sedimentary basins. CSS Bookshops Ltd, Lagos, pp. 565.

Obiefuna, G.I., Nur, A., Baba, A.U. and Bassey, N.E. (1999). Geological and Geotechnical Assessment of Selected Gully Sites, Yola Area, North-East Nigeria. Journal of Environment Hydrology **7:** 11-12.

Ofomata, G.E.K. (1981). Acrtual and Potential erosion in Nigeria and measures for control. *Soil Science Society of Nigeria Special Monograph 1*, 151-165.

Okagbue, C.O. and Uma, K.O. (1987). Performance of gully erosion control measures in southeastern Nigeria. Proc. Inter. Symp. Forest Hydrology and watershed management, Vancouver, Canada, IAHS Publ., No. 167, pp. 163-172.

Okengwo, O.N., Okeke, O.C., Okereke, C.N. and Paschal, A.C. (2015). Pascal. Geological and Geotechnical Studies of Gully Erosion at Ekwulobia, Oko and Nanka Towns, Southeastern Nigeria. **20:** 114-122

Oliveira, S.P.D., Lacerda, N.B.D., Blum, S.C., Escobar, M.E.O. and Oliveira, T.S.D. (2015). Organic Carbon and Nitrogen Stocks in Soils of Northeastern Brazil Converted to Irrigated Agriculture, Land Degrad. Dev., 26, 9–21, 2015.

Onwuemesi, A.G. and Egboka, B.C.E. (1991). Implication of Hydrogeophysical Investigations of the Agulu-Nanka Gullies Area of Anambra State of Nigeria. Journal of African Earth Science, 13, 519.

Reyment, R.A. (1965). Aspects of the Geology of Nigeria. University Press: Ibadan, Nigeria, 154 pp.

Rydgren, B. (1993). Environmental Impacts of Soil Erosion and Soil Conservation – A Lesotho Case Study. Uppsala University, Department of Physical Geography, UNGI Rapport nr. 85. ISBN 91-506-1005-8.

Ufot, U.O., Iren, O.B., and C.U. Chikere-Njoku (2016). Effects of Land Use on Soil Physical and Chemical Properties in Akokwa Area of Imo State, Nigeria. International Journal of Life, Science and Scientific Research, 2 (3):1-6.

Van Olphen, H. (1977). An introduction to clay colloid chemistry. 2 nd edition. Wiley-Interscience Publications, New York. 318p.

Walker, D.J.H. (1997). Dispersive soils in KwaZulu-Natal. MSc Thesis, University of Natal, Durban, South Africa, 101 pp.

Wright, J.B. (1968). South Atlantic Continental Drift and the Benue Trough. *Tectonophysics,* Vol. 6, pp. 301-310.