Erodibility Characteristics of Three Geological Sediments in the Idah-Ankpa Plateau of the Anambra Basin, Nigeria

L.A Oparaku, Enokela O. Shadrach and I. Aho

***Abstract*— Three geological sediments, namely, the Upper Coal Measures (UCM), the Ajalli Sandstones (AS), and the Lower Coal Measures (LCM), underlie 100% of the landscape of the Idah-Ankpa Plateau (IAP) of the Anambra Basin, Nigeria. The total number of gullies in occurrence on the IAP formation has been estimated at 740, 100, and 1 for AS, UCM and LCM respectively. A total of 34 samples were randomly collected from gully side walls at a depth range of 0 – 15 cm. At sites where gullies did not exist, sampling pits were dug up to a depth of 15 cm within which samples were collected. Fifteen samples were collect from the AS, 14 from the UCM, and 5 from the LCM. Particle size distribution was determined by the hydrometer method, and the dry bulk density was computed from undisturbed cores after weighing, drying at 105oC, and reweighing. The two sets of data were analyzed using descriptive statistics. Results show that the AS had a mean % sand plus %silt = 95, %clay = 5, and a mean dry bulk density = 1.31 g/cm3; the UCM had values of 80, 20, and 1.57 g/cm3; and the LCM 61, 39, and 1.71 g/m3 respectively. The data indicate that the AS sediments are the most prone to detachment and transport, followed by the UCM. Therefore, the vulnerability of the sediments to erosion can be ranked as AS>UCM>LCM, and this can be attributed to their wide variations in particle size distribution and dry bulk density. The findings also agree with the order of proliferation of gullies on the IAP. Activities that trigger accelerated erosion on the AS should be controlled.**

***Index Terms*— Dry Bulk Density; Erodibility; Idah-Ankpa Plateau; Soil Particle Distribution; Soil Vulnerability**

I. Introduction

Soil erodibility is a property of the soil which can be evaluate as the soil's vulnerability to erosion. Erodibility is specifically and solely a property of the soil, and the different amount of soil erosion occurring on two or more soils located in the same ecological zone when brought under the same management practices are attributable to their inherent erodibility [1]. Reference [2] identified the soil factors that influence erodibility to include texture, structure, aggregate stability, shear strength, permeability, infiltration capacity and the chemical contents. Reference [1] Stated that the most important factors for the assessment of the vulnerability to erosion of a soil are those properties that affect infiltration, permeability and water retention; such as texture, dry bulk density, consistency limits, and Shear strength. Reference [3] Stated that soil physical properties are the most important factors influencing the vulnerability of soils to erosion.

Particles size distribution affects erodibility of soils in the sense that the large soil particles are easier to detach but, when detached, are more difficult to transport, whereas the smaller particles, bound together by cohesive forces, are more difficult to detach but easier to transport. Reference [4] Observed that soils that are high in silt, low in clay, and low in organic matter are the most erodible. However, [5] cited by [2], emphasized the influence of sand particles on erodibility when he stated that the %sand plus the %silt in a soil sample is a direct function of soil erodibility. Reference [6] Confirmed this assertion when he stated that soils high in sand and silt fractions are highly erodible. This shows that the higher the sand and silt fractions of a soil, the more is its vulnerability to erosion. Conversely, the more the clay content, the less is the soil exposed to detachment and transport.

Dry bulk density influences both the porosity and permeability of soils, for it expresses the tightness or looseness of the packing of soil particles that allows for restricted or easy infiltration and transmission of soil water. Dry bulk density also affects the shear strength of soils and their vulnerability to erosion. It is also a measure of the level of compaction of a soil. Compacted soils shed more runoff on the soil surface that causes erosion and sedimentation problems than loose soils.

Reference [7] Showed that an increase in dry bulk density of a soil reduces its vegetative cover, exposes the soil to erosion, and leads to water logging in areas of flat surfaces. Reference [8] reported that an increase in dry bulk density increases the erodibility of silty soils. In his own contribution, [9] observed that when the dry bulk density of medium to fine-textured soils exceeds about 1.7 g/cm3, the permeability values will be so low that drainage will be restricted.

Reference [10] reported that gullies proliferate the landscape of the Idah-Ankpa Plateau (IAP) of the Anambra Basin, Nigeria, which is underlain 100% by three geological sediments [11]. These geological units comprise the Upper Coal Measures (UCM) (36%), the Ajalli Sandstones (AS) (44%), and the Lower Coal Measures (LCM) (20%). It was estimated that the total number of gullies in occurrence on the UCM [9] was 100, with a mean length = 361.66 m, mean average depth = 5.96 m, and mean average width = 6.23 m; and the total number formed on the AS was 740, with a mean length = 452.27 m, mean average depth = 6.69 m, and a mean average width = 7.95 m. Only one independent gully unit, initiated and accelerated by coal mining activities, was observed on the LCM formation. It therefore, can be concluded, though tentatively, that the vulnerability to erosion of the three sediments is of the ranking: AS > UCM > LCM based on the order of proliferation of gullies on the geological units.

Published on December 1, 2016

L.A. Oparaku is with the Department of Agricultural and Environmental Engineering, University of Agriculture Makurdi, Nigeria (soil and water option)

E.O. Shadrach is with the Department of Agricultural and Environmental Engineering, University of Agriculture Makurdi, Nigeria (soil and water/environmental option) (e-mail: enokladidish@gmail.com)

I. Aho is with the Department of Agricultural and Environmental Engineering, University of Agriculture Makurdi, Nigeria

Studies on soil erosion on the IAP have been few and very much restricted to the AS. Reference [12] and [13] observed that most soil erosion sites in the southeastern Nigeria are located on either the Nanka Sands or the AS. Reference [14] reported that gully erosion processes are localized on the fine-to-medium grained AS of the Anambra-Imo Basin region. The geological causes of the proliferation of gullies at Ankpa, a growing semi-urban town located on the AS, was the subject of study by [15]. These geological processes were also reported by [16] as the principal causes of the evolution of gullies in the southern states of Nigeria. However, information and data on the influence of the inherent properties of these sediments on the relative proliferation of gullies on the IAP lands were not considered by these researchers.

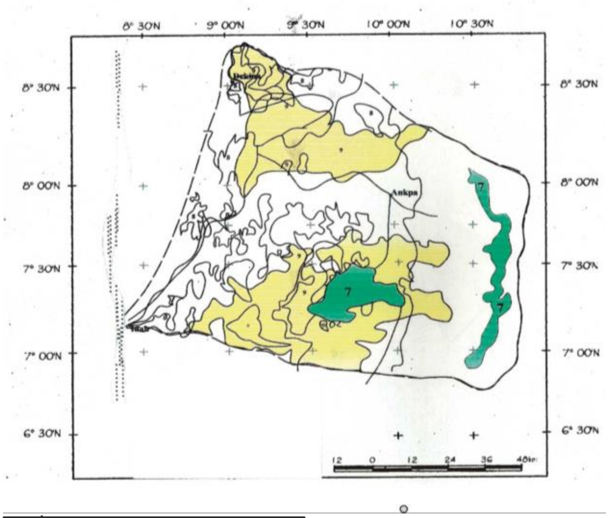
This study was, therefore, conducted to explain the influence of soil physical properties in the relative proliferation of gullies on AS, UCM, and LCM underlying the IAP. The soils' physical properties assessed were the particle size distribution and the dry bulk density.

II. Procedures and Methods

A. The Study Area

The Idah-Ankpa Plateau of the Anambra Basin of Nigeria comprises the Western Ankpa Plateau and the Idah Flood Plains. It has been so named because the latter consists of an insignificant percentage of the whole area [17]. Nestled in the Guinea Savana ecological zone of Nigeria, it lies between Latitudes 7° 17′ 00″N and 7° 23′ 30″N and Longitudes 8° 20′ 20″E and 9° 00″E. Parts of Benue and Kogi States are the only land areas encompassed by the IAP, the study area.

The underlying geology of the IAP consists of cretaceous sediments made up of the aforementioned geological sediments. Reference [11] reported that the geological successions of these sediments are as follows: UCM – AS – LCM, ie, the UCM is the overlying formation, the LCM the underlying formation, and the AS is sandwiched in between the two. The AS is exposed to the erosive processes of the elements at locations where the UCM, which provides a protective overburden, has been denuded away by geological processes. And where both the UCM and AS are eroded away, the LCM becomes exposed and subject to erosive processes [11]. A full description of the study area is detailed in [12]. The geological map of the IAP is shown in Fig.1.



⊚	Town
– –	Study Area Boundary
—	Roads
	Upper Coal Measures
	Lower Coal Measures
	False bedded sandstones
	Rivers

Fig 1: Geological map of the Idah-Ankpa plateau Source: National remote sensing centre, Jos, Nigeria

B. Sampling Method

Soil sampling sites were selected based on the three dominant geological units of the area (UCM, AS, and LCM). These units were chosen because [13] had observed that the textural uniformity of each is unique. On each unit, and for the determination of the particle size distribution and dry bulk density, soil samples were collected randomly at gully sites, with each sample collected from a gully wall at depths ranging from 0 to 15 cm. At sites where gullies did not exist, soil samples were collected from sampling pits dug up to a depth of 15 cm after the removal of surface litter. A total of 34 samples were collected, 15 from the AS, 14 from the UCM, and 5 from the LCM.

Particle size distribution was determined by the hydrometer method using calgon plus NaOH for dispersion. The dry bulk density was determined by collecting an undisturbed soil sample in a sampling tube, drying it in a soil can at a temperature of 105oC, and dividing the dry weight by the volume of the sampling tube. Data generated from the laboratory on particle size distribution and dry bulk densities were subjected to disciptive statistics as presented in Table1

III. Results

Findings from the laboratory analysis of the investigation on the erodibility of the study area as subjected to simple descriptive statistics and the result is as presented in Table1.

TABLE I: DESCRIPTIVE STATISTICS OF THE PARTICLE SIZE DISTRIBUTIONS/DRY BULK DENSITY OF THE THREE GEOLOGICAL SEDIMENTS IN THE 0 – 15 CM SOIL DEPTH

Soil parameters		Range	Mean	SD	CV(%)
%Sand	UCM	43 – 68	56	6.72	11.91
	AS	49 – 96	80	15.15	19.52
	LCM	12 – 52	37	15.53	42.68
%Silt	UCM	15 – 40	24	7.62	31.10
	AS	2 – 48	15	7.62	31.10
	LCM	8 – 57	24	19.26	80.26
%Clay	UCM	16 – 27	20	3.50	18.18
	AS	2 – 9	5	2.45	49
	LCM	31 – 46	39	4.28	11.08
DBD(g/cm^3)	UCM	1.48 – 1.63	1.57	0.04	2.54
	AS	1.20 – 1.41	1.31	0.07	5.45
	LCM	1.44 – 1.87	1.71	0.18	10.61
Typical texture			SCL	LS	CL

SD = Standard deviation, CV = Coefficient of variation, LS = Loamy sand, SCL = Sandy clay loam, and CL = Clay loam. DBD = Dry bulk density

IV. DISCUSSION

A. *The Upper Coal Measures (UCM)*

The mean proportion of sand in the UCM sediments is moderate (56%) with a range varying from 43% - 68% and SD of 6.72 (Table 1). The variability is very low with a CV of 11.91%. The mean silt fraction is 24% with an SD of 7.62, an equally low CV (31.10%), and range of 15% to 40% (Fig.2). The clay proportion ranges from 16% - 27% with a mean of 20%, and a CV of 18.12%. The range of DBD in the UCM varies from 1.48 to 1.63 g/cm3 with a mean value of 1.57 g/cm3 and a CV of 2.54%. This shows that the dry bulk density is nearly uniform in the UCM. Nevertheless, with a mean higher than that indicated in the AS, but less than Michael's threshold, the unmistakable deduction is that the UCM is more compact; favours less infiltration, percolation, and ground water flow; sheds more runoff; and, therefore, less vulnerable to erosion than the AS. The typical texture of the sediments is sandy clay loam.

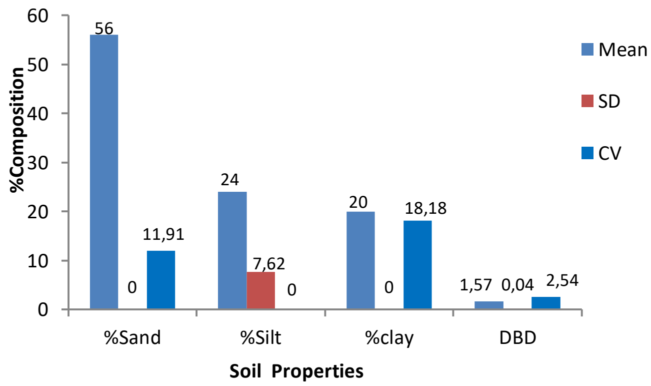


Fig 2. Normalised nomograph of distinctive statistic of UCM

B. *The Ajalli Sandstones (AS)*

The proportion of sand in the AS is in the range of 49% - 96% with a mean of 80%, and a standard deviation (SD) of 15.15 although low variability of the sand fraction can be observed in this formation with a coefficient of variation (CV) of 19.52%. The high percentage is consistent with the report of [18] in their work on the hydraulic, textural, and geochemical characteristic of the Ajalli formation that reported a mean sand proportion of 89%. The silt content of the AS in the surface soil has the highest variability with a CV of 99.55%, an SD of 14.93, a range from 2% - 48% and a mean of 15% was established. The clay proportion has a moderate variability with a CV of 49%, an SD of 2.45, a mean of 5%, and a range from 2% to 9% (Fig.3).

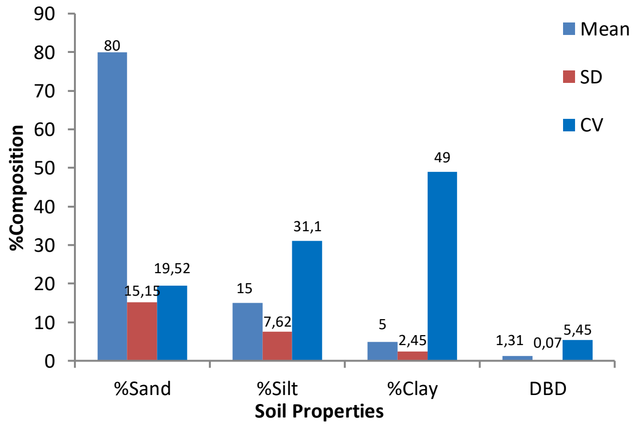


Fig 3. Normalised nomograph of distinctive statistic of AS

In the AS, the dry bulk density varies from 1.20 to 1.41 g/cm3. The variability is low over this geological unit with a CV of 5.45%, an SD of 0.07, and a mean of 1.31 g/cm3. This shows that the dry bulk density does not vary much over the AS. With a mean (1.31 g/cm3) and an upper range (1.41 g/cm3) far less than Michael's (1978) threshold (1.7 g/cm3), the indication is that the AS is a highly loose and permeable formation that favours high infiltration, percolation, and hence minimal surface runoff generation. However, where appreciable surface runoff occurs, this will combine with subsurface flows to cause massive soil detachment and movement down slope and from gully heads and sides. The textural class is loamy sand and thus highly vulnerable to erosion.

C. *The Lower Coal Measures (LCM)*

The mean proportion of %sand plus %silt in the LCM is low with a value of 61 (37 + 24) (See Table 1). However, the clay fraction with a value of 39% is relatively high. The SD of the sand particles is 15.53 with a moderate CV of 42.68%. The silt content has the highest CV of 80.26% and an SD of 19.26.

The clay fraction is the least in variability with a CV of 11.08% and an SD of 4.28 (Fig.4). This implies that on this formation, the clay fraction is the most uniformly distributed, whereas the sand particles are the least. In addition, the value of the clay fraction (39%) and its CV (11.08%) show that the LCM is a compact erosion resistant formation. In the LCM, the mean dry bulk density is significantly high at a value of 1.71 g/cm3 and is barely higher that the threshold (1.7 g/cm3). The range varies from 1.44 to 1.87 g/cm3 and the CV is 10.61%, which confirms that the LCM is spatially a homogenous clay loam soil. With a dry bulk density (1.71 g/cm3) higher than the value determined for the UCM (1.57 g/cm3) and a range (1.44 – 1.87 g/cm3) that spans beyond the threshold (1.7 g/cm3), it is evident that the LCM is tighter, less permeable, and, therefore, generates more surface runoff than the UCM. Even though more runoff is generated on the LCM, the value of the mean cohesive clay particles present in this formation (39%) is higher than that in the UCM (20%). So that there is more runoff generation but less soil detachment and erosion in the LCM than the UCM. Conclusively, therefore, the UCM is more vulnerable to erosion than the LCM.

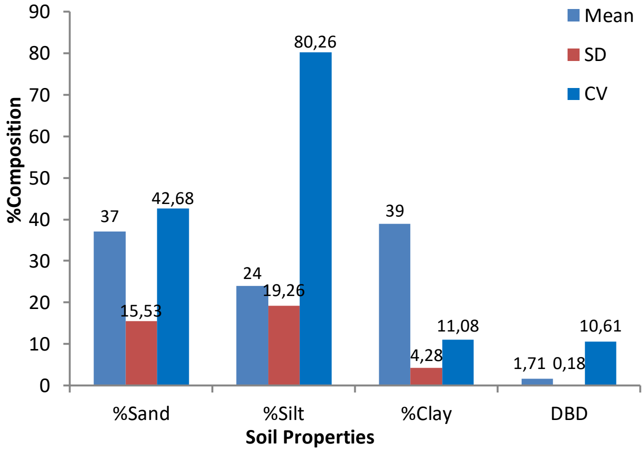


Fig 4. Normalised nomograph of distinctive statistic of LCM

Comparing the descriptive statistics of the particle size distributions of the sediments on the AS and UCM, the %sand plus %silt of the AS is 95 and higher than that of the UCM(80). With a value of 5%, the clay content of the AS is significantly less than that of the UCM (20%). The drastic reduction in the %sand plus% silt content from 95 (AS) to 80 (UCM) and an increase in the %clay from 5 on the AS to 20 on the UCM show that the UCM is more cohesive and, therefore, more resistant to erosion than the AS. In other words, the AS is more vulnerable to erosion than the UCM. Notably, a high mean proportion of % sand plus %silt (80 + 15 = 95), and a very low value of the mean in %clay (5) show that the AS is highly vulnerable to erosion.

However, a comparison of the values of the %sand plus %silt (80) and the %clay (20) in the UCM with their equivalents in the LCM (61 and 39 respectively) shows that the sediments of the LCM are more compact and more resistant to erosion than those of the UCM. Therefore, from the foregoing discussion and assuming that each of the formations is strikingly uniform over its thickness [12], the resistance to erosion of the sediments can be ranked as LCM > UCM > AS. And their vulnerability to erosion can thus be ranked as AS > UCM > LCM.

Clearly, an assessment of the particle size distributions and bulk density of the three geological sediments indicates that the LCM is the most resistant to erosion. This is followed by the UCM, whereas the AS is the least. Thus the vulnerability to erosion of the three sediments on the IAP can be ranked as AS > UCM > LCM.

V. Conclusions And Recommendation

The results of this study lead to the following conclusions:

1. The AS sediments are immensely loose, porous, and permeable. They have a low capacity for erosion-causing runoff generation. However, wherever appreciable runoff occurs on the soil surface, it combines with groundwater flow to cause soil lubrication that results in massive soil movements down slope. The AS, therefore, consists of highly erodible materials.
2. The UCM is relatively more compact and less permeable to water infiltration than the AS.
3. The LCM is more cohesive, tighter and sheds more runoff than the UCM. Because of the cohesive nature of the LCM sediments, soil detachment and transport are more restricted on this formation than the UCM. It follows then that the LCM is more resistant to erosion than the UCM.
4. The vulnerability to erosion of these geological sediments on the IAP based on their particle size distributions can, therefore, be ranked as: AS > UCM > LCM.
5. An assessment of the dry bulk density of the sediments also confirm that their vulnerability to erosion is in the order of AS > UCM > LCM.
6. The results of the study agree with the observation at the outset that the proliferation of gullies on the IAP follows the same order of magnitude: AS > UCM > LCM.

Activities that trigger accelerated erosion on the AS formation should be controlled. However, separate assessments of other physical and chemical properties of the sediments are needed to determine in comprehensive details the factors that influence the proliferation of gullies on the three geological units.

References

[1] R. Lal, Soil Erosion in the Tropics: Principles and Management. (1990). McGraw Hill, 588P.
[2] R.P.C. Morgan, Soil Erosion and Conservation 3rd ed; Blackwell public. (2005). Ltd, USA.
[3] A.M. Michael, and Ojha, T.P. Principles of Agricultural Engineering. Vol II (2013). Jain Brothers New Delhi 1124P.
[4] W .H Wlschmeier And J.V. Mannering, Relation of Soil Properties to its Erodibility Division S-6—soil and water management and conservation. SOIL SCI.SOC.AMER.PROC.,VOL.33,1969
[5] G.J Bouyoucos,. The clay ratio as a criterion of susceptibility of soils to erosion.J. Amer. Soc. Agron. 1935.27(9): 738–41.
[6] O'Green, A.T.; Elkins, R. and Lewis, D. Erodibility of agricultural soils with examples in Lake and Mendacina Counties (2006). ANR Publications. 8194P.
[7] D.G. Price, Engineering Geology: Principles and Practices. (2008).Springller ISB, 3540292497.44 – 65
[8] E.H Grissinger,. Resistance of selected clay soils to water erosion. USA Water Resources Research 2(1), (2000).131 – 138.
[9] A.M Michael, Irrigation: Theory and Practice. Vikas Publ. House, (1978). New Delhi, India. 453p.
[10] L.A. OparakuGully Erosion on the Idah – Ankpa Plateau of the Anambra Basin, Nigeria. A Ph.D thesis submitted to the Department of Geography and planning, University of Jos, Plateaus State, Nigeria. (2015).

[11] J.W Preez, and W. Barber, The distribution and chemical quality of ground water in Northern Nigeria. Geological Survey of Nigeria, (1965). Bulletin 36.
[12] K.M.S Onuoha,. and K.O. Uma, An appraisal of recent geologic and hydrologic hazards in Nigeria. In: Natural and Manmade Hazards. (1988). Kluwer Academic Publishers, the Netherlands.
[13] Hudec, P.P; F Simpson, E.G Akpokodje, M.O Umenweke,. and M. Ondrasik, (1988). Gully Erosion of the coastal plain sediments of Nigeria. In: D. Moore and O. Hunger (eds) Proceedings Eight International Congress, International Association for Engineering Geology and Environment. 21 – 25 Sept. Vancouver, Canada, A.A. Balkema Rotterdam, 1835 – 1841.
[14] P.P Hudec, F. Simpson, E.G Akpokodje. and M.O Umenweke, Termination of gully processes in Eastern Nigeria. Proceedings of the Eight Federal Interagency Sedimentation Conference. (2006) Reno NY, USA.
[15] A.D Schneidegger and D.E Ajakaiye.Mass movementin hilly areas(with examples from Nigeria. National hazards 9.191 - 196 (1994). © Clawer academic publication, printed in Netherland
[16] B.C.E, Egboka GI, Nwakwor and I.P Orajaka Implications of palæo - and neotectonics in gully erosion -prone areas of southeasternnigeria. (1990). Natural Hazards, 3:219-220 231
[17] ECAN. Gully Erosion Control Measures for Ankpa. Federal Ministry of Agriculture, Lagos, Nigeria (1982)
[18] M.N. Tijani, and M.E. Nton, Hydraulic, textural, and geochemical characteristics of the Ajalli Formation, Anambra Basin, Nigeria: implications for ground water. Journal of Environmental Geology: (2008).0943 – 1105.