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Original Research Article

Assessing the Potentials for Gully Erosion and the Relationship between Gully Length and Average Sediment Volume on the Ajalli Sandstones' Geological Formation

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Abstract

Gullies proliferate the landscape of the Ajalli Sandstones (AS) geological formation in the North Central Nigeria. This study was carried out to assess the vulnerability to gully erosion of the Ajalli Sandstones geological sediments, and to examine the relationship between gully length and average gully sediment volume on this formation. Soil samples, collected from each sidewall of 15 gully erosion sites at two depth ranges, the rilling depth, d_1 (0 – 60 cm) and the gullying depth, d_2 (60 – 120 cm), were tested to determine their particle size distribution using the hydrometer method as well as compute their erodibility indices (K). Further, samples were collected using sampling tubes to determine the soils' dry bulk density (DBD). Additionally, 37 gullies developed on the AS formation were measured to determine their lengths (L), average widths (W), and average depths (D). From each gully, three additional variables of average gully sediment volume (V), average cross sectional area (A), and average form factor (W/D) were computed. For the two respective depth ranges, the particle size distributions, the K values, and the DBD as well as the sets of six variables of L, W, D, C, A, and W/D from each gully were analysed using descriptive statistics. And the pairs of L and V for each gully were further analysed using inferential statistics to examine their relationship. Results show that the rilling depth (d_1) and the gullying depth (d_2) are both highly erodible with the mean %sand d_1 + $\%silt_{d1}$ = 95%, $\%clay_{d1}$ = 5%, K_{d1} = 24.40, and DBD_{d1} = 1.31 g/cm^3; and the mean $\%sand_{d2}$ + $\%silt_{d2}$ = 82%, $\%clay_{d2}$ = 18%, K_{d2} = 8.40, and DBD_{d2} = 1.34 g/cm^3. The cross sectional shape of the gullies formed on the AS is trapezoidal. The mean W/D ratio on this formation is 1.46. This shows that the surface soil is eroding faster than the subsurface soil. The length is significantly, positively, but moderately correlated with the average sediment volume. And a simple bivariate regression shows that the relationship between gully length and the average gully sediment volume is of the form: V = 27,066.643 + 147.213L (R = 0.503, $R^2 \times 100$ = 25.30%). The study also shows that gully length is a moderate predictor of average sediment volume on homogeneous, erodible formations.

Keywords: Relationship, Sediment volume, Gully length, Erodibility, Moderate predictor.

INTRODUCTION

Gullies proliferate the landscape of the Idah-Ankpa Plateau (IAP) of the Anambra Basin of the North Central Nigeria. They are surface expressions of man-induced or accelerated erosion, and are caused by the concentration of flows on the land surface such that the amount of soil detachment and transport leads to the formation of channels that cannot be completely smoothened out by normal cultivation methods [1]. Brice [2] defined a gully as any channel that carries ephemeral flows, having a steep-sided or vertical headwall, a width greater than 0.30 m, and a depth greater than 0.60 m.

Gully erosion problems have been observed to be most serious in regions with deep unconsolidated soil mantles such as those of the Loess soil zones of North America, the Loess Plateau of China, and the soils of southeastern Nigeria [3-5]. In addition to the nature of the soil, the climate, vegetal cover and topography are other important natural factors that influence the vulnerability of a soil to gully erosion.

Gullies fragment farm lands, yield sediments that silt up reservoirs and surface water conveyance systems, lower the ground water table, and offer a safe haven to social miscreants. In addition, roadside gullies inundate roadways with sediments that lower their trafficability. Therefore, the volume of sediment production should constitute a criterion for targeting expenditure on gully erosion control.

The length of a gully is a key variable that determine the volume of sediments produced by the gully. Cheng *et al*., [6] reported a strong and significant correlation between the length and volume of a gully and suggested that length could be a useful index for the estimation of the volume of sediments production by gullies. Nachtergaele *et al*., [7], in their study in Portugal, found a power relationship between gully volume and gully length given as:

$$V = 0.05L^{1.27} \text{ ……….. (1)}$$

Where,
V = gully volume (m^3)
L = gully length (m).

In a model calibration for the estimation of gully volume in Sicily, Italy, Capra *et al*., [8] also found a power function relationship between gully volume and length of the form:

$$V = 0.0082L^{1.416}, R = 0.64 \text{ ……………. (2)}$$

Oparaku and Iwar [9] investigated the relationships between the average gully depth (D) and average width (W) on the Ajalli Sandstones (AS) and the Upper Coal Measurer's (UCM) respectively and found that on the highly erodible AS, D correlates moderately, positively, and significantly with W ($R = 0.565$, $P < 0.01$), whereas the relationship is positive, stronger, and significant on the more resistant UCM ($R = 0.997$, $P < 0.01$). The results of their study suggest that for gullies cut on deep, homogeneous formations, the correlation of D with W diminishes with increasing vulnerability to erosion of the sediments, whereas the effectiveness of D as a predictive tool of W increases with the resistance of the sediments to erosion.

No studies have hitherto been carried out to determine the relationship between gully length and average gully volume (sediment production) on the highly erodible Ajalli Sandstones' geological sediments of the Anambra Basin, Nigeria. Onuoha and Umah [10] and Hudec *et al*., [11] observed that the Ajalli Sandstones of the Idah-Ankpa Plateau, the Nanka Sands, and the Ajalli Sandstones of the southeastern states of Nigeria, where the most destructive gully erosion activities are in occurrence in the country, bear striking textural similarities. This study was, therefore, carried out to assess the vulnerability to gully erosion of the Ajalli Sandstones' geology sediments, and to examine the relationship between gully length and average sediment volume on this formation. It is believed that gully length is the simplest index for the assessment of sediment production from a gully since it is easily measured in the field and from air photos and Satellite images.

MATERIALS AND METHODS

The Study Area

The Idah-Ankpa Plateau (IAP) 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 [12]. 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' 00"E. Parts of Kogi and Benue States are the only land areas encompassed by the study area.

The underlying geology consists of cretaceous sediments made up of three uniquely homogeneous individual geologic formations, namely: The Upper Coal measures (UCM), the Ajalli Sandstones (AS), and the Lower Coal Measures (LCM) (Figure 1). These three geological units underlie 100% of the plateau landscape in the order of UCM = 36%, AS = 44%, and LCM = 20% [13]. Oparaku [14] estimated that there were about 100 gullies in occurrence on the UCM, 740 on the AS, and only one on the LCM. In an assessment of the relative vulnerability to gully erosion of the three geological sediments, Oparaku *et al*., [15] tentatively ranked the order of erodibility of the sediments as AS>UCM>LCM. Gullies are most predominant on the AS because not only is it the most erodible formation, most urban towns and villages are located on this geologic unit. The full descriptions of other environmental aspects of the study area are detailed in Oparaku *et al*., [16] and Oparaku and Iwar [9].

The Ajalli Sandstones Geological Formation

The Ajalli Sandstones' geological sediments of the IAP consist predominantly of poorly sorted and unconsolidated sandstones, of which vary from white to pale grey, but sometimes stained from yellow to red by iron oxides [17]. The rocks are loose, cross-bedded and easily detached with the slightest disturbance, thus rendering them vulnerable to rapid detachment and transport.

However, not much information is available with respect to the textural characteristics of the Ajalli Sandstones of the IAP. Laboratory tests were, therefore, carried out to determine the resistance of the sediments to soils erosion (erodibility). The tests included the determination of both the particle size distribution and the dry bulk density of the sediments.

Soil samples were collected from 15 widely dispersed but randomly selected gully erosion sites. At each site, two samples were collected from the sidewall of the gully at two depths. The first depth, rilling depth, ranged from 0 – 60 cm and was designated as d_1, while the second depth, gullying depth, ranged from 60 – 120 cm and was designated as d_2 Fig-2. In reality, the gulling depth varies from 60 cm below the ground surface to the gully floor since Brice [2] stated that any ephemeral water channel with a depth greater than 60 cm (0.60 m) could be called a gully. At a treated gully site, a sampling pit was dug on the adjoining land area up to a depth of 120 cm from the ground surface and soil samples collected from the two depth ranges.

The particle size distribution was determined by the hydrometer method using calgon plus NaOH for dispersion. The dry bulk density (DBD) was determined by collecting undisturbed soil samples in a sampling tube from the two depth ranges of the gullies, drying them in soil cans at a temperature of 105°C, and dividing each dry weight by the volume of the sampling tube. The erodibility indices (K) of the two depth ranges were computed using the Bouyoucos [18] formula given by %sand + %silt/%clay. Thereafter, the particle size distribution, the computed K values, and the dry bulk density were analysed using descriptive statistics.

Field Evaluation of Gullies

A total of 37 randomly selected gully sites developed on the Ajalli Sandstones' geological sediments were sampled. Of the 37 gullies, 9 could be described as rural gullies, having been developed in rural environments, whereas the remaining 28 were formed in urban areas. Although the processes of accelerated erosion (evident in gully formation) are more rapid in urban environments than in rural ones, for this study, the two processes occurring in the two environments have been grouped together and evaluated as same.

Sixteen of the 37 gullies were observed to be treated, 14 inactive, and 7 active. The dimensions of the 16 treated gullies were obtained from the Lower Benue River Basin Development Authority (LBRBDA) Makurdi, whereas the remaining 21 of them, active and dormant, were measured in the field using the method described by Oparaku and Iwar [9]. The gullies were sampled and measured irrespective of the average ground slopes on which they were formed.

The dimensions collected from the LBRBDA and measured in the field were the lengths (L), average depths (D), and average widths (W). Other variables computed from these three parameters were the average volume (V), average cross sections area (A), and the average form factor (W/D). These sets of six variables were analysed using descriptive statistics, and the relationship between the length and volume components were further examined using correlation analysis and the simple bivariate regression.

Results and Discussion

Descriptive Statistics of the Ajalli Sandstones Sediments

Particle Size Distribution

In Table-1 is shown the descriptive statistics of the particle size distribution, the computed erodibility indices, and the dry bulk density of the sediments of the AS formation.

The proportion of sand is high in the d1 (0 – 60 cm) depth range with a mean of 80%, a range of 49 % - 96 %, and a standard deviation (SD) of 15.50. Low variability of the sand fraction can be observed in this formation with a coefficient of variation (CV) of 19.52%. Tijan and Nton [19], working on the hydraulic, textural, and geotechnical characteristics of the Ajalli formation, reported that the sand proportion varied from 79% to 99%, which is consistent with the mean reported in this study. The silt content has the highest variability with a CV of 99.55%, an SD of 14.93%, a mean of 15%, and a range varying from 2% to 48%. The %clay has a moderate variability (CV = 49%), the least content (mean = 5%), an SD of 2.45, and a range varying from 2% to 9%. Notably, the high content of the mean %sand plus %silt (95%) and a low % clay content (5%) renders the sediments highly vulnerable to erosion in the d_1 depth range. The mean erodibility index (K) in this rilling depth is 24.40 (Table-1), and its typical texture in loamy sand.

Table-1: Descriptive statistics of the physical properties of the Ajalli Sandstones (AS) sediments

Soil depth (cm)	Descriptive statistic	Particle size (%)			Typical texture	Erodibility index (K)	Dry bulk density (DBD)
		Sand	Silt	Clay			
d_1	Range	49–96	2–48	2-9	LS	9.00-49.00	1.20-1.41
	Mean	80	15	5		24.40	1.31
	SD	15.15	14.93	2.45		14.90	0.70
	CV (%)	19.52	96.55	49		61.15	5.45
d_2	Range	34-92	1-55	4-30	SL	2.30-28.00	1.22-1.50
	Mean	67	15	18		8.40	1.34
	SD	14.91	15.32	9.06		7.60	0.80
	CV (%)	22.41	98.60	48.36		90.46	4.80

Sample count = 15, d_1 = soil depth between 0 – 60 cm, d_2 = soil depth between 60 – 120 cm, SD = Standard deviation, CV = Coefficient of variation, LS = Loamy Sand and SL = Sandy Loam.

The proportion of the mean sand content in the d_2 (60 – 120 cm) (gulling depth) depth range is equally high at 67% (Table-1) with values ranging from 34% to 92%, and an SD of 14.91. Its variability in this depth remains low with a CV of 22.41%. Equally, the mean silt and clay fractions do not vary much over the formation in the subsurface. While the silt fraction remains constant at 15%, the clay fraction increases from 5% to 18%. This increase in clay content could be attributed to eluviation processes taking place in the soil. The sum total of the mean %sand and %silt (82%) is high in this depth range, which indicates a high vulnerability of the subsoil to erosion despite the increase of the clay fraction from 5% to 18%.

Notably, the increased clay content in the subsoil has deleterious effects on gully development on this formation. Foremost of all is that it perches ground water above the clay layer. This results from the fact that it increases the soil's dry bulk density which lowers the permeability of the soil. The perched water table, in turn, lubricates the gully sides and head, causing the soil to flow like wetted granulated sugar. These phenomena lead to mass wasting and sloughing of the sides and head, and the subsequent expansion of the gully in length and width. The typical texture of the gullying depth is sandy loam and the mean K-value is 8.40, which is slightly more resistant to erosion than loamy sand.

Bouyoucos [18], cited by Morgan [20], stated that the %sand plus %silt in a soil is a direct function of its erodibility. O'Green *et al.*, [21] confirmed this assertion, stating that soils high in %sand plus %silt are highly erodible. Evans [22], on the other hand, showed strong interest in the use of clay content in the assessment of soil erodibility, stating that soils with restricted clay contents less than 30% are erodible. This implies that soils with a total sum of %sand plus %silt greater than 70% are erodible. This shows that the lower the clay content, the more is a soil exposed to erosion. In addition, Bouyoucos [18] stated that a soil with its mean K-value greater than 10 is erodible.

Although the %sand plus %silt in the d_1 depth range (80% + 15% = 95%) is greater than the equivalent value in the d_2 depth (67% + 15% = 82%), each of the two values is greater than 70%, which shows that soils in the two depth ranges are erodible. However, it can be seen that sediments in the d_1 range are more erodible than those in the d_2. In addition, the clay content of d_1 equals 5% and that of d_2, 18%. Since both values are less than 30% (Evans, 1980) with d_2 higher at 18%, soils at both depths can again be classified as erodible, with d_2 soils showing more resistance to erosion than d_1 soils. Furthermore, the mean K-value in d_1 (24.40) is greater than the value in d_2 (8.40, which approximates to 10). Therefore, the confirmation is that soils in the two depths are erodible.

Dry Bulk Density, DBD

Within the rilling depth (d_1), the DBD varies from 1.20 to 1.41 g/cm^3 (Table 1) with a mean of 1.31 g/cm^3. The variability is low over this depth range with an SD of 0.07 and a CV of 5.45%. In the gullying depth (d_2), the dry bulk density ranges from 1.22 – 1.50 g/cm^3, with a mean of 1.34 g/m^3. The variability is slightly lower in this lower depth range with an SD of 0.80 and a CV of 4.80%

Michael [30] observed that when the dry bulk density of medium to fine-textured soils exceeds about 1.70 g/cm^3, the permeability values will be so low that drainage will be restricted. The dry bulk density at the rilling and gulling depths (1.31 and 1.34 g/cm^3 respectively) are each lower than 1.70 g/cm^3. This favours high infiltration, percolation, and hence less runoff generation on the AS formation. The higher DBD in d_2 evidences a higher clay content which perches ground water in this depth range than in d_1. Thus a combination of high infiltration, high percolation, and a perched water table lubricates the soil and lowers its resistance to shear failure. This exposes the gully sidewalls to rapid slumping, sloughing, sliding, and general mass wasting as stated earlier. Thus gullies formed on the AS formation have high tendency to expand in length and width due to the influence of its low dry bulk density.

In conclusion, analyses of the particle size distribution and dry bulk density show that the AS sediments are highly erodible from the rilling depth to the gulling depth. And once a gully is initiated on the surface, it deepens and enjoys unimpeded invasion of the subsoil, provided that there is a base level for flood waters to flow. This agrees with the report of Preez and Barber [13] who stated that the Ajalli Sandstones is about 170 m thick and is composed mainly of homogeneous, fine to coarse-grained, poorly cemented, and erodible sandstones all through its depth.

Gully Characteristics

Gullies formed on the AS are all in independent units, making their dimensions relatively easy to measure. Their sizes range from very small, small, medium, deep and narrow, to ravenous; depending on the volume of flow feeding the gully. And their cross sections are generally trapezoidal in shape (Figure-3), with the sides of each gully inclined at appreciable angles to the gully floor. This is because the sediments are so poorly cemented together that they (the sides) cannot assume a vertical posture with respect to the gully floor without slumping.

The observation made in the field that gullies on the AS formation are all trapezoidal in their cross sectional shapes agrees with the report of Soufi [23] who noted a similar cross sectional shape for gullies in the Fars Province of Iran. However, in their studies of gullies in varying environments and climatic regions, Ebisemiju [24], Udosen [25] and James *et al.*, [26] were in agreement that their studied gullies were V-shaped in cross section. On his part, Iorkua [27] stated that a wide and deep gully cut in the highly erodible Makurdi Sandstones geological unit in Makurdi, Nigeria, had a V-shaped cross section.

Oparaku [14] argued that, from his field experience in the project area and in the southeastern Nigeria, nowhere has a gully been observed to develop a V-shaped cross sectional area from its head to the mouth. The commonest shape is a V-shape a few meters from the gully head in the Upper section. Thereafter, the gully floor widens and flattens up to its mouth in the middle and lower sections, with the sides inclined at some angles to the floor, for erodible materials. However, U-shaped gully cross sections are more common shapes from the gully head to the mouth for highly resistant materials. Hence, the idea of a V-shaped gully developed on an erodible materials somewhat misleading from the viewpoint of the author.

The trapezoidal shape of the cross sections of the gullies formed on the AS formation can, therefore, be explained by the paucity of binding materials in the sediments, and the inclination of the sides is a posture taken by the channel to withstand sloughing, slipping, and other forms of shear failure.

Descriptive Statistics of the Measured Gully Morphology

The descriptive statistics of the parameters of the gullies formed on the AS are shown in Table-2. The total length of the gullies is 16,700.00 m with a mean of 452.27 m. The mean depth is 6.49 m and their mean width is 7.95 m.

The average volume shows the highest dispersion when the gullies on the AS are assessed based on their standard deviation (SD) of 31,416.29 m^3. This is widely followed by the length with an SD value of 322.12 m. The form factor is the least dispersed variable with an SD 0f 1.20. The average width equally has a low dispersion with an SD of 5.53 m. In terms of relative variability, the average form factor has the highest variability with a CV of 82.19%. This is closely followed by the average volume with a CV of 79.51%. The least CV of 38.76% is indicated by the average CSA. Notably, the mean form factor of the gullies is 1.46. A mean average gully volume of 39,513.00 m^3 shows that gullies on the AS are high in sediment production. This explains why sediments rapidly silt up urban drainage structures as well as river channels traversing the area, giving the rivers muddy and murky appearances during the rainy season. This further explains why in areas underlain by the AS sediments, large sections of roadways are taken over by massive sediment deposits from gullies, thus reducing vehicular use of the roadways.

A mean form factor of 1.46 shows that more land surface is being attacked by gully erosion than the subsoil on this formation. This has adverse implications for agricultural and urban land development in the area.

Table-2: Descriptive statistics of the 37 gullies formed on the Ajalli Sandstones geological formation

Gully Morphometry	Unit	Total	RG	$\bar{x}$	SD	CV (%)
Length (L)	M	16,700.00	45.20-1,400	452.27	322.12	71.22
Average depth (D)	M	240.06	1.05-16.30	6.49	3.47	53.47
Average width (W)	M	294.04	2.20-30.00	7.95	5.53	69.56
Average volume (V)	m^3	$146x10^4$	1,277.92-540,000	39.513.00	31,416.29	79.51
Average CSA (A)	m^2	2,300	3.26-360.00	62.16	24.09	38.76
Average Form Factor (W/D)	-	54.02	0.25-6.26	1.46	1.20	82.19

RG = Range, $\bar{x}$ = Mean, SD= Standard deviation, CV=Coefficient of variation (%), and CSA = Cross sectional area.

Inferential Statistics of the Measured Gully Parameters

The inferential statistics used in analyzing the relationship between gully length and average volume on the AS were the correlation coefficient, R, and the simple bivariate regression. The results of the Pearson's correlation matrices showing the interrelationships among the six gully variables, and especially between gully length and average volume, are presented in Table-3.

Table-3: Correlation of the variables of the gullies formed on the Ajalli Sandstones formation

	Length L	Average Depth, D	Average Width, W	Average Volume V	Average CSA, A	Form Factor W/D
Length, L	1					
Average Depth, D	0.004	1				
Average Width, W	0.201	0.565**	1			
Average Volume, V	0.503**	0.447**	0.849**	1		
Average CSA, A	0.243	0.78**	0.913**	0.870**	1	
Form Factors, W/D	- 0.076	- 0.380*	0.346	0.130	0.021	1

** Correlation is significant at the 0.01 level (2 – tailed)

* Correlation is significant at the 0.05 level (2 tailed)

CSA = Cross Sectional Area

Source: Statistical computer analysis by the author

Correlation of Gully Length with the Average Volume

It is observed from Table-3 that, out of 30 correlation coefficients on the AS, 18 were significantly correlated (4 at the 0.05 level and 14 at the 0.01 level), representing 60% of the total (13.33 and 46.67% respectively). This result agrees with those of Ebisemiju [24], Udosen [25] and Iorkua [27] who respectively reported 60%, 60.67%, and 42.90% of significant correlation in their related gully erosion studies.

The results of the correlation further show that on the AS formation, the length is significantly, positively, but moderately correlated with the average volume (R = 0.503) at the 0.01 level. The interpretation is that as the length of the gully increases, so does the volume of eroded materials, and that the length can constitute a moderate indicator of the volume of materials eroded from a gully.

Expectedly, gully length has a positive and significant influence on the average volume for the reason that the AS sediments on which the gullies were formed are loose and, therefore, highly erodible. This outcome can be explained when it is visualized that an extension of gully length into the gully catchment area is accompanied by corresponding increases in both the width and depth at various cross sections of the gully, leading to an increase in the gully volume (V = L x W x D). An increase in width is brought about by gully sidewall slope failures and debris clean out by bed flow [28], whereas an increase in depth results from both incision and bed scouring [9].

Cheng *et al*., [6] reported that gully length was very strongly and significantly correlated with gully volume on the highly erodible loess plateau of China, and they suggested that gully length could represent a critical index for the estimation of gully volume in the area. Nachtergaele and Poesen [29] found a positive correlation between gully volume and length in 80% of the gullies in the loose, erodible Loess-derived soils of Portugal, and they concluded from their findings that gully length was a good estimator of the volume. The results of the correlation analysis reported in this study agree with those of Cheng and his colleagues [6] and Nachtergaele and Poesen [29].

Simple Regression of Gully Length on the Average Volume

A simple regression analysis was carried out to determine the effectiveness of gully length as a tool for the prediction of average gully volume on the Ajalli sediments. The relationship between average gully volume and gully length is given by the regression equation as:

$$V= -27{,}066.643+147.213L \quad \ldots\ldots\ldots\ldots\ldots (3)$$

(R=0.503, *CV* (R^2 x 100) = 25.30%).

Where,
V= gully average volume (dependent variable).
L= gully length (independent variable).
CV = Coefficient of Variation (%)

The regression line is linear, positive, and significant at the 0.01 level (Figure-4). However, the scatter of points around the line of best fit evidences a moderate relationship. The regression coefficient (RC), 147.213, is positive, and the coefficient of variation (*CV*) is 25.30%.

The positive linearity of the line of best fit shows that on this formation, the average volume of a typically gully increases as the length increases. This assertion is also confirmed by a positive RC (147.213) of the regression line. However, a *CV* of 25.30% indicates that an increase in gully length accounts for only 25.30% of the increase in the average gully volume. So that it can be stated that gully length is a moderate predictor of gully volume on the Ajalli Sandstones geological formation. The results of this study agree with those of other authors earlier cited in this report [29, 6].

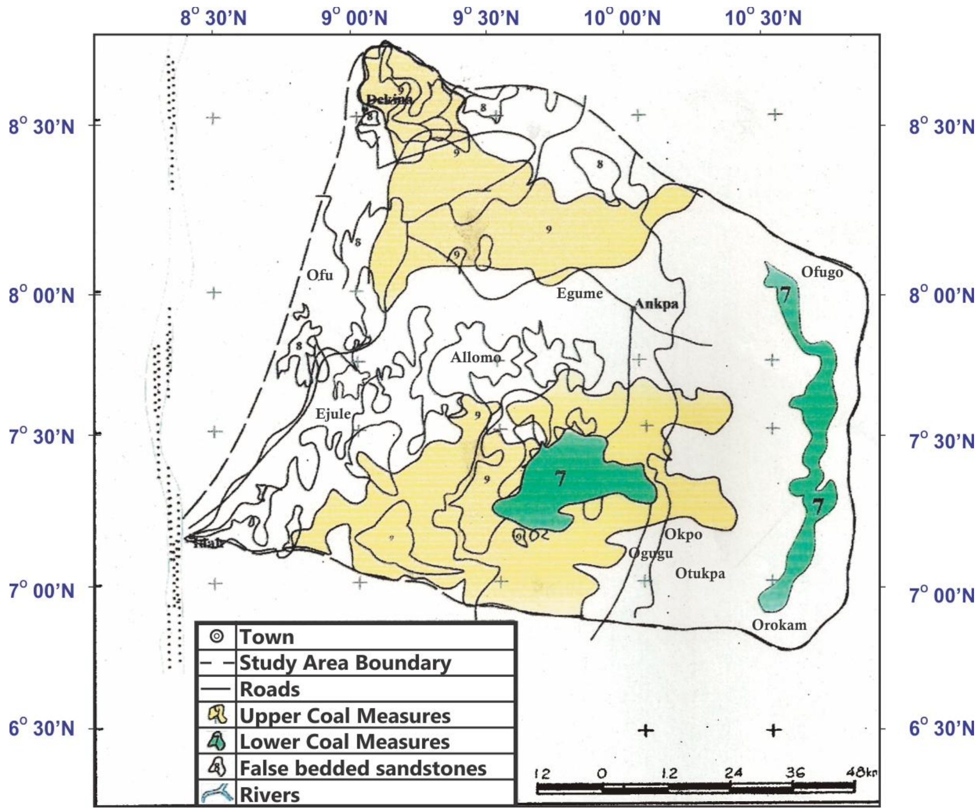

Fig-1: Geological map of the Idah-Ankpa Plateau

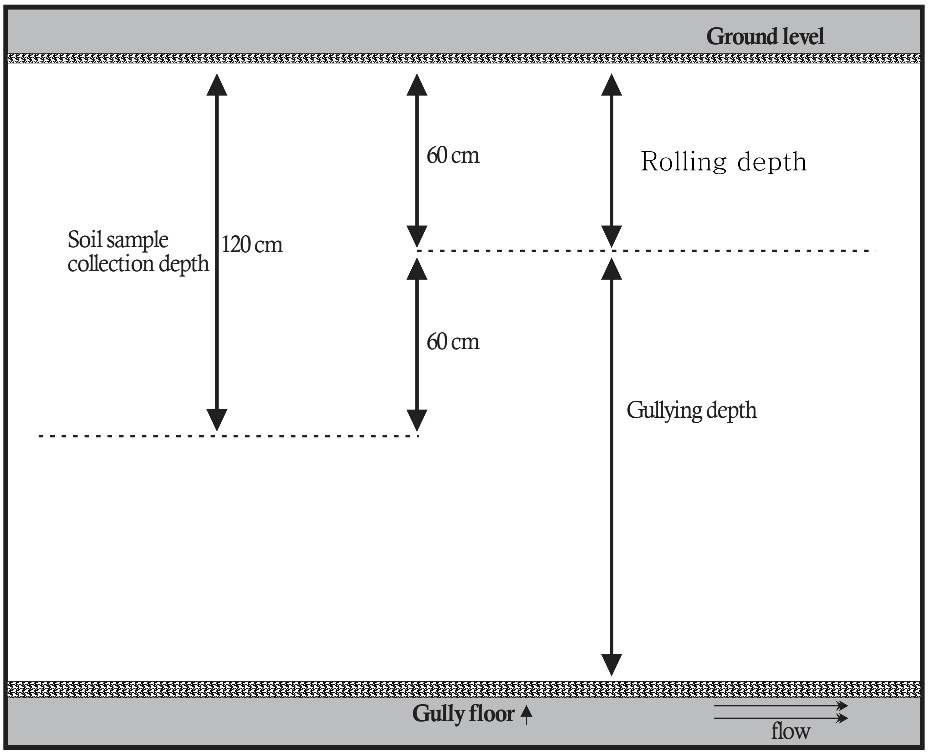

Fig-2: A schematic portrayal of a gully sidewall showing the rilling depth and the gullying depth [2]

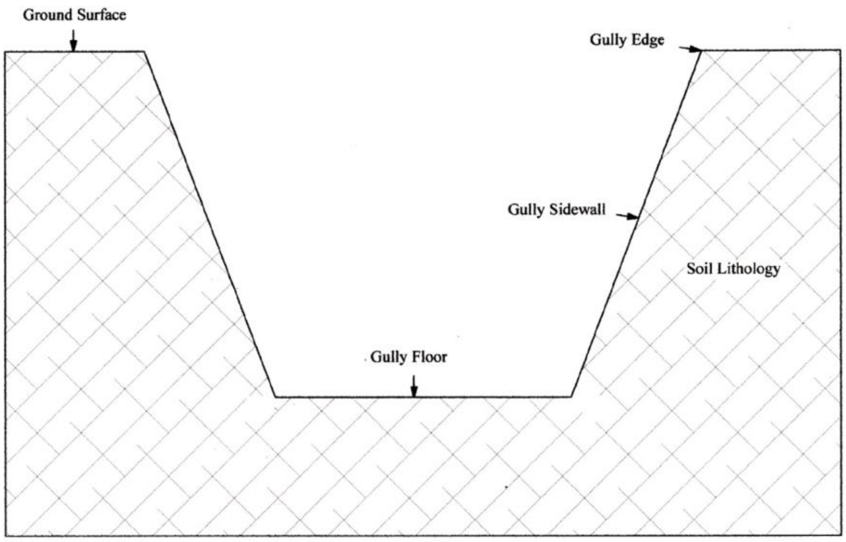

Fig-3: The Trapezoidal shape of the cross section of gullies formed on the Ajalli Sandstones geological formation

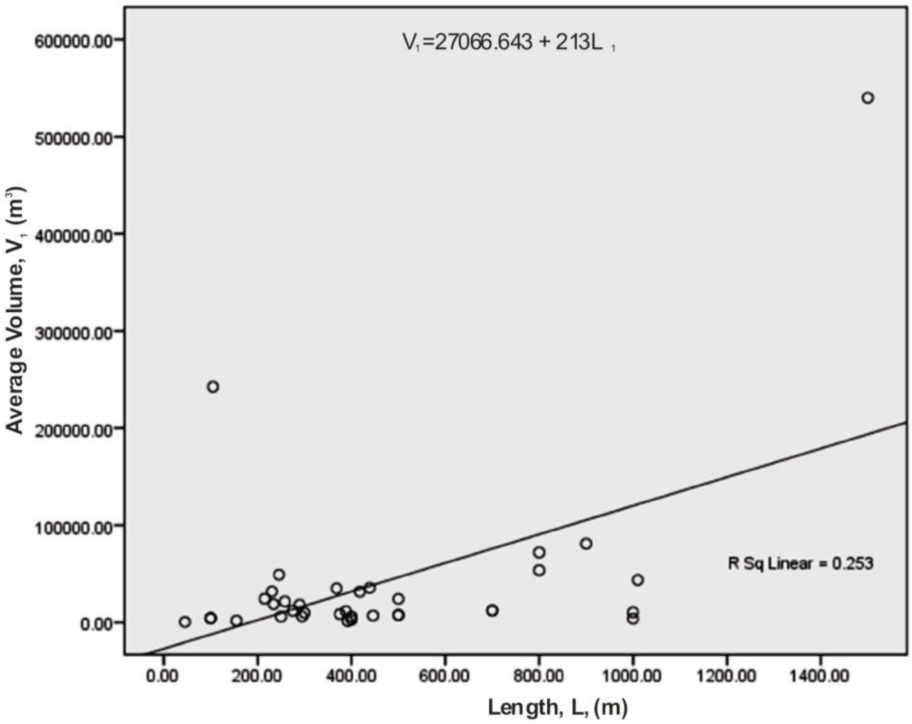

Fig-4: Regression of the gully length on the average gully sediment on the Ajalli Sandstones formation

CONCLUSIONS

This study leads to the following conclusion about the AS formation:

- The rilling depth and the gullying depth are highly erodible and the formation is, therefore, vulnerable to gully erosion,
- The gullies are high in sediment production,
- The gully cross sections are trapezoidal in shape,
- A high degree of surface soil is lost to gully erosion than the subsurface soil (w/D = 1.46),
- Gully length is significantly, positively, but moderately correlated with the sediment volume (R = 0.503, P < 0.01),
- The average volume of eroded sediments from a gully increases as its length increases,
- An increase in gully length accounts for 25.30% of all variations in the average sediment volume, and
- Gull length is a moderate predictor of the average sediment volume.

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