Gully Erosion: A comparison of contributing factors in Njaba Watershed, Imo State, Nigeria

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Abstract

This study compared the contribution of various soil erodibility factors in the formation of gully erosion channels in the study area. Gully cross sectional area were measured in the field. Soil samples were collected at the top, middle and gully floor and analyzed for various soil physical/geotechnical parameters. Field measurements as well as the laboratory results of the soil analyses were used as input data for the statistical analyses. The study showed that gullies in Njaba sub-basin fall into two major soil groups. Sandstones of lignite and shale in and around Njaba and the Alluvium soil formation in and around Awomama and Oguta area. The gullies in Njaba are deep and sharp despite the presence of shale because the area is a transition zone between Bende-Ameki and the Benin Formation. Six Erodibility factors were identified to have contributed in great measure to the formation of gully channels. Shear strength accounted for 63.0% of all the variance that predicted gully size in the study location, followed by Soil consistency. The six Erodibility indices include Shear strength, Soil Consistency, bulk density, elevation, slope and dry density accounting for 92.0% of variance in the development of gully erosion channels across Njaba watershed. The study further showed that slope (.001) and Shear strength ((.000) had the strongest individual relationship in determining gully size, closely followed by dry density (.003). We anticipate that any control work to be done in the area should take cognizance of the factors highlighted in this study that contribute 80% to the development of gully erosion profiles

Keywords: Soil, Gully, Erosion, Slope, Shear strength, cohesion, watershed, bulk density

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1. Introduction

Gullies are very common in the southeast of Nigeria. Gullies and landslide may probably pass as the most devastating of environmental hazards in the region (Adekalu *et al.*, 2007). Gullies in particular are extensively distributed in Imo State and accounts for approximately 12,000km^2 of badland in the total area (Egboka, 2004). Gullies of all types and form have presented engineering problems in their control (Amangabara, 2012) are persistent threat to human activities in the area (Amangabara, 2014), increases in population, intensive and extensive agriculture, excavation of slopes and red mud(laterite) to produce roads and course grade /sub grade for roads amplify the impacts of gulling and their environmental challenges. Furthermore, owing to nature of the gullies and high cost of controlling them through engineering measures and rational measures, casualties and economic losses are increasing (Abdulfatai *et al.*, 2014)

Proper understanding on the mode of formation, characterization of the size distribution and knowing the factors causing them is extremely important in determining gully hazard and effective control (Amangabara, 2014). What has been the practice is to use general knowledge instead of sight specific knowledge. Also the relying upon of only engineering measures without taking cognizance of other methods of control has also made every effort to fail.

Several factors are known to have cause or influenced the formation of gully erosion. Erosivity factors such as amount and duration of rainfall, surface runoff etc. Erodibility factors such soil properties in addition to relief and slope. Topography affect slope hydrological processes and thus slope stability, and has been studied by several researchers (e.g. Sidle and Onda, 2004, Xu *et al.,* 2013) Topographic features that influence erosion are degree of slope, length of slope and size and slope of the watershed. The extent of erosion is not just proportional to the steepness of the slope, but rises rapidly as the slope increases. Thus, as stated by Hudson *et al* (1971), the erosion per unit area is related to the slopes as graphically shown below:

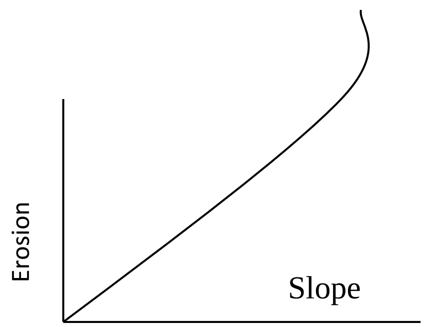

Fig.1 a: The relationship between erosion and slope

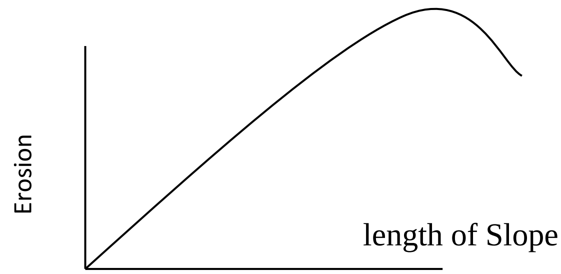

Fig.1b: The relationship between erosion and length of slope.

That is : E æ S^a

Where: E = is the erosion

S = the slope (%)

a = is an exponent = 1.35 (from field plot experiments).

The length of slope has a similar effect on soil loss. On a long slope, there is a bigger build up of the amount of surface runoff and its velocity. This will lead to scour erosion which would not occur on a shorter length of slope.

Thus: E æ L^b

Where: b= 0.6

L= length of slope.

Several studies have reported where the topographical threshold concept in combination with a hydraulic threshold has been applied to predict areas at risk of gullying (e.g. Ofomata, 1987; Dietrich *et al.*, 1993; Prosser and Abernethy, 1996; Onu, 2011).

However, for erosion to occur, the soil itself must be susceptible to detachment and transportation by the agents of erosion. The soil properties influencing this susceptibility are mainly soil structure & texture - especially with respect to cohesiveness, particle size distribution, structural stability, aggregate stability, shear strength, infiltration captivity and organic and chemical content (Morgan, 1986) and nature of the underlying substratum.

Considerable research has addressed influence of soil properties on the formation of gully erosion (for example Mararakanye and Sumner, 2017; van Zijl *et al.*, 2013; Igwe, 2012).

Nachtergaele (2001) analysed 38 ephemeral gully erosion events that occurred over a 15-year period in central Belgium and found critical P values of 15 mm in (late) winter (n = 21) and of 18 mm in (early) summer (n = 17) which is attributed to a difference in soil moisture content between winter and summer. Øygarden (2003) documented how the combination of frozen subsoil, saturated top soils with low strength and intense rainfall led to the development of ephemeral gullies in Norway, even in areas with gentle slope gradients. These observations point to the fact that soil strength is a major determinant and where conditions (e.g. saturation and drying up combined with intense rain and slope) is likely to increase the risk of gully erosion

In the present study, the contribution of the various soil parameters that influences gully formation alongside slope is evaluated. The aim is to measure the cross sectional area of sampled gullies in the watershed and determine the percentage contributions of factors of gully formation which can guide the adoption of right techniques and methods in their control.

2. Materials and Methods

2.1 Study Area

The watershed under study has a shape of a clover leaf and it's comprised of two major sections. The upper region which comprised of Njaba River and River Awbana can be described as the upper course while the lower section which is comprised of Utu Stream, Oguta Lake and the braided section of Orashi River can be described as the floodplain or alluvial section. The total area of the watershed is about 1,600.84 km^2; Njaba River is a 35km long tributary of Orashi River and rises at Ihitte located at Isunjaba in Isu Local Government Area of Imo State. It forms a dendritic pattern as it drains the entire Isu and Njaba Local Government Areas, Eziama and Amucha to the North, Amaigbo to the West, Umundugba, Amandugba and Ekwe, Okwudo, Umuaka and Awo-Omama to the South and runs through the rolling hills in a meandering flow and empties into Oguta Lake. As it approaches Oguta Lake it becomes braided. The lake in question is a major hydrological formation, the largest natural lake in Imo State formed from a natural depression. During the dry season the surface area of the lake is about 1.8 km^2 while during the rainy season it is about 2.5 km^2. The maximum depth is about 8.0 m with a mean depth of 5.5 m. The average total length of the shoreline is 10 km. The floodplain is occupied by the lower reaches of Orashi River as it flows in from Anambra State. In this section, it is highly braided and the drainage pattern is trellis. The morphometric characteristics of this watershed reflect the nature of the relief of the area. There are about seven first order stream, one second order stream and two each of third and fourth order streams. Drainage density (Dd) is 0.15Drainage Intensity (DI) is 0.001 while the stream frequency in this watershed is 0.01. The bifurcation ratio is 2.84 (Amangabara 2012). Studies of many stream networks confirm the principle that in a region of uniform climate, rock type and stage of development, the bifurcation ratio tends to remain constant from one order to the next. The closeness of 2.84 to 3 is indicative of the characteristics of streams that have two major sections.

2.1.1 Gullies in Njaba Area

Umuaka Gully Erosion site consists of several complex gullies with the Njaba River as the base line of erosion. The depth, width and length of the gullies are over 50m, 500m and 2000m respectively. In 1994, one of the major gully advanced by over 60m within one rainy season. The gullies mainly originated from poorly constructed side drains and termination of culvert at unsafe points at the Njaba River valley along the abandoned old Owerri – Orlu road. The cracks of the incipient landslip failure plane of the advancing gully now runs along the edge of the bituminous running surface.

Amucha & Okwudor Gullies are located on the northern riverbank some four kilometers away from each other. The Okwudor gully is approximately 500m long and has a maximum depth of about 25meters. The gully growth was said to have commenced in 1979 after the construction of the new Owerri –Orlu road, along this road a drain was constructed to collect the water from the uphill area along the road. Due to a small depression in the road it was not possible to discharge the water into the nearby river by gravitational flow but a culvert had to be constructed under the road to enable the water to pass the road and flow to the river at a different location. At the outlet however no further precautions were taken to transport the water to the river. The large volume of water concentrated in one culvert is the main cause for initiating this gully.

The main gully near Amucha is over 1000 meter long and at some locations 30 meters deep. The gully was first mentioned in 1970 as a 100 meter long incision, 10m deep and 10m wide (Castenmiller, 1988). The main cause of the tremendous gully is probably because it is located on the flood path of a large catchment (approximately 23km^2) of the Njaba River. After the gully was developed, it enlarged due to the enormous volume of water, concentrated by the road and hardened areas that rush down the sandy steep slope into the Njaba River after and during a torrential rainstorm. The gully is underlain by geologic formation of a sedimentary origin of lignite and sandstone of Benin formation of the late tertiary age which is deep, porous, loose, unconsolidated and fragile. These structural and textural properties of the soil make it highly unstable and prone to soil erosion. The soil has low clay content thereby increasing the soil erodibility

2.1.2 Gullies in Oru West & East Areas

Mgbidi/Mgbenlle Gully Erosions are on an elevation 53.5m. These are small gully erosions features on the slope of the Mgbelle along the Oguta 1- Mgbidi road off the Deeper Life Church Junction. Each gully has a network of branches developing in the zones of weakness measuring about 400m to 600m from the top of the slope to the stream valley (Njaba River). Some of the rills are 3m in width and 10m in depth.

Umuehi Mgbidi Gully Erosion (Elevation 63m). The gully has a single gully head but along the length develops into three branches measuring in width between 14m and 16.8m with depths varying between 9.0m to 13.1m. This particular gully appears stabilized.

2.1.3 Gullies in Oguta Area

Orsu – Obodo Gully Erosions (Oguta 2) (Elevation 81.9m). The gully was said to have started in 2009 after the road construction. Average width of gully from the head area to the middle section is 3.1m and depth 1.9m respectively. The gully is still very active in the middle reaches. Community efforts include sandbagging, digging and filling. The soil is in this area are sandy loam and very loose in some area and clayey in some area especially towards the lake.

Nkwensi gully erosions (Oru Ward A, Oguta 2) (Elevation 81.9m). The depth of this gully is about 5.7m with a width of 1.7m. The erosion developed at the edge of the Nkwensi – Motel Road, aggregating all the runoff in that vicinity.. The gully drains into the Oguta Lake.

Mgbenle Gully (Oguta 2) Elevation 60.5m. The average length of the gullies on this slope is about 7.3m down to the Oguta Lake. Width 19.8m, Gully developed just in the same way the Nkwensi gully developed in 2009

Fig 2a Google earth Satellite image of gullie in Oguta Area

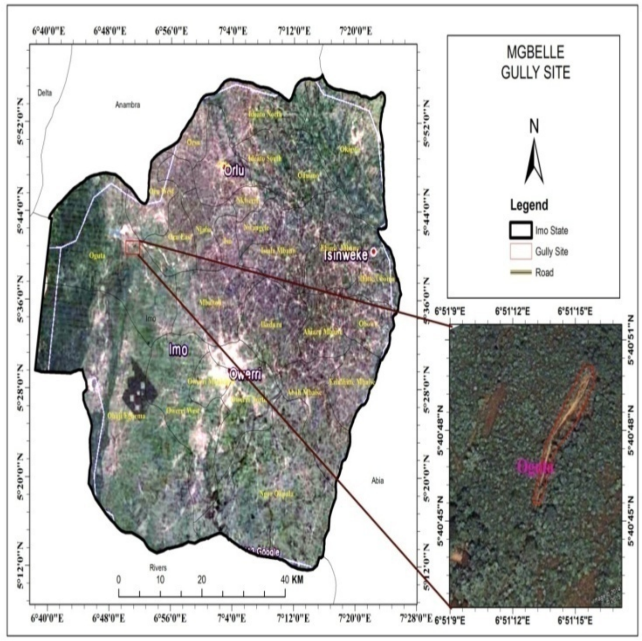

Fig 2b Location of Oguta in the Map

Fig 2c: A typical gully erosion channel in the study area

2.2 Data Generation/Instrumentation

The fieldwork provided the raw data for the laboratory experiment. The outputs from our laboratory experiment were further used as input data for our statistical analyses in testing the objectives/hypotheses.

In the field, on each gully wall, relatively undisturbed soil samples were collected at three distinct positions including the topsoil (0 – 15cm, 15cm – 30cm and up to 6m), midway and gully bottom (a few meters to the bed floor) for the determination of soil texture, soil structure and bulk density. The samples collected were placed in black cellophane bags designed for the purpose, tied and labeled accordingly and transported to the Soil Laboratory of the Erosion Research Centre of the Federal University of Technology, Owerri

The cross section of each gully was also measured and this was done with aid of measuring tape and rope as follows:

i. The length of the gully was measured from head to mouth with a measuring wheel.
ii. The length of the gully was divided into four segments.
iii. On each of this segment, depth and width was measured.
iv. The four measurements taken at each of the segment was summed and divided by four to get average value for the cross section of the gully.

2.3 Statistical Analyses

Statistical analyses was done using data generated from the laboratory and field measurements following the various factors that aid gully formation as hypothesized and these are grouped as follows:

The Dependent variable

- gully erosion size (the Cross Sectional Area)

The Independent or predictor variables

- Soil erodibility – particle size, bulk density, texture, structure (aggregates), moisture content/shear strength.
- Relief factors – terrain altitude, slope

To examine which soil properties, topography, and slope contributes to the development of gully erosion in the watershed the Multiple Linear Regression statistical analysis was used.

The multiple linear regression models assume that there is a linear, or "straight line," relationship between the dependent variable and the predictors. This relationship is described in the following formula

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + b_4 x_4 \text{-----} + e_i \ldots\ldots\ldots\ldots \text{(i)}$$

Where

Y	=	Gully Size (Cross Sectional Area)
$b_0 + b_1 x_1$	=	Intercepts
X_1	=	Elevation
X_2	=	Slope
X_3	=	Soil Texture
X_4	=	Soil Consistency
X^5	=	Shear Strength
X_6	=	Bulk Density
X_7	=	Dry Density

Gully Size (the Cross Sectional Area) is the Dependent Variable while the Independent or predictor variables include elevation, slope, soil texture, soil consistency, shear strength, Bulk density and Dry Density.

In general, the multiple regression equation of Y on X_1, X_2, …, X_k is given by:

$$\boldsymbol{Y = b_0 + b_1 X_1 + b_2 X_2 + \ldots\ldots\ldots\ldots + b_k X_k} \ldots\ldots\ldots\ldots \text{(ii)}$$

Where:

b_0 is the intercept and b_1, b_2, b_3, …, b_k are analogous to the slope in linear regression equation and are also called regression coefficients. They can be interpreted the same way as slope. Thus if $b_i = 2.5$, it would indicates that Y will increase by 2.5 units if X_i increased by 1 unit. The appropriateness of the multiple regression models as a whole can be tested by the F-test in the ANOVA table. A significant F indicates a linear relationship between Y and at least one of the X's.

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3 Results

3.1 Laboratory Analyses

Table 1 below is the result for gully morphometry showing the length, depth and width of the gullies measured in this watershed. The result for soil physical properties/characteristics of gully soil shows that atterberg limits for Njaba watershed are low (Table 2), for example Umuaka (liquid limit of 32.4%; plastic limit of 21.3%, plasticity index of 11.1%) and Nnenassa (liquid limit of 30.5%; plastic limit of 22.3% and plasticity index of 8.2%). The bulk density for the gully soil ranges between 1.39mg/m^3 (at Umuaka) to 1.71mg/m^3 (at Awo Ndemili). The low bulk density values trends across all gully soils in the watershed (table 2). Macro pores space may be similar between well-aggregated finer textured soil and sandy soils, but lack of micro pores gives sandy soils high bulk density and since high bulk density reduces pore spaces it gives rise to increased runoff and storm water flow which on the long term provides the needed kinetic energy to cross the threshold of the angle of repose of the soil and cause detachment and erosion. Soils with low bulk densities have greater infiltration rate which minimizes runoff and reduces storm water flow. Fine textured soils for example silt loams or sandy soils with high organic content have extra pore space (intraped micropores) which contributes to the overall pores space and lowers the bulk density. Usually, soils that are loose and porous have low weight (mass) per unit volume and those that are compact will have a high value. Factors such as organic matter, porosity, compactness, sand particle distribution etc affect the bulk density.

Table 1. Gully Morphometry

Watershed	Area of Watershed (sq.Km)	Gullies found in the watershed	L.G.A.	N	E	Avg Length (m)	Avg Depth (m)	Avg Width(m)	Elevation (m)
Njaba/Lower Orasahi	1,600.84	Umuaka	Njaba	05 43 00.8	007 02 27.4	215	32	18	64.7
		Nnenasa	Njaba	05 33 44.8	007 09 29.9	235	30	22	72.0
		Amucha	Njaba	05 44 61.4	007 02 67.7				
		Orsu - Obodo (Ukwuoji)	Oguta	05 41 56.3	006 47 39.0	202	1.9	3.1	81.9
		Nkwensi (Oru Ward A)	Oguta	05 40 54.5	006 50 52.2	55	5.7	1.7	81.9
		Mgbenle	Oguta	05 40 47.1	006 51 0.36	7.3	5	19.8	60.5
		Eziama - Egbe	Oguta	05 42 37.1	006 49 25.7	80	1	1.3	56.5
		Mgbidi	Oru West	05 43 29.3	006 53 20.8	500	1	5	53.5
		Umuehi Uzurumu Mgbidi	Oru West	05 43 39.8	006 52 58.2	152	16.8	14.8	63
		Umuoke Ubiri – Elem	Orsu	05 50 49.8	007 00 06.1	900	1	1.4	
Proposed Sample Size = 30% of Gully Erosion Sites			4.5						
Sample Size			**5**			2346.3			

Table 2: Soil Characteristics/Physical Properties

S/N	Watershed	LGA	Town	Grain Size Distribution	Coefficient of	Coefficient of	Soil	Grade

		Soil Consistency				Shear Strength			Density	
Gullies in Njaba watershed	LGA	Liquid Limit	Plastic Limit	Plasticity Index	Permeability	τ (kpa)	C (kpa)	σ(°)	Dry Density (mg/m3)	Bulk Density (mg/m3)
Umuaka	Njaba	32.4	21.3	11.1	7.8×10^{-2}	87.9	5	25	1.27	1.39
Nnenasa	Njaba	30.5	22.3	8.2	8.8×10^{-2}	88.1	5	23	1.30	1.41
Amucha	Njaba	NP	NP	0	7.8×10^{-2}	85.5	-9	28	1.51	1.62
Nkwensi (Oru Ward A)	Oguta	NP	NP	0	3.6×10^{-2}	102.7	0	30	1.47	1.56
Mgbenle	Oguta	NP	NP	0	3.9×10^{-2}	95.7	-7	30	1.33	1.55
Eziama – Egbe	Oguta	NP	NP	0	6.8×10^{-2}	100.6	2	29	1.41	1.51
Mgbidi	Oru West	NP	NP	0	5.3×10^{-2}	91.9	-15	31	1.58	1.64
Umuehi Uzurumu Mgbidi	Oru West	NP	NP	0	5.7×10^{-2}	98.6	0	29	1.38	1.45
Awo Ndemili	Oru East	33.4	20.2	13.2	2.3×10^{-2}	105.5	-10	33	1.53	1.71
Umuoke Ubiri – Elem	Orsu	33.1	20.2	12.9	2.0×10^{-2}	107.5	-17	35	1.34	1.42

Key: C = Cohesion. Ø = Angle of internal friction. **τ** = Shear strength (c + **τ** n tan Ø). Kpa = Kilo Pascal (Kilo Newton/meters squared)

TABLE 3 GRAIN SIZE DISTRIBUTIONS (GRADATION OF SOIL) AT GULLY EROSION SITES

0				(mm)					Uniformity (Cu)	Curvature (Cc)	Class	
				D_{10}	D_{30}	D_{50}	D_{60}	D_{80}				
1	Njaba	Njaba	Umuaka	0.22	.425	0.60	0.70		3.18	0.574	Sandy	Poor
2	Njaba	Njaba	Nnenasa	0.28	0.40	0.68	0.80		2.85	0.35	Sandy	Poor
3	Njaba	Oguta	Orsu Ukwuoji	0.22	0.35	0.47	0.56		2.54	0.311	Sandy	Poor
4	Njaba	Oguta	Nkwensi Oru Ward	0.28	0.40	0.62	0.80		2.85	0.457	Sandy	Poor
5	Njaba	Oguta	Mgbenle	0.19	0.35	0.50	0.60		3.15	0.386	Sandy	Poor
6	Njaba	Oru West	Umuehi Uzurumu	0.23	0.36	0.58	0.68		2.95	0.383	Sandy	Poor
7	Njaba	Oru West	Mgbidi	0.26	0.38	0.52	0.58		2.23	0.322	Sandy	Poor

Table 3 shows the percentage composition of gully soil. Gully soils at Njaba watershed shows percentage composition of gravel is nil while sand is 90%, silt 10%. The effective size of the soil (D_{10}) is 0.22 for Umuaka gully and 0.28 for Nnenasa gully. The coefficient of uniformity (Cu) for both Umuaka and Nnenasa are 3.46 and 2.86 while their (coefficient of curvature) Cc 1.25 and 0.71 respectively. The data further showed that with decrease in particle size the Atterberg limit increases

3.2 Statistical Analyses

The analysis of variance (ANOVA) was applied to determine if there is any significant spatial variability of gullies in the watershed. Table 4 is the SPSS output for the ANOVA

Table 4 Njaba/Lower Orashi Summary of SPSS output for ANOVA

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	28923.908	3	9641.303	.081	.970
Within Groups	4308240.981	36	119673.361		
Total	4337164.889	39			

From the table above Table 4 Njaba watershed, at 0.05 level of significance and 39 degree of freedom, The F.cal = .081 p-*value* of .970 was established which implies that there was no significant statistical variability of gully profiles in the study area, meaning there is no significant variability of cross sectional areas (CSA) of all gully channels in this watershed with just marginal differences.

To examine which soil properties, topography, and slope contributes to the development of gully erosion in the watershed the Multiple Linear Regression statistical analysis was used. Table 5 below summarizes the analysis results explaining the measure of relationship between Y (Gully CSA) and the seven predictor variables selected for inclusion in the equation. The Multiple Correlation Coefficient R is the measure of the strength of the relationship between the criterion variable Y (Gully CSA) and the seven predictor variables. The coefficient of determination (R^2) is the square of this measure of correlation and indicates the proportion of the variance in the criterion variable which is accounted for by the model

Table 5 Model Summary of the SPSS out for Multiple Linear Regression Analysis

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.794[a]	.630	.620	205.50678	.630	64.696	1	38	.000
2	.902[b]	.813	.803	147.93989	.183	36.327	1	37	.000
3	.917[c]	.841	.828	138.41063	.028	6.270	1	36	.017
4	.938[d]	.880	.866	121.92797	.039	11.391	1	35	.002
5	.946[e]	.896	.880	115.31829	.016	5.127	1	34	.030
6	.959[f]	.920	.906	102.49637	.024	10.039	1	33	.003

a. Predictors: (Constant), Shear Strength

b. Predictors: (Constant), Shear Strength, Soil Consistency

c. Predictors: (Constant), Shear Strength, Soil Consistency, Bulk Density

d. Predictors: (Constant), Shear Strength, Soil Consistency, Bulk Density, Elevation

e. Predictors: (Constant), Shear Strength, Soil Consistency, Bulk Density, Elevation, Slope

f. Predictors: (Constant), Shear Strength, Soil Consistency, Bulk Density, Elevation, Slope, Dry Density

The model summary of the stepwise regression showed that six independent variables satisfied the criteria for entry into the model. From the model, shear strength accounted for 63.0% (Adjusted R^2 value of .620 or 62.0%)) of all the variance that predicted gully size in the study location. At Step 2, Soil consistency entered the model increasing the total variance explained from 63.0% to 81.3% an increase of .183 (18.3%) indicating that soil consistency by itself explained 18.3% of the variance accounted for in the dependent variable (gully size) but since it was itself correlated with the shear strength, a portion of what it could explain had already been attributed to shear strength. The six independent variables: Shear strength, Soil Consistency, bulk density, elevation, slope and dry density accounted for 92.0% (R^2 of 90.6%) of variance accounted for in gully size across Njaba watershed.

The Correlation matrix of the regression (table 6) shows that slope (.001) and Shear strength (.000) had the strongest individual relationship with the dependent variable (gully size), closely followed by dry density (.003). Gully size (cross sectional area) is correlated with slope, soil texture, shear strength, dry density bulk density and soil consistency with a p-value of 0.001, 0.016, 0.000, 0.003, 0.016 respectively (Table 6) The model summary (Table 5) shows that the model: Gully size = 1065.35 -97.113 shear strength + 22.082 soil consistency + 2157.266 bulk density + 5.038 elevation + 31.132 slope – 1292.561 dry density is significant at p- value (0.003) < 5%. The adjusted R^2 explained by the variable is 0.906. Thus, shear strength soil consistency, bulk density, elevation, slope and dry density in that order are good predictors of the dependent variable (gully size).

Table 6 Correlations Matrix for Njaba Watershed

		Cross Sectional Area	Elevation	Slope	Soil Texture	Shear Strength	Dry Density	Bulk Density	Soil Consistency
Pearson Correlation	Cross Sectional Area	1.000	-.051	.483	.340	-.794	-.432	-.340	.329
	Elevation	-.051	1.000	.029	-.102	.298	-.236	-.372	.310
	Slope	.483	.029	1.000	.156	-.365	-.069	-.182	.065
	Soil Texture	.340	-.102	.156	1.000	-.556	.062	-.088	-.334
	Shear Strength	-.794	.298	-.365	-.556	1.000	.449	.447	.121
	Dry Density	-.432	-.236	-.069	.062	.449	1.000	.892	-.326
	Bulk Density	-.340	-.372	-.182	-.088	.447	.892	1.000	-.238
	Soil Consistency	.329	.310	.065	-.334	.121	-.326	-.238	1.000
Sig. (1-tailed)	Cross Sectional Area	.	.378	.001	.016	.000	.003	.016	.019
	Elevation	.378	.	.430	.265	.031	.072	.009	.026
	Slope	.001	.430	.	.168	.010	.337	.130	.346
	Soil Texture	.016	.265	.168	.	.000	.352	.296	.018
	Shear Strength	.000	.031	.010	.000	.	.002	.002	.228
	Dry Density	.003	.072	.337	.352	.002	.	.000	.020
	Bulk Density	.016	.009	.130	.296	.002	.000	.	.070
	Soil Consistency	.019	.026	.346	.018	.228	.020	.070	.
N	Cross Sectional Area	40	40	40	40	40	40	40	40
	Elevation	40	40	40	40	40	40	40	40
	Slope	40	40	40	40	40	40	40	40
	Soil Texture	40	40	40	40	40	40	40	40
	Shear Strength	40	40	40	40	40	40	40	40
	Dry Density	40	40	40	40	40	40	40	40
	Bulk Density	40	40	40	40	40	40	40	40
	Soil Consistency	40	40	40	40	40	40	40	40

4 Discussions

The findings on the soil physical properties gave credence to the assumption that the nature of the soil as a result of the underlying geology is the principal factor responsible for the massive gully erosion in the study area. The principal variable of soil erodibility factor is the soil structure which is reflected in the Consistency (Moisture content/Atterberg limits), shear strength, Soil texture and bulk density.

Soil consistency (moisture content/Atterberg limits) shows that out of the ten gully erosion channels investigated six of them are none plastic meaning they have no binding materials in the soil and as such they are less cohesive. The gully soil exhibiting plasticity has their plots clustered within the low plastic range. The values of the plastic index obtained is an indication that they are cohensionless and non-adhesive, this is characteristic of the Nanka sands of the Bende-Ameki Formation and also the coastal plain sands (the Benin Formation). The non-cohesive or the friable nature of the soils in the area may account for the gully erosion problems as it aids percolation and move the soil particles down slope.

This finding corroborate the assertions of Akpokoje *et al* (2006) that plasticity is the main factor that affects the loss of soil strength. Furthermore, the results also show that the soil in the gully erosion area are prone to instability due to their nature and can easily lose their strength when under the weight of water, which generally will lead to erosion. Soils with such low angle of internal friction are coarse, gravelly pebbles usually sandy soil. Soils with low angle of internal friction have low bearing capacity and slope instability. If the slope on the leeward side of topography becomes steeper than 30˚ to 35˚, the slopes becomes unstable and sand grains will roll down the slope until another angle of repose is reached. Other than the topography, the angle of repose which represents the angle of internal friction or shearing resistance in its loosest state depends on a number of factors such as the soil texture and structure, so an area with gently to steep topography, high bulk density with coarse texture soil (which are usually non-cohesive) are highly susceptible to erosion which gives credence to the very high density and rate of erosion in the study area.

Average bulk density of the area is 1.7g/cm^3 Obasi and Ijeoma (1991); Hudec *et al.*, (2006) and Onu, (2011) have reported similar result for the area. The standard measurement for bulk density is 1.6g/cm^3 when soil bulk density is above this limit it tends to hardened up the soil. There are two possible scenarios that can result from this: first, the compaction will lead to cracks on the soil surface during the Dry season and during the rainy season, these cracks will form the channels for water to flow and since most of the underlying geology is gravely and poorly sorted, erosion will begin to occur by the formation of rills, incipient gullies and gullies a process scientifically known as Liebig's minimum.

Secondly, when the underlying formation is shale or lateritic, as a result of the leaching of silica in the sand alongside sodium, potassium and calcium by percolating water; iron, aluminum oxides and hydroxides stay behind, the clay mineral will swell, increase in volume, become plastic and cover the pore spaces preventing percolation and infiltration resulting in excessive overland flow and at a threshold velocity of 3.0 – 3.5cm/s cause the soil to slide because it is saturated and weakened. In areas where sand and shales are the dominant geologic formation the sands are unconsolidated, loose, friable and poorly cemented with thin shale layers. The sands are very permeable while the shales are not, such that during the wet season, the high permeable sandy formation receives sufficient water from surface runoff which causes the water table to rise resulting in high groundwater flow rates saturating the sands and shale formation below the water table affecting their strength. During the dry season, the water table falls as a result of hydraulic head decay, this produces decreased flow rates, and an increase in the depth of the unsaturated zone, according to Akpokodje *et al.,* (1986); Okagbue & Ezechi (1987); Okagbue, (1988), and Hudec *et al.,* (2005) in areas, where there are overlying lateritized soils the less permeable clay layers are lubricated and saturated with water. The clays subsequently expand and lose their shear strength, the behaviour of the interbedded shales, which undergo large changes in volume as a result of alternate wetting and drying, enhance the gullying.

The study area has 97% sand texture. The mean effective size is 0.177, coefficient of uniformity 3.458 and coefficient of curvature 0.316. This is indicative of coarse grain (medium – fine). Coarse grain soils have little to no binding materials and as such allow quick passage of water which ultimately enhances sediment transportation. This finding tallies with the report of Imasuen *et al.,* (2011). The sandstone units are porous and permeable and have less "fines' than the clay/shale units. Water infiltrates and flow through the top soil and sand units readily but get trapped in the sand/shale interface. The clay/shale units' serves as barriers to downward water flow and therefore confine water to certain sand units which creates two undesirable conditions, namely: excess overland flow (runoffs) and high pore-water pressure build-up in the sands.

This excess overland flow subject the thin soil horizon to stress and sooner or later breaks the thin and fragile soil horizon thereby initiating soil erosion. The entrapped water in the porous and permeable loose sands (low in "fines" which ordinarily serves as cementing materials) leads to high pore-water pressure build-up. This is in turn leads to low shear strength of the interface and reduce the shear resistance at this boundary and cause the surface to be slippery and finally results in the sliding and slumping of the sand units. Keller (1978) ascribed the real cause of most translational slide to the potential of materials to slide upon long weak, clay layers and not to the immediate heavy rains which saturate the earth material. Egboka and Okpoko (1984) had earlier established this fact for gullies in Anambra State.

Topography (Elevation & Slope): In the study conducted by Ofomata (1987), relief accounted for about 26% of variation in the cause of erosion in the whole of south eastern Nigeria. In the present study Topography (Slope and elevation) were finger printed alongside shear strength to contributing 80.1% variation in the development of gully erosion profiles. For Njaba/Lower Orashi p-value is .001 while the adjusted R^2 with five other variables accounted for .880. The length and shape of the slope are main topographic factors which influences soil erosion. The general tendency is for sheet erosion to be common over fairly uniform and gentle slopes while gullying is expected to be more characteristic of steeper slopes, it is known however, that gullying also takes place on gentle slopes and even more common on such gentle slopes than on very steep slopes. Runoff requires such gentle slopes to be concentrated, and concentrated runoff is a prerequisite for gullying. Slope gradient greatly influences flow velocity and hence the kinetic energy of the runoff. However, for the flow velocity to cause scour and incision depends largely on the influence of the underlying lithology of the area.

5 Conclusion

This study compared the contribution of various soil erodibility factors in the formation of gully erosion channels in the study area. The study showed that gullies in Njaba sub-basin fall into two major soil groups. Sandstones of lignite and shale in and around Njaba and the Alluvium soil formation in and around Awomama and Oguta area. The gullies in Njaba are deep and sharp despite the presence of shale because the area is a transition zone between Bende-Ameki and the Benin Formation. Six Erodibility factors were identified to have contributed in great measure to the formation of gully channels. Shear strength accounted for 63.0% of all the variance that predicted gully size in the study location, followed by Soil consistency. The six Erodibility indices include Shear strength, Soil Consistency, bulk density, elevation, slope and dry density accounting for 92.0% of variance in the development of gully erosion channels across Njaba watershed. The study further showed that slope and Shear strength had the strongest individual relationship in determining gully size, closely followed by dry density. We anticipate that any control work to be done in the area should take cognizance of the factors highlighted in this study for effective result

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