Relationship between Soil Erodibility, Rainfall Erosivity and Geotechnical Parameters for Soils in Gully Erosion Sites in Urualla, Imo State, Nigeria

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Abstract: ***The purpose of this paper was to determine the geotechnical properties of soils in gully erosion sites in the study area and relate them to the soil erodibility factor for the area. Samples were collected from erosion sites. Values of liquid (LL) limits varied from 29.1% to 38% while plastic limits(PL) ranged from 14.0% to 18.1% and plasticity index(PI) went from 14.3 % to 18.2% for the samples. These values are reflective of silty soils. Particle size analysis showed that fine sand /silt dominate the entire size population. The soils are not cohesive and have low shear strength. The soil erodibility factor, k for the area is greater than 0.4 which shows high erodibility. This factor also correlated with the silt/fine sand soil population. Results also show that the study area has high rainfall erosivity hence making it very susceptible to erosion. The study shows the need to relate geotechnical properties to soil erodibility investigations.***

Keywords: Urualla; gully erosion sites; soil erodibility; geotechnical parameters; rainfall erosivity

1. Introduction

Soil erosion isa menace all over the world. Wherever it occurs it leads to loss of lives, disruption of infrastructure, destruction of the aesthetics of landscapes, geomorphological modification, negative impacts on agriculture and reduction of land suitability for various applications. Ouyang and Batholic (2001) considers it to be a major global environmental problem that causes sedimentation and generally increases the potential of flood occurrence.

The challenge for soil scientists, geomorphologists and geologists is to predict the susceptibility of soils to erosion in order to prevent it but in many parts of world this has not been the approach. Gobin et al (1999) in assessing soil erosion at the Udi-Nsukkacuesta of southeastern Nigeria noted that the relevant authorities use the crises approach in managing soil erosion. A more effective approach would have been to study various soils in the region, establish their susceptibility to erosion and put preventive measures in place.

When soil scientists estimate the susceptibility of a soil to erosion, theyuse the term “soil erodibility”. Erodibility relates to soil susceptibility to erosion and therefore depends on soil structure and stability. It is also a measure of the soil’s ability to resist the forces of runoff. Hjulstrom(1939) was the first to study the erodibility of materials in canals. He found that water velocity and soil particle diameter were relevant in determining the erodibility of a soil material. The concept of water velocity helping to make a soil material erodible can be applied to the concept of erosivity.Erosivity is a measure of the aggressiveness of a rainfall event. Very erosive rainfalls are those rainfall events with high kinetic energy capable of moving soil particles from one location to another.The concept of rainfall erosivity as an erosion catalyst and predictor of erosion risk has been applied in some parts of Ghana (Baffour et al, 2012), in the Africa continent by Vrieling et al (2014) and in Europe by Panagos et al, (2015).

The study of erosion by soil scientists has been focused largely on estimating soil erodibility and rainfall erosivity. While erodibility deals with soil texture and structure, erosivity deals with measuring the kinetic energy generated by rainfall events. In estimating erodibility, it is customary to use the USLE (universal soil loss equation) or its modified form known as RUSLE (Revised Universal Soil Loss Equation). These two equations (given as equations 1) usually estimate erosion in terms of number of tonnes of soil removed per acre per year from a particular plot size. The Universal Soil Loss Equation is given by

$$E = R * K * S * L * C * P \quad (1)$$

where E = Erosion prediction equation or Soil loss in tonnes per acre per year

R = Rainfall erosivity index. This is actually the kinetic energy of rainfall events

K = soil erodibility factor

L = Slope length factor

S = Slope steepness factor

C = Plant cover. If the land is devoid of grasses or vegetation, it will be assumed to be1 where there is a forest, it is 1/1000 but if it is a soil with grasses it is 1/100.

P = Specific erosion control practices factor. It ranges from 1 for bare soils to 1/10 in areas with ridges or gentle slopes.

Very often, though equation 1 is called a universal equation, it cannot be applied universally due to the fact that different parts of the world would normally have different vegetation covers; different kinds of slopes and complex topographic features. For this reason, those who use it have to create a “correction factor” (f) which modifies it to suit the topographic, vegetative and erosivity factors of the chosen study area. When the “f” factor is introduced into a particular area, equation 1 becomes the Revised Universal Soil loss Equation.

$$E = F * R * K * S * L * C * P \quad (2)$$

where f = correction factor and all the other terms have their usual meanings.

Soil erodibilty factor, K can be estimated from either equation 1 or 2 but it is pertinent to observe the absence of geotechnical parameters from these equations. This means that it will not be possible to predict or determine erodibility by simply checking the soil classification schemes offered by geotechnical engineers. FAO (2013) laments that there is no relationship between soil erodibility and the current soil classification schemes. This is unfortunate because erodibility which deals with a soil susceptibility or resistance to erosion in reality should relate to the geotechnical properties of the soil. Geotechnical properties of soils include their sizes, shapes, moisture contents, plasticity, shear strength etc. All of this should define soil structure and perhaps help determine the soilerodibility of the rainfall erosivity factor and other factors in place.

The aim of this paper therefore is to determine the geotechnical properties of soils in gully erion sites at Urualla, Imo State Nigeria and check if they correspond to the soil erodibility and rainfall erosivity characteristics of the area. Such a correspondence should lead to the integration of geotechnical properties into soil erodibility calculations in the future. It should be possible in future to predict areas with high erosion risks based on these concepts.

2. Study Area

(i) Location

The study area, Urualla is situated between latitude 5^0 50'N and 5^0 55'N and longitudes 7^0 00'E and $7^0$05'E (figure 1) covering an areal extent of about 85 square kilometers. It has an estimated population of about 10,000 people and serves asthe headquarter of Ideato North Local Government area in Imo State, southeastern Nigeria. It is bordered by Obodoukwu, Akokwa and Isu. All these towns are semi-urban, agricultural and all have varying degrees of gully erosion problems. Gully erosion is the greatest environmental problem in this part of southeastern Nigeria. Grove (1951); Obi et al. (1989); Ezechi and Okogbue (1990); Idike (1992) and Igwe et al. (1995) have studied extensively on gully erosion disasters in other parts of southeastern Nigeria. Gobin et al (1999) identified three major erosional features in the region as ravines, gullies and rill erosion while Onu et al., (2012) include the study area as part of the "gully erosion belt" of southeastern Nigeria.

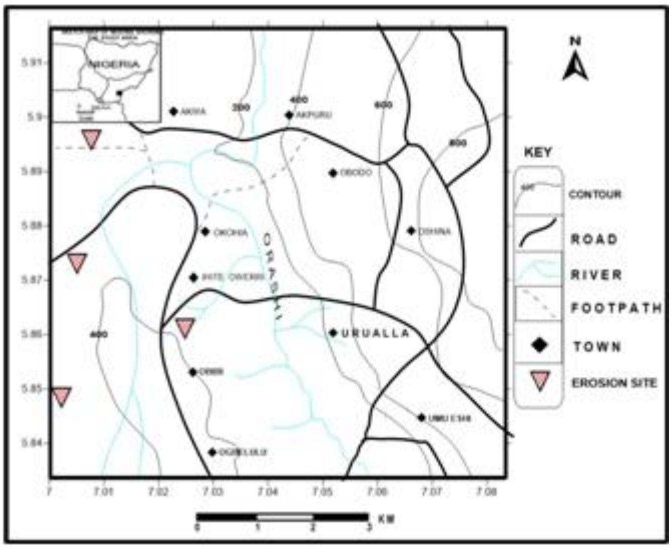

Figure 1: Topographic map of Urualla and environ

(ii) Physiography, Climate and Vegetation

Urualla has a gentle undulating topography. The highest points range from 80m-100m above sea level. Two major rivers drain the area and they are: the Imo River and Kwa Ibo River. The major climatic conditions are the wet season (from April to October) and dry season (from November to March).The vegetation falls within the tropical rainforest of eastern Nigeria (Igbozuruike, 1975). Presently deforestation due to bush burning and urbanization is gradually giving rise to the presence of equatorial savanna vegetation (Guinea Savanna) in the area (Angassa, 2012). This savanna bears luxuriant grasses but with reduction in the tree population.

(iii) Geology and soil characteristics

Figure 2 shows the geologic map of Urualla. Urualla is underlain by Bende/the Ameki Formation (Eocene) which is part of the Anambra basin. The basin comprises clastic deposits ranging in age from Campanian to Recent. It is part of the Ameki Group which comprises Ameki formation, Nanka Sands and Nsugbe Formation. These rocks consist of siltstones, fine to coarse sands with lenses of calcareous shales (Nwajide, 2013). Arua (1981) described the following as members of Ameki formation: pebbly sandstone, silty sandstone, shale and clay, but in the study area, only medium to coarse grained sandstones were seen. The medium to coarse grained sandstone is overlain by silty sandstone. Both units have colours ranging from reddish brown to whitish at lower horizons. All the units dip 5^0 - 8^0 west. Two soils are in the area. These are arenosols and rhodicferralsols. All the erosion sites are located within the arenosols. Gobin et al (1999) states that arenosols are more susceptible to erosion than the ferralsols.

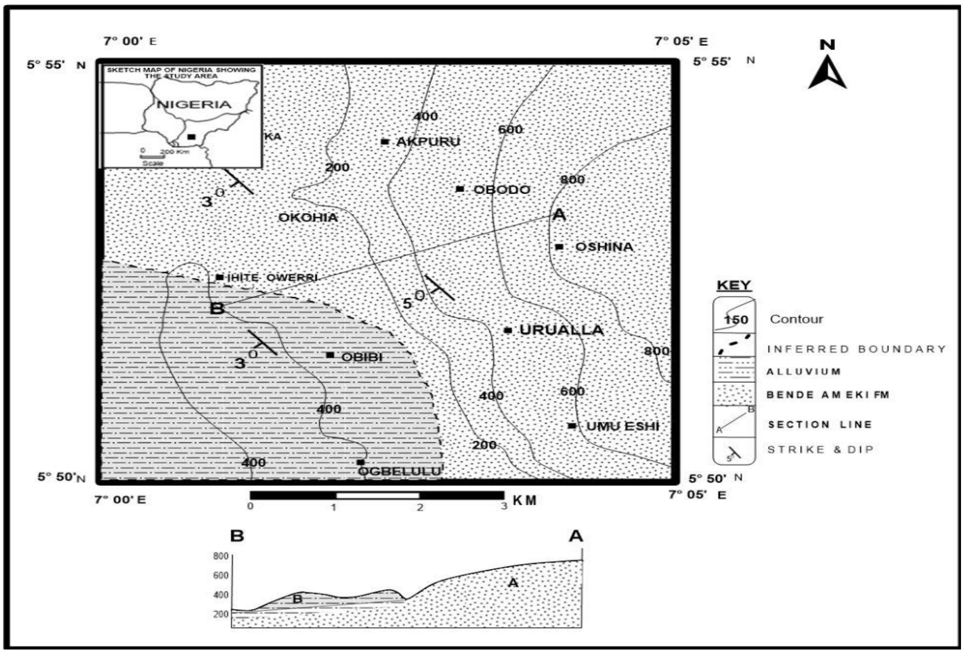

Figure 2: Geologic map of the study area

3. Materials and Methods

Desk, field and laboratory studies were used. Desk studies involved gathering all available published and unpublished works on the area in order to obtain sufficient background information on Urualla. Field work involved identification of major gully erosion sites and discussions with affected community residents and collection of soil samples from the erosion sites. Soil samples were collected from the gully erosion sites using the protocol established by Spangler and Handy (1973). After the sampling, a number of geotechnical tests ranging from particle size analyses, Atterberg limits (eg plastic limits and shrinkage limits), compaction and shear strength tests were conducted on the samples using the procedures developed by American Society for Testing Materials (ASTM) and the British Standard Methods for testing soils or Civil Engineering applications (B.S., 1377 - 1990).

4. Results and Discussion

Table 1 shows the geotechnical properties of the soil samples taken from gully erosion sites at Urualla.The values of liquid limits for the area ranges from 29.1% to 36.0% which correspond to silt values. The plastic limits vary from 14. 0% to 18.1% while the plasticity index varies from 14.3% to 18.2%. The Atterberg Limits of soils include the liquid limit, shrinkage limit and plastic limit.

These limits basically try to determine the water contents of fine grained soils and also help to distinguish between silt and clay. When the water contents of these soils exceed these values, the soil will flow like a liquid. It is obvious that the saturated hydraulic conductivity of these soils will increase during intensive rainfall events. This will increase the water content of the soil and make it more erodible. Hence there is a connection between rainfall erosivity, saturated hydraulic conductivity and these Atterberg limits.

Table 1 also includes the results of particle size analysis in the form of coarse sand, medium sand and fine sand percentages. The dominant size is fine sand which has between 50% - 56% of the particle sizes population.

Table 1: Geotechnical parameters of soils at gully erosion sites in Urualla

Parameter		*Oshina*	*Obodo*	*IhiteOwerri*	*Obidi*	*Ogbelul*	*Akpuru*
Liquid Limits L. L. %		32.4	29.1	36.7	35.1	36	31.1
Plastic Limits P. L. %		18.1	14	18.5	18	18.1	16.3
Plasticity Index P.I %		14.3	15.1	18.2	17.1	17.9	14.8
Particle Size	Coarse Sand %	12	10	13	14	12	11
	Medium Sand %	24	27	23	24	22	26
	Fine Sand %	53	51	54	56	55	55
Dry Density g/m^3		1.89	1.85	1.92	1.89	1.81	1.89
Max. Dry Density g/m^3		1.91	1.91	1.93	1.92	1.91	1.91
OMC% Optimum Water Content		12.5	12.9	13.1	13.5	13.3	12.7
Water Content %		7.4	9.7	11.9	11.5	13.7	13.6
Cohesion (KN/m^2		20	20	15	13	10	1.9

According to Hjulstrom, fine sand is the easiest to be removed by runoff. It isestimated that 20.2% of the precipitation from the Urualla catchment area drainss off as runoff. The high energy of runoff in the area would remove most of the silt/fine size populations of the Urualla soil hence increasing its erodibility. Although the plasticity indices (P.I) for these soils is greater than 5, FAO (2013) has shown that fine sands are highly susceptible to internal erosion (piping) because they have large pores and also lack the necessary cohesion to keep the particles together. The values of dry density range from 1.81g/m^3 to 1.92g/m^3 while maximum dry density values go from 1.91g/m^3 to 1.93g/m^3. The optimum moisture content goes from 12.5% to 13.5% and is consistent with soils containing a mixture of sand – silt – clay particles which easily yields to erosion. The cohesion values range from 10KN/m^2 to 20KN/m^2 which again corresponds to silty – loam soils. From these geotechnical parameters of Urualla soils, it is clear that they have low shear strength.

A modified form of the USLE equation was used to compute the average soil loss in Urualla per year. This is given by equation 3:

E = R*K*L*S*C*P (3)

where A = Estimated average soil loss per acre per year.

R = Average rainfall for the previous 20 years

K = Soil erodibility factor

L = Slope length factor

S = Slope steepness factor, usually this is the same as the dip amount

C = Management factor (Organic manure)

P = Support practice factor

Evaluation of equation 3 led to 2002 tons per acre per year as the average soil loss in Urualla and a K (i.e. soil erodibility) value of 0.4. This shows that the volume of soil lost every year to erosion in Urualla is very high. It has been established that soil erodibility can be influenced by rainfall factors like size of rain drops, rainfall intensity, duration and even speed of run off (Gobin et al, 1999; Obi and Salako, 1995).

From the works of Lal and Elliot (1994) and Gonzalez-Hidalgo et al.,(2007), it is clear that the soil erodibility and the erosivity of rainfall play significant role in the creation and sustenance of gullying processes. This view is supported by Baffour et al. (2012). While erodibility is a function of the soil structure and use, erosivity deals with the aggressiveness of rain and its ability to initiate erosion. In measuring erosivity,

the physical dimensions of rain drops become relevant. Obi and Salako (1995) measured physical dimensions of rain drops in Nsukka, another town in southeastern Nigeria that is also prone to gully erosion and found that medium raindrop sizes ranged from 1.1 to 2.9mm during the very erosive months (between May and August). In other words, the aggressiveness of rainfall events also promote erosional processes. A modified version of the Fournier index used in Baffour et al. (2012) was used to estimate rainfall erosivity for Urualla. Rainfall at the study area peaks between May and September (Ofomata, 1985). Values obtained by the evaluation of equation 4 for Urualla range from 75mmh^{-1} to 126 mmh^{-1} which far exceeds the 25mmh^{-1} threshold value suggested by Hudson (1981). In other words, Urualla by virtue of its rainfall erosivity has great risks of erosion. The rainfall erosivity for Urualla was estimated by using equation 4.

Cp =P^{2}max/P Where Cp = Fournier index (mm)

Pmax = rainfall amount in the wettest month (4)

P = annual precipitation (mm)

If the values of the geotechnical results are integrated with the soil erodibility factor, K = 0.4 and erosion risk due to rainfall erosivity as summarized in table 2, it is then clear that gullying processes in Urualla are inevitable. Again, the table shows that K >0.4 which is common in silty soils. Plate1 shows the various erosion sites in Urualla.

Table 2: Relationship between erodibility, soil type and grain size

K –factor value	Erodibility	Soil Type	Grain Size(mm)
→ 0. 4	High	Silt	0.016 – 0.062
0.25 – 0.4	Moderate	Silt - loam	0.004 – 0.016
0.05 - 0.2	Low	Sandy soil	0.062 – 1.19
0.05 – 0.15	v. low	Clay	0.001 – 0.004

Plate 1: Various erosion sites in Urualla, Imo State

5. Conclusion

Urualla and environs are underlain by rocks and soils belonging to the Eocene Ameki Formation. The soil cover over the geologic formation range from Arenosols and rhodicferralsols. Arenosol soils host the major gully erosion sites in Urualla. Geotechnical properties of the soils, soil erodibility and rainfall erosivity values determined for Urualla have shown that the soils are highly susceptible to erosion. It is therefore suggested that future studies of soil susceptibility to erosion should always integrate geotechnics with concepts of erodibility and erosivity in order to achieve a deeper understanding of the problems of gully erosion. This integrated approach will provide a better framework or preventing the formation of deep ravines and gullies that are ravaging southeastern Nigeria and perhaps save more lives and properties.

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