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RESEARCH ARTICLE

The Underlying Factors of Soil Susceptibility to Erosion in Central Parts of Southeastern Nigeria

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ABSTRACT

Soil erosion in southeastern Nigeria has a high devastating tendency which created a natural geologic hazard is causing loss of arable farm lands, destroying properties and other social infrastructures like pipelines, roads, bridges, over head and underground cables that are being exposed and or washed away by deep gully erosions. Investigations into the underlying factors of soil susceptibility to soil erosion in southeastern Nigeria led to this work. The study areas are the twenty six Local Government Areas within the centre of the zone which are Anaocha, Orumba North, Aguata, Nnewi South and Orumba South in Anambra State; Umunneochi, Bende, Ohafia, Arochukwu and Isuikwuato in Abia State; Afikpo North, Afikpo South, Ivo, Ohaozara and Onicha in Ebonyi State; Aninri, Oji River, Ezeagu, Udi and Awgu in Enugu State, and Idea to North, Idea to South, Okigwe, Orlu, and Orsu in Imo State. The dataset for this research work are from secondary and primary sources. Secondary Data were extracted from other journal publications among others, while primary data were in the form of measurement during field visit, photographs and geophysical soil survey and verification. Descriptive Statistics, Student t-test and Chi-square test analysis were used. The result shows that the soils across the study area generally are predominantly sandy with a mean of fine sand at 28.22% and coarse sand at 43.40%, while the mean of clay and silt are very low, 17.82% and 10.56% respectively. The study concludes that high sand content in the composition of soil in the study area is responsible for high rate of soil erosion in the area and therefore recommends a policy framework from the government of Nigeria that will encourage a paradigm shift from roots and tubers crop production that exposes the soil, to orchard plantation.

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Introduction

Soil erosion in southeastern Nigeria has a high devastating tendency which created a natural geologic hazard is causing loss of arable farm lands, destroying properties and other social infrastructures like pipelines, roads, bridges, over head and underground cables that are being exposed and or washed away by deep gully erosions (Emeh and Igwe, 2018).

Soil erosion is a geomorphological process where soil and loosed rock materials are being carried away, transported and deposited by running water elsewhere. Its action is devastating to the extent that houses, agricultural land, properties and other economic valuables are swept away (Emeh and Igwe, 2018). The rate of occurrence of soil erosion in southeastern Nigeria is devastating and has formed subject of research as recorded by authors like Skyes (1940); Groves (1951); Ologe (1971, 1973); Ofomata (1964, 1965, 1981a, 1981b, 1985); Igwe (2012); Ndulue, et al,

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(2021); Ayadiuno and Ndulue (2021). With growing population in the study area, continuous urbanization of rural areas and deforestation to pave way for development, land surfaces of the study area have been sculped and eroded severely. Efforts by Government, individuals, communities and donor agencies to curb the menace are still inadequate (Ocheli, Ogbe, and Aigbadon, 2021).

Several erosion types exist in the area such as rill, splash and gully as enunciated by Ofomata (1985) and other scholars like Ologe (1971, 1973); Jeje (1978); Sada and Omuta (1979); Ndulue, et al. (2021); Ayadiuno and Ndulue (2021) among others who carried out related studies in different parts of Nigeria on soil erosion. Gully erosion is the most conspicuous type of soil erosion and leaves its imprint on the soil surface. Sheet is the most pernicious type and very damaging to agricultural activities in the study area (Ofomata, 1985). Ofomata (1985) remarked that about 1.6% of the entire land area of southeastern Nigeria is occupied by erosion activities. These sites are scattered all over the area including the infamous Agulu-Nanka erosion sites, Ozuitem, Oko, Orlu, Arochukwu, 9th Mile Nsude and Onicha erosion sites to mention but a few.

The rate of occurrence of these gullies are more pronounced at the fringe of the urban areas especially in unpaved surfaces that serves as flow channels for urban runoffs. Before now, formation of gullies was attributed to geology, geotechnical properties and geochemical composition of the underlying soils (Peng & Sun, 2015).

The aggregate stability of soil in water is one of the major factors determining soils susceptibility to water erosion (Egashira, Kaetsu and Takuma, 1983; Igwe, 2005; Ayadiuno and Ndulue, 2021). The interaction between soil and water is as a result of chemical composition of the soil aggregate, water polarity and the chemical composition of the prevailing aqueous solution. Prove to this assertion was provided by Arlauckas, Hurowitz, Tosca & McLennan (2004), Peng & Sun (2015) on dissolution of iron oxide which was revealed to be dependent on hydrogen ion concentration of the dissolving solution. Several researches on environmental pollution by Kjeldsen et al (2002), Aluko Sridhar and Oluwande (2003), Tiwari, Manoj and Bisht (2007), Hill (2010), Efe and Mogborukor (2012) and Okengwo et al (2015) have revealed that the presence of chemical compounds causes deflocculation, dispersion and dissolution of soil aggregate in rain and run off samples.

The power of the rain to erode is called rainfall erosivity. Rainfall attribute is linked to its physical characteristics such as the amount, drop size, distribution, duration, intensity, velocity and kinetic energy (Salako, 2003). The quantity of rainfall is measured in unit of depth (mm). The amount of rainfall and how long it fall influences infiltration and overland runoff. Problems of flooding and soil erosion are basically related to amount and duration of rainfall and the soil strength and ability to hold runoff (Ayadiuno and Ndulue, 2021).

Soil erosion is one of the very most important environmental challenges that are responsible for land degradation, poor water quality, stream water pollution and flooding (Odunuga, et. al., 2018). According to these authors, more than 10% of land resources in Nnewi South L.G.A are already lost to erosion. Soil erosion is increased due to the decrease in the erosional resistance of the land surface or increase in the erosivity factors acting on the land (Ofomata, 2000). Soil erosion process involves interaction of different complex biophysical and authropogenic factors including soil properties, topography, climatic condition, landuse and management practices. These factors vary both spatially and temporally from one location to the other (Shi, et. al., 2013).

The land degradation as a result of soil erosion is at the detriment of the farmers whose source of livelihood is on farming, and who knowingly or unknowingly have aided the erosion hazard based on the type of crops planted and land use practices applied. According to Odunuga, et. al. (2018) there is also serious implication of erosion on water quality and downstream siltation with great consequences on biodiversity and the ecosystem.

This study however, aims at looking at the soil particles size composition in the study area as the underlying factors of soil susceptibility to erosion. Ayadiuno and Ndulue, (2021) opined that soils across Anambra state shows that they contained more of sandy soil (57-89 %), very low clay and silt (8-23%) and (3-28%) respectively. And that it has been reported by Toy et al., (2002) that soils of such proportion promote runoff and are highly erodible. Evans (1980) was cited also by Ayadiuno and Ndulue, (2021) as reported that soil with clay contents of between 9% and 30% are susceptible to erosion due to its high dispersion rate. “This could explain why the soils in most of the locations in Anambra state are highly erodible and susceptible to soil erosion” Ayadiuno and Ndulue, (2021). The big question is “could that be said about Anambra state in particular or the whole of southeastern part of Nigeria in general”?

Hypotheses 1

Let H_o be that “there is no statistical significant difference in the mean of clay and silt on one hand, and fine and coarse sand on the other put together in the study area”.

Let H_1 be that “there is a statistical significant difference in the mean of clay and silt, on one hand, and fine and coarse sand on the other put together in the study area”.

Hypotheses 2

Let H_o be that “there is no statistical significant relationship between the soil particles size composition and soil susceptibility to erosion in the study area”.

Let H_1 be that “there is a statistical significant relationship between the soil particles size composition and soil susceptibility to erosion in the study area”.

The Study Area

The study area is Southeastern Nigeria comprising five states of Anambra, Abia, Enugu, Ebonyi and Imo. Twenty five Local Government Areas were chosen from these states and they include – Anaocha, Orumba North, Aguata, Nnewi South and Orumba South all in Anambra State;

Umu-Nneochi, Bende, Ohafia, Arochukwu and Isuikwuato all in Abia State; Afikpo North, Afikpo South, Ivo, Ohaozara and Onicha in Ebonyi State, and Aninri, Oji River, Ezeagu, Udi and Awgu are all in Enugu State while Ideato North, Ideato South, Okigwe, Onu-Imo, and Orsu all in Imo State (figure 3). The study area was chosen for reasons of contiguity, similar geological materials with different formations and origin, and all these experience soil erosion though with different degrees (figure 3 and 4).

The study area is located within Latitudes 5°28' - 6°50' N and Longitudes 7°00' - 8°05'E. The total land area covered by the study area is 9018 square kilometers. There is numerous soil erosion sites scattered all over the study area. Some of the erosion sites have received the attention of the Nigerian Erosion and Watershed Management Project (NEWMAP) while others are there ravaging and sculpturing the topography of the host environment. Some of the erosion sites are at Oko, Agulu, Ekwulobia, Nnewi, in Anambra State; Ngwo gully erosion site, Agbaja, Amaekwulu-Abor in Udi and Achi in Oji River, all in Enugu. There are some in Ivo, Onicha in Ebonyi state, Okigwe, Bende in Imo state, Umu-nneochi in Abia state, among others that are scattered all over the study area.

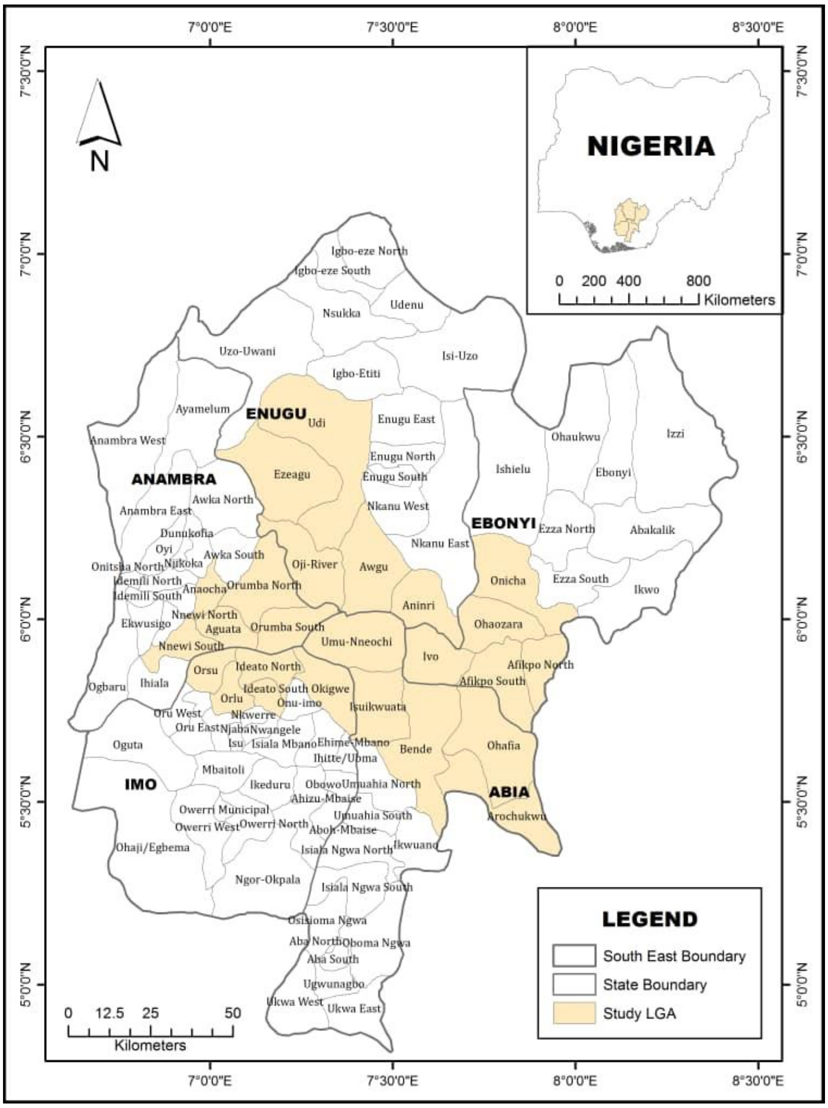

Fig. 1. Southeastern Nigeria and the Study Area
Source: Google earth, Modified by the Authors, (2021).

Climate

The study area has a tropical wet and dry climate (Koppen, 1936). The area experiences two seasons (Wet and dry) which both of them are warm. The mean annual rainfall is between 1800mm and 2000mm (Inyang, 1975; Anyadike, 2002). The rainfall dropsize in our study area is 3.4mm and this plays a significant role in rainfall erosivity of the study area (Salako, 2003). The rainy season starts in April and last till late October, while the dry season lasts from November to March. These rains and associated runoff are responsible for triggering soil erosion. The study area experiences the little dry season called "August Break" (Ilesami, 1981; Ozor and Nnaji, 2011) which occurs between July and August depending on the annual trend as its occurrence varies between these two months. Temperatures in the study area are high and vary between 26°C to 30.5°C with the maximum very close to the start of rainy season. This is as a result of its location close to the equator about 530km (Anyadike, 2010) and regular high solar radiation. Rainfall has power to detach soil particles and also have ability to produce runoff and cause erosion and produce sediment yields as recorded by (Suresh, 2008, Odunuga, et al, 2018).

Relief and Drainage

The land surface of our study area consists of two major land forms – the topographically elevated areas of the Awka-Orlu upland and the low-lying plains. According to Ofomata (2010) the Southeastern states is dominated by plains under 200 metres above sea level. These areas have characteristic trend of topography made up of gradual slow ascent from the east, south and west to the high areas of Nsukka-Okigwe cuesta. The central part of our study area is part of the Cuesta called Awka-Orlu upland with network of rivers, stream and lakes that drain the area. The major rivers include Imo River, Ebonyi River, Orashi, Idemili, Mamu and Aghomili rivers and lakes like Uchu lake, Agulu lake, Otajiri and Vuluvu lakes.

The plains include the undulating lowlands and the Cross River plains. Some of the plains extend to Aninri, Onicha and parts of Oji River. These are generally undulating and underlain by the argillaceous sediments of the lower part of the cretaceous sequence. The Cross River Plain is characterized by a monotonous, rocking type of landscape only diversified by a few sand bodies and isolated igneous bodies (Ofomata, 2009). The plains are generally below 200m above sea level. These plains support agricultural activities in the area. The relief in the study area also contributes to soil erosion especially from the high rising grounds that generate much of the high velocity runoffs.

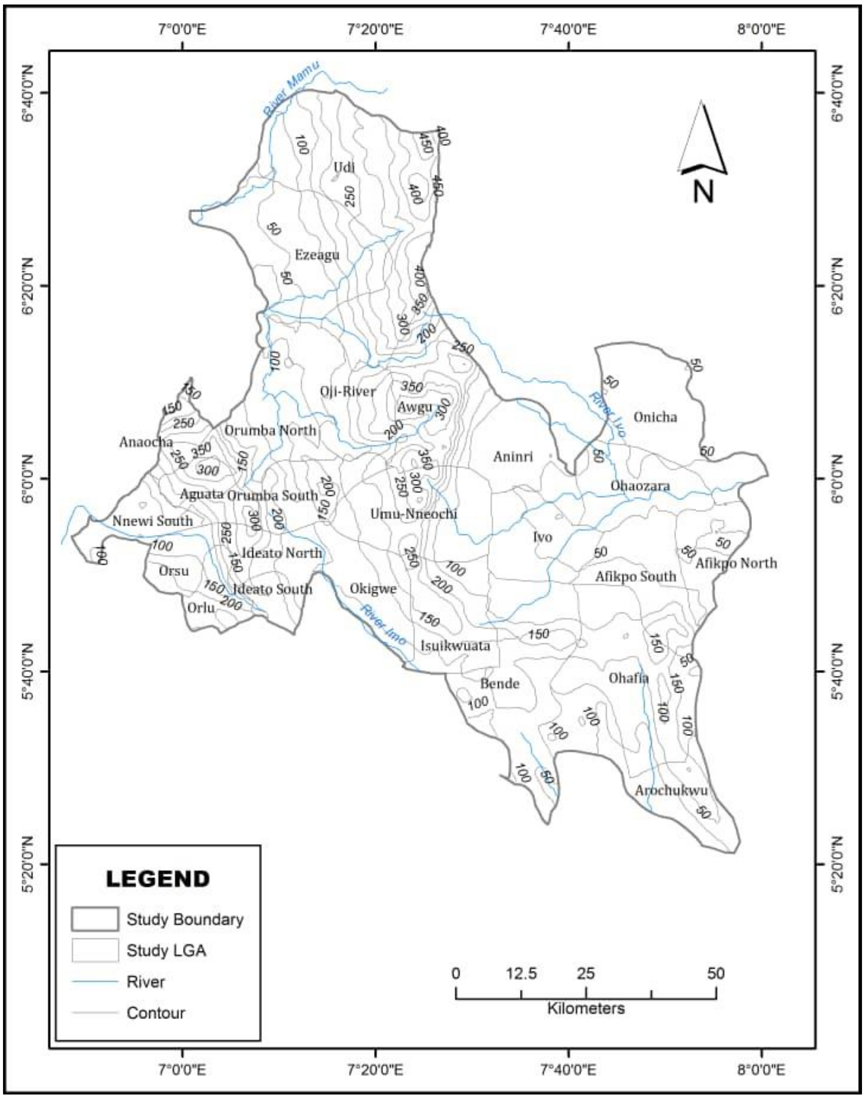

Figure 2. Relief and Drainage of the study area

Source: Google earth, Modified by the Authors, (2021).

Geology

The entire southeastern Nigeria is underlain by sedimentary rocks which filled the Abakaliki-Benue trough (Umeji, 2002). The history of the sedimentation covered three periods of Cretaceous, the Tertiary and Quaternary. The Quaternary period which is the most recent with Alluvium and Fresh water swamps overlying the Tertiary sediments mostly found in the study area. These Tertiary sediments include the Ameki Formation overlying the Imo Shale. The Imo Shales are in turn overlying the Maestrichian formations of Mamu and Ajali (Igwe & Egbueri 2018). Most of the outcrops of these rocks in our study area are unconsolidated sandstones especially the Nanka sands which overlie the Imo Shale in many locations in the study area. The Nanka formation is dominated by a generalized sequence of unconsolidated, unstable, loose, friable and poorly cemented sandstone with intercalating clay/shale layers (Okoyeh et al., 2014; Igwe & Egbueri 2018). These are the main geologic units that are extensively exposed and are being sculptured and ravaged by erosion. These units are part of the sloping Awka-Orlu upland which is over 325m above sea level and aids runoffs. Figure 1 is the geological map of the study area.

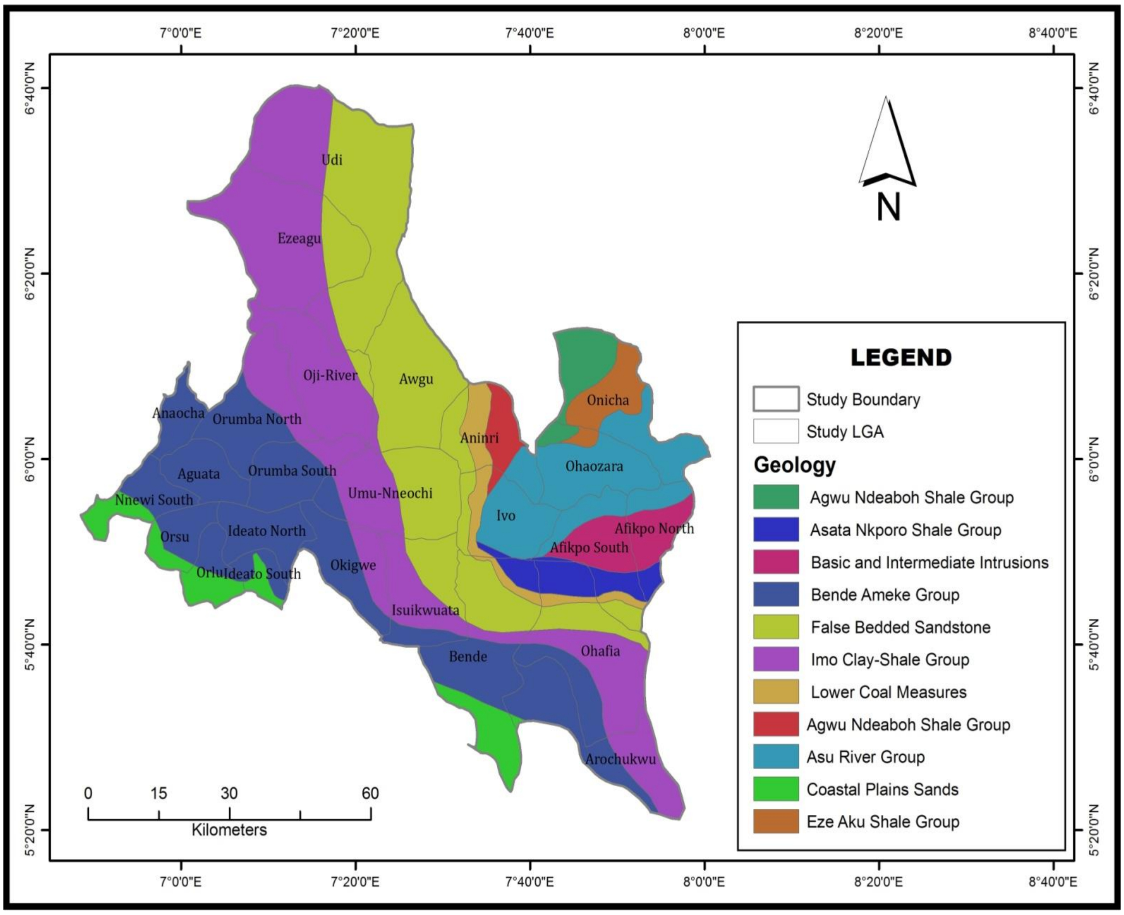

Fig. 3. Geology of the Study Area
Source: Google earth, Modified by the Authors, (2021).

Soil

The soils of the study area are recognized based on the geological formations of the area, their related landscape features, and their degree of profile development (Ofomata, 2010). The soils are of different classes depending on the location. Major part of the study area is made of Lithosols which are shallow and stony soils, and occur on steep slopes where profile development is retarded due to erosion (Jungerius, 1964; Ofomata, 2010). These soils are derived from sandy shales found over parts of the escarpment zone and cuestas of Udi and Awka-Orlu upland in the study area. In other parts, there are relics of hydromorphic soils which are pale brown loamy alluvial soils found in areas around Anambra and Mamu basins. There are other pockets of soils in the study area including the Ferrallitic soils which are red in colour and often used for engineering works.

Vegetation

There are three major vegetation zone that are recognized in Central Southeastern Nigeria and these according to Igbozurike (1975) trending from north to south are Forest-Savanna Ecotone, the Lowland Rain Forest and Rain Forest Savanna. Our study area is dominated by the Lowland Rain Forest, unfortunately most of this zone has been deforested by human activities especially for urban development and now reduced to secondary growth. Parts of our study area also have Rain Forest-Savanna Ecotone at the northern fringes of our study area. There are also pockets of Freshwater Swamp Forest especially along the basins where you have streams or rivers. Among the biomass productivity in our study area, there is over 150 species of plants though these have been decimated by human activities and soil erosion. Dominant grasses in our study area are *Pennisetium purpureum, Hyparrhenium* spp, *Andropogen* spp, whereas the dominant trees include *Ceiba, Milicia excelsa* and *Elaeis guinensis* possibly because of its economic value. There are also other trees like Mahogany (*Khaya ivorensis*) and some epiphytes like *Platycerium microcarpum*.

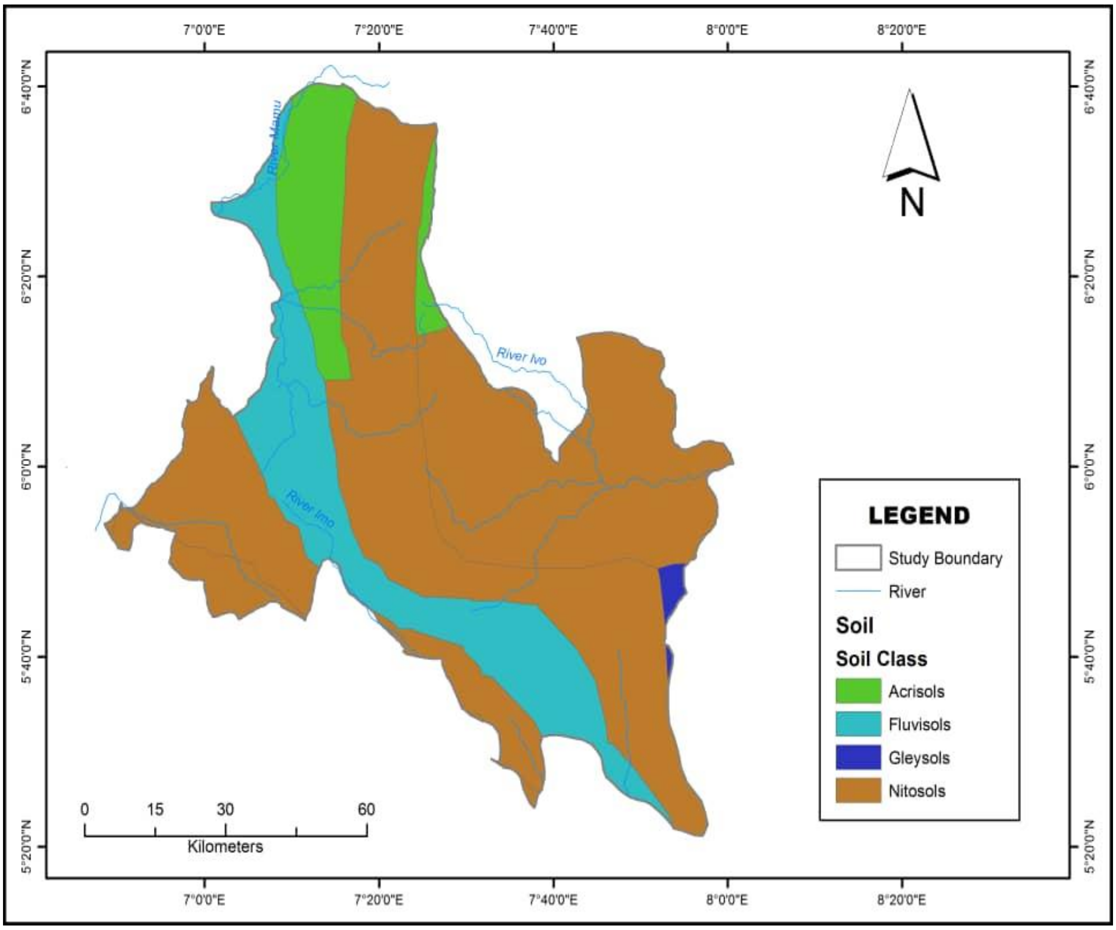

Fig. 4. Soil Distribution in the Study Area
Source: Google earth, Modified by the Authors, (2021).

Materials and Methods

Research Design

This research adopted empirical research survey based on data generated in the field and complimented by the use of Geographic Information System (GIS) and Remote Sensing Technology.

Soil analysis results use in this study were extracted from various researchers like Dim, (2014); Ndulue, Ayadiuno and Mozie, (2021); Ndulue, et al, (2021) and Ayadiuno and Ndulue, (2021) who have done various research works on gully erosion and soil particles composition in the study area. The results were extracted and complied based on the three main soils dominant in the study area which are Lithosols (shallow and stony soils); hydromorphic soils (pale brown loamy alluvial soils) and Ferrallitic soils (red in colour and often used for engineering works).

The soil results (percentage fine sand, coarse sand, silt and clay respectively) were analyzed using Descriptive statistics in Microsoft Excel to determine the mean, mode, standard deviation among others of the soil particles size, Student t-test to test if there is a significant difference between the mean of clay and silt on one hand and the mean of fine sand and coarse sand on the other, and Chi-square test analysis using Student Package for the Social Sciences (SPSS) version 25 to test for the hypothesis.

Methods of Data Collection

The dataset for this research work were from both primary and secondary data sources. Secondary Data pertaining to the factors of soil susceptibility to erosion in the study area were generated and or extracted from unpublished thesis, other journal publications, topographic maps, FAO guidelines, United States Geological Survey, existing soil nomograph, Soil Map of Nigeria and Satellite imageries in addition to analytical tools in GIS and Remote Sensing Technology. Soil results were extracted from published and unpublished literatures of various researchers who had carried out related research in the study area.

There are different physiographic features and soil erosion affected sites and settlements within the study area. This observation was made during primary data collections. Other primary data collected were in the form of measurement during field visit, photographs and geophysical soil survey and verification.

Data Analysis and Discussion

Sixty (60) soil sample results extracted and compiled for this study were analyzed using descriptive statistics and student t-Test in Microsoft Excel; Chi-square test analysis in SPSS and their outputs are presented in the tables and charts below:

Table 1. Table of Descriptive Statistics

Descriptive Statistics	*% Silt*	*% Clay*	*% Fine Sand*	*% Coarse Sand*
Mean	10.56	17.82	28.22	43.40
Standard Error	0.67	1.50	1.57	2.13
Median	10	16	25.55	49.18
Mode	8	11	23	55
Standard Deviation	5.17	11.64	12.20	16.51
Sample Variance	26.73	135.41	148.78	272.58
Kurtosis	1.54	9.77	-0.17	0.53
Skewness	1.10	2.74	0.72	-1.21
Range	23.72	67	51	63
Minimum	3.28	5	6	1
Maximum	27	72	57	64
Sum	633.5	1069.33	1692.9	2604.27
Count	60	60	60	60

Source: Microsoft Excel Output

The table above shows that the soils across the study area generally are predominantly sandy with a mean fine sand of 28.22% and coarse sand of 43.40% respectively, while the mean clay and silt are very low at 17.82% and 10.56% respectively. Various authors have it that, soils with more proportion of sand (fine and coarse) than clay and silt at the topsoil promote high infiltration and runoffs that loosens the binding properties of soil, and therefore makes it susceptible to erosion.

The soil sample results showing the soil particles size composition were rendered in charts, and are also presented below:

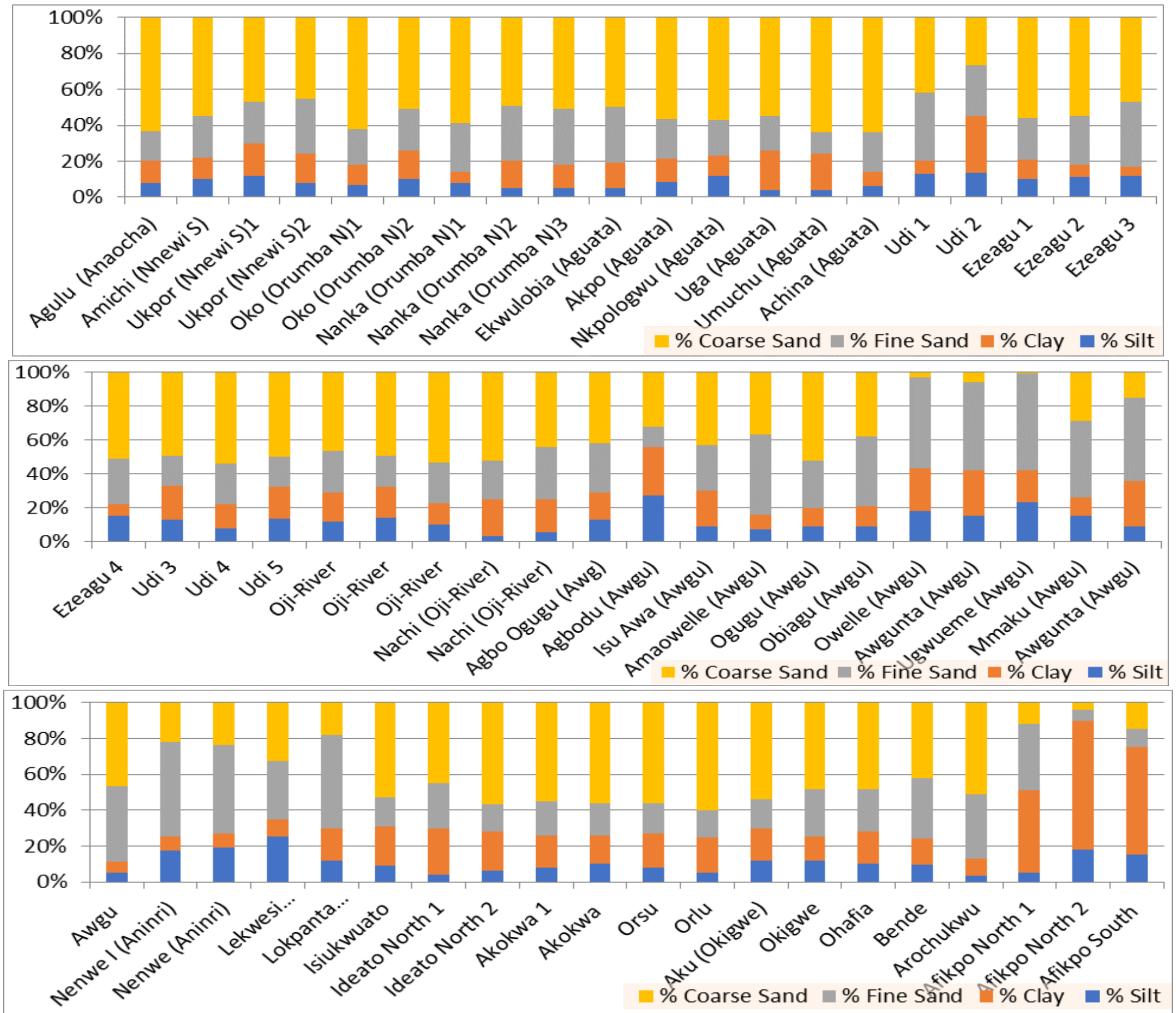

Fig. 5. Soil Particle Size Compositions in the Study Area

Source: Authors' Compilation and Microsoft Excel Output, (2021).

The charts above show the soil particles size composition of the sampled soils in the study area. Percentage Coarse sand is represented in purple, percentage fine soil is represented in vegetal green; percentage clay is represented in red, while percentage silt is represented in blue. These are default colours selected by the Microsoft Excel software used for the analysis. The chart shows the pattern of soil composition in the study area. Soils in Agulu (Anambra state) through to Obiagu (Enugu state) show that they consist of higher coarse and fine sand than clay and silt except in Udi 2 and Agbodu (both in Enugu state), where clay is relatively higher. From Owelle (Enugu state) through to Lokpanta (Abia state), the soils composition there show more of silt than coarse sand, fine sand and clay. Isiukwuato through to Arochukwu have soils composition of higher coarse sand than the others. The soil samples from Afikpo show a different trend where clay and silt are higher than fine and coarse sand in the area, and that may explain the low level or non existence of gully erosion in that part of the study area.

The soil samples generally show high content of coarse sand with a range of 1 – 64; a mean of 43.40%, meaning that coarse sand makes up 43.40% of the soil composition in the study area, a standard deviation of 16.51 and is depicted in purple colour in the chart. The soil samples also show high content of fine sand with a range of 6 – 57; a mean of 28.22%, meaning that fine sand makes up 28.22% of the soils composition in the study area, a standard deviation of 12.20 and is depicted in vegetal green colour in the chart. On the other hand, there are low clay and silt contents in the soil samples. The clay has a range of 5 – 72; a mean of 17.82%, meaning that clay makes up 17.82% of the soil composition in the study area, a standard deviation of 11.64 and is depicted in red colour in the chart. While silt has a range of 3.28 – 27; a mean of 10.56%, meaning that silt makes up 10.56%, of the soil composition in the study area, a standard deviation of 5.17 and is depicted in blue colour in the chart.

Generally, sand (fine and coarse) makes up 71.62% of the soils composition in the study area, leaving clay and silt with 28.38%. This shows that the soils composition in the study area is more of sands than clay and silt put together, hence the natural disposition of the area to gully erosion, all other factors being constant.

Table 2. Student t-Test of the mean of clay and silt put together, and fine and coarse sands

t-Test: Paired Two Sample for Means		
	Clay & Silt	*Fine & Coarse Sand*
Mean	28.3805	71.6195
Variance	181.1057608	181.1057608
Observations	60	60
Pearson Correlation	-1	
Hypothesized Mean Difference	0	
df	59	
t Stat	-12.44386063	
P(T<=t) one-tail	1.91867E-18	
t Critical one-tail	1.671093033	
P(T<=t) two-tail	3.83735E-18	
t Critical two-tail	2.000995361	

Source: Microsoft Excel Output, (2021).

Test of Hypothesis 1

The table above is the hypothesis test for the statistical significant difference in the mean of clay and silt put together, and fine and coarse sand.

The table above shows a Pearson Correlation of -1 which implies inverse perfect Correlation, P-value of less than .05 at approximate 0.00, indicating that the model is significant. The table statistics is -12.44 and a critical value is 2.00 respectively. Since critical value of 2.00 is less that table statistics of 12.44, we reject the null hypothesis which states that, there is no statistical significant difference in the mean of clay and silt, and fine and coarse sand put together.

Test of Hypothesis 2

Chi-square test analysis in Student Package for the Social Sciences (SPSS) version 25 was used to test for the hypothesis that states thus:

Let H_o be: “there is no statistical significant relationship between the soil particles size composition and soil susceptibility to erosion in the study area”.

Let H_1 be: "there is a statistical significant relationship between the soil particles size composition and soil susceptibility to erosion in the study area".

The result is presented in the table below:

Table 3. Hypothesis Test Summary

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The categories of Location occur with equal probabilities.	One-Sample Chi-Square Test	.000[1]	Reject the null hypothesis.
2	The distribution of % Silt is normal with mean 10.19 and standard deviation 5.031.	One-Sample Kolmogorov-Smirnov Test	.000[1]	Reject the null hypothesis.
3	The distribution of % Clay is normal with mean 15.99 and standard deviation 8.179.	One-Sample Kolmogorov-Smirnov Test	.000[1]	Reject the null hypothesis.
4	The distribution of % FS is normal with mean 28.75 and standard deviation 11.540.	One-Sample Kolmogorov-Smirnov Test	.000[1]	Reject the null hypothesis.
5	The distribution of % CS is normal with mean 45.43 and standard deviation 14.705.	One-Sample Kolmogorov-Smirnov Test	.000[1]	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

[1] Lilliefors Corrected

Source: SPSS Output, (2021)

Conclusion and Recommendations

The study concludes that high sand content in the composition of the soils in the study area is responsible for high rate of soil erosion in the area. Soil types and particles determine the use of every tract of land. It has been discovered in this study that the composition of the soil is the major determinant of the degree of cohesiveness and strength vis a vis the stability and erodibility rate. Soils with high sand contents are more stable and good for engineering purposes, even though they are friable, loose and easily detachable. While soil with high clay content discourages infiltration and as a result is always water logged and swollen when wet and shrinks and cracks when dry. Good soil must have the acceptable proportion of particles size, 30 percent and above of clay which will increase the soil bonding rate and encourages soil stability, in the absence of which remediation is very necessary.

Hence, the study therefore recommends a policy framework from the government of Nigeria that will encourage a paradigm shift from roots and tubers crop production that exposes the soil, to orchard plantation. The kind of farming practices been carried out (roots and tubers) in the study area expose the soils bare. Slash and burn should be discouraged and in its place adoption of orchard plantations, since the roots of trees bind the soils and their leaves protects the soil surfaces from rain droplets.

Opening up of soil surfaces and leaving them bare over a long period of time should be discouraged, as this is the case being witnessed in most abandoned project sites that are scattered all over south east and Nigeria at large.

Open bush burning as a traditional method of hunting, and or reducing vegetation growth as well as trimming of trees should be controlled, since these actions in most cases expose the soil surface to erosivity agents.

References

Aluko, O.O., Sridhar, M.K.C., and Oluwande, P.A. 2003. Characterization of Leachates from a Municipal Solid Waste Landfill site in Ibadan. *Nigeria Journal of Environmental Health Research*, 2(1): 32-37.

Anyadike, R.C.N. 2002. *"Climate and Vegetation"*. In Ofomata G.E.K. (ed), A survey of Igbo Nation, African First Publishers Ltd: Onitsha: 56-72.

Anyadike, R.C.N., 2010. *Statistical Methods for the social and Environmental Sciences*. Spectrum Books Limited: Ibadan.

Arlauckas, S.M., Hurowitz, J.A., Tosca, N.J. and Mclenna, S.M. 2004. Iron Oxide Weathering in Sulfuric Acid: Implications for Mars. *35th Lunar and Planetary Science Conference, League City, Texas,* abstract no 1868.

Ayadiuno, R.U. and Ndulue, D.C. 2021. An Investigation into some Soil Indices as Indicators of High Soil Erodibility in Anambra State Southeastern, Nigeria. *International Journal of Modern Agriculture*, *10*(2): 3451-3464.

Dim, L. 2014. *The Impact of Gully Erosion in Uga, Umuchu and Achina in Aguata L.G.A., Anambra State*, Unpublished B.Sc. Project, Department of Geography, University of Nigeria, Nsukka.

Efe, S.I., and Mogborukor, J.O.A. 2012. Acid rain in Niger Delta Region: Implication on Water Resources Quality and Crisis. *AFRREV STECH,* 1(1): 17-46.

Egashira, K., Kaetsu, Y., and Takuma, K. 1983. Aggregate Stability as an Index of Erodibility of Ando Soils. *Soil Science and Plant Nutrition*, 29(4): 493-481.

Emeh, C., and Igwe, O. 2018. Effect of Environmental Pollution on Susceptibility of Sesquioxide-rich Soils to Water Erosion. *Geology, Ecology, and Landscape,* 2(2): 115-126.

Evans, R., 1980. *Mechanics of Water Erosion and their Spatial and Temporal Controls: An Empirical Viewpoint:* In Soil Erosion. Ed. by Kirkby, M.J. and Morgan, R.P.C. John Wiley & Sons, pp 116-122.

Grove, A.T. 1951. Landuse and Soil Conservation in Parts of Onitsha and Owerri Provinces. *Geological survey of Nigeria, Bulletin*, 21: 25-58.

Hill, K.J. (2010). *Understanding Environmental Pollution* (3rd ed). New York, NY: Cambridge University Press.

Igbozurike, M.U. 1975. *Vegetation Types.* In: Ofomata GEK (ed.). Nigeria in Maps: Eastern States. Benin City, Ethiope Pub. House: 146.

Igwe, C.A. 2005. Erodibility in relation to Water-Dispersible Clay for some Soils of Eastern Nigeria. *Land Degradation and Development* 16(1): 87-96.

Igwe, C.A. 2012. Gully Erosion in Southeastern Nigeria: Role of Soil Properties and Environmental Factors, *InTech Open Science*, 157-171.

Igwe, O., and Egbueri, J.C. 2018. The Characteristics and the Erodibility Potentials of Soils from Different Geologic Formations in Anambra State, Southeastern Nigeria. *Journal of the Geological Society of India* 92(4): 471-478.

Ilesanmi, O.O., 1981. Aspect of the Precipitation Climatology of the July–August Rainfall Minimum of Southern Nigeria. Preprints, *N.G.A. Regional Planning Committee Seminar on Urban and Regional Problems in Nigeria,* Ile-Ife, Nigeria, University of Ife, 12.

Inyang, P.E.B., 1975. *Climatic Regions.* In Ofomata, G.E.K (ed.). In Nigeria in Maps: Eastern States, Ethiope Publ. House, Benin City: 27.

Jeje, L.K. 1978. A preliminary Investigation into Soil Erosion on Cultivated Hillsides in Parts of Western Nigeria. *Goe-Eco-Trop,* 1: 175-187.

Jungerius, P.D. 1964. The Soils of Eastern Nigeria. *Publication Service geologique due Luxemburg,* XIV: 185-198.

Kjeldsen, P., Barlaz, M.A., Rooker, A.P., Baun, A., Ledin, A., and Christensen, T.H. 2002. Present and Long-term Composition of MSW Landfill Leachate: A Review, *Critical Reviews in Environmental Science and Technology,* 32(4): 297-336. http://doi.org/10.1080/10643380290813462

Koppen, W., 1936. Das geographische System der Climate IN W. KOPPEN and R GEIGER (ed): *Handchurch de Climatologie,* 1. Part C. Berlin.

Ndulue, D.C., Ayadiuno, R.U. and Mozie, A.T., 2021. Investigating and Mapping the Terrain, and Analysis of Soil Particles in Awgu Local Government Area of Enugu State, South East Nigeria. *Psychology and Education,* 58(1): 5922-5932.

Ndulue, D.C., Ayadiuno, R.U., Mozie, A.T. and Ndichie, C.C., 2021. A Comparative Analysis of Soil Erosion Models for Tropical Humid of Southeastern Nigeria and Comparable Environments. *Psychology and Education,* 58(1): 5821-5835.

Ocheli, A., Ogbe, O.B., and Aigbadon, G.O., 2021. Geology and Geotechnical Investigations of the Anambra Basin, Southeastern Nigeria: Implication for Gully Erosion Hazards, *Research Square*.

Odunuga, S., Ajijola, A., Igwetu, N., and Adegun, O., 2018. Land Susceptibility to Soil Erosion in Orashi Catchment, Nnewi South, Anambra State, Nigeria. *Proceedings of the International Association of Hydrological Sciences*, 376: 87-95.

Ofomata, G.E.K., 1964. Soil Erosion in Enugu Region of Nigeria. *African Soils,* IX(2): 289-348.

Ofomata, G.E.K., 1965. Factors of Soil Erosion in Enugu Area of Nigeria. *Nigerian Geographical Journal*, 8(1): 45-59.

Ofomata, G.E.K., 1981a. The Management of Soil Erosion Problems in Nigeria. *Paper presented at 24th Annual Conference of the Nigerian Geographical Association, Kano,* April 6-10.

Ofomata, G.E.K., 1981b. Actual and Potential Erosion in Nigeria and Measures of Control. *Paper presented at the 9th Annual Conference of the Soil Science Society of Nigeria Owerri,* December 6-10.

Ofomata, G.E.K., 1985. Soil Erosion in Nigeria. The Views of a Geomorphologist. *University of Nigeria Inaugural Lecture Series No. 7,* University of Nigeria Press Nsukka, Nigeria.

Ofomata, G.E.K. 2000. Classification of soil erosion with specific reference to Anambra State of Nigeria. *Environmental Review,* 3(2): 252-2551.

Ofomata, G.E.K., 2001. *Geographical Perspectives on Environmental Problems and Management in Nigeria*, Jamoe Publications, Enugu.

Ofomata, G.E.K., 2009. *Basic Geomorphology for Africa.* Jamoe Publications, Enugu.

Okengwo, O.N., Okeke, O.C., Okereke, C.N., and Paschal, A.C., 2015. Geological and geotechnical studies of gully erosion at ekwulobia, oko and nanka towns, southeastern nigeria. *Electronic Journal of Geotechnical Engineering,* 20: 113-122.

Okoyeh, E.I., Akpan, A.E., Egboka, B.C.E., and Okeke, H.I. 2014. An Assessment of the influences of Surface and Subsurface Water Level Dynamics in the Development of Gullies in Anambra State, Southeastern Nigeria. *Earth Interactions,* 18(4): 1-24.

Ologe, K.O., 1971. *Gully Development in Zaria Area, Northern Nigeria (with Particular Reference to the Kubanni Basin).* Unpublished Ph.D Thesis, University of Liverpool.

Ologe, K.O., 1973. Soil Erosion, Sediment Yield and Water Resource Development in the Savanna Area of Nigeria. *Paper presented at the Conference on Environmental Resource Management in Nigeria,* University of Ife, July, 1973.

Ozor, N., and Nnaji, C., 2011. The Role of Extension in Agricultural Adaptation to Climate Change in Enugu State, Nigeria; *Journal of Agricultural Extension and Rural Development,* 3(3): 42-50. http:// academicjournals.org/

Peng, X., and Sun, H., 2015. Assessing the Contributions of Sexquioxides and Organic Matter to Aggregation in an Ultisol under Long-Term Fertilization. *Soil and Tillage Research,* 146: 89-98.

Sada, P.O., and Omuta, G.E.D., 1979. Auchi Area – A Preliminary Report on Erosion and Environmental Problems and Planning, In: Sada, P.O. and Omuta G.E.D. (Editors) Spatial Perspectives in National Development, *Proceedings, 22nd Annual Conference Nigeria Geographical Association, Beruin,* March 28 – April 1, 1979: 130-152.

Salako, F.K., 2003. Susceptibility of Coarse-textured Soils to Soil Erosion by Water in the Tropics. *Lecture given at the College on Soil Physics, Trieste*, 3-21 March, 2003.

Shi, Z.H., Ai, L., Li, X., Huang, X.D., Wu, G.L., and Liao, W., 2013. Partial Least-Squares Regression for Linking Land-cover Patterns to Soil Erosion and Sediment Yield in Watersheds. *Journal of Hydrology,* 498: 165-176.

Suresh, R., 2008. *Watershed Hydrology*. Standard publishers, New Delhi, India.

Tiwari, S., Manoj, K.S., and Bisht, D.S., 2007. Chemical Composition of Rainwater in Panipat, an Industrial City in Harana. *Indian Journal of Radio and Space Physics*, 37: 443-449.

Toy, T.J., Foster, G.R., and Renard, K.G., 2002. *Soil Erosion; Processes, Prediction, Measurement, and Control*. John Wiley & Sons, Inc., New York.

Umeji, A.C., 2001. The Geology and Mineral Resources of Igboland, In Ofomata G.E.K. (Ed). (2001) *A Survey of the Igbo Nations;* Africana FEP, Onitsha: 50 - 72.

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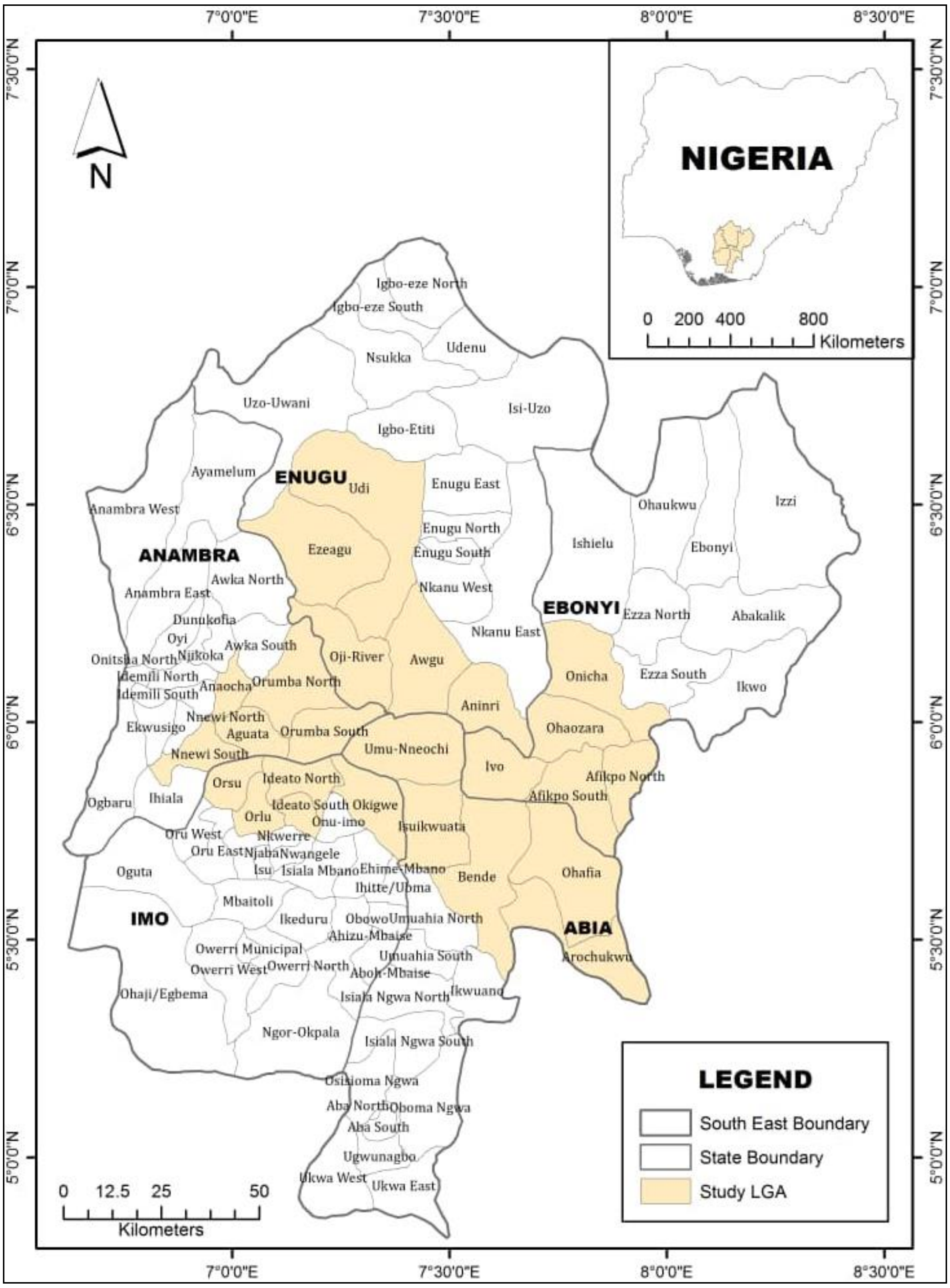
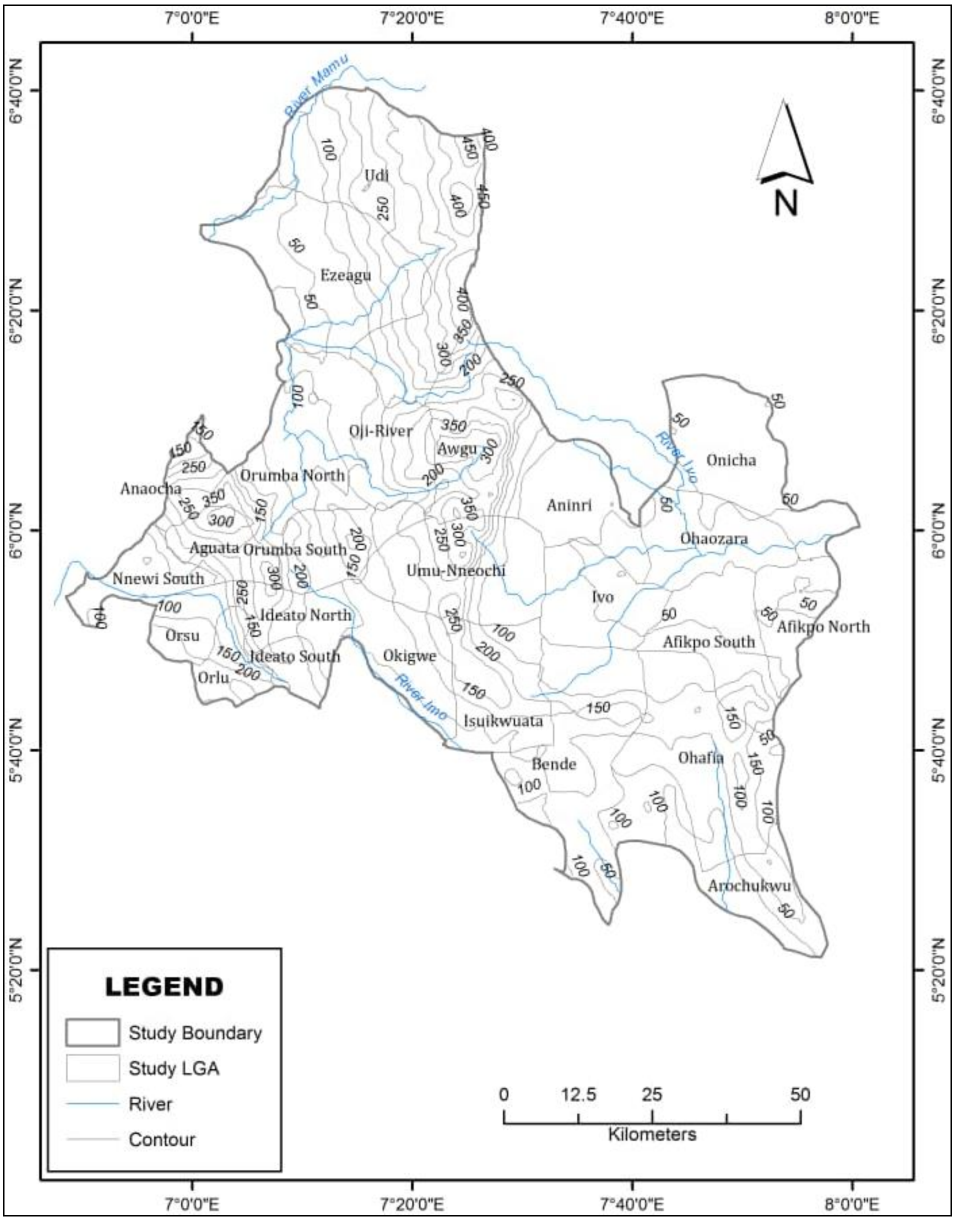
Appendix A



Appendix B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Udi
Ezeagu
Oji-River
Awgu
Orumba North
Anaocha
Aguata
Orumba South
Nnewi South
Ideato North
Orsu
Ideato South
Orlu
Okigwe
Umu-Nneochi
Aninri
Onicha
Ohaozara
Ivo
Afikpo South
Afikpo North
Isuikwuata
Bende
Ohafia
Arochukwu
River Ivo
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LEGEND
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Kilometers