A Comparative Analysis of Soil Erosion Models for Tropical Humid of Southeastern Nigeria and Comparable Environments

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ABSTRACT

The variables of soil erosion in tropical humid of Southeastern Nigeria were observed and measured in forty–two locations in Southeastern Nigeria. The data obtained were subsequently analyzed using the Principal Component Analysis (PCA) to search for the correlation and relationships between and among the variables. The variables are Elevation (X1), Total annual rainfall (X2), Duration of rainfall (X3), Population density (X4), Mean slope angle (X5), Slope length (X6), Percentage vegetation cover (X7), % clay (X8), % silt (X9), % fine sand (X10), % coarse sand, (X11) % moisture (X12), % Area of roof top cover (X13) and Rates of gully side expansion (Y). The correlation coefficients were computed using the Statistical Package for the Social Scientist (SPSS) software version 16. While the topography of the mapped study area as was presented in a three dimensional digital elevation model. The model was created in an ArcGIS software. The calculated correlation coefficients revealed significant relationships between some pairs of erosion variables and their directions. A soil erosion model for the tropical humid environments of the world based on the revealed relationships between the variables was developed and presented for the control and remediation of soil erosion damage in the tropical humid of Southeastern Nigeria and other environments having comparable characteristics as Southeastern Nigeria.

Keywords

Soil, Erosion, Gully, Environment, Model, Tropical, Southeastern Nigeria

Article Received: 10 August 2020, Revised: 25 October 2020, Accepted: 18 November 2020

Introduction

The word erosion means reduction in size (Webster-Merriam, 2006). Soil erosion is the removal of soil particles and soil nutrients by the agents of erosion (Ofomata, 1987). The agents of erosion are flowing water, wind or ice. The dominance of any of these agents of erosion depends on the climatic zone where the erosion is taking place Christopherson, 2006). There are two types of soil erosion. The first type is the gradual type which progresses very slowly and is virtually equal to the rate of soil formation. This type of soil erosion is called *geologic erosion.* It poses no problems for man (Bell, 2000). The second type of soil erosion progresses at an accelerated pace with the result that soil is lost much faster than it is formed is called *accelerated erosion.* This type of soil erosion poses problems to man. It threatens man's source of food, livelihood and destroys man's property and investments (Abegunde et. al., 2003; Getis et. al.; 2011; Dim, 2014).

Literature on the studies of soil erosion, especially gully erosion in Southeastern Nigeria abound and contain some theses on the variables responsible for gully erosion in the study area: Hailey (1935), Stamp (1938) and Grove (1951) proposed the population density, land use intensity and bad land use thesis of soil erosion. Ofomata (1987) advocated the relief- (fragile) geology- dense population and improper land use practices thesis of soil erosion. Egboka and Nwankwor (1985); Akpokodje et.al. (1986, 2010) proposed the geology- geotechnical framework thesis for understanding soil erosion in Southeastern Nigeria. Ijioma (1988) advocated the ecosystem preservation and conservation approach to soil erosion management. Hudec et. al. (2006) explained soil (gully) erosion from the perspective of improper land use and poor runoff management thesis of soil (gully) erosion. Egboka, Nfor and Banlanjo (2006) presented a hydrological cum pedological explanation of soil erosion (gully incision and slope failures) in Southeastern Nigeria. The World Bank (2011, 2014) proposed a runoff driven explanation of soil erosion in the Nigerian Erosion Watershed Management Project (NEWMAP) Obetta, et. al, (2011).

Igbozurike (1993) contended that soil erosion must always occur as a normal process of ground loss and the response of the land surface to the activities of man. It was the view of Igbozurike that once the balance in the soil-slope system has been disrupted by the introduction of any constraint in the system, the system starts adjusting itself towards attaining a new state of equilibrium. The adjustment process continues, until the balance between the land-soil surface and the intensities of the agents of erosion in the environment is restored via the surface attaining the natural angle of repose under which the soil-slope system naturally exists. Surfaces being eroded may sometimes attain equilibrium via natural self adjustment (Ogbukagu, 1976). In most cases however, the equilibrium necessarily needs to be imposed upon the land surface by manipulating the variables of erosion artificially, based on the understanding of their types, the relationships between the erosion variables, their magnitudes and relationships with other variables in the erosion matrix. The imposition of the equilibrium by man is the gully erosion control.

The need for a basis to carry out the artificial manipulation of the erosion system gave rise to the formulation of soil erosion models (Musgrave, 1947; Wischmeier and Smith, 1978). The artificial control of soil erosion is necessary where lives and properties are in danger of being destroyed or have been actually destroyed and lost in various parts of the study area (Ajaero and Mozie, 2010). Ofomata (2001) said that a proper understanding of the erosion processes which include the identification of the relevant variables, the understanding of their relationships and their dynamics is fundamental to containing the menace of soil erosion generally and gully erosion in Southeastern Nigeria. The works referred to above have not been adverted to the promises that a quantitative analysis of the relationships between the soil erosion variables simplifier or an understanding of the relationships between the variables would offer a viable step towards identifying the magnitudes of the relationships between the variables and the rates of soil loss. The quantitative measures obtained can be used to evolve strategies for controlling the menace posed by gully erosion. The import of measurable and precise data in soil erosion control has become necessary because of the increasing global population and the resulting pressure on the land as the world comes to grip with the reality of global food shortages.

Even as the food production dropped and still dropping, the soils are becoming depleted due to land degradation especially through soil erosion. Thus from the first decade of the last century, soil erosion became recognized as a major environmental problem. For example, it took the occurrence of the soil erosion in the Dust Bowl, Arizona, USA in the late 1920s for the American government to encourage her soil scientists to intensify their efforts at finding plausible explanations to soil erosion from field data and experiments. Their efforts culminated in the formulation of models that consisted of the variables of soil erosion, their individual characteristics, magnitudes, and the pathways of their relationships with each other and the prediction of soil loss that would result from their interactions. The detected pathways were presented schematically as models.

Models are representations of the real world being investigated (Ofomata, 2001). They contain only the essential features of the phenomenon being studied. They are tools for simplifying the problems of research. By their nature, models introduce economy into research by directing the energy of the researcher to the significant variables, leaving the relatively insignificant aspects of the research for attention if and when the need later arises for greater elucidations of the subject-matter of the research. The first soil erosion model was put forward by Musgrave (1947) and is stated as follows:

$E= IRS^{1.35}L^{0.35}P^{1.75}$

Where: E is the soil loss in acre/inch; I is the erodibilty; R is the cover factor; S is the slope in percent; L is the length in feet and P_{30} is the maximum 30 minutes rainfall amount, 2 year frequency in inches. Musgrave's (1947) model was followed by the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) which passed various stages of tests before it was finally advertised to the global community of soil scientists. The USLE has been elaborated in textbooks (Hudson, 1999; Brady and Weil 1999) and monographs (Gabriels, 1993). The model is stated thus:

A= R.K.L.S.C.P.

The model derived soil loss as a product of the empirical values of the variables. A is the average annual soil loss over the area of a hill slope expressed in tonnes/hectare per year or per storm because storms of varying intensities achieve varying levels of soil erosion; R is the rainfall erosivity measured in Mega Joules (MJ) per hour of rainfall (mm hr – 1) per hectare (ha – 1) per year (yr – 1) (MJ mm hr – 1 ha – 1 yr – I); K is the soil erodibility factor measured in tones (+) hour (hr) Mega Joule (MJ) millimeter of rainfall (mm) (KC + hr MJ – 1. mm – 1); L is the slope length factor which, with the slope angle S are dimensionless factors; C is the cropping factor which is also a dimensionless factor. It ranges from 1.0 for bare unprotected soil to 0.01 for protected surfaces with top cover, and P as the conservation practice factor or support practice factor or erosion control practice factor is the ratio of a specific control practice to the soil loss with up and down slope culture. The erosion control practices considered are contouring, contour strip-cropping and terracing. The values assigned for land slope and each practice ranges from .01 to 1.0.

The USLE predicts soil loss. Its applications have not been without problems. The model true to the nature of models does not yield exact soil loss figures but gives fairly accurate values. The soil loss being a product of the factors meant that geologic erosion was denied if any value of the variables was zero. This short- coming led to its modification and the propagation of its variants such as the Revised Universal Soil Loss Equation (RUSLE) (Rennard et.al. 1999), Modified Universal Soil Loss Equation (MUSLE) (Williams 1975) and the Morgan, Morgan and Finney (MMF) Model (Morgan et. al. 1984); Some of the models have been developed to meet the specific character of soil erosion in some parts of the world such as the Soil Loss Estimator for Southern Africa (SLEMSA) (Elwell, 1978); Pan-European Soil Erosion Risk Assessment (PESERA) and European Soil Erosion Model (EUROSEM) models. All the soil erosion models recognize the sub units of the erosion system. The operation of the model determines the measurement and roles of the variables in the model.

One major development resulted from the shortfall of the USLE. The first is the development of concept of "Tolerable Soil Loss" called the T-value. The T-value is the maximum amount of soil loss that can occur annually through the combination of water and wind erosion on a particular soil without degrading the soil's long-term productivity (Brady and Weil 1999: 677). T-values range from 5 – 11 mg/hectare in the United States of America (Brady and Weil 1999, 617). Ande, Alaga and Oluwatosin (2009) obtained T-values of 1.275kg/m^2 yr^{-1} from rocky and hilly terrain on 15%; slope; 0.942kg/m^2/yr^{-1} on flat riparian lands and a mean soil loss of 1.112 kg m^{-2} yr^{-1} for both surfaces in Ekiti, Southwestern Nigeria. These figures were less than the tolerable soil loss of 1kg/1233m^2/yr^{-1} proposed for tropical humid environments. (Ande et. al. 2009).The results cited above indicate the spatial variation of soil erosion and why soil erosion in each environment must be treated specially and differently from other places according to the peculiarities of each environment. The spatial variations in soil erosion gives justification for the development of the environment-specific soil erosion models already named and opens up the activity of soil erosion modeling and control to any and every methodologically sustainable and valid approach. It is for the reasons of quantification, simplicity, philosophical and methodological justification, validity, ease of ranking and prioritization of erosion control targets that the model in this paper is presented.

Study Area

The models presented in this paper are developed in the tropical humid environment of Southeastern Nigeria. The models are designed to function by means of the observation and careful measurement of the relevant soil erosion variables in any locus from field activities. Within the area under study, the soil erosion variables were measured using appropriate techniques and instruments. The data were collated and analyzed with the correlation model with the intention of determining the existence of statistically significant relationships between the soil erosion variables and further simultaneously determine the direction of the relationships between the rate of soil loss and soil erosion variables. Thus, the measure of the relationships between the soil erosion variables on the one hand, and the measure of the relationship between the rate of soil loss and the variables of soil erosion in any area on the other hand is proposed to be the framework for managing soil erosion in any area of study while using this model. The parameters were measured in randomly selected sections of the erosion zone. The places of observation were within the rectangular or triangular grid units selected randomly within the area of study. The sample frame was customized for analysis spatially; the values of the variables were geo- referenced and identities given to the sample collection locations within a raster and vector format processed in a GIS software using ArcGIS 10.2.2 (Ogbonna, 2012). See figure 1.

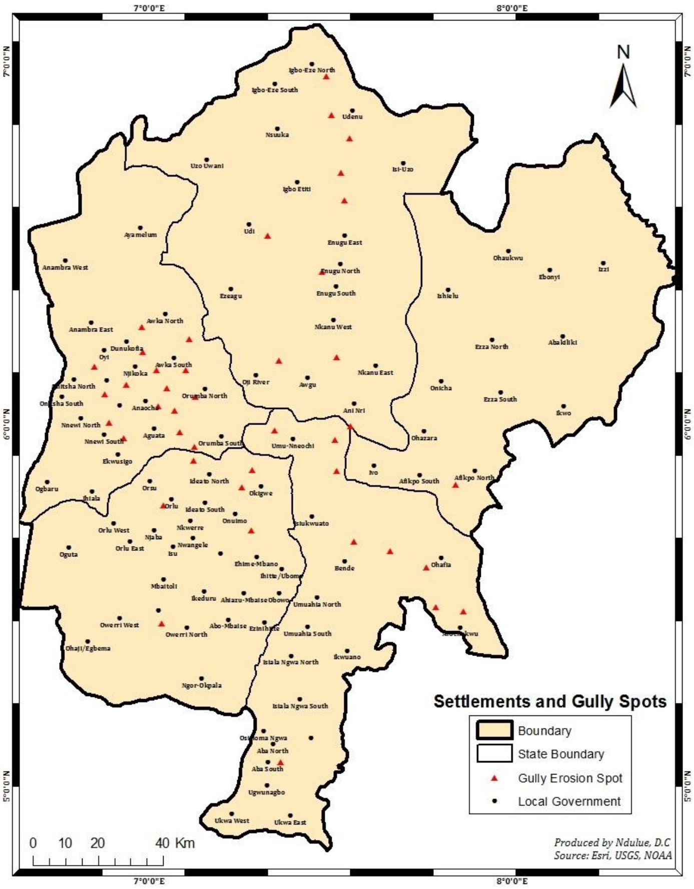

Fig 1*a*: The States in Southeastern Nigeria Showing Sample Collection Points

Source: Esri.com (2019)

Location

Southeastern Nigeria is made up of five Igbo speaking States of Nigeria. They are Abia, Anambra, Ebonyi, Enugu and Imo. The States formed one of the six geo-political zones and is located between latitudes 4º 20′ to 7º 10′ north and longitudes 6º 35′ to 8º 25′ east, with a land size of about 28,983km^2. The region shares boundary with Benue and Kogi states to the north, Rivers state to the south, Akwa Ibom to the southeast, Cross River states to the east and Delta state to the west (Akukwe, T.I, Krhoda ,G.O, Oluoko-Odingo, A.A. 2018). See figure 1.

The region is acknowledged as a region ravaged by soil erosion especially of the gully type which has taken away land, lives and property (Grove 1951; Ofomata, 1964,1965,1975,1978, 1981, 2001; Egboka, 2004; Hudec et.al 2006; Mozie, 2010; Ezezim, 2011; Dim, 2014). Southeastern Nigeria has a sedimentary geology composed mainly of marine-derived friable sandstones and sands on the surface, underlain by shale. The materials had been subjected to several cycles of folding and faulting and subsequently been deeply weathered to form lateritic crusts of varying thickness (Ofomata 2001; Umeji, 2001; Aneke, 2007). The region has seven to nine months of rainfall with intensities that vary from 65mm/ hr^{-1} to 112mm/hr^{-1} with mean rainfall durations of 2.85 hours (Eze, 2014). The mean erosivity of the rainfall determined according to the formula of Kim, Kim, Park and Choi (2003) was 83.75 mm, which is highly erosive rainfall. The mean population density is about 850 persons/km^2, approaches the range of 1200 persons/km^2 in and around the urban centers in the region (NPC, 2007). The entire region is practically urban or sub-urban, especially in the relatively higher areas of sandstone and sand geology (Ofomata, 2001; Umeji, 2001). The relatively high population resulted in the near total clearance of the pristine vegetation of tropical rain forests (Igbozurike, 1978). The soil in the study area is rated as generally exhausted due intensive uses resulting from progressively shortening fallow periods (Igbozurike, 1978). See figure 1.

Conceptual Framework

The models are also conceptually founded on the concept of a coherent whole. The idea of conceiving of the erosion system as a functional whole is at the core of systems theory (von Bertalanffy, 1962). The system is an entity whose state can be studied and understood through the interrelationships between its components (Ofomata, 2001). The idea of association is autochthonous to geography and is the gravamen of systems theory which is a research paradigm in geography, particularly in geomorphology (Chorley, 1967; Ofomata, 1987). One of the established measures of association is the correlation coefficient (Anyadike, 2009). It is a time tested measure which is not difficult to interpret. This is why the correlation model was used to examine the relationship between the variables of erosion and the relationship between the rate of soil loss and other components of the erosion system (Melton 1957a; 1958b). The models were applied to forty-two locations in the five states of the tropical humid of Southeastern Nigeria.

Materials And Methods

The study used primary and secondary data. Primary data were collected through field observations, interviews and measurements, among others. Secondary data were from the internet, other literatures and Google earth, among others. Soil samples were collected from forty-two locations in Southeastern Nigeria over a period of ten years (2010 - 2019). The points of observation and samples collection are shown in figure 1. The topographic surface is summarized by the digital elevation model of the study area as shown in figure 2 processed using ArcGIS software 10.2.2.
The soil erosion variables that were observed are as follows: Elevation (X_1), Total annual rainfall (X_2), Duration of rainfall (X_3), Population density (X_4),. Mean slope angle (X_5), Slope length (X_6), Percentage vegetation cover (X_7), percentage of roof cover in the vicinity of the gully sites (X_{13}) and Rates of gully side expansion (Y). Variables X_8 (% clay); X_9 (% silt); X_{10} (% fine sand); X_{11} (% coarse sand) and X_{12} (% moisture) were determined from the soil samples collected constantly at 1 metre beneath the earth surface, placed in soil bags and analyzed in the laboratory of the Soil Science Department of the University of Nigeria, Nsukka. The particle size analyses were done for the soil fractions by the sieve method and the moisture content by baking the soil sample for 24 hours in a Gallenkamp soil oven at 105^0C for 24 hours. The points of data collection are marked with red and black dots (*triangle*) in figure 1*a* and *b* - the map of Southeastern Nigeria.
The rates of gully expansion were obtained by direct measurement after purposively selected respondents had indicated the positions of the gully sides in the last seven years before the field study. The respondents that were chosen were persons living in the vicinity of the gullies in the locations visited who were at least fifty years old and had sojourned in the study location for more than fifteen years. The researchers chose school teachers and knowledgeable local people such as retirees as their respondents.

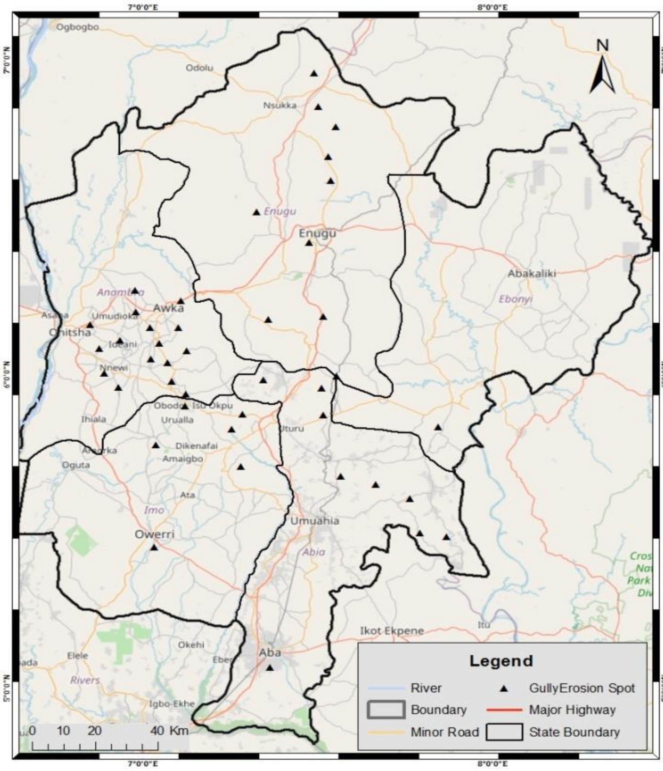

Fig 1*b*: The States in Southeastern Nigeria Showing Sample Collection Points
Source: Esri.com (2019)

Data Analysis

The data obtained were analyzed using Principal Component Analysis (PCA) model (Davis, 1969; Anyadike, 2009). The interpretations of the coefficients of correlation have been fully explained by several authors (Davis, 1969; Anyadike, 2009). In this paper, the statistically significant coefficients at 95% and 99% were discussed as they indicate significant associations between and among the variables. The correlation coefficients were computed using the Statistical Package for the Social Scientist (SPSS) software version 16.0. The correlation coefficients are contained in Table1. The topography of the study area was summarized by the creation of a digital elevation model (DEM) of the study area from the satellite photograph obtained from the Esri, USGS, NOAA and Google Earth library (www.esri.com, 2019; www.googleearth.com, 2019). The model was created in an Arc GIS software 10.2.2. The digital elevation model is shown in figure 2. The cross section of the soils in part of the study area is shown also in figure 3.

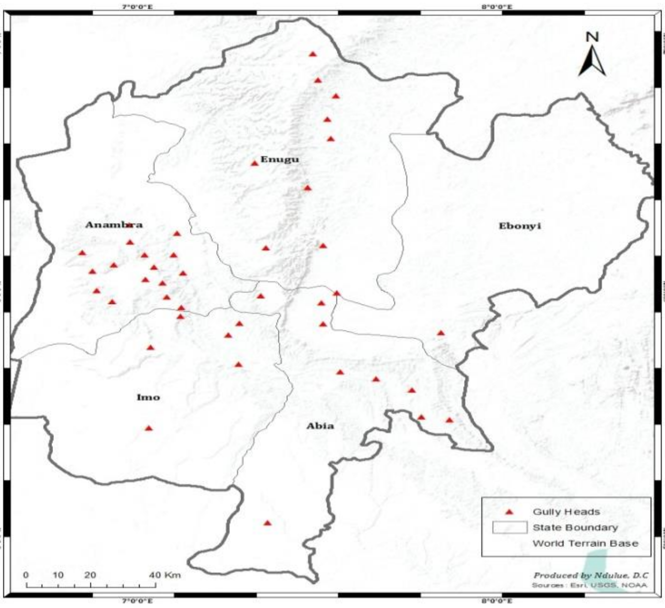

Fig 2*a*: The Digital Terrain Model of Southeastern Nigeria Showing Gully Heads

Table 1: Correlation coefficients between pairs of observed soil erosion variables in Southeastern Nigeria
Source: Author's Fieldwork and Computations, (2020)
' means significant at 95% confidence level.
" means significant at 99% confidence level.

	Elevation (X_1)	Total annual rainfall (X_2)	Duration of rainfall (X_3)	Pop. Density (X_4)	Mean slope angle (X_5)	Mean slope length (X_6)	% Vegetation cover (X_7)	% Clay (X_8)	% Silt (X_9)	% Fine Sand (X_{10})	% Coarse sand (X_{11})	% Soil moisture content (X_{12})	% Area of roof top cover (X_{13})	Rates of gully side expansion (Y)
Elevation	1.0	0220	-.542'	.243	.449	.821"	.529'	-.347	-.347	-.219	.352	-.273	-.207	.220
Total annual rain fall		1.0	-.423	.213	.373	.232	.242	-.495	.309	.286	-.390	.389	.377	-.257
Duration of Rainfall			1.0	.371	-.667"	-.702"	-.323	.277	-.229	.245	.251	-.305	.204	.516"
Population Density				1.0	-.525	.219	-.574'	-.214	.323	.474	-.405	-.487	.769"	.595"
Mean slope Angle					1.0	.667"	.435	.243	.315	.213	-328	.425	-.289	-.660"
Mean slope length						1.0	.340	-.349	-.412	.323	.240	-.360	.387	-.236
% vegetation cover							1.0	-.341	-.341	0.258	.375	.201	-475	.287
%Clay								1.0	.381	-.594"	-.616"	.630"	-.304	-.534"
% silt									1.0	.259	-.842"	.523'	0.223	.367
% Fine sand										1.0	-559'	-.522'	.340	-.509
% Coarse sand											1.0	-.575'	-.416	.404
% Moisture content.												1.0	-504'	-.733
% Area of Roof top Cover													1.0	.469
Rate of gully side expansion														1.0

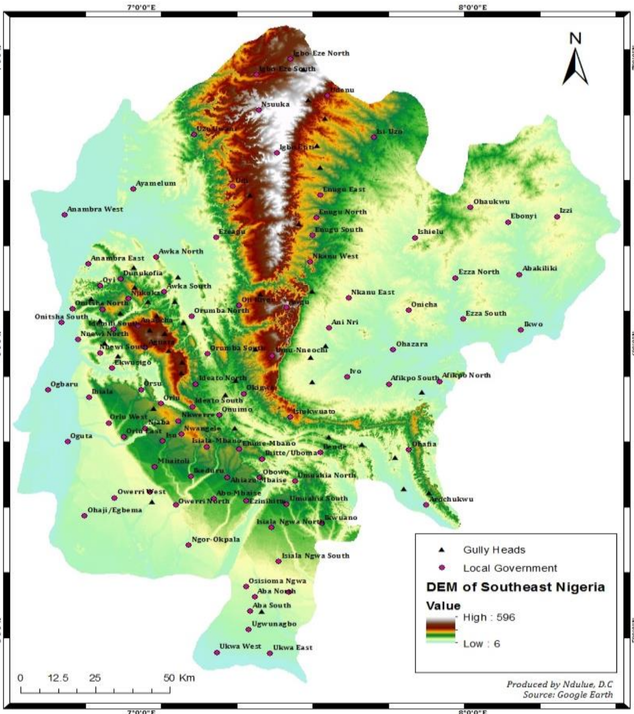

Fig 2*b*: The Digital Elevation Model of Southeastern Nigeria

Source: Google Earth, (2019)

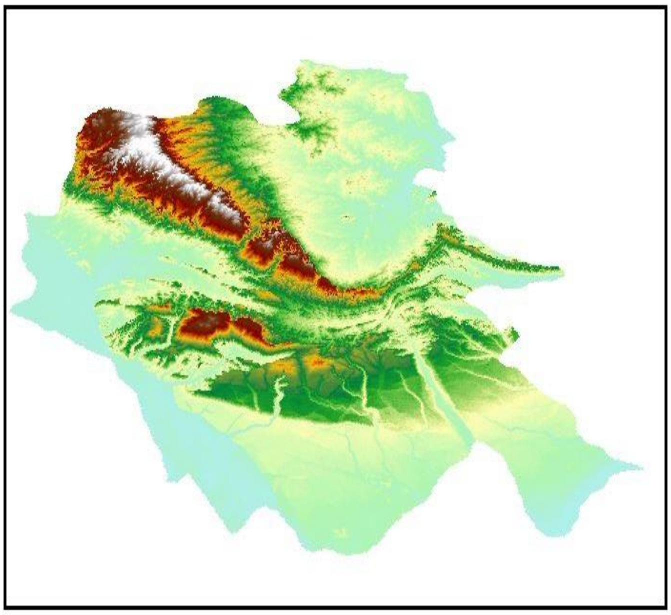

Fig 2*c*: The Digital Elevation Model of Southeastern Nigeria

Source: Google Earth, (2019)

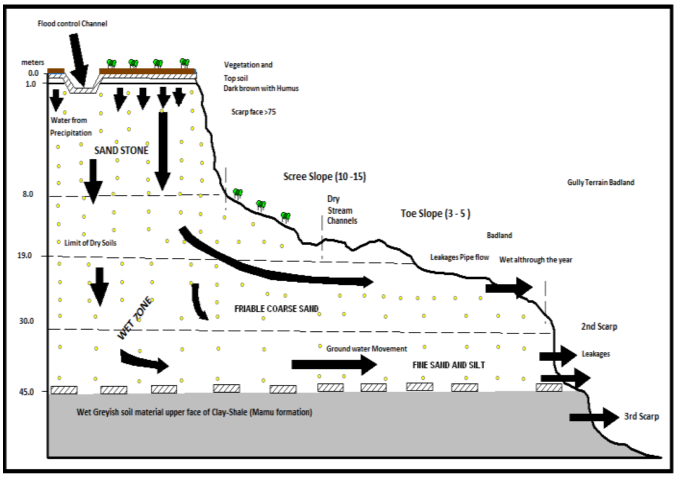

Fig 3: A Cross Section of the Soil Profile at the Gully Front in Agulu, Anambra State, Nigeria.

Source: Adopted from *'Some Observations on the Causative Factors and Slide Processes in the Ududo Nka Gully Head, Isiama Igbo, Agulu, Anaocha L.G.A, Anambra State'*, Modified by the Authors, (2019)

Results And Discussion

With reference to Table 1, the following associations were observed: Elevation is significant, negative and has weak correlation with duration of rainfall; it is significant, strong and has positive correlation with mean slope length and it is also significant, weak and has a positive correlation with vegetation cover. The longer duration of rains with decrease in altitude is explained by the dry-dripping of the clouds which is longer at low altitude vis-a–vis the high altitudes. The greater rainfall on the lower slopes is further accentuated by the downward infiltration of water through the sandy soils on the surface in the study area as depicted in figure 3. The relationship between elevation and vegetation indicates that there is greater vegetation cover on the higher elevations. This result is supported by field evidence. The finding is explained by the fact that settlements were first established on the elevations which were safer and healthier for habitation at the time than the lowlands which were still wet from the pluvial periods of the Quartenary (Hartle, 1972, Ofomata, 1981). For some decades, the people have embarked on re-vegetation though restricted deforestation still goes on due to population pressure on the land and the reliance by the rural people on bio-fuels for their cooking. In the areas of active gully erosion, the gullies have made land relatively scarce and costly. Thus, the areas unaffected by gully erosion are under intense use by the local people in need of land to build upon (Ajaero and Mozie, 2010). The summary of the topography of the study area is contained in the three-dimensional elevation model in figure 2. The feature of the elevated areas is that the highest portions are made up of veneers of lateritic crusts called the Upper Coal Measures (Umeji, 2001). They are of white/dark brown colour on the model. They are the cuesta's summit according to Ofomata (1975). Beneath the lateritic crusts are the friable, false-bedded sandstones which are porous and loose due to low clay content (yellowish brown and less than 8%). The seepage of water from the top through this stratum appears to have washed down the finer sand fractions to the zone which lie immediately above the clay-shale (Imo clay-shale: Mamu formation) The combination and interactions between the geology (stratigraphic succession), soil, rainfall, land use and topography is reflected in the results in Table 1 and explains the processes of gully development and the loci of the gullies.

Total annual rainfall has no significant correlations with any other variables. This result suggests that it is not in itself directly, an important variable of soil erosion in the study area. The mean durations of rainfalls is negative and has a strong correlation with mean slope angle and mean slope length; it has a positive correlation with the rate of gully expansion. The strong and negative correlations with duration of rainfall on the one hand, mean slope angle and mean slope length respectively, corroborate the correlation with elevation and duration of rainfall. The pattern of correlation suggests that more rainfall is received at the lower and gentler slopes than on the upper slopes in the study area. This pattern can be explained by the phenomenon of a longer period of dry dripping of rainfall on the lower slopes vis-à-vis the upper slopes as the moisture laden clouds slide down slope to release their moisture contents (Barry and Chorley, 1969).

Duration of rainfall is significant, weak and has a positive correlation with the rate of gully erosion. The weak correlation suggests that there could be other variables contributing to the rate of gully erosion in the study area such as the soil composition, etc. The significant, weak and positive correlation however, indicates that runoff is an important agent of gully erosion.

Population density is significant, weak and has a negative correlation with vegetation cover; it is significant, strong and has a positive correlation with the rate of gully expansion and it is also strong and has a positive correlation with the percentage area of rooftop cover. The correlation coefficients suggest that deforestation in the study area is due to cultivation and infrastructural development which characteristically do not include drainage channels for the safe conduct of runoff yielded by rooftop interceptions. Infrastructural development proceeds principally by organic growth because of the irregular shapes of the land plots. This fact makes proper physical planning difficult especially with the customary attachment of the local people to their land. These are therefore important factors in explaining gully erosion in the study area (Hudec, et. al., 2006). The problem is, at the evolving stage of settlements, no development plans were prepared to guide structural development in Nigeria (Uchegbu, 2000).

Slope angle is significant, weak and has a negative correlation with duration of rainfall. This result means that more rains are received at lower slopes (the middle to toe slopes) as had been seen earlier. Slope angle is significant, strong and has a positive correlation with mean slope length; it is significant, strong and has a positive correlation with rate of gully expansion. The results suggest that gullies are associated with wet area characterized by long slopes and tracts of short steep slopes.

The topographic conditions in the study area encourage maximum erosion in the talus (middle) and toe slopes. The later process of gully growth occurs by backward erosion and extension of the gullies into the scarp face and ultimately the waxing slopes (brows) of elevations along the incised runoff channels by hillside under-cutting and slope failure processes. This scenario is depicted in Plate 1. The relationships between elevations and mean slope length and durations of rainfalls have been discussed. This relationship gives a clue on the loci of the initiation of the gullies. An examination of the elevation – rainfall duration relationship, suggests that for the lower topographic positions, there is greater runoff competence because more runoff accumulates with increase in the tributary area and distance down slope from the divide (Knighton, 1984). It is a truism that the greater the runoff competence, the greater the soil that is eroded to areas further down slope. We found out in the field that the greater residence of moisture in the soil, the longer and more the soil is weathered, the weaker the resistance of the soil to erosion. In the circumstances, basal weakening becomes an important process of backward wearing of the slopes via mass wasting processes. The wetting of the lower slopes especially at the gully heads was seen in the Ududo Nko gully head in Agulu. (Latitude 5^0 57̓N and Longitude 6^0 53̓E), Anaocha Local Government Area, Anambra State. The wetting process additionally proceeds by way of rainfall which infiltrates through the sandy soils and upon reaching the sand clay-shale interface is intercepted and issues as springs. The gullies in this area have springs issuing from them. This process is depicted in the cross section in figure 3.

Percentage vegetation cover is significant, weak and has a positive correlation with elevation and it is also significant, weak and has a negative correlation with population density. The population density and percentage vegetation cover relationship has been explained by way of vegetation depletion via human activities in the study area. In the Agulu section of the study area, topography and landscape had 31.32 % of bare ground, 34.32 % of built up area and 33.76 % of vegetated land estimated from (Mozie et. al. 2013) contained by automated computation from Landsat 5 imagery of the study area. The incidence of gully erosion in the study area can be further understood in the context of the interactions between the sub-units of the erosion system.

The mean annual rainfall of the study area is 1790mm. The wettest month has a mean rainfall of 175.55 mm (NIMET 2019). Active erosion by runoff goes on for a minimum of seven months in the year. The mean duration of rainfalls in the area is 2.75 hours per rainfall event (Eze 2014). The erosivity of the rainfall determined according to the formula of Kim, Kim, Park and Choi (2003) was 83.75 mm/yr^{-1} which means that the rain storms are highly erosive. Flood waters in the gullies achieve velocities of about $150m/s^{-1}$. These rainy season floods undercut gully side slopes and cause the slopes to fail and bring about the expansion of the gullies. The erosivity of the rainfall is aggravated by the depletion of vegetation and the poor management of the run off generated from the roof tops. The runoff is barely controlled and where controlled, the channels prove to be of insufficient dimensions to contain the flood discharge. The excessive runoff spill over the brink of the drainage channels and erode the soils ultimately making the incompetent drainage channels to break up with time. Observed run off velocity is in excess $150m/s^{-1}$ during long rainstorms. The erosivity of the runoff is increased by the long slopes. There are steep slope segments (18^0 and above) though the slopes are generally gentle (6^0). The steepest slopes are found at the gully erosion fronts which are demarcated by scarps of varying degrees of steepness depending on the properties of the earth materials on which they are formed. In the erosion system, the soil- slope (land) surface is the passive part of the system which suffers the erosive action of the eroding agent subject to the presence and magnitude of other contributing variables including man (Brady and Weil, 1999; Ofomata, 2001).

Percentage of clay content of the soils at the erosion sites in the study area is significant, weak and has a negative correlation with percentage of fine sand and coarse sands in the soils of the study area, it is significant, strong and has a positive correlation with percentage moisture in the soils. The dominance of coarse sand fractions in the soils of the study area is complimented by low fine sand and clay content. The clay-shale and fine sand and silt layers beneath the coarse sand over-burden retain moisture at the base and so aid the failure of the coarse sands on top which do not retain infiltrated water. The effect of the arrangement of the earth materials in the study area is that the gullies are housed in the sands. Field observations indicate that when the erosion of the sands by the springs (head streams) reach the underlying clay, fine sand and silt layers, lateral expansion of the gullies commence. This is a later stage development which marks the severe losses of farmlands, lives and property as the gully fronts advance especially during the wet seasons.

Percentage of silt content of the soils in the erosion sites in the study area is significant, strong and has a negative correlation with the coarse sand content of the soils in the gully erosion sites in the study area and significant, weak and has a positive correlation with percentage moisture content in the soils of the gully sites in the study area. Silts hold more water than coarse and fine sands and are washed further below fine sand by the infiltrating moisture. Percentage fine sand content of the soils in the study area is significant, weak and has a negative correlation with percentage content of: clay, coarse sand, soil moisture, and rate of gully expansion. Percentage coarse sand content of the soils at the gully sites in the study area is significant, weak and has a negative correlation with percentage silt, it is significant, weak and has a negative correlation with percentage of fine sand content and it is also significant, weak and has a negative correlation with percentage moisture content of the soils at the gully sites in the study area. Percentage moisture content of the soils at the gully erosion sites in the study area is significant, weak and has a positive correlation with clay and silt; it is significant, weak and has a negative correlation with percentage fine and coarse sand content of the soils.

Percentage of roof top cover is significant, strong and has a positive correlation with population density at the gully erosion sites in the study area. The rate of gully expansion is significant, weak and has a positive correlation with the duration of rainfall, population density, mean slope angle, percentage of fine sand. It is significant, weak and has a negative correlation with percentage clay content of the soils at the gully sites, percentage vegetation cover and it is also significant, strong and has a negative correlation with moisture content of the soils in the gully erosion sites. The sands have high porosity (45%) and hydraulic conductivity (422m/year^{-1}) (Egboka and Nwankwor, 1985). The high water transmission of the sand explains the basal sapping at the sand-clay interfaces in the study area (Egboka et. al. 2006).

The results obtained can be explained by stating that the study area by reason of its geology and soils was *ab initio* susceptible to erosion. The high rainfall receipt; the intensity and erosivity of the rainstorms appear to have commenced erosion slowly at the outset, until man came on the scene to upset the balance in the erosion system. Erosion was native to the study area. Landslide had its name *(Mbize)* among the native peoples. If the slides which occurred with explosive sounds were strange to the local people, they would not have a place in the native lexicon of the people. The high population density, population pressure on the land resources and the cultural attachment of the people to land in the area led to the early and fast stripping of the hitherto pristine vegetation cover in the study area. The absence of land use control led to the haphazard arrangement of infrastructure in the study area. Further to this, the virtual absence or insufficiency of runoff control structures enhanced the accelerated soil loss in the study area. The most important attitudinal factor that led to the poor response to gully expansion is the native value of individuation which hampered collective response until such a point in time when the affected population found out that the advancing gullies spared no persons.

Remediation And Conclusion

Remediation

It is the respectful view in this paper that the remediation of the damages done to the land surface by erosion starts from the mind of the population(s) living close to the gully erosion sites. This view accords with the doctrine of environmental sustainability which places the duty of environmental protection on the people.

The very first action in remediation is to control the flow of water so as to stop it from doing further damage. Splash erosion is effectively controlled by re- vegetation and mulching so as to stop the direct impact of raindrops on the soil. The roots of plants open up the soil enabling the rain drops to percolate into the soil.

Sheet wash/erosion is also controlled by re-vegetation. Re-vegetation especially grasses have the ability to open up the soil with their roots and allow greater absorption of water into the soil. The greater absorption of water reduces or obviates the formation of puddles that would constitute runoffs. The grasses also form protective cover over the soil and additionally prevent the water flow from reaching or exceeding the critical velocity at which it starts eroding the soil particles from the land surface.

Rill erosion can be checked by controlling the run offs at surface and filing up the rill lines after which vegetation is re-established in the area.

The incipient gully stage starts with the development of the marks of the flow paths of runoff. As an important step, there is the need for a proper survey to determine if the gully is the natural pathway of runoffs or whether the absence of runoff control channels caused runoffs to flow in the position of the gully. The first action would be to correct the anomaly by re- directing the flow of water and putting the people in the affected area on notice as to what they should not do. When the water is controlled filing and re-vegetation must follow. The natural flow path should then be built with concrete and ended properly in a stream channel. There is the need to say that most gullies in and around urban environments are caused by the improper ending of runoff control channels. In those cases, runoffs from the channels with full force; create gullies at the soil-concrete interface which continues beyond the interface. After the establishment of the concrete runoff control channel, the land surface is to be leveled and re-vegetated. In some cases, sandcrete have been used to treat the soil. This is erroneous because the sandcrete does not allow infiltration and creates secondary runoffs which re-initiate erosion beside the main runoff control channel.

At the advanced gully stage, the gullies are usually deep and wide. The magnitudes of gullies vary and they can be of great extents. A badland landscape characterizes advanced gully erosion landscape. Plates 1, 2, 3, 4, 5 and 6 are various types of gullies recorded in parts of the study area. Gullies are generally housed in the sand formations. The very first control measure is to carry out a proper survey of the environment of the gully site. This survey enables the field team to collect data with which to create the model. One of which is the maximum quantity of runoff that flows into the gully. The gully side channel leveling should follow and a channel of adequate discharge capacity constructed within the gully to conduct storm water safely away. Once again, the precaution should be taken to avoid the wrong- ending of the water channel. It is suggested that the channel should terminate in a natural stream channel.

Plate 1: Gully Site at Akara, Isiukwuato Local Government Area, Abia State
Source: Authors Fieldwork, (2019)

Plate 2: Gully Under-cut at Iyi – Nzu in Udenu Local Government Area, Enugu State
Source: Authors Fieldwork, (2019)

Plate 3: Gully Site at Awgbu in Orumba North Local Government Area, Anambra State
Source: Authors Fieldwork, (2019)

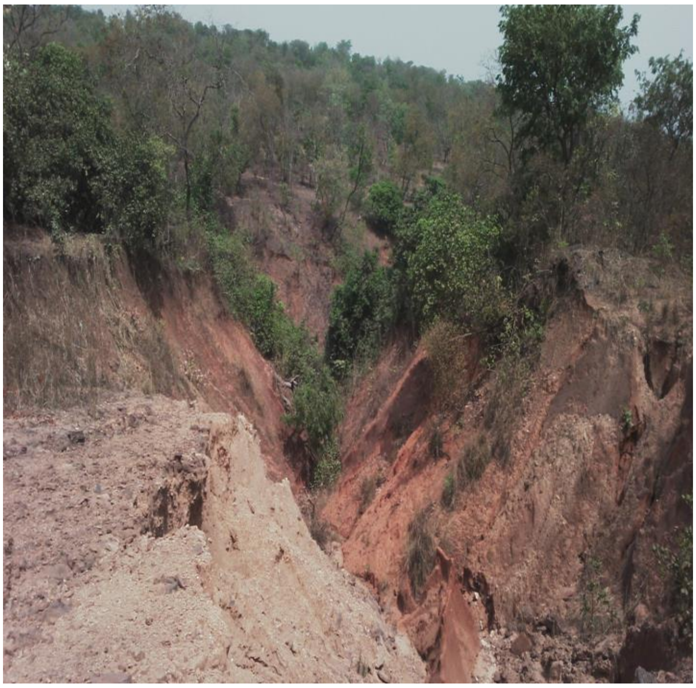

Plate 4: Gully Site at Ideato North Local Government Area, Imo State
Source: Authors Fieldwork, (2019)

Plate 5: Gully Site at Obollo Afor in Udenu Local Government Area, Enugu State
Source: Authors Fieldwork, (2019)

Plate 6: Man induced gully erosion as a result of diversion and wrong- ending of the drainage which has become a treat to buildings around the gully site in Oba, Idemili South Local Government Area, Anambra State
Source: Authors Fieldwork, (2019)

Where the gully has reached the badland stage, the remedy lies in undertaking of re- designing of the landscape. One very important task at this stage is to ensure that the soils in the area being recovered lie below their natural angles of repose or angle of internal friction at which shear stress is very minimal. When this is done the task at hand is resolved into runoff control alone. Natural run off paths must be strengthened and artificial ones created and not to be wrong or short-ended. These measures will result to a re-invented landscape that can then be terraced to prevent sheet wash and soil loss there by using block walls and gabions as applicable. The area should then be re-vegetated and allowed to recover. To assure that the area recovers, legislation will suffice by designating the area a wild life sanctuary and by criminalizing trespass into the area. In areas where the topography has not yet been badly damaged, the direct determination of the maximum amount of runoff donated to the gully should be carried out even at the risk of delay before the repair of the gully is commenced. This step is totally missing in virtually every soil erosion control work in Nigeria. Further to this, the engineers who undertake the construction of the storm water channels do not utilize the hierarchical structure of channels as they occur in nature within river basins. What obtains is that channels of similar dimensions run throughout the constructed drainage system even when the quantities of water donated to the drainage channels have increased two to three folds. The principle of hierarchical arrangement of channels in the natural drainage system which should serve as a model is demonstrated in the Horton-Strahler (1964) drainage basin model and also directly demonstrable in Kirchoff's first law of electrical circuits in the sense that where two channels are donating

water to a larger channel, the receiving channel must have the capacity to accommodate the waters donated such that the sum of the water at the junction of the three channels is zero (Mozie, 2011).
It becomes apposite at this point to discuss the role of water both as splash, runoff and infiltrated water in the initiation and continuation of soil erosion on any surface. There is a general, historical and world-wide consensus that flowing water is the most widespread agent of erosion (Summerfield 2000; Ofomata, 2008). If there is no agent of erosion even when the surface to be eroded exists, there would be no erosion. In this respect, the submission of Ofomata (1987) lies in breach of a fundamental geomorphological truth. Gilbert (1877) had stated that slopes are steeper in dry environments and gentle in humid environments because of the action of water. From the table of correlation coefficients, the duration of rainfall which yields splash, runoff and infiltrated soil moisture is linked to twelve out of the thirteen variables indicating the very suffusion influence of water within the erosion system. It influences and is influenced by a myriad of factors singly or in combination in its erosion task (Brady and Weil 1999).

Conclusion

This paper provides an empirical basis for making inferences into the interconnectedness between the soil erosion variables in any erosion system once the relevant variables are measurable. It directly suggests the strategy for repairing gullies depending on the understanding of the interactions of the erosion variables in the locale of the gully, the size and housing of the gully and peculiar soil-water relationship in the gully zones. It is also the view in this paper that gully erosion control is a multi-disciplinary task. Adequate and appropriate gully erosion containment must issue from a proper scientific conceptualization of the problem from indepth investigations before any structures are designed and emplaced to check gully erosion. The results in this paper differ from the findings of Ofomata (1987) though the five groups of variables that account for soil erosion are accounted for. While Ofomata (1987) arrived at relief explaining about 26% of the variations in the type of soil erosion; 14% by rainfall; 3% by surface materials, 0.1% by vegetation and 0.3% by population, our results rank rainfall first as accounting for erosion via its multiple influences and activities in the erosion cycle. Soil is ranked second after rainfall, followed by topography, population and vegetation cover. The difference in this work and that of Ofomata (1987) indicate the diverse ways in which soil erosion studies can be designed and undertaken. What is important is for any approach to yield rationally explicable results that will contribute meaningfully to the understanding of the very complex phenomenon of soil erosion which varies in details as the variables vary over space and time due to the dynamic nature of the earth's surface and the human society. The first step in the control of gully erosion is awareness and readiness of the people to combat the initiation of gullies in their environment. The result of the data analysis in this paper implicates moisture (splash and run off) as the dominant agent of soil erosion in the study area.

Acknowledgment

The authors are grateful to the authorities of the University of Nigeria Nsukka, their colleagues in Department of Geography University of Nigeria Nsukka, their students in the basic geomorphology and soil erosion classes and their families who gave their moral and financial support in the course of the data collection and analysis used in this research. The authors also acknowledge all the sources (Authors) of the body of literature on which this work is founded.

Conflict of Interest

The authors declared no conflict of interest

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