SPATIAL VARIABILITY OF SEDIMENT YIELD ON LAND USE COVER TYPES IN CALABAR RIVER BASIN CATCHMENT, CROSS RIVER STATE, NIGERIA

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ABSTRACT

This study investigated the spatial variability of sediment loss from five land use types in the humid sub-tropical watershed region, characterized with high incidence of rainfall. Five contiguous experimental runoff plots were designed to represent the land use types: urban, farm, grass, bare and forest surfaces and a 2 inch pipe installed in the midway of the lower boundary of each plot/land use type ($5.4m^2$) to a metal sedimentation box (31 by 23cm); arranged in a convex slope series on a foothill of 20% gradient slope oriented at the strike of the slope. Seven independent variables were examined simultaneously from each experimental plot/land use type. These include rainfall amount and intensity, particle-size characteristics, infiltration capacity, vegetation cover, slope length and gradient. The fieldwork was conducted between October, 2014 and December, 2015 to cover the two seasons and all rainfall events. A total of 65 rainy days capable of dislodging sediments were registered over the period of investigation. Equations of sediment loss for the individual stations were derived to develop a stochastic empirical model. Rainfall amount had the greatest relationship in the study and it was significant at the 99.9% probability level. Forest and grass surfaces with mean values of 5.66kg and 14.95kg of sediment loss respectively recorded significantly less than farm 33.50kg, bare 33.91kg and urban 28.78kg surfaces. To ameliorate hazards associated with sediment loss, the study recommends among others reforestation and establishment of forest reserves at designated areas of the basin. This will enhance sustainable watershed management in the humid tropical environment.

KEYWORDS

Rainfall; soil erosion; river basin; morphology; experimental plot.

1. INTRODUCTION

Soil erosion is undoubtedly one of the many environmental phenomena that have spurred quite a number of studies over the years. The importance of soil erosion is not limited to its place in landform processes, but also as a threat to the environment. Though soil erosion and water quality management have become major concern in land management in United States over the years, the ever-increasing studies on one form of erosion or another by many researchers in the last 50 years in Nigeria is an indicator of Nigeria's recent interest in water quality management and land management (Faniran & Areola, 1974; Jeje & Nabegu, 1982; Eze, 1996; Abua, 2017).

Calabar river catchment, a foremost coastland of Cross River State, Nigeria had witnessed unprecedented land use changes and soil degradation. There is enormous pressure on coastlands around the world as a result of their economic viability, thereby constantly resulting in growing human population and increasing economic activities (Oyegun, 1993; Umeuduji, 2001; Cunningham, Cunningham & Siago, 2005). Human activities such as massive deforestation, agriculture and urbanization are assuming greater importance and are responsible for a steady increase in soil degradation in Calabar region (Adefolalu, 1978; NEST, 1991; UNEP, 1995; Umoh, 2004; Abua & Ajake, 2015; Abali & Abua, 2016; Abali, 2017). Logging of a watershed for urbanization processes increases sediment yield which induces flood and erosion hazards (Megahan & Kidd, 1972; Oyegun, 1984). Ntukidem (1980) posits that many physical attributes on the earth surface are effectively altered as soon as urbanization process sets in. This means that the soil cover will be altered from green vegetation to open surface and built-up slopes. Similarly, valleys are exposed to greater surface flow, some without adequate provision of drainage channels as in the study area. Consequently, where simultaneous provision for adequate urban runoff disposal system is lacking as in the study area, then, the contributive role of urban surface characteristics are severe erosion and flooding as well as other environmental hazards.

Anderson (1970); Abali and Abua (2016); Abua (2017) asserted that the infiltration capacity of the soil within the urban areas is further minimized by the replacement of ground cover with impermeable urban surface and condition as a result the only means to discard excess rain is through surface flow. It should be noted that the tendency of water flow to overland is determined by undisturbed landscape and excess water infiltration capacity of the soil. The movement of surface water to the ground is referred to as infiltration. According to Amin (2005), studies have revealed the effect of several factors on infiltration rate of a given soil, include ''the nature of the soil layer, the moisture content of the soil, rainfall intensity, temperature, vegetation cover, hydraulic characteristics, permeability and moisture content''. Surface runoff is mainly determined by the nature of the soils, the topography and rainfall intensity. Abua (2017) opined that erosion process of the soil can be attributed to low infiltration capacity of the soil resulting to flooding of streams and other regional lowlands. It has been observed by many scholars that soil infiltration related problem is associated with, and can be traceable to high rainfall intensity.

This study therefore posits that the intensity of soil loss (erosion) in the study area is dependent on rainfall amount and intensity and the land use that has changed overtime due to increasing human activities. Studies of soil loss (erosion) has identified the causes to include excessive rainfall, land use changes, nature of slope, soil texture and vegetation cover (Ward, 1973; Obi & Asiegbu, 1980; Abali & Abua, 2016; Nduji, Nnam & Ekpete, 2012). The aim of this study was to examine the variation of sediment loss from five land use types in Calabar River Basin Catchment, Cross River State, Nigeria.

2. THE STUDY AREA

This study was conducted at Akim-Akim in Odukpani LGA, Southern Cross River State, Nigeria. The study area lies on Latitude $5^0 06^1$-31.72"N and Longitude $8^0 17^1$-8.08"E at an altitude 42m (Fig. 1). Calabar region lies within the sub-equatorial climatic belt. This makes the region possesses a distinctive climate type peculiar to those found in the humid sub-tropical region. The region ranks very high among stations receiving heavy precipitation in the coastal zone of Nigeria and West African sub-region (Inyang, 1980). The region like many other areas in the sub-tropical humid climate experiences double maxima, usually in the months of July and September. There is hardly any month of the year without rainfall even when there is a marked rainy season lasting between March to October. The relative humidity remains high throughout the year, except during the short harmattan spell. The relative humidity is estimated to reach 90 percent much higher in the morning. The region is characterized by a long wet season between April and November, and relatively short dry season from December to March (Abali & Abua, 2017).

The general geology of the study area is within Cross River Basin. The geology of Cross River Basin consists of crystalline basement complex, overlain

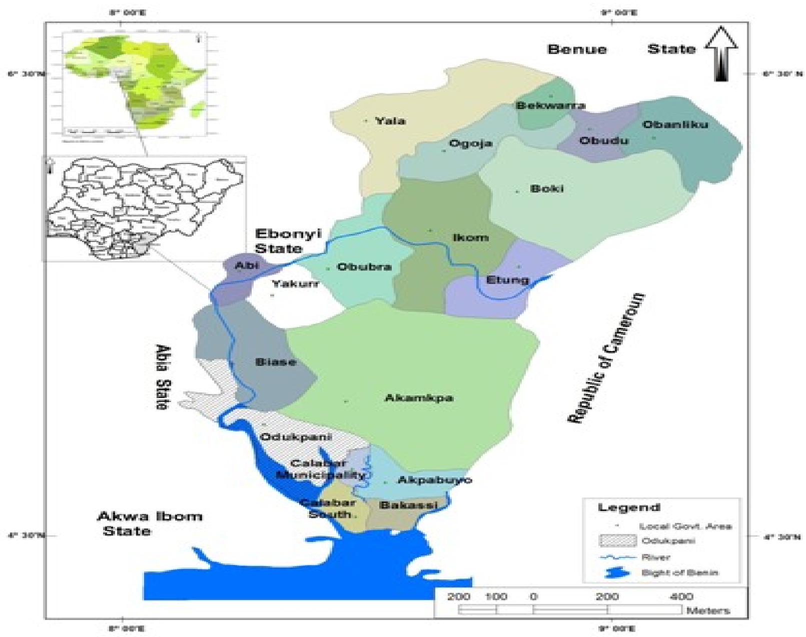

Figure 1: Showing map of Odukpani Local Government Area in Cross River State, Nigeria

by various sedimentary formations. The sediment texture ranges from silty-clay to sandy-clay, with the abundance of silt/clay in the lower reaches (estuary) and sandy mud in the upper reaches predominating at regions greater than 2m to the shoreline (Asuquo & Ewa-oboho, 2006). The study area has a characteristic type of soil and vegetation typical of humid tropical environment. The humid tropics are associated with the tropical rainforest belt. The major vegetation type found in the coastlands is the mangrove swamp forest.

3. Research Methodology

Five land use types were examined viz: forest, grass, farm, urban and bare surfaces using contiguous experimental plots of size (3 x 1.8m) each and installing a 2 inch pipe in the midway of the lower boundary of each plot/land use to a metal sedimentation box (31 by 23cm) (Sensoy & Kara, 2014). Both fine (≤ 2 mm) and coarse (>2 mm) soil particles were filled in each plot of mean size of $5.4m^2/0.0054kg$ and the grass, trees and cassava planted for grass, forest and cassava plots respectively and allowed to sprout. Bahama/iron grasses, Teak/Mmelian trees and Cassava were respectively planted for the grass, forest and farm plots. The reason for chosen cassava is because it is a staple food and industrial crop in the area. For urban plot, the surface was concretized before filling. Neither planting nor concretization was carried out on the bare plot. Two days were used to prepare the plots and test run after a month **(Plates 1 and 2)**. In each of the plots/land use types; rainfall, morphological and hydraulic factors were determined. The fieldwork was conducted between October, 2014 and December, 2015 to cover the two seasons and all rainfall events using a standard rain guage. A total of 65 rainfall events capable of dislodging sediment were registered. Measurements of the dependent (Y) variable: sediment loss and independent (X) variables: rainfall amount, rainfall intensity, slope length, slope gradient, particle-size characteristics, infiltration capacity and vegetation cover were simultaneous for all rainfall events from beginning to end of experimentation.

Plate 1: Researchers' Experimental Plot with Ranging Poles and Rainguage

Plate 2: Researchers' Experimental Plot with Sedimentation Boxes

4. METHODS OF DATA ANALYSIS

The data derived in this study were presented in standard management tools such as tabulations, means, standard deviations and percentages for the purpose of statistical analysis. To this end, it was relevant to establish both individual and joint contributions of the independent variables of rainfall amount, rainfall intensity, slope length, slope gradient, particle - size characteristics, infiltration capacity and vegetation cover on the dependent variable of sediment loss from the Calabar river basin. The Pearson's Product Moment Correlation as built into Statistical Package for the Social Sciences (SPSS) computer model was used to establish the relationship between the dependent variable and the independent variables. Similarly, a stepwise multiple regression analysis was executed on the study's data using the (SPSS) computer programme for the data generated.

Sediment loss, the dependent variable was regressed on rainfall amount, rainfall intensity; slope length, slope gradient, particle-size characteristics, infiltration capacity and vegetation cover processes in the basin. The idea was to determine which of the independent variables would enter the predictor equation. Thus, there arose the need to employ the student 't' test within the context of the study's explanatory framework to determine their contributions from the results of multiple regression summary tables, correlation matrix as well as Analysis of Variance (ANOVA). The acquired data were then processed and subjected to inferential analysis. Equations of sediment loss for the individual stations in the study area were developed while the data for all stations were collapsed to develop a sediment loss model for the Calabar river catchment. The resultant was the multiple linear regression model for estimating sediment loss in the study area. The equation for this study is of the form:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + e$$

Where:

Y = sediment (soil) loss in kg/m^2
a, b_1, b_2 ……… b_m are regression coefficients
e = error term
X_1 = rainfall amount in mm
X_2 = rainfall intensity in mm/min
X_3 = slope gradient in %
X_4 = slope length in m
X_5 = particle-size characteristics in kg
X_6 = vegetation cover in dummy variable
X_7 = infiltration capacity in cm/hr

5. RESULTS AND DISCUSSION

The variables found to be significant in the various sediment loss models of the land use types were developed. The seven variables are rainfall amount, rainfall intensity, infiltration capacity, slope length, slope gradient, particle size and vegetation cover. Of all the variables, rainfall amount had the greatest significant in all the land use types. Similarly, in all the sediment loss equations developed in this study, at least one of the variables was linearly related to sediment loss either directly or indirectly. Below is the summary table and accompanied explanations of regression results of the five land use types **(Table 1)**.

Table 1: Regression Models Developed in the Study

Land use	Sediment Loss (kg)	Coefficient of Determination %	F – ratio (Regression Equation)
Urban Surface	28.8	17.6	$Y = 11.580 + 0.434x_1 + e$
Bare Surface	33.9	41.0	$Y = 5557.614 + 0.965x_1 - 0.445x_2 + 26.606x_3 - 26.356x_4 + 0.231x_7 + e$
Farm Surface	33.5	38.1	$Y = 20.307 + 0.576x_1 + e$
Grassland	14.9	14.7	$Y = 27.213 + 0.400x_1 + e$
Forest Ground	5.7	8.4	$Y = 2.683 - 0.356x_3 + e$
Model		42.4	$Y = 62.521 + 0.268x_1 + 0.229x_3 - 0.532x_4 - 0.160x_6 + e$

Source: Computer Analysis Output of SPSS (*significant at the 99% probability Level)

The summary of the models developed in the study above at the 99.9% probability level show the explanation provided by the various land use types for sediment loss. For instance, 28.8kg of sediment loss, that is 17.6% of variation in sediment loss is explainable by urban surface, 33.9kg of sediment loss, that is 41.0% of variation in sediment loss is explainable by bare surface, 33.5kg of sediment loss, that is 32.1% of variation in sediment loss is explainable by farmland, 14.9kg of sediment loss, that is 14.7% of variation in sediment loss is explainable by grassland, 5.7kg, that is 8.4% of variation in sediment loss is explainable by forest ground and 42.4% of variation in sediment loss is explainable by the model developed for the study. The regression equations shown above depicts that rainfall amount is the major predictor variable. Forest and grass surfaces land use types recorded the least amounts of sediment loss. However, all the models developed in this study are useful in explaining sediment loss in Calabar River catchment. The statistical summary of measured variables of interest in the study (**Table 2)**:

Table 2: Summary of Measured Variables of Interest in the Study

Variables	**Land use Types**					
	Urban Surface	**Bare Surface**	**Farm Surface**	**Grass Surface**	**Forest Surface**	**Totals**
Sediment Loss (kg) $(\bar{x})$	28.7754	33.9138	33.4992	14.9477	5.6646	**116.8007**
Rainfall Amount (mm) $(\bar{x})$	41.7385	41.7385	41.7385	41.7385	41.7385	**208.6925**
Rainfall Intensity (mm/min) $(\bar{x})$	0.5682	0.5682	0.5682	0.5682	0.5682	**2.841**
Slope Gradient						

(%) (x) ‾	52.0000	52.0000	52.0000	52.0000	47.6292	**255.6292**
Slope Length (m) (x) ‾	5.2020	4.0180	4.6177	4.5746	4.4365	**22.8488**
Particle size (kg) Sand (%) Silt (%) Clay (%)	58.0 11.0 31.0	49.0 13.0 38.0	48.0 18.0 34.0	56.0 12.0 32.0	57.0 7.0 36.0	**268.0** **61.0** **171.0**
	100%	**100%**	**100%**	**100%**	**100%**	**500%**
Vegetation Cover (dummy variable) (x) ‾	4.2469	1.0263	2.3462	5.0917	7.0705	**19.7816**
Infiltration Capacity (cm/hr) (x) ‾	4.8200	5.9554	4.7831	4.5015	5.0723	**25.1323**

Source: Researchers' Fieldwork (2015)

6.CONCLUSION

In the five experimental plots representing the various land use types, forests and grass surfaces lost significantly less sediment than farm, bare and urban surfaces. Urban, bare and farm land use types recorded the most significant amount of sediment loss. This means sediment losses increase more with the degree of exposure of the surface to rainfall impact. Generally, the amount of sediment loss depends on the rainfall amount and intensity, infiltration capacity of the soil, nature of vegetation cover, particle size characteristics, length and gradient of slope. The relationships are linear and hold for all surfaces and morphological conditions. The relationship between rainfall amount and sediment loss in Calabar River Basin catchment reveals that rainfall amount played the dominant role in sediment loss in all land use types.

Rainfall intensity had a negative relationship in the study. Sediment loss by rainfall (raindrop splash) was greatest and most noticeable during short duration accompanied by high-intensity rainstorms. The sediment lost caused by long-lasting and less intense storms was not as spectacular or noticeable as that produced during heavy rainstorms. Infiltration capacity had a low positive relationship in the study. This is attributable to the fact that a large portion of the basin has been made impervious, coupled with the high incidence of rainfall, increase surface runoff and sediment yield. However, the infiltration capacity of the soils varied with the level of vegetal cover on the land use types. Vegetation cover of Calabar river catchment had a positive relationship. This means that the absence of vegetation cover or depletion at the surrounding environment of the basin in the study area is the result of increased sediment loss. Slope length and gradient had low positive relationships that were insignificant. Particle size characteristics had a low relationship in the study. Lighter aggregate materials such as very fine sand, silt, clay and organic matter were easily removed by the raindrop splash and surface runoff; greater raindrop energy or runoff amounts was required to move the larger sand and gravel particles of Calabar river catchment.

The study recommends reforestation aimed at increasing the vegetation cover and infiltration capacity of the soil, thereby reducing the surface runoff. The researchers also recommend sustainable forest resource management in the basin by preserving the already existing forest at certain reaches of the stream. This is because mature vegetation has a high rainfall interception rate, a tendency to reduce rates of overland flow and generate soil with higher infiltration capacity and better structure. This will in turn displace the particle size characteristics, giving room for permeability as well as creating public awareness aimed at educating the populace on the hazards associated with sediment loss. The presence of vegetation in this basin will also reduce nutrient and material loss to the river.

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