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# Predicting Soil Erosion from Field Losses in Calabar River Basin using the Universal Soil Loss Equation (USLE)

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## ABSTRACT

*The Universal Soil Loss Equation (USLE) model was adopted in predicting soil erosion from rainfall-induced sediment yield in an urbanizing river catchment. It entailed the use of contiguous experimental plots for five land use types: urban, farmland, grassland, bare and forest surfaces, generated by installing a 2 inch pipe 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. In each of the experimental 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. 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. Forest surfaces and grass surfaces lose significantly less sediment than farmlands, bare and urban surfaces. The study recommends among others reforestation to ameliorate hazards associated with sediment loss. This would foster sustainable watershed management in the region.*

**KEY WORDS:** Soil erosion, sediment yield, river basin, urbanization, slope, rainfall

## INTRODUCTION

Human-induced modifications of the vegetation cover in river basins may cause strong geomorphic responses by disturbing sediment supply, transport and deposition regimes. The increasing land use changes triggered by human activities such as deforestation and urbanization necessitate soil erosion (Abali, 2016). Soil erosion is associated with heavy and prolonged rainfall, the degree of slope, which either will accelerate or impede surface runoff, the nature of the soil and the extent of the vegetation cover. Logging of a watershed for urbanization processes increases sediment yield which induces erosion hazard. 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 (Ntukidem, 1980). Similarly, valleys are exposed to greater surface flow, some without adequate provision of drainage channels as in the study area.

Studies have revealed the effect of several factors on infiltration rate of a given soil (Amin 2005; Eze et al., 2010). They include the nature of the soil layer, the moisture content of the soil, rainfall intensity, temperature, vegetation cover, hydraulic characteristics, permeability and moisture content. Runoff of water is mainly determined by the nature of the soils, the topography and rainfall intensity. Erosion process of the soil can be attributed to low infiltration capacity of the soil, as a result, might result to flooding of streams and other regional lowlands. It has been observed by many scholars that excess soil infiltration related problem is associated with, and can be traceable to high intensity rainfall.

Soil loss is a direct consequence of soil erosion which is a function of several environmental factors. These factors include rainfall amount, intensity and duration, surface configuration (relief/slope); nature of surface materials and vegetation. In general terms, a decrease in vegetation cover is associated with increased sediment production and vice versa (Walling, 1999). The environment within urban areas and with the infiltration capacity 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 Universal Soil Loss Equation (USLE) is a method for estimating annual soil erosion on the basis of soil loss from a field or hillslope. It was empirically derived from data collected over a twenty-year period from runoff plots at experimental stations established in the 1930s in the United States by the Soil Conservation Service under H.H. Bennett (Goudie, 2004). The object was to measure soil erosion rates under natural rainfall on different soils, slope conditions, cropping and tillage practices, as a basis for soil conservation recommendations. Eventually data were available for twenty-three soils between the Rocky Mountains and the US east coast. Continuing attempts to develop a reliable equation to predict soil erosion culminated in the USLE in 1958 (Wischmeier *et al*., 1958).

The metric version of the equation is:

$E = R.K.L.S.C.P$

where E is mean annual soil loss (t ha_1), R is annual rainfall erosivity (107Jha_1), K is soil erodibility (relative to a control soil without vegetation cover), L is slope length (relative to a standard slope length of 22.6 m), S is slope gradient (relative to a standard 9 per cent slope), C is crop management (relative to a cultivated bare field), and P is a conservation practices factor (relative to a bare surface without conservation measures).

The most complex and critical factor is annual rainfall erosivity, based on regression analysis of rainfall characteristics to determine those most strongly correlated with soil loss from the runoff plots. The most effective measure is a composite measure involving the total kinetic energy (E; J m2) during a rainstorm and the maximum rainfall intensity recorded over a 30-minute period during the storm (I30; mm h_1). Annual rainfall erosivity is the sum of EI30 for all storms during a year, divided by 1,000. Calculations should be based on records spanning at least twenty-five years, but there are not many locations where such long term records of rainfall intensity exist. Available data show the highest values from humid tropical areas like the Gold Coast of West Africa, where erosivity exceeds 1,700 (Roose, 1977), and the lowest values in temperate and arid regions.

Sediment delivery ratios have been widely used to estimate stream sediment loads from erosion rates predicted by the Universal Soil Loss Equation (USLE) and its successor, the Revised USLE (RUSLE). These empirical equations are designed to predict gross rates of erosion at the soil surface. Because the USLE and RUSLE were developed from studies of small test plots, they define 'erosion' as the movement of soil particles from one location to another – but, importantly, not necessarily from their point of origin to a stream channel. A fraction of the sediment mobilized by surface erosion will be intercepted (for example, in densely vegetated zones or low gradient foot slopes) before it reaches the channel network. Of the sediment that reaches the channel network, a further fraction will be deposited on the floodplain or stored in the channel. The proportion that is delivered to a sampling point in the channel network–rather than intercepted on the soil surface, deposited on the floodplain, or stored in the channel–is the sediment delivery ratio. Sediment delivery ratios are commonly estimated from the measured sediment yield (from sediment gauging methods or accumulation in a sediment trap) at a given point in the channel network. This is then divided by the estimated rate of erosion in the surrounding catchment (derived from the USLE/RUSLE or, in some cases, direct field measurements). Thus sediment delivery ratios will not only reflect sediment interception, storage and deposition, but will also reflect any errors made in estimating sediment yields or rates of surface erosion; both are subject to significant uncertainties (Meade 1988; Trimble and Crosson 2000).

This paper therefore examined soil erosion on the basis of soil loss from rainfall erosivity, soil erodibility, nature of slope, soil texture and vegetation cover.

To achieve the aim above, the specific objectives were to:
i. Determine the intensity of sediment loss in the basin of the study area
ii. Develop a predictive model of sediment loss based on its explanatory variables.

## THE STUDY AREA

The study area, located in south - eastern Nigeria lies between Latitudes $4^0 45^1$N and $5^0 10^1$ N and Longitudes $8^0 05^1$ and $8^0 45^1$ E. It is within the Hydrological Boundary of the Calabar River system. It is a fourth–order river catchment with an estimated area of 460km$^2$. It is a lowland underlain by coastal plain sands of Benin Formation. The mean annual temperature remains around 27$^o$C throughout the year and, with a total rainfall of about 300cm. The relative humidity is estimated to reach 90 percent (Fig. 1).

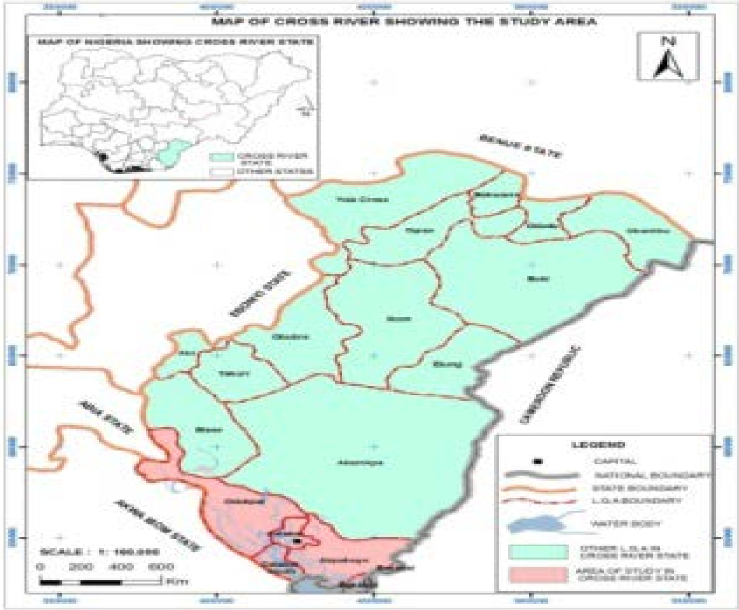

**Fig. 1:** Cross River State Showing Study Location

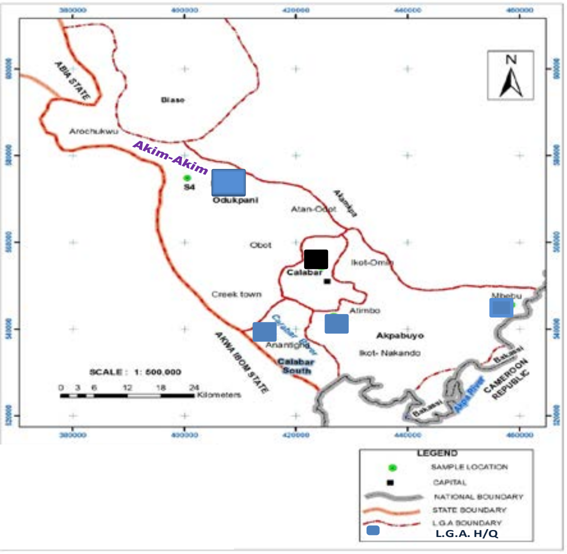

**Fig. 2:** Study Area Showing Sample Location

**Plate 1:** Experimental Plots with Sedimentation Boxes

## METHODS OF DATA COLLECTION

### MEASUREMENT OF RAINFALL AMOUNT AND INTENSITY

Preliminary studies and literatures have shown that rainfall is a key element in the determination of runoff, infiltration rate of soils and sediment yield. Arising from this, a rainfall station was cited near the experimental site to capture the rainfall amount, duration and intensity. To achieve this, a standard rainguage was mounted at the study site at a height devoid of vegetal obstruction. This was achieved using a 100mm plastic rainguage which inner cylinder filled by 25 mm of rain, with overflow flowing into the outer cylinder. The gauge had markings on the inner cylinder down to 0.25 mm resolution marking.

After the inner cylinder was filled, the amount inside discarded, then filled with the remaining rainfall in the outer cylinder until all the fluid in the outer cylinder is gone, adding to the overall total until the outer cylinder is empty. In citing the station, all meteorologically prescribed precautions regarding the monitoring of rainfall were taken into consideration. For instance, it was cited in an open ground devoid of obstacles and the rainguage was placed firmly in the ground but not in such a way that raindrops can splash into it. The amount, duration and intensity of rainfall were measured for the respective stations. Its intensity is a measure of the amount in depths that falls over time. In the present study, the intensity of rainfall is considered as rainfall that is the measure in depth (mm) of the water layer covering the ground in a period of one (1) hour duration. It means that if the rain stays where it falls, it would form a layer of a certain depth. It is calculated by dividing the depth (mm) by the duration (min).

Rainfall intensity (mm/min) = $\frac{\text{Rainfall amount (mm)}}{\text{Rainfall duration (min)}}$

Intensity and duration of rainfall are usually inversely related. High intensity storms are likely to be of short duration and low intensity storms can have a long duration (Udo et al., 2002). Deviations can occur for small droplets and during different rainfall conditions. Falahah and Suprapto (2010) noted that it is simply according to rate of rainfall as follows:

- Light rain —rainfall rate is less than 2.5mm per hour.
- Moderate rain — rainfall rate is between 2.5 - 7.6mm or 10mm per hour.

- Heavy rain — rainfall rate is greater than 7.6mm per hour, or between 10 mm and 50mm per hour.
- Violent rain — rainfall rate is greater than 50mm per hour.

There is an existing relationship between soil loss and rainfall factors such as amount, duration and intensity. These factors are necessary since they greatly determine the rate of material loss and accretion along slope sides. These operational processes were observed or measured simultaneously for all rainfall events starting from the beginning to the end of the experiment. Hence, this study established a direct relationship between soil loss and rainfall. The statistical summaries of measured variables of interest in the study are presented in the Table below:

**Table 1: Summary of Measured Variables of Interest in the Study**

| **Variables** | **LANDUSE TYPES** | | | | | |
|---|---|---|---|---|---|---|
| | **Urban Surfaces** | **Bare surfaces** | **Farm Surfaces** | **Grass Surfaces** | **Forest Surfaces** | **Totals** |
| Sediment Loss (kḡ) (x) | 14.9477 | 33.9138 | 28.7754 | 33.4992 | 5.6646 | **116.8007** |
| Rainfall Amount (mm̄) (x) | 41.7385 | 41.7385 | 41.7385 | 41.7385 | 41.7385 | **208.6925** |
| Rainfall Intensity(mm/m̄in) (x) | .5682 | .5682 | .5682 | .5682 | .5682 | **2.841** |
| Slope Gradient (%) | 52.0000 | 52.0000 | 52.0000 | 52.0000 | 47.6292 | **255.6292** |
| Slope Length (m̄) (x) | 5.2020 | 4.0180 | 4.6177 | 4.5746 | 15.4365 | **33.8488** |
| Particle size (kg)<br>sand (%)<br>silt (%)<br>clay (%) | 58.0<br>11.0<br>31.0 | 49.0<br>13.0<br>38.0 | 48.0<br>18.0<br>34.0 | 56.0<br>12.0<br>32.0 | 57.0<br>7.0<br>36.0 | **268.0**<br>**61.0**<br>**171.0** |
| Vegetation Cover (dummy variable) | 4.2469 | 1.0263 | 2.3462 | 5.0917 | 7.0705 | **19.7816** |
| Infiltration Cap̄acity (cm̄/hr)(x) | 4.8200 | 5.9554 | 4.7831 | 4.5015 | 5.0723 | **25.1323** |

**Source:** Researcher's Fieldwork (*significant at the 0.001 Level)

## MEASUREMENT OF SLOPE LENGTH AND GRADIENT

Slope length and gradient constitute the morphological factors in soil erosion. Slope measurement in this study was carried out with the abney hand level, a 30m-field tape, a plumb bob and ranging poles. The gradients were measured both up and down the slope and the profiles measured along the steepest slope, according to King (1966). The distances were measured along the ground between ranging poles fixed at breaks of slope. Where there is a continuous curvature, and where the slope is uniform, the ranging poles were positioned to cover the full length of the tape apart. The acquired survey results were converted into vertical and horizontal distances by multiplying the measured distance by the sine and cosine of the slope angle respectively as proposed by Young (1964).

## MEASUREMENTOF PARTICLE-SIZE

Particle-size analysis is aimed at separation of the soil particles into a number of distinctive fractions between certain size limits such as sand, silt and clay contents. This was obtained using Robinson's pipette method. In this method, the soil samples are taken 15cm near the surface and at 30cm depth with the aid of an auger. Each soil sample was put in a well labeled transparent bag. This was repeated in each of the sample stations and taken to the laboratory at Soil Science Department, University of Calabar for analysis. The soil samples taken from the different land use sites were measured with the aid of a weighing balance, placed in a graduated sieve.

The sieves were arranged from the highest to lowest mesh and shaken for nine minutes. Before the dispersal and sieving, the clay cementing agents and insoluble salts were removed. Carbonates were removed using dilute Hydrochloric acid (Hcl).Organic matter was also removed with Hydrogen Peroxides as an oxidizing agent. The dispersal for subsequent analysis involved replacement of the exchangeable cations present in the clay with Sodium ions ($Na^+$). A five percent (5%) solution of the dispersal was added to the sample which suspended in the de-ionized water and shaken over night. The sieving dispersed clogged particles and used the wet sieve method and then the dispersed sample was poured onto a 0.063mm sieve and washed with de-ionized water until all the fines had passed through. The clastic particles on each of the sieve compactment were subsequently oven-dried at $100^0$C. The weights of the fractions of the soil samples as contained in each of the set of sieves were recorded in kilograms. Soil particle-size analysis is important to erodibility factor hence, a relationship between it and soil loss was established at the different land use types.

## MEASUREMENT OF VEGETATION COVER

Vegetation or cover crops were chosen to reflect all the possible surface management types in the region. Data set on vegetation cover was measured with the aid of a dummy variable technique. In which case, the value of one (1) was used to indicate the presence of vegetation and zero (0) was given to indicate where vegetation was not present or partially or sparsely present. Consequently, all measurements relating to vegetation were made by observation. Vegetation in the present study provided an environment over which soil loss was measured. Significantly, forests are scattered around the study area, farmlands are found around all over the region, grass lawn/gardens and bare ground are also found in numerous places as well as urban land use also situated in the built-up area, especially in the municipality.

## MEASUREMENT OF INFILTRATION CAPACITY

The maximum rate at which water can enter the soil at a particular point under a set of conditions is called infiltration capacity. Infiltration capacity of any basin is necessary in soil loss studies since its decrease or increase affects the soil water retention capacity at any given land use type. Hence infiltration capacity was chosen as one of the independent variables of this study to assess the water holding capacity of the different land use types. To achieve this, soil samples at the various land use sites were obtained with the aid of an auger. These were taken to the laboratory for test analysis of its capillary nature. In essence, the capillary characteristics of the samples denoted an index for the basin infiltration capacity of its soil. In the laboratory, a small sample of soil was put in a test tube and a small quantity of barium sulphate powder was added. Distilled water was then added and the test tube was shaken vigorously. A few drops of Butanol De-Hydrogenase (BDH) universal soil indicator were added and the solution was left for a few minutes for the reaction to take place. The soil particles settled at the bottom of the test tube leaving the liquid on top. The colours of the test tube were matched with the colours on the BDH soil pH colour chart. The soil capillary nature gives an ideal state of soil water retention and infiltration capacity. Therefore, there was need to compute soil infiltration capacity at varying land use types of the study area. For every event of rainfall, the pH values for each land use type were measured, giving rise to sixty-five times of measurements. Urban land use type (5.9-6.5), bare surface (6.4-7.1), farmland (6.4-7.2), grassland (5.9-6.4), forest (6.1-6.9). The results were then expressed in centimeters per hour (cm/hr), recorded and tabulated.

## MEASUREMENT OF RAINFALL-INDUCED SEDIMENT LOSS

Sediment loss measurement in this study involved the use of experimental plot approach. The methods entailed the use of experimental plots for five land use types - urban, farmland, grassland, bare and forest surfaces; generated by installing a 2 inch pipe 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 at 20% gradient slope oriented parallel to the topography.

The fieldwork was conducted for twelve months or one year between September, 2014 and October, 2015 to cover the two seasons and all rainfall events. During the period, every geomorphic variable during the one-year was monitored. Only sheet flows strong enough to dislodge sediments were included. Measurements of the dependent (Y) and independent (X) variables were simultaneous for all rainfall events from beginning to end of experimentation. Furthermore, only clastic sediment were evaluated. The study considered surface erosion limited to sheet flow process and not channel erosion.

Arising from the above, after every rainfall events, the sediments were removed from the sedimentation boxes and taken to the laboratory, oven-dried at a temperature range of $105\text{-}110^0$C. The sample were then placed in a Gallekamp Hotbox oven whose maximum operating temperature is $200^0$C and weighed. Weighing was done with a weighing scale as shown in **Plate 9** above. The measurements were multiplied with the dimensions of the experimental plot and then projected for kilograms per metre (kg/m). This was repeated for samples collected from every land use type of the study area and the results recorded and tabulated.

## METHODS OF DATA ANALYSIS

The data derived in this study were presented in standard management tools such as tabulations, means, standard deviations, percentages, scatter plots and graphical transformations for the purpose of statistical analysis. The acquired data were then processed and subjected to inferential analysis to give room for hypotheses testing. 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 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
$X_5$ = soil particle-size characteristics in kg
$X_6$ = vegetation cover in dummy variable
$X_7$ = infiltration capacity in cm/hr

## RESULTS AND DISCUSSION

The dependent and independent variables from five slope sides/land use types were generated for the purpose of the study, using experimental plots designed at GPS: Latitude $5^0 06^1$ -31.72"N and Longitude $8^0 17^1$ - 08.08"E of the study area. Consequently, the models below were developed in the study.

**Table 2: Models Developed in the Study**

| **Landuse Types** | **Coefficient of Determination %** | **F – ratio (Regression Equation)** |
|---|---|---|
| Urban Surfaces | 17.6 | $Y = 11.580 + 0.434x_1 + e$ |
| Bare Surfaces | 41.0 | $Y = 5557.614 + 0.965x_1 - 0.445x_2 + 26.606x_3 - 26.356x_4 + 0.231x_7 + e$ |
| Farm Surfaces | 32.1 | $Y = 20.307 + 0.576x_1 + e$ |
| Grass Surfaces | 14.7 | $Y = 27.213 + 0.400x_1 + e$ |
| Forest Surfaces | 8.4 | $Y = 2.683 - 0.356x_3 + e$ |
| Models | 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 0.001 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 17.6% of variation in sediment loss is explainable by urban surface, 41.0% of variation in sediment loss is explainable by bare surface, 32.1% of variation in sediment loss is explainable by farmland, 14.7% of variation in sediment loss is explainable by grassland, 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 in the Calabar River catchment.

Below are the detailed individual and joint contributions of the independent variables to sediment loss (dependent variable) from the various land use types.

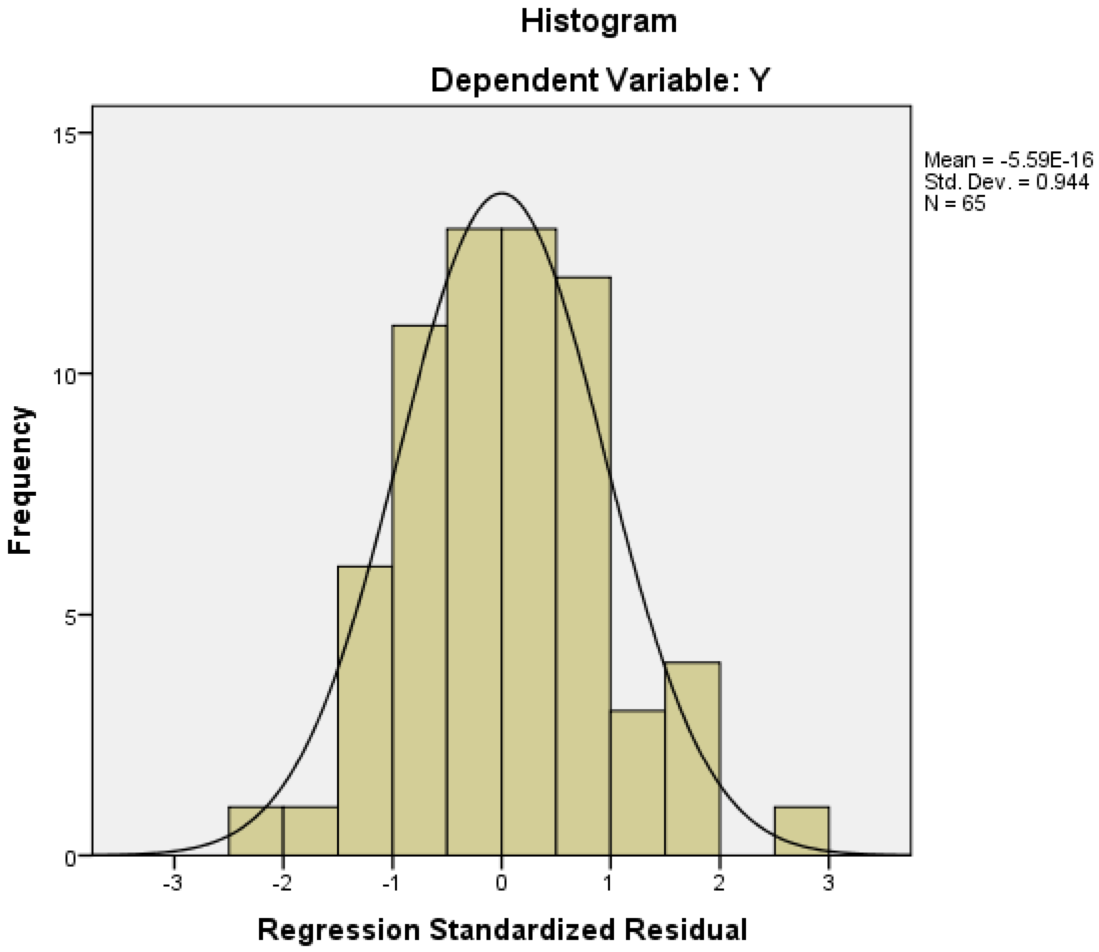

**Fig. 3:** Regression Standardized Residuals for Urban Surfaces

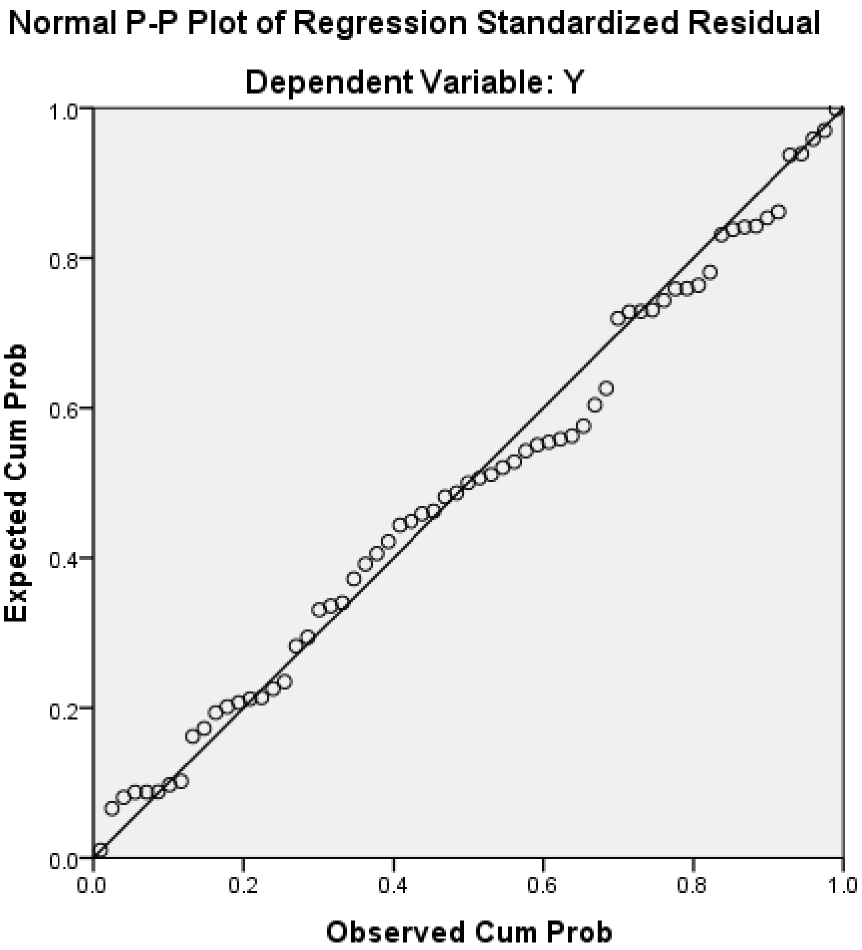

**Fig. 4:** Normal P- P Plots of Regression Standardized Residual for urban

**Table 3: Correlation Matrix for Bare surfaces**

| **Pearson correlation** | **Sediment Loss** | **Rainfall Amount** | **Rainfall Intensity** | **Slope Gradient** | **Slope Length** | **Particle-Size** | **Vegetation cover** | **Infiltration Capacity** |
|---|---|---|---|---|---|---|---|---|
| Sediment Loss | 1.000 | *.505 | .174 | -.148 | -.152 | .115 | -.246 | .036 |
| Rainfall Amount | | 1.000 | *.599 | -.602 | -.601 | .102 | -.424 | .063 |
| Rainfall Intensity | | | 1.000 | -.462 | -.464 | -.018 | -.373 | .543 |
| Slope Gradient | | | | 1.000 | 1.000 | .075 | .285 | -.175 |
| Slope Length | | | | | 1.000 | .076 | .289 | -.177 |
| Particle-size | | | | | | 1.000 | -.058 | -.015 |
| Vegetation cover | | | | | | | 1.000 | -.094 |
| Infiltration Capacity | | | | | | | | 1.000 |

**Source:** Computer Analysis Output of SPSS (*significant at the 0.001 Level)

The Table above arranges the independent variables based on their individual contributions to sediment loss. The result of Pearson product moment correlation coefficient of urban surface built into SPSS computer model shown above established positive correlation between rainfall amount and sediment loss of the basin. The coefficient (r) value of 0.505 was obtained and it was significant at 0.001 level.

The summary table arranges each of the independent variables according to the level of explanation which they provide for the dependent variable. The joint contribution of all the variables to the explanation of sediment loss is 99.9%. This shows that the choices of the independent variables are valid as they can be held to predict sediment loss from bare surfaces in Calabar river catchment.

The Analysis of Variance (ANOVA) shows that five independent variables significantly explain variation in sediment loss from bare surfaces in Calabar river catchment. From the Table, it is evident that rainfall amount, rainfall intensity, slope gradient, slope length and infiltration capacity can be used to predict sediment loss from urban surfaces. The equation for sediment loss from bare surfaces in Calabar river catchment is:

$Y = 5557.614 + 0.965x_1 – 0.445x_2 + 26.606x_3 – 26.356 x_4 + 0.231x_7 + e$ ….**eqn. 1**

The coefficient of determination signifies that all the five variables contributed to 41.0% to the sediment loss from bare surfaces. The coefficient of rainfall amount, rainfall intensity, slope gradient, slope length and infiltration capacity is $0.965x_1, -0.445x_2, 26.606x_3, -26.356x_4$ and $0.231x_7$ respectively and the intercept is 5557.614. The regression equation showed that rainfall amount is the major predictor in the model.

Other variables included in this study such as rainfall intensity, slope gradient, vegetation cover and particle-size were not included in the sediment loss model for Calabar river catchment. Their non-inclusion does not mean that these variables play no role in sediment loss from Calabar River Catchment. It only means that the extent is not statistically significant. The regression plots for the variable of significance in the explanation of sediment loss on bare surfaces are presented in Figs 5 and 6.

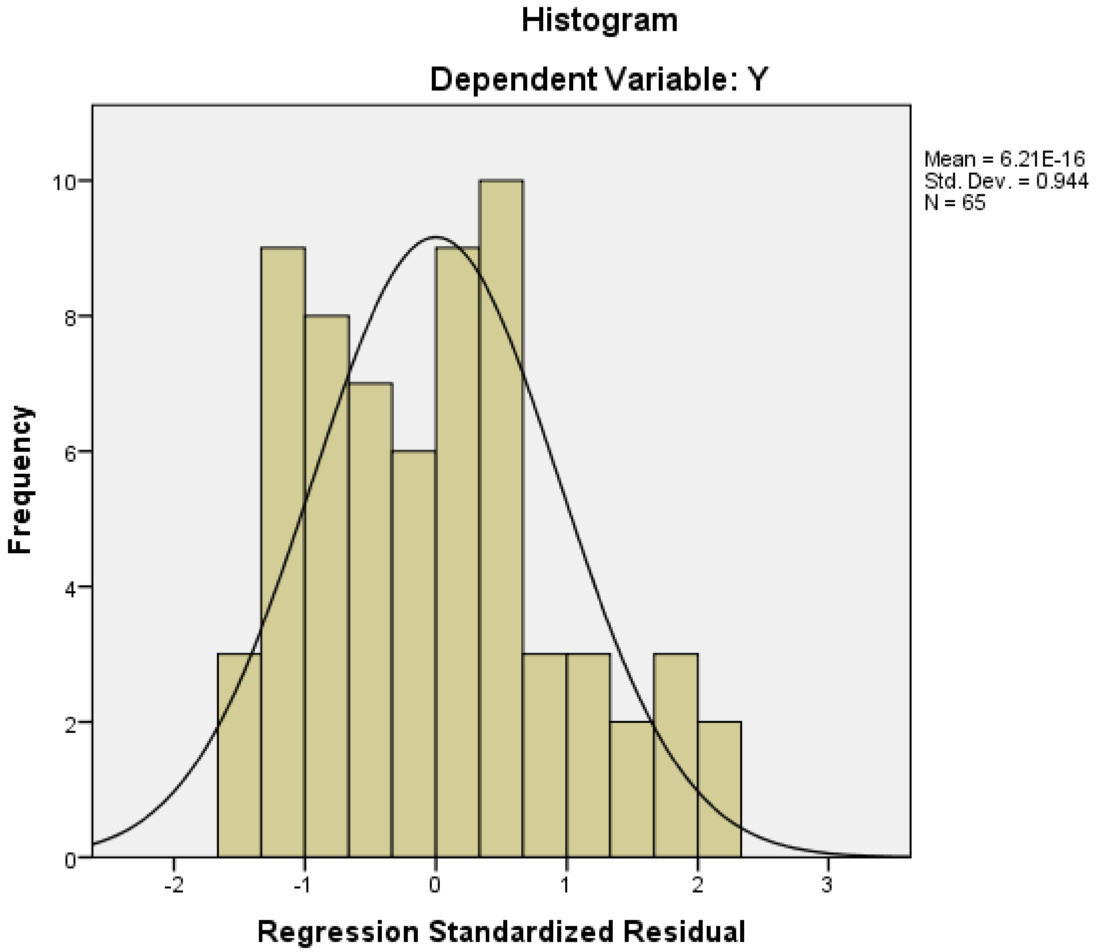

**Fig. 5:** Regression Standardized Residuals for Bare Surfaces

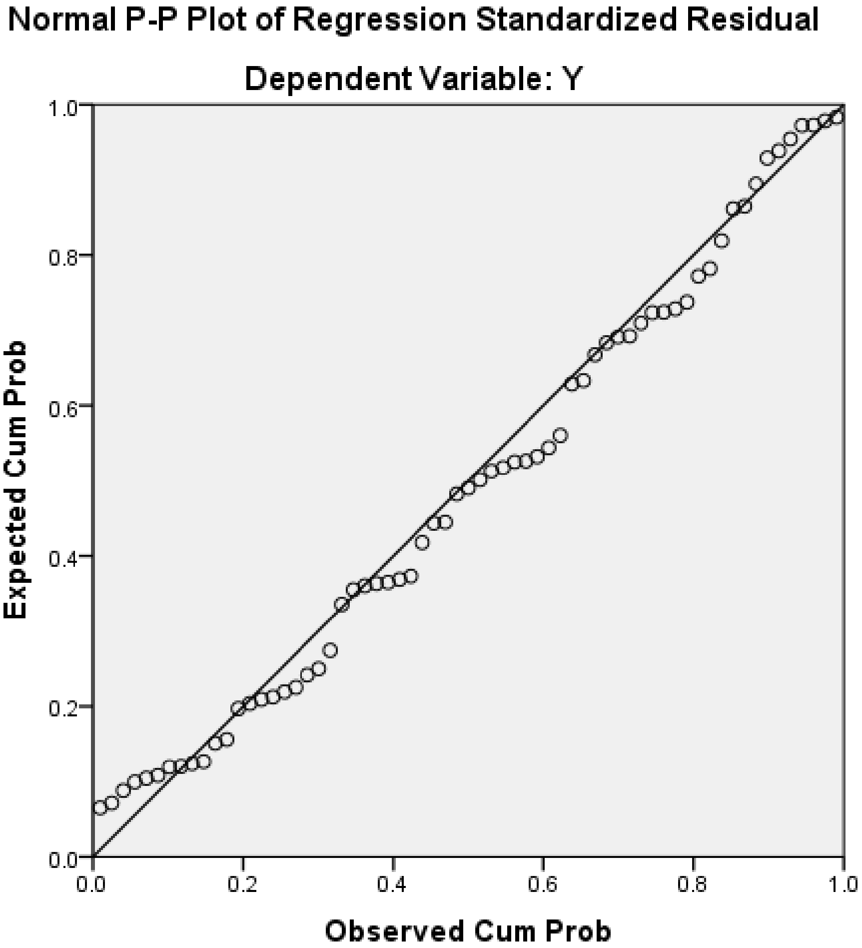

**Fig. 6:** Normal P- P Plots of Regression Standardized Residual for Bare surfaces

**Table 4: Correlation Matrix For Farm Surfaces**

| **Pearson correlation** | | **Sediment Loss** | **Rainfall Amount** | **Rainfall Intensity** | **Slope Gradient** | **Slope Length** | **Particle-Size** | **Vegetation cover** | **Infiltration Capacity** |
|---|---|---|---|---|---|---|---|---|---|
| | Sediment Loss | 1.000 | *.576 | .372 | -.447 | -.448 | .084 | -.336 | .112 |
| | Rainfall Amount | | 1.000 | *.599 | -.601 | -.604 | .102 | -.630 | .161 |
| | Rainfall Intensity | | | 1.000 | -.462 | -.464 | -.018 | -.541 | *.824 |
| | Slope Gradient | | | | 1.000 | 1.000 | .075 | .713 | -.356 |
| | Slope Length | | | | | 1.000 | .077 | *.720 | -.357 |
| | Particle-Size | | | | | | 1.000 | .059 | -.098 |
| | Vegetation cover | | | | | | | 1.000 | -.380 |
| | Infiltration Capacity | | | | | | | | 1.000 |

**Source:** Computer Analysis Output of SPSS (*significant at the 0.001 Level)

The table above arranges the independent variables based on their individual contributions to sediment loss. Sediment loss strongly correlated to rainfall amount on farmland in Calabar river catchment. The correlation coefficient (r) between the variables is 0.576 and was significant at 0.001 level.

The summary table arranges each of the independent variables according to the level of explanation which they provide for the dependent variable. The joint contribution of all the variables to the explanation of sediment loss is 99.9%. This shows that the choice of the independent variable is valid as it can be held to predict sediment loss from farmland in Calabar river catchment.

The Analysis of Variance (ANOVA) shows that one independent variable significantly explains variation in sediment loss in Calabar river catchment. From the Table, it is evident that only rainfall amount can be used to predict sediment loss from farmland surfaces. The equation for sediment loss under farmland in Calabar river catchment is:

$Y = 20.307+0.576x_1 + e$……………………..**eqn.2**

The coefficient of determination signifies that rainfall amount contributed 32.1% to the sediment loss from farm surfaces. The coefficient of rainfall amount is $0.576x_1$ and the intercept is 20.307. The regression equation showed that rainfall amount is the only predictor in the model.

Other variables included in this study such as rainfall intensity, slope gradient, slope length, infiltration capacity, vegetation cover and particle-size were not included in the sediment loss model for Calabar river catchment. Their non-inclusion does not mean that these variables play no role in sediment loss from Calabar River Catchment. It only means that the extent is not statistically significant. The regression plots for the variable of significance in the explanation of sediment loss on farm land surfaces are presented in Figs.7 and 8.

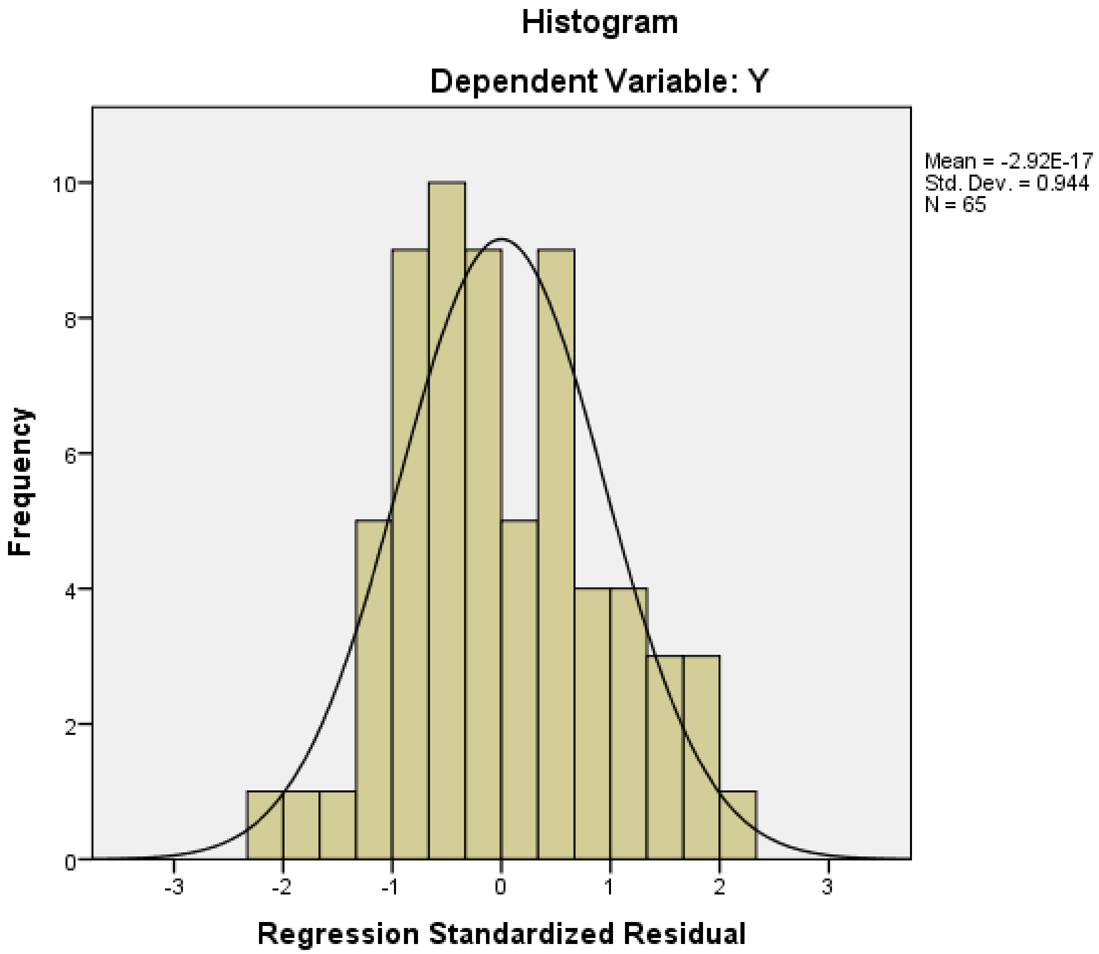

**Fig. 7:** Regression Standardized Residuals for Farm Surfaces

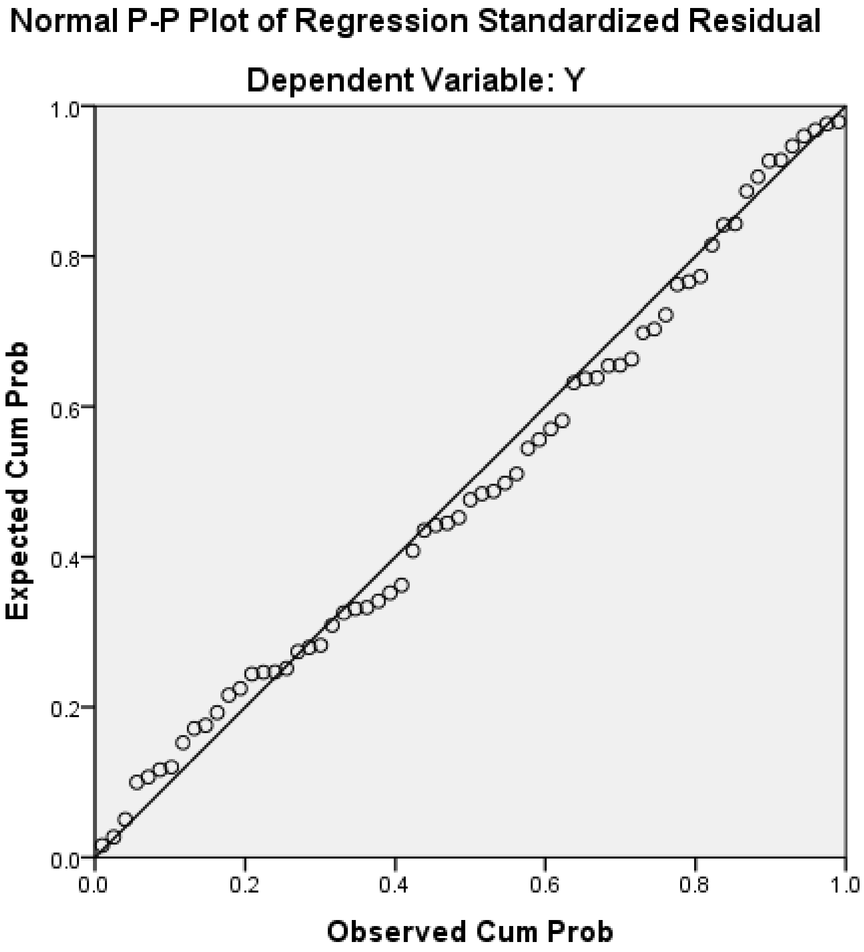

**Fig. 8:** Normal P- P Plots of Regression Standardized Residual for Farm Surfaces

**Table 5:** **Correlation Matrix For Grass Surfaces**

| **Pearson correlation** | **Sediment Loss** | **Rainfall Amount** | **Rainfall Intensity** | **Slope Gradient** | **Slope Length** | **Particle-Size** | **Vegetation cover** | **Infiltration Capacity** |
|---|---|---|---|---|---|---|---|---|
| Sediment Loss | 1.000 | *.400 | .223 | -.126 | -.124 | .110 | -.012 | .012 |
| Rainfall Amount | | 1.000 | *.599 | -.601 | -.605 | .102 | -.400 | .106 |
| Rainfall Intensity | | | 1.000 | -.462 | -.461 | -.018 | -.495 | *.782 |
| Slope Gradient | | | | 1.000 | *.999 | .075 | .675 | -.283 |
| Slope Length | | | | | 1.000 | .077 | *.667 | -.280 |
| Particle-Size | | | | | | 1.000 | .102 | -.112 |
| Vegetation cover | | | | | | | 1.000 | -.461 |
| Infiltration Capacity | | | | | | | | 1.000 |

**Source:** Computer Analysis Output of SPSS (*significant at the 0.001 Level)

The table above arranges the independent variables based on their individual contributions to sediment loss. Sediment loss is positively related to rainfall amount. The correlation coefficient (r) between these variables is 0.400 and was significant at the 0.001 level.

The summary table arranges each of the independent variables according to the level of explanation which they provide for the dependent variable. The joint contribution of all the variables to the explanation of sediment loss is 99.9%. This shows that the choice of the independent variable is valid as it can be held to predict sediment loss from Calabar river catchment.

The Analysis of Variance (ANOVA) shows that one independent variable significantly explains variation in sediment loss from Calabar river catchment. From the table, it is evident that only rainfall amount can be used to predict sediment loss from grass surfaces. The equation for sediment loss under grass surfaces in Calabar river catchment is:

$Y = 27.213 + 0.400x_1 + e$……….............**eqn.3**

The coefficient of determination signifies that rainfall amount contributed to 14.7% to the sediment loss from grass surfaces. The coefficient of rainfall amount is $0.400x_1$ and the intercept is 27.213. The regression equation showed that rainfall amount is the only predictor in the model.

Other variables included in this study such as rainfall intensity, slope gradient, slope length, infiltration capacity, vegetation cover and particle-size were not included in the sediment loss model for Calabar river catchment. Their non-inclusion does not mean that these variables play no role in sediment loss from Calabar River Catchment. It only means that their extent is not statistically significant. The regression plots for the variable of significance in the explanation of sediment loss from grassland surfaces are presented in Figs. 9 and 10.

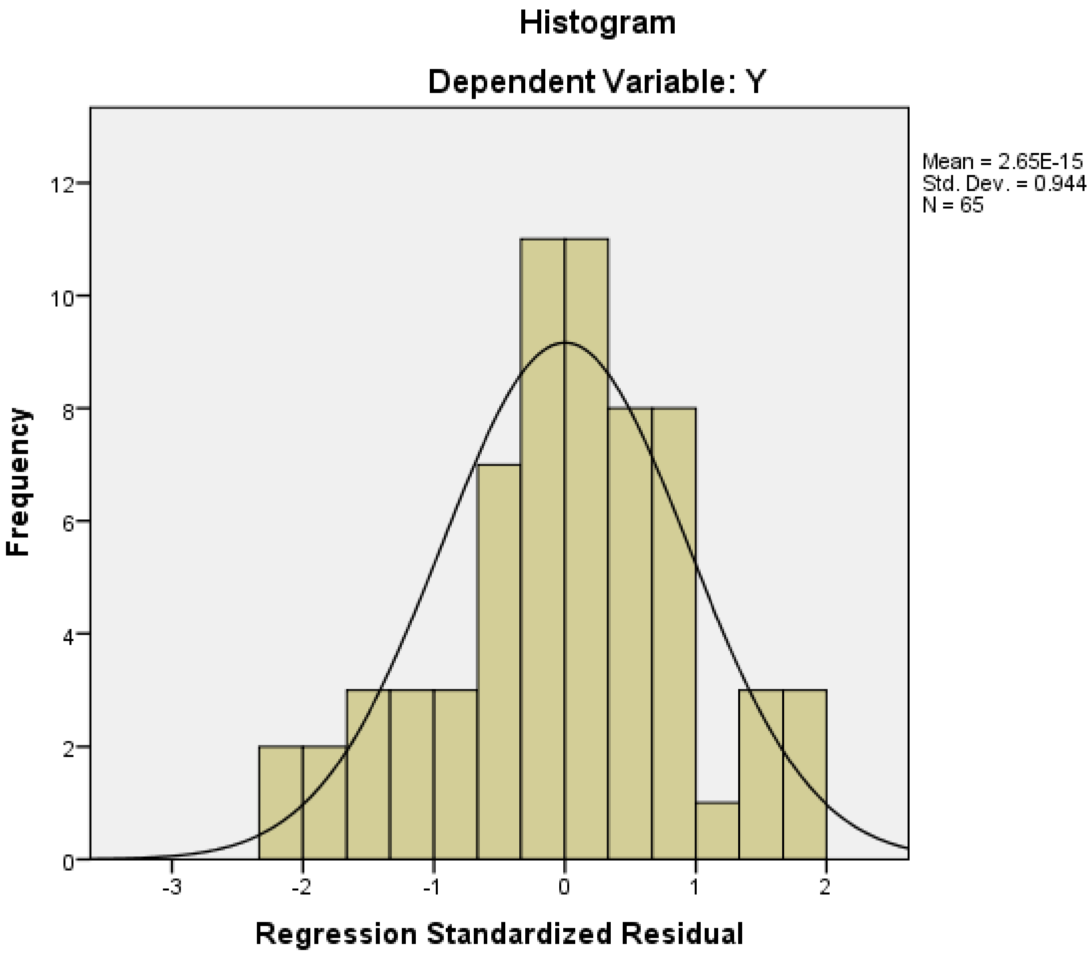

**Fig. 9:** Regression Standardized Residuals for Grass Surfaces

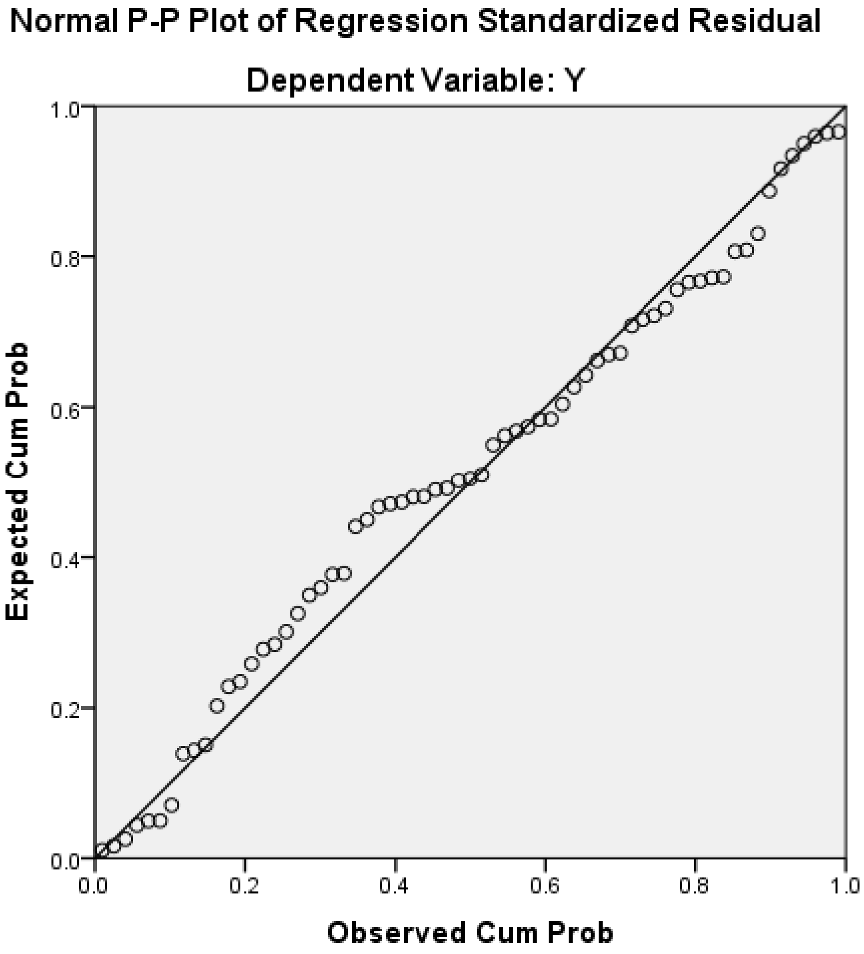

**Fig. 10:** Normal P- P Plots of Regression Standardized Residual for Grassland Surfaces

**Table 6:Correlation Matrix for Forest Surface**

| **Pearson Correlation** | | **Sediment Loss** | **Rainfall Amount** | **Rainfall Intensity** | **Slope Gradient** | **Slope Length** | **Particle-size** | **Vegetation cover** | **Infiltration Capacity** |
|---|---|---|---|---|---|---|---|---|---|
| | Sediment Loss | 1.000 | .067 | .241 | -.275 | .094 | -.218 | -.148 | .278 |
| | Rainfall Amount | | 1.000 | *.599 | -.472 | .359 | .114 | -.671 | .080 |
| | Rainfall Intensity | | | 1.000 | -.396 | .320 | -.011 | -.625 | *.790 |
| | Slope Gradient | | | | 1.000 | -.280 | -.038 | *.657 | -.250 |
| | Slope Length | | | | | 1.000 | -.184 | -.522 | .173 |
| | Particle-size | | | | | | 1.000 | .075 | -.134 |
| | Vegetation cover | | | | | | | 1.000 | -.375 |
| | Infiltration Capacity | | | | | | | | 1.000 |

**Source:** Computer Analysis Output of SPSS (*significant at the 0.001 Level)

The table above arranges the independent variables based on their individual contributions to sediment loss. Sediment loss was positively related to rainfall amount but not significant in the model. The correlation coefficient (r) between these variables is 0.067 and was significant at 0.001 level.

The summary table arranges the independent variables according to the level of explanation which they provide for the dependent variable. The joint contribution the variable to the explanation of sediment loss is 99.9%. This shows that the choice of the independent variable is valid as it can be held to predict sediment loss in Calabar river catchment.

The Analysis of Variance (ANOVA) above shows that one independent variable significantly explains variation in sediment loss in Calabar river catchment. From the table, it is evident that slope gradient can be used to predict sediment loss on forest surfaces. The equation for sediment loss from forest surfaces in Calabar river catchment is:

$Y = 2.683 – 0.356x_3 + e$.……......................................**eqn. 4**

The coefficient of determination implies that slope gradient accounted for 8.4% of sediment loss on forest surfaces in the Calabar river catchment. The coefficient of rainfall amount is $-0.356x_3$ and the intercept is 2.683.

Other variables included in this study such as rainfall amount, rainfall intensity, infiltration capacity, particle-size, slope length and gradient were not included in the sediment loss model also play indirect roles in sediment loss over Calabar river catchment. Their non-inclusion does not mean that these variables play no role in sediment loss from Calabar River Catchment. It only means that their extent is not statistically significant. The regression plots for the variables of significance in the explanation of sediment loss on forest are presented in Figs 11 and 12.

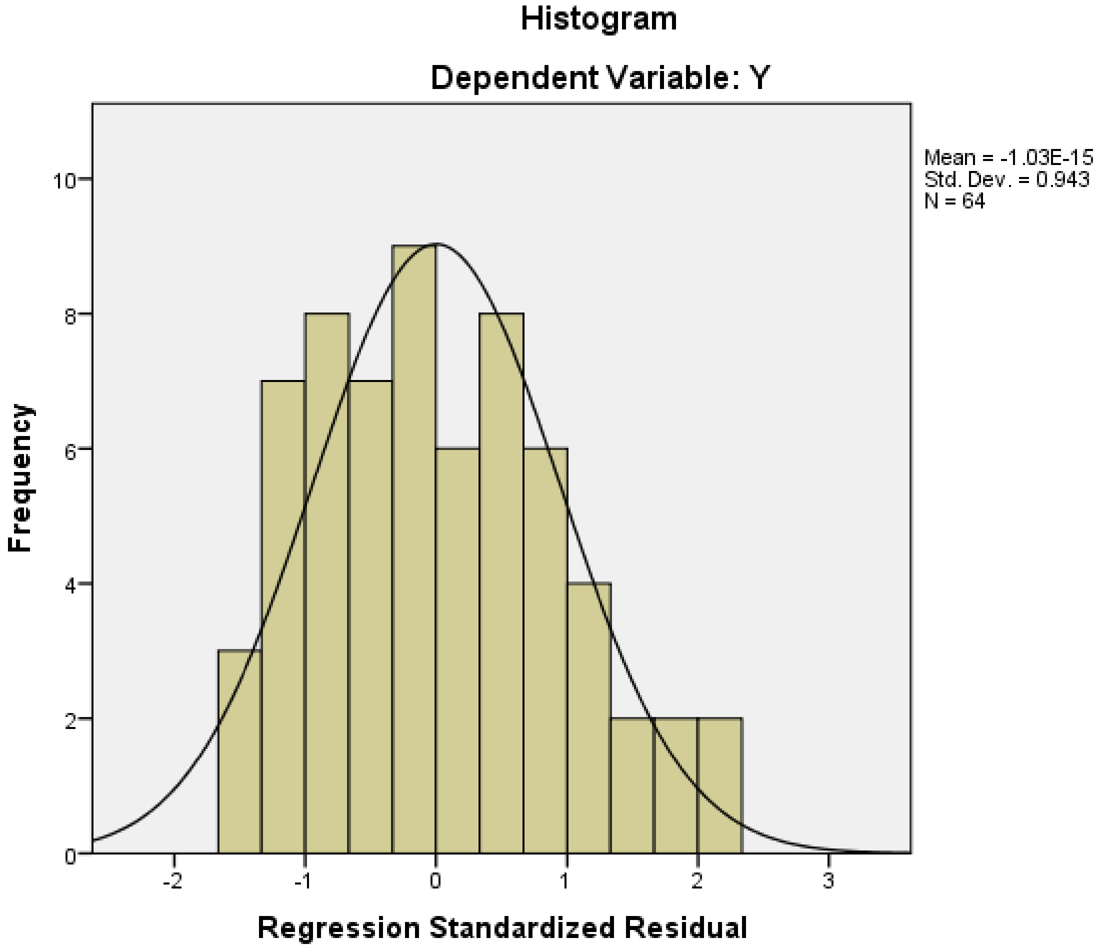

**Fig. 11:** Regression Standardized Residuals for Forest Surface

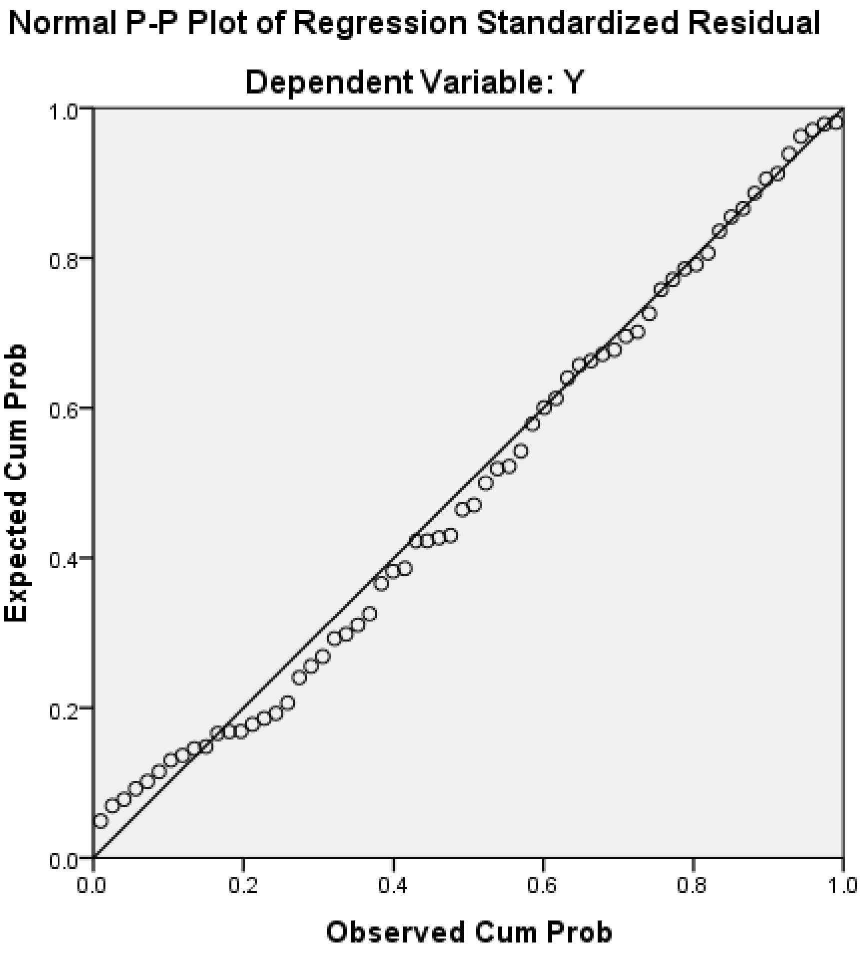

**Fig. 12:** Normal P- P Plots of Regression Standardized Residual for Forest Surface

**Table 7: Correlation Matrix For theModel of the Study**

| **Pearson Correlation** | **Sediment Loss** | **Rainfall Amount** | **Rainfall Intensity** | **Slope Gradient** | **Slope Length** | **Particle-size** | **Vegetation cover** | **Infiltration Capacity** |
|---|---|---|---|---|---|---|---|---|
| Sediment Loss | 1.000 | *.273 | .161 | -.173 | -.602 | .039 | -.518 | .045 |
| Rainfall Amount | | 1.000 | *.599 | -.601 | -.241 | .102 | -.199 | .069 |
| Rainfall Intensity | | | 1.000 | -.462 | -.183 | -.018 | -.227 | *.704 |
| Slope Gradient | | | | 1.000 | .419 | .075 | .204 | -.221 |
| Slope Length | | | | | 1.000 | .044 | *.673 | -.115 |
| Particle-size | | | | | | 1.000 | .015 | -.089 |
| Vegetation cover | | | | | | | 1.000 | -.203 |
| Infiltration Capacity | | | | | | | | 1.000 |

**Source:** Computer Analysis Output of SPSS (*significant at the 0.001 Level)

The table above arranges the independent variables based on their individual contributions to sediment loss. Sediment loss is positively related to rainfall amount. The correlation coefficient (r) between these variables is 0.213 and was significant at 0.001 level.

The summary table arranges the independent variables according to the level of explanation which they provide for the dependent variable. The joint contribution the variable to the explanation of sediment loss is 99.9%. This shows that the choices of the independent variables are valid as they can be held to predict sediment loss in Calabar river catchment.

The Analysis of Variance (ANOVA) shows that four independent variables significantly explain variation in sediment loss in the Calabar river catchment. From the table, it is evident that rainfall amount, slope gradient, slope length and vegetation cover can be used to predict sediment loss in the model. The equation for sediment loss in the model in Calabar river catchment is:

$Y = 62.521 + 0.268x_1 + 0.229x_3 – 0.532x_4 – 0.160x_6 + e$.................. **eqn. 5**

The coefficient of determination implies that rainfall amount, slope gradient, slope length and vegetation cover accounted for 42.4% of sediment loss in the model. The coefficient of rainfall amount, slope gradient, slope length and vegetation cover are $0.268x_{1,}$ 0.229, -0.532 and -532 respectively and the intercept is 62.521.

Other variables included in this study such as rainfall intensity, infiltration capacity, particle-size also included in the sediment loss model also play indirect roles in sediment loss over Calabar river catchment. Their non-inclusion does not mean that these variables play no role in sediment loss from Calabar River Catchment. It only means that their extent is not statistically significant. The regression plots for the variables of significance in the explanation of sediment loss on for the model are presented in Figs 13 and 14.

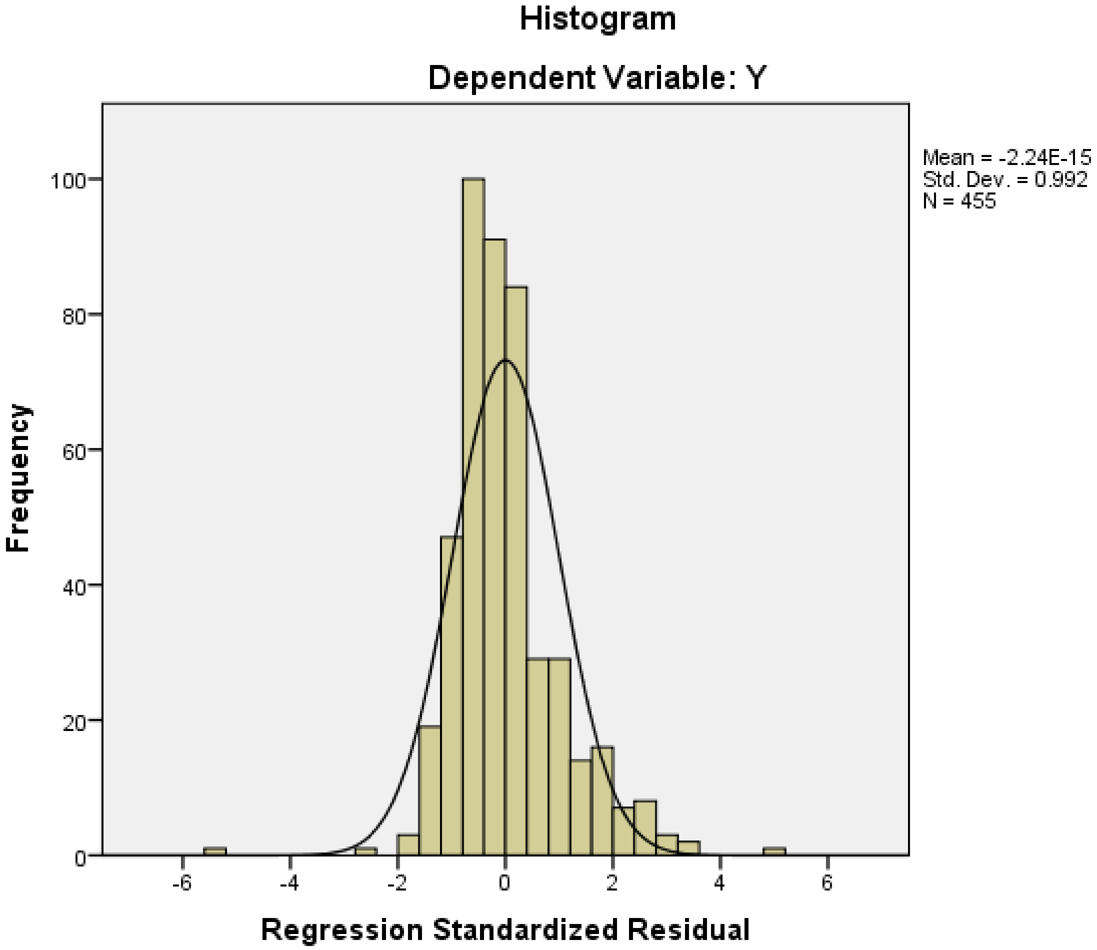

**Fig. 13:** Regression Standardized Residuals for the Model

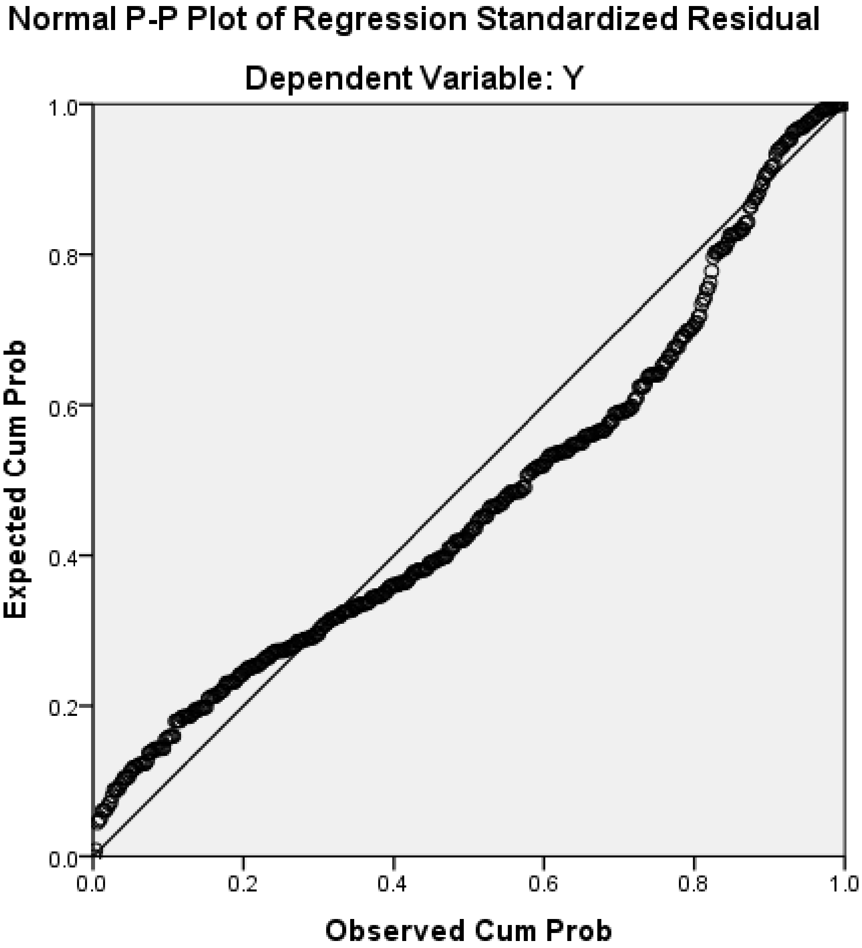

**Fig. 14:** Normal P- P Plots of Regression Standardized Residual for the Model

## SUMMARY AND CONCLUSION

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. To this end, all the models developed in this study are useful in explaining sediment loss in Calabar River catchment.

### VARIABLES OF SIGNIFICANT

In all the models of sediment loss developed, rainfall amount was significant at the 0.001% level. However, the degree of sediment lost in the landuse types varied in the model.

### RAINFALL AMOUNT

Rainfall amount had the greatest positive relationship and was significant at 0.05 level in all the landuse types in the study.

### RAINFALL INTENSITY

In this study, rainfall intensity had a negative relationship. Sediment loss by rainfall (raindrop splash) was greatest and most noticeable during short duration accompanied by high-intensity thunderstorms. The sediment lost caused by long-lasting and less intense storms was not as spectacular or noticeable as that produced during thunderstorms rather increased flood waters.

### INFILTRATION CAPACITY

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 increased runoff and sediment yield. However, the infiltration capacity of the soils varied with the level of vegetal cover on the landuse types.

### VEGETATION COVER

Vegetation cover of Calabar river catchment had a positive relationship that was not significant at the 0.001 level. This means that the absence of vegetation cover or depletion predominant at the surrounding environment of the basin in the study area is the result of increased sediment loss.

### SLOPE LENGTH AND GRADIENT

Slope length and gradient in the study had low positive relationships that were insignificant at the 0.001 level. In a region of high rainfall as Calabar river catchment, it implies that there is always sediment loss irrespective of slope length and gradient.

### PARTICLE-SIZE

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 runoff water; greater raindrop energy or runoff amounts was required to move the larger sand and gravel particles of Calabar river catchment.

## RECOMMENDATIONS

### MONITORING OF SEDIMENT LOSS

Calabar river catchment is an urbanizing area. Consequently, some of the surfaces are paved or cemented. Monitoring of sediment losses requires reforestation aimed at increasing the vegetation cover and infiltration capacity of the soil, thereby reducing the surface runoff. The presence of vegetation in this basin can also reduce nutrient and material loss to the river. Furthermore, legislation against indiscriminate felling or burning of trees is recommended. Furthermore, the researcher recommends sustainable forest resource management in the basin. There is the need to preserve the already existing forest at certain reaches of the stream. This is recommended because mature vegetation has a higher rainfall interception rate, a tendency to reduce rates of overland flow and generates soil with higher infiltration capacity and better general structure.

## MONITORING OF RAINFALLAMOUNT AND INTENSITY

In built-up areas like, storm wash from roofs and runoffs from paved surfaces concentrate into narrow paths. In a high rainfall region such as Calabar river catchment, the use of urban master plan incorporating well designed drainages is essential for the protection of surfaces from sediment loss.

## MONITORING OF SLOPE LENGTH AND GRADIENT

To reduce the velocity of sediment loss down the slopes requires that where slopes are extensive, structures constructed along them should be broken into reaches or terraces in order to shorten lengths and gradients. This is because the steeper the slope of a field, the greater the amount of sediment loss from erosion by water. Furthermore, soil erosion by water also increases as the slope length increases due to the greater accumulation of runoff and increased velocity of water which permits a greater degree of scouring (carrying capacity for sediment). Agriculturally, certain conservation measures can reduce soil erosion. Tillage and cropping practices, as well as land management practices, directly affect the overall soil erosion problem and solutions on a farm. For example, contour ploughing, strip cropping, or terracing may be considered

## MONITORING OF INFILTRATION CAPACITY

To increase the infiltration capacity of the soil aimed at reducing sediment loss, reforestation and establishment of forest reserves at designated areas should be encouraged. This will in turn increase permeability by displacing the soil particle size characteristics. Furthermore, legislation against indiscriminate felling/burning of trees and public enlightenment on dangers associated with felling/burning of trees. Generally, soils with faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion.

## MONITORING OF VEGETATION COVER

To reduce the amount of sediment loss, there is need for an increase in vegetation cover. To achieve this, reforestation and establishment of forest reserves are required. Plant and residue cover protects the soil from raindrop impact and splash, tends to slow down the movement of surface runoff and allows excess surface water to infiltrate. Soil erosion potential is increased if the soil has no or very little vegetative cover of plants and/or crop residues. The erosion-reducing effectiveness of plant and/or residue covers depends on the type, extent and quantity of cover. Vegetation and residue combinations that completely cover the soil, and which intercept all falling raindrops at and close to the surface and the most efficient in controlling soil (e.g. forests, permanent grasses).

## MONITORING OF PARTICLE SIZE

Sand, sandy loam and loam textured soils tend to be less erodible than silt, very fine sand, and certain clay textured soils. To displace the particle size characteristics by increasing the permeability/infiltration capacity of the soil requires increasing the vegetation cover by planting of trees and establishment of forest reserves.

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