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Impact of Rainfall Erosivity on Soil Loss Rates in Biu Area, Borno State, Nigeria

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Abstract:

Soil loss rate from rill erosion is severe because of high rainfall erosivity in Biu Area. The aim of this present study is to assess the magnitude of soil loss from erosivity of rainfall in Biu Area. Rain gauges were installed at six locations; Kigir, Daura, Garwashina, Mirnga, Tum and Piku from April to October (2016), to measure rainfall amounts. Wischmeier and Smith 1958, 1978 models were used to calculate rainfall and runoff factor (R). The Revised Universal Soil Loss Equation 2, (2008) was used to calculate erosivity and soil loss rates. The soil textures range from clay loam, loam, silty loam and sandy clay loam in the study area. Bulk density and percentage slope steepness range from 1.25 – 1.38 g/cm³ and 10.5 – 12.0 %, respectively. Kigir, Piku, Daura, Mirnga, Garwashina and Tum sites recorded the erosivity of 726, 730, 780, 710, 715, 701 MJmmha⁻¹hr⁻¹ and soil loss due to erosivity were 207.14, 248.96, 248.68, 243.02, 351.85 and 240.40 kg ha⁻¹yr⁻¹, respectively. Both erosivity and soil loss rates were significant ($P < 0.05$) at locational bases. The models showed low to high prediction strength at locational and annual bases.

Keywords: Erosivity, rainfall and runoff factor, bulk density, texture, slope steepness

1. Introduction

Erosivity reflects the effects of both rainfall amount and rainfall intensity on erosion. Intensity is the most important rainfall property which determines the amount of erosion in a specific location. Combination of high amount of rainfall with high intensity produces high erosion risk [3]. Rainfall characteristics become more variable and stochastic in the context of climate change, which increases the uncertainties and risk of water erosion in the real world [4]. The changes in precipitation are not the same all over the world. Rainfall amount was expected to increase in the USA [5], whereas Karl [6], denoted a decreasing rainfall trend for the Mediterranean area [7]. A number of theoretical modelling and empirical analysis have suggested that the striking changes in the frequency and intensity of extreme events including floods may occur even when there are only small changes in the mean climate [8, 9]. Thus soil erosion is a function of erosivity and soil erodibility (soil physical conditions, topography and vegetation / land use) [10]. Soil erosion on the sloping land has different level of difficulty in controlling erosion, the steeper the slope; the more the number of grains of soil is splashed by the impact of raindrop. This problem leads to the loss of soil slope stability due to the physical changes in the soil [11]. The eroded soil will be retained in chemical and physical properties such as loss of nutrient and organic matter, the increasing soil density and penetration resistance, the decreasing soil infiltration capacity and ability of soil to retain water. These events resulted in the decrease of land productivity and ground water recharge [12].

Biu lies on the Biu plateau at an average elevation of 768 m, the region is semi – arid, the local Government Area (LGA) is mostly located in the Northern Guinea Savannah (NGA) agro ecological zone with small portion in the north east, the kimba area lies in the drier Sudan savannah zone [13]. Despite the high erosivity problems, there is still lack of information on the scale and magnitude of scourge in Biu. The present research is expected to provide necessary information on the extent, measures and direction for prospective users including governmental agencies and a number of policy makers on their effort to manage erosion problems in the area.

2. Materials and Methods

The study was conducted in Biu, North Eastern Nigeria, in 2016. Biu town is located on latitude 10° 36' N and longitude 10° 13' E, with an elevation of 768 m above sea level. Six locations Garwashina, Piku, Mirnga, Tum, Kigir, and Daura were used for the analysis in the study area. Biu town has tropical climate consisting of dry season from November to March followed by wet season from April to October. The average rainfall of the area is 917.19 mm [31]. The soil types vary according to the slopes of the land and locations along which they are found [32].

2.1. Field Study

The rainfall data is the 10 year – twenty four hours (24) rainfall amount and was collected using a rain gauge device for all rainfall events during the study period. In this study the 10 year – 24 hours is term as the amount of rainfall received using a rain gauge between 9.00 am (the first day) and 9.00 am (the next day) totalling 24 hours duration having a 10 years return period. At each of the six locations, rain gauge was installed. And, rainfall data were collected from April to October, 2016. To determine the runoff factor (R) [18, 19] models were used. The models are as follows;

- $R = P \times 0.5$ [14]
- $E(KE < 25) = 9.28P - 8838$ [15]
- $EI_{30} = 0.276P \times I_{30}$ [16]

Where;

- R = run off factor
- P = precipitation
- E = erosivity
- KE = kinetic energy
- EI_{30} = energy x 30 minutes Intensity rainfall

Then the rainfall and run off factor gotten from the above equations was use to calculate erosivity and erosivity density of the study locations. The average of the above three models was taken for the analysis. The Universal Soil Loss Equation version two of 2008 (RUSLE 2,) was used to calculate soil loss at the various sites in the study area. The model is as follows;

$$a_i = r_i k_i l S c_i p_i \quad [2]$$

Where;

- a_i = long term average soil loss for ith day
- r_i = erosivity factor
- k_i = soil erodibility factor
- l = slope length factor
- S = slope steepness factor
- c_i = cover and management factor
- p_i = support practice factor

The above model (soft ware program) was used to generate soil loss in the study area in $\text{kg ha}^{-1} \text{ yr}^{-1}$. The erodibility computed in accordance with the corresponding erodibility factor units (k – values) for tropical soils describe by [17]. Slope length and steepness factor was measured using Theodolite. The length was measured in metres, and the steepness in percentage. Cover and management factor (C) was measured using [19] method. Support practice factor was estimated by [17] method.

2.2. Determination of Soil Physical Properties

The determination of soil physical properties was conducted in the laboratory following standard procedures. The particle size distribution was determined by Bouyous hydrometer method [20]. The bulk density (B_d) was determined by cloud method [29], while the water holding capacity was measured by gravimetric water content of a given quantity of soil fully saturated with water [20].

2.3. Soil Sampling Procedures

Soil sampling was conducted at six locations (Kigir, Piku, Daura, Mirnga, Garwashina, and Tum), in the study area. Large plot or water shed with the size of 100 m^2 [21], was used at each site. At each site one (1) large plot was selected at random and three soil samples were collected at each site for laboratory analysis. Eighteen composite samples were collected for one growing season for one year (2016), using bucket auger. Each soil sample was collected when moist in a new well – labelled Polyethene bag. The samples were air- dried ground and sieved through a 2 mm then prepared and analyse for some physical parameters that relates to soil erosion.

3. Data Analysis

The data generated were subjected to the RUSLE 2 model software program (RUSLE version 2.0) (2008), and used to generate the estimate of soil loss in the study area. Generalised linear model of statistic 10, statistical package version 10, (2013), statistically different means at $p < 0.05$ were separated using SE and LSD. The soil loss trend was determined using a polynomial curve for r^2 values, which showed monthly increase (positive) and decrease (negative) rates over seven months period.

4. Results and Discursions

4.1. Erosivity Distribution and Runoff in the Study Area

Table 1, shows annual rainfall, rainfall and runoff factor, and erosivity distribution of the various sites in the study area, based on 10 year – 24 hours precipitation. Daura site with high annual precipitation has high rainfall and runoff factor, high erosivity and high risk of erosion than Piku, Kigir, Garwashina, Mirnga and Tum sites. Precipitation and runoff factor and erosivity are significant at ($p < 0.05$). The average annual erosivity (R) is an index of erosivity at a location (the study area). Erosivity reflects the effects of both rainfall amount and rainfall intensity. The R – values in the study area

ranged from moderate to high. And, this showed that most of the rill and inter rill erosion were caused by moderate to high rainfall conditions within the study sites, that was why the 10 years – 24 hours precipitation was chosen for calculation of runoff [1,2]. Intensity is the most important rainfall property, which determines the amount of erosion in a specific location. Combination of high amount of rainfall with high intensity produces high erosion risk [3].

Study Site	Annual Precip. (mm)	Rainfall and Runoff Factor (mm)	Erosivity EI_{30} (MJmmha ⁻¹ hr ⁻¹)
Kigir	784.90	327.00	726
Piku	796.82	346.52	730
Daura	827.66	396.87	780
Mirnga	712.81	299.80	710
Garwashina	752.81	310.82	715
Tum	697.56	697.56	701
SE ± 0.05	20.58	16.01	11.44

Table 1: Annual Precipitation, Rainfall and Runoff Factor and Erosivity of the Study Sites

Key: EI_{30} = Energy X 30 Minutes Intensity Rainfall

Source: (Based On Field Study, 2016)

4.2. Topography, Texture and Bulk Density of the Study Sites

Table 2, shows the soil texture, percentage slope, and bulk density of the study sites. Piku and Tum sites have texture of loam, and Kigir and Garwashina have clay loam, while Daura and Mirnga have silty loam and sandy clay loam, respectively. The site topography was not the same, Kigir, Daura, and Garwashina portray mountainous topography while Mirnga and Tum depicted a hilly topography and Piku showed a steep topography. The least resistant particle to erosion is silts and fine sands. Thus soils with high silts content are highly erodible. Similar observations were made by [23, 24, 25, and 3], that soils with high silt content are the most erodible and soil with restricted clay fraction, are the most susceptible to erosion. Daura, Mirnga and Tum sites with slope percentage of 10.5, and Kigir, Piku and Garwashina have slope percentages each of 12.0% and are high erodible, because the slope percentage surpasses 5%. This observation concurs with that of [26], that percentage slope steepness less than 5% erosion hazard is negligible. Bulk density played a mitigating effect on soil loss (erosion) in the study area. This concurs with the report of [22, 28 and 3], that soil loss bulk density is a strong mitigatory of erosion process as obtained in this study.

Site	Slope	%Slope Steepness	Texture	Bulk Density (g/cm ³)
Kigir	mountainous	12.0	CL	1.25
Piku	steep	12.0	L	1.38
Daura	mountainous	10.5	SL	1.38
Mirnga	hilly	10.5	SCL	1.38
Garwa.	Mountainous	12.0	CL	1.38
Tum	hilly	10.5	L	1.33
SE (± 0.05)		0.011 ns		0.029 ns

Table 2: Slope Percentage, Texture and Bulk Density of the Study Sites

Source: (Based on Field Data, 2016); CL = clay loam, L = loam, SL = silt loam, SCL = sandy clay loam

4.3. Soil Loss in the Study Area

Table 3, shows soil loss at various sites in the study area. High soil loss was recorded at Garwashina, Piku, Daura, Mirnga and Tum sites with the values of 351.85, 248.96, 248.68, 243.02, and 240.40 kgha-1yr-1, respectively. And, Kigir site depicted low value of soil loss at 207.14 kgha-1yr-1. Erosivity distribution EI_{30} ranged from 780 to 701MJmmha-1hr-1 (Table 1). Daura recorded the highest erosivity followed by Piku, Kigir, Garwashina, Mirnga and Tum in the order of 780, 730, 726, 715, 710 and 701MJmmha-1hr-1, respectively. Increase in rainfall erosivity will lead to increase in soil loss, and decrease in rainfall erosivity depicts a reduction in soil loss. Daura recorded high erosivity but with lower soil loss than Garwashina which recorded erosivity value lower than Daura site. These may be due to slope percentage differences at both sites (Table 2). These observations agree with that of [22 and 2], that storm erosivity is a function of both amount of rainfall and rainfall intensity and these caused soil loss in the study area.

Study Site	RUSLE 2, Predicted (kgha ⁻¹ yr ⁻¹)
Kigir	207.14
Piku	248.96
Daura	248.68
Mirnga	243.02
Garwashina	351.85
Tum	240.40

Table 3: Soil Loss at the Study Area

Source: (Based On Field Data, 2016)

5. Conclusion

The impact of rainfall erosivity was quantified using [18, 19 and 30], under same condition of Biu environment. The pattern and rate of erosivity and mass of soil loss confined to rainfall amount as the season progressed. Daura recorded the highest erosivity followed by Piku, Kigir, Garwashina, Mirnga and Tum sites in the order of 780, 730, 726, 715, 710, and 701 MJmmha-1hr-1, respectively. And, high soil loss due to rainfall erosivity was depicted at Garwashina, Piku, Daura, Mirnga, and Tum sites with the values of 351.85, 248.96, 248.68, 243.02 and 240.40 kgha-1 yr-1, respectively. Kigir site showed low value of soil loss at 207.14 kgha-1yr-1. Daura site recorded high erosivity, but with lower soil loss than Garwashina, which depicted erosivity value lower than Daura site. These may be due to slope percentage differences at both sites. The model showed low to high prediction strength at locational bases.

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