Rainfall Erosivity Estimation in North central Nigeria using Monthly Rainfall Data

Article · February 2017

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Abstract
Soil erosion and flooding are major sources of pollution in most states in north central Nigeria. North central Nigeria is reputed as the food basket of Nigeria. Effective planning and execution of soil erosion control measures for the region requires knowing the quantitative values of the factors that contribute to soil erosion. One of such factors is rainfall erosivity factor. In this study, rainfall erosivity factors for selected states in north central Nigeria was estimated using long-term daily, monthly and annual rainfall data. Results showed that the rainfall received between 1981 and 2010 were highly erosive, with the annual rainfall erosivity for the study period being consistently greater than the threshold value of 160 mm. Correlation between annual rainfall and annual erosivity for the studied period revealed a low ($r = 0.490$) and high ($r = 0.898$), ($r = 0.770$) and ($r = 0.827$) significant ($p<0.01$) positive relationship for Ilorin, Lokoja, Jos and Minna climatic stations, respectively. It is concluded that the states being covered in this study are highly prone to soil erosion hazard. The study provides information on the aggressiveness and erosive power of rain in north central Nigeria that is necessary for better planning of soil and water conservation measures in the region.

Keywords: Rainfall erosivity, soil erosion, storms, soil and water conservation.

Introduction

Soil erosion which is the detachment of soil particles, its transportation and eventual deposition away from its original site is undesirable from the standpoint of soil and water conservation, crop productivity and environmental sustainability. The perturbations arising from soil erosion include the washing away of top soil, sedimentation of surface waters and reservoirs, pollution of aquatic ecosystems, increased turbidity of rivers and streams, decreased soil fertility with consequent reduction in crop yield and less income to the farmer. Rainfall erosivity is the potential ability of rainfall to cause erosion under different conditions. It is one of the most important of the six soil erosion dependent factors used for the quantitative evaluation of soil loss in the Universal Soil Loss Equation (Wischmeier and Smith, 1978). Research has shown that rainfall amount and intensity are the most significant causes of high soil erosion rates in the tropics (Foster *et al.,* 1982). The rainfall erosivity factor (R-factor) is the product of the storm kinetic energy (E) and the maximum 30 minutes rainfall intensity (I_{30}). The sum of the values of the R-factor for all the rain in a month gives the monthly value, while the sum of monthly values gives the annual value. The average value of the factor in a definite period is estimated based on the arithmetic mean of the average values.

It has been established that EI_{30} is a reliable index for the prediction of erosivity (Lal, 1994; Yin *et al.,* 2007). In order to compute storm EI_{30} values, continuous rainfall intensity data are needed. More importantly, at least 20 years of pluviograph data are needed for the computation to accommodate the natural climatic variation as recommended by Wischmeier and Smith (1978). However, in most developing countries such as Nigeria, detailed information on both rainfall amount and intensity necessary for a direct estimation of the R-factor is usually not available. This has led to research efforts on alternative means of computing the erosivity factor for a given watershed based on available data. Accordingly, Renard and Freimund (1994) summarized methods for estimating the R-factor in various parts of the world and also developed a new set of relationships for calculating the R-factor using mean annual rainfall data and the modified Fournier index.

As pointed out by Ezemonye and Emeribe (2012), rainfall erosivity studies in Nigeria have received very little attention especially as regards their spatial variations. Most studies on soil erosion and its effects undertaken in Nigeria are limited to Southern Nigeria (Lal, 1976; Lal, 1984; Ahaneku, 1998; Salako, 2008; as well as Ezemonye and Emeribe, 2012).Attempts to extrapolate the research information on soil erosion from the south for use in the north are seldom satisfactory due to large variability of climate, soil and topography between the two regions.

The aim of this study was to evaluate the spatial variation of rainfall erosivity in north central Nigeria using long-term rainfall depth data.

Materials and Methods

Study Area

The north central states of Nigeria include Nasarawa, Kwara, Plateau, Niger, Kogi, and Benue. The north central states of Nigeria lie in the upland Guinea savanna of Nigeria. This study is limited to Kwara, Kogi, Niger and Plateau states because Benue and Nasarawa states did not have reliable and consistent long-term rainfall data as at the time of data collection. Ilorin, Lokoja, Minna and Jos are the capitals of the states, respectively. Ilorin covers an area of 36,825 square kilometers. The area lies between Latitude 8° 30' 16" N, and Longitude4° 34' 13" E, it has mean annual relative humidity of 76%. The annual temperature ranges from 24.5^{0}C to 35^{0}C, while the mean annual rainfall is 1318mm.Lokoja lies between latitude 7°30'N and longitude 6°42'E, and covers an area of 29,833 square kilometers, with annual relative humidity of 73%. The annual temperature ranges from 22.8^{0}C to 33.2^{0}C, and the annual average rainfall is 1016mm. Minna is located between latitude 9°39'N and longitude 6°28'E, and covers an area of 76,363 square kilometers. It has annual average temperature of 27°C, mean annual rainfall of 1300mm and mean annual relative humidity of 44.4%. Jos covers an area of 53,600 square kilometers, and lies between latitude 9°56'N and longitude 8°53'E, with altitude of 1,217 m above sea level. It has the most temperate climate compared to other parts of Nigeria with average monthly temperatures range from

21° to 25°C. From mid-November to late January, night time temperatures drop as low as 11°C resulting in chilly nights. There is the presence of hail stones during the rainy season due to the cool high altitude weather. The city of Jos receives about 1,400 mm rainfall annually, coming from both conventional and orographic sources due to its location on the Jos plateau. Generally, the soils of the study areas support plant cultivation which has contributed to large scale food production in these areas and the country at large. As a result of this, large percentages of the inhabitants are involved in farming activities. The people practice both mixed cropping and shifting cultivation. The most commonly grown crops in this region are maize, melon, yam, pepper, rice, tomatoes, okra, groundnut, beans, sorghum, and sugar cane, among others. Fig.1 shows the map of Nigeria indicating the study areas.

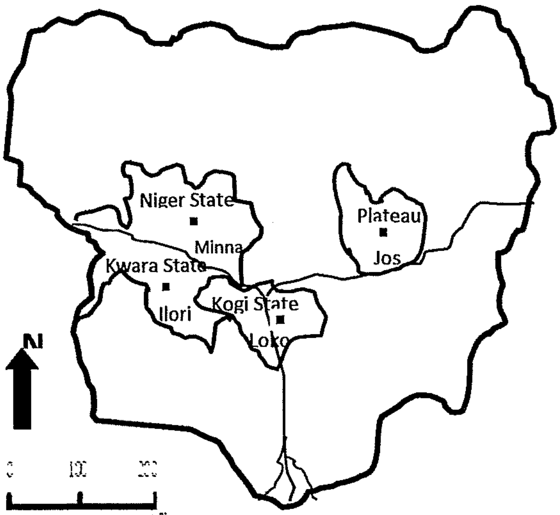

Fig 1: Map of Nigeria showing Kwara, Kogi, Niger and Plateau States.

Calculation of Erosivity Index

Rainfall erosivity factor signifies the erosive power of rainfall. It is the index that defines the interdependence of soil loss and rainfall.

North central Nigeria fall under zones which receive limited rainfall relative to states in southern Nigeria, and several procedures have been developed to estimate erosivity index (R) for such areas. The rainfall data used in computing the rainfall erosivity index (R) for the study areas was obtained from the Nigeria Meteorological Agency (NIMET), Abuja for a period of 30years (1981-2010). The data include the daily, monthly and annual rainfall depths for the areas. The erosivity index R for the study areas was estimated using the modified Fournier index (Arnoldus, 1977) given as:

$$EI_{30} = 0.0302 \times (RI)^{1.9} \qquad (1)$$

Where RI = $\sum (MR)^2 / AR$; MR = Monthly rainfall, AR = Annual rainfall, and 0.0302 (constant for kinetic energy for places with limited rainfall such as Northern Nigeria).

The method was considered ideal due to the fact that rainfall data in the study areas lack rainfall intensity records necessary to compute the erosivity index EI_{30}. The rainfall data used for the computation of rainfall erosivity index (R) in this study were only rainfall amount that are greater than or equal to 25mm for 30minutes. This is in line with the submission of Hudson (1981) that only rainfall amount that are greater than or equal to 25mm in depth could cause erosion in the tropics. The annual rainfall amount was obtained by summing up the entire monthly rainfall amount for a given year. This was calculated for 30years (1981 to 2010) for Ilorin, Lokoja, Minna and Jos stations.

In computing the rainfall erosivity for a station, a program was written to generate the rainfall erosivity using the personal home package tool (PHP version 5.1) using average monthly and annual rainfall values. Microsoft Excel was used to calculate the erosivity in other to cross check the values gotten from the personal Home package tool (PHP).

Statistical Analysis

Correlation and regression analysis of the data was carried out using Statistical Package for the Social Scientists (SPSS, version 20.0) software. To establish the degree of relationship between the annual rainfall amount and the estimated annual rainfall erosivity, Karl Pearson's Coefficient of Correlation was used.

Results and Discussion

Rainfall erosivity

The results of the annual rainfall erosivity (R) estimated for Ilorin, Lokoja, Jos and Minna stations for the period 1981-2010 are presented in Tables 1, 2, 3 and 4, respectively.

Table 1. Annual Rainfall Erosivity for Ilorin, 1981-2010

Year	Annual Rainfall (mm)	Annual Erosivity (mm)	Year	Annual Rainfall (mm)	Annual Erosivity (mm)
1981	742.00	370.88	1996	426.80	248.63
1982	593.50	248.67	1997	787.70	428.97
1983	634.20	1078.66	1998	1086.70	898.85
1984	730.00	310.12	1999	741.60	208.23
1985	497.50	286.93	2000	424.80	118.41
1986	706.30	196.60	2001	272.10	110.45
1987	637.10	318.84	2002	312.40	234.81
1988	476.50	83.07	2003	634.20	1078.66
1989	201.90	135.98	2004	771.60	363.47
1990	371.60	180.89	2005	849.90	382.08
1991	791.00	359.75	2006	679.20	187.05
1992	506.70	243.32	2007	790.40	335.54
1993	429.20	159.29	2008	721.40	412.95
1994	686.00	220.01	2009	700.30	357.01
1995	714.20	281.50	2010	387.50 714.20	117.60

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				714.20	

Table 2. Annual Rainfall Erosivity for Lokoja, 1981-2010

Year	Annual Rainfall (mm)	Annual Erosivity (mm)	Year	Annual Rainfall (mm)	Annual Erosivity (mm)
1981	638.40	274.02	1996	784.10	344.47
1982	376.10	112.02	1997	945.60	540.61
1983	418.10	147.00	1998	637.40	218.04
1984	513.10	184.04	1999	1218.80	782.12
1985	401.00	220.43	2000	540.80	194.40
1986	693.90	383.06	2001	622.30	335.93
1987	654.40	357.43	2002	849.00	357.87
1988	878.40	652.02	2003	649.90	425.08
1989	1078.50	595.75	2004	870.10	487.30
1990	577.40	223.21	2005	544.30	133.44
1991	819.40	336.16	2006	1288.40	1122.6
1992	463.90	305.19	2007	955.90	405.86
1993	478.10	211.59	2008	565.20	272.80
1994	711.30	317.32	2009	1009.30	639.35
1995	791.50	326.59	2010	608.40	163.61

Table 3. Annual Rainfall Erosivity for Jos, 1981-2010

Year	Annual Rainfall (mm)	Annual Erosivity (mm)	Year	Annual Rainfall (mm)	Annual Erosivity (mm)
1981	478.80	145.62	1996	493.00	184.46
1982	605.00	498.41	1997	631.20	347.03
1983	509.00	362.85	1998	468.80	230.06
1984	560.10	223.49	1999	308.20	78.04
1985	333.80	155.52	2000	476.20	230.28
1986	578.40	344.29	2001	584.50	375.96
1987	673.10	369.08	2002	760.00	392.66
1988	441.70	122.03	2003	551.50	281.73
1989	552.10	348.60	2004	420.70	135.44
1990	487.50	206.39	2005	460.40	205.57
1991	646.30	279.30	2006	453.10	139.00
1992	512.40	260.09	2007	609.50	363.93
1993	379.60	391.78	2008	451.60	142.12
1994	454.00	151.08	2009	364.20	159.59
1995	310.10	72.69	2010	484.20	266.73

Table 4. Annual Rainfall Erosivity Minna, 1981-2010

Year	Annual Rainfall (mm)	Annual Erosivity (mm)	Year	Annual Rainfall (mm)	Annual Erosivity (mm)
1981	960.8	673.42	1996	1130.3	888.52
1982	976	542.60	1997	1256.4	659.27
1983	834.5	508.91	1998	997.7	515.85
1984	991.5	493.53	1999	1154.6	596.10
1985	1358.7	1040.64	2000	1180	992.13
1986	935.3	473.99	2001	1256.6	1038.31
1987	1183.5	1017.41	2002	1015.6	570.56
1988	1094.5	637.71	2003	1068	549.63
1989	1116.4	715.22	2004	1181.4	785.47
1990	1202	728.37	2005	1190.7	767.33
1991	1363.5	872.53	2006	1116	850.34
1992	936.7	425.00	2007	1295	872.92
1993	1366.6	877.28	2008	1340.4	1036.79
1994	1159.8	1079.98	2009	1523	1464.09
1995	1066.8	701.94	2010	1273.4	936.42

Based on rainfall erosivity index classification (Table 5), the annual rainfall erosivity for Ilorin, Lokoja, Jos, and Minna fell within the very high erosivity category. Ilorin recorded the highest rainfall erosivity of 1078.66 mm in both 1983 and 2003, while the lowest rainfall erosivity of 83.07mm was recorded in 1988.

Table 5. Rainfall erosivity index classification based on Modified Fournier Index.

Rainfall Erosivity Range	Interpretation
0-60	Very low
61-90	Low
91-120	Moderate
121-160	High
Above 160	Very High

Source: Arnoldus (1980).

Low erosive years generally coincided with years of low monthly rainfall amounts and vice versa. This is because EI_{30} is a power function of RI which depends on monthly rainfall depth. The highly erosive rain for Ilorin station has a return period of 20 years (Table 1).Such erosive rains lead to high floods as witnessed in Ilorin and environs in 2003 when Asa river overflew its banks. The highest rainfall erosivity for Lokoja amounting to 1122.36 mm was recorded in 2006, while the lowest (112.02 mm) was recorded in 1982.Though the long-term average rainfall erosivity for Lokoja station is high (Fig.2),it did not show a clear cyclic trend. The highest erosivity for Jos of 498.41mm was recorded in 1982, while the lowest (72.69mm) was recorded in 1995.

Jos station has the least long-term average erosivity among the four stations studied (Fig. 2). Minna had the highest rainfall erosivity of 1464.09mm in 2009 and the lowest (425.00mm) in 1992.

Table 4. Annual Rainfall Erosivity Minna, 1981-2010

Year	Annual Rainfall (mm)	Annual Erosivity (mm)	Year	Annual Rainfall (mm)	Annual Erosivity (mm)
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1985	1358.7	1040.64	2000	1180	992.13
1986	935.3	473.99	2001	1256.6	1038.31
1987	1183.5	1017.41	2002	1015.6	570.56
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1989	1116.4	715.22	2004	1181.4	785.47
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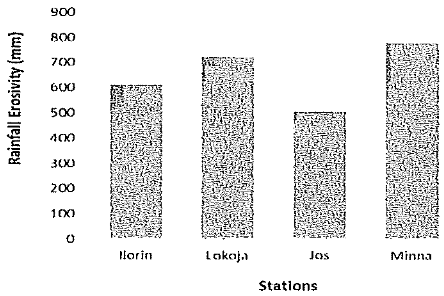

Fig. 2: Long- term average rainfall erosivity for the stations

Fig. 2 shows that the long-term average rainfall erosivity in Minna station (777.08mm) was generally greater than the average erosive power of rainfall in Lokoja (719.43mm), Ilorin (610.14mm), and Jos (501.30mm) stations. This is due to the fact that Minna station recorded higher mean monthly rainfall than other stations. Minna station also witnessed more frequent higher rainfall erosivity values that were greater than 1000mm which occurred 6 times within the study period of 3 decades. The outcomes of this study are in accordance with the findings of Angulo-Martinez and Begueria (2009) that very few events are responsible for a large part of annual rainfall erosivity. Annual rainfall erosivity displayed temporal variability in all the climatic stations for the study interval (Tables 1-4). In particular, the annual rainfall erosivity for Minna climatic station were similar to those of south eastern Nigeria with annual rainfall exceeding 2500mm. Ezemonye and Emeribe (2012) reported 1111.0mm annual rainfall erosivity for Owerri with over 8 months of rainfall per year and 1400.0mm annual rainfall erosivity for Calabar with over 9 months of rainfall per annum. The higher erosivity values of Minna and Lokoja stations may probably be the reason why the two states of Niger and Kogi were adversely affected by flood than the other states in north central Nigeria during the 2012 rainy season when flood ravaged many states in Nigeria.

Annual Rainfall-Rainfall Erosivity Relationship

The result of the Karl Pearson's Coefficient of Correlation (Table 6) indicates very high positive degree of relationship between annual rainfall amount and annual rainfall erosivity for the 30 years period for Lokoja, Minna and Jos and moderate positive relationship for Ilorin. The r values for Ilorin (0.490), Lokoja (0.898), Jos (0.770) and Minna (0.827), indicate a high degree of positive correlation between annual rainfall and annual rainfall erosivity.

Table 6. Product Moment Correlation Coefficient for the climatic stations

Location	r Value
Ilorin	0.490
Lokoja	0.898
Jos	0.770
Minna	0.827

*r was significant at 0.01 level

Furthermore, the regression analysis of rainfall erosivity and rainfall depth for these stations (Table 7) displayed great closeness between the Karl Pearson's coefficient of correlation r and the coefficient of correlation (R) in the regression. This is also reflected in the coefficient of determination (R^2) obtained, especially those of Lokoja, Jos and Minna stations as indicated in Table 7.

Table7. Deterministic relationship between Annual Erosivity and Annual Rainfall

Location	R	R^2	Adjusted R of the estimate	Std. Error	Sig. (2-tailed)
Ilorin	0.490	0.240	0.213	224.423	0.006
Lokoja	0.898	0.807	0.800	97.809	1.618
Jos	0.737	0.543	0.527	75.563	3.391
Minna	0.827	0.684	0.673	135.199	0.001

R was significant at 0.01level of significance.

The adjusted R of the estimates and their corresponding standard errors indicate that the estimation of the parameters is satisfactorily accurate at the given level of significance (0.01) and that the results are reliable. Angulo-Martinez and Begueria (2009) using daily rainfall data found that daily rainfall erosivity models accurately predicted annual rainfall erosivity.

The results of this study show that rainfall amount received within Ilorin, Lokoja, Jos, and Minna is highly erosive as revealed by the erosivity index of the areas which are greater than the threshold value of 160 mm (Arnoldus, 1980). This result is in agreement with that of earlier researchers (Salako, 2008; and Balogun *et al.*, 2012) who obtained similar results independently in southern Nigeria. However, there was slight variation in the results reported by Salako (2008) and Balogun *et al.* (2012). This may probably be due to the fact that the areas in their study fell under the regions that receive high intensity rainfall. Atawoo and Heerasing (1997) also obtained similar result in Mauritius using the same method adopted in this study. However, there was little variance in the estimated rainfall erosivity values in this study compared with that obtained in Mauritius. This may probably be due to differences in rainfall pattern in the two different regions, and also the quality of rainfall data used by Atawoo and Heerasin (1997) which were not long-term data, as only a year data was used in their study. According to Klik and Konecny (2011), for good and reliable result to be obtained in the estimation of rainfall erosivity factor of a place, long-term data of at least two decades is needed to reduce coarseness of the result.

Conclusion

Rainfall erosivity factor in north central Nigeria was estimated using 30 years monthly rainfall data. The results obtained showed that rainfall received within Ilorin, Lokoja, Jos and Minna stations and by extension north central Nigeria were highly erosive as indicated by their erosivity indices that are greater than the threshold value (160mm) for the study locations for most of the years. Also, the results of the correlation analysis revealed a positive degree of relationship between rainfall amount and rainfall erosivity. The estimated erosivity indices which are very high for the study locations signify risk of soil erosion hazards, especially under conditions of increasing rainfall amount and some anthropogenic activities such as over grassing, felling of trees, inappropriate cultivation methods, among others which take place in most parts of north central Nigeria. The results of this study will serve as a useful guide in developing soil protection and management strategies that would assist in minimizing the risk of soil erosion within the region.

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