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NATURE AND PATTERN OF RAINFALL EROSIVITY (R) BASED ON ANNUAL RAINFALL DISTRIBUTION OVER SOME CITIES IN SOUTHERN NIGERIA

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Abstract

The present study is aimed to the nature and pattern of rainfall erosivity based on annual rainfall distribution over some cities in Southern Nigeria. Synoptic stations covered include Warri, Benin City, Akure and Ibadan. Monthly rainfall data was collected from the office of Nigeria Meteorological Agency for the period 1970-2012. Rainfall Erosivity Factor (R) was determined using estimation models proposed by Nguyen (1996), Teh (2011), Renard and Fremund, Yu and Rosewell and Roose (1976). Modified Fournier Index was adopted in estimating rainfall intensity (R). Warri town recorded the highest mean monthly rainfall value of 227.34mm while Ibadan had the least value of 96.69mm. Annual rainfall was also highest in Warri with an annual mean value of 2779.85mm, while Ibadan also recorded least annual mean value of 1289.35mm. This pattern is expected. as Warri town is a coastal and lies about 4,409 km from Atlantic Ocean and 304 km to the Gulf of Guinea which may play important roles in influencing evaporation and cloud formation, wind and precipitation pattern across the town. Monthly rainfall pattern over study area assumes a bi-modal distribution and sufficient rainfall would not start until April. Rainfall peaks between July and September, followed by a short dry break in August known as the 'August break', before the second peak in September. Warri recorded highest rainfall erosivity index which correlates to the rainfall intensity, rainfall kinetic energy and rainfall amount. This was followed by pattern observed for Benin City. The fact that Warri town and Benin City are characterized by very high erosive rainfall is an indication that depending on the nature of soil texture and predominate land use activities, these areas are highly prone to erosion by running water. It is recommended that sustainable environmental practices including planting of tress should be supported by policies to reduce the intensity, velocity of flow and kinetic energy of rainfall drop on soil.

Keywords: Annual rainfall, flooding, rainfall erosivity, rainfall intensity, soil loss

1. Introduction

Soil loss by runoff is a severe ecological problem occupying 56% of the world wide area [1] and the same is true specifically in Nigeria, because of its implications for food security, the natural environment and in view of climate change impact. Since independence, like with most countries of the world, Nigeria has witnessed growing populations and economies both of which are driving expansion of urban built-up areas in the form of urbanization across the country. From 2017 to 2050, nine countries including Nigeria are expected to account for half of the world's projected population increase [2]. About 70% of this population is expected to dwell in urban centers, and as urbanization progresses, urban land use changes, making room for the area of impervious surfaces and, as a consequence, result in reduced infiltration during storm events, hence increased direct runoff that will eventually alters urban hydrologic processes [3, 4]. Soil erosion is a product of an altered hydrological process, and a serious environmental problem across the world. In many cases, soil erosion causes an almost irreversible decline in soil productivity and other soil functions [5, 6]. Soil erosion selectively detaches the colloidal fractions of soils and carts them away in runoff [7]. These soil colloidal fractions (clay and humus) ordinarily are required for soil fertility, aggregation and structural stability of soil.

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The negative impacts of soil removal is expected to be on the rise in Africa, owing to increasing pressure occasioned by population expansion, coupled with fragmentation of land resources. For example [8] reported that the shortage of land, rapid growth of population and demand for more food production intensified the pressure on the land and aggravated the process of land degradation in Ethiopia. In the humid tropics, soil erosion by water is a key factor limiting soil productivity and affecting agricultural outputs. This is evident in many regions of Africa, mainly in the humid and sub-humid zones of Sub-Saharan Africa (SSA) where population pressure and deforestation exacerbate the situation and the rains come as torrential downpours, with the annual soil loss put at over 50 tons ha^{-1} [9]. Considering the different factors involved in soil loss, rainfall erosivity R, is one of the most important factors as it plays a major role in the initial detachment of top soil. Rainfall erosivity is the potential ability of rainfall to cause soil loss [10], and represents the climate influence on water related soil erosion [11]. Higher velocity and larger size of the raindrops results in higher kinetic energy and higher soil loss. Soil particles are detached from the soil surface by the beating action of raindrops and shearing force of flowing water [12]. Most soil erosion researchers and soil conservationists recognize the positive correlation between erosivity and rainfall intensity [13,14,15]. The Universal Soil Loss Equation (USLE) is an empirical erosion model for predicting long-term average annual soil loss resulting from rainfall events from field slopes in specified cropping and management systems and rangelands [16]. Many authors have used rainfall erosivity index (R factor) in RUSLE as indicator of soil erosion [17-22], because rainfall is the main source of energy for detachment and transport of soil particles from the soil profile [23]. Studies have also found that R factor for a particular soil varies considerably on storm, season and year bases and geographic location [24, 22]. The reason is mainly due to the variation in rainfall and antecedent soil conditions. In view of the above this has become undertake a potentials ability of rains to induce erosion on spatial basis in the tropical environment of Nigeria. Generally rainfall erosivity indices are divided into two; based on kinetic energy and rainfall intensity, and secondly, based on rainfall available data. In the first group rain intensity or kinetic energy or both of them are used to some extent in calculating erosivity index. The most famous indices of this group are EI_{30} [25] ArIm [26], KE>1 [27] and $P/\sqrt{t}$ [28] where P is the mean annual precipitation (mm) and t is time in years. Unfortunately, one of the drawbacks of the indices based on kinetic energy and rainfall intensity is that they require long–term statistics (above 20 years) of rainfall intensity (with short interval) of weather stations equipped with rain gauge[25]. Unfortunately these long statistics are usually not readily available in most developing countries especially for long-term periods [20]. To improvise studies have adopted the indirect method based on annual and monthly rainfall distribution especially in the tropics (e.g. [29-36]). In the absence of data on rainfall intensity, the present utilizes the estimation methods based on monthly and annual rainfall distribution as have shown to be suitable in other studies.

2. Study Area

The study area include selected towns in southern Nigeria (Fig. 1). Synoptic stations covered include Warri, Delta state (05:31'N and 05:44'E), Benin City, Edo State (06:19'N and 05:06'E), Akure, Ondo State (07:06'N and 04:50'E) and Ibadan, Oyo State (07:26'N and 03:54'E). The climate is tropical monsoonal and is marked by two distinct seasons: the dry season and the rainy season. The dry season lasts from about November to April and is significantly marked by the cool "harmattan" dusty haze from the north-east winds. The rainy season spans May to October with a brief dry spell in August, but it frequently rains even in the dry season. Mean annual rainfall in the study area ranges from 1290mm in Ibadan to 2800 in Warri. The study area has a mean annual temperature of 32.8 °C and annual rainfall amount of 2768.8 mm. There are high temperatures of 28 °C and 32 °C.

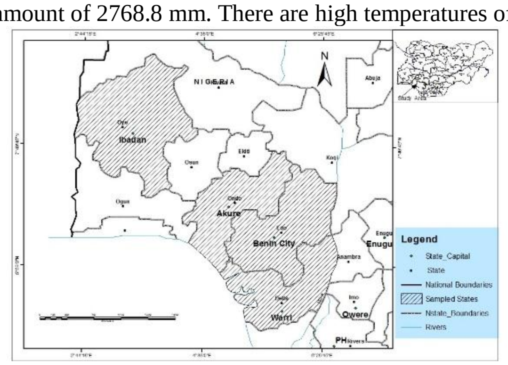

Fig 1: Map Showing Ibadan, Akure, Benin City, and Warri

2.1. Rainfall Data

Monthly rainfall data was collected from the office of Nigeria Meteorological Agency at different periods for the selected synoptic stations as follows, Warri (1983-2012), Akure (1980-2012), Benin City (1970-2012) and Ibadan (1970-2012)**.** Rainfall data was used in computing Erosivity (R) value over Benin City.

2.2. Rainfall Intensity

One major limitation to a wide use of the USLE in the tropics is the lack of data to estimate the rainfall intensity *R*. An alternative procedure to estimate *R* is the MFI of Arnoldus [37]. The formula to calculate Modified Fournier Index (MFI), as used in previous research on Mauritius, is as follows [37];

$$\text{MFI} = \sum^{12} i = 1 \frac{(\text{MR})2}{AR} \text{AR} \quad (1)$$

Where *MR* is the monthly rainfall and *AR* is the annual rainfall.

MFI has a direct correlation with the rainfall intensity and as such the MFI results can be used as Rainfall intensity [38]. The correlation of the R factor with the data measured was calculated by applying the Modified Fournier Index (MFI) for a linear relationship. It further strengthens the relationship between the R and the F/MFI/P that had already been proven by numerous researches earlier, however, it does not exclude further analyses.

2.3. Kinetic Energy from Rainfall Intensity

The erosiveness of storms in the study area was determined as a function of rainfall kinetic energy using the model developed by [39]. The choice of the model was based on the fact that the method was developed using tropical rainfall samples. Besides, its development was based on direct measurements of rainfall kinetic energy with a piezoelectric sensor that can convert impact strain of a rainfall into an electrical signal within the sensing element The equation for computing Kinetic energy of rain is given as;

$$K.E = (41.4\,Ra - 120) x\,10^3 [38] \quad (2)$$

Where K.E is rainfall kinetic energy (ergscm-2)

Ra is rainfall amount per storm (mm).

2.4. Erosivity Index (EI_{30})

Then *RI* was substituted in the equation below to estimate EI_{30}:

$$E1_{30} = 0.0302\,x\,R1^{1.9} \quad (3)$$

Where RI is the rainfall intensity

The Modified Fournier Index uses mean monthly and mean annual precipitation data for the same period. Thus, the correlation between the rainfall intensity (R) and the Modified Fournier Index (MFI) data series was estimated. The results derived from the MFI was used to calculate values for the rainfall intensity and the erosivity index. The so-gained correlation between the R and the MFI was used to do the calculations for this period. By employing it as a linear relationship, we could estimate the R values as we also had knowledge of the MFI values of this period.

2.5. Rainfall Erosivity Factor (R)

R factor is the coefficient of the average erosion by rain (J/m^2). Rain is a direct impact to the surface of soil; its kinetic energy is destroying the soil structure and brings the soil components together with runoff water. According to Wischmeier and Smith [25], the R coefficient is calculated based on maximum rain volume in 30 minutes, the equation is following:

$$R = \frac{EI_{30}}{1000} \quad (4)$$

In which E is the kinetic energy of the rain (J/m^2)

I is the maximum rain volume in 30 minutes (mm/h)

2.6. Estimation of R from annual Rainfall Distribution

In the absent of data on rainfall intensity data for the study area, this study adopted equations to estimate the R factor based on the available rainfall data.

Nguyen [40] method is based on the average rainfall year, the equation is following:

$$R = 0.548257P - 59.9 \quad (5)$$

In which P is the average rainfall year (mm/year) [39].

According to Teh [36] method, R is in MJmm/(hahr) and P is the annual precipitation in mm.

$$R = \frac{2.5P^2}{100(0.073P+0.73)} \quad (6)$$

Renard and Fremund [30], developed a power function to estimate the rainfall erosivity as a function of mean annual precipitation in the Continental US. Their equation had an r^2 value of 0.81.

$$R = 0.04830P^{1.510} \quad (7)$$

Also using a power function, [31] established a relationship to estimate the R factor based on mean annual precipitation in Southeastern Australia in 1996. Their relationship was y good, with an r^2 value 0.91.

$$R = 0.0438P1^{1.61} \quad (8)$$

Roose [41] model for estimating values of rainfall erosivity from rainfall amounts for West African climates. The equation is given as:

$$R = (0.0158\,H\,x\,1_{30}) - 1.2 \quad (9)$$

Where R is the index of erosivity in mmh^{-1}, H is rainfall amount (mm) and I_{30} is rainfall intensity in 30minutes. Rainfall erosivity values computed for our study area were compared with the Rainfall Aggressivity Index (RAI) developed by Fournier [42] and modified by Arnoldus, [37] Table 1.

Table 1: Rainfall Aggressivity Index (RAI)

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

(Source: Modified from Arnoldus, 1980)

3. Results

Average monthly and annual rainfall distribution is well represented in the Figures 2 - 9 From Figs 2 & 3, it can be seen that in the year 1995, Warri experienced the highest rainfall distribution of 3436.8mm and the least with 2368.6mm in 2005. Fluctuation in rainfall distribution over Warri town showed sign of a steady trend line. Rainfall was highest in Benin City in the year 2011 with a total value of about 3064mm and a least value of 1234.7mm in 1977. The trend line of the rainfall distribution over Benin City exhibited almost a constant increasing trend as well as marked difference between wet and dry years. Similarly, in the year 1991, Akure experienced the highest rainfall distribution of 1909.3mm and the least with 1026.4mm in 2001. The trend-line of the rainfall distribution was almost constant because there was no much difference in the rainfall distribution. It was discovered that in the year 1980, Ibadan experienced the highest rainfall distribution of 1967.7mm and the least with 600.8mm in 1970. On the whole, Ibadan town showed a steady rise in rainfall during the year under investigation. On seasonal basis, Warri town recorded the highest seasonal rainfall distribution in the month of July with 465.03mm and the least seasonal rainfall distribution in the month of January with 30mm. Benin City on the other hand had the highest seasonal rainfall distribution in the month of July with 302.65mm and the least seasonal rainfall distribution in the month of January with 14.65mm (Figs 4 and 5). In Akure town seasonal rainfall was highest in the month of September with 232.14mm and the least seasonal rainfall distribution in the month of December with 8.25mm (Figs 6 and 7). It was discovered that Ibadan has the highest seasonal rainfall distribution in the month of September with 176.3mm and the least seasonal rainfall distribution in the month of January with 4.16mm (Figs 8 and 9).

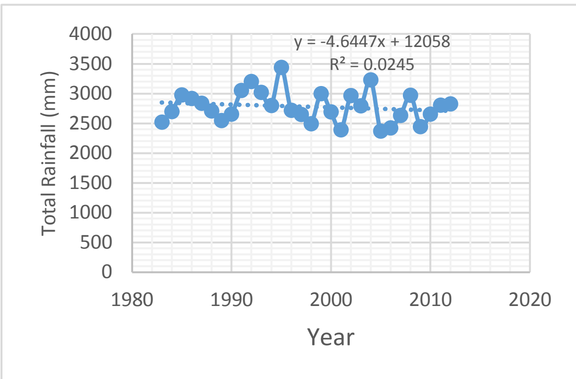

Fig 2: Annual Rainfall Distribution over Warri (1983-2012)

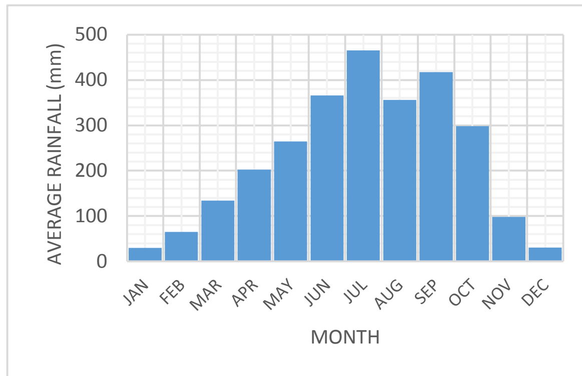

Fig 3: Seasonal Rainfall Distribution over Warri (1983-2012)

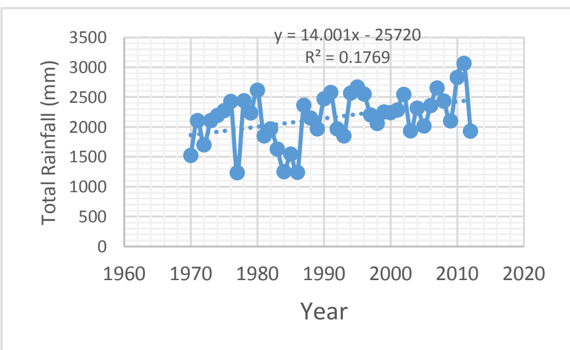

Fig 4: Annual Rainfall Distribution over Benin-City (1970-2012)

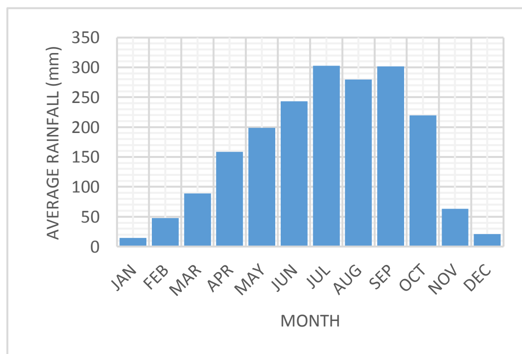

Fig 5: Seasonal Rainfall Distribution over Benin-City (1970-2012)

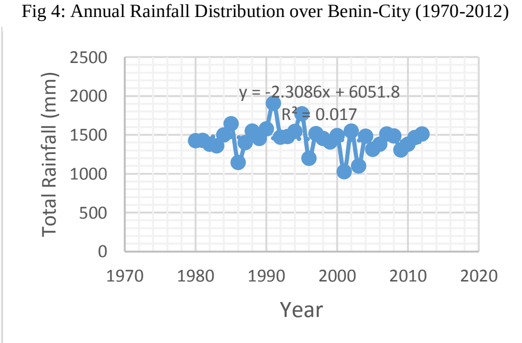

Fig 6: Annual Rainfall Distribution over Akure (1980-2012)

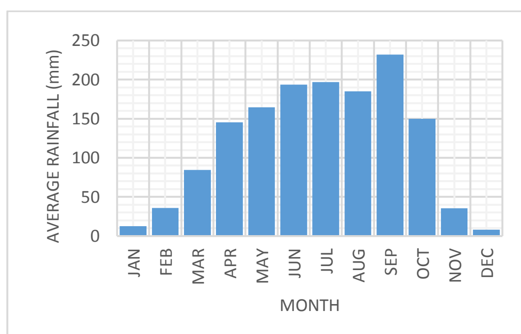

Fig 7: Seasonal Rainfall Distribution over Akure (1980-2012)

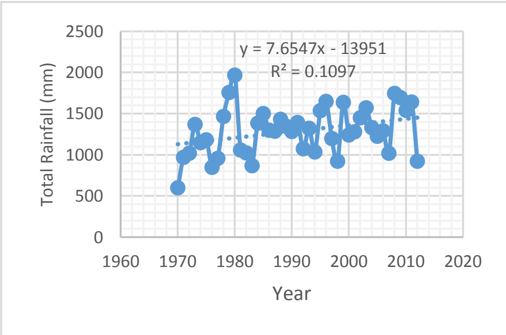

Fig 8: Annual Rainfall Distribution over Ibadan (1970-2012)

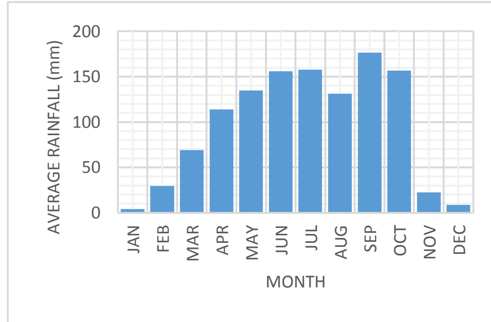

Fig 9: Seasonal Rainfall Distribution over Ibadan (1970-2012)

In Table 2 Warri town had the highest mean value of 227.34 while Ibadan had the least value of 96.69. This was because Warri had the highest seasonal rainfall distribution and as such had the highest mean value. This can also be related to Ibadan town which had the lowest seasonal rainfall distribution and as such had the lowest mean value (Table 2). In Table 3, it was found that Warri town recorded the highest mean value of 2779.85 while Ibadan had the least value of 1289.35. This may be attributed to the fact that Warri town had the highest annual rainfall distribution and as such had the highest mean value. This can also be related to Ibadan which had the lowest annual rainfall distribution and as such had the lowest mean value.

Table 2: Descriptive Statistics of Seasonal Rainfall Distribution of the Study Areas

Synoptic Station	Mean	SE	SD	VAR	Ran	Min	Max	Sum	CV
Warri	227.34	44.79	155.15	24072.46	435.08	29.94	465.03	2728.12	68.25
Benin City	161.72	31.87	110.40	12188.50	288	14.65	302.65	1940.66	68.27
Akure	120.33	23.22	80.43	6469.28	223.9	8.25	232.14	1443.94	66.84
Ibadan	96.69	18.89	65.44	4281.75	172.14	4.16	176.3	1160.29	67.67

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Table 3: Descriptive Statistics of Annual Rainfall Distribution of the Study Areas

Synoptic station	Mean	SE	SD	Var	Ran	Min	Max	Sum	CV
Warri	2779.85	47.74	261.49	68374.76	1068.2	2368.6	3436.8	83395.4	9.41
Benin City	2155.47	63.75	418.01	174735.4	1829.3	1234.7	3064	92685.4	19.4
Akure	1443.94	29.81	171.27	29333.63	882.9	1026.4	1909.3	47649.93	11.86
Ibadan	1289.35	44.26	290.26	84252.08	1366.9	600.8	1967.7	55442.07	22.51

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

In Table 4, it can be seen that Warri town had the highest rainfall intensity in July with 79.27mm/h and least in January with 0.323mm/h. Benin City had the highest rainfall intensity in July with 47.2mm/h and least in January with 0.11mm/h. Akure had the highest rainfall intensity in September with 37.32mm/h and least in December with 0.05mm/h. Ibadan had the highest rainfall intensity in September with 26.79mm/h and least in January with 0.01mm/h. In Table 5, Warri recorded the highest mean value of 27.03 while Ibadan had the least value of 11.44. This was because Warri had the highest rainfall intensity and as such had the highest mean value. This can also be related to Ibadan which had the lowest rainfall intensity and as such had the lowest mean value.

Table 4: Computed Average Rainfall Intensity of the Study Areas (mm/h

Synoptic Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Warri	0.323	1.57	6.60	15.03	25.68	49.07	79.27	46.54	63.92	32.54	3.53	0.34
Benin City	0.11	1.18	4.08	13	20.37	30.47	47.2	40.32	46.94	24.85	2.06	0.23
Akure	0.11	0.88	4.96	14.62	18.75	25.99	26.8	23.71	37.32	15.56	0.87	0.05
Ibadan	0.01	0.75	4.14	11.21	15.62	20.95	21.39	14.81	26.79	21.11	0.43	0.07

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Table 5: Descriptive Statistics of Rainfall Intensity of the Study Areas

Synoptic station	Mean	SE	SD	Var	Ran	Min	Max	Sum	CV
Warri	27.03	7.87	27.26	743.27	78.95	0.32	79.27	324.41	100.85
Benin City	19.23	5.34	18.51	342.7	47.09	0.11	47.2	230.81	96.26
Akure	14.14	3.68	12.74	162.24	37.27	0.05	37.32	169.62	90.1
Ibadan	11.44	2.88	9.98	99.65	26.78	0.01	26.79	137.28	87.24

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

In Table 6, Warri town had the highest rainfall kinetic energy in July with 191.31MJ/ha and least in January with 11.2MJ/ha. Benin City had the highest rainfall kinetic energy in July with 124.1MJ/ha and least in January with 4.87MJ/ha. Akure had the highest rainfall kinetic energy in September with 94.91MJ/ha and least in December with 2.21MJ/ha. Ibadan had the highest rainfall kinetic energy in September with 71.79MJ/ha and least in January with 0.52MJ/ha. Warri had the highest rainfall kinetic energy and Ibadan had the least rainfall kinetic energy. Similarly, Warri town had the highest mean value of 92.92 while Ibadan had the least value of 38.83. This was because Warri had the highest rainfall kinetic energy and as such had the highest mean value. This can also be related to Ibadan which had the lowest rainfall kinetic energy and as such had the lowest mean value (Table 7).

Table 6: Computed mean seasonal Rainfall Kinetic Energy over the Study Areas (MJ/ha) Using [39] Model

Synoptic Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Warri	11.2	25.85	54.37	82.63	108.37	150.27	191.32	146.31	171.68	122.16	39.43	11.46
Benin City	4.87	18.65	35.63	64.55	81.12	99.47	124.1	120.82	123.75	89.71	24.98	7.6
Akure	4.06	13.59	33.83	58.95	66.92	79	80.24	75.4	94.91	60.85	13.43	2.21
Ibadan	0.52	11.03	27.48	46.02	54.53	63.34	64.03	53.08	71.79	63.59	8.07	2.48

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Table 7: Descriptive Statistics of Seasonal Rainfall Kinetic Energy over the Study Areas

Synoptic station	Mean	SE	SD	Var	Ran	Min	Max	Sum	CV
Warri	92.92	18.54	64.23	4125.85	180.12	11.2	191.32	1115.05	69.12
Benin City	66.27	13.38	46.34	2147.51	119.23	4.87	124.1	795.25	69.93
Akure	48.62	9.61	33.3	1108.87	92.7	2.21	94.91	583.39	68.49
Ibadan	38.83	7.8	27.09	733.93	71.27	0.52	71.79	465.96	69.77

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

The various computations for the rainfall erosivity factor is given is shown in Table 8 -19. In Table 8, the results of erosivity using [37] model shows that Warri town reordered highest rainfall erosivity index in July with 122.54Jmm/ha/h and least in January and December with 0Jmm/ha/h. Benin City had the highest rainfall erosivity index in July with 45.76Jmm/ha/h and least in January and December with 0Jmm/ha/h. Akure had the highest rainfall erosivity index in September with 29.29Jmm/ha/h and least in January and December with 0Jmm/ha/h. Ibadan had the highest rainfall erosivity index in September with 15.6Jmm/ha/h and least in January, November and December with 0Jmm/ha/h. Warri had the highest rainfall erosivity index and Ibadan had the least rainfall erosivity index. In Table 9, Warri had the highest mean value of 28.45 while Ibadan had the least value of 5.9. This was because Warri had the highest rainfall erosivity index and as such had the highest mean value. This can also be related to Ibadan which had the lowest rainfall erosivity index and as such had the lowest mean value.

Table 8: Computed Seasonal Rainfall Erosivity Index (EI_{30}) Over the Study Areas Using [37] Model (Jmm $ha^{-1}h^{-1}$)

Synoptic Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Warri	0	0.07	1.09	5.20	14.39	49.27	122.54	44.55	81.41	22.58	0.33	0
Benin City	0	0.04	0.44	0.11	9.27	19.92	45.76	33.92	45.28	13.52	0.12	0
Akure	0	0.02	0.63	4.94	7.92	14.73	15.61	12.37	29.29	5.56	0.02	0
Ibadan	0	0.02	0.45	2.98	5.6	9.78	10.18	5.06	15.6	9.92	0	0

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Table 9: Descriptive Statistics of Seasonal Rainfall Erosivity Index (EI_{30}) Over the Study Areas

Synoptic station	Mean	SE	SD	Var	Ran	Min	Max	Sum	CV
Warri	28.45	11.38	39.41	1553.33	122.54	0	122.54	341.43	138.52
Benin City	14.03	5.22	18.09	327.08	45.76	0	45.76	168.38	128.94
Akure	7.59	2.61	9.04	81.69	29.29	0	29.29	91.09	119.1
Ibadan	5.9	2.02	6.99	48.80	21.11	0	21.11	70.78	118.47

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Using [40] model as seen in Table 10, Warri town was seen to record highest rainfall erosivity factor in July with 195.05MJmm/ha/hr and had no values in January, February, November and December. Benin City had the highest rainfall erosivity factor in July with 106.03MJmm/ha/hr and had no values in January, February, March, November and December. Akure had the highest rainfall erosivity factor in September with 67.37MJmm/ha/hr and had no values in January, February, March, November and December. Ibadan had the highest rainfall erosivity factor in September with 36.76MJmm/ha/hr and had no values in January, February, March, November and December. Warri had the highest Rainfall Erosivity in July with a value 195.05MJmm/ha/hr and no values in the month of January, February, November and December for all regions. These regions recorded low amount of rainfall distribution and intensity and as such no value for erosivity factor was recorded. Similarly, Table 11, shows that Warri Town had the highest mean value of 111.71 MJmm/ha/hr while Ibadan had the least value of 20.46 MJmm/ha/hr. This was because Warri had the highest rainfall erosivity and as such had the highest mean value. This can also be related to Ibadan which had the lowest rainfall erosivity and as such had the lowest mean value.

Table 10: Computed Seasonal Rainfall Erosivity Factor over the Study Areas Using [40] Model (MJmm/ha/hr).

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Warri	-	-	13.69	51.11	85.20	140.7	195.05	135.45	169.04	103.46	-	-
Benin City	-	-	-	27.18	49.11	73.42	106.03	93.46	105.57	60.49	-	-
Akure	-	-	-	19.76	30.31	46.31	47.96	41.54	67.37	22.27	-	-
Ibadan	-	-	-	2.64	13.90	25.57	26.48	11.98	36.76	25.90	-	-

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Table 11: Descriptive Statistics of Seasonal Rainfall Erosivity Factor over the Study Areas Using [40] model

Synoptic station	Mean	SE	SD	Var	Ran	Min	Max	Sum	CV
Warri	111.71	21.42	60.58	3669.63	181.36	13.69	195.05	893.7	54.23
Benin City	73.61	11.33	29.99	899.11	78.85	27.18	106.03	515.26	40.74
Akure	39.36	6.31	16.68	278.28	47.61	19.76	67.37	275.52	42.38
Ibadan	20.46	4.34	11.48	131.69	34.12	2.64	36.76	143.23	56.11

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

In Table 12 results of rainfall erosivity using [36] Model are presented. it is seen that Warri town had the highest rainfall erosivity factor in July with 155.90MJmm/ha/hr and had the least rainfall erosivity factor in January with 7.69MJmm/ha/hr. Benin City had the highest rainfall erosivity factor in July with 100.33MJmm/ha/hr and had the least rainfall erosivity factor in January with 2.98MJmm/ha/hr. Akure had the highest rainfall erosivity factor in September with 76.22MJmm/ha/hr and had the least rainfall erosivity factor in December with 1.28MJmm/ha/hr. Ibadan had the highest rainfall erosivity factor in September with 57.13MJmm/ha/hr and had the least rainfall erosivity factor in January with 0.42MJmm/ha/hr. Warri had the highest Rainfall Erosivity in July with a value 155.90MJmm/ha/hr and Akure had the least value in the month of January with 0.42MJmm/ha/hr. This was as a result of the difference in rainfall distribution (Table 12). On the whole, Warri had the highest mean value of 74.72 MJmm/ha/hr while Ibadan had the least value of 30.37 MJmm/ha/hr. This can be attributable to the fact that Warri town had the highest rainfall erosivity and as such had the highest mean value. This can also be related to Ibadan which had the lowest rainfall erosivity and as such had the lowest mean value (Table 13).

Table 12: Computed Seasonal Rainfall Erosivity Factor over the Study Areas Using [36] Model (MJmm/ha/hr)

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Warri	7.69	19.41	42.78	66.08	87.34	121.97	155.90	118.69	139.66	98.73	30.5	7.89
Benin City	2.98	13.59	27.39	51.17	64.83	79.99	100.33	92.49	100.04	71.92	18.7	4.95
Akure	2.44	9.56	25.91	46.55	53.12	63.08	64.11	60.12	76.22	48.12	9.44	1.28
Ibadan	0.42	7.56	20.74	35.91	42.91	50.17	50.74	41.72	57.13	50.38	5.3	1.43

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Table 13: Descriptive Statistics of Seasonal Rainfall Erosivity Factor over the Study Areas Using [36] Model

Synoptic station	Mean	SE	SD	Var	Ran	Min	Max	Sum	CV
Warri	74.72	15.27	52.9	2797.98	148.21	7.69	155.9	896.64	70.8
Benin City	52.37	10.81	37.46	1403.05	97.35	2.98	100.33	628.38	71.53
Akure	38.33	7.81	27.05	731.56	74.94	1.28	76.22	459.95	70.57
Ibadan	30.37	6.29	21.78	474.21	56.71	0.42	57.13	364.41	71.72

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Using [30] Model Warri town had the highest rainfall erosivity factor in July with 515.04MJmm/ha/hr and had the least rainfall erosivity factor in January with 8.19MJmm/ha/hr (Tables 14 and 15). Benin City had the highest rainfall erosivity factor in July with 269.25MJmm/ha/hr and had the least rainfall erosivity factor in January with 2.78MJmm/ha/hr. Akure had the highest rainfall erosivity factor in September with 180.4MJmm/ha/hr and had the least rainfall erosivity factor in December with 1.17MJmm/ha/hr. Ibadan had the highest rainfall erosivity factor in September with 119.06MJmm/ha/hr and had the least rainfall erosivity factor in January with 0.42MJmm/ha/hr. Warri had the highest Rainfall Erosivity in July with a value 515.04MJmm/ha/hr and Akure had the least value in the month of January with 0.42MJmm/ha/hr. This was as a result of the difference in rainfall distribution (Table 14). In the descriptive statistics, Warri town also recorded the highest mean value of 204.74MJmm/ha/hr while Ibadan had the least value of 56.59 MJmm/ha/hr. This was because Warri had the highest rainfall erosivity and as such had the highest mean value. This can also be related to Ibadan which had the lowest rainfall erosivity and as such had the lowest mean value (Table 15).

Table 14: Computed Seasonal Rainfall Erosivity Factor over the Study Areas Using [30] Model (MJmm/ha/hr)

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Warri	8.19	26.6	78.88	146.75	219.9	358.58	515.04	344.51	437.78	262.98	49.16	8.45
Benin City	2.78	16.67	42.39	101.70	142.78	193.5	269.25	239.06	268.12	165.87	25.32	4.88
Akure	2.24	10.69	39.29	88.91	107.27	137.27	140.51	128.07	180.4	93.18	10.52	1.17
Ibadan	0.42	8.02	29.06	61.69	79.23	98.89	100.47	76.13	119.06	99.46	5.28	1.31

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Table 15: Descriptive Statistics of Seasonal Rainfall Erosivity Factor over the Study Areas Using [30] Model

Synoptic station	Mean	SE	SD	Var	Ran	Min	Max	Sum	CV
Warri	204.74	51.47	178.31	31792.92	506.85	8.19	515.04	2456.82	87.09
Benin City	122.69	30.07	104.15	10847.39	266.47	2.78	269.25	1472.32	84.89
Akure	78.29	18.22	63.13	3985.77	179.23	1.17	180.4	939.52	80.64
Ibadan	56.59	13.01	45.06	2030.55	118.64	0.42	119.06	679.02	79.63

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

In Tables 16 and 17, [32] Model reveals that Warri town had the highest rainfall erosivity factor in July with 863.20MJmm/ha/hr while least rainfall erosivity factor was recorded in January with 10.43MJmm/ha/hr. Benin City had the highest rainfall erosivity factor in July with 432.3MJmm/ha/hr and had the least rainfall erosivity factor in January with 3.30MJmm/ha/hr. Akure had the highest rainfall erosivity factor in September with 282.06MJmm/ha/hr and had the least rainfall erosivity factor in December with 1.31MJmm/ha/hr. Ibadan had the highest rainfall erosivity factor in September with 186.09MJmm/ha/hr and had the least rainfall erosivity factor in January with 0.43MJmm/ha/hr. Warri had the highest Rainfall Erosivity in July with a value 863.2MJmm/ha/hr and Akure had the least value in the month of January with 0.43MJmm/ha/hr. This was as a result of the difference in rainfall distribution (Table 16). Also, Warri had the highest mean value of 331.62 MJmm/ha/hr while Ibadan recorded the least value of 84.48 MJmm/ha/hr. This was because Warri town had the highest rainfall erosivity and as such had the highest mean value. This can also be related to Ibadan which had the lowest rainfall erosivity and as such had the lowest mean value (Table 17).

Table 16: Computed Seasonal Rainfall Erosivity Factor over the Study Areas Using [32] Model (MJmm/ha/hr)

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Warri	10.43	36.64	116.76	226.34	348.35	586.75	863.20	562.23	725.86	421.57	70.52	10.79
Benin City	3.30	22.26	60.22	153.09	219.81	303.94	432.3	380.81	430.36	257.9	34.76	6.01
Akure	2.62	13.86	55.56	132.65	162.05	216.05	216.07	195.75	282.06	139.45	13.62	1.31
Ibadan	0.43	10.2	40.26	89.84	117.3	148.57	151.12	112.42	186.09	149.5	6.53	1.48

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Table 17: Descriptive Statistics of Seasonal Rainfall Erosivity Factor over the Study Areas Using [32] Model

Synoptic station	Mean	SE	SD	Var	Ran	Min	Max	Sum	CV
Warri	331.62	86.3	298.96	89379.	852.77	10.43	863.2	3979.44	90.15
Benin City	192.06	48.5	168	28224.68	429	3.3	432.3	2304.76	87.47
Akure	119.25	28.52	98.79	9759.7	280.75	1.31	282.06	1431.05	82.84
Ibadan	84.48	19.94	69.08	4771.79	185.66	0.43	186.09	1013.74	81.77

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

In Tables 18 and 19, it can be seen that highest rainfall erosivity factor in Warri town was recorded in July with 581.21MJmm/ha/hr and had no values in January and December. Benin City had the highest rainfall erosivity factor in July with 224.5MJmm/ha/hr and had no values in January, February and December. Akure had the highest rainfall erosivity factor in September with 135.69MJmm/ha/hr and had no values in January, February, November and December. Ibadan had the highest rainfall erosivity factor in September with 73.41MJmm/ha/hr and had no values in January, February, November and December. Warri had the highest Rainfall Erosivity in July with a value 581.21MJmm/ha/hr and no values in the month of January, February and December for all regions. No value was recorded in the month of November for Akure and Ibadan. These regions recorded low amount of rainfall distribution and intensity and as such no value for erosivity factor was recorded. Results of descriptive statistics shows that Warri town had the highest mean value of 186.75 MJmm/ha/hr while Ibadan had the least value of 38.84 MJmm/ha/hr. This was because Warri had the highest rainfall erosivity and as such had the highest mean value. This can also be related to Ibadan which had the lowest rainfall erosivity and as such had the lowest mean value (Table 19).

Table 18: Computed Seasonal Rainfall Erosivity Factor over the Study Areas Using [41] Model (MJmm/ha/hr)

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Warri	-	0.42	12.81	46.88	106.17	282.47	581.21	260.79	420.49	152	4.27	-
Benin City	-	-	4.53	31.42	62.8	115.87	224.5	177	222.62	85	23.63	-
Akure	-	-	5.43	32.36	47.54	78.34	82.11	68.1	135.69	35.64	-	-
Ibadan	-	-	3.33	19.01	32.02	50.39	52.06	29.49	73.41	50.99	-	-

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Table 19: Descriptive Statistics of Seasonal Rainfall Erosivity Factor over the Study Areas Using [41] Model

Synoptic station	Mean	SE	SD	Var	Ran	Min	Max	Sum	CV
Warri	186.75	62.4	197.32	38934.95	580.79	0.42	581.21	1867.51	105.66
Benin City	105.26	28.32	84.95	7215.8	219.97	4.53	224.5	947.37	80.7
Akure	60.65	14.08	39.83	1586.70	130.26	5.43	135.69	485.21	65.67
Ibadan	38.84	7.84	22.16	491.29	70.08	3.33	73.41	310.7	57.05

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Using Gunn and Kinzer model [43] as shown in Tables 20 and 21, Warri town recordered the highest rainfall erosivity factor in July with 3569.50MJmm/ha/hr and had the least rainfall erosivity factor in January with 182.56MJmm/ha/hr. Benin City had the highest rainfall erosivity factor in July with 2306.20MJmm/ha/hr and had the least rainfall erosivity factor in January with 65.59MJmm/ha/hr. Akure had the highest rainfall erosivity factor in September with 1757.67MJmm/ha/hr and had the least rainfall erosivity factor in December with 15.75MJmm/ha/hr. Ibadan had the highest rainfall erosivity factor in September with 1323.18MJmm/ha/hr and had no value for rainfall erosivity factor in January. This was as a result of the low amount of rainfall here. Warri had the highest Rainfall Erosivity in July with a value 3569.50MJmm/ha/hr and Ibadan had the least in January. This was as a result of the difference in rainfall distribution. Similarly, results of descriptive statistics revealed that Warri had the highest mean value of 1720.16 while Ibadan had the least value of 769.30. This was because Warri had the highest rainfall erosivity and as such had the highest mean value. This can also be related to Ibadan which had the lowest rainfall erosivity and as such had the lowest mean value (Table 21).

Table 20: Computed Seasonal Rainfall Erosivity Factor over the Study Areas (Special Erosion Situation) Using [43] model (MJmm/ha/hr)

Station	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Warri	182.56	459.99	995.88	1526.90	2010.69	2798.15	3569.50	2723.69	3200.32	2269.72	715.07	189.45
Benin City	65.59	340.23	643.78	1187.26	1498.54	1843.47	2306.20	2127.87	2299.65	1659.96	443.60	116.94
Akure	50.48	229.49	609.83	1081.99	1231.68	1458.69	1482.13	1391.05	1757.67	1117.68	226.59	15.75
Ibadan	-	181.41	490.64	839.02	998.91	1164.48	1177.35	971.59	1323.18	1169.15	125.81	20.78

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Table 21: Descriptive Statistics of Seasonal Rainfall Erosivity Factor over the Study Area under Special Erosion Situation [43]

Synoptic station	Mean	SE	SD	Var	Ran	Min	Max	Sum	CV
Warri	1720.16	348.52	1207.32	1457631	3386.94	182.56	3569.5	20641.9	70.19
Benin City	1211.09	247.53	857.48	735264.7	2240.61	65.59	2306.2	14533.0	70.8
Akure	887.75	180.64	625.76	391572.7	1741.92	15.75	1757.67	10653.03	70.49
Ibadan	769.30	144.14	478.07	228546.6	1302.4	20.78	1323.18	8462.32	62.14

Warri synoptic station: 1983-2012; Akure synoptic station: 1980-2012; Benin City and Ibadan stations: 1970-2012

Comparing the mean values of erosivity in the study area with Rainfall aggressiveness Index standard developed by Arnoldus, [37] as shown in Table 1, the interpretation is given in the Table 22. It indicated that Warri had a very high rainfall aggressivity index compared to other locations. Ibadan had a very low rainfall aggressivity index compared to other regions. There will be more erosivity rains in Warri than the other locations in study areas and less erosivity in Ibadan compared to the other locations.

Table 22: Interpretation of Results

Synoptic Station	Mean Rainfall Erosivity Factor (MJmm/ha/hr)	Interpretation
Warri	186.75	Very High
Benin City	105.26	Moderate
Akure	60.65	Low
Ibadan	38.84	Very Low

Discussion

It can be seen that Warri town recorded highest mean rainfall both seasonally and annually, followed by Benin City, while Ibadan had the least values. Nigerian climate is dominated by the influence of three major atmospheric phenomena, namely: the maritime tropical (mT) air mass, the continental tropical (cT) air mass and the equatorial easterlies. The mT air mass originates from the southern high-pressure belt located off the coast of Namibia, and in its trajectory it picks up moisture from over the Atlantic Ocean, crosses the equator and enters Nigeria. The cT air mass originates from the high-pressure belt north of the Tropic of Cancer. It picks up little moisture along its path, and thus is dry. The two air masses (mT and cT) meet along a slanting surface called the intertropical discontinuity (ITD). The equatorial easterlies are rather erratic, cool air masses that come from the east and flow in the upper atmosphere along the ITD [44]. Occasionally, however, the air mass dives down, undercuts the mT or cT air mass and gives rise to a line of squalls or dust devils [45]. Over the country, rainfall varies from place to place. The most clearly marked differences are between the coastal areas and the interior [46]. The overall implication is a reduction in annual rainfall as one moves from the south as shown by previous studies [47, 48, and 49]. Thus, the pattern observed across the study area is expected. Warri town is a coastal and lies about 4,409 km from Atlantic Ocean and 304 km to the Gulf of Guinea. Studies have shown that oceans play important roles in influencing the earth's climate system through, evaporation and cloud formation, wind and precipitation pattern as well as the transport of enormous amount of heat around the globe [50-53]. The oceans' thermal inertia is communicated to the atmosphere via turbulent and radiative energy exchange at the sea surface. These energy fluxes in turn depend on a single oceanic quantity, the sea surface temperature (SST), as well as several atmospheric parameters including wind speed, air temperature, humidity, and cloudiness. Some studies of the relationship between SSTs and the atmospheric parameters in the Atlantic have been concerned with the influence of SSTs on rainfall and have produced evidence both direct forcing by SSTs and of complex changes of atmospheric parameters which force both SSTs and rainfall [54-56]. A phenomenon called ENSO also referred to as El Nino (an exclusive warming of the upper ocean in the tropical eastern pacific lasting three or more season) influences SST and has a drastic effect on coastal rainfall [51]. The SSTs thus play a key role in regulating climate and its variability [57]. Odekunle [58] have also identified strong relationships between SSTs in the Gulf of Guinea, the source regions of the Guinea and Benguela current and the little Dry Season (LDS), with warmer SSTs associated with higher rainfall during the LDS (i.e. less intense LDS). Parker and Diop-Kane [59] highlighted the role of high pressure over the Gulf of Guinea and the St Helena high pressure cell: the effect of this high pressure extends to the coastal regions, where the associating sinking motion reduces convection during the LDS. Flood and erosion in Warri town has also been linked to heavy rainfall [60]. Another study on Thua Thien Hue Province in the north central coast region of Vietnam, have shown that the amount of soil erosion fluctuates widely depending on many factors, with annual rainfall as the most influential [61]. With the high tide in the Atlantic Ocean, rivers in the study area (and their tributaries), for example the forcados and Ethiope Rivers in Delta State experienced a back lash and surge of water into the hinterlands. Thus, all the areas along the plains of the two rivers experienced flooding for some time and erosion in the interior. According to [62], has linked flood in Warri to heavy rainfall, in Benin City, [63] has attributed flooding to heavy rainfall while in Ibadan City and Akure Town, [64] and [65] respectively have also linked rainfall to floods. In addition, rain-splash or splash erosion will prevail in these locations where soil-infiltrating capacity is high, being unfavorable for overland flow. The most intensive erosion occurs when thin sheet flow combines with falling raindrops. The depth of overland flow has to be less than approximately three raindrop diameters [64]. Water induced soil erosion is characterized by the detachment, entrainment, and transport (and deposition) of soil particles caused by one or more natural or anthropogenic erosive forces (rain, runoff) [66]. Water from a raindrop acts both as a wetting source and as an energy source causing detachment. The shear strength of soil decreases with increasing wetness. The overland flow exerts shear stress on the surface thereby inducing both detachment and transportation of soil particles. Deposition of detached material takes place when the transport capacity of flow is smaller than the quantity of material being transported [67].

Heavy rainfall and flood on one hand have been linked to severe soil erosion [68, 66]. The surplus floodwater during flood season is a key element in the subsequent flood damage and risk [69-71]. The amount of surplus floodwater is the product of the coefficient of surplus floodwater and the runoff during flood season [71]. The observed rainfall distribution of the study area thus will have direct link to overland flow. Thus, the resultant running water will carry away small particles of loose material, detaching them from soil aggregates thus initiating gully erosion, especially, on bare soils. As the world faces global warming, it is most likely that rainfall amount will increase in around the coastal Nigeria with associated hydrological consequences. Changes in precipitation have a major role in natural hazards such as droughts, floods, landslides and severe soil erosion [72]. Monthly rainfall pattern over study area assumes a bi-modal distribution as shown in Figs. 2-9 and sufficient rainfall would not start over the study area until April. For the entire study area rainfall peaks between July and September, followed by a short dry break in August known as the 'August break', then followed by the second peak in September. The pattern over Warri, Benin City and Ibadan has some similarities; firstly, there was marked reduction in the Rainfall of August. it has been shown that while the majority of West Africa experiences one primary monsoonal wet season per year [73,74], a region in the southern part of West Africa, encompassing parts of southern Ghana, Benin, Togo, Ivory Coast and south-west Nigeria experiences two wet seasons [75, 76, 59]. The northward progression of the tropical rain belt in boreal spring brings the first wet season from April-June; the second wet season in September and October is associated with the returning southward progression of the tropical rain belt in boreal autumn. Separating the two wet seasons is the 'Little Dry Season' (LDS), a period of lower and less frequent rainfall [77-79]. The study also found that Warri recorded highest rainfall erosivity index which correlates to the rainfall intensity, highest rainfall kinetic energy and rainfall amount as compared to other locations. In the tropics, the most important factor that is of direct relevance to erosion studies is rainfall, while other factors include topography, soil, geology and land management techniques [80]. Several attributes of rainfall bear direct relevance to the incidence of erosion in the human landscape. Such attributes include: rainfall intensity, drop size, duration of fall, annual total amount, and frequency of fall, kinetic energy and terminal velocity [80].These rainfall characteristics have been observed by [82] to have the ability to loosen up soil structures and consequently remove earth materials from different surfaces. The relationship between the character of rainfall and erosivity has been confirmed in many studies (eg, [33,83-85,18, 36, 21]. Rainfall is a prerequisite for runoff and soil water erosion, and the soil erosion amount and runoff amount are determined not only by rainfall intensity and rainfall quantity but also by land use patterns. The changes in precipitation, the presence of extreme values affect the soil erosion, and unlike some other natural factors, such as relief or soil characteristics, is not responsive to human modification. The soil erosion by water is very complex phenomenon and it is one of the major threats to soil degradation [86]. On the whole, erosivity values were highest in July, followed by September. This patterns follows the bi-modal rainfall character of the study area. It also follows that that under disturbed conditions rains between the months of June - September will contribute significantly to the detachment of soil material in the study area hence enhancing accelerated erosion.

Conclusion and Recommendations

The focus of this research was to examine the character of rainfall erosivity over selected towns in southern Nigeria with Benin City, Warri, Ibadan and Akure as case study. On the whole, it was discovered that Warri had the highest amount of rainfall distribution, highest rainfall erosivity index which correlates to the rainfall intensity, highest rainfall kinetic energy and highest rainfall erosivity as compared to other regions. This was as a result of the high seasonal and annual rainfall distribution in the region. This was closely followed by erosivity pattern found in Benin City. This value represents the ability of rainfall to detach and induce erosion. Ibadan had the least amount of rainfall distribution, least rainfall intensity, least rainfall kinetic energy and least rainfall erosivity factor as compared to others. The fact that Warri town and Benin City recorded very high erosive rainfall fall is an indication that depending on the nature of soil texture and predominate land use activities, these areas are highly prone to erosion by running water. In view of the fact that the study area continues to record annual floods with documented cases of gully erosion on the account of heavy rainfall and high erosivity values, it is recommended that sustainable environmental practices including planting of tress should be supported by policies to reduce the intensity, velocity of flow and kinetic energy of rainfall drop on soil.

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