Rainfall Erosivity Pattern of Ogun River Basin Area (Nigeria) using Modified Fournier Index


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Abstract: The study was based on 20 years rainfall data representing twenty rainfall stations under Ogun River Basin Area with the objective as; to determine rainfall erosivity pattern of Ogun River Basin Area using modified Fournier index by FAO. An FAO linear regression model which relates monthly El3o index of Universal Soil Loss Equation (USLE) values with monthly rainfall erosivity values of the Modified Fournier Index was used. The annual rainfall erosivity table showed a range of 5756.68 MJ.mm/ha.h.yr to 19,583.82 MJ.mm/ha.h.yr. The highest rainfall erosivity values are 19,583.82 MJ.mm/ha.h.yr for Lagos, 13,296.25 MJ.mm/ha.h.yr for Ijebu – Ode and Ibadan with 11382.91MJ.mm/ha.h.yr. While the least values, 5756.68 MJ mm/ha.h.yr, 6905.18 MJ mm / ha.h.yr and 7395.25 are for MANR Ilaro, Ebute Igboore and Igbogila respectively. Regression analysis between the annual rainfall and annual rainfall erosivity showed a high correlation of $r^2 = 0.77$, which suggest that the annual rainfall erosivity for Ogun River Basin Area is closely related to the annual rainfall values. The Iso – erodent map using the both annual / rainfall erosivity values and geographical location of each rainfall stations, interpreted with FAO erosivity class range showed that Southwestern zone of Nigeria is a zone with high erosive rainfall.

Keywords: Iso-erodent, precipitation values, erosivity.

1. INTRODUCTION

Soil loss estimation is a capital intensive and time consuming exercise by which conservation practices may be based on the quantification of the relevant nature of soil, land topography, vegetation and climatic factors and the relation of these factors to regional and temporal characteristics. Soil loss estimation started in first decades of the 20th century and has increased in number and variety using either the Universal Soil Loss Equation (ULSE) of Wischmeier and Smith (1978) or Revised Universal Soil Loss Equation, of Renard et al (1997). Both Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RULSE) have empirical relationships, while USLE quantifies soil erosion as the product of six factors representing rainfall and run-off erosivity (R), soil erodibility (K), Slope length (L), Slope steepness (S), cover and management practice (C) and supporting conversation practice (P). The equation is thus:

$$A = R.K.L.S.C.P$$  \hspace{1cm} (1)

where, A is the computed spatial and temporal average soil loss per unit of area. RUSLE utilizes the same basic equation but in a computerized version.

Rainfall erosivity factor (R) of the USLE and RUSLE in estimating soil loss depends on the availability of suitable quantifiable rainfall erosivity parameters. These parameters must describe adequately the ability of rain detachment and down slope of soil particles according to intensity of rain and amount of energy. Since the early stage of soil loss research, Kinetic E, of falling rain and its maximum 30 minutes intensity I3o, designated El3o, has attained wide recognition as a causative factor in the erosion process and spatial distribution of mean annual rainfall energy for use in soil loss estimation model. However, the use of El3o alone is not sufficient to describe the relative rainfall erosivity of any two locations with varying intensity of rainfall especially in developing countries (Cohen et al. 2005). Therefore, index based on kinetic and momentum of run-off can also
be used to estimate the monthly and/or annual values of rainfall erosivity with accurate record usually available for a long period. A number of indices which relate the erosivity of kinetic energy and its associated run-off to soil loss estimation have been established. The most widely used index is the Fournier index (Fournier 1960). It has been found to have a good relationship with annual values of rainfall erosivity. However, this Fournier index has shortcomings and subsequently modified into Modified Fournier Index (MFI) (Arnoldus 1980). This modified index is summed for a whole year and found to be linearly correlated with EI₃₀ index of the USLE.

Soil erosion by water is due to the dispersive action and transportation power of water affected by soil erodibility and rainfall erosivity. Soil erodibility is a function of physical properties and management of the soil such as soil structure, moisture content, soil porosity and vegetation, while rainfall erosivity is a measure of potential ability of rainfall to cause erosion and it is mainly a function of rainfall characteristics such as rain amount, rain intensity, rain drop size and shape, rain frequency, rainfall distribution, rainfall duration and kinetic energy. Among the natural factor affecting soil erosion, rainfall erosivity is of paramount importance, as its events are responsible for the largest part of the soil erosion and sedimentary delivery (Gonzalez-Hidalgo et al. 2007).

Soil erosion by water has been of much concern in Ogun-Oshun River Basin and Rural Development Authority (O-ORBRDA), whose among its statutory function is the provision of irrigation infrastructure, the control of floods and erosion, water-shed management and handing over of all lands to be cultivated under irrigation scheme to farmers (Akinkoye et al. 1998).

Soil loss or relative erosion rate for different management purposes are estimated to assist farmers and other agencies by government. It is useful in determining the adequacy of conservation measures in farm planning and in predicting non-point sediment losses in pollution control programme. This study was aimed at producing data on pattern of erosivity in Ogun-Oshun River Basin Area. This data is necessary in determining the soil erosion pattern of the area.

The study area, Ogun River Basin Area (figures 1a and 1b), is a sub-humid zone which lies roughly between latitude 7º 15' N and 8º58' N and longitude 2º 40' E and 4º 10' E of Nigeria. The total land area of the basin is about 23,700 square kilometers. The mean annual temperature is about 27°C and relative humidity is approximately 83% at 10 am.

2. METHODOLOGY

The study determined the Rainfall erosivity pattern of Ogun River Basin Area using Modified Fournier Index (M.F.I) and Rainfall data (daily, monthly and annual rainfall data) for twenty stations, scattered across Ogun River Basin were used. These rainfall data, which at most stations spanned a period of twenty years (from 1990 to 2010) from the Nigerian Meteorological Agency, (NMA) Lagos and Ogun Osun River Basin Development Authority, (OORBDA) Abeokuta, were analyzed using the Modified Fournier Index (Arnoldus, 1977, 1980), defined as

\[ C = \frac{\sum p^2}{P} \]  

(2)

where, \( C \) = Modified Fournier Index
\( p \) is the monthly rainfall of the wettest month
\( P \) is the annual rainfall

The index was summed for the whole year and linearly correlated with EI₃₀ (R), of the USLE as follows:

\[ R = b + a(C) \]  

(3)

where \( R \) = rainfall and run-off erosivity according to USLE and the constants (a and b) vary widely
among different climatic zones.

![Map of Nigeria showing Ogun Basin](image1)

Figure 1a: Nigeria showing Ogun Basin

![Map of Ogun River Basin in Nigeria](image2)

Figure 1b: Ogun River Basin Area in Nigeria.

The general approach used to estimate R-factor values for areas without data and/or resources required to calculate R can be summarized as the following four-step process:

1. R-factor values are calculated by the prescribed method (Wischmeier and Smith 1978; Renard et al. 1993) for stations with recording rain gauges.
2. A relation is established between the calculated R-values and more readily available types of precipitation data (i.e. monthly or annual totals).
3. The relation is extrapolated and R-values estimated for stations with the associated precipitation data.
4. Isolines are drawn between stations—R-values for sites between iso-erodent map estimated by linear interpolation.
This approach has been used by several authors to develop R-value selection guidelines or provisional iso-erodent maps for many parts of the world (Stocking and Elwell, 1976; Roose, 1977; Arnoldus, 1977; Bollinne et al., 1980; Smithen and Schulze, 1982; Lo et al., 1985). Examples of guidelines derived relations used to estimate the R factor for location other than the continental United States is represented below:

In West Africa, Roose (1977) reported a simple relation between the average annual R in units of hundreds of foot tons inch acre-1 h-1 year-1 and the average annual rainfall in millimeters (P) over 5-10 year period where recording rain gauge records were available. The relation:

\[
R = [(0.5 \pm 0.05) P]
\]  

was found to work for 20 meteorological stations in Ivory Coast, Burkina Faso, Senegal, Niger, Chad, Cameroon, and Madagascar. It was not valid for stations in mountainous regions, for stations directly on the coast, or for stations in the tropical transition zones between unimodal and bimodal annual rainfall distributions (Roose, 1977). Based on the relation established for the 5-10 years periods of records, Roose used long-term annual precipitation records (20-50 years) to estimate average annual R-values. These values were used to develop an iso-erodent map (in hundreds of foot tonf inch acre-1 h-1 year-1 units) for West Africa south of Nouakchott, Mauritania and west of Sudan.

All stations are located in Ogun River Basin map and each erosivity factors determined were computed on each station. This is to create an isopleth map (Iso-erodent) which shows the values using Geographical Information System (GIS) software (Arc View). The latitude and longitude of each station were located on the map and the contours representing the erosivity were generated from the annual rainfall erosivity values.

<table>
<thead>
<tr>
<th>Table 1: FAO (1979) Rainfall Erosivity Ratings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratings (mm)</td>
</tr>
<tr>
<td>0 - 50</td>
</tr>
<tr>
<td>50 - 500</td>
</tr>
<tr>
<td>500 - 1000</td>
</tr>
<tr>
<td>&gt;1000</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

The results of the erosivity indices for the study area are shown in Table 2. The Table shows the values of both annual precipitation values (P) and average annual rainfall and run-off erosivity (R-values). The R-values in the table were calculated using the FAO modification of Fournier. It was observed from the table that the R-value for Lagos is 19,583.82 MJ.mm/ha.h.yr, Ijebu-Ode (13,296.25 MJ.mm/ha.h.yr) and Ibadan (11382.91MJ.mm/ha.h.yr) had the highest values while the lowest values were recorded at MANR Ilaro (5756.68 MJ.mm/ha.h.yr), Ebute-Igbo-Ora (6905.18 MJ.mm/ha.h.yr) and Igbogila (7395.25 MJ.mm/ha.h.yr). However, Regression analysis between average annual precipitation values and average annual rainfall erosivity (Figure 2), showed a high correlation coefficient of \( r^2 = 0.77 \), which suggest that the annual rainfall of all the stations is closely related to the annual rainfall erosivity values. There is a strong positive relationship which shows that the trend of rainfall erosivity strongly depends on annual rainfall. From this linear regression graph, it shows that the higher the annual rainfall, the higher the annual rainfall erosivity, on the other hand the lower the annual rainfall, the lower the rainfall erosivity. This significant relationship between annual rainfall and annual rainfall erosivity agrees with previous observations of Lal (1998), Obi and Salako (1991, 1995), Salako (2008) noted that high intensities of rainfall can result in high erosivity of rain in regions with high rainfall amounts compared with regions with relatively low amount of rain.
Table 2: Rainfall Erosivity Indexes for Ogun River Basin

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>P(MM)</th>
<th>R-VALUES (MJ.MM/H/JR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBUTE-IGBOORO</td>
<td>151.14</td>
<td>6905.16</td>
</tr>
<tr>
<td>IBADAN</td>
<td>199.56</td>
<td>11382.91</td>
</tr>
<tr>
<td>SHAKI</td>
<td>174.54</td>
<td>9069.00</td>
</tr>
<tr>
<td>OYO</td>
<td>160.91</td>
<td>7808.67</td>
</tr>
<tr>
<td>OGBOMOSHO</td>
<td>176.11</td>
<td>9214.35</td>
</tr>
<tr>
<td>OYAN</td>
<td>175.02</td>
<td>9113.55</td>
</tr>
<tr>
<td>IJEBU ODE</td>
<td>920.25</td>
<td>13,296.25</td>
</tr>
<tr>
<td>LAGOS</td>
<td>288.24</td>
<td>19,583.82</td>
</tr>
<tr>
<td>OSHOGBO</td>
<td>188.08</td>
<td>10,321.36</td>
</tr>
<tr>
<td>MANR ILARO</td>
<td>138.72</td>
<td>5756.68</td>
</tr>
<tr>
<td>AJILETE</td>
<td>184.45</td>
<td>9985.62</td>
</tr>
<tr>
<td>ILESHA</td>
<td>165.19</td>
<td>8204.42</td>
</tr>
<tr>
<td>EGBADO (IGBOGILA)</td>
<td>156.44</td>
<td>7395.25</td>
</tr>
<tr>
<td>ODEDA</td>
<td>186.08</td>
<td>10,136.40</td>
</tr>
<tr>
<td>ISEYIN</td>
<td>180.02</td>
<td>9575.93</td>
</tr>
<tr>
<td>SEPETERI</td>
<td>162.97</td>
<td>7999.24</td>
</tr>
<tr>
<td>OFIKI</td>
<td>175.90</td>
<td>9194.81</td>
</tr>
<tr>
<td>ABEOKUTA</td>
<td>174.62</td>
<td>9076.32</td>
</tr>
<tr>
<td>EGBADO TECHNICAL</td>
<td>170.525</td>
<td>8697.91</td>
</tr>
<tr>
<td>OKE-ODAN</td>
<td>166.34</td>
<td>8310.84</td>
</tr>
</tbody>
</table>

P = Precipitation, R = rainfall and run-off erosivity

Then, they suggested that rainfall intensity is a key measure of erosivity rather than just annual rainfall. From Table 2, the high R values recorded in some locations could be attributed to torrential rains with more erosive effects normally recorded in the months of July, August and September.

The correlation between annual precipitation values and annual rainfall erosivity is given in Figure 2 and the Iso-erodent map given as Figure 3.

As shown in Figure 3, the estimated R-values for the stations with twenty years of data were used to draw the iso-erodent map by Arc View software for the study area. When the Iso-erodent
map of Ogun River Basin area was interpreted with FAO erosivity class range on Table 1. Ogun River Basin area was classified into high erosivity class, with high erosive rainfall except for Lagos which have the highest erosive rainfall and can be classified as region with severe risk of erosion. This trend could be as a result of industrialization and urbanization of the area which attribute to the climatic changes induced by Global warming. Also, the trend could be as a result of the area been close to the ocean (Atlantic Ocean). This study results agrees with previous observation of Salako (2008) who reported Southwest zone an areas with high erosive rainfall which is classified under high erosivity class. The trend therefore calls for concerted effort in tackling the impact of global climatic change. This trend could be as a result of industrialization and urbanization of the area which attribute to the climatic changes induced by Global warming. Also, the trend could be as a result of the area been close to the ocean (Atlantic Ocean). This study results agrees with previous observation of Salako (2008) who reported Southwest zone an areas with high erosive rainfall which is classified under high erosivity class. The trend therefore calls for concerted effort in tackling the impact of global climatic change.

Apart from land degradation due to rainfall induced soil erosion, the effect of high amount and intensity of rainfall include flooding especially in areas where soil management practices are inadequate. The rehabilitations of degraded lands which are usually very expensive can best be achieved when quantitative data on course of soil degradation are available. Therefore, the data contained in this work can be relevant in understanding the process of land degradation and implementation of land development and rehabilitation programmes. Also, there is a call for concerted effort, on tackling the impact of global climatic change.

The Iso-erodent map produced from this study is useful as an important source of information for predicting erosion risk of the entire Ogun River Basin Area and to guide in planning land development and rehabilitation programmes. The map also allows for a better comprehension of the process with geographical imprint and important step for large scale soil erosion assessment, soil conservation management of natural resources, agronomy and agrochemical exposure risk assessment.

Figure 3: Iso-erodent Map of Ogun River Basin Area
In conclusion, erosion assessment and prediction is not merely for quantifying the erosion rate but such outcome of erosion assessment by utilizing it for policy formulation of maintaining the land productivity and the environment as a whole.

REFERENCES


Arnoldus, H M J., (1977): Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco. FAO, soil bulletin 34:39-48


