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EVALUATION OF RAINFALL EROSIVITY INDEX FOR ABUJA, NIGERIA USING LOMBARDI METHOD

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ABSTRACT

Rainfall erosivity index is one of the important factors influencing soil erosion. Erosivity index for Abuja, Nigeria was evaluated using the Lombadi method. Twelve (12) years rainfall data (2001 – 2012) used was obtained from Nigerian Meteorological Agency (NIMET) Abuja. Daily kinetic energy – intensity interaction was computed using EI = $1.03V_d^{1.51}$. The results showed that the average annual rainfall erosivity index for the city for the period of study was 1131.86 MJmm/hr. The correlation between annual erosivity index and average annual precipitation was expressed as Y = 8.2209X + 34.659. The coefficient of Determination R^2 was 0.5011. During this period, the month of August (in all the years) had the highest erosivity index except for 2001, 2002, 2005 and 2008. The analysis of rainfall seasonal distribution showed that the most intensive erosion menace in the area can be expected in August, especially in the areas that are not protected by vegetation cover, which also depends on the climatic change. It is recommended that soil surfaces should not be left bare.

Keywords: *Rainfall intensity, kinetic energy, Erosion, Erosivity, infiltration, runoff.*

1. INTRODUCTION

Soil degradation resulting from erosion by stormwater is perceived as one of the main climate-related problems worldwide since it has large environmental and economic impacts, especially in agricultural areas [1]. One of the most important factors in soil erosion by water is the erosive potential of raindrop impact. The rainfall erosivity factor (R) in the Universal Soil Loss Equation (USLE) is generally recognized as one of the best parameters for the prediction of the erosive potential of raindrop impact [2].

Various properties of raindrops, such as intensity, velocity, size, and kinetic energy, are among the most frequently used parameters to develop erosivity indices. The A_rI_m (rainfall amount × maximum intensity), EI_{30} (rainfall energy× maximum 30-min intensity), and KE > 1(total kinetic energy of all of the rain falling at more than 25 mm h^{-1}) are the most important rainfall erosivity indices. These 3 indices were developed by Lal, Wischmeier and Smith, and Hudson [3, 4] and are suggested for use in certain geographical locations with specific climatic and local conditions.

Many studies around the world have focused on selecting appropriate rainfall erosivity factors. In Spain, [5] found some factors, such as rainfall volume I_{30} and I_{60} (maximum 30-min and 60-min intensity), that had high correlations with sediment and runoff amounts on artificial slopes in a Mediterranean environment. [6] also showed that some rainfall parameters such as EI_{60} (rainfall energy × maximum 60-min intensity) and I_{60} could be used as the best linear estimators for explaining soil splash erosion in the Tekala River catchment in Malaysia. [7] found that in a region with a Mediterranean climate, the total kinetic energy of rainfall has a better correlation with the amount of soil loss compared to EI_{30}, I_{30} and rainfall duration.

A direct computation of rainfall erosivity factors requires long-term data for both the amount and intensity of rainfall. In such a situation, more readily available types of parameters (rainfall amount-based indices) such as monthly or annual rainfall data could

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be utilized to predict rainfall erosivity indices. This makes it possible to adopt the correct strategies for soil conservation. Factors affecting the rate of soil erosion are rainfall, runoff, wind, soil, slope, plant cover and the presence or absence of conservation measures [8]. Studies have identified the characteristics of extreme rainfall that are associated with flood frequency to include duration, intensity, frequency, seasonality, variability, trend and fluctuation.

Rainfall erosivity is the potential ability of rainfall to cause soil loss [9]. The rainfall erosivity index represents the climate influence on water related soil erosion [10]. Rainfall erosivity is the impact of the kinetic energy of raindrops on soil. Higher velocity and larger size of the raindrops results in higher kinetic energy and higher soil loss. According to [10], most soil erosion researchers and soil conservationists recognize the positive correlation between erosivity and rainfall intensity.

The potential for erosion is based on many factors including soil type, slope, and the energy or force of precipitation expected during the period of surface disturbance. Typically, rainfall erosivity is measured indirectly using the Revised Universal Soil Loss Equation (RUSLE) developed by the United States Department of Agriculture (USDA) to help farmers control topsoil losses. The equation estimates erosivity values, also called "R factors," which relate primarily to the average annual energy and intensity of rain events for specific rainfall distribution zones throughout the country of USA. The USDA has collected annual R factor data for each rainfall distribution zone that reflects average precipitation patterns in each area. Lower R factors correspond to a lower probability of significant storm-induced erosion.

Rain erosion can be determined by two methods of direct measurement and using indices [11,12]. Direct measurement is a good method to determine the rain erosive power that is used by measuring the amount of splash. Due to the fact that direct measurement of rain erosive power for all the rainfalls is hard and time-consuming, numerous investigators [12,13,14,15] simultaneously measured the amount of splash (soil loss) and rainfall properties. By correlation they found erosivity indices based on the rainfall properties.

Generally rainfall erosivity indices are divided into two; based on kinetic energy and rainfall intensity, and 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} [13,] A_rI_m [14], KE>1 [12] and $P/\sqrt{t}$ [16]. P is the mean annual precipitation (mm) and t is time in years. One of the drawbacks of the indices based on kinetic energy and rainfall intensity is that they require the long–term statistics (above 20 years) of rainfall intensity (with short interval) of weather stations equipped with rain gauge [13]. As there is not such statistics in most of the countries especially for long-term periods, the investigators by rainfall available statistics that are seen in rain gauge stations, could provide simple indices. These indices are obtained through either regional analysis of sediment yield or by having correlation with EI_{30} index [17]. The most famous indices of this group are Fournier index and modified Fournier index [18]. Erosive maps as the most important information source can be a considerable aid for watershed managers and agriculture experts to provide soil conservation, erosion control and land management strategies.

In many Nigerian environments, particularly on steep cultivated lands, pronounced riling is abundant. Rill erosion is present on gentler slopes with deep sediments, and may also be found in direct association with gully systems. Rills can also be found on coarser soils, and are particularly abundant when a coarse soil is overlaying a fine-grained and less permeable one. Many erosion phenomena are induced by human activities, like rills and gullies caused by road construction or improperly constructed or maintained soil conservation structures. The main physical parameters influencing the intensity of erosion processes are climate regime, soil characteristics, topography and vegetation. Increases in soil losses are sometimes associated with increased precipitation, and sometimes more likely associated with decreased crop cover brought about by heat or drought under climate change [19]. Vegetation intercepts rain, reducing its energy and preventing splash erosion. It also slows runoff, reduces sheet erosion, and anchors and reinforces the soil with its root system.

Surface water runoff from vegetated areas is much less than that from bare soil due to a combination of surface roughness, infiltration, interception, lower the density of the soil, and improve the structure of surface soils.

Soil erodibility is the sensitivity of a soil to erosion, in other words soil resistance to erosion. It is determined by long-term field experiments and is normally correlated with texture, organic matter, drainage and structure. In Abuja, field research on these and other parameters have been conducted at several soil erosion research stations for periods of different lengths. From these stations it is possible to obtain reliable data on soil erodibility. In general, soil erosion is a three-process phenomenon. It begins with particle detachment, which is followed by particle transport and finally by deposition of transported particles in a new location [20]. The steps are influenced to a large extent by the nature and properties of the soil. Four major factors that govern erodibility have been identified as: texture (particle size distribution), structure, organic matter content, and permeability.

Erosion is seen as a multiplier of rainfall erosivity (the R factor, which equals the potential energy); this multiplies the resistance of the environment, which comprises K (soil erodibility), SL (the topographical factor), C (plant cover and farming techniques) and P (erosion control practices). Since it is a multiplier, if one factor tends toward zero, erosion will tend toward zero. This erosion prediction equation is composed of five sub-equations, and is given as shown in equation 1

$$A = R.K.L.S.C.P \qquad (1)$$

Where, A is the average annual soil loss ($Mg\ ha^{-1}\ yr^{-1}$); R is the rainfall erosivity index; K is the soil erodibility factor; L is the slope length factor; S is the slope gradient factor; C is the vegetation cover factor, and P is the conservation protection factor.

Each intensity has a corresponding kinetic energy, according to the equation 2, [13].

$$KE = 11.87 + 8.73\log_{10} I \qquad (2)$$

Wischmeier's index, $EI_{30} = KE \times I_{30}$, KE = kinetic energy of rainfall expressed in metric tons × m/ha/cm of rainfall. I_{30}= is 30 minutes rainfall intensity in mm/hr.

The intensity of rainfall is determined from the rainfall amount and duration using equation 3 below;

$$I = \frac{\text{Rainfall Amount}}{\text{Change in Time}} \qquad (3)$$

Lombardi also related several USLE factor including rainfall erosivity and daily rainfall using equation 4

$$EI = 1.03V_d^{1.51} \qquad (4)$$

Where EI is the daily rainfall energy – intensity interaction or the erosion index in MJ.mm/hr, V_d is the daily rainfall in mm. This method is most suitable for daily rainfall from manual rainguage. The objective of this study was to compute the rainfall erosivity index of Abuja Nigeria using Lombardi Method.

2. MATERIALS AND METHOD

2.1 The Study Area

Abuja, the Federal Capital Territory (FCT) of Nigeria is located in the middle belt of the country. It falls within latitude 7° 25¹ and 9° 20¹ N of Equator and longitude 5° 45¹ and 7° 39¹ E of Meridian. It has a land area of 8,000 square kilometres. The city has two distinct seasons namely rainy season (April – October) and dry season (November – March). Within the dry season, is a brief harmattan period that is occasioned by the north east trade wind and attendant dust haze, increased cold and dryness. The weather conditions over Abuja are influenced by its location with the Niger- Benue trough in the windward side of the Jos Plateau and at the climate transition zone between the essentially 'humid' south and 'sub- humid' north of the country. The high temperature and the relative humidity in the Niger-Benue trough give FCT a heating effect but the increasing elevation towards the north east reduces the heat in the areas like Gwagwa plains than the Iku- Gurara plains to the west. Rainfall pattern of the location shows that monthly rainfall distribution intensifies during the months of July-September with annual rainfall ranging from 1,100-1600mm.

The Federal Capital Territory (FCT) is almost predominantly underlain by high grade metamorphic and igneous rocks of Precambrian age which is of hydro geological significance in terms of groundwater yield and exploitation [21].

According to [21], the soil is dominated by alluvial soils which are referred to as sediment made up of mud, silt, and sand, that is deposited on flood plains and deltas by rivers and streams during seasonal flooding. Alluvial soils are typically very rich and fertile thereby supporting the cultivation of lowland rice, vegetables, yam, guinea corn, beans, millet and irrigated crops. The soil is prone to erosion due to its texture.

The lowest elevation in FCT is found in the extreme southwest where the flood plain of River Guraja is at an elevation of about 70m above sea level. From there, the land rises irregularly eastwards, northwards and north-westwards. The highest part of the territory is in the northeast where there are many peaks over 760m above sea level. Indeed, about fifty-two percent of the FCT consists of plain. With the low relief of Abuja, sizeable portions of the area is waterlogged and flooded during heavy rainstorms. Population increase leads to deforestation thereby making it prone to erosion caused by high rainfall intensity [21].

2.2 Data Collection and Handling

The data that was used for this work were from secondary sources based on rainfall occurance. The daily rainfall data used was from manual rain gauge and was obtained from the Nigerian Meteorological Agency, Abuja collected over a period of twelve years (2001 – 2012). The erosivity index was determined using the equation 4, i.e Erosivity Index, EI = $1.03V_d^{1.51}$

Average Annual Erosivity Index for rainy months was found using equation 5.

$$\text{Average annual erosivity index} = \frac{\textit{Sum total of erosivity index for the raining months}}{\textit{Number of raining month}} \quad (5)$$

Note that the number of raining months as obtainable in the study area ranged from the month of March to the month of October of each calendar year which was 8.

3. RESULTS AND DISCUSSION

The calculation of rainfall erosivity in this paper was based on the analysis of rainfall measurement between the periods of 2001 to 2012. The erosivity index was estimated using Lombardi Method for all rain episodes in the minimal duration of 30 minutes.

Figures 1 – 4 show the combined plot representations of the monthly erosivity index from 2001 – 2012. Figure 5 shows the combined plot of annual erosivity index and the annual precipitation values while Figure 6 shows the correlation of annual erosivity index versus average annual precipitation values.

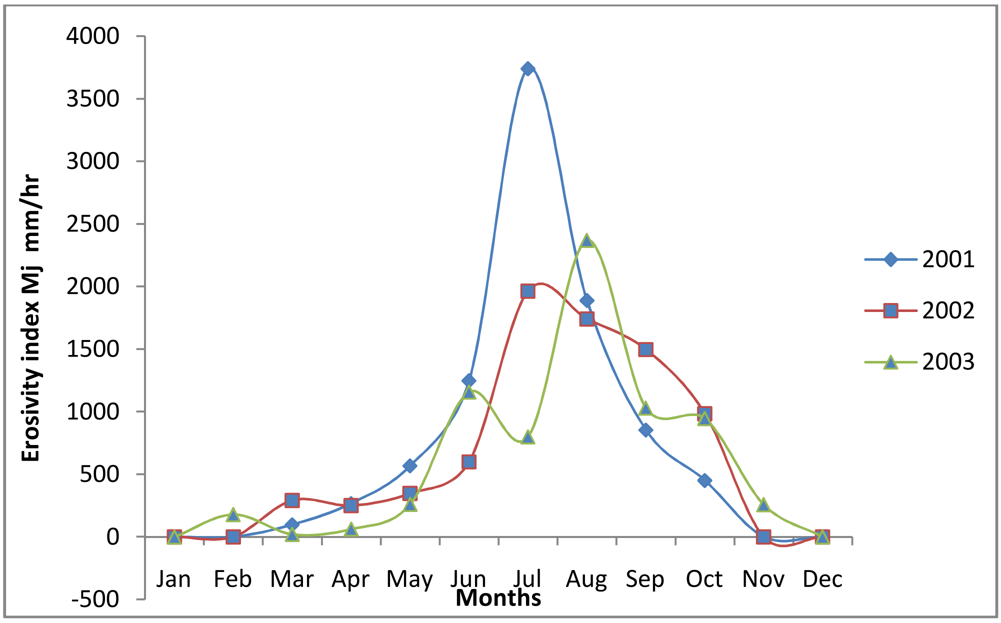

Figure 1: Monthly Variation of Erosivity Index for 2001 – 2003

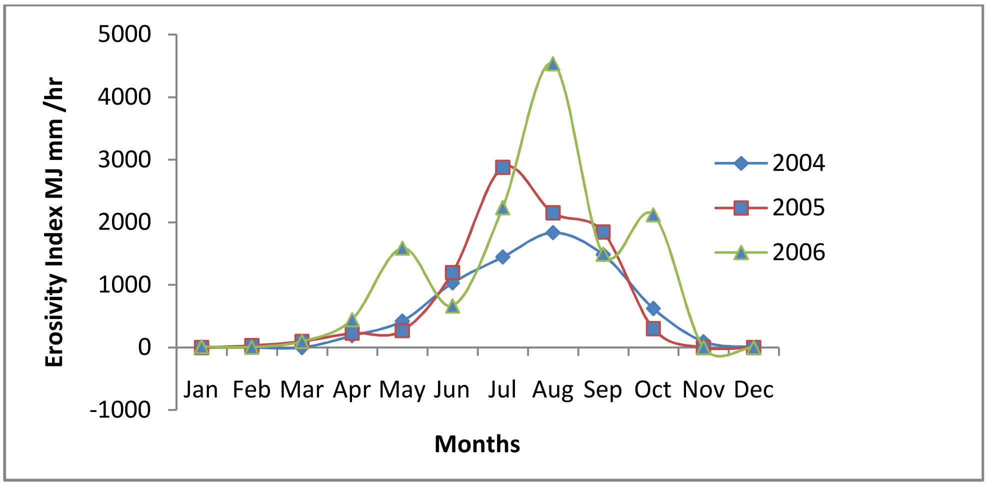

Figure 2: Monthly Variation of Erosivity Index for 2004 – 2006

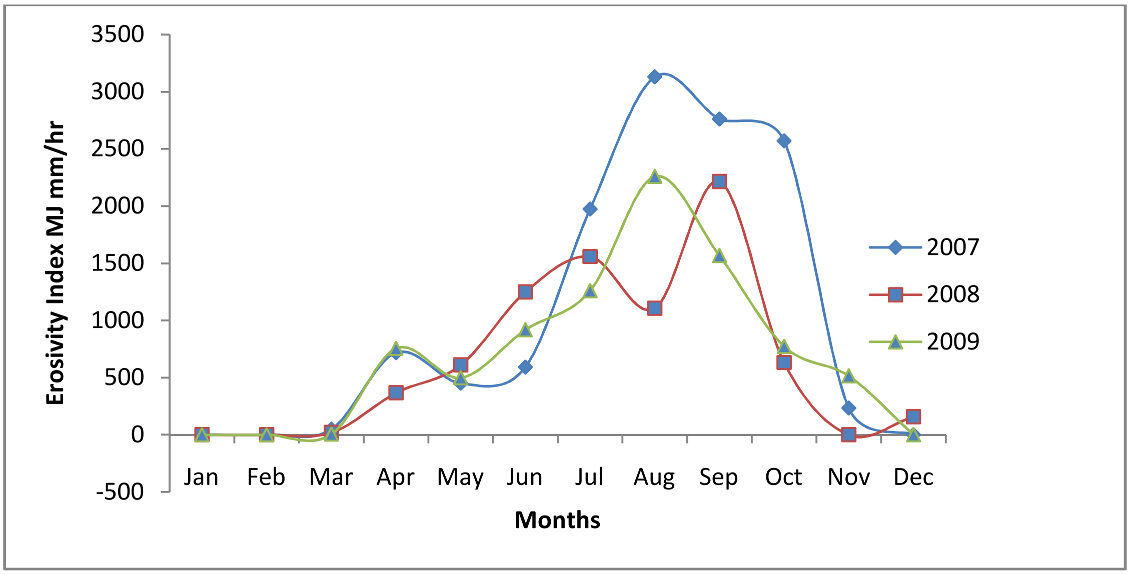

Figure 3: Monthly Variation of Erosivity Index for 2007 – 2009

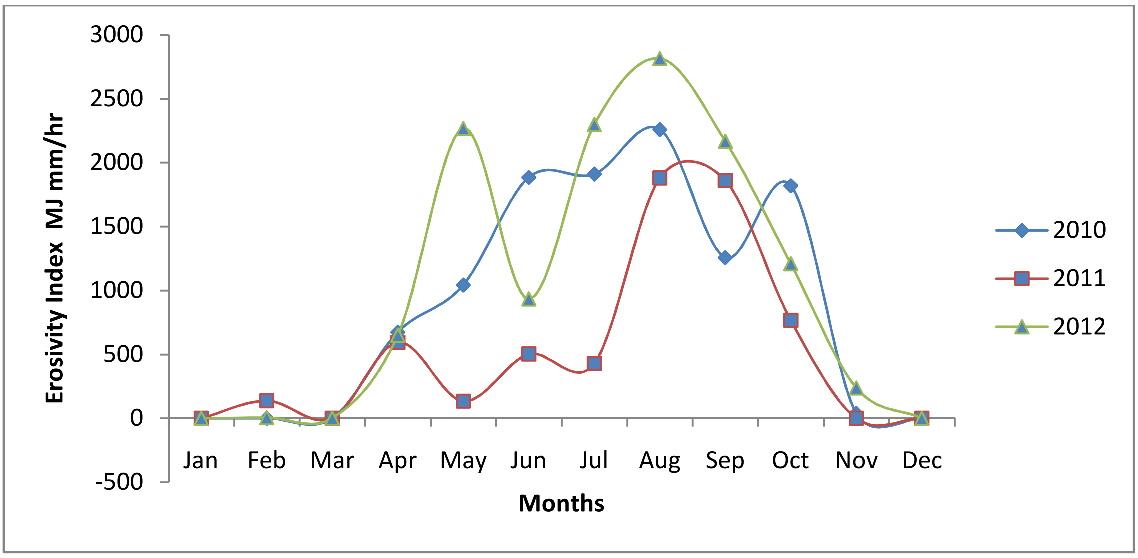

Figure 4: Monthly Variation of Erosivity Index for 2010 – 2012

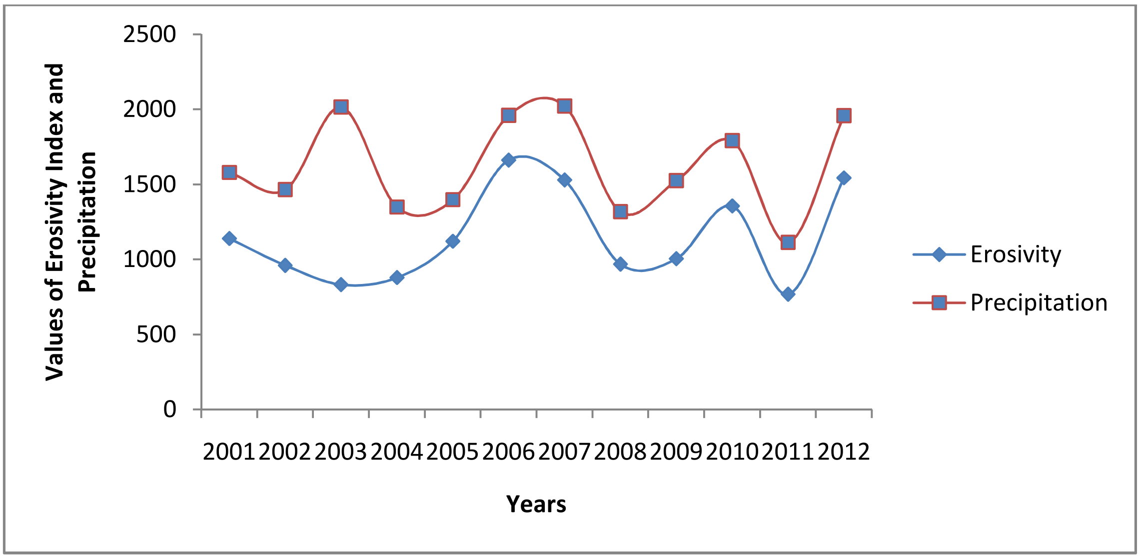

Figure 5: Annual values of erosivity index and precipitation

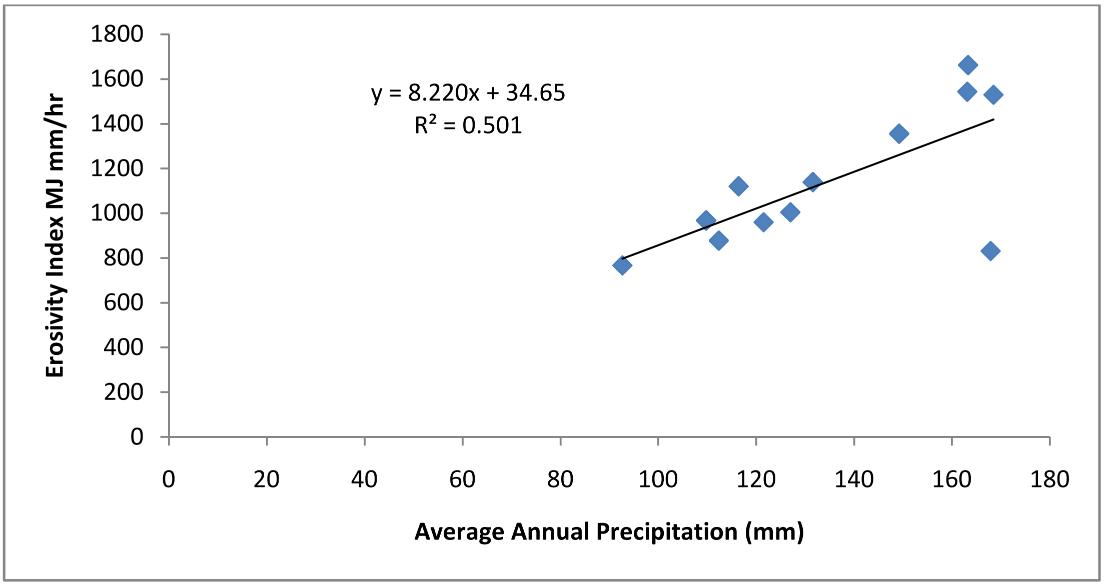

Figure 6: Correlation between annual erosivity index and average annual precipitation

It is interesting to note that within the period under consideration as could be seen from Figures 1 – 4, the month of August has the highest erosivity index except for 2001, 2002, 2005 which had the highest erosivity index in the month of July respectively (Figures 1 and 2). Another exception was in the year 2008 which had the highest erosivity index in the month of September (Figure 3). From the rainfall records, these months were observed to have highest rainfall values for those years. These observations were deviation from the historical rainfall pattern in Nigeria of double maxima (June and September) with a short dry spell in between called August break. This is a clear indication of the effect of climate change which affected the pattern of rainfall.

The year 2012 which had a severe flood destruction in Nigeria, unlike the years before it, had three (3) months (July – September) of high erosivity index at a stretch (Figure 4). The effect of flood in Nigeria in 2012 was devastating and its effect is still being felt today. The months with highest erosivity indices were the months with highest kinetic energy which caused heavy erosion. Also the months with low rainfall had low kinetic energy and hence low erosivity index. The months with zero rainfall had zero KE and zero EI.

Figure 5 shows that the erosivity index followed the pattern of precipitation. As the years go by, the relationship between precipitation pattern and erosivity index becomes more pronounced, i.e higher the precipitation, the higher the erosivity index. This is confirmed by the finding of review of rainfall erosivity in Brazil by [22] that higher erosivity values observed in the tropics are caused by the high amount of precipitation, intensity, and KE of rain. Also that the ranges of rainfall erosivity values in tropical regions are similar and they are higher than those observed in other temperate climate regions.

Further confirmation was by Figure 6, the correlation between annual erosivity index and average annual precipitation. The correlation between annual erosivity index and average annual precipitation was expressed as $Y = 8.2209X + 34.659$. The coefficient of Determination R^2 of 0.50 (50 %) is an indication that there are other key factors (other than rainfall) that determine the extent of soil erosion. It further shows precipitation alone contributed 50 % of erosion hazard during the period of study. The remaining percentage could be explained by soil, conservation, management and anthropogenic factors. The increase in precipitation could be as a result of climate change as pointed out by [23] after rainfall data studies in Ghana that some evidences of climate change include increase in surface temperature, and change in precipitation.

The impact of these indices on agricultural production cannot be overemphasized. [24] reports that the vulnerability of agriculture is not determined by the nature and magnitude of environmental stress like climate change per se, but by the combination of the societal capacity to cope with and/or recover from environmental change.

Climate change is one of the most serious environmental threats facing mankind worldwide. It affects agriculture in several ways, including its direct impact on food production. Climate change, which is attributable to the natural climate cycle and human activities, has adversely affected agricultural productivity in Africa [25]. Available evidence shows that climate change is global, likewise its impacts; but the most adverse effects will be felt mainly by developing countries, especially in Africa, due to their low level of coping capabilities [26,27]. Nigeria is one of these developing countries [28]. As the planet warms, rainfall patterns shift, and extreme events such as droughts, floods, and forest fires become more frequent which results in poor and unpredictable yields, thereby making farmers more vulnerable, particularly in Africa [29]. Peasant farmers (which constitute the bulk of the poor in Africa), face prospects of tragic crop failures, reduced agricultural productivity, increased hunger, malnutrition and diseases. To better address the food security concerns that are central to economic and sustainable development agenda, it is desirable to also address the aspects of climate change and agriculture.

4. CONCLUSION

Rainfall erosivity index for Abuja, the Federal Capital Territory (FCT) of Nigeria was evaluated using Lombadi equation (which was best suited for manual rain gauges) covering a period of 2001 – 2012.

It was discovered that higher rainfall values resulted in high erosivity index values which was in line with other tropical climates.. The average annual erosivity index for the city during the period of study was 1131.86 MJ mm/hr. The R^2 of 0.5011 shows that precipitation alone contributed 50% of the erosion risk within the study period. The knowledge of impact of rainfall on erosivity is essential in soil erosion risk assessment and for soil and water conservation planning.

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