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Assessing the Potentials for Rainfall Erosion on the Idah-Ankpa Plateau- Nigeria Using Insufficient Data

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Abstract— **In the tropical catchments of most developing countries, soil erosion research endeavours are hampered by sparse, short-term and inadequate weather records. This study attempted to find a part-solution to this problem by assessing the potentials for rainfall erosion on the Idah-Ankpa Plateau of the Anambra Basin, Nigeria, using a point, short-term (14 years) daily rainfall data. The variables computed and considered relevant to the study were the average monthly rainfall amount (mm), the average monthly rainy days, and the average monthly erosivity indices (EI). The EI values were computed using the Lombardi's method. The average monthly rainfall amount, rainy days and EI values were analyzed using descriptive statistics. Results show that the months running from May to October are the rainiest and have EI values greater than 1000 MJ.m/ha.hr, and these are the months highly prone to soil erosion wherever devegetation occurs on the landscape. September is the most erosive month with the highest average monthly rainfall amount and EI value of 242.20 mm and 1721.21 MJ.mm/ha.hr respectively. Bush burning and other land preparation practices that strip the land of its surface litter should be controlled between the months of November and March. Deforestation and construction activities occurring between May and October should be regulated.**

Index Terms— **Basal erosion rates, proliferation, Rainy days, Rainfall erosion.**

I. INTRODUCTION

Soil erosion research in the developing countries of the Tropics is a daunting undertaking as a result of unavailable, unreliable, or short-term weather records. Erosion studies require the use of long-term, time-intensity rainfall records which are not available in most tropical areas.

What are available in such areas are short-term daily rainfall data for use in erosion models [1]

Most tropical catchments are considered remote and inaccessible and are, therefore, grossly neglected in the provision of weather-monitoring stations and equipment. Reference [2] noted that what are available in these areas are data manufactured and churned out by practicing engineering consultants and contractors who have no interest in the research values of such data. Hence, more often than not, soil erosion studies and designs of soil and water control structures in these areas are usually based on guess-estimates of quantitative climatic data.

The Idah-Ankpa Plateau (IAP) of the Anambra Basin of Nigeria is a geographical region beset by the twin problems of non-availability of weather records and a proliferation of gullies on its landscape. It is estimated that about 840 treated, active, and dormant gullies [3] are in occurrence on the plateau lands where government neglect, ignorance, and insufficient and unavailable rainfall records hamper scientific interest in soil erosion research in this region. Reference [4], a firm of engineering consultants, reported that the accelerated soil erosion on the IAP started after the Nigerian civil war in the 1970s when intensified urbanization activities, high intensity rainfalls, steep slopes, and fragile soils combined to scarify the landscape.

Remarkably, most literature on the problems of soil (gully) erosion in Nigeria come from the southeastern parts of the country as if this is the only ecological zone afflicted by this environmental problem. The southeastern states are located in the semi-humid climatic region. Soil erosion also constitutes a problem in other ecological zones of the country [5, 6, 7]. However, erosion research in such areas have either been neglected because of sparse rainfall data or are two general to make any appreciable meaning to the scientific community. This study was, therefore, an attempt to extend a more detailed scientific erosion research endeavour to a typical Guinea -Savanna zone with geological and topographic features, as well as erosion intensity similar to those the southeastern states. The study assesses the potentials for rainfall erosion on the IAP using a point, short-term daily rainfall data.

II. LITERATURE REVIEW

A.Rainfall erosivity index (EI)

Rainfall erosivity index, EI, is the potential ability of rain to cause erosion. To be a valid index of the potential for soil erosion, EI must be significantly correlated with soil loss. Experiments by various investigators [8, 9, 10] have shown that neither the rainfall amount nor the intensity is very highly correlated with soil loss. Various attempts have been made to find a combination of different rainfall parameters that would be satisfactory indices of erosivity. Hence, there has arisen a multiplicity of indices for the assessment of the potential ability of rainfall to cause erosion. The most notable are the EI_{30} and the KE > 25 indices.

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B. EI_{30} index

The EI_{30} index developed by [11] is defined as the product of kinetic energy and the maximum 30-minutes rainfall intensity. Wischmeier and his colleague found that soil loss by overland flow, splash, and rill is related to a combination of kinetic energy and the maximum 30-minutes intensity (I_{30}). Their equation relating kinetic energy to rainfall intensity is expressed as a regression equation:

$$E = 1.213 + 0.89 \log I \qquad (1)$$

Where E is the kinetic energy in kg.m/(m^2.mm) and I is the rainfall intensity in mm/hr.

The EI_{30} index has been open to many criticisms, the foremost of which is that it is an equation derived from temperate environments and, therefore, may not be valid for tropical environments where rains fall at higher intensities. In addition, it assumes that all rains are erosive.

C. KE > 25 index

Reference [12] argued that in the tropics all rains falling at intensities less than 25 mm/hr are not erosive and, therefore, should be discarded. He related the kinetic energy of rainfall to it's intensity in the equation.

$$E = 29.80 - \frac{127.50}{I} \qquad (2)$$

Where E and I are as defined above.

The use of equations (1) and (2) in the computation of erosivity indices (EI) requires the use of long-term rainfall intensity records which are not available in most tropical lands. Since daily point rainfall data are much more available, [13], cited [14], related several factors of the Universal Soil Loss Equation (USLE), including rainfall erosivity, to daily rainfall and obtained the equation.

$$EI = 1.03 V_d^{1.51} \qquad (3)$$

Where EI is the erosivity index in MJ.mm/ha.hr and V_d is the daily rainfall in mm.

Since daily rainfall totals contain no information about rainfall duration or intensity, a relationship such as Lombardi's is required to assess the potentials for rainfall erosion in under-instrumented basins with short-term daily rainfall data. Reference [15] used the Lombardi's equation (3) to estimate EI values from daily rainfall totals in the daily rainfall option of the Creams Model [16].

III. THE STUDY AREA

The Idah-Ankpa Plateau (IAP) of the Anambra Basin of Nigeria comprises the Western Ankpa Plateau and the Idah flood plains. It has been so named because the latter consists of an insignificant percentage of the whole area [4]. Nestled in the Guinea Savannah ecological zone of Nigeria, it lies between Latitudes 7° 17` 00``N and 7° 23` 30``N, and Longitudes 8° 20` 20``E and 9° 00` 00``E. Parts of Kogi and Benue States are the only land areas encompassed by the IAP. The total land area is about 5174.52 km^2 with a perimeter of 793531.76 km.

The IAP is in the Middle Belt of Nigeria, which is located in the hot tropical Guinea Savannah climatic zone of the country. It is considered remote and farflung from the major urban centres of the country. The area has only one manually operated weather recording station built in 1993 at Ejule Ajobe by the Lower Benue River Basin Development Authority (LBRBDA), Makurdi. However, the operators of the station only started releasing climatic data from it in 1996. In fact, this study was based on 14 years of rainfall data collected from the station from 1996 to 2009.

Rainfall in this area is seasonal and it can vary considerably from month to month and from year to year. There are two major seasons in a year: the rainy season and the dry season. The rainy season lasts from the middle of April to the end of October, and it responds to the prevalence of the moisture – laden southwesterly maritime winds that originate from the Atlantic Ocean. The dry season is an exceedingly dry period that lasts, on the average, from October to April. It responds to the dry continental northeasterly winds that blow from the Sahara Desert. The seasonality of the rainfall is the most important feature of the climate that affects geomorphological processes in the area.

The monthly climatic data released by the LBRBDA (Table 1) for the 14 years' period show that the mean annual rainfall is 1260 mm with a range from 714 to 1890 mm. Evaporation is high, ranging from 73.40 mm in July to 166.90 mm in December. The relative humidity may be as high as 98.78% in October and as low as 75.20% in January. The mean monthly temperatures vary from 31.40°C in December to 34.50°C in March. A full description of other environmental aspects of the study area is detailed elsewhere [17].

Table 1: Average Monthly Climatic Data for Ejule Ajobe, Idah-Ankpa Plateau (1996-2009).
Source: Lower Benue River Basin Development Authority (LBRBDA) Makurdi, Nigeria.

Data	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec
Rainfall (mm)	-	3.8	42.3	109	171	207	161	212	242	140	14.9	-
Evapotranspiration (mm)	108	121	113	101	118	93.8	73.4	78.6	98.9	114	151	167
lative humidity (%)	75.2	80.9	88.4	89	94.6	95.7	98	97.8	98.4	98.7	92.6	83.6
Temperature (°C)	32.6	33.7	34.5	34.4	31.7	33.8	31.8	34.3	32.2	32	32.5	31.4

IV. MATERIALS AND METHODS

A. Computation of the rainfall variables

The 14-years point daily rainfall data available at Ejule Ajobe were collected from the LBRBDA for the study. Since this weather recording station was the only one available in the area, it was assumed that the rainfall data collected from it were representative of the rainfall pattern of the study area. The variables computed for the study were the yearly rainfall amounts, the average monthly rainfall amounts, the average monthly rainy days, and the average monthly erosivity indices (EI). However considering the seasonality of rainfall in the area, the average monthly variables were used in the assessment of rainfall potentials for the area because the same volume of rainfall concentrated over a few months of the year will be more destructive of the soil than if it were spread over an entire year.

B. Procedure

a. Yearly rainfall amounts

The daily rainfall data, tabulated and recorded in mm, were obtained in sheets of monthly records for each year. For each month of records for a particular year, the daily rainfall records were summed up to give the rainfall amount for that month. Then the rainfall amounts for all the rainy months of that year were summed up to obtain the rainfall amount for that year. The same process was repeated for the 14 years of record to obtain their yearly rainfall amounts.

b. Average monthly rainfall amounts

For any month of records in a year, the daily rainfall amounts were summed up to give the rainfall amount for that month. Then the sum of the rainfall amounts for that particular month for the 14-years period of record was divided by 14 to obtain the average monthly rainfall amount for the month. The same procedure was followed in the computation of the average monthly rainfall amounts for all the rainy months in the area.

c. Average monthly rainy days

The number of rainy days for a rainy month of a year was added up to obtain the total rainy days for that month. Then the total rainy days for that same month for the 14 years period were added up and divided by 14 to obtain the average monthly rainy days for the month. The same procedure was followed to obtain the average monthly rainy days for all the rainy months of the 14 years period.

d. Average monthly erosivity indices (EI)

Because intensity-duration rainfall records were unavailable in the area, Lombardi's equation (3) was employed in the computation of the average monthly EI values. Each daily rainfall record (mm) in each month of the 14 years of records was substituted into equation 3 and the values obtained were recorded and tabulated as daily EI data (MJ.mm/ha.hr) for that month. The procedures followed in the computation of the average monthly rainfall amounts above were adopted to obtain the average monthly EI values.

The yearly amounts; average monthly rainfall amount, rainy days and the EI variables were analyzed using descriptive statistics.

V. RESULTS AND DISCUSSION

A. Descriptive statistics of the rainfall variables

Substantial variations in the rainfall characteristics of the area are observed except for the annual rainfall amount, which varies from 714.40–2021.70 mm with a mean of 1261.40 mm, a standard deviation (SD) of 362.82 mm, and a coefficient of variation (CV) of 28.76% (Table 2). The average monthly rainfall ranges from 3.80 to 242.42 mm with a mean of 134.42 mm, an SD of 80.65 mm, and a CV of 60.00%. The average monthly EI values range from 7.70 to 1721.20 MJ.mm/ha.hr, with a mean of 912.94 MJ.mm/ha.hr, an SD of 523.95 MJ.mm/ha.hr, and a CV of 57.39%. The minimum for the average number of rainy days per month is 0.60, maximum = 8.00, mean = 5.32, SD = 2.74 and CV = 51.50%.

The low CV of the yearly rainfall amount shows that it does not vary much. It is also an indication that the weather pattern remains consistent and reliable over the area, delivering near-uniform yearly amounts of rainfall every rainy season. However, the high variability of the average monthly amounts shows that the rainfall distribution in the area varies with months, starting from the onset of the rains in March to the peak in September down to their cessation in November (Table 3).

Table 2: Descriptive Statistics of the Rainfall Characteristics of the Idah-Ankpa Plateau (IAP)

Variable	Unit	Range	Mean	SD	CV (%)
Yearly amount	mm	714.40-2021.70	1261.40	362.82	28.76
Average monthly rainfall amount	mm	3.80-242.42	134.42	80.65	60.00
Average monthly EI	MJ.mm/ha.hr	7.70-1721.20	91.94	523.95	57.39
Average monthly rainy days	Number	0.60-8.00	5.32	2.74	51.50

SD = Standard deviation, CV = Coefficient of variation (%), and EI = Erosivity index

.The average monthly erosivity indices and the average monthly rainy days also vary widely with CVs of 57.39% and 51.50% respectively.

B. Assessing the average monthly rainfall and rainy days

The average monthly number of rainy days and the average monthly amounts of rainfall follow the same pattern (Table 3). The least average monthly number of rainy days occurs in March (1.2) whereas the highest occurs in September. On the other hand, the least average monthly rainfall occurs in February (3.8 mm) while the maximum occurs in September (242.20 mm) also. It appears surprising that the month of the first recorded rain (February) does not coincide with month of the days the first rains were recorded to have commenced (March). It could either be that the 3.8 mm of rain recorded in February was a rare event that occurred only once in the 14 years period or it could be attributed to human error.

Similarly, the coincidence in the occurrence of the maximum average monthly number of rainy days (8) and the average monthly rainfall amount (242.20mm) simultaneously in September is consistent with the weather pattern of the Middle Belt of Nigeria where [2] reported that September was the rainiest month of the year.

The average monthly number of rainy days and rainfall amounts observed for the IAP are significantly less than those reported by [18] for Uyo, Akwa Ibom State, Nigeria. They reported 25 days as the maximum average rainy days occurring in July and 368.50 mm maximum average monthly rainfall in June. Uyo is in the humid southern part of Nigeria, whereas the IAP is in the sub-humid Middle-Belt region.

Expectedly, the potential for soil erosion is less on the IAP than in the Uyo area because of reduced erosive potentials of rainfall and runoff. However, where the land has been stripped of its vegetative cover, soil erosion can be catastrophic on the IAP, leading to gullying processes.

Table 3: Average Monthly Characteristics of the Computed Rainfall Variables of the Idah-Ankpa Plateau

Months	No. of rainy days	Rainfall amount (mm)	Erosivity index (EI) (MJ.mm/ha.hr
January	0.00	0.00	0.00
February	0.00	3.80	7.70
March	1.20	42.30	291.60
April	3.70	109.40	771.60
May	6.00	170.60	1076.10
June	7.30	206.80	1680.90
July	6.60	160.80	1112.30
August	7.50	212.40	1413.00
September	8.00	242.20	1721.20
October	7.10	139.70	1027.60
November	0.60	14.90	37.40
December	0.80	0.00	0.00
Min	0.06	3.80	7.70
Max	8.00	242.20	1721.20
Mean	5.32	134.42	912.94

The dry season, which runs from November to March, experiences little or no rainfall (Table 3). Consequently, runoff and erosion are minimal in these months. However, during this period, the land surface is usually left bare from bush burning and other land preparation activities for the planting of crops in the rainy season that starts in March. Between March and May, the bare soil surfaces persist as volunteer vegetation begins to sprout, attempting to accord protection to the soil from the destructive raindrops and runoff from the early rains. Reference [4] reported that the early rains of the IAP fall at destructive intensities causing extensive damage to exposed soil surfaces. This suggests that in the study area, most of the erosion or gullies are initiated between the months of March and May before volunteer vegetation matures and is able to reach sufficient density to cover and protect the soil.

The average monthly rainfall values are high from June to October, reaching a peak in September (242.20 mm) before it dips to its lowest value in November (14.90 mm). Erosion is not expected to occur on well forested lands in the area between June and November because of the cover forest canopy provides on land. However, where the land surface has been devegetated, erosion can be widespread.

C. Erosivity Indices

The average monthly erosivity values are also shown in Table 3. Sheridan et al. (1989) used the Lombardi's equation to assess the seasonal distribution of rainfall erosivity in Peninsular Florida in the United Stated of America. Notably, both the Peninsular Florida and the study area (IAP) are located in tropical environments where local thunder storms as well as tropical storms result in rather intense erosive events.

The highest average monthly EI value occurs in September (1721.20 MJ.mm/ha.hr). This is followed by the value recorded in June (1680.90 MJ.mm/ha.hr). February has the least EI value (7.70 MJ-mm/ha.hr), an event that occurred once in the 14 years of record. The variations of the average monthly EI values follow exactly the same pattern as those of the average monthly rainfall amounts (Table 3) in which the rainiest month tallies with the most erosive month (September), and the second rainiest month (June) is also the second most erosive month. March is both the least rainy and erosive month.

As stated earlier, considering the seasonality of rainfall in the area, the average monthly EI values are more important than the annual values from the point of view of the potentials of rainfall to cause erosion and the timing of the critical periods of the year when implementation of soil conservation practices are required on the land.

The EI values exceed 1000 MJ.mm/ha.hr from the months of May to October (Figure 1), stressing the need for adequate vegetative soil conservation measures to be applied on the land in these months to minimize soil detachment and transport that give rise to rilling and gullying. However, September and June still remain the most critical months in terms of the provision of vegetative and mechanical protection on the land surface for erosion control, as well as the initiation of construction activities that expose the soil to the elements. The EI is virtually zero from November to March. Water erosion is, therefore, not a problem during this period compared to Harmattan – induced wind erosion.

D. Hypothetical Potentials for Soils Erosion on the IAP

The depiction in Figure 2 is the hypothetical potentials for the occurrence of soil erosion on the Idah-Ankpa Plateau on (A) a land surface devoid of vegetative cover and (B) a land surface protected by natural vegetation. In the case of the former, condition A, erosive processes are initiated in March with the onset of the rains. As the months progress, these erosive activities increase with increasing monthly rainfall amounts and runoff, reaching their peaks in September synchronously with the peak of the rainfall amount and EI values. Thereafter, they decline to a zero value with the cessation of the rains in November.

For a naturally vegetated landscape as in the latter case (B), erosion starts with the rains in March, but increases more slowly in April and May as volunteer vegetation sprouts with the onset of the rains to accord protection to the soil. In June, vegetation would have become dense enough, giving more adequate protection to the soil and thus causing erosive activities to drop to their basal level in that month. The basal rate of erosion continues up to the end of the rainy season in November because the dense vegetative cover provides nearly uniform protection to the soil throughout the rainy season from June to November.

The portrayal in Figure 2 gives one explanation for the location and proliferation of gullies in the urban and semi-urban centres of the IAP. On the urban and semi-urban lands, bare soil surfaces brought about by human developmental activities create compacted and paved land surfaces that favour the concentration of runoff on highly erodible soils in the area leading to the initiation of gullies and sediment production. On the other hand, the rural environments remain permanently protected by undisturbed vegetative cover. Even with the prevalence of bush burning, the occurrence of gullies in the rural communities remains few and far between.

Reference [19] agree that urbanization and other developmental projects induce gullying and a high sediment production by concentrating runoff on bare soil surface. Reference [20] reported that the intense rains of the Mediterranean environments cause gully erosion in that region. Reference [21] reported that urbanization activities are the major causes of the initiation and occurrence of gullies in the Enugu area of Nigeria. Similarly, urbanization, intense rains, fragile soils, and a rugged terrain have combined to expose the IAP to high potentials for soil erosion [2].

VI. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The results of the study lead to the following conclusions:

(1) Although the period spanning from November to March is consider dry and devoid of any vegetal cover on the land surface of the IAP resulting from bush burning, agricultural land preparation, and other cultural practices, the potentials for rainfall erosion is lowest during this period.

(2) The high intensity, destructive early rains arrive in the months between March and May to meet the exposed, bare soil surfaces left behind in the dry season, thus causing widespread erosion on the surface.

(3) Between March and May, volunteer vegetation sprouts to accord protection to the soil.

(4) By the month of June, volunteer vegetation matures, providing maximum canopy density to protect the soil.

(5) Under natural conditions, the landscape of the IAP will remain covered by lush, protective vegetation from June to November.

(6) The months running from May to October have average monthly EI values greater than 1000 MJ.mm/ha.hr and these are the critical months with high potentials for the occurrence of soil erosion when the land surface is devegetated.

(7) September is the most erosive month of the year with maximum average monthly rainfall and EI values of 242.20 mm and 1721.21 MJ.mm/ha.hr respectively.

B. Recommendations

1 Bush burning and other farming and cultural practices that strip the land of its surface litter cover between the months of November and March should be controlled.

2 Deforestation activities should be regulated between the months of May and October.

3 Construction projects to be carried out between the months of May and October should provide adequate measures for runoff and sediment control.

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