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Determination of Erosivity of Enugu State

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***Abstract*— *To combat erosion, there is need for adequate examination of soils and factors of erosion. The study of Erosivity is vital for effective soil conservational planning and agricultural activities in Enugu State of Nigeria of West Africa, and other parts of the world. In this study, rainfall amount and duration were obtained and used in the determination of rainfall intensities in Enugu regions. These rainfall records were used in calculating the three erosivity indices namely; the maximum 30-minute intensity, kinetic energy greater than 25, and peak storm intensity. With the aid of the above data, erosivity of Enugu was uncovered. This was achieved by taking the average of the calculated years. This Erosivity value can be used in modeling a general soil loss equation for all soil types in Enugu. This general soil loss equation can be used to predict erosion in Enugu region. Also, from the force impact of rain capable of causing erosion, erosive rain were separated from non erosive rain using the method based upon the concept that there is a threshold value of intensity at which rain starts to be erosive. With this insight, one can also predict future erosive rain and non erosive rain using the weather forecast data. With the knowledge of these predictions, erosion prevention technique may be applied in areas of possible future occurrence rather than remediating soil after erosion hazard.*

***Keywords*— Erosivity, Soil Erosion, Rainfall, Soil Loss, Storm Intensity.**

I. INTRODUCTION

Erosivity refers to the intrinsic capacity of rainfall to cause erosion. Water erosion would not occur if all rain were non - erosive, therefore erosivity is fond of the physical properties of rainfall. Rainfall indices represent the climatic influence of rainfall on water related soil erosion (Yu, 1998). The basic erosivity factors include; Amount: This is the quantity of rain that falls in any given rainfall event. The higher the amount the more erosive it becomes. Intensity: This refers to the amount of rain received during a unit time. High intensity rain are usually received during short duration, thus low intensity are of long duration. High intensity storm have large drop sizes thus will cause more erosivity. Rain-drop size: Raindrops ranges from 0.0039 inches (0.1cm) to 0.35 inches (1.0cm) in mean diameter above which they tend to break up. Smaller drops are called cloud droplets and their shape is spherical. As raindrop increases in size, its shape becomes more oblate with its larges cross section facing the on-coming air flow. Large raindrops are increasingly flattened on the bottom like hamburger buns and very large ones are shaped like parachutes. The large size is explained by condensation on large smoke particles or by collision between drops of liquid water. Drop size distribution: Some rain are made up of drops of all sizes, the proportion of large and small drops (size distribution) and how it varies in different rain affects erosivity. Much bigger rain drop sizes from thunder storm have high intensities, and are highly erosive as they strike the soil with combine force. Terminal velocity: Falling rain drop reach a maximum (terminal) velocity when the force of gravitational acceleration is equated by resistance to the drop falling through the air. The terminal velocity is a function of the drop size and it increases up to 9ms^{-1} from the largest drop. Mathematically, terminal velocity is calculated as;

$$V_t = \frac{2gr^2(e-\sigma)}{9N},$$

where, V_t = Terminal velocity; g = Acceleration due to gravity; r = Radius of the raindrop, e = Density of water, σ = Density of air (1kgm^{-3}), N = Viscosity of air (Assume 1 x 10^{-3}). Another factor in Erosovity determinant is the Kinetic Energy of Rainfall. This is the force impact of rain and it is a major factor in splash erosion. It is mathematically calculated as; $KE = 210.3 + 89Log_{10}I$,

where, KE = Kinetic energy (metric ton ha^{-1}); I = Rainfall intensity (mmhr^{-1}).

II. THE STUDY AREA

The study area Enugu State of Nigeria in West Africa is bounded by several other states; in the North by Benue and Kogi states, in the South by Abia and Imo states, while in the West and East by Anambra and Ebonyi State respectively. Minerals mined in Enugu state includes; coal, iron ore, fine clay, silica sand, lime stone, and marble (Wikipedia, 2014). The climate is tropical hinterland in nature and is comparatively congenial, characterized by high temperature, high humidity and substantial rainfall which is entirely seasoned, most of it falling between May and October. Rainfalls in the tropical regions are more erosive than those in the temperate regions due to the presence of strong winds and high temperature. Annual distributions of rainfall also influence the erosivity of rain.

III. MATERIALS

The major materials used in this work are the rainguage, the automated scientific weather station, and rainfall data. Rainfall data include rainfall amounts and duration. These rainfall records were obtained using the rain gauge and the automated scientific weather station which is equipped with a standard set of sensors that record; air temperature, relative humidity, rainfall amount, duration, speed and direction, soil temperature and moisture, etc., automatically every five minutes interval.

IV. METHODOLOGY

Rainfall amount, A (mm) was obtained by daily reading of the rainfall while rainfall duration, T (hr) was obtained by timing each rainstorm using the scientific automated weather station. These rainfall records were carried out in the four geographical zones of the study area; Enugu North (Nsukka), Enugu South (Awgu), Enugu West (Udi), and Enugu East (Enugu capital city). Erosivity indices were calculated as below;

i. The Peak storm intensity index (AIM):

This erosivity index is the product of the amount of rain per storm and the peak intensity of storm. This index was developed by Lal (1976) and is generally referred to as AIM index.

The peak storm intensity index is stated as thus;

$$AIM = A(mm)x\,IM(mmhr^{-1}) \quad - \quad - \quad \textbf{(i)}$$

Where, A=Total Amount of rainfall; IM= Maximum rainfall intensity (peak intensity) within the period.

Procedures: Identify the total rainfall amount, A (total in month) from the daily rainfall data (Appendix 4) and multiply it with the maximum rainfall intensity that occurred in that month. That is; A (mm) x IM ($mmhr^{-1}$). Multiply the result by (10^{-2}) to convert the unit mm^2hr^{-1} to cm^2hr^{-1}. Example: In January 2014, Total amount, A = 58.00mm, and maximum Intensity, I occurred on 27^{th} day with 229.17$mmhr^{-1}$(From appendix 2.1.1). Thus;

Jan. 2014 =58.00mm X 229.17$mmhr^{-1}$ =13291.86mm^2hr^{-1} x 10^{-2} =132.9186cm^2hr^{-1}; or Jan. 2014 = 58.00mm x 229.17$mmhr^{-1}$, = 5.8cm x 22.917$cmhr^{-1}$, = 132.9186cm^2hr^{-1}

ii. The Kinetic Energy of Rainfall (KE):

Kinetic energy of rainfall is the force impact of rainfall, its role in soil detachment has long been recognized (Ellison, 1944), It is mathematically defined using the energy intensity relationship equation developed by Wischemeier (1969) and it stated as thus;

$$KE = 210.3 + 89log_{10}I \quad - \quad - \quad \textbf{(ii)}$$

Where; KE = Kinetic energy (ton metric hr^{-1}); I = Rainfall intensity ($mmhr^{-1}$)

iii. The Maximum 30 Minutes Intensity Index (EI_{30}):

This is a product of kinetic energy of storm and the 30-minutes intensity (greatest intensity during any 30 minute period).EI_{30} Index was computed from rainfall data by locating the greatest amount of rain that fell in any 30 minutes intensity, and multiplying the value with Kinetic energy. Wischemeier (1969) found this index to be most significantly suitable for erosion.

$$EI_{30} = EXI_{30} \quad - \quad - \quad - \quad \textbf{(iii)}$$

Where; E = kinetic energy of rainfall; I_{30} = Maximum 30minutes intensity

iv. The Kinetic Energy Greater Than 25 Index (KE > 25)

This is the force impact of rain that is capable of causing erosion. Thus, this index is used to separate erosive rain from non erosive rain (KE > 25 index is used to identify erosive rain). Hudson (1971) developed KE > 25 index after he found accumulated Kinetic energy of storms with intensity greater than 25mmhr^{-1} with soil loss. This method was based upon the concept that there is a threshold value of intensity at which it starts to be erosive. This value is 25mmhr^{-1}. Mathematically;

$$KE > 25 = 210.3 + 89 log_{10}(I > 25) \quad - \quad - \quad \textbf{(iv)}$$

Where; I> 25 = Intensities above 25mmhr^{-1}**;** I = Rainfall intensity (mmhr^{-1}).

V. RESULTS AND DISCUSSION

The following results were generated using the procedures discussed above. The procedure was generated for other months and years and was tabulated as thus;

Table.1: Peak Storm Intensity Index (AIM) for year 2014.

Month	TOTAL RAINFALL AMOUNT, A (mm)	MAXIMUM RAINFALL INTENSITY, IM (mmhr^{-1})	PEAK STORM INTENSITY INDEX, AIM (cm^{2}hr^{-1}) = A x IM
Jan	58.00	229.17	132.9186
Feb	8.00	72.73	5.8184
March	78.50	145.16	113.9506
April	156.00	165.00	257.4000
May	169.50	139.29	236.0966
June	371.50	218.18	810.5387
July	214.50	84.62	181.5100
Aug	211.00	184.21	388.6831
Sept	381.00	187.50	714.375
Oct	59.50	115.38	68.6511
Nov	60.50	222.73	134.7517
Dec	0.00	0.00	0.0000
Total	1768.0	1763.97	3044.6938

Note: 2014 Total rainfall Amount (A) and maximum Intensity (IM) were taken from NIMET, NWFS, Enugu State Min. Of Agriculture, while AIM index is multiplication of both A and IM.

Table.2: Peak Storm Intensity Index (AIM) for year 2013.

Month	TOTAL RAINFALL AMOUNT, A (mm)	MAXIMUM RAINFALL INTENSITY, IM (mmhr^{-1})	PEAK STORM INTENSITY INDEX, AIM (cm^{2}hr^{-1}) = A x IM
Jan	47	75.81	35.6307
Feb	0.00	0.00	0.0000
March	28.00	121.43	34.0004
April	139.00	125.00	173.7500
May	279.00	115.38	321.9102
June	236.50	72.22	170.8003
July	235.50	185.71	437.3471
Aug	168.00	140.54	236.1072
Sept	417.10	183.33	764.6694
Oct	182.60	118.64	2042.2637
Nov	59.00	91.89	54.2151
Dec	2.00	40.00	0.8000
Total	1793.7	1269.95	4271.4941

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Note: 2013 Total rainfall Amount (A) and maximum Intensity (IM) were taken from NIMET, NWFS, Enugu State Min. of Agriculture, while AIM index is multiplication of both A and IM.

Table.3: Peak Storm Intensity Index (AIM) for year 2012

Month	TOTAL RAINFALL AMOUNT, A (mm)	MAXIMUM RAINFALL INTENSITY, IM ($mmhr^{-1}$)	PEAK STORM INTENSITY INDEX, AIM (cm^2hr^{-1}) = A x IM
Jan	4.00	44.44	1.7776
Feb	3.20	41.67	1.3334
March	2.80	26.00	0.7280
April	139.50	136.36	190.2222
May	298.00	157.14	468.2772
June	269.90	195.45	527.5196
July	343.50	175.00	601.1250
Aug	161.00	133.33	214.6613
Sept	223.00	142.31	317.3513
Oct	265.00	172.22	456.3830
Nov	49.00	125.00	61.2500
Dec	0.00	0.00	0.0000
Total	1758.9	1348.92	2840.6286

Note: 2012 Total rainfall Amount (A) and maximum Intensity (IM) were taken from NIMET, NWFS, Enugu State Min. of Agriculture, while AIM index is multiplication of both A and IM.

Table.4: Peak Storm Intensity Index (AIM) for year 2011.

Month	TOTAL RAINFALL AMOUNT, A (mm)	MAXIMUM RAINFALL INTENSITY, IM ($mmhr^{-1}$)	PEAK STORM INTENSITY INDEX, AIM (cm^2hr^{-1}) = A x IM
Jan	0.00	0.00	0.0000
Feb	112.00	52.24	58.5088
March	96.60	68.00	65.6880
April	223.40	71.96	160.7586
May	454.80	164.55	748.3734
June	637.60	162.00	1032.9120
July	482.40	174.00	839.3760
Aug	281.60	153.85	433.2416
Sept	581.60	161.54	939.5166
Oct	175.50	111.11	194.9981
Nov	0.00	0.00	0.0000
Dec	0.00	0.00	0.0000
Total	3045.5	1119.25	4473.3731

Note: 2011 Total rainfall Amount (A) and maximum Intensity (IM) were taken from NIMET, NWFS, Enugu State Min. of Agriculture, while AIM index is multiplication of both A and IM.

Table.5: Peak Storm Intensity Index (AIM) for year 2010.

Month	TOTAL RAINFALL AMOUNT, A (mm)	MAXIMUM RAINFALL INTENSITY, IM ($mmhr^{-1}$)	PEAK STORM INTENSITY INDEX, AIM (cm^2hr^{-1}) = A x IM
Jan	16.60	70.91	11.7711
Feb	16.00	136.00	21.7600
March	14.40	160.00	23.0400
April	448.60	174.29	781.8649

May	354.40	166.67	590.6785
June	658.00	142.86	940.0188
July	808.20	157.14	1270.0055
Aug	734.40	197.27	1448.7509
Sept	852.60	152.00	1295.9520
Oct	456.20	148.00	675.1760
Nov	0.00	0.00	0.0000
Dec	0.00	0.00	0.0000
Total	4359.4	1505.14	6118.9989

Note: 2010 Total rainfall Amount (A) and maximum Intensity (IM) were taken from NIMET, NWFS, Enugu State Min. of Agriculture, while AIM index is multiplication of both A and IM.

Table.6: Peak Storm Intensity Index (AIM) for year 2009.

Month	TOTAL RAINFALL AMOUNT, A (mm)	MAXIMUM RAINFALL INTENSITY, IM ($mmhr^{-1}$)	PEAK STORM INTENSITY INDEX, AIM (cm^2hr^{-1}) = A x IM
Jan	66.00	131.91	87.0606
Feb	0.60	30.00	0.1800
March	36.40	173.33	63.0921
April	378.40	160.00	605.4400
May	776.00	166.67	1293.3592
June	432.20	176.92	764.6482
July	736.60	165.52	1219.2203
Aug	506.80	157.11	796.2335
Sept	541.60	170.37	922.7239
Oct	756.00	205.45	1553.2020
Nov	106.20	138.46	147.0445
Dec	0.00	0.00	0.0000
Total	4336.8	1675.74	7452.2043

Note: 2009 Total rainfall Amount (A) and maximum Intensity (IM) were taken from NIMET, NWFS, Enugu State Min. of Agriculture, while AIM index is multiplication of both A and IM.

Table.7: Kinetic Energy of Rainfall for year 2014.

Month	RAINFALL INTENSITY, I ($mmhr^{-1}$)	KINETIC ENERGY, KE (metric ton ha^{-1}) = $210.3 + 89 \log_{10}(I)$
Jan	304.17	431.2959×10^{-6}
Feb	72.73	375.9913×10^{-6}
March	402.74	442.1450×10^{-6}
April	550.01	454.1956×10^{-6}
May	601.34	457.6399×10^{-6}
June	1030.23	478.4481×10^{-6}
July	481.38	449.0425×10^{-6}
Aug	640.01	460.0518×10^{-6}
Sept	1028.87	478.4036×10^{-6}
Oct	277.63	427.7715×10^{-6}
Nov	372.73	439.1546×10^{-6}
Dec	0.00	210.3000×10^{-6}
Total	5761.84	4673.1439×10^{-6}

Note: 2014 rainfall intensity, I ($mmhr^{-1}$) were taken from NIMET, NWFS, Enugu State Min. of Agriculture.

Table.8: Kinetic Energy of Rainfall for year 2013.

Month	RAINFALL INTENSITY, I ($mmhr^{-1}$)	KINETIC ENERGY, KE (metric ton ha^{-1}) = 210.3 + 89 log_{10}(I)
Jan	75.81	377.5933 x 10^{-6}
Feb	0.00	210.3000 x 10^{-6}
March	206.05	416.2460 x 10^{-6}
April	563.75	455.1479 x 10^{-6}
May	751.03	466.2373 x 10^{-6}
June	361.12	437.9353 x 10^{-6}
July	751.68	466.2640 x 10^{-6}
Aug	428.67	444.5569 x 10^{-6}
Sept	1332	488.3805 x 10^{-6}
Oct	536.63	453.2433 x 10^{-6}
Nov	181.18	411.2709 x 10^{-6}
Dec	40	352.8869 x 10^{-6}
Total	5227.92	4980.0623x 10^{-6}

Note: 2013 rainfall intensity, I ($mmhr^{-1}$) were taken from NIMET, NWFS, Enugu State Min. of Agriculture.

Table.9: Kinetic Energy of Rainfall for year 2012.

Month	RAINFALL INTENSITY, I ($mmhr^{-1}$)	KINETIC ENERGY, KE (metric ton ha^{-1})= 210.3 + 89 log_{10}(I)
Jan	44.44	356.9542 x 10^{-6}
Feb	65.00	371.6481 x 10^{-6}
March	44.75	357.2212 x 10^{-6}
April	719.66	464.5819 x 10^{-6}
May	1343.88	488.7276 x 10^{-6}
June	1350.25	488.9056 x 10^{-6}
July	1584.1	495.0822 x 10^{-6}
Aug	788.16	468.0974 x 10^{-6}
Sept	133.13	488.3271 x 10^{-6}
Oct	1631.14	496.3905 x 10^{-6}
Nov	206.82	416.3884 x 10^{-6}
Dec	0.00	210.3000 x 10^{-6}
Total	7911.33	5102.6242x 10^{-6}

Note: 2012 rainfall intensity, I ($mmhr^{-1}$) were taken from NIMET, NWFS, Enugu State Min. of Agriculture.

Table.10: Kinetic Energy of Rainfall for year 2011.

Month	RAINFALL INTENSITY, I ($mmhr^{-1}$)	KINETIC ENERGY, KE (metric ton ha^{-1}) = 210.3 + 89 log_{10}(I)
Jan	0.00	210.3000 x 10^{-6}
Feb	145.45	402.7803 x 10^{-6}
March	129.28	398.2235 x 10^{-6}
April	245.48	423.0100 x 10^{-6}
May	1059.71	479.5428 x 10^{-6}
June	1298.59	487.4015 x 10^{-6}
July	880.77	472.3961 x 10^{-6}
Aug	857.56	471.3637 x 10^{-6}
Sept	1637.42	496.3638 x 10^{-6}
Oct	422.19	443.9695 x 10^{-6}

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Nov	0.00	210.3000 x 10^{-6}
Dec	0.00	210.3000 x 10^{-6}
Total	6676.45	4714.9512x 10^{-6}

Note: 2011 rainfall intensity, I ($mmhr^{-1}$) were taken from NIMET, NWFS, Enugu State Min. of Agriculture.

Table.11: Kinetic Energy of Rainfall for year 2010.

Month	RAINFALL INTENSITY, I ($mmhr^{-1}$)	KINETIC ENERGY, KE (metric ton ha^{-1}) = 210.3 + 89 $\log_{10}$(I)
Jan	104.24	389.9020 x 10^{-6}
Feb	184.00	411.8672 x 10^{-6}
March	160.00	406.4649 x 10^{-6}
April	930.12	474.4965 x 10^{-6}
May	904.66	473.4285 x 10^{-6}
June	950.59	475.3420 x 10^{-6}
July	1353.60	489.0035 x 10^{-6}
Aug	1594.00	495.3225 x 10^{-6}
Sept	1504.43	493.0886 x 10^{-6}
Oct	826.17	469.9219 x 10^{-6}
Nov	0.00	210.3000 x 10^{-6}
Dec	0.00	210.3000 x 10^{-6}
Total	8511.81	4999.4376x 10^{-6}

Note: 2010 rainfall intensity, I ($mmhr^{-1}$) were taken from NIMET, NWFS, Enugu State Min. of Agriculture.

Table.12: Kinetic Energy of Rainfall for year 2009.

Month	RAINFALL INTENSITY, I ($mmhr^{-1}$)	KINETIC ENERGY, KE (metric ton ha^{-1}) = 210.3 + 89Log_{10} (I)
Jan	189.05	412.9174 x 10^{-6}
Feb	30.00	341.7619 x 10^{-6}
March	173.33	409.5621 x 10^{-6}
April	842.98	470.6962 x 10^{-6}
May	1087.32	480.5396 x 10^{-6}
June	843.42	470.7140 x 10^{-6}
July	1376.43	489.6532 x 10^{-6}
Aug	1294.48	487.2769 x 10^{-6}
Sept	1257.37	486.1555 x 10^{-6}
Oct	1161.64	483.0939 x 10^{-6}
Nov	245.39	423.0011 x 10^{-6}
Dec	0.00	210.3000 x 10^{-6}
Total	8501.41	5165.6718x 10^{-6}

Note: 2009 rainfall intensity, I ($mmhr^{-1}$) were taken from NIMET, NWFS, Enugu State Min. of Agriculture.

Table.13: The Maximum 30 Minutes Intensity Index (EI_{30}).

YEAR	KINETIC ENERGY, E (metric ton ha^{-1})	MAXIMUM 30MINUTES INTENSITY, I_{30}($mmhr^{-1}$)	MAXIMUM 30MINUTES INTENSITY INDEX, EI_{30}=E X I_{30}($mmhr^{-1}$)
2014	4673.1439 x 10^{-6}	139.29	650922.2138 x 10^{-6}
2013	4980.0623 x 10^{-6}	42.55	211901.6509 x 10^{-6}
2012	5102.6242 x 10^{-6}	42.55	217116.6597 x 10^{-6}
2011	4714.9512 x 10^{-6}	123.27	581212.0344 x 10^{-6}
2010	4999.4376 x 10^{-6}	139.17	695771.7308 x 10^{-6}
2009	5165.6718 x 10^{-6}	133.33	688739.0211 x 10^{-6}
Average	4939.3152 x 10^{-6}	103.36	507610.5518 x 10^{-6}

Table.14: Yearly Kinetic Energy, Kinetic Energy Greater Than 25, Peak Storm Intensity, and Erosivity.

YEAR	KINETIC ENERGY,KE (metric ton ha^{-1})	KINETIC ENERGY GREATER THAN 25, KE>25(metric ton ha^{-1})	PEAK STORM INTENSITY, AIM(cm^2 hr^{-1})	EROSIVITY, E (metric ton ha^{-1})
2014	4673.1439 x 10^{-6}	4723.2153 x 10^{-6}	3044.6938	650922.2138 x 10^{-6}
2013	4980.0623 x 10^{-6}	4976.9473 x 10^{-6}	4271.4941	211901.6509 x 10^{-6}
2012	5102.6242 x 10^{-6}	5061.3727 x 10^{-6}	2840.6286	217116.6597 x 10^{-6}
2011	4714.9512 x 10^{-6}	4694.3403 x 10^{-6}	4473.3731	581212.0344 x 10^{-6}
2010	4999.4376 x 10^{-6}	4998.2806 x 10^{-6}	6118.9989	695771.7308 x 10^{-6}
2009	5165.6718 x 10^{-6}	5165.6718 x 10^{-6}	7452.2043	688739.0211 x 10^{-6}
AVERAGE	4939.3152 x 10^{-6}	29619.828 x 10^{-6}	4700.2321	507610.5518 x 10^{-6}

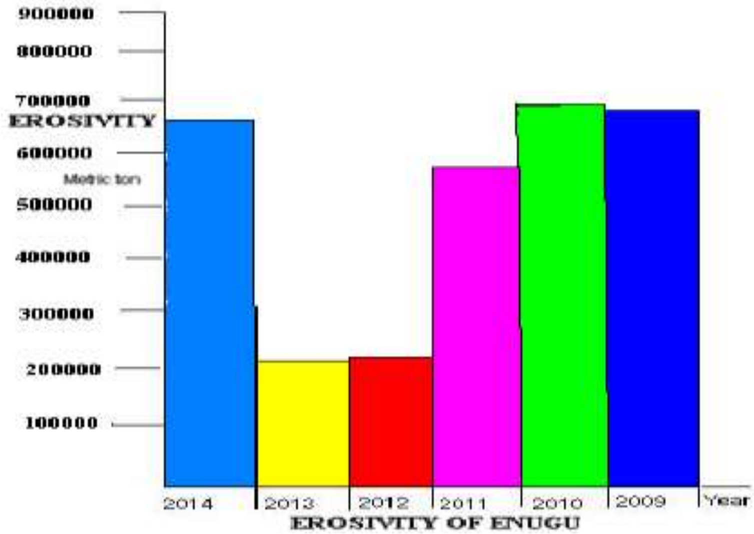
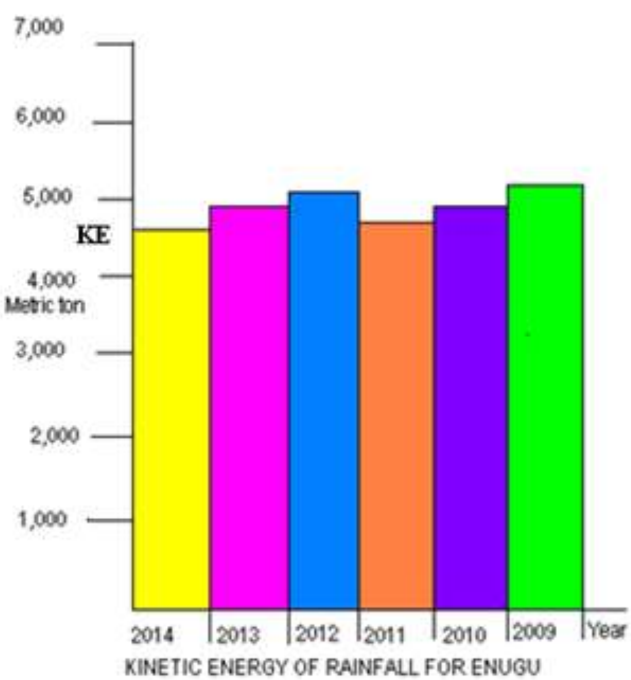


Fig. 1: Erosivity of Enugu.



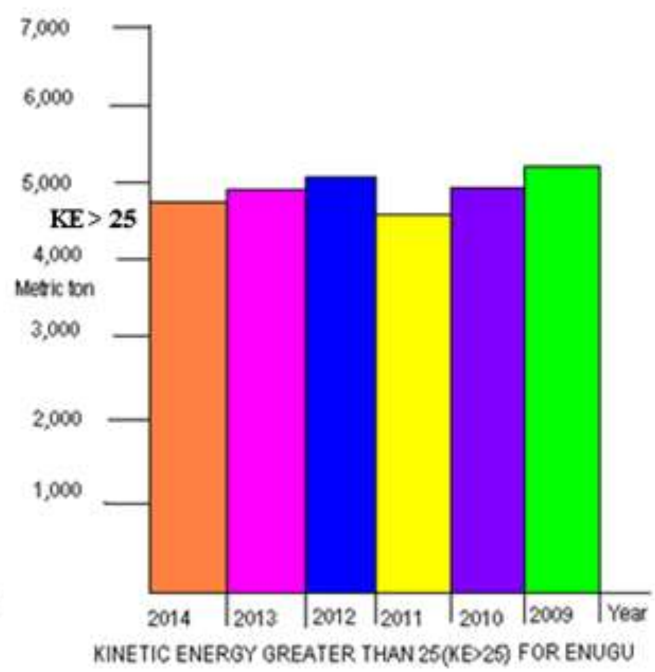


Fig. 2: Kinetic Energy and Kinetic Energy Greater Than 25 index Chart for Enugu Region.

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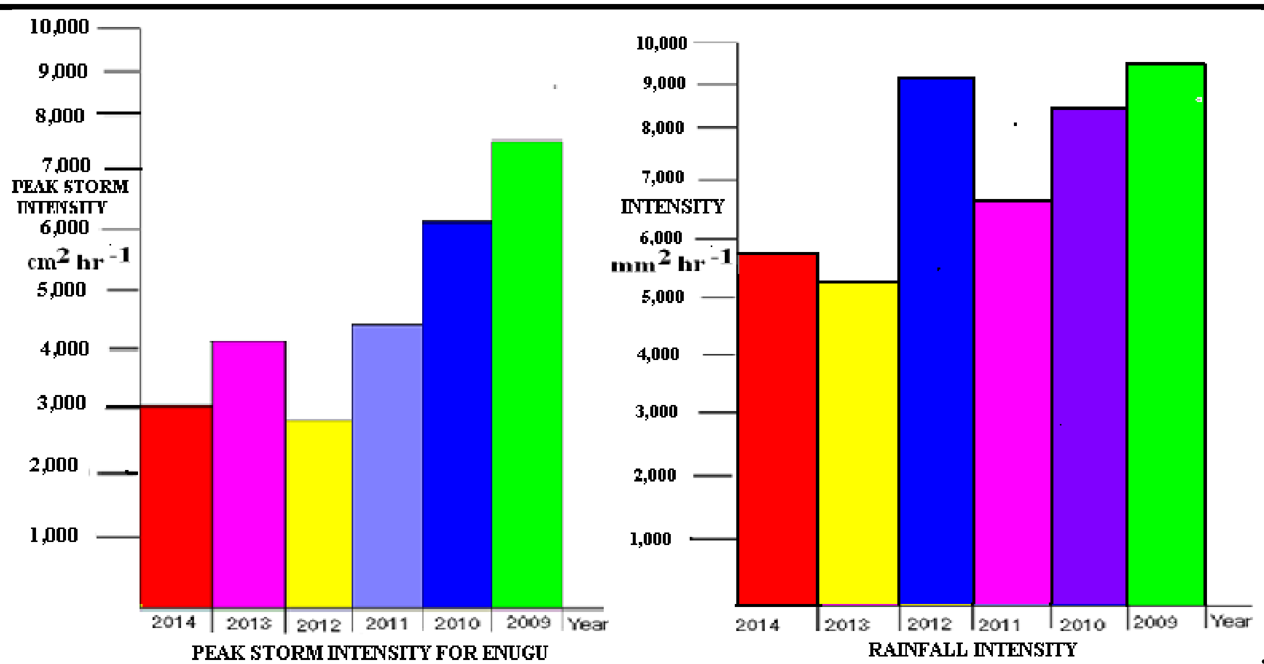

Fig.3: Peak Storm Intensity and Rainfall Intensity Chart for Enugu Region.

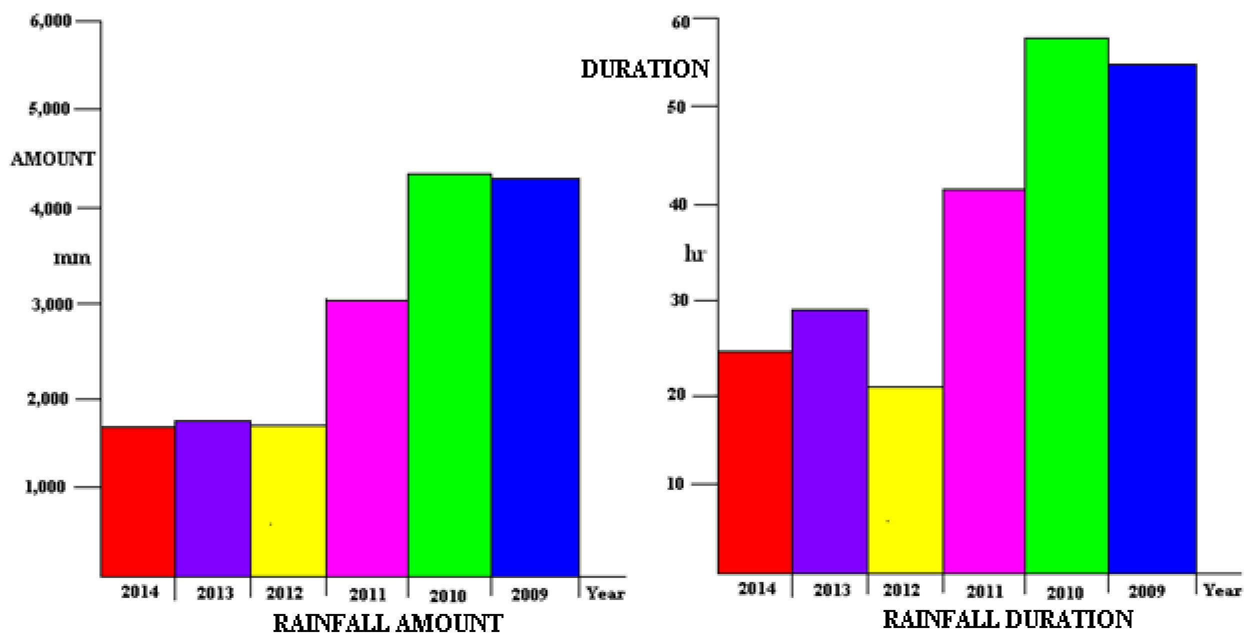

Fig. 4: Rainfall Amount and Rainfall Duration of Enugu.

VI. DISCUSSIONS

From the above calculations, Erosivity (R) in Enugu area is 507610.5518x 10^{-6}. This is equivalent to 0.5076105518and by approximation, it is 0.5. From the results, Erosivity (R) in Enugu area is not very intense since the value is 507610.5518x 10^{-6} or 0.51.Erosive rains were separated from non erosive rains in tables 1 to 6. This method maybe deployed in forecasting future erosive rains and non erosive rains. With the forecast, future erosive rainfalls, preventive measures may be carried out in spotted locations prior predictions. From universal soil loss equation, annual erosion equals the product of all the erosion variables (A = RKLSCP), thus if Erosivity, K is well manage to minimal, erosion will not occur in the controlled locations.

VII. CONCLUSION

The knowledge of Erosivity is essential to understand erosion processes, estimate soil erosion rates, predict future

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erosive rainfall and non-erosive ones and in designing erosion control practices.

VIII. RECOMMENDATION

Conducting subsequent studies on Erosivity in the future years will help monitor any change.

More work and effort should be put in the prevention of erosion rather than remediation of eroded soil.

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