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Determination of rainfall erosivity in akwa ibom state using modified forunier index

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Abstract

In the tropics, rainfall is known to be the cause of soil erosion through the detachment and runoff process. This issue has been known to be a global issue causing environmental threat and deterioration. In modeling soil erosion by water, rainfall is considered as the energy driving force. Its study is important in understanding the aggressivity of the rainfall and its interpretation. Modified Fournier index defines the aggressivity of a rainfall to cause erosion. It was used in this study based on the availability of the monthly and annual rainfall data. A rainfall data of 34 years was obtained from Nigerian Meteorological Agency (NIMET). The amount of rainfall ranges from 1840.7 to 3837.9mm representing 2000 and 2012 respectively. From the monthly MFI obtained, it shows that lower MFI values are associated with dry season while higher MFI values are associated with rainy season. July has the highest monthly MFI. The yearly MFI ranges from 220.2 to 561.3. From the statistical analysis carried out, a high variance was observed among the grouped data. P-value was given as 0.76 which signifies that the grouped data are not equal therefore differs from each other. The result obtained from the study shows that the aggressivity of the rainfall within the study area is very high in nature, therefore, having the ability to cause detachment and of soil particles and transportation.
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Keywords: Modified Fournier Index, Rainfall Aggressivity, Soil Erosion, Rainfall Erosivity

1. Introduction

In the tropics where rainfall is the driving factor for soil erosion and agriculture is the main stay of the economy. The improper use of land resources, population growth and climate change has put pressure on the available land, hereby leading to decline in crop yield, environmental degradation and pollution of nearby surface water. Soil erosion by water has been recognized to be a major environmental threat globally (FAO, 2019; Wang *et al.,* 2018; Aga *et al*., 2018) based on its onsite and offsite impact on the environment (Schoonover and Crim, 2015; Adimassu, 2014). Wischmeier and Smith (1978) observed soil erosion to be caused simultaneously by rainfall, soil, vegetation, topography and anthropogenic factors. Empirical modeling such as; universal soil loss equation and revised universal soil loss equation has been used globally to model soil erosion (Fashae *et al*., 2013; Chadli, 2016; Gelagay and Minale, 2016). The considered input for the models are rainfall erosivity (*R),* soil erodibility *(K)* slope length and steepness *(LS),* crop cover factor *(C)* and land management factor (*P)*. The rainfall-runoff factor *R* is generally known as one of the most important indicators of the erosive potentials of raindrop impacts (Lobo *et al*., 2015). Soil loss is closely related to rainfall, partly through the detachment power of raindrops striking the ground and partly through the contribution of rainfall to runoff (Giadrossich *et al*., 2016; Merten *et al*., 2015). For water erosion to occur there must be rainfall erosivity and soil erodibility. The erosive force of rainfall is expressed as rainfall erosivity (Asadi *et al.,* 2008; Panagos *et al*, 2015).

Rainfall erosivity is the ability of the rainfall to cause detachment of soil particles while soil erodibility is the ability of the soil to resist detachment as a result of rainfall impact. The expanse of erosion caused by rainfall depends on the intensity, amount, duration and frequency of the rainfall, which are climate related (Mondal *et al*., 2016; Arun *et al*., 2016; Panagos *et al.*, 2015). The factor *R* is the sum of erosive storm values EI_{30} occurring during a mean year, which is a function of the product of the total storm energy *E* multiply by the maximum 30 minutes intensity (I_{30}) (Wischmeier and Smith, 1978) where *E* is in MJ/ha and I_{30} is in mm/hr. The detailed data for the determination of rainfall erosivity is a major setback in developing countries such as Nigeria. In soil planning and management, it is necessary to evaluate the rainfall within the study area for adequate soil and water resource management. Several researchers have made attempt worldwide to establish correlations between the *R* factor for areas of scarce data. Readily available rainfall data, such as the daily and monthly rainfall data have been used to determine the erosivity of rainfall globally (Leo and Heo, 2011; Bonilla and Vidal, 2011; Henando and Romana, 2015; Reinard and Freimund, 1994; Arnold, 1980). In this case, one of the most used method for *R* estimation is given by the Modified Fournier Index (MFI) (Arnoldus, 1980), which uses the average amount of precipitation for important number of years to determine the aggressivity of the rainfall. The aggressivity of the rainfall describes the erosivity of the rainfall. The objective of this paper is to determine the rainfall erosivity *R* through the aggressivity of the rainfall within Akwa Ibom State for soil erosion study using the rainfall average monthly data and the Modified Fournier index.

2.0 Material and methods

2.1 Study Area:

The location of the study is Akwa Ibom state, Nigeria. The study area is located within the trigonometric boundaries of $4^o32'$ and $5^o33'$ north latitude and $7^o25'$ and $8^o25'$east longitude. The climate is divided into two seasons. The wet season last from April to October and the dry season last from November to March. The annual total rainfall ranges from 1875mm to 2500mm with a mean annual temperature that varies between 21^oc and 29^oc and a relative humidity of 60% and 85% (Ogban and Obi, 2010).

2.2 Data:

Rainfall climatic data was used for this study. An average monthly rainfall data of 34 years (1985-2018) was obtained from the Nigerian Meteorological Agency (NIMET), Uyo.

2.3 Methods:

The method used in this study is the Modified Fournier Index. It is based on the monthly and annual rainfall data to estimate the rainfall erosivity *R*-values through the aggressivity of the rainfall as developed by Fournier (1960) and modified by Arnoldus, (1980). It is an alternative procedure to estimate *R* in data scarce region. Table 1 shows the rainfall aggressivity index of rainfall, it has been used globally in areas of limited data for estimating the properties of the rainfall (Andoh *et al*., 2012; Renard and Freimund, 1994; Coman *et al*., 2019). The equation is given as shown in equation (1);

$$F = \sum_{i=1}^{12} \frac{P_i^2}{P} \quad (1)$$

F = Modified Fournier Index

Pi = Monthly rainfall (mm)

P = Total annual rainfall (mm)

Table 1: Rainfall Aggressivity Index (RAI)
Developed by Fournier (1960) and Modified by Arnoldus, 1980.

Rainfall Erosivity ($MJmmha^{-1}hr^{-1}$)	Interpretation
0 – 60	Very Low
61 – 90	Low
91 – 120	Moderate
121 – 160	High
Above 160	Very High

Source: Arnoldus, 1980.

3.0 Results and Discussion

3.1 Results

3.1.1 Presentation of Monthly Rainfall Aggressivity

The results of the monthly rainfall aggressivity using the modified fournier index for the area are presented in table 2 to 5. The monthly rainfall aggressivity were grouped into 1985-1994, 1995-2004, 2005-2014 and 2015-2018 for the study area as shown on Table 2 to 5.

Table 2: Modified fournier index for monthly rainfall in akwa ibom state (1985-1994)

Month	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994
January	0	0	0	0	0	0.37	0	0.025	0	0.019
February	1.89	2.08	0.82	0	0	0	0.39	0	0	0.014
March	11.63	22.69	22.56	9.35	0.57	0.36	0.76	5.69	6.65	8.81
April	17.14	5.23	12.13	23.57	14.98	12.4	69.55	5.95	7.63	10.53
May	37.21	20.75	78.22	17.77	25.45	46.85	19.24	27.36	8.97	33.84
June	21.39	12.52	18.87	24.59	18.63	6.29	45.46	41.93	51.82	37.28
July	35.2	51.63	14.69	43.64	113.82	102.38	65.56	98.22	55.73	78.12
August	72.31	6.1	40.34	28.51	40.9	85.91	73.08	65.03	98.41	54.37
September	24.03	83.71	48.34	101.91	76.56	11.41	2.72	46.17	47.08	80.54
October	26.96	46.09	37.39	20.6	72.92	20.57	25.62	6.06	28.51	32.57
November	3.36	2.04	0.32	6.15	12.35	7.6	2.14	12.17	4.22	5.63
December	0	0	0	8	0	0.83	2.62	0	0	0

Table 2 shows the local conditions of the modified Fournier index which represents the aggressivity of the rainfall within the study area for 1985 to 2004. The results obtained shows that MFI is affected by the seasonal climatic condition of the study area. Dry season is associated with low values of MFI representing the month of November to April. Wet season contributes to high MFI ranging from the month of May to October. The lowest value of MFI for the decade is given as 0.014 for the month of February 1994, which coincides with the dry season. The highest value of MFI is given as 113.82 for July, 1989 which corresponds to the rainy season.

Table 3: Modified fournier index for monthly rainfall in akwa ibom state (1995-2004)

Month	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
January	0	0.56	0.16	0.345	1.453	0.539	0	0	0.1909	0
February	0	5.89	0	0	2.88	0	0.0319	0.0498	0.88	1.46
March	12.58	7.17	6.69	3.27	3.84	6.16	22.81	7.8	5.162	0.26
April	2.99	8.15	7.6	8.55	67.61	8.53	20.75	29.18	23.84	12.37
May	44.24	8.13	19.83	10.2	12.51	55.77	49.8	41.68	26.49	21.41
June	21.61	40.65	29.36	45.2	9.56	11.61	109.27	27.95	15.74	59.57
July	80.98	35.4	62.09	42.05	17.75	35.05	20.7	17.95	120.47	57.4
August	43.38	77.61	55.52	31.47	42.59	37.49	14.39	51.43	22.81	37.57
September	26.18	77.5	11.98	44.37	87.47	42.9	31.6	43.73	27.63	59.08
October	50.81	22.66	51.55	15.68	70.57	16.17	21.96	73.49	20.69	35.52
November	6.66	0	3.43	28.72	3.6	4.9	6.04	2.1	6.5	0.2
December	0	0	0.16	2.31	0	1.13	0	0.0346	0	0

Table 3 shows the local condition of the MFI of the study area for the second decade representing 1995 to 2004. The lowest value of MFI for the period is given as 0.0319 for February, 2001 which reflects the dry season of the study area. The highest value of the MFI is given as 109.27 for June 2001; this reflects the wet season of the study area.

Table 4: Modified fournier index for monthly rainfall in akwa ibom state (2005-2014)

Month	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
January	0.1658	0	0	0.594	3.48	0.93	0	0.5067	0.1676	5.84
February	3.11	1.096	0.373	0	3.39	1.57	0.8	0.976	5.97	0
March	8.04	22.87	9.36	6.05	1.85	1.07	18.98	18.64	37.72	1.79
April	26.8	26.11	41.24	38.64	40.38	9.03	6.17	36.37	9.85	34.12
May	11.52	40.75	38.28	82.05	43.5	15.57	22.91	32.12	29.03	56.1
June	35.02	104.13	64.15	58.85	59.67	117.99	46.05	219.87	19.43	77.32
July	25.72	52.11	43.61	57.78	13.15	17.4	203.02	31.94	43.28	12.61
August	134.35	38.52	28.53	102.8	22.23	193.04	41.92	136.77	38.15	86.49
September	34.92	95.23	45.56	13.7	26.09	31.76	30.54	77.56	25.64	94.76
October	84.42	41.66	186.11	18.45	14.36	37.12	31.6	6.25	125.93	11.65
November	14.17	0.72	2.53	2.14	1.24	2.88	6.2	0	8.27	7.12
December	0	0	0	1.27	0	0	0	0	0.11	0.19

Table 4 represents the local conditions of the aggressivity of the rainfall through the modified Fournier index for 2005 to 2014 for the study area. The lowest value of MFI is given as 0.1656 for the month of February, 2005. While the highest value of MFI is given as 219.87 for the month of June, 2014.

Table 5: Modified fournier index for monthly rainfall in akwa ibom state (2015-2018)

Month	2015	2016	2017	2018
January	0	0	0	0
February	10.14	3.45	0.422	4.77
March	5.56	8.17	5.58	1.29
April	13.31	18.52	7.96	9.75
May	5.7	27.55	25.83	37.83
June	60.53	65.06	46.5	50.08
July	98.38	66.88	102.72	68.17
August	51.07	31.98	46.36	47.32
September	39.79	29.49	26.26	27.97
October	47.59	34.2	56.1	53.39
November	23.09	4.05	15.19	0.122
December	0	0.0682	0.03	0.11

Table 5 represents the local conditions of the rainfall within the study area through the modified Fournier index for 2015 to 2018. The results obtained shows that the MFI is low at dry season and high at wet season. The lowest value of MFI is given as 0.03 while the highest value of MFI is given as 102.72 for the month of June, 2017.

Table 6 represents the yearly amount of rainfall data and the monthly MFI for the study area for 1985 to 2018. The rainfall data ranges from 1840.7 to 3837.9mm representing the year 2000 and 2012 respectively. The lowest value of the MFI is given as 220.2 for the year 2000 with an annual yearly rainfall data of 1840.7mm and the highest value is given as 561.3 for the year 2012 with an annual rainfall data of 3837.9mm.

3.1.2 Presentation of Yearly Rainfall and Yearly Modified Fournier Index of Akwa Ibom State

Table 6: Yearly rainfall and modified fournier index for akwa ibom state (1985-2018)

Year	**(*P*)mm**	**MFI**	**Year**	**(*P*)mm**	**MFI**
1985	2132.6	251.2	2002	2341.4	295.4
1986	1904.7	252.8	2003	2095.2	270.4
1987	2244.4	275.2	2004	2221.6	285
1988	2215	278.1	2005	3026.9	378.2
1989	2688.7	376.2	2006	3373.7	423.2
1990	2032.8	295	2007	3396.8	459.7
1991	2246.7	307.1	2008	2970.6	383.3
1992	2256.8	308.6	2009	1944.1	229.3
1993	2229.5	309.02	2010	2762.1	428.4
1994	2668.5	341.7	2011	2880.3	408.2
1995	2268.4	289.7	2012	3837.9	561.3
1996	2143.8	283.7	2013	2941.3	343.5
1997	1921.3	248.4	2014	3027.2	388
1998	2033.8	232.2	2015	2967.4	355.2
1999	2510.4	319.8	2016	2477.9	289.4
2000	1840.7	220.2	2017	2643.6	333
2001	2317.2	297.4	2018	2317.9	300.8

3.1.3 Analysis of MFI

Table 7: Analysis of Variance

Groups	*Count*	*Sum*	*Average*	*Variance*		
1985 - 1994	12	299.9368	24.994733	543.70621		
1995 - 2004	12	274.17562	22.847968	364.22081		
2005 - 2014	12	400.19291	33.349409	911.91215		
2015 - 2018	12	319.58305	26.631921	702.72678		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	740.4384	3	246.8128	0.3913678	0.759793	2.816465817
Within Groups	27748.23	44	630.64149			
Total	28488.66	47				

The statistical analysis of the MFI is shown as given on table 7. The result indicates that the mean of the rainfall for grouped years is given as 299.94, 274.18, 400.19 and 319.58 representing 1985 – 1994, 1995 – 2004, 2005 – 2014, and 2015 – 2018 respectively. The average values indicate that (1995 – 2004) has the lowest averaged value of 22.85 while (2005 – 2014) has the highest average value of 33.35. The variance obtained indicates a high variation within grouped data. *P-value* is given as 0.76 which signifies that the grouped data are not equal therefore differs from each other.

3.2 Discussion

The rainfall data obtained from the study area shows that the area is experiencing high precipitation annually. The rainfall data shows the local climatic condition of the study area to depict a tropical rainforest (Ezemonye and Emeribe, 2012). The monthly MFI obtained for 1985 to 2018 using the monthly and yearly rainfall data shows a similar trend as shown on Table 2 to 5. The monthly MFI obtained shows that low value of MFI occurs in dry season ranging from the month of November to March, while high value of MFI coincides with the wet season starting from April to October. The aggressivity of the rainfall obtained using the MFI shows that the aggressivity of the rainfall over the study area ranges from very low (0-60) to very high (above 160) as given by (Arnoldus, 1980), thereby making it to be erosive. The highest amount of MFI is found in July for the study area. This shows that July is the month with the highest rainfall event throughout the year. The MFI result shows that the amount, intensity and duration of rainfall affect its aggressivity (Mondal *et al*., 2016; Arun *et al*., 2016; Panagos *et al.*, 2015). This can be seen graphically on figure 1 as high yearly rainfall gives high value of MFI. the lowest yearly rainfall and the lowest yearly MFI is given as 1840.7mm and 220.2 respectively for the year 2000 while the highest yearly rainfall and the highest yearly MFI is given as 3837.9mm and 561.3 respectively for the year 2012.

Figure 1 shows the temporal variation of annual rainfall and modified fournier index of Akwa Ibom (1985-2018). When compared to the aggressivity of the rainfall on table 1, it shows that MFI within the region is highly erosive as the annual values were found to be above 160 (Arnoldus, 1980). This signifies the occurrence of erosive rainfall within the study area as gullies have been recorded within the study area Udoumoh *et al.,* (2018). Similar work has been done by Comman *et al*., (2019) in Spain; the MFI was known to produce an accurate estimate of the rainfall aggressivity than other methods. Andoh *et al*., (2012) carried similar research in the tropics of Ghana and found the MFI to increase with the rainfall. Ezemonye and Emeribe, (2012) in their study observed that the MFI worked for southeastern Nigeria. From the statistical analysis of the results obtained as shown on table 7, it can be seen that there is a variance across the grouped MFI data. This is an indication of the changing climate and its effects on the MFI. The trend analysis of the MFI shows that the MFI data obtained from 1985 had a peak in 1989 decreased in 1994 and further decreased in 1999 and had a peak in 2007. A sharp decrease occurred in 2009 and a peak was observed in 2012 which later keeps dropping the previous year as displayed on figure 2. The implication of this research shows that the rainfall within the study area is the driving factor of soil erosion and it is being affected by climate change. Presently, there is a decline in the MFI. This implies loss of soil nutrients, pollution of nearby surface water by pollutants carried by runoff, siltation of drainages and flood occurrences, gully erosion formation within the study area amongst others.

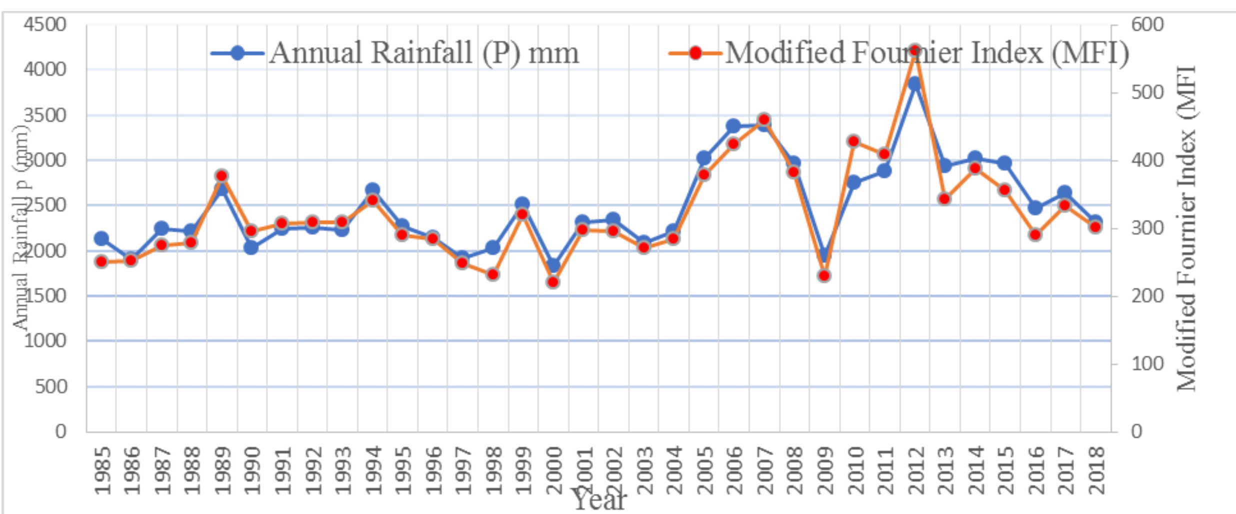

Figure 1: Temporal Variation of Annual Rainfall and Modified Fournier Index of Akwa Ibom (1985-2018)

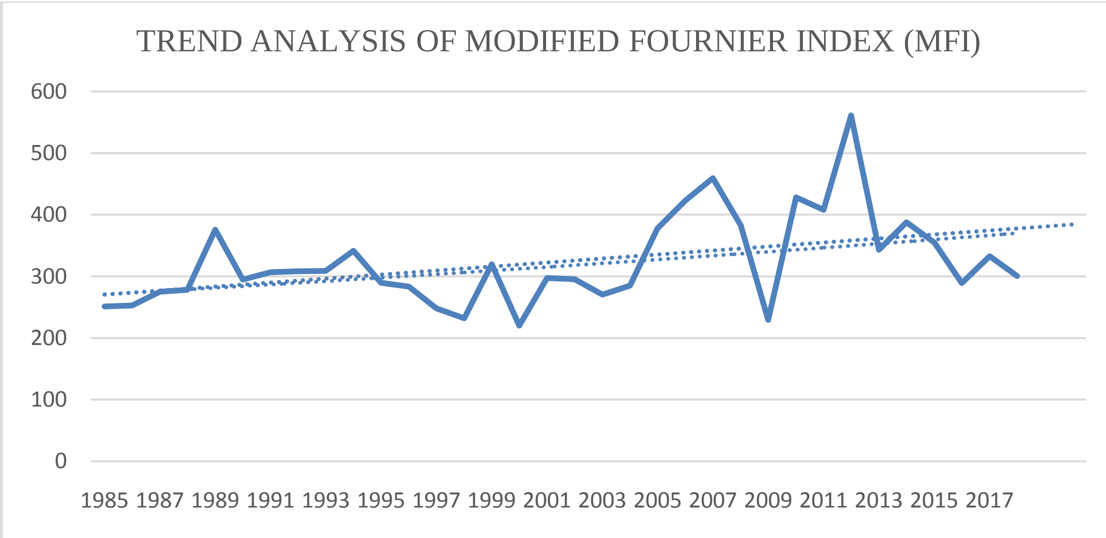

Figure 2: Trend Analysis of MFI from 1985 to 2018

4.0 Conclusion

The MFI for Akwa Ibom state has been determine, showing that the study area is experiencing erosive rainfall. In soil erosion management, the first step is to understand the rainfall aggressivity that affects soil loss and degradation. Rainfall is an important parameter in soil erosion modeling, since it initiates the detachment of the soil and further its occurrence through runoff. The monthly MFI shows that erosive rain coincides with the growing stage of plants within the study area which affects the productivity of the crops cultivated and yield. The modified fournier index shows that the aggressivity of the rainfall within the study area is very high. However, the statistical analysis showed that there is a high variance among the grouped data which signifies the impact of climate change. It therefore signifies that rainfall is the driving force in initiating soil erosion within the study area. Therefore, it is necessary to adapt sound land management techniques in mitigating soil erosion within the study area for soil and water resource management.

5.0 Recommendation

From the result of the study, rainfall has been known to be the causative factor of soil erosion within the study area. As such, with the attendant effect of climate change effect on the environment, the aggressivity of the rainfall should be evaluated continually for proper understanding of the aggressivity of the rainfall. Weather stations should be provided across the study to show the spatial differences. Therefore, proper soil conservative measures should be taken to ensure adequate productivity of the soil for food security and environmental sustainability.

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