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Determination of Rainfall Erosivity Indices Using Fournier's Method for Owerri Municipal

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ABSTRACT

This paper determined rainfall erosivity indices using Fournier's method for Owerri Municipal in Imo State. Climatic data were collected from Meteorological Department, Federal Ministry of Aviation, Owerri. The collected data include; monthly rainfall, monthly relative humidity as well as monthly temperature for the period of twenty years (1998-2018). The data collected were subjected to statistical analysis and the rainfall erosivity indices were determined using the Fournier's method for the period of twenty years covering 1998 to 2018. The results varied from year to year depending on the intensity and amount of rainfall received in each year. The study showed that Owerri Municipal experienced the highest rainfall erosivity in 2009 with rainfall erosivity indices of 436.10 mm and also experienced the lowest rainfall erosivity in 2017 with rainfall erosivity indices of 229.06 mm. The study also recorded 329.16 mm as average rainfall erosivity of Owerri Municipal.

1. INTRODUCTION

The problems of soil erosion in the humid tropical region of Nigeria leave much to think about. It has been observed by Lekan, (2013) that erosion has devastated a large extent of Nigerian soils mostly in Imo state. Obviously, the action of raindrops and runoff on the soil constitutes two major aspects of water erosion which are soil erodibility and rainfall erosivity. Raindrops which possess potential energy and can be converted to kinetic energy (shear force) as the drops reach the ground. In dealing with erosion, therefore, the ease with which soil is eroded is an important factor; hence, the determination of erosivity using Fournier's method. Uguru, (2012) defined soil erosion as the gradual removal of top soil by water or wind. The particles dislodged by water (rainfall) has been noted to depend on the size of the Raindrops (R), Intensity (I) and Time duration of the rainfall (T) hence, the following equation put forward by Uzoamaka (2013);

$$F_n = RIT \tag{1}$$

Where: F_p is the force of particles dislodged by rainfall, (cms^{-1}); R is the size of raindrop, (cm); I is the intensity of rainfall, (cm/hr); T is the Time of rainfall, (hr). He further remarked in his proposal that this force was needed to overcome the resistance (r) of the soil.

$$R = (C - \tan\theta) \tag{2}$$

Where: R is the resistance of the soil, (ohm m); C is the cohesion of the soil or normal reaction, (cms^{-1}); θ is the angle of shear detachment, (^{0}).

According to Dave (2008), soil is naturally removed by the action of water or wind. Soil erosion has been occurring for some 450 million years. Natural processes moved the loosed rock or regolith off the earth's surface just has happened on the planet mars. In general, erosion removes soil at roughly the same rate as soil is formed, unlike accelerated soil erosion there is loss of soil at a much faster rate than it is formed which is always as a result of man's unwise actions, such as overgrazing or unsuitable cultivation practice that leaves the land unprotected and vulnerable. Then, during times of erosive rainfall or windstorms such soil may be detached, transported and deposited. Accelerated soil erosion by water or wind may affect both agricultural areas and natural environment and it'is one of the most widespread of today's environmental problems. It has impacts which are both on-site (at the place where the soil is detached) and off-site (wherever the eroded soil ends up). More recently, the use of powerful agricultural tillage implements has in some parts of the world led to tillage erosion of soil. This involves the movement down slope merely under the action of gravity. According to Yoder (2012), soil erosion is just one form of soil degradation. Other kinds of soil degradation include salinization, nutrient loss, acidification, desertification, crusting and compaction.

Soil erodibility was defined by Keller (2010) as the ease with which soil materials can be removed by water or wind. According to Uzoamaka (2013), soil with high erodibility suffers more serious damages than one with low erodibility under constant erosivity. Stalling (2012) noted that several physical and chemical properties have been reported to be key factors influencing porosity, permeability, soil structure, clay mineral, organic matter content, interparticle cohesion and dispersion. These factors include; rock type, nature of fluid, soil grain size, the nature and characteristics of sand and other sediments that accumulate, the uniformity of the sand grains and the amount of cementation. According to Morgan and Lekan (2013), erosion detaches individual soil grains from the soil mass and carries it along on raindrop splash and moving water which affects the fertility and productivity level of the soil. As a matter of fact, no nation can successfully improve on its agricultural productivity when the soil resources are continually being lost by erosion. Excessive erosion causes problems such as desertification, decrease in agricultural productivity due to land degradation, sedimentation of water ways and ecological collapse due to loss of the nutrient in upper soil layer (Stalling, 2012). It is therefore important and necessary for land use and conservation planners to give urgent attention to soil erosion menace hence meaningful suggestions and methods aimed at minimizing the effects of the phenomenon and carrying out proper assessment of the causes.

Wischmeier and Smith (2014) defined rainfall erosivity as the potential ability of rain to cause erosion or the aggressiveness of rainfall to induce erosion while erosivity index was defined as a rainfall pattern which describes its capacity to erode soil from an unprotected field. According to Uzoamaka (2013), rainfall erosivity is the action of raindrops, intensity and duration of rainfall to cause soil erosion. He added that, raindrop possessed kinetic energy to be converted to shear force as the drops reached the ground, which dislodge the particles from the soil mass. Lombardi (2009) defined erosivity index as the method formulated to estimate or calculate rainfall erosivity. Food and Agricultural Organisation (FAO, 2010) also stated that rainfall erosivity index was a formulated method adopted for estimating or determining rainfall erosivity with reference to the difference in rainfall regions as influenced by the intensity and duration. Rainfall erosivity indices were formulated and developed to determine the rainfall erosivity (Fournier, 2012).

According to Fournier (2012), estimation of rainfall erosivity can be presented mathematically as:

$$FI = \sum \frac{pi^2}{p} \tag{3}$$

Where: FI is the Fournier's index, (cm/h); Pi^2 is the square of annual rainfall intensity, (cm/h); P is the annual rainfall, (cm/h)

OR $$C = \sum \frac{pi^2}{p} \quad (4)$$

Where: C is the climatic index in unit of length, (cm/h); Pi^2 is the square of annual rainfall intensity, (cm/h); P is the annual rainfall, (cm/h); Σ is the summation. Wischmeier (2012) expressed that the inherent susceptibility of a given soil type to water erosion is its erodibility factor, it is used to indicate the different ways in which different soil are eroded when the other erosion producing factors i.e. Slope, rainfall, vegetation cover, length factor, crop management factor and conservation practice factor remain constant. It is the measure of susceptibility of the soil to erosion. Some soils erode more easily than others, which is to say that soils vary in their inherent susceptibility to erosion and this intrinsic property is referred to as soil erodibility. The erodibility factor (k) represents the ground tonnage carried away from an area. Primarily, erodibility is a function of soil properties. Soil properties that influence erodibility may be grouped into two types; firstly, those that affect infiltration, cohesion and structural stability and resistance to dispersion and strength. Secondly, those influenced indirectly by land use, crop cover and management practices.

Wischmeier (2012) established the dependence of soil susceptibility to erosion by water, textural, structural and hydrological properties. They developed equations and monograms which were recommended for estimating erodibility factor (k) whenever experimental values are not available. The author further explained soil erodibility as a function of soil interaction among its physical and chemical properties. He developed a method of predicting soil erodibility using the soil properties such as texture, organic matter content, soil structure and soil permeability. He developed the following relationship;

$$K = 2.1\,X\ 10^{-6}(12 - OM)M^{1.4} + 0.0325(S-2) + 0.025(P-3) \quad (5)$$

OR $$100K = 2.1\,X\ 10^{-4}(12 - OM)M^{1.4} + 3.25(S-2) + 2.5(P-3) \quad (6)$$

Where; 0M is the organic matter content, (%); M is the silt and very fine sand fraction (%); P is the permeability (class); S is the structural index (i.e. Soil structure code or class). The average annual soil loss as determined by Wischmeier (2012) can be estimated from the universal soil loss equation:

$$A = RKLSCP \quad (7)$$

Where; A is the average annual soil loss, (kg/hec); R is the rainfall and runoff erosivity index per geographic location, (ms^{-1}); K is the soil erodibility factor. It varies to account for seasonal variation in soil erodibility. It can be calculated from the regression equation:

$$K = 2.8 \times 10^{-7}\, m^{1.14}(12 - a) + 4.3 \times 10^{-3}(b - 2) + 3.3 \times 10^{-3}(c - 3) \quad (8)$$

Where: M is the particle size parameter (%silt +%very fine sand) × (100 - %clay); a is the organic matter content (%); b is the soil structure code (very fine granular 1, fine granular 2, medium or coarse granular 3, blocky, platy or massive 4); c is the profile permeability class (rapid 1, moderate to rapid 2, moderate 3, slow to moderate 4, slow 5, very slow 6)

$$L = 1/22^{m} \quad (9)$$

Where: L is the slope length factor (cm); m is the dimensionless exponent;

$$m = \sin\theta / \sin\theta + 0.269(\sin\theta)^{0.8} + 0.05 \quad (10)$$

Where: θ is the field slope steepness, (^{0}); θ is the $\tan^{-1}$(s/100); s is the field slope, (%)

$$s = 3.0(\sin\theta) + 0.56 \quad (11)$$

For slope longer than 4m and s<9 percent

$$s = 10.8\sin\theta + 0.03 \quad (12)$$

For slope longer than 4m and s≥9 percent

$$s = 16.8\sin\theta - 0.50 \quad (13)$$

$$P = Pc \times Ps \times Pt \quad (14)$$

Where; P is the conservation practice factor, (code); Pc is the contouring factor based on slope, (code); Ps is the strip cropping factor, (code); Pt. is the terrace sedimentation, (code).

The main purpose of this paper is to determine the erosivity indices using the Fournier's method for Owerri Municipal as well as making suggestions on appropriate measures to mitigate the effects of rainfall on soil erosion.

2. METHODOLOGY

Some of the information used is primary in nature which includes collection of rainfall and other climatic data and information for a period of 20 years (1995-2014) from the office of the Nigerian meteorological agency Imo airport. Secondary data was also obtained from texts, journals, manuals, workshops, addresses, theses and seminar papers. Some of this information was collected from private and public libraries as well as newsletter and seminar presentations. The data which provided the basis for the determination of erosivity using Fournier's method were analyzed and presented accordingly. The totality and mean of analyzed information were recorded and subjected to descriptive analyses as follows;

$$Annual\ Rainfall\ Amount = \sum pi^2 \quad (15)$$

Where;

Pi^2 is the square of annual rainfall intensity, (cm/h)

Σ is the summation of monthly rainfall.

$$Annual\ Rainfall\ Intensity = \sum \frac{pi^2}{12} \quad (16)$$

Where;

Pi^2 is the square of annual rainfall intensity, (cm/h)

12 represent twelve months in a year

3. RESULTS AND DISCUSSION

Table 1 shows the annual rainfall, rain days and mean annual rainfall in Owerri municipal for twenty years. The annual temperature and mean annual temperature in Owerri municipal for twenty years is presented in Table 2. Moreover, Table 3 displayed the annual relative humidity and mean annual relative humidity in Owerri municipal for twenty years while Table 4 reveals the Rainfall Erosivity Indices for twenty years.

The data collected showed that Owerri municipal experienced the highest rainfall in 2016, highest temperature in 2017 and highest relative humidity in 2015, with annual rainfall of 2899.9mm and mean annual rainfall of 241.7mm, annual temperature of 392 and mean annual temperature of 32.67 as well as annual relative humidity of 72.6% respectively. It also experienced the lowest rainfall in 2017, lowest relative humidity in 2016 and lowest temperature in 2006 with lowest annual rainfall of 1671.5mm and lowest mean annual rainfall of 139.3, lowest annual temperature of 355 and lowest mean annual temperature of 29.58 and lowest annual relative humidity of 654% and lowest mean annual relative humidity of 54.3% respectively.

The rainfall erosivity for these twenty years (1999-2018) are; 323.21 for 1999, 324.17 for 2000, 276.60 for 2001, 335.66 for 2002, 283.56 for 2003, 265.16 for 2004, 333.96 for 2005, 323.54 for 2006, 327.36 for 2007, 333.52 for 2008, 436.10 for 2009, 369.05 for 2010, 313.66 for 2011, 280.37 for 2012, 390.14 for 2013, 361.65 for 2014, 388.42 for 2015, 357.01 for 2016, 229.06 for 2017 and 331.09 for 2018. (All in millimeters). The above rainfall erosivity data showed that Owerri Municipal experienced the highest rainfall erosivity in 2009 with rainfall erosivity indices of 436.10mm and also experienced the lowest rainfall erosivity in 2017 with rainfall erosivity indices of 229.06mm. The study also showed that average rainfall erosivity of Owerri Municipal was recorded as 329.16mm. According to Austin (2015), the average rainfall erosivity for Owerri West for the period of twenty years (1993 – 2012) was recorded as 229.16, being lower than that of Owerri Municipal. This may be the reason for much gully erosion issues experienced in Owerri Municipal.

Table 1: Annual rainfall, rain days and mean annual rainfall in Owerri municipal for twenty years

Years	Annual rainfall(mm)	Annual rain-days(mm)	Mean annual rainfall
1999	2394.4	124	199.5
2000	2112.4	115	176.0
2001	2345.1	148	195.4
2002	1754.6	88	146.2
2003	2154.3	120	179.7
2004	2103.5	111	175.3
2005	2482.7	123	206.9
2006	2075.5	125	173.0
2007	2563.7	131	213.6
2008	2581.5	119	215.1
2009	2726.9	135	227.2
2010	2564.1	96	213.7
2011	2424.1	113	202.0
2012	2179.1	115	181.6
2013	2368.8	90	197.4
2014	2622.3	128	218.5
2015	2699.6	132	225.0
2016	2899.9	136	241.7
2017	1671.5	90	139.3
2018	2516.4	126	209.7
Total	**47242.4**	**2365**	**3936.8**
Mean	**2362.12**	**118.3**	**196.84**

Source: Meteorological Department, Federal Ministry of Aviation, Owerri.

Table 2: Annual temperature and mean annual temperature in Owerri municipal for twenty years

Years	Annual Temperature	Mean Annual Temperature
1999	373	31.08
2000	372	31.00
2001	372	31.00
2002	381	31.75
2003	380	31.67
2004	380	31.67
2005	373	31.08
2006	355	29.58
2007	377	31.42
2008	376	31.33
2009	374	31.17
2010	374	31.17
2011	373	31.08
2012	377	31.42
2013	378	31.5
2014	377	31.42
2015	386	32.17
2016	383	31.92
2017	392	32.67
2018	375	31.25
Total	**7528**	**627.35**
Mean	**376.4**	**31.37**

Source: Meterological Department, Federal Ministry of Aviation, Owerri.

Table 3: Annual relative humidity and mean annual relative humidity in Owerri municipal for twenty years

Years	Annual relative humidity (%)	Mean annual relative humidity (%)
1999	786	65.5
2000	751	62.5
2001	654	54.5
2002	671	56.1
2003	688	57.3
2004	771	64.3
2005	767	63.9
2006	747	62.2
2007	716	59.7
2008	689	58.2
2009	711	59.7
2010	766	63.8
2011	670	55.8
2012	662	55.2
2013	689	57.4
2014	704	58.6
2015	872	72.6
2016	652	54.3
2017	697	58.1
2018	752	62.7
Total	**14415**	**1193**
Mean	**720.8**	**59.7**

Source: Meteorological Department, Federal Ministry of Aviation, Owerri.

Table 4: Rainfall Erosivity Indices for twenty years

Year	Erosivity indices (mm)
1999	323.21
2000	324.17
2001	276.60
2002	335.66
2003	283.56
2004	265.16
2005	333.96
2006	323.54
2007	327.36
2008	333.52
2009	436.10
2010	369.05
2011	313.66
2012	280.37
2013	390.14
2014	361.65
2015	388.42
2016	357.01
2017	229.06
2018	331.09

The average rainfall erosivity indices for these twenty years (1999 – 2018) = 329.16mm

4. CONCLUSIONS

In conclusion, high rainfall erosivity enhances soil erosion and this occurs when conditions are favorable for the detachment and transportation of soil material. Climates, soil erodibility, slope gradient and length, surface and vegetative conditions influence how erosion take place.
In order to solve soil erosion problems, the following should be considered:

i. Synoptic stations should be established with equipment for regular readings and equipment that have gone bad should be repaired.
ii. Soil excavation for sand and stones should be controlled as well as soil erosion when it has not developed into gully erosion.
iii. Construction or reconstruction of roads should be done with drainage or road side drains to channel out flood and should be made a condition for an award of contract.
iv. Enough employees should be employed for collection of adequate readings at Meteorological centers for optimum and accurate result.
v. Environmental protection awareness campaign should be mounted, to enlighten the masses on implications of soil erosion.

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