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Determination of Erodibility Index of Soils in Some Selected Locations of Girei Local Government Area, Adamawa State, Nigeria

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Abstract:
The effects of Soil erosion in Girei Local Government Area (LGA), Adamawa State Nigeria developed over the years and led to problems like loss of soil fertility, increased pollution and sedimentation in streams, rivers and clogging of water ways which worsen flooding and thus reduce its ability to support biodiversity. The erodibility indices of soil samples from five randomly selected locations were determined using Wischmeier and Smith formula for some soil characteristics namely, organic matter content (OMC), permeability class index (PCI), structural class index SCI), percent silt + very fine sand and percent sand (100 - % clay). These parameters were investigated and used to determine the soil erodibility factor (SEI), with Wuro Hausa having the highest K value of 0.087, the most erodible and prone to erosion while Sabon Pegi has the lowest K value of 0.0041, the least erodible. The mean K value was calculated as 0.045, which is the erodibility index of Girei soils. Furthermore, laboratory analyses of the soils showed that they have greater proportions of sand and silt thus, found to be erodible, after comparing with standard erodibility indices chart. The average annual soil loss in t/ha/yr was also estimated for each location to confirm the area that is more prone to erosion; Wuro Hausa has the highest soil loss of 61.29 t/ha/yr, while Sabon Pegi has the lowest soil loss of 2.89 t/ha/yr whereas at Tashan Mai Tulare, Anguwan Tampol and Chakamin Dari have soil loss of 10.57, 30.29 and 53.54 t/ha/yr respectively. Provision of various diversion terraces, grade control structures, retarding structures, grass or paved pathways, adequate soil conservation structures, drainage facilities such as buried pipe outlets, shelter belts was recommended to protect the top 60cm depth within these areas.

Keywords: *Girei LGA, Soil erodibility index, Soil erosion, Soil loss equation*

1. Introduction

Soil is very important to agricultural production in Nigeria, where agricultural Production is crucial to development. The livelihoods of the majority of the population depend on this natural abundant resource [1]. Agricultural soils are the richest supply of nutrients for plant growth and production because of the presence of organic matter and humus which support microbial activities that result in proper soil aeration and good drainage conditions for water movement. These enable plants to grow and yield expected outputs [2]. Soil being a key factor of production is subject to degradation due to environmental and human activities which prevents it from offering the expected quality; this particularly is as a result of erosion. It not only causes severe land degradation and soil productivity loss, but also threatens the stability and health of society in general, and sustainable development of rural areas in particular [2].

Soil erosion is one of the most serious forms of land degradation in the world [3, 4]. More than 56% of land degradation is caused by soil erosion, raising a global concern on land productivity [5]. Globally, it is estimated that one-sixth of the world's soils are affected by water erosion. In Africa, 8.5% of the mean yield loss is associated to past water erosion [6]. Soil erosion occurs when soil particles are carried off by water or wind and deposited elsewhere [2, 7]. Soil degradation due to erosion could lead to life threatening disaster to the lives of the residents, agricultural and general economics of areas prone to erosion. Currently, efforts to achieve sustainable agricultural development and food self-sufficiency in the country are threatened by widespread environmental degradation resulting from soil erosion menace, characterized by massive soil loss estimated at 30 million tons per annum [8].

Soil erodibility is the susceptibility or vulnerability of a soil detachment by rainfall and or surface flow by runoff flow force [9, 10]. Soil erosion occurs when the ability of the soil to withstand agents of denudation is overcome; this ability is regarded as soil erodibility. Erodibility is the resistance of the soil to detachment and transport [1]. Erodibility varies with soil textures, aggregates, stability, shear strength, soil structures, infiltration capacity, soil depth, bulk density, soil organic matter and chemical constituents [1].

Soil erodibility factor *K* is a quantitative expression of the inherent susceptibility of a particular soil to erode at different rates when other factors affecting erosion are standardized [11]. Generally, soils with faster infiltration rates, higher levels of organic matter and improved structure have a greater resistance to erosion [12]. A soil with relatively low erodibility factor may show signs of serious erosion, yet a soil could be highly erodible and suffer little erosion. This is because soil erosion is a function of many factors as stated in the Universal Soil Loss Equation (USLE) [11]. These factors include rainfall (*R*), soil erodibility factor (*K*), slope factor (*LS*), crop factor (*C*) and control practice factor (*P*).

This is represented in the universal soil loss equation 1.

$$A = R * K * LS * C * P \qquad (1)$$

Where *(A)* = the computed soil loss per unit area, *(R)* = Rainfall, *(K)* = Soil erodibility factor, *(LS)* = Slope factor, *(C)* = Crop factor and *(P)* = Control practice factor

The term "soil erodibility" is distinctly different from that of the term "soil erosion". Soil loss by erosion is also affected by other factors such as: rainfall characteristics, slope percentage and length, plant cover and land management, [12], in addition to the inherent soil properties that determine soil erodibility. Wischmeier and Smith [13] and Middleton [14] were the first generation who attempted to apply an index of erodibility. Their work resulted in several formulae being suggested as erodibility indices, for instance, the Clay Ratio. The dispersion ratio and aggregate stability were also used as indices of erodibility by Bouycucos [15].

In this work, soil samples from some selected locations in Girei Local Government Area were collected, analyzed and used to determine the erodibility indices of the soils. The results obtained were used to identify the areas that are prone to erosion. Girei Local Government Area was considered as a research area because of the destructive effects of gully erosion easily noticed along farm roads, and farm lands. The proximity of the research area to the University laboratory facility made analyses of the samples obtained from the site easier.

2. Methodology

2.1 Description of the study area

The study area is Girei local government area of Adamawa State, Nigeria. Girei is located between latitude 9°11'0"and 9°33'0" N and longitude 12°12'0" and 12°49'0" E. The climate is broadly divided into wet or rainy season and dry season. Rainy season commence in May and reaching its peak in August and stop in November. The area has an average rainfall of 972mm [16]. Temperature within the area varies with season, although the temperature is relatively high which ranges from 27 to 40ºC. The coldest month being December and January with mean average temperature of 15ºC, while the hottest period within the area is around April and May with an average temperature of 34ºC. The average annual relative humidity is 40.9% and average relative humidity range from 15% in February to 68% in August [16].

2.2 Collection of Soil Samples

The soil samples for analysis were collected from five randomly selected locations in this area. The locations are as shown in Table 1 below.

Table 1: Sample Depths and Location

Plot	Sample Depth (cm)			Location
	0-30	31-60	61-90	
A	1	2	3	Tashan Mai Tulare
B	4	5	6	Sabon Pegi
C	7	8	9	Anguwan Tampol
D	10	11	12	Chakamin Dari
E	13	14	15	Wuro Hausa

From each sampling plot, three soil samples were collected at different depths as shown in Table 1. Grain size analysis, Organic matter and organic carbon tests laboratory analysis involved in this work were carried out at the Soil Science Department of Modibbo Adama University Yola whereas permeability tests of the soil samples were done at the Department of Civil engineering, Adamawa State Polytechnic Yola.

2.3 Particle size analysis

The hydrometer method was used to determine the particle size analysis. 50 g of soil sample from a 2 mm sieve was poured in a conical flask. 50 ml of Sodium hexametaphosphate was added to the soil sample in the flask after which 100 ml of distilled water was added. This is in accordance with the works of Adebayo [17], Di Stefano, *et al.* [18] and Neyshabouri, *et al.* [19]. The solutions were carefully stirred in a 1000 ml measuring cylinder. The solution was then allowed to stand for 24 hours.

2.3.1 Determination of OMC

The organic matter content (OMC) of a soil is related to its organic carbon content. Walkley Blanks method was used to measure the organic carbon content of the soil samples. The titre values were recorded and used in finding the organic carbon content of a soil, which is given by the formula in equation 2.

$$\% \, OCC = \frac{(B-T)ml \; x \; 0.003 \; x \; 1.33 \; x \; o.5N \; x \; 100}{Weight \; of \; the \; soil} \qquad (2)$$

Where *B* = Blank titre value, *T* = Titre value for each soil sample solution, 0.003 = Milli equivalent of carbon, 0.5N = Normality of Fe (NH_4) SO_4 used

NB: The Blank titre value must be greater than the other titre values. The Organic matter content (OMC) is calculated from the relation given in equation 3:

$$\% \, OMC = \% \, OCC \; x \; 1.724 \qquad (3)$$

2.3.2 Soil textural classification

After obtaining the percentage of sand, silt and clay in the soil samples through grain size analysis by hydrometer method, the soil texture of each sample was classified using the United States Department of Agriculture (USDA) soil texture triangle (See Appendix VI)

2.3.3 Soil Structural Class Index

The structure of the soil was determined by physically examining the soil samples collected using an auger and a core sampler at the stipulated depth. The relative sizes of the particles, aggregation, and the entire structure in terms of grade, form and entire structure and size were properly analyzed. This is in accordance with the works of Centeri, *et al.* [20]. The analysis was compared with the structural class index table as shown below to obtain the structure code of each soil sample.

Table 2: Structural Class Indices of Soils: Source [21].

Soil Structure	Class Index
Very fine granular	1
Fine granular	2
Medium or coarse granular	3
Blocky, platy or massive	4

2.3.4 Permeability test (Falling Head)

The soil samples were prepared and by turns, each were placed in a permeability mould. The samples were placed into the mould in layers and compacted to reduce void spaces. The upper chamber of the mould was screwed. The length and diameter of the soil samples were recorded. The diameter of the burette was recorded and the area of the soil samples and the burette were determined. The valve on top of the mould was opened to allow water pass through the soil sample. The time it took for each soil sample to saturate was recorded. After that, the valve was opened and a measure of 50ml of water was collected. The initial and final heights and the time taken for the water to be collected in the measuring cylinder were recorded according to a method by Wischmeier and Smith [22]. All data obtained were tabulated and the coefficient of permeability was determined with the formula in equation 4.

$$K = \frac{aL}{At} \ln \frac{ho}{h1} \quad (4)$$

Where a = Area of burette, A= Area of soil sample, L= Length of soil sample, t = Time taken, h_0 = Initial height, h_1 = Final height

Table 3: Permeability class Codes: Source [23].

Permeability Class	Fast	Moderate to fast	Moderate	Slow to Moderate	Slow	Very Slow
Code	1	2	3	4	5	6

2.3.5 Calculation of Soil Erodibility Factor

The soil erodibility index of each soil sample was calculated based on Atawoo and Heerasing [24], equation 5:

$$K\ 2.1 \times 10^{-6} M^{1.14} (12 - OM) + 0.0325\ (S - 2) + 0.025 (P - 3) \quad (5)$$

Where K = erodibility factor of soil, OM = organic matter content, M = % silt + % very fine sand and % sand (i.e. 100 - % clay), P = permeability class index, S = structural class index.

2.3.6 Erosion Prediction

For calculating the soil losses for the various sampling locations. The revised USLE, (A), as shown in equation 6 was adopted, [25].

$$A = 2.24R * K \quad (6)$$

Where A = Soil loss in t/ha/yr, R = mean annual rainfall factor, K = erodibility factor

The mean annual rainfall factor, R was obtained using [26], equation 7. Thus,

$$R = 0.5\ H \quad (7)$$

Where H = mean annual rainfall in mm.

The mean annual rainfall record of Girei Local Government for over ten years (2010 to 2020) was obtained from the Weather Station situated at Geography Department, Modibbo Adama University Yola. The mean annual rainfall factor, R at each soil sample collected from study site was determined using the data obtained from the Department of Geography as represented in appendix I.

3. Results and Discussion

The five randomly selected locations and the experiments conducted - Tashan Mai Tulare taken as location A; Sabon Pegi taken as location B; Anguwan Tampol taken as location C; Chakamin Dari taken as location D; and Wuro Hausa taken as location E; - in Girei Local Government are presented in Appendix II, III, IV accordingly in their order of arrangement. Sabon Pegi, Anguwan Tampol, Chakamin Dari, and Wuro Hausa have the same average structural index of 3. Sabon Pegi has the lowest structural index of 2. Tashan Mai Tulare, Chakamin Dari and Wuro Hausa have same average permeability class indices of 5 while Sabon Pegi and Anguwan Tampol have same average permeability indices of 3. Wuro Hausa has the highest average (%) organic matter content of 0.65% followed by Tashan Mai Tulare with 0.44%. Chakamin Dari has the lowest average organic matter content of 0.22% while Anguwan Tampol has 0.37%, and Sabon Pegi, 0.32%. The results of the erodibility factor value of soils are presented in Table 4.

The results in Table 4 show that Wuro Hausa has the highest K value of 0.0087. While Sabon Pegi has the lowest K value of 0.00041. The mean K value was therefore calculated to be 0.045 which is the soil erodibility value of Girei Local Government soil. The results of the average annual soil loss at the locations are presented in Table 5.

The results in Table 5 show corresponding values of soil loss with the erodibility factor values for the locations. Wuro Hausa has the highest average annual soil loss of 61.29 tons /ha/yr, while Sabon Pegi has the lowest soil loss of 2.89 tons /ha/yr. The mean average annual soil loss was calculated to be 31.72 tons/ha/yr.

Table 4: Soil Erodibility Factor

Plots (Samples)	Depth (cm)	Erodibility Factor (K)
A	0 – 30	0.00395
	31 – 60	0.00366
	61 – 90	0.03654
	Mean	**0.01472**
B	0 – 30	0.00422
	31 – 60	0.00417
	61 – 90	0.00399
	Mean	**0.00413**
C	0 – 30	0.05420
	31 – 60	0.03680
	61 – 90	0.03679
	Mean	**0.04260**
D	0 – 30	0.05450
	31 – 60	0.08678
	61 – 90	0.08694
	Mean	**0.07607**
E	0 – 30	0.08712
	31 – 60	0.08720
	61 – 90	0.08694
	Mean	**0.08708**
Mean Erodibility Factor		**0.045**

Table 5: Calculated Soil Losses at Various Locations

Plots	**R = 0.05 H**	**Erodibility Index (K)**	**Erosion Loss A = 2.24 RK (t/ha/yr)**
A	314.51	0.015	10.57
B	314.51	0.0041	2.89
C	314.51	0.043	30.29
D	314.51	0.076	53.54
E	314.51	0.087	61.29
Mean	314.51	0.045	31.72

From the results in Tables 4 and 5, it is observed that Wuro Hausa has the highest erodibility factor value, the lowest clay content and Sabon Pegi with the lowest erodibility factor value has a considerable high percentage of clay content. Soils with higher erodibility factor values should have lower clay content and are more prone to erosion. Low clay percentage results in lower binding forces and poor cohesion. Therefore, the interlocking forces between the grains will be reduced and hence the resistance to the detachment by any force whatsoever will be reduced. But soils with lower erodibility factor values are less erodible. In an earlier study by Roose [27], erodibility value of 0.20 was obtained for the soil in Modibbo Adama University farm which is located in Girei. This is far greater than result obtained at the selected study sites which falls within the range of 0-1. The differences maybe be due to the difference in soil texture, permeability, climatic condition, and organic matter content in the soil.

These values of low erodibility ensure a high cohesion and a good interlocking force which could resist the forces due to detachment and transportation by water. Also comparing the erodibility factor value of Girei soils with the standard erodibility indices by Tya and Oluwaseye [28], presented in appendix II, the soil from the selected plots in Girei lies between 0 – 0.1 range, which is classified as erodible and such soil is designated as permeable well drained soil having slowly permeable substrata. Furthermore, from the calculated erosion losses, Wuro Hausa which has the highest value of erodibility also has the highest rate of soil loss and Sabon Pegi with the lowest value of erodibility has the lowest rate of soil loss under constant mean, annual rainfall factor "R". This implies that the erodibility index of soil in an area is directly proportional to erosion in that area. All the soils worked on have greater percentage of silt. The soil textural classification of the study area is silt loam.

3. Conclusion

From the results, the soils in Girei are predominantly silt loam and have low binding forces. The results obtained show that Wuro Hausa has the highest erodibility factor value of 0.087. Tashan Mai Tulare, Anguwan Tampol and Chakamin Dari have erodibility factor value of 0.015, 0.043 and 0.076 respectively. Sabon Pegi has the lowest erodibility index of 0.0041. The mean value of erodibility factor was calculated as 0.045 which stands as the erodibility index value for Girei Soils.

The erodibility indices of soils at the various locations range from 0.0041 to 0.087. Comparing this result with the standard erodibility indices provided by [28] as represented in appendix ii, the soil in Girei lies between 0-0.1 range which is classified as erodible and designated as permeable well drained soil having slowly permeable substrata. The calculated average annual erosion loss was highest for Wuro Hausa with the value of 61.29 t/ha/yr. Sabon Pegi has the lowest soil loss of 2.89 t/ha/yr. Tashan Mai Tulare, Anguwan Tampol and Chakamin Dari have soil loss of 10.57, 30.29 and 53.54 t/ha/yr respectively. The average annual soil loss is therefore 31.72 t/ha/yr.

Soil cover provides organic matter and cohesion of soil particles. Bush burning should be discouraged in order to avoid the destruction of soil structure and discouragement of activities of soil microorganisms that facilitate organic matter build up in soil. There is need to plant cover crops such as leguminous species in places with high erodibility index such as Wuro Hausa in order to add nutrients to the soil as well as hinder erosion.

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Appendix I: Annual rainfall data record (mm)

Year	Jan	Feb.	Mar.	Apr.	May	Jun.	July	Augt.	Sept.	Oct.	Nov.	Dec.	Total
2010	-	-	1.6	33.80	48.50	157.90	88.30	150.00	115.50	77.30	-	-	672.90
2011	-	-	-	2.8	62.00	59.70	61.50	142.30	79.80	28.70	-	-	436.80
2012	-	-	-	10.80	62.30	70.50	128.90	131.20	129.30	57.30	-	-	590.30
2013	-	-	11.80	27.00	67.90	96.40	85.30	74.80	114.40	55.20	-	-	532.80
2014	-	-	3.90	45.00	82.80	130.70	124.60	130.00	123.70	39.10	-	-	679.80
2015	-	-	-	7.6	17.7	100.00	92.20	94.60	106.80	34.20	-	-	453.10
2016	-	-	4.70	16.80	71.90	158.80	63.40	132.10	105.70	27.20	-	-	580.60
2017	-	-	-	24.90	96.90	56.60	125.40	67.50	127.70	-	-	-	499.00
2018	-	-	-		71.50	103.80	148.40	98.60	172.60	89.80	-	-	684.70
2019	-	-	-	20.60	57.60	134.50	119.90	218.00	92.70	152.30	-	-	795.60
2020	-	-	14.20	38.50	31.50	60.00	95.50	79.50	39.40	6.00	-	-	364.60
Mean	-	-											**6290.2**

Source: Geography Department, Weather Station Modibbo Adama University, Yola

Appendix II: Soil Textural Classification

Plots (Plots)	Depths (cm)	% Clay	% Sand	% Silt	Textural class
A	0 – 30	12.40	16.00	71.60	SILT LOAM
	31 - 60	12.40	14.00	73.60	SILT LOAM
	61 – 90	10.40	10.00	79.60	SILT LOAM
	Mean	**11.73**	**13.33**	**74.93**	**SILT LOAM**
B	0 – 30	8.40	20.00	71.60	SILT LOAM
	31 - 60	10.40	22.00	67.60	SILT LOAM
	61 – 90	12.40	20.00	67.60	SILT LOAM
	Mean	**10.40**	**20.67**	**68.93**	**SILT LOAM**
C	0 – 30	8.40	10.00	81.60	SILT
	31 – 60	8.40	16.00	75.60	SILT LOAM
	61 – 90	6.40	14.00	79.69	SILT LOAM
	Mean	**7.73**	**13.33**	**78.93**	**SILT LOAM**
D	0 – 30	4.40	8.00	87.60	SILT
	31 – 60	6.60	8.40	85.00	SILT
	61 – 90	6.40	4.00	89.60	SILT
	Mean	**5.80**	**6.80**	**87.40**	**SILT**
E	0 – 30	2.40	8.00	89.60	SILT
	31 – 60	0.6	3.80	95.60	SILT
	61 – 90	4.40	12.00	83.60	SILT
	Mean	**2.47**	**7.93**	**89.60**	**SILT**

Appendix III: Percentage Organic Carbon and Organic Matter Content

Plots (Samples)	Depths (cm)	% Organic Carbon	% Organic Matter
A	0 – 30	0.3099	0.5343
	31 – 60	0.1399	0.2413
	61 – 90	0.3199	0.5515
	Mean	**0.2566**	**0.4424**
B	0 – 30	0.2099	0.3619
	31 – 60	0.1199	0.2068
	61 – 90	0.2399	0.4137
	Mean	**0.1899**	**0.3275**
C	0 – 30	0.2799	0.4826
	31 – 60	0.1199	0.2068
	61 – 90	0.2599	0.4481
	Mean	**0.2199**	**0.3792**
D	0 – 30	0.1199	0.2068
	31 – 60	0.2599	0.4481
	61 – 90	0.0099	0.0172
	Mean	**0.1299**	**0.2240**
E	0 – 30	0.0799	0.1380
	31 – 60	0.1099	0.1896
	61 – 90	0.1899	0.3275
	Mean	**0.1266**	**0.6551**

Appendix IV: Permeability and Soil Structural Class Indices of Soil Samples

Plots (Samples)	Depth (cm)	Coefficient of permeability (cm/s)	Permeability Class Index	Code	Soil Structure	Code
A	0 – 30	0.01175	Moderate	3	Fine granular	2
	31 – 60	0.01310	Moderate	3	Medium, coarse Granular	3
	61 – 90	0.01069	Moderate	3	Medium, coarse Granular	3
	Mean	**0.01185**	**Slow**	**5**	**Medium, coarse Granular**	**3**
B	0 – 30	0.01354	Moderate	3	Fine granular	2
	31 – 60	0.00983	Moderate	3	Fine granular	2
	61 – 90	0.00585	Moderate	3	Fine granular	2
	Mean	**0.00974**	**Moderate**	**3**	**Fine granular**	**2**
C	0 – 30	0.01180	Slow	5	Fine granular	2
	31 – 60	0.01060	Moderate	3	Medium, coarse Granular	3
	61 – 90	0.00550	Moderate	3	Medium, coarse Granular	3
	Mean	**0.0093**	**Moderate**	**3**	**Medium, coarse Granular**	**3**
D	0 – 30	0.01400	Slow	5	Fine granular	2
	31 – 60	0.00802	Slow	5	Medium, coarse Granular	3
	61 – 90	0.01900	Slow	5	Medium, coarse Granular	3
	Mean	**0.01367**	**Slow**	**5**	**Medium, coarse Granular**	**3**

Appendix V: Standard Erodibility Indices: Source: [21]

GROUP	K-Value	Nature of Soil
I	0.0 – 0.1	Permeable out wash well drained soil, slowly permeable substrata.
II	0.11 – 0.17	Well grained soils in sandy gravel free material.
III	0.18 – 0.28	Graded loams and silt loams
IV	0.29 – 0.48	Poorly graded moderately fine textured soil.
V	0.49 – 0.64	Poorly graded silt, very fine sandy soil, well and moderately graded.

Appendix VI: USDA Soil Textural Classification Source: [29].