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The Effect of Land Uses on Soil Erodibility (Index) and Soil Loss of the Keana Geological Sediments of Parts of Nasarawa State, Nigeria

M. G. Abubakar[1], M. O. Udochukwu[2] and O. S. Enokela[2*]

[1]Lower Benue River Development Authority, Makurdi, Nigeria.
[2]Joseph Sanwuam Tarka University Makurdi, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. Author MGA designed the study, performed the laboratory and statistical analysis and wrote the protocol. Author MOO reviewed the first draft of the manuscript. Author OSE managed the analyses of the study, managed the literature searches and formatting to template. All authors read and approved the final manuscript.

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ABSTRACT

The effect of land uses on soil erodibility and soil loss of the Keana geological sediments of parts of Nasarawa State, Nigeria was investigated in this study. Geographic positioning system (GPS) was used to identify three land uses (agricultural, forested, and residential). Soil samples were collected from top soils at 0-30 cm depth using core sampler from 1 ha of each land use in 8 settlement communities (16 locations). Standard laboratory methods for soil analysis were followed for determination of Dispersion ratio, Erosion ration, Clay ratio and Modified clay ratio. Linear regression and correlation were used to determine the logical relationship between the erodibility index and corresponding soil loss. The soils from the study area were classified as sandy loam and sandy clay loam with high density, high permeability and porosity making them less vulnerable to shear stress. Dispersion ration (DR) modified clay ratio (MCR), Clay ratio (CR) and Erosion ratio (ER) where high, which suggests that soils from the study area are vulnerable to erosion at various degree of susceptibility. Mean value of erodibility factor (K) and predicted soil loss of 0.0492, 0.0460 and 0.0357; 7.77, 7.20 and 5.48 tonnes/hectare/year for agricultural, forested, and residential lands

*Corresponding author: E-mail: enokladish@gmail.com, enokladish@yahoo.com;

respectively. The findings suggest that land uses influence the soil erodibility in the formation is in this order residential land > agricultural land > forested land use. The erosion class is 'very low' for forested (soils in this class have very slight to no erosion potential), 'low' (soil losses will occur) for agricultural and residential land uses respectively. These findings suggest that soil erodibility has been significantly influence by land use change in Keana geological sediment.

Keywords: Keana geological sediments; land uses; erodibility; soil loss.

1. INTRODUCTION

Soil erosion is a disastrous economic, social, environmental and public health problem worldwide affecting landscape [1]. It is a very dynamic and complex process that causes the loss of topsoil and increases runoff, decreases the productivity of natural and agricultural ecosystem, increasing sediment of water resources, reducing water and nutrients storage capacity and thus crop yields[2,3,4,5,6]. Soil erosion is a major part of land degradation that affects the physical and chemical properties of soils [7]. The intensification of this problem is being frequently associated with land-use changes [8,9,10].Generally, cultivated lands experience the highest erosion yield [11,12] because they are most vulnerable to erosion because of the scarce vegetative cover and seasonal disturbance of the soil surface.

Soil erosion control can be attained by knowing soils' susceptibility and the factors responsible for the susceptibility. Thus, the soil erosion is the function of both erosivity and erodibility. When erosivity exceeds the soil erodibility after any rainfall event, soil erosion occurs. Changes in land use due to urbanization, agricultural expansion, and monoculture productions have led to accelerated and spatial increase in erosion. The main causes of soil erosion are inappropriate agricultural practices, land abandonment, deforestation, overgrazing, forest fires and construction activities [13,14].

[15] Reported gullies in Karu, Lafia and Wamba LGA of Nasarawa state by 80%. They further stated that majority of the gullies are characterized by U-S shape cross-section by 60% and V-U shape 30% and V shape by 10%. Their findings also include mean volume of soil loss at14200.39tonnes/ha, gully length of 254.77, depth of 11.86 for large gullies, while that of very small gullies was length 65.16, depth was 4.66 and slope angle was 9.0. Gullies in the area are long narrow linear to rectangular shaped. 55.6% of gullies are at their continuous stage of development while 44.4% of gullies were at their continuous stage of development. [16] also reported 75% experienced changes in soil erosion due to changes in rainfall and land use in Nasarawa state. In overall, they reported decreasing erosion for the past 30-year while rainfall and soil cover increased meaning that, erosion is likely to be more affected by changes in soil cover than changes in rainfall amount. Despite these findings, there has not been any document data on erosion status in relation to land uses of Keana formations in Obi LGA of the State.

Keana geological sediment of Nasarawa State, Nigeria is one of the areas where land use conversion and erosion are widespread problems due to increasing demand for constructions, firewood, timber, pasture, shelter and food crops The natural land covers, forests, are being destroy or converted to cropland at an alarming rate in the last few decades. The consequences are the intensification of natural disasters like destructive floods, casualties and financial losses, the irreversible erosion of the soil, and consequently economic and social problems [17]. The impacts of soil erosion in the area are siltation leading to the disappearance of river Yabala in Bature and Osungu in Kadarko, blockage and damage of sewage lines and drainage channels. Washing away of township and rural roads and culverts, destruction of farmlands and land meant for other purposes, collapse of buildings, loss of lives and properties, damage to aquatic life, the disappearance of village water supply sources, degraded inter and intra communal roads, electricity and telephone structures have been lost to gully erosion. Data on the soils characteristics from the area necessary for the effective land use planning, soil management, soil erosion risk assessment and design of conservation structures is lacking. These have limited the implementation of many soil conservation programmes in the area, and the direct measurement of soil erodibility. Recognizing the seriousness of the problems necessitated this research to determine the erodibility characteristics of Keana geological sediments underlying the landscapes of parts of

Nasarawa State, Nigeria based on Agricultural, Forested, and Residential land uses in the sediment and the effect of land uses on soil erodibility (index) and soil loss of the formation.

The study has provided available data on soil erodibility indices, and factor/index and soil loss in the area. It is useful for agricultural and land use planning formulation of preventive control policies of soil erosion by the rural communities, government at all levels, students, researchers, extension workers, conservationists and engineers. The data obtained can also form data bank for the design of conservation structures. Estimation of soil losses or relative erosion rates for different soil and crop management systems are valuable in assisting farmers and governmental agencies in evaluating existing farming systems or in planning to decrease soil losses.

1.1 Description of the Study Area

Keana geological sediments in Nasarawa state is located at the middle of Benue Trough and is part of a long narrow stretch of sedimentary basin extending from the Gulf of Guinea upwards to the northeast [18]. Geographically, the area is located between Latitude 8^0 7''60'' N and 8º15'0'' N of the equator and between Longitude 8º30' 0'' E and 8^0 48'0E of the Greenwich meridian It has an estimated land area of about 1,048 km² and a projected of population of about 79, 253 [19].

The climate of the area is typical of the tropical zone characterized by two distinct seasons; dry and rainy (wet). The dry season spans from November to April, while the rainy season is from May to October. Annual rainfall ranges from 1100 mm to about 2000 mm. The mean monthly temperatures ranged between 20°C and 34°C, with the hottest months being March/April. The months of December, January and February are cold due to harmattan wind blowing across the area from the Northeast [20].

The geological sediments underlying the landscape of Keana formation resulted from the Cenomanian regression, which deposited fluvio-deltaic sediments. The formation or rather Keana Sandstone was named by Cratchley and Jones [21], it consists mainly heavily cross-bedded, fine to very coarse grained, sometimes conglomeritic, sandstones, at times indurated, gritty and arkosic [22]. The thickness was estimated at 1500 m (Fig. 1).

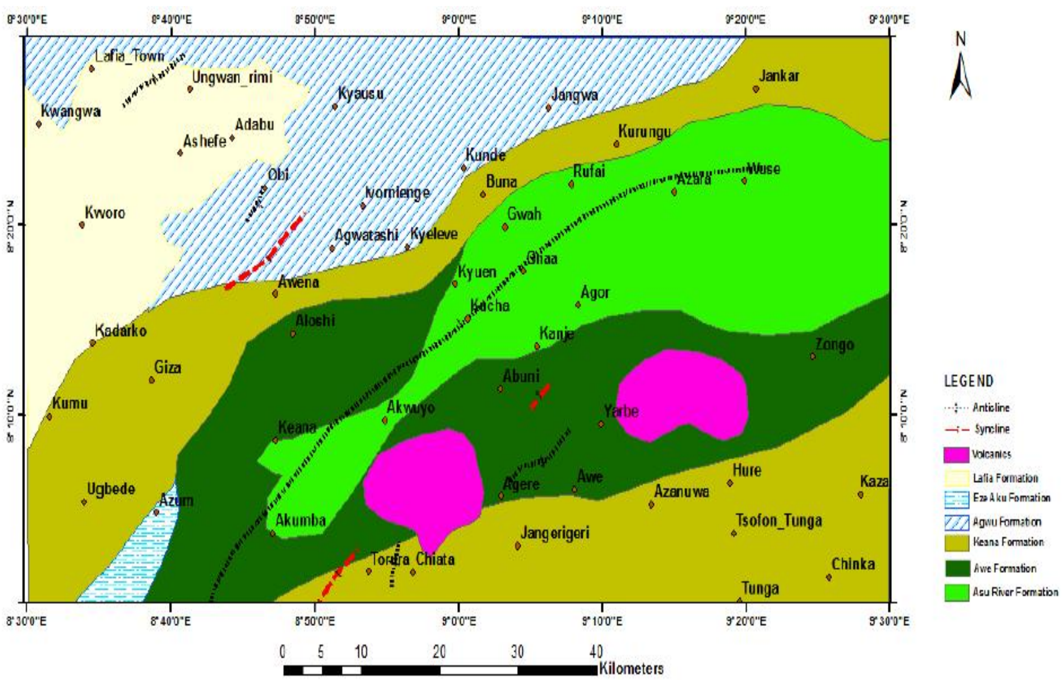

Fig. 1. Geological map of study area
Source: [18]

The major soil units of Keana belong to the category of laterite, silty sandstone, coarse and grained. The soils are derived mainly from the basement complex and old sedimentary rocks. Soils were typically with very fertile soil, largely sandy clay loam suitable for all kinds of crops cultivation. The top soil contains higher proportion of sand and clay with low silt. The vegetation of the study area falls within the southern guinea savanna zone.

The area is drained by numerous flowing streams that take their source from caves or springs and often flow down the slope; available are river Opu, Kilike and Osungu in Kadarko, river Yabala in Bature, river Uyina in Giza which are dendritic in shape. Due to alternating periods of rainfall and dry seasons, most of the streams are seasonal, seasonal ponding in raining season of depression is common.

2. MATERIALS AND METHODS

2.1 Soil Sample Collection

Geographic positioning system (GPS) was used to identify the three land uses (agricultural, forested, and residential). Soil samples were collected from top soils at 0-30 cm depth using core sampler (core cutter) by placing the core cutter on top of the soil and the rotated by means of the rod and crossbar handle. Little effort is required to screw the cutting cylinder into the soil. This was performed in 16 different locations for determination of bulk density, porosity, permeability and moisture content and particle size for the three land uses.

2.2 Analytical Procedures

Particle size analysis was carried out by hydrometer method and the data was used to classify the soils of the study area based on the United State Department of Agriculture (USDA) system. Moisture content were determined by weight loss after oven dried; Organic Matter Content was determined using Walkley-black method; Erodibility Indices (Dispersion ratio, Erosion ration, Clay ratio, Modified clay ratio, and Erosion ratio) were determined from each of the soil samples using the test results of the particle size distribution of % silt + % clay in undispersed soil and divide by % silt + % clay after dispersed of the soil in water.

The clay ratio was determined according to [23] using formula CR = $\frac{\%\,sand + \%\,silt}{\%\,clay}$ (1)

Modified clay ratio was determined according to [24] as; MCR = $\frac{\%\,sand + \%\,silt}{\%\,clay + organic\ matter}$. (2)

The erosion ratio of the soil samples was determined according by [25] as;

$$ER = \frac{Dispersion\ ratio}{Colloidal\ content/\ moisture\ equivalent\ ratio} \quad (3)$$

The Dispersed ratio of the soil samples was determined according by [26] as;

$$DR = \frac{\%\,silt + \%\,clay\ in\ undispersed\ soil}{\%\,silt + \%\,clay\ after\ dispersal\ of\ the\ soil\ in\ water} \quad (4)$$

The Aggregation Ratio of the soil samples was determined according to [27] as;

$$AR = \frac{Surface\ area\ of\ particles > 0.05mm}{\frac{\%\,Silt + \%Clay\ in\ Dispersed\ soil -}{\%Silt + \%Clay\ in\ Undispersed\ Soil}} \quad (5)$$

The Instability Index (IS) of the soil samples was determined according to [27] as;

$$IS = \frac{\%silt + \%clay}{Ag_{air} + Ag_{alcohol} + + Ag_{benine}} \quad (6)$$

Where;

Ag is the % aggregate > 0.2 mm after wet sieving for no pretreatment and pretreatment of soil the by alcohol and benzene respectively.

Soil Erodibility factor (K) for the sample areas was determined by Bouyoucos Method while the predicted soil losses for the various land uses were calculated using the Revised Universal Soil Loss Equation (RUSLE) by [28].

The Guidelines for Assessing Potential Soil Erosion Classes as performed by [29] was also applied. Linear regression and correlation were used to determine the logical relationship between the erodibility index and corresponding soil loss. The graphical representation of relationship between the various indices of erodibility with their corresponding soil losses for Forested land, Agricultural land and Residential land were developed

3. RESULTS AND DISCUSSION

3.1 Results

The means of the Dispersion ratio, Clay ratio, Modified Clay ratio, and Erosion ratio of the soil sample are presented in Table 1 while Table 2 presents the mean erodibility index/factor K and predicted soil losses. The relationship between the various factors of erodibility with their corresponding soil losses for three land uses are shown in Fig 1, Fig 2 and Fig 3 respectively.

3.2 DISCUSSION

Sandy soils (>21%) dominated the formation, followed by clay (<21%) and silt (<10%) which classified the soils as sandy loam and sandy clay loam (Table 1). According to [30] Santos et al., (2003), soils having more percentages of sand have reduced effects of raindrops impact because of higher infiltration velocity, they produce less runoff. The high dominance of sand in the area implies that higher particles of silt, clay and other colloidal materials are carried away leaving the heavier sand particles with poor nutrient [31].

Table 1. Mean value of particles size distribution analysis and textural class for the three land uses

Land Use	%Sand	%Clay	%Silt	OMC	Textural class
Forested	64.313	20.815	8.575	1.719	Sandy clay loam
Agricultural	67.525	17.286	8.938	1.843	Sandy loam
Residential	67.570	16.305	9.875	1.663	Sandy loam

OMC= Organic matter content

Table 2. Mean value of erodibility indices for the three land uses

Land Use	DR	CR	MCR	ER
Forested	0.9675	3.570	3.301	0.854
Agricultural	0.9975	4.560	4.125	0.934
Residential	0.9425	4.919	4.483	1.008

DR= Dispersion Ratio; CR=Clay Ratio; MCR=Modified Clay Ratio; ER= Erosion Ratio

Table 3. Erodibility factor/index (k) and predicted soil losses for the various locations

Location	Forested Land		Agricultural Land		Residential Land	
	K	SL	K	SL	K	SL
Kadarko1	0.0558	6.24	0.0395	6.24	0.0481	7.59
Kadarko2	0.0481	7.59	0.0658	10.39	0.0481	7.59
Bature 1	0.0331	5.23	0.0331	5.23	0.0558	8.81
Bature 2	0.0268	4.23	0.0505	7.98	0.0372	5.87
Giza 1	0.0331	5.23	0.0421	6.65	0.0458	7.23
Giza 2	0.0400	6.32	0.0478	7.55	0.0604	9.54
Keme 1	0.0318	5.02	0.0517	8.16	0.0372	5.87
Feme 2	0.0356	5.62	0.0429	6.77	0.0296	4.67
Ugbede 1	0.0318	5.02	0.0558	8.81	0.0658	10.39
Ugbede 2	0.0372	5.87	0.0658	10.39	0.0558	8.81
Awene 1	0.0318	5.02	0.0356	5.62	0.0658	10.39
Awene 2	0.0528	8.34	0.0297	4.69	0.0436	6.88
Agwatashi 1	0.0318	5.02	0.0318	5.02	0.0604	9.54
Agwatashi 2	0.0331	5.23	0.0583	9.21	0.0558	8.81
Kyeleve 1	0.0242	3.82	0.0421	6.65	0.0356	5.62
Kyeleve 2	0.0242	3.82	0.0372	5.87	0.0421	6.65
Total	0.5712	87.62	0.7297	115.23	0.7871	124.26
Mean	0.0357	5.48	0.0460	7.20	0.0492	7.77
SD	0.0092	1.17	0.0118	1.86	0.0116	1.83
Erodibility Class	Very Low		Very Low		Very Low	
Linear Equation	SL= 1.2622+118.0466EI		SL= 6.6993 + 10.2168 EI		SL = 0.0083 + 158.04 EI	

k: Erodibility Factor/Index, SL: Soil Loss (tonnes/hectare/year), SD. Standard deviation

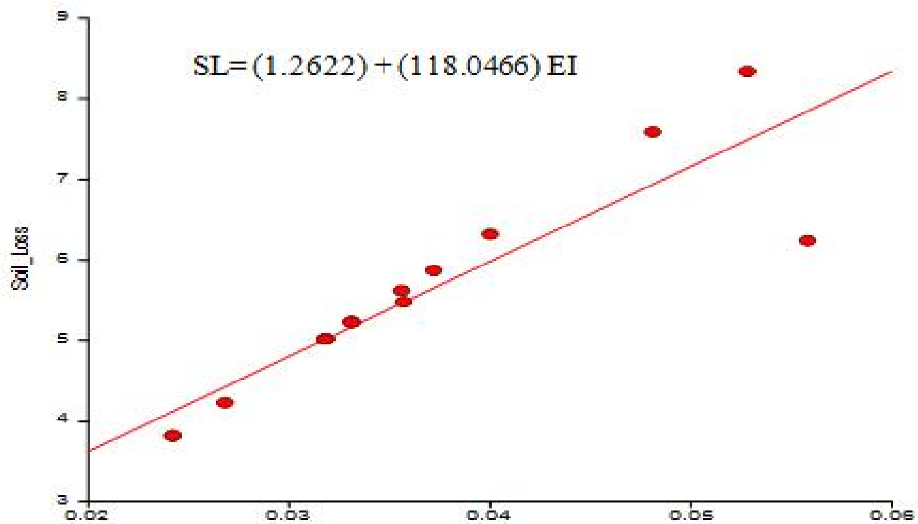

Fig. 2. Relationship between soil loss (SL) and erodibility index (EI) for forested land

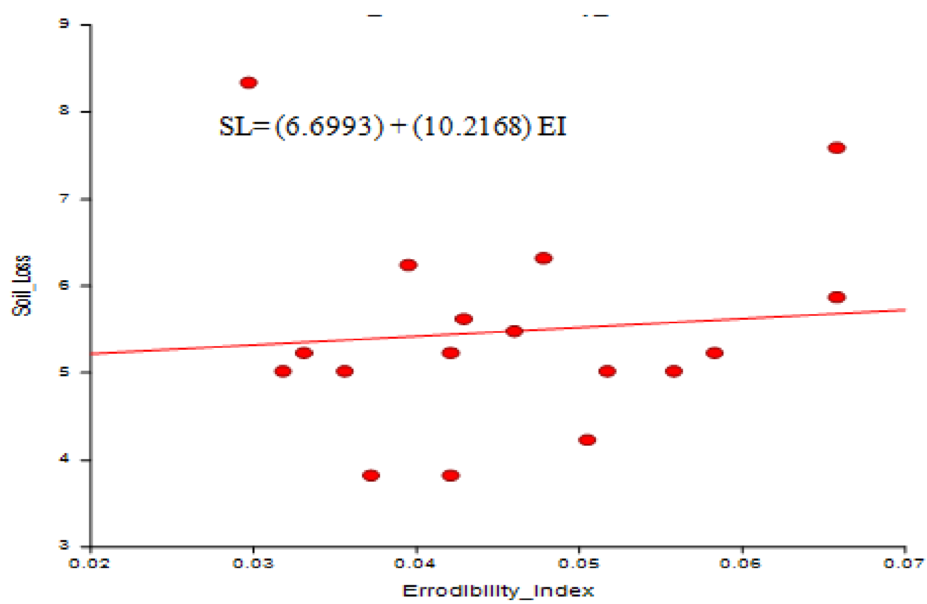

Fig. 3. Relationship between soil loss (SL) and erodibility index (EI)) for agricultural land

There is higher clay content in forested land compare to the agricultural land. This is in agreement with the work of [30] which show selective loss of clay due to forest conversion to agricultural lands. [32] examined erodibility in terms of the clay content indicating that soils low of clay fraction are most susceptible to erosion. Residential land use had the lowest percentage mean clay value indicating high erodibility.

Organic matter content in residential land ranges from 0.45% - 3.35%; 0.40% - 3.44% in Forested land and 0.34% - 4.24% in agricultural land with means of 1.843%, 1.719%, and 1.663% respectively. Based on the ratings of [33], it was low in all the three land uses however, among the three land uses it is highest in agricultural which could be attributed to use of livestock manure and inorganic fertilizer in this land use.

[34] attested to this fact by reporting that conversion of pasturelands into croplands in northern Iran led to the enrichment of organic matter in micro aggregate fraction (>0.25 mm) in the croplands. Different land-use systems cause variation in the levels of soil organic matter contents. The low organic matter content of the soils indicates poor aggregate stability and predisposes the soil to dispersion and erosion [35]. Low organic matter content implies poor macro aggregate disruption making soils vulnerable to erosion [36], hence agricultural land in this study is less susceptible to erosion compared to residential and forested land.

Various soil erodibility indices derived from soil physical properties results have been tabulated in Table 3. Among different land uses, dispersion ratio (DR) was observed to be the highest for agricultural land 0.998, followed by forested land 0.968, lowest under residential land 0.943. There were or no significant variation in these indices as attested to by their SD. According to the standard of [31], soils having dispersion ratio > 0.15 are erodible in nature. This is an established fact as [37] remarked that DR was found to be good indices for predicting erodibility in some soils of southeastern Nigeria. [38] also concluded that DR is a good index of soil erodibility. So, the soils were found to be erodible under all land uses using above standards. Furthermore, the areas have the susceptibility to be eroded because of their high values of dispersion ratio.

The mean results of clay ratio (CR) were in the order of residential 4.919 > agricultural 4.561 > forested land 3.570. The low value of clay ratio in the forested land use compared to other land uses may due to high clay content of 20.815% in the area. The clay ratios were higher than modified clay ratios, which may be due to inclusion of organic matter in the denominator in case of modified clay ratios. Decrease in Clay Ratio in soils reflects the increase of resistance to erosion [39]. According to [23], a high clay ratio indicates a low structural stability. This is because it is ratio of sand over silt over silt plus clay.

The mean results of modified clay ratio (MCR) were in the order of residential 4.483 > agricultural 4.125 > forested land 3.301. Erosion ratio (ER) was in the order of residential 1.008 > agricultural 0.934 > forested land 0.854. These values can be considered as high compared to standard values given by [40] that soils having erosion ratio > 0.10 are erodible in nature. So, the soils were found to be highly erodible under all land uses using above criteria. This is in agreement with the findings of [38] and [41] that forested land and agricultural land had lower values of erosion ratios as compared to residential land. [42] concluded that ER is a good index of soil erodibility. [43] while studying vertisol soils of Karnatka observed that ER was better index of soil erodibility than DR. The erosion ratio ER < 10 indicates to non-erodible soil, while ER range of 12 - 115 shows erodible soils [21].

The erodibility index (K) and predicted soil losses (SL) in the three land uses indicated that Residential land use is more erodible, having highest K value of 0.0492 with very low erodibility class because of high percentage sand of 67.570%. The result is in agreement with [44] which stated that soils high in sand content have high K- factor values. The high sand content contributes to less binding of aggregates hence easily eroded. On the other hand, the high K-factor value in eroded soils was primarily due to low organic matter content 0.965 % because organic matter has the capacity to bind soil particles together [45]. The least predicated soil losses were found in soils from forested land of K value 0.0357 and followed by agricultural land of K value 0.046 each with very low erodibility class respectively. The results agree with [44], soils high in clay content have low K- factor values because they are resistant to detachment because of the binding effect of clay. This is evidenced by the high clay content for forested land 20.815% and agricultural land 17.286% and organic matter content for forested 1.719% and agricultural 1.843%. This organic matter binds the soil particles together and creates forces between particles and thus creating stability [45]. Moreover, the removal of native vegetation accompanied with the decrease of soil qualities induced by land use change from residential land to the forested land, and finally made the soils more susceptible to soil erosion.

The plots of the 16 observations in this dataset relating soil loss and erodibility index for forested land, Agricultural land and Residential lands with their expression of linear equations are as presented in Fig. 2, 3, 4.

The y-intercept is the estimated value of soil loss when erodibility index is zero. This value for Forested land is 1.2622 with a standard error of

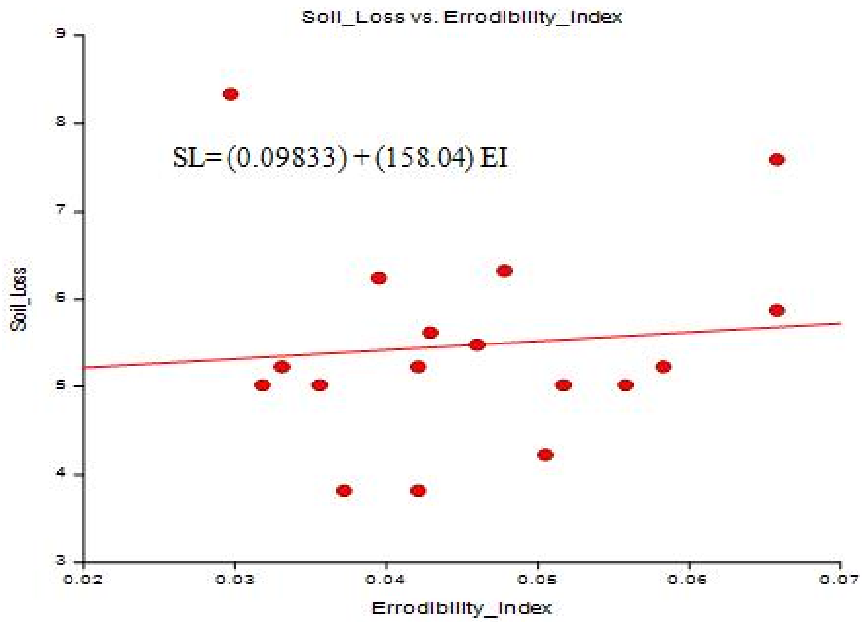

Fig. 4. Relationship between soil loss (SL) and erodibility index (EI)) for residential land

0.5362. The slope is the estimated change in soil loss per unit change in erodibility index and the value is 118.0466 with a standard error of 14.5903. The R-Squared is the proportion of the variation in Soil Loss that can be accounted for by variation in erodibility index and the value is 0.8136. The correlation between soil loss and erodibility index for Forested land is 0.9020. A significance test that the slope is zero resulted in a t-value of 8.0907. The significance level of this t-test is 0.0000. Since 0.0000 < 0.0500, the hypothesis that the slope is zero is rejected. The estimated slope is 118.0466. The lower limit of the 95% confidence interval for the slope is 86.9480 and the upper limit is 149.1451. The estimated intercept is 1.2622. The lower limit of the 95% confidence interval for the intercept is 0.1193 and the upper limit is 2.4051.

The y-intercept is the estimated value of soil loss when erodibility index is zero. This value for Agricultural land is 6.6993 with a standard error of 2.1782. The slope is the estimated change in soil loss per unit change in erodibility index and the value is 10.2168 with a standard error of 43.2376. The *R-Squared* is the proportion of the variation in soil loss for that can be accounted for by variation in erodibility and the value is 0.0040. The correlation between Soil loss for and erodibility index is 0.0630. A significance test that the slope is zero resulted in a *t-value* of 0.2363. The significance level of this *t-test* is 0.8166. Since 0.8166 > 0.0500, the hypothesis that the slope is zero is not rejected. The estimated slope is 10.2168. The lower limit of the 95% confidence interval for the slope is -82.5187 and the upper limit is 102.9522. The estimated intercept is 6.6993. The lower limit of the 95% confidence interval for the intercept is 2.0275 and the upper limit is 11.3710.

4. CONCLUSION

The soils from the three land uses are predominantly sandy soils, clay, and traces of silt, making the soil to be classified as sandy loam and sandy clay loam. Keana soils have high density with low permeability and porosity making them less vulnerable to shear stress. The results also indicated that organic matter, particle size distribution, permeability and aggregate stability had a great impact on soil erodibility. Dispersion ration (DR) modified clay ratio (MCR), Clay ratio (CR) and erosion ratio (ER), where high, which suggests that soils from the study area are vulnerable to erosion at various degree of susceptibility. Residential land had the highest mean value of erodibility factor K of 0.0492 and highest predicted soil loss of 7.77 tonnes/hectare/year, While agricultural land had K of 0.0460 and predicted soil loss is 7.20 tonnes/hectare/year. In addition, forested land had the lowest K value of 0.0357 and lowest predicted soil losses of 5.48 tonnes/hectare/year. The findings suggest that land uses influence the soil erodibility. It can be deduce from this study that the erosion pattern in the formation is in this order residential land > agricultural land > forested land use. The soil loss is of the erosion class of very low forested (soils in this class have very slight to no erosion potential), low (soil losses will occur) for agricultural and residential land uses respectively according to [44]. The findings suggest that soil erodibility has been significantly influence by land use change.

5. RECOMMENDATIONS

Thus, preventing soil loss is almost certainly a more efficient management strategy than attempting to recover lost soils. This therefore calls for public enlightenment programme on erosion and need to adopt environmental friendly land use and management practice to the rural dwellers with the help of the local government, chairmen, the traditional rulers, the village heads and the youth

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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