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Effect of Land Uses on Soil Erodibility in the Njala Area of Southern Sierra Leone

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Abstract

Soil loss through erosion continues to pose serious challenges to increasing the smallholder agricultural productivity in Sierra Leone. While emphasis on sustainable land use practices continue to gain attention among land users, however, the rate of adoption among smallholder farmers is still very low and hence, in most part of the country soil fertility has been declining at alarming rates. In the Njala area, studies have shown that soil loss ranges from moderate to high. Though soil erosion has been identified as a major soil fertility declining factor, however, the effect of land use practices on the inherent resistance of soil materials to erosion is lacking. This study was therefore conducted to assess the effect of land uses on soil erodibility. The results showed that the soils are coarse sandy loam with high sand content. The dispersion ratios and erosion indices of soils under cassava, plantain, maize and guava were above the minimum thresholds of 15.0 and 10.0 respectively, thus indicating that these soils are highly erodible compared to soils under fallow and sweet potato which have dispersion ratios and erosion indices below the minimum thresholds. Clay content was inversely proportional to and significantly correlated with dispersion ratio and erosion index while the correlations between silt + clay, dispersion ration and erosion index, and silt, silt + clay and dispersion ratio were negative and non-significant. Considering the coarse nature of soils, landscape features and high erodibility indices, these soils would need special soil and water conservation practices to counter further degradation. These may include following, agroforestry, silvi-pasture, controlled and rotational grazing. In addition, awareness of sense of self-responsibility and forest policies and regulations are needed.

Keywords

Soil Erosion, Land Use, Agriculture, Smallholders, Soil Texture, Erodibility, Soil Fertility, Deforestation

1. Introduction

Globally, soil erosion has escalated in recent times, especially in Africa [1]. According to Oldeman *et al.* (1992) [2], about 85% of soil is lost to erosion annually, accounting for a 17% decrease in crop productivity. The report further states that in Africa, about 5 $Mg \cdot ha^{-1}$ of productive topsoil is lost to lakes and oceans annually. According to Bomah (1988) [3], tropical rains are generally more erosive than those of the mid-latitudes. This is probably due to the large drop size, high intensities and consequently high kinetic energy of precipitation, as the rains are often accompanied by high intensity winds which further increase their aggressiveness [1].

The rapid rate of land use conversion is a serious challenge affecting sustainable land use planning in many parts of the world. In many cases, land use practices are not only environmentally unfriendly but also unsustainable and this results in severe land degradation. For this reason, several studies have been conducted by researchers to establish the relationship between erodibility and soil properties under different land uses. Dutta *et al.* (2017) [4] conducted a study to determine the soil erodibility characteristics under various land use patterns in the Nagaland region of India where they observed that the dispersion ratio and erosion index were higher than the threshold limits., and that clay showed significant negative correlation with dispersion ratio and erosion index. Karagül (1999) [5] noted that conversion of forest areas to range or cultivated lands increases the erodibility of soils. Similarly, Korkanc *et al.* (2008) [6] reported that land use conversion affects some properties of soils which results in significant correlations among erodibility indices and certain soil properties such as clay and sand fraction of soils.

In Sierra Leone, land use practices are not in tandem with landscape positions, and hence erosion rates are severe (Millington, 1984) [7]. A study conducted by Amara and Oladele (2014) [8] revealed that the Mokoli silty clay soils in the Njala area are more susceptible to erosion than the Momenga gravelly clay soils. This was attributed to the nature of these soils. Though both soils have characteristic clay properties, it is possible that the gravelly and well-drained nature of the Momenga gravelly clay soils may offer more macro pores with better water infiltration and hence less runoff than the Mokoli silty clay soils, which are imperfectly drained and have more micro pores. The silty nature of the Mokoli silty clay soils offers higher percentage of micro pores than macro pores and hence, these soils may require more time for water infiltration, which if the intensity of the rainfall (*i.e.* kinetic energy) is high, there is greater possibility for runoff build-up and hence high soil losses. Soil erodibility (K-factor) indices for Gbonjema loam, Nyawama sandy clay loam, Kania clay loam, Pujehun fine sandy clay loam and Gbesebu silty clay soils show that these soils are moderately susceptible to erosion.

The climate of Sierra Leone is tropical and hot to humid with rainfall ranging between 2000 - 4500 mm per annum, and the highest along the coast [9] [10]. Rainfall-induced climate changes, particularly high precipitation, have resulted in soil fertility degradation through soil erosion which has adversely affected agricultural production in Sierra Leone [11]. There are reported cases of unpredictable flooding and dry spells during the growing season, and prolonged dry season as a result of erratic rainfall which poses serious challenges for water management. This has resulted in the abandonment of land, with greater consequences on food production and food security and a substantial decline in land value.

The Njala area is severely affected by soil erosion due to high rates of deforestation and unsustainable land use practices like shifting cultivation, which are intensified or even caused by socio-economic conditions [10] [12]. Keeping this in view, this study was undertaken to evaluate the effect of different land uses on soil erodibility in the study area. Specifically, the study was intended to 1) find out how soil texture affects soil erodibility under different land uses, 2) determine the susceptibility and/or resistance of soils to erosion under different land uses, and 3) assess the degree of relationship between soil texture and erodibility indices.

2. Materials and Methods

2.1. Study Area

The study area is situated within the Njala area on 8.12˚N - 8.122˚N Latitude and 12.065˚W - 12.063˚W Longitude covering a total area of 3 ha in Kori Chiefdom, Moyamba District in the Southern Province of Sierra Leone (**Figure 1**). The Njala area has been previously described by Amara *et al.* (2014) [8]. The study is bounded on the east and northeast by a stream and Inland valley swamp

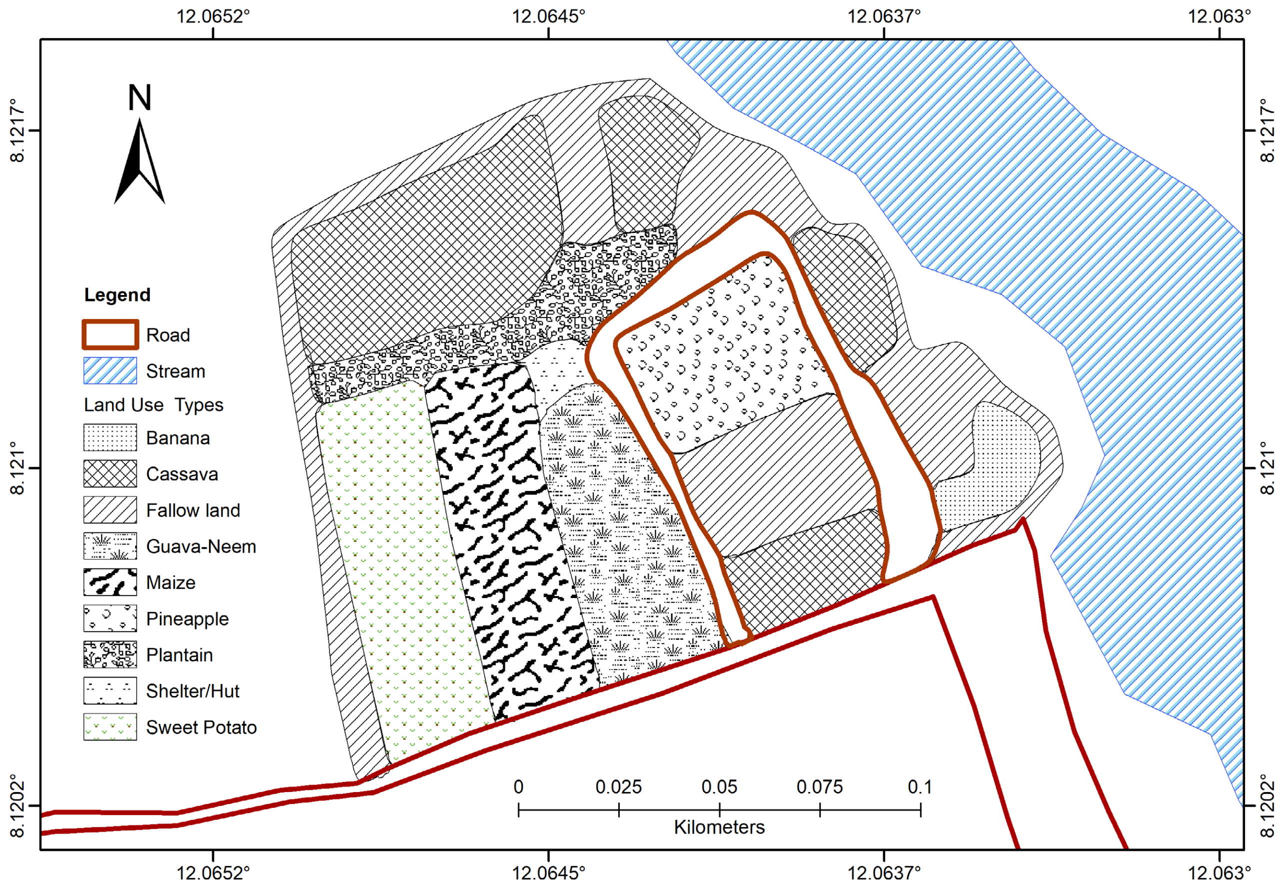

Figure 1. Study area showing the different land types.

(IVS), south and southeast by a farm road, and west and north by a fallow land. The main community in the study area is Njala. It is a famous and popular community that hosts the famous and popular Njala University, which is the country's first and most renounced university for agricultural studies. This makes Njala a cosmopolitan community where different tribes, race, religion, and categories of people are found. The climate of Njala is warm to hot, with marked rainy and dry seasons. The annual rainfall is high, averaging 2750 mm. However, about 90% of this rainfall occurs during the rainy season from May to November [10]. Eleven land uses/land cover are common to the study area including: 1) fallow (bare soil), 2) cassava 3) plantain 4) sweet potato, 5) maize, 6) guava-neem, 7) banana, 8) pineapple, 9) settlements/habitations, 10) roads, and 11) water bodies. The parent material is gravelly colluvium overlying gravelly residual material over weathered bedrock. According to Odell *et al.* (1974) [13], the soils of Njala area are sandy and gravelly to very gravelly and are located on slopes ranging from 3% - 15%, and generally less productive because they are not only low in fertility but also droughty during the dry season as a result of low moisture holding capacity. Three soil series: Njala slopping, Pelewahun and Mokonde series are generic to the study area but the most extensive one is the Njala slopping series. These soils have thin gravel-free surfaces ranging from 0 -

25 cm depending on topography. The textures are usually gravelly sandy loam to sandy clay loam in the surface soil and gravelly clay loam to gravelly clay in the subsoil. The colour ranges from very dark grayish brown to dark yellowish brown in the surface and yellowish brown to yellow in subsurface. In some cases, strong brown and yellowish red colours occur depending on the mottle content. The soils are well to moderately well-drained and are never waterlogged. The nutrient status, CEC, exchangeable cation and base saturation status are generally low, especially in the subsurface horizons. The erosion hazard is moderate to severe and permeability is rapid. These soils are generally used for upland rice, cassava, groundnuts etc, in a traditional slash and burn system of shifting cultivation. One major challenge of Njala soils is the very low moisture content during dry season.

2.2. Soil Sampling, Analysis and Interpretation

Eight agricultural land types were selected for investigation including: 1) fallow (bare soil), 2) cassava 3) plantain 4) sweet potato, 5) maize, 6) guava-neem, 7) banana, and 8) pineapple. The entire area was gridded on 25 m × 25 m, which formed the traverses for sample collection. The point of intersection of a longitude and latitude was selected as a soil sampling point and these points were entered into a handheld Global Positioning System (GPS) for easy navigation in the field. A total of 30 composite samples were collected with an auger at 0 - 30 cm depth from within the eight land uses and put into a zip locked bag for laboratory analysis. These samples were processed and analyzed for the selected parameters that influence soil erodibility following standard analytical procedures at the Njala University Quality Control Laboratory, as explained below:

1) The texture of soils under different land uses was determined by hydrometer method as explained by Pandey *et al.* (2009) [14].

2) To determining the dispersion ratio, the hydrometer readings at 4 min (R1) and at 2 hours (R2) were taken using sodium hexametaphosphate as dispersing agent [15]. The dispersion ratio was then calculated using the relationship proposed by Middleton (1930) [16] as given below:

$$\text{Dispersion ratio} = \frac{\%\ \text{water dispersible silt} + \text{clay}}{\%\ \text{total silt} + \text{clay}} \quad (1)$$

3) Moisture equivalent is generally determined by Briggs McLane centrifuge. In this study, this equipment was not available. Hence the moisture requirement was determined by the indirect relationship suggested by De (1962) [17] as given below.

$$\text{Moisture Equivalent}(\%) = 0.02\ \text{Sand}(\%) + 0.22\ \text{Silt}(\%) + 1.05\ \text{clay}(\%) \quad (2)$$

4) Erosion index was calculated using Middleton's formula (1930) [16] as given below:

$$\text{Erosion index} = \frac{\text{Dispersion ration}}{\text{Clay/ME ratio}} \quad (3)$$

where ME = Moisture Equivalent

5) The correlation coefficient between the selected parameters was assessed using Spearman's correlation test and the significance of correlation coefficient was determined at probability level of 1% using t-test as given below:

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r2}} \quad (4)$$

where, t = calculated value of t-test, r = correlation coefficient and n = no. of observations.

3. Results

3.1. Descriptive Statistics of Particle-Size Distribution on Soil Erodibility Parameters

The particle size distribution affects soil water characteristics, erosion potentials, plant nutrient budget and dynamics of organic matter. The results of investigation conducted to assess the effect of soil texture on soil erodibility are presented in Table 1 and Table 2. The sand content varies from 66% - 72% with a mean of 69.7% and standard deviation of 2.3 (Table 1). The lowest sand content (66%) is observed in soils under maize cultivation and the highest (72%) is in soils under plantain cultivation and fallow (Table 2).

The silt content varies from 16% - 18% with a mean of 17% and standard deviation of 1.1 (Table 1). The lowest silt content (16%) is seen in soils cultivated with maize and guava and the highest (18%) is in soils under cassava, plantain, sweet potato and fallow (Table 2).

The clay content varies from 10% - 18% with a mean of 13.3% and standard deviation of 1.12 (Table 1). The lowest clay content (10%) is observed in soils under fallow and the highest (18%) is in soils under maize cultivation (Table 2).

The dispersion ratio varies from 11.6 - 38 with a mean of 25.6 and standard deviation of 12.8, while the erosion indices range from 12.1 - 22.9 with a mean of 17.3 and standard deviation of 4.2 (Table 1). Overall, the texture of soils in the study area is sandy loam (Table 2).

Table 1. Descriptive statistics of soil and erodibility parameters in the Njala area.

Soil and erodibility parameters	Descriptive Statistics						
	Minimum	Maximum	Mean	Standard error of mean	Standard deviation	Skewness	Kurtosis
Sand	66.0	72.0	69.7	0.95	2.34	−0.67	−0.45
Silt	16.0	18.0	17.0	0.45	1.10	0.00	−3.33
Clay	10.0	18.0	13.3	1.12	2.73	0.89	1.34
Silt + Clay	28.0	34.0	30.3	0.95	2.34	0.67	−0.45
Dispersion ratio	11.6	38.0	25.6	5.21	12.76	−0.08	−3.10
Erosion index	12.1	22.9	17.3	1.71	4.19	0.03	−1.60

Table 2. Textural classes of soils under different land uses in the Njala area.

Land Use	Sand	Silt	Clay	p-value	Texture
		(%)			
Fallow	72	18	10	0.026	Sandy loam
Cassava	68	18	14	0.029	Sandy loam
Plantain	72	16	12	0.030	Sandy loam
Sweet potato	70	18	12	0.027	Sandy loam
Maize	66	16	18	0.036	Sandy loam
Guava-Neem	70	16	14	0.031	Sandy loam
Banana	69	17	14	0.030	Sandy loam
Pineapple	68	16	16	0.033	Sandy loam

3.2. Dispersion Ratios and Erosion Indices of Soils

The dispersion ratios and erosion indices of soils under the different land uses is presented in Table 3 and Table 4 respectively. The lowest dispersion ratio is observed in soils under sweet potato (11.6) and the highest is observed in soils under cassava (38.0). The dispersion ratios of soils under fallow, guava, maize and plantain are 13.4, 17.3 and 36.7 respectively.

On the other hand, the erosion indices of soils under different land uses are high and range from 12.1 (sweet potato) to 13.4 (fallow), 16.0 (guava), 19.0 (cassava), 20.4 (maize) and 22.9 (plantain) (Table 4). Such high erosion indices are a pointer that these soils are highly susceptible to erosion.

3.3. Correlation between Erodibility Parameters and Soil Separates

The correlation of soil texture with various indices of erodibility is presented in Table 5. According to Dabral *et al.* (2016) [15], erosion ratio is a good indicator of soil erodibility. Therefore, in the present study, the need to work out a correlation of soil textural properties with various indices of erodibility was inevitable. The results reveal that dispersion ratio is directly proportional to erosion index. The correlation between erosion index and dispersion ratio was found to be highly significant and positive (0.931).

Similarly, there was a highly significant and positive correlation between clay and silt + clay (0.918**), and between sand and dispersion ratio (0.968**) and erosion index (0.953**). The clay content was found to be inversely proportional to and significantly correlated with dispersion ratio and erosion index (−0.568* and −0.575*), respectively.

The correlations of silt + clay with dispersion ratio (−0.478) and erosion index (−0.253), silt with silt + clay (−0.156) and dispersion ratio (−0.396) were found to be non-significant. The correlation of sand with silt + clay was found to be highly significant, negative and perfect (−1.000**).

Table 3. Dispersion ratio of soils under different land uses in the Njala area.

Land use	Dispersion ratio
Fallow	13.4
Cassava	38.0
Plantain	36.7
Sweet potato	11.6
Maize	36.7
Guava-neem	17.3
Banana	12.3
Pineapple	14.2

Table 4. Erosion index of soils under different land uses in the Njala area.

Land use	Erosion Index
Fallow	13.4
Cassava	19.0
Plantain	22.9
Sweet potato	12.1
Maize	20.4
Guava-neem	16.0
Banana	12.8
Pineapple	14.8

Table 5. Correlation between erodibility parameters and soil separates.

Soil texture and erodibility parameters	Sand	Silt	Clay	Silt + Clay	Dispersion ratio
Silt	0.556*	1			
Clay	−0.918**	−0.535*	1		
Silt + Clay	−1.000**	−0.156	0.918**	1	
Dispersion ratio	0.968**	−0.396	−0.568**	−0.478	1
Erosion index	0.953**	−0.645*	−0.575*	−0.253	0.931**

4. Discussion

4.1. Effect of Particle-Size Distribution on Soil Erodibility under Different Land Uses

Soil texture is an important physical property that indicates the proportional distribution of soil particles, and is commonly used in soil classification and estimation of several related soil properties [18]. According to the results (Table 1), the particle size distribution of soils under the different land uses indicates that the soils are coarse textured. This might be due to the granite and acid gneiss geology, which produces very gravelly ferralitic soils over colluvial gravels. In **Table 2**, the results indicate significant difference in sand fractions under different land use types, and this finding confirms the conclusion of Nkana and Tonye (2003) [19] and Braimoh and Vlek (2004) [20]. Also, Wu and Tiessen (2002) [21] observed significant difference between sand fraction in soils of long term farmlands (*i.e.* 40 years), rangelands and slightly and moderately degraded rangelands. Vandenbygaart *et al.* (1999) [22] indicated that the sand fraction of 11 year tilled soils was higher (277.4 g/kg) than no-tilled soils (221.1 g/kg). In a study conducted by Deng *et al.* (2015) [23] along an alluvial plain, it was reported that soils of bare land had the highest sand content (69.2%), which was attributed to collapsing gullies that produces high sand fractions in alluvial fan.

The amount of silt fractions show no significant difference among land use types. However, the lowest silt content was recorded in soils cultivated with maize and guava and the highest in soils under cassava, plantain, sweet potato and fallow (**Table 2**). Similarly, Wu and Tiessen (2002) [21] described in their study that there is no significant difference between silt fraction of rangelands and tilled soils. Furthermore, Evrendilek *et al.* (2004) [24] reported that cropland, forest and grassland soils has similar silt, clay and sand content.

Similarly, no significant difference exists among clay fraction of soils under the different land use types (**Table 2**). As described by Nkana and Tonye (2003) [19], land use changes may affect clay fraction of soils. Turudu (1981) [25] found that clay fraction in soils of farmlands was highly significant than in forest and rangelands. In another study, Karagul (1999) [5] reported that clay fraction in topsoils of farmlands, forest and rangelands were 27.2%, 22.1% and 23.7% respectively but there was no significant difference in clay fraction of the topsoils of these different land use types. However, Wu and Tiessen (2002) [21] found that there was a significant difference in clay fraction of the topsoils between slight and moderately degraded rangelands and tilled farmlands for a long time (*i.e.* 40 years). The clay fraction in soils of rangelands was higher than farmlands. Su *et al.* (2004) [26] observed that clay content in soils of ungrazed grassland was higher and significantly different from clay content of cultivated cropland for 3 years.

Overall, the texture of soils in the study area as sandy loam. This was irrespective of land use type, which may be attributed to the kind of parent material (*i.e.* granite and acid gneiss) from which these soils were formed. The relatively higher percentage of coarse soil fractions is a recipe for soil erosion especially in poorly managed agricultural lands where organic matter is low.

4.2. Susceptibility and Resistance of Soils to Erosion under Different Land Uses

In this study, the dispersion ratios and erosion indices have been calculated to assess soil susceptibility and resistance to erosion under the different land uses (**Table 3** and **Table 4**). According to Middleton (1930) [16], the dispersion ratio of a soil is directly proportional to its aggregate stability. Soils having dispersion ratio of <5 are very stable, 6 - 10 are stable, 11 - 15 and fairly stable, 16 - 25 are somewhat unstable, 26 - 30 are unstable, and >30 are very unstable. The dispersion ratio of soils under cultivation were higher than soils under fallow with the exception of soils cultivated with sweet potato (**Table 3**). The highest dispersion ratio was recorded for soils cultivated with cassava (38.0). This was followed by soils cultivated with plantain and maize (36.7) and guava (17.3). Overall, the dispersion ratios of soil is high ranging from 11.6 (*i.e.* fairly stable) to 38.0 (*i.e.* very unstable). The high dispersion ratios may be ascribed to the high sand content and moderately well drained nature of the soils in addition to the effect of topography as influenced by their occurrence on terrace and colluvial footslopes. However, the dispersion ratios of soils under the different land uses show significant difference but soils under cultivation especially cassava, plantain and maize recorded high dispersion ratios, and this conforms to the findings of Korkanc *et al.* (2008) [6], which stated that dispersion ratio is higher in farmlands compared to forests and rangelands. Similarly, these findings conform to Evrendilek *et al.* (2004) [24] that soil erodibility index is higher in cropland than forest. It should be noted that dispersion ratio depends on aggregation of soil particles. According to Karagul (1999) [5], rangelands and forests have higher structural stability than farmlands due to minimum disturbance.

The erosivity indices for all land uses were higher than the minimum threshold of 10.0 as suggested by Middleton (1930) [16], thus indicating that these soils are more susceptible to erosion. According to Singh and Prakash (1995) [27], coarse textured soils containing high sand content normally show high soil erodibility indices, thus, indicating higher susceptibility to erosion and soil degradation. Based on the results of this study, it should be noted that sand and clay fractions are significant indicators of soil erodibility. The high sand content, dispersion ratio and erosion indices is an indication of soil susceptible to erosion. A further confirmation is that soils under cultivation recorded high erosion indices. This therefore necessitates proper education and awareness raising on appropriate soil conservation practices that discourage forest conversion into farmlands and other unsustainable land uses [4].

As per criteria developed by Middleton (1930) [16], soils with dispersion ratio above 15.0 and erosion index above 10.0 are considered to be erodible. Based on these criteria, it can be concluded that soils under cassava, plantain, maize and guava land uses are highly erodible. According to Amara *et al.* (2014), Singh and Prakash (1995) and Data *et al.* (1990) [12] [27] [28], low aggregate stability resulting from low clay and organic carbon content in soils may resort to high structural instability, and hence high dispersion ratios and higher susceptibility of soils to erosion.

4.3. Relationship between Soil Texture and Erodibility Indices

The results in **Table 5** reveal that dispersion ratio is directly proportional to erosion index and the correlation between erosion index and dispersion ratio is highly significant and positive (0.931). As the dispersion ratio increases, the erosion index also increases, thus indicating that these soils are highly susceptible to erosion. This indicates a direct relationship between dispersion ratio and erosion index. Similar findings have earlier been reported by Dabral *et al.* (2001) [15], Sharma *et al.* (1987) [29] and Agnihotri *et al.* (2007) [30].

Similarly, there was a highly significant and positive correlation between clay and silt + clay (0.918**), and between sand and dispersion ratio (0.968**) and erosion index (0.953**). This indicates that there is a direct relationship between these parameters which necessitates further research on how this relationship may influence soil loss in the study area.

The clay content was found to be inversely proportional to and significantly correlated with dispersion ratio and erosion index (−0.568* and −0.575*), respectively. This supports the finding of Middleton (1930) [16], which stated that as the clay content increases, the dispersion ratio and erosion index reduces and hence the soil loss and vice versa. It can then be concluded that soils having high clay content are of high resistance to erosion and vice versa. Similarly, silt was found to be inversely proportional to but significantly correlated with clay and erosion index (−0.535* and −0.645*), respectively which implies that as the silt content increases, the clay content and erosion index decreases and vice versa.

The correlations of silt + clay with dispersion ratio (−0.478) and erosion index (−0.253), silt with silt + clay (−0.156) and dispersion ratio (−0.396) were found to be non-significant. This non-significant degree of relationship indicates that soil loss is irrespective of increase or decrease in silt content. The correlation of sand with silt + clay was found to be highly significant, negative and perfect (−1.000**).

4.4. Management Implications

The study has revealed that the area is extensively covered by sandy loam soils. The sand content do not seem to vary much among the land use types but is however higher than silt and clay. Although this may appear an insignificant difference, the lower silt and clay content may influence important characteristics such as water holding capacity and nutrient retention. The high dispersion ratios (*i.e.* unstable nature) and erosion indices together with the geology type and strong weathering indicate that the management of these soils is problematic. Under such situations, sustainable soil conservation practices do not often produce the maximum results in the short term even when large amounts of nutrients are added because the soils do not have the capacity to hold enough nutrients on the exchange complex due to the very low silt and clay contents. The amelioration of these soils requires an integrated soil fertility management approach through appropriate land management techniques such as strip cropping, contour farming, tie and moon ridging, green manuring, liming, fertilization and application of organic matter, clay and other mineral soil amendments, maintenance of soil organic matter, balanced fertilization, watershed management. Green manure has been considered to be useful, though its extension has not been successful due to lack of proper techniques of cultivation and utilization of suitable plants. The management of soils should technically be aligned to agricultural productivity and sustainability.

5. Conclusion

This study was conducted to assess the effect of different land uses on soil erodibility in the Njala area. The results showed that the soils are coarse sandy loam with high sand content. The dispersion ratios and erosion indices were above the minimum thresholds of 15.0 and 10.0 respectively, which indicates that the soils are erodible. Areas cultivated with cassava, plantain, maize and guava showed dispersion ratios and erosion indices above these limits and hence, are considered highly erodible. The correlation between erosion index and dispersion ratio, clay and silt + clay, and sand and dispersion ratio and erosion index were highly significant and positive. The clay content was inversely proportional to and significantly correlated with dispersion ratio and erosion index while the correlations of silt + clay with dispersion ration and erosion index, silt with silt + clay and dispersion ratio were found to be negative and non-significant. Considering the coarse nature of soils, terrain conditions and high values of erodibility indices, these soils may need special management practices for soil and water conservation and permanent vegetative cover to serve as checks for further land degradation. In addition, more effective soil and water resource conserving systems like agroforestry, silvi-pasture, controlled and rotational grazing and natural regeneration are needed to reduce soil erosion and its damaging effects. Other approaches such as awareness on sense of self-responsibility and forest policies and regulations that protect and favour the growth of natural vegetation should be discussed in cooperation with the rural population.

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Authors' Contributions

DMKA, IB, JF development of research proposal. OSV, GAM and RMM supervise soil sample collection. IB, DHS, FB and FT collection of soil samples. DHS, IB, FB and FT analysis of soil samples. DMKA, JF, DHS, OSV, RMM and SAK interpretation of results. DMKA, IB, SAK, RMM, OSV, DHS, JCAM and MJ quality control checks and preparation of manuscript. DMKA, SAK, GAM, OSV, RMM and JCAM editing and reviewing of manuscript. DMKA, JF, OSV, SAK and GAM revised the final manuscript. All authors have read and approved the manuscript.

Conflicts of Interest

The authors declare that they have no conflicts of interests regarding the publication of the article.

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