Chapter

Spatial Soil Loss Assessment Using USLE in Lake Ol Bolossat Catchment

John Mwangi, Charles K. Gachene, Stephen M. Mureithi and Boniface Kiteme

Abstract

Erosion by water is one of the most common types of soil degradation which occurs in all climatic regions and is widely considered to be a serious threat to the long-term viability of agriculture in many parts of the world. Lake Ol Bolossat in Nyandarua County, Kenya, is a high altitude lake that was formed on Rift Valley escarpment and faces the challenge of siltation due to increased soil erosion. Over the last few decades, the lake has been encroached and lake area has been overgrazed reducing the vegetation cover around the Lake. An assessment of spatial soil erosion loss was conducted using USLE model and GIS which showed that most parts of the Lake catchment have soil loss beyond tolerable levels of nine tons per year. The soil erosion range was between zero and 22, 525.5 tons per year. The land uses that were more vulnerable to soil loss are croplands, grazing lands with sparse vegetation and barelands which had soil loss ranges of 10–50 tons, 100 to 1000 tons and 500 to 22,525.5 tons per year respectively. The study recommended for immediate interventions by policy makers, researchers and development partners in curbing the soil loss problem.

Keywords: USLE, spatial soil erosion, Nyandarua, soil degradation, modelling, GIS

1. Introduction

Soil is a prerequisite for food production [1] especially at the wake of rapidly increasing world population placing a high demand for food resulting to agricultural intensification globally. However, food productivity is fast declining due to increased soil degradation [2]. Often, rapid land use transformation, for example, conversion of forests to agricultural land results to soil degradation which normally takes four main forms: water erosion; wind erosion; chemical degradation; and physical degradation. Each form of soil degradation, occurring both individually and in combination with the other forms, can result in the loss or damage to key ecosystem functions and processes [3–5]. Among the four forms of soil degradation, erosion by water is the most common which occurs in all agro-climatic zones and is widely considered to be a serious threat to the long-term agricultural production in many parts of the world [6–8]. It is a primary agent of soil degradation [9], affecting 1094 million ha, or roughly 56% of the land experiencing human-induced degradation worldwide [2, 10, 11]. Soil erosion has also been recognised to be the major non-point pollution source in many areas, which causes a large amount of damage every year [6, 12].

Soil erosion, considered as the most widespread form of soil degradation, has greatly affected agricultural production globally and in particular, Sub Saharan Africa [2, 6, 11, 13–16]. One-third of arable land globally has been estimated to have been lost over the last four decades due to soil erosion [2, 11] at a rate of over 10 million hectares per year [4]. Soil erosion by water dislodges soil particles from the surface due to impact of rain drops [14, 17, 18] which generate enough power to carry the particles far away causing sedimentation of water bodies [16, 19] and other environmental hazards [4, 20, 21]. These negative environmental effects usually deprive soil its capacity to perform its functions and the links between soil and other ecosystem components [2].

Soil erosion by water is sometimes considered to be a purely natural process caused by rainfall and water flow [4]; however human activities greatly aggravate the erosion through alteration of land cover and disturbance of soil structure through cultivation [2, 5, 11].

The main physical parameters influencing the intensity of erosion processes are climate regime, soil characteristics, topography and vegetation. Apart from these physical parameters, man and man-induced land use often have a significant influence on erosion intensity. When the protection of the natural vegetation cover is replaced by a temporary cover such as during the cultivation cycle, the erosion intensity might increase significantly [22]. Wischmeier and Smith [23] noted six (6) factors that affect soil erosion which include rainfall erosivity, soil erodibility, slope length and angle, crop management and conservation practices.

Assessment of soil erosion remains critical as it enables different players to formulate mitigation measures [4]. Various methods employed in assessing soil erosion - either by water or wind - vary depending on the causes, magnitude of erosion and on the scale of assessment as well as the applicability of the methods in different environments [8, 21, 24]. The most common methods of assessment are: expert opinions, land users' opinions [25, 26], field monitoring, observations and measurement, modelling [27, 28], estimates of productivity changes and remote sensing [29, 30].

The soil loss prediction models include Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), and Soil Loss Estimation Model for Southern Africa (SLEMSA) and can be helpful in designing sustainable land use practices in order to curb soil erosion menace [6, 11, 20]. These methods differ in their use and application depending on various factors such as the intentions for use; characteristics of study area; data requirement and availability; validity and reliability of the method [16, 21, 26]. These mathematical models are continually being improved and scientists from many countries have adopted them to meet the requirements of their local conditions [24, 31].

The USLE model is widely used to predict average annual rate of soil erosion based on rainfall intensity, type of soil, slope steepness, crop and soil management practices [7, 8, 16, 21, 24, 28, 31]. It is based on the product of rainfall-runoff erosivity (R), soil erodibility (K), slope length and steepness (LS), surface cover and management (C) and supporting conservation practices (P) [7, 21]. Nontananandh and Changnoi [10] noted that USLE requires relatively simple data and it is compatible with a geographic information system (GIS). Several studies point out that USLE remains the best available model that has been tested in virtually all environments of the world in spite of having been criticised and accused of giving erroneous results [17, 19, 28, 31]. The main criticism of the USLE has emanated from people having applied the model in environments in which it was not intended to be used [31]. This study aimed at assessing spatial soil loss using USLE model and GIS in Lake Ol Bolossat Catchment.

2. Materials and methods

2.1 Study area

Lake Ol Bolossat catchment is located on latitude 00 09′S and longitude 360 26′E in Nyandarua County, Central Province of Kenya. The lake with an area of 43.3 km^2 lies at an average altitude of 2340 m above sea level in a wedge shaped rift valley floor sloping eastwards and northwards [32] and forms the headwaters of Ewaso Narok River which is the major tributary of Ewaso Ng'iro North River (see **Figure 1**).

The region enjoys favourable climate for most periods of the year, with temperatures ranging between 10° and 28°C. The climate is sub-humid and is strongly influenced by local topography of the surrounding central highlands with mean

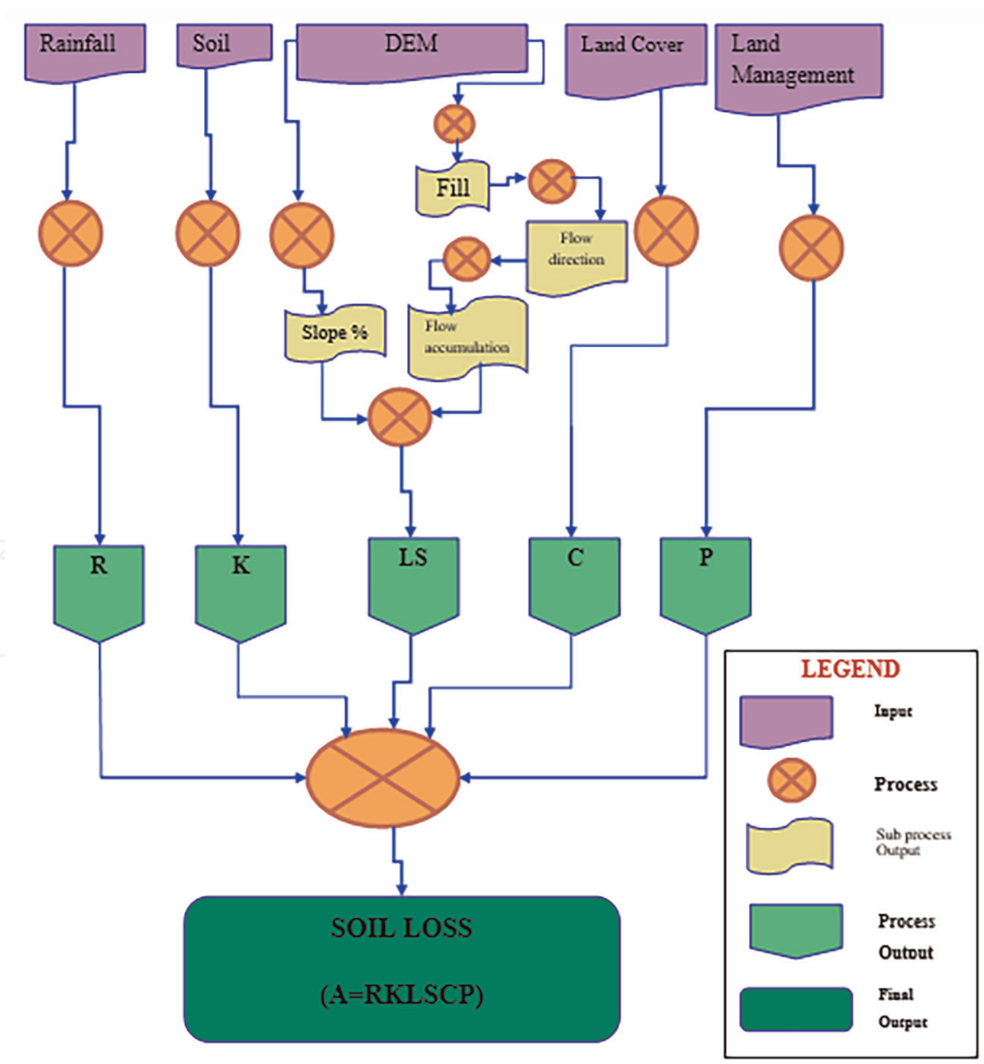

Figure 1.
Flow chart analysis of soil loss.

annual rainfall of 980 mm and increases southwards and westwards. Rainfall is bimodal, with long peaks between April and June and the shorter peaks between October and November [32].

The areas is dominated by small holder mixed farmers who grow crops and rear livestock on parcels of land ranging from 1 to 4 hectares. Nearly 60% of the families own less than 2 ha of land. Since they have free access to pasture around the lake, most of them own more livestock than their 2-ha plots can support. The human population density in the lake basin and the lake's watershed is approximately 202 per km^2 [33].

2.2 Data sources

Different data sources were referred to analyse the soil loss in the study area. A digital elevation model (DEM) with 90-meter resolution developed by NASA was used to calculate the slope length and slope gradient of the study area. The land cover classification map for 2014 was used for the analysis of crop management factor (C-value) while a soil map made by Centre for Training and Integrated Research in ASAL Development (CETRAD) was used in the analysis of soil erodibility factor (K-value).

Analysis of soil erosivity factor (R-value) was derived from annual rainfall data for different rainfall stations in the catchment which was obtained from CETRAD database. Conservation practices factor (P-value) was derived from land use types aligned to specified slope of the study area. The estimation of soil loss was then done by map overlays, pixel by pixel which enabled accurate multiplication of USLE parameters.

2.3 Methodology

The universal soil loss equation (USLE), developed by [23], was employed to assess the amount of soil loss in Lake Ol Bolossat Catchment. The USLE was applied in GIS based on the flow chart shown in **Figure 2**.

Mathematically the equation is denoted as:

$$A(tons/ha/yr) = RXKXLXSXCXP \quad (1)$$

Where A is the mean annual soil loss, R is the rainfall erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the crop management factor and P is the erosion control practice or land management factor. The analysis of each process factors of USLE was derived procedurally as illustrated in **Figure 2**.

2.3.1 Rainfall erosivity factor (R)

There are three equations which have been used to derive R-factor in different parts of the world [30] namely;

$$R = 9.28XP - 8838 \quad (2)$$

Mean annual erosivity (KE > 25) where P is mean annual precipitation.

$$R = 0.276XPX130 \quad (3)$$

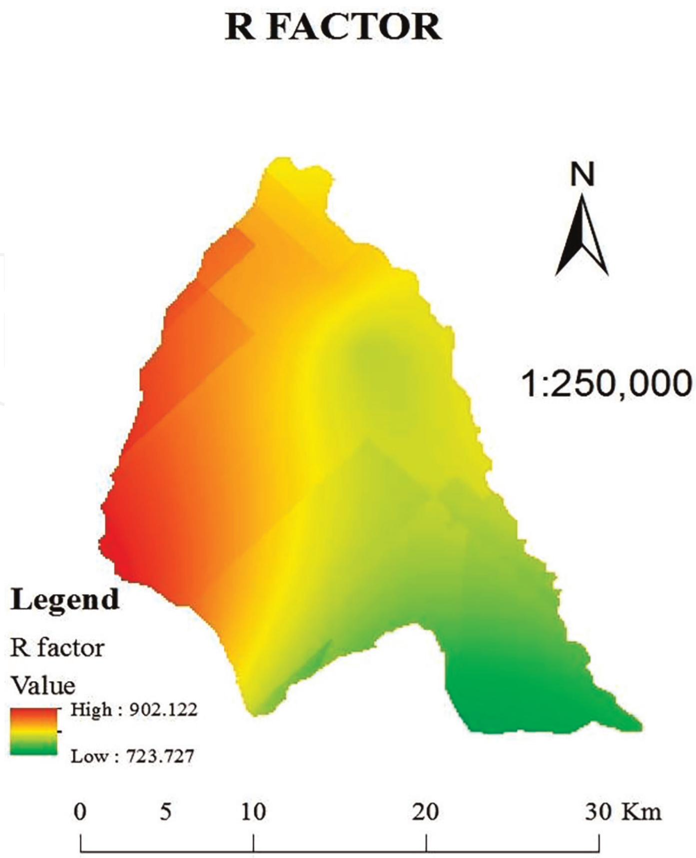

Figure 2.
Rainfall erosivity factor.

Mean annual EI30, where P is mean annual precipitation.

$$R = 0.5XP \text{ (in US unit) and } R = 0.5XPX1.73 \text{ (in Metric unit)} \qquad (4)$$

The study noted that the Eq. (2) is applicable in Peninsular Malaysia while the Eq. (3) requires I30 factor which is difficult to calculate. Eq. (4) is applicable in humid and sub-humid areas with mean annual rainfall of between 900 mm and 1700 mm [30]. This equation Eq. (4) was applied in this study where it was integrated into Arc GIS 10.3 software to derive R-factor. The rainfall data was obtained from CETRAD database. Average annual rainfall for at least twenty years was computed for ten weather stations in the catchment with respective rainfall erosivity factor using Arc GIS 10.3 [e.g., **Table 1** and **Figure 3**).

2.3.2 Soil erodibility factor (K)

Bizuwerk et al. [30] defines Soil Erodibility Factor (K) as mean annual rainfall soil loss per unit of R for a standard condition of bare soil, recently tilled up-and-down with slope with no conservation practices and on a slope of 50 and 22 m length. Hellden [34] in [30] developed a USLE for humid and sub-humid highlands condition by adapting different sources and proposed the K values of the soil based on their colour. This soil classification was adopted for the study and modified according to four soil types found in the area. Soil map was obtained from CETRAD database.

Name of station	Location		Mean annual rainfall (P)	Erosivity (R)
	Longitude	Latitude		
Shamata Gate	−0.19457	36.52173	1121.72	970.29
Ndaragwa Forest Station	−0.06568	36.53005	921.82	797.37
Nyahururu Meteorological Station	0.02973	36.36449	1048.13	906.63
Ol bolossat Forest Station	−0.05476	36.33653	972.18	840.94
Ol Joro-Orok KARI	−0.01097	36.38219	765.5	662.16
South Marmanet Forest Station	0.04496	36.37365	970.75	839.70
Mirangine Chief's Camp	−0.17906	36.24434	1171	1012.915
Kangui Secondary School	−0.05081	36.39671	897	775.905
Ol Kalou Railway station	−0.27275	36.37752	694	600.31
Rumuruti MOW office	0.26748	36.54844	703.2	608.268

The rainfall stations were selected based on their proximity to the study area. Where there was no rainfall station existing near the study area, another station was selected and then extrapolation of data was carefully done in order to have the most representative rainfall data.

Table 1.
Computation of rainfall erosivity factor (R Factor) for the study area.

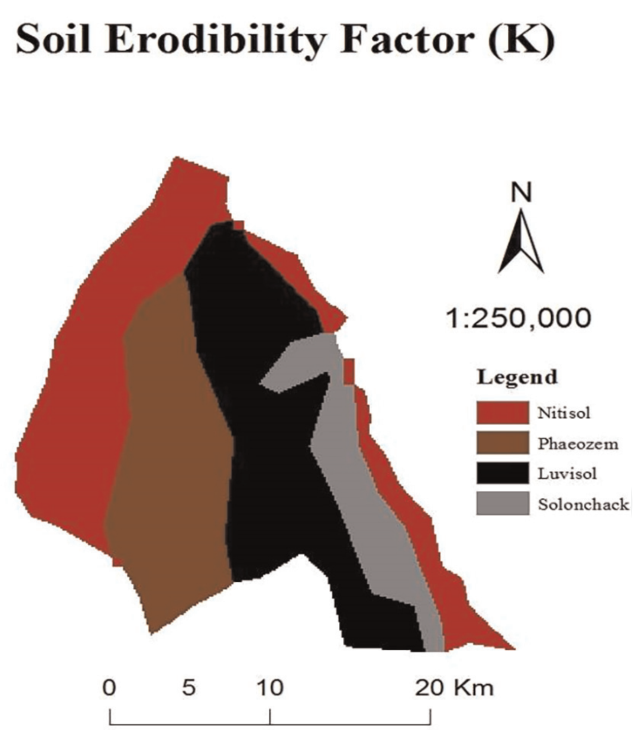

Figure 3.
Soil erodibility factor.

However, the soil data were in their geomorphologic names but not their colour and hence an attempt was made to match the soil names with their colour referring to World Reference Bureau (WRB) classification. The k value was then computed using Arc GIS 10.3 and results presented in raster format as shown in **Figure 4**.

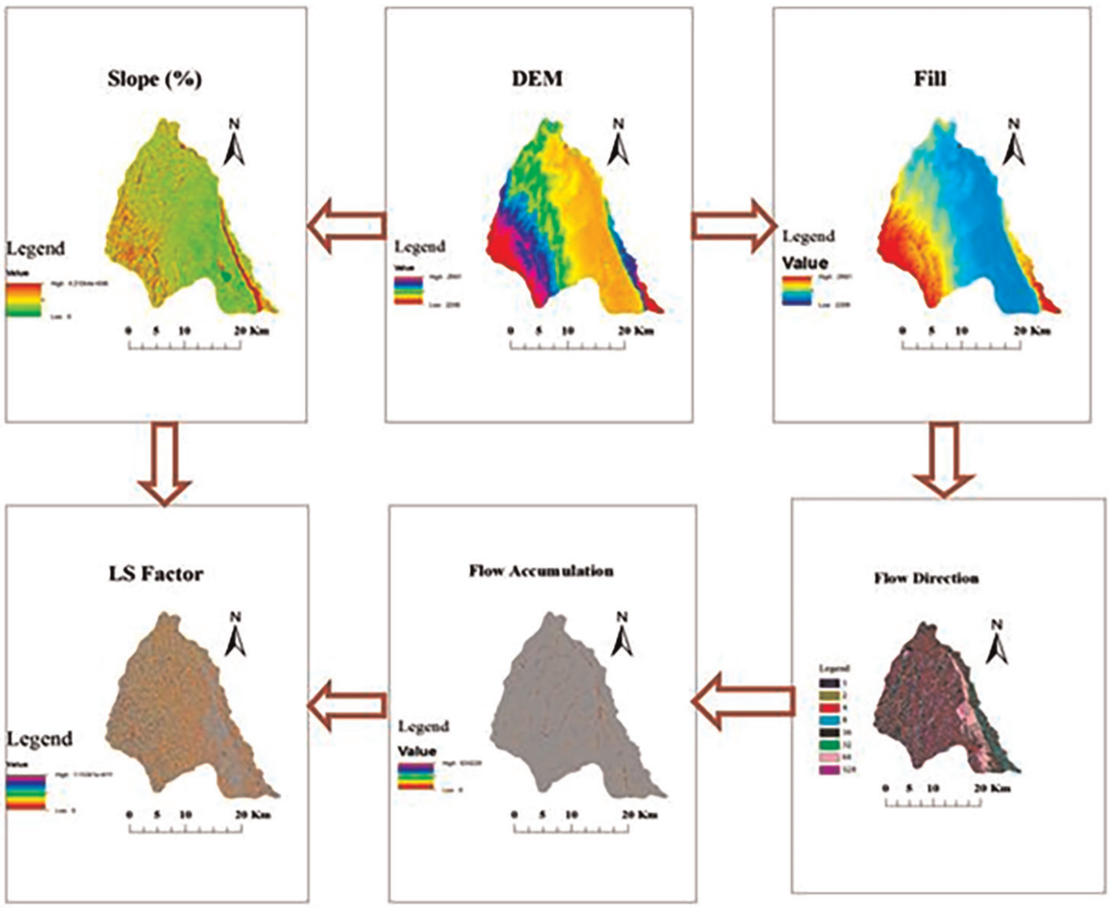

Figure 4.
LS factor.

2.3.3 Slope length and slope steepness factors (LS)

Wischmeier and Smith [23] noted that slope length and slope steepness can be used in a single index to express the ratio of soil loss using the following equation.

$$LS = (X/22.1)^m \left(0.065 + 0.045S + 0.0065S^2\right) \tag{5}$$

Where X = slope length (m) and S = slope gradient (%).

The values of X and S were derived from DEM. To calculate the X value, Flow Accumulation was derived from the DEM after conducting FILL and Flow Direction processes in Arc GIS 10.3

$$\mathrm{X} = (\text{Flow accumulation}^* \ \text{Cell value})$$

By substituting X value, LS equation was:

$$\mathrm{LS} = (\text{Flow accumulation} * \text{Cell value}/22.1)^{\mathrm{m}} \left(0.065 + 0.045\ \mathrm{S} + 0.0065\ \mathrm{S}^2\right)$$

Moreover slope (%) was directly calculated from the DEM using the same software. The value of m varies from 0.2–0.5 depending on the slope as shown in **Table 2** [23]. The result of LS factor analysis is shown in the **Figure 5**.

m-value	Slope (%)
0.5	> 5
0.4	3–5
0.3	1–3
0.2	<1

The slope for the study area ranged from less than 1%–5% and therefore the m-value (slope length) ranged from 0.2 to 0.5 (dimensionless).
Source: Bizuwerk et al. [30].

Table 2.
m-value.

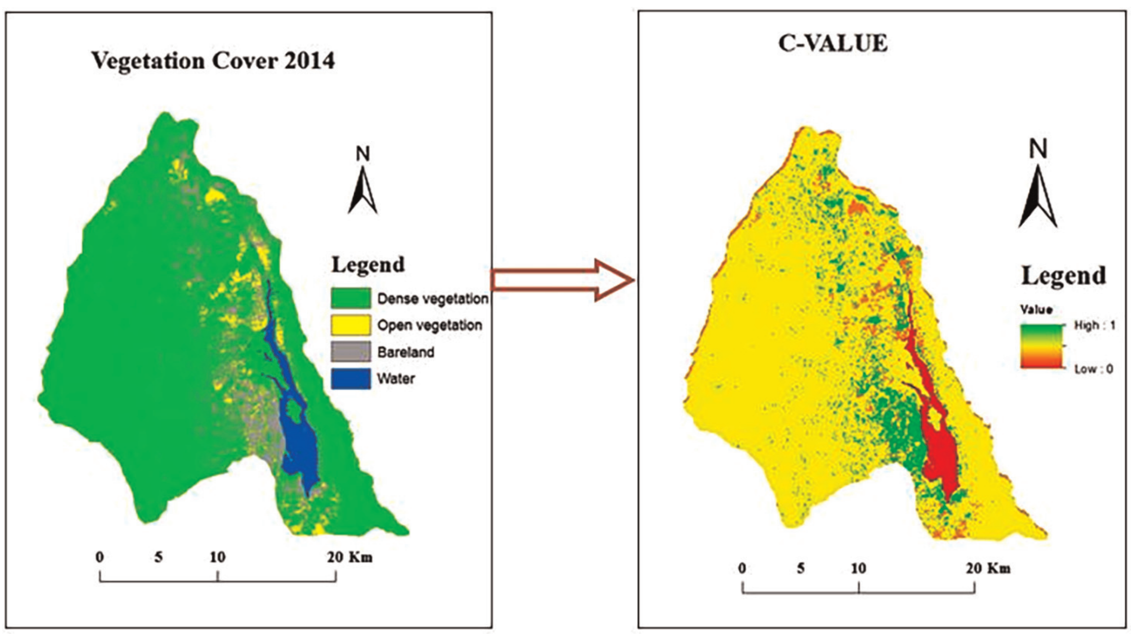

Figure 5.
Crop management factor.

2.3.4 Crop management factor (C)

The crop management factor which represents the ratio of soil loss under a given crop to that of the base soil [30] is perhaps the most important USLE factor because it represents conditions that could be managed most easily to reduce erosion [10]. The land use map was developed and used for analysing the c-value. The coverage was changed to grid where a corresponding c-value was assigned to each land cover class using reclass method in ArcGIS 10.3 and results presented as shown in **Figure 6**.

2.3.5 Erosion management practice factor (P-value)

The support practice factor, P, is a soil loss ratio for a specific support practice to the corresponding soil loss with up-and-down slope tillage [10]. The P-value ranges from 0 to 1 depending on the soil management activities applied in the specific plot of

Land use type	Slope (%)	P-factor
Agricultural land	0–5	0.1
	5–10	0.12
	10–20	0.14
	20–30	0.19
	30–50	0.25
	50–100	0.33
Other land	All	1.00

Source: Bizuwerk et al. [30].

Table 3.
P-value.

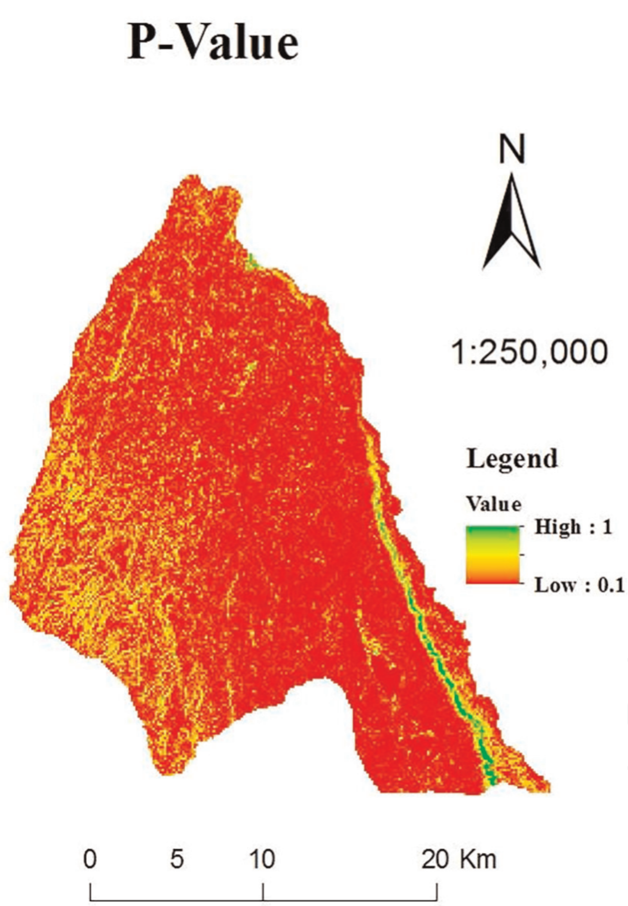

Figure 6.
Erosion management factor.

land. These management activities highly depend on the slope of the area [30]. Wischmeier and Smith [23] calculated the P-value by delineating the land into two major land uses, agricultural land and other land. The agricultural land sub-divided into six classes based on the slope percent to assign different P-value as shown in **Table 3**. The study applied this same technique to assign the P-value of the catchment. The results were computed and presented in raster format as shown in **Figure 7**.

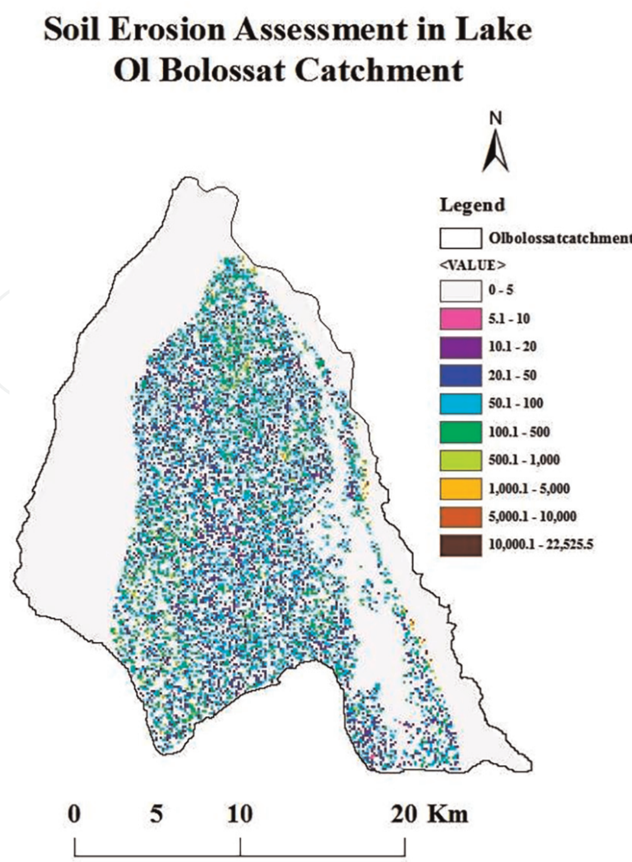

Figure 7.
Estimated soil loss.

3. Results

The results of this study show that the amount of soil loss in Lake Ol Bolossat catchment ranges between zero (0) and 22, 525.5 tons per year from 57, 800 hectares as shown in **Figure 8**. This implies that the mean annual soil loss is approximately 0.389 tons per hectare per year. However, averaging the soil loss would suggest that the study area is experiencing low soil erosion which is much lower than tolerable levels of 9 ton per hectare [35].

The study revealed that areas covered with dense vegetation i.e. along Ndudori Tumaini escarpment and South Marmanet forest have little or no soil loss while areas with sparse vegetation and Bareland have high soil loss. It is also noted from the study that areas dominated by agricultural activities and areas around the Lake have experienced high soil loss. In addition, barelands and areas with sparse vegetation have high soil erosion rate. Most parts of the study area did not have soil conservation measures as indicated by low value of P factor in **Figure 7** and this could be another possible reason why these areas have high erosion rate.

4. Discussion

Rainfall erosivity factor (R) plays a vital role in soil loss. The catchment under study has R-value of between 723.7 and 902.1 (**Table 1** and **Figure 3**). High R-factor is usually associated with soil loss due to high kinetic energy of rain drops that dislodges

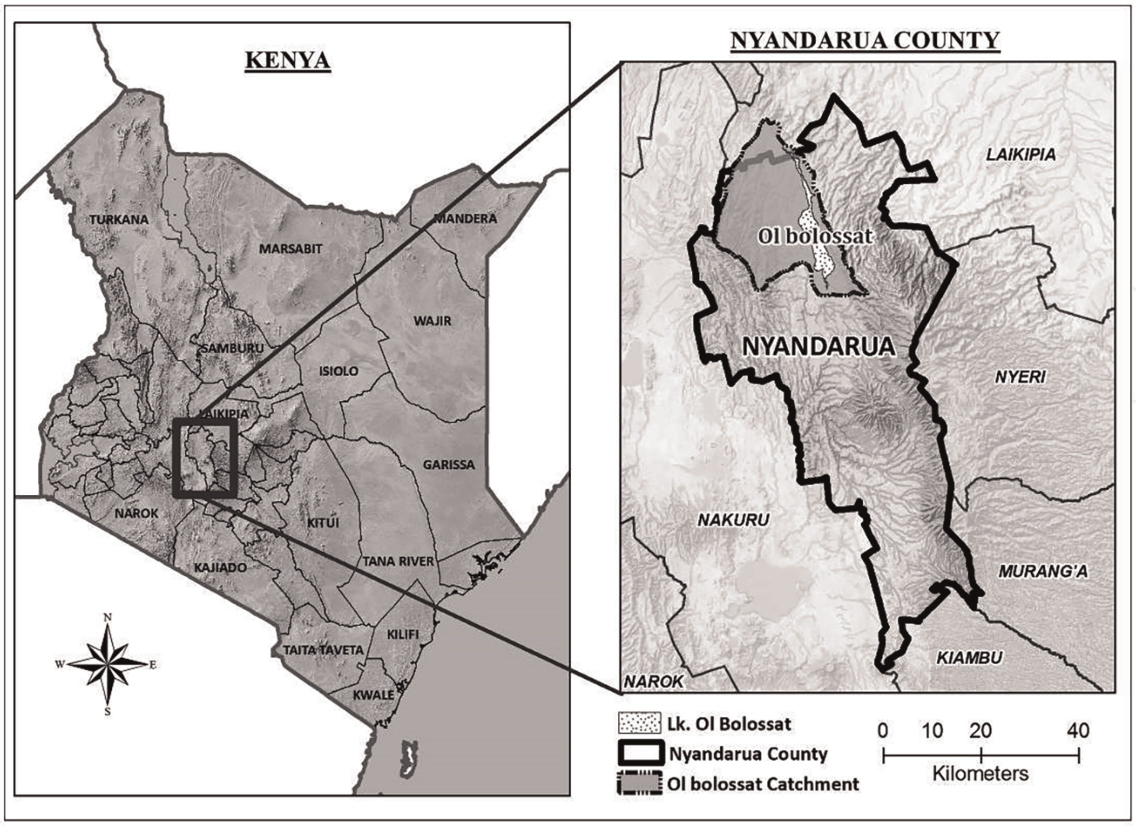

Figure 8.
Study area.

and disintegrates soil particles that are easily carried away by surface runoff [3, 36, 37]. However, other factors such as vegetation cover and erosion management factors also determine the rate of soil erosion [22, 36]. According to the study areas with high R-values and high vegetation cover such as western strip of study area have little soil loss (less than 5 tons/year). In comparison, areas with moderate R-value (about 723.7) and little or no vegetation cover experience high soil loss indicating that C-factor plays a major role in controlling soil erosion. In the view of this, it can be concluded that there is no soil erosion factor acts in isolation but all USLE factors are interrelated.

Vegetation cover is an important determinant of soil erosion. Vegetation intercepts the rain drops reducing their impact on soil particles. In addition, vegetation cover slows down the surface runoff allowing for more for water to infiltrate and consequently reducing the scouring ability of the runoff [29, 36, 37].

The type of soil in an area determines the soil erodibility value. The study area has four dominant soil types i.e. nitisol, phaeozem, luvisol and solonchack which have different erodibility values (**Table 4**). The results of the study show that nitisol is erodible even though they have a high erodibility value (0.25) because these soils are deep and supports dense vegetation. Solonchacks are highly erodible (K-value of 0.35) and areas dominated by this type of soil have high erosion rate. Most of these areas are around the Lake and have a soil loss of over ten tons per hectare per year which is above tolerable values of 9 tons per hectare per year [35, 37]. Luvisols and phaeozems are relatively erodible and areas dominated by these soils have high rate of soil erosion. In addition to soil types, overgrazing also contributes to high soil erosion rate

Soil colour	Reddish brown	Brown	Black	Grey
Soil Type	Nitisol	Phaeozem	Luvisol	Solonchack
K factor	0.25	0.2	0.15	0.35

Modified from Bizuwerk et al. [30].

Table 4.
k-values.

especially around the Lake. The same observation was made by [35] when they were assessing erosion hazard in Upper Ewaso Ng'iro Basin of Kenya.

Slope length and slope angle (LS factors) also influence the rate of soil erosion. Steep slope especially Satima escarpment experience high rate of soil erosion. These sloppy areas have relatively high vegetation cover and erosion management practices as shown in **Figures 5** and **6** respectively, however the erosion rate is high possibly due to high erosivity factor.

The results of this study are based on use of empirical model, USLE. It is therefore recommended that other methods such as experimental plots be used so as to compare the results. The results of prediction models can be improved by carrying out semi-detailed or detailed soil surveys so as to enable a better way of computing erodibility factor. In addition, field assessment of soil and water conservation measures would help to accurately determine erosion management practices (P-factor). In addition, further research is recommended on assessment of soil erosion hot spots so as to formulate immediate soil conservation measures.

The study revealed that the spatial rate of soil loss in Lake Ol Bolossat catchment is between zero (0) and 22,575.5 tons per year. The rate of soil loss in most of the parts of the study area is alarming and requires mitigation measures for it is above the tolerable levels of 9 tons per hectare. The study also revealed that rainfall intensity, soil erodibility, slope length, slope angle, vegetation cover and erosion management are factors that contribute to soil erosion in Lake Ol Bolossat catchment. The spatial locations of high erosion rates are agricultural areas (croplands) and grazing areas around the Lake which are dominated by barelands and sparse vegetation.

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Conflict of interest

The authors and other stakeholders involved in the study have no conflict of interest whatsoever.

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