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Estimation of average annual soil loss rates and its prioritization at sub-watershed level using RUSLE: A case of Finca'aa, Oromiya, Western Ethiopia

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Abstract

Background: Because of natural and anthropogenic phenomena, most mountain areas experience significant soil loss. It is critical for watershed management to identify high soil loss rates and prone areas. Therefore, the present research aimed to estimate spatial annual soil loss rates and prioritize soil erosion prone areas of the Finca'aa watershed at sub-watershed level.

Methods: The revised universal soil loss equation (RUSLE) model, the extension of geographic information system based on five parameters: rainfall erosivity (R), soil erodibility (K), slope length and slope steepness (LS), vegetation cover (C), and conservation techniques (P), was applied. This study also used weather data, a soil type map, a digital elevation model (DEM), and land use land cover, which were all analyzed using ArcGIS 10.4.

Results: Annual soil loss rates ranged from negligible to 234 t ha^{-1} yr^{-1}. The average rates of soil loss was 33.3 t ha^{-1} yr^{-1}. Approximately 63.36% of the catchment was within and 36.64% of the catchment was above the maximum permissible level, respectively. Approximately 1.96% were in critical condition. Agricultural practices were the primary cause in the watershed's mountain and hilly areas.

Conclusion: The outcome is critical for planners and resource managers interested in long-term watershed management. Also, it is very important for sustainable growth development of 2030 agendas.

Keywords: Geographic information system, Prone area, Soil erosion, Water movement

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Introduction

Soil erosion is a major environmental, ecological, and economic issue worldwide (1). It is a critical issue of the 21st century that threatens agricultural production and terrestrial ecosystems, as approximately 2 billion ha of soil resources have been degraded globally, and approximately 22% of total cropland, pasture, forest, and woodland have been lost (2).

Understanding cause-effects through long-term expression in terms of soil quality, soil degradation, and resilience in relation to specific function, critical limits to key soil properties, and process and restoration through management, respectively, can help to solve global soil degradation and its agricultural impacts (3). Land degradation is the primary cause of increased runoff and soil erosion, nutrient depletion, organic matter loss, acidification, and salination (4-7).

Unsustainable agricultural practices, overgrazing, and overexploitation of forest and woodland resources have resulted in land degradation of approximately 51%, 41%, 23%, and 22% in Tanzania, Malawi, Ethiopia, and Kenya, respectively, increasing soil loss (8). Ethiopia loses approximately \$106 million per year due to soil and nutrient loss caused by land degradation, particularly in agricultural areas, which exacerbates food production and people's livelihood (9).

Because of the lack of protection capacity and attention to watershed management, soil erosion is more severe in developing countries. Ethiopia is experiencing severe soil erosion problems, particularly in the highlands, as a result of natural (topography) and anthropogenic factors (9).

Soil erosion in the Blue Nile River Basin's upstream area, followed by sedimentation in the downstream area, resulted in a rapid loss of storage volume due to excessive sedimentation (10). The Finca'aa watershed is a part of the Blue Nile River basin that has experienced land use change, environmental degradation, and severe erosion problems, with annual soil losses of 24 to 160 $Mgha^{-1}$ (11).

The revised universal soil loss equation (RUSLE) has long been used by researchers to estimate soil loss based on five parameters including rainfall erosivity (R), soil erodibility (K), topography (LS), vegetation cover and management (C), support and conservation practice (P) as a global including in Ethiopia (12-21).

Soil erosion is a serious and common occurrence in the Finca'aa watershed, a vulnerable and fragile area of the Blue Nile basin. It has a significant impact on the Grand Renaissance Dam and the Guba hydraulic dam, both of which are under construction, because the watershed is one of the contributors to the area. Topography, climate, land use, changes in land cover, variations in soil properties, anthropogenic activities, and the lack of best management practices all contribute to soil erosion.

Prior assessment of the spatial distribution of soil erosion, determination of soil loss rates, and identification and prioritization of prone areas at the sub-watershed level are thus critical for planning and long-term management programs. Therefore, this research aimed to estimate the current state of soil erosion, create a spatial soil distribution map using the RUSLE model, and identify the watershed's prone erosion areas.

Materials and Methods

Description of the study area

The study area is located in Horro Guduru Wollega Zone, Oromiya National Regional State, Ethiopia, in the Abay River Basin. It is situated between the latitudes of 9° 9′ 53″ N and 10° 1′ 00″ N, and the longitudes of 37° 00′ 25″ E to 37° 33′ 17″ E. (Figure 1). The study area encompasses 2619 km^2. The catchment elevation ranges from 902 m in the lowlands to 3171 m in the highlands. The Finca'aa watershed has a tropical highland monsoon climate with an average annual rainfall of 1763.6 mm and a mean monthly temperature ranging from 14.6 to 17.7°C. The majority of the rain falls from June to September, with the highest amounts falling from July to August. From November to April, it is mostly dry. The watershed is divided into six districts: Jimma Ganati, Horro, Abbayyi Coman, Ababo Guduru, Guduru, and Jimma Rare. The Abbay River borders the watershed on the north, the Guder River Basin on the east, the Awash River Basin on the south, and the Dhidhessa River Basin on the west.

Materials/tools used

The tools used in this study for data collection, preparation, and analysis include Arc GIS 10.4.1, various maps, and Microsoft Excel 2010. ArcGIS was used for map creation, database management, and the execution of GIS processing tools such as clipping, overlay, and spatial analysis.

Data collection, preparation and analysis

The primary input data were precipitation, 30 m resolution digital elevation model (DEM), land use land cover (LULC), and soil type. The data were provided by the Ethiopian National Metrological Agency and the Ministry of Water, Irrigation, and Electricity. The collected input data were prepared in accordance with the compatibility of the models. Field observations were also conducted to locate the outlet and visualize the catchment. According to the DEM, the Finca'aa watershed has two distinct landscapes: the highlands, a ragged mountainous area in the upper and western parts of the watershed, and the lowland valley area, which is flat in the lower part of the watershed. The study area's altitude ranges from 902 m to 3,171 m above mean sea level. The study area's elevation was divided into four classes. The majority of the watershed area was located between 2006 and 2388 m above mean sea level.

Watershed delineation process

The study area's watershed was delineated using a DEM and divided into 21 hydrologically connected sub-watersheds.

Analysis of RUSLE parameters

Rainfall erosivity (R) factor, soil erodibility (K) factor, slope length and slope steepness (LS) factor, vegetative cover (C), and soil and water conservation practice (P) factor are the main RUSLE input parameters.

The rainfall erosivity (R) factor

It is a quantitative expression of the erosive power of local average annual precipitation and runoff causing soil erosion (22) and computed using Eq. (1).

$$R = -0.82 + (0.562 * P) \quad (1)$$

Where p is the mean annual precipitation from nearby rain gauge stations (mm), calculated from daily rainfall data collected from four rain gauge stations (Kombolcha, Fincha, Hareto, and Shambu) over a 25-year period from 1990 to 2014 and the corresponding R-factor values were 582.91, 990.03, 531.74, and 717.58 MJ ha^{-1} yr^{-1} hr^{-1}, respectively. GIS 10.4.1 interpolated rainfall point data using the inverse distance weighted method to form a scattered set of point data. From continuous rainfall data, the R-factor values for each grid cell were calculated in a GIS database raster calculator.

The soil erodibility factor (K)

The K-factor is a measure of soil particle susceptibility to detachment and conveyance by rainfall and surface runoff, and it reflects the combined effect of soil properties, indicating the general susceptibility of a particular soil type to erosion. The organic matter and texture of the soil, as well as its permeability and profile structure, determine the K-factor, which represents erosion susceptibility and rate of runoff under standard plot conditions (23,24). It is the ratio of soil loss from the field's slope length and

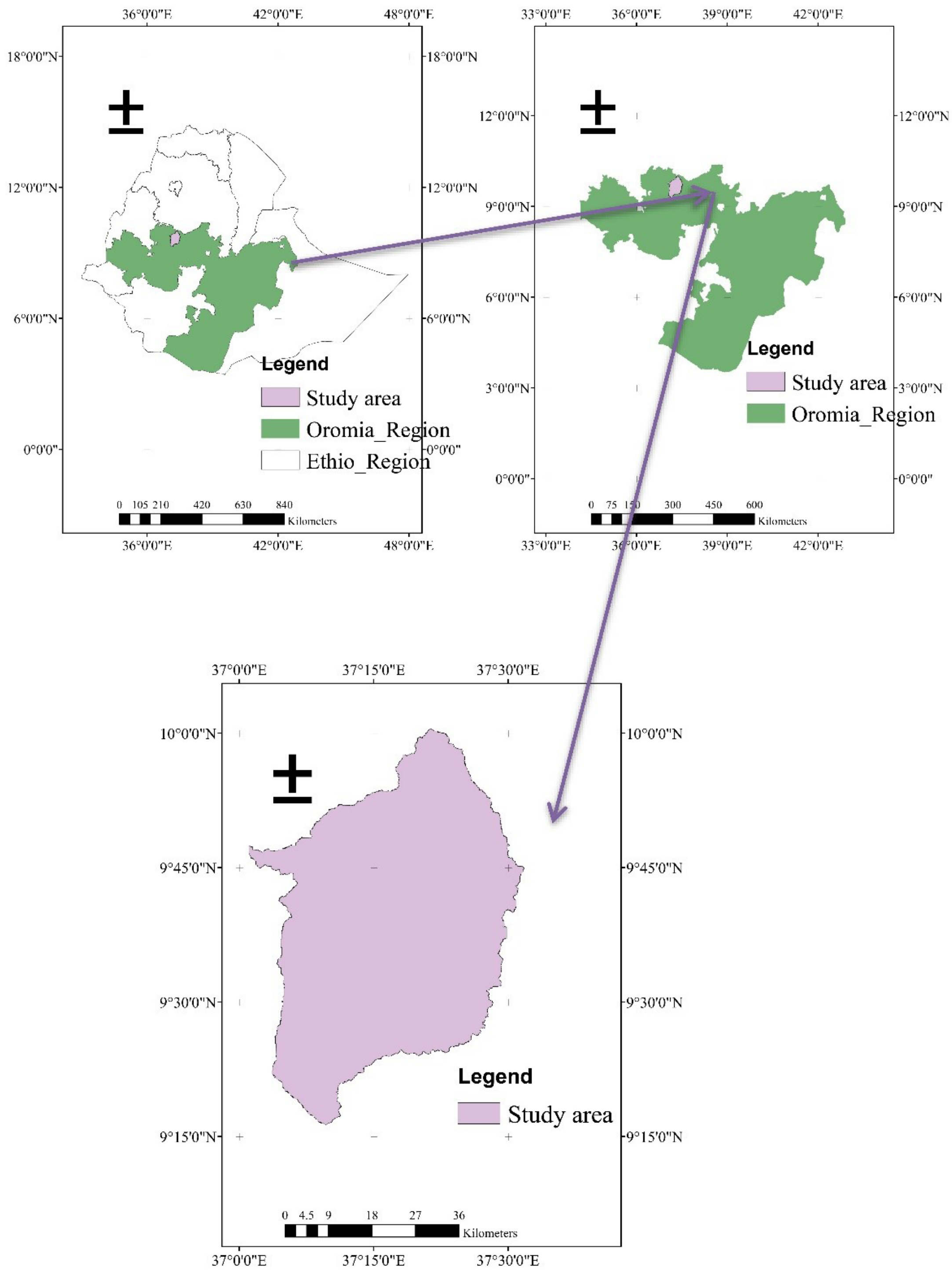

Figure 1. Location of the Finca'aa watershed

steepness to a standard slope length and steepness of 22.1 m and 9%, respectively. Soil properties, resistance to erosion and erodibility (K) factor values vary between soils. According to the study of the study of Bewket and Teferi (12), it is difficult to obtain detailed information on soil data and K-factor values in Ethiopia. So, the soil erodibility (K) factor of the study area was determined using different literature, and most researchers believe that K-factor values are based on soil color (25).

Factors of slope length and slope steepness (LS)

It is a topographical factor that computes slope length (L) and slope steepness (S) on soil erosion based on slope length and gradient. It describes the impact of topography on the risk of soil erosion. The greater the cumulative runoff and the higher the velocity that contribute to soil erosion, the longer the slope length and the steeper the slope, respectively. The combination is critical for estimating soil loss and managing it in RUSLE (26,27). It is the ratio of soil loss per unit area from a field slope to that of a standard field slope, with a length of 22.1 m and a slope of 9%. The catchment's land use, land cover, and land management techniques have a significant impact on the LS factor value for RUSLE soil loss computation (28,29).

For LS computation used three parameters including flow accumulation (FA), resolution (30 m DEM), and slope classes (percent), was used. The FA and slope values were calculated using GIS software from a DEM (30 m) of the catchment. To generate the LS-factor map from the GIS database's raster calculator, Eq. (2) was used.

$$LS = Power\left[\left(FA * \frac{Resolution}{2.1}\right), 0.6\right] * power\left[\left(\frac{\sin(slope * 0.01475)}{0.09}\right), 1.3\right] \quad (2)$$

Where *FA* (flow accumulation) is the raster-based total of accumulated flow to each cell, and resolution is pixel size (30 m × 30 m).

Factor of plant cover (C)

The C factor incorporates plant cover, production level, and cropping techniques. Exact determination of C-factor values is difficult because the catchment's land use, land cover, and management techniques change over time, both globally and locally, and have an effect on soil erosion rate (30).

Several researchers have attempted to estimate the cover management (C) factor for delicate, practical, and reliable use in soil loss estimation using RUSLE (31). It denotes the ratio of soil loss in a field with a specific vegetation cover to the corresponding soil loss in a continuous fallow with the same rainfall. The current LULC of the study area and their corresponding C-factor values were bush land, dominantly cultivated, moderately cultivated, irrigated land, grass land, water bodies, swamp area, woodland open and 0.05, 0.15, 0.15, 0.16, 0.05,0, 0.05, and 0.06, respectively.

Conservation of soil and water (P) factor

P is a factor in the RUSLE model that accounts for specific erosion control practices such as contour tilling or mounding, or contour ridging, bench terrace, and hillside ditch. The P-factor is the ratio of soil loss caused by a specific conservation practice to the corresponding loss caused by up and down slope cultivation (zero management), with a value of one. Its value ranges from 1 on bare soil with no erosion control to about 1/10 on a gentle slope with tied ridging. The actual value is determined by the catchment's land use and land cover, as well as practical soil and water conservation techniques.

It is critical for runoff reduction, increased infiltration, soil loss reduction, catchment sustainability, and good soil conditions (32,33). Socioeconomic and conservation techniques are two factors that influence soil and water conservation practice (34). The most common management practices in Ethiopia are crop rotations, contour farming, and contouring with terracing. According to the field visits and scenario, contour farming was the most common conservation practice in the catchment, and the scenario is contour terracing. Because the furrows are perpendicular to the slope of a hill, contour ploughing reduces soil erosion. It helps to slow down water runoff during rainfall, allowing more water to enter the ground. In this paper, the slope was classified as < 3, 3-6, 6-9, > 9% and their corresponding P-factor values were 0.6, 0.65, 0.70, and 0.90 based on contour farming conservation techniques in the study area.

Annual soil loss estimation

Finally, using five parameters, the RUSLE predicts the long-term average rate of erosion (A). Using the raster calculator in the GIS database, these parameters are rainfall pattern (R), soil type (K), topography (LS), crop system (C), and management practice (P). Equation presents the most empirical equation used to calculate annual soil loss from the watershed (3).

$$A = R*K*LS*C*P \quad (3)$$

Where *R* is rainfall erosivity factor [MJ mm ha^{-1} hr^{-1} yr^{-1}], *K* is soil erodibility factor [t ha^{-1} MJ^{-1} mm^{-1}], *LS* is slope length and slope steepness factor, which is [dimensionless], *C* is LULC, which is [dimensionless], and *P* is support practice, which is [dimensionless].

Results

Analyses of RUSLE model parameters

The R-value

The study area's mean annual rainfall ranges from 947.60 to 1763.63 mm, and the estimated rainfall erosivity factor value varies from 531.74 to 990.03 MJ $ha^{-1}yr^{-1}hr^{-1}$ at the Hareto and Fincha stations, respectively. Mean annual rainfall and rainfall erosivity have a direct relationship based on the empirical equation for R-factor calculation and the computed values (as mean annual rainfall increases, erosivity also increases). The catchment's northern and southern reaches had lower R-values, indicating that they were less prone to soil erodibility. The higher the R-values were in the eastern parts, which were more prone to soil erodibility than the other parts. The medium R-values were mostly found in the catchment's center. According to the R-factor values, the susceptibility of soil erosion increases from the southern and northern parts of the watershed to the central and, finally, to the eastern parts of the watershed (Figure 2).

K-Factor

The SWAT output identified nine soil types with their respective textures, and the soil erodibility factor (K) values ranged from 0 to 0.33 (Table 1). The higher the soil

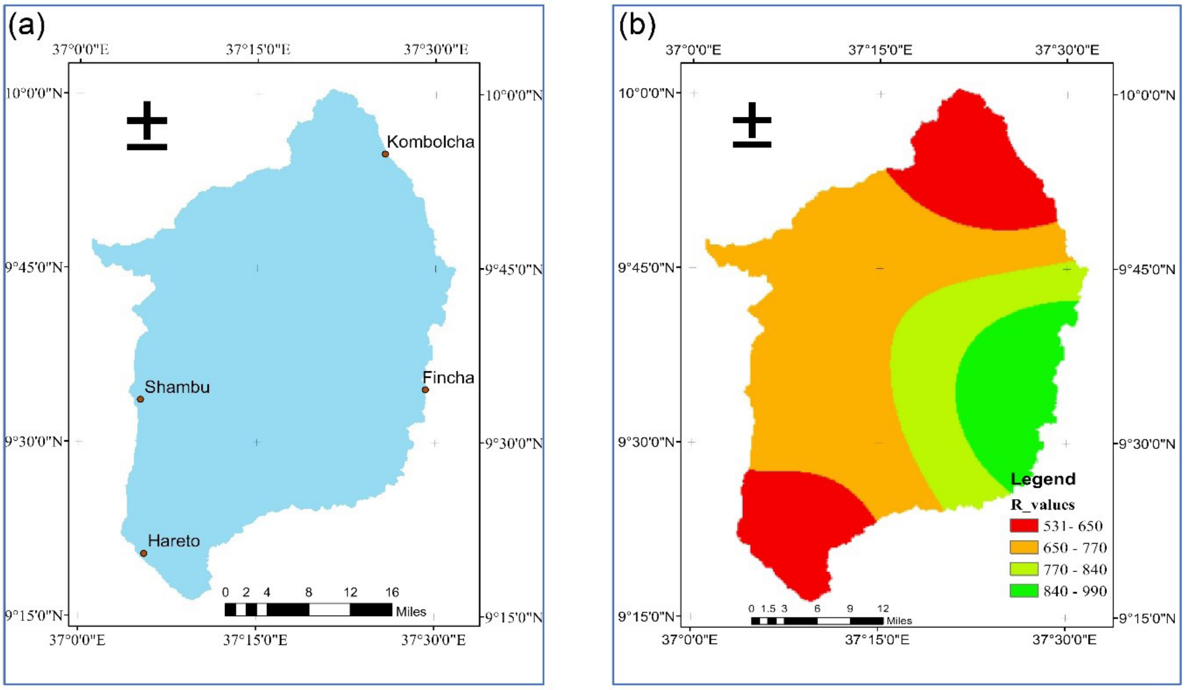

Figure 2. (a) Stations and (b) corresponding R-factors values

Table 1. Soil category, area covered and erodibility (K) factor values

Classes	Soil category	Texture	Soil Group	Area covered (%)	K-factor values
	Eutric Regosols	Brown	C	20.82	0.31
1st	Humic Cambisols	Black	C	5.08	0.27
	Dystric Cambisols	Gray	B	23.7	0.27
	Chromic Luvisols	Clay	C	0.1	0.26
2nd	Eutric Cambisols	Red	C	16.28	0.26
	Haplic Phaeozems	Loam	D	1.33	0.25
	Eutric Nitosols	Brown	C	0.83	0.23
3rd	Chromic Vertisols	Gray	C	20.17	0.21
	Water	Water	D	11.7	0

erodibility, the lower the K-factor value, and vice versa. This means that as the K-factor value approaches zero, the soil has a high resistance to erosion; as the K-factor value approaches one, the soil has a lower resistance to erosion. As the K-factor values are classified into three ranges, the first class includes Eutric Regosols, Humic Cambisols, and Dystric Cambisols, the second class includes chromic luvisols, Eutric Cambisols, and Haplic Phaeozems, and the third class includes Eutric Nitosols, Chromic Vertisols, and water. The first, second, and third classes each account for 49.6, 17.71, and 32.7% of the total area. This means that 49.6% of the catchment area was extremely vulnerable to soil erosion. The second soil class, accounting for 21.65% of the total area of the watershed, was Eutric Regosols and Eutric Nitosols. The third category included chromic vertisols and luvisols, which accounted for approximately 20.27% of the catchment

LS-factor

The LS-factor values of the study area range from 0 (flatter and lower) to 70% (steeper and upper) (Figure 3). Higher LS-values, ranging from 50% to 70%, resulted in the catchment's mountainous and hilly terrain, which contributes to cumulative runoff and higher soil erosion. In comparison, the south-western and central parts of the study area had such conditions, while the northern parts had lower LS-factor values, resulting in less soil erosion.

C-factor

Lower C-factor values cover 30.78% of the study area, which includes water bodies, swamp area grasslands, and wooded open land (Figure 4). These conditions were mostly found in the catchment's center and resulted in less soil erosion based on the C-value because they are inversely proportional to each other. Under uncontrolled conditions, the remaining 69.22% of the study area is covered with agricultural practice, which is easily exposed to runoff during the heavy rainy season. As a result, high soil erosion can be expected in these areas when compared to other parts of the catchment. Agriculture was practiced in the western, southwestern, and central parts of the north.

P-factor

Based on the catchment's existing land management practice (contour farming), the P-factor value ranges from 0.6 to 0.9, with corresponding slope classes less than 3% and greater than 9%, respectively. As a result, the steepest area has the highest P-factor value. The central part of the area has lower P-factor values, while the rest of the area has higher P-factor values (Figure 5).

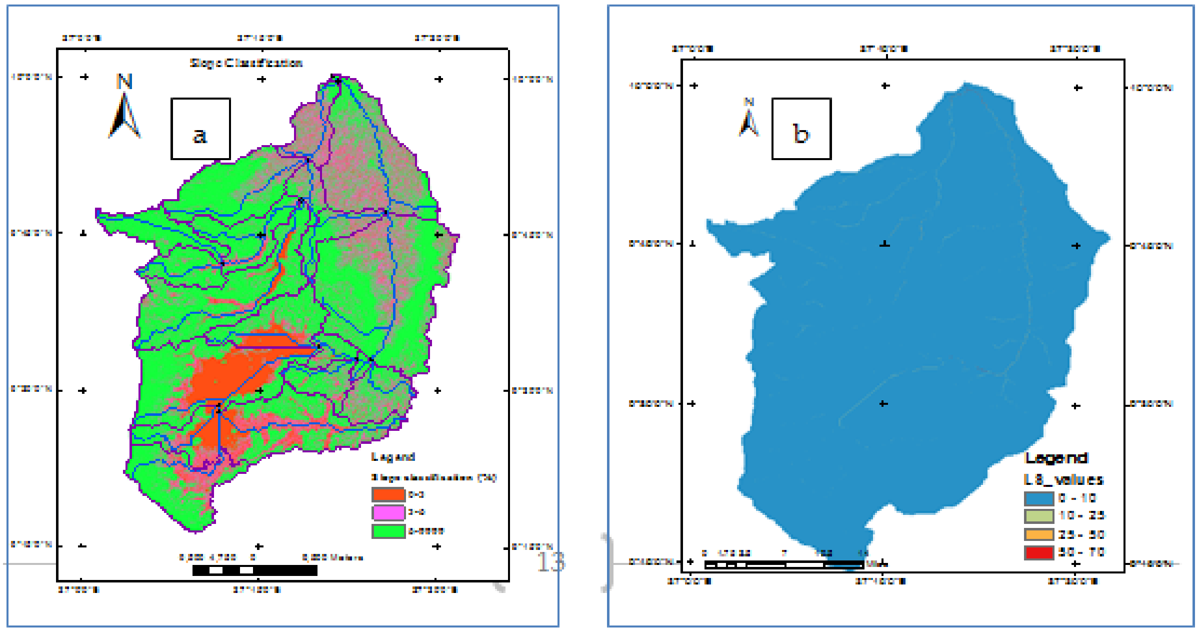

Figure 3. (a) The slope classes and (b) LS-values of the Finca'aa watershed

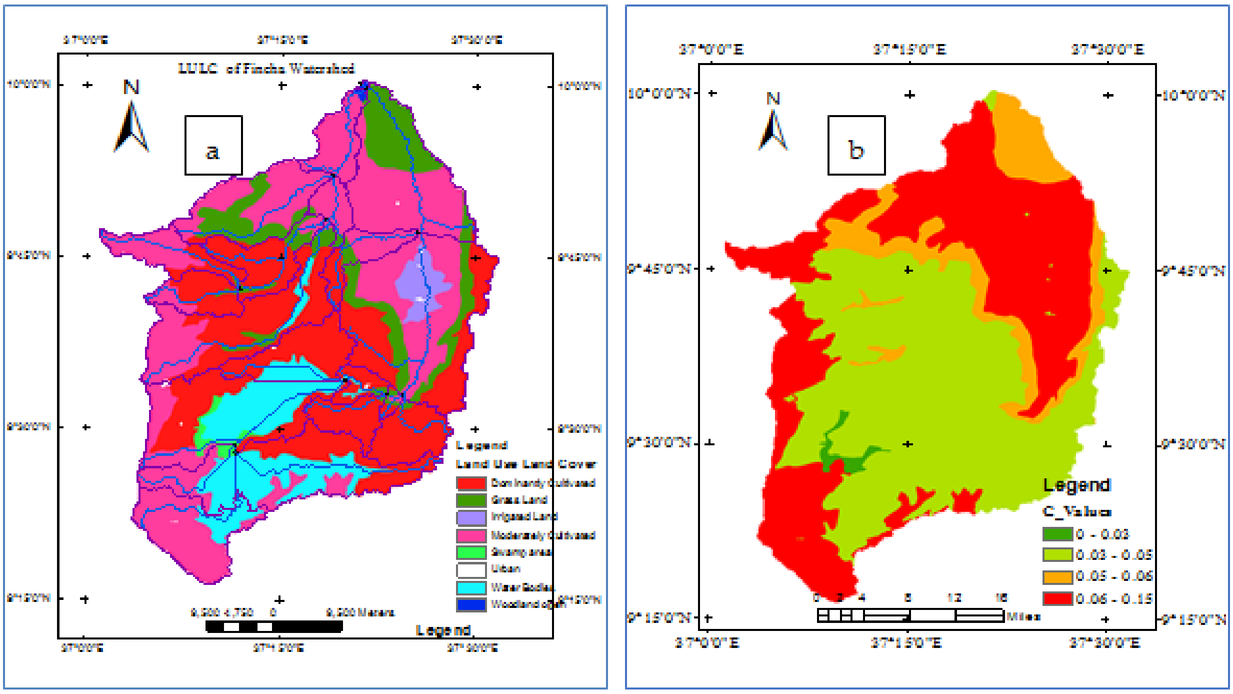

Figure 4. (a) LULC and (b) corresponding C-values of Finca'aa watershed

Estimation of annual soil loss

The spatial annual soil loss rates ranged from 0 to 234 t ha^{-1} yr^{-1} in lower and flat to mountain/hilly or degraded sloped areas, according to the model results. The catchment's average annual soil loss was 33.3 t ha^{-1} yr^{-1}. As the results show, soil losses vary greatly across the catchment due to factors such as topographical (LS) conditions, land use, land cover, soil type, and rainfall intensity. As a result, the watershed was classified as severe, very high, high, moderate, and low that ranges from 0-5, 5-10, 10-25, 25-50, and > 50 t ha^{-1} yr^{-1}, respectively. According to the findings, 21.34% of the catchment had low and moderate soil erosion and covers approximately 42.02% of the watershed. High, very high, and severe soil erosion rates occupied about 18.82, 15.86, and 1.96% of the study area, respectively.

Prioritization of sub-watershed

Prioritization entails ranking the sub-watershed based on total soil loss for soil and water conservation techniques.

In this study, approximately 21 sub-watersheds were obtained from GIS delineation based on drainage systems, and the erosion prone area map was reclassified for prioritization (Table 2, Figure 6). Soil loss occurred along the stream as a result of the watershed's severe and very high risk. The spatial distribution of the soil loss map classified five sub-basins, 11, 13, 14, 17, and 20, as class I (>50 t ha^{-1} yr^{-1}) and the III classes as sub-basis 3, 17, 18, and 19. The classes I, II, and III, which cover 36.64% of the watershed, required more attention to conserve the watershed because their soil loss rates were higher than their soil loss tolerance. In sub-watersheds 1-9, 10, 12, 15, and 16, the remaining percentage was classified as limited soil loss tolerance.

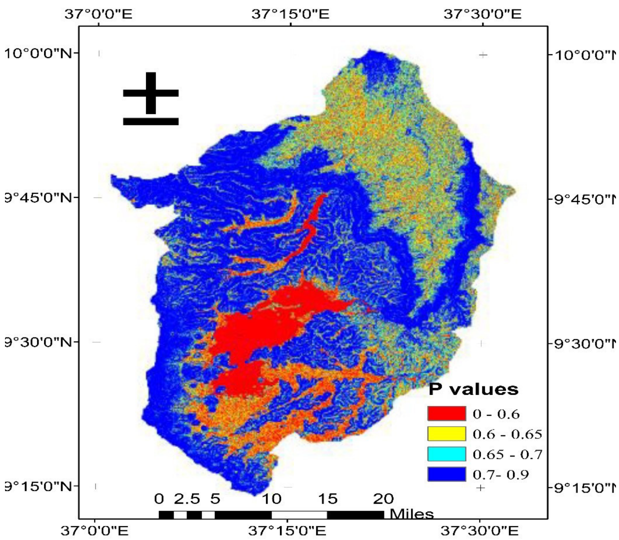

Figure 5. P-factor values of the watershed

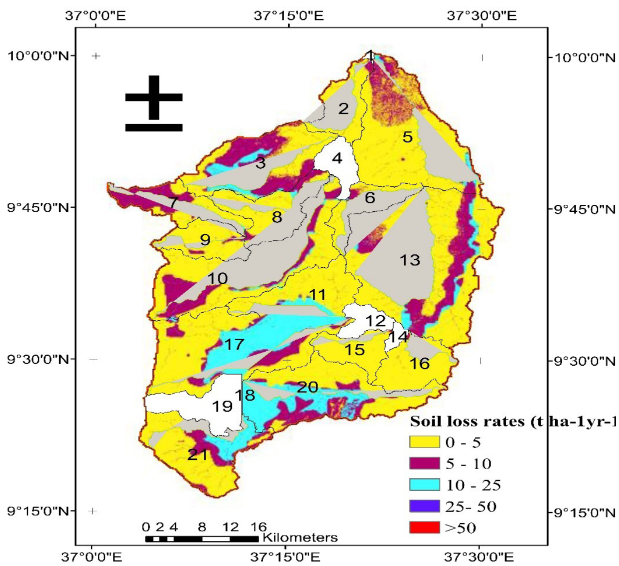

Figure 6. Spatial distribution of prone area at sub-watershed

Table 2. Prioritization of sub-watershed and corresponding area covered

Soil loss rate (t $ha^{-1}yr^{-1}$)	Priority classes	Sub-watershed	Area (km^2)	Covered area (%)
>50	I	11, 14 and 21	51.3	1.96
25–50	II	1 and 10	415.4	15.86
10–25	III	17, 18, 19 and 20	492.9	18.82
5–10	VI	3, 7 and 13	1100.5	42.02
0–5	V	2, 4, 5, 6, 8, 9, 12, 15, 16	558.9	415.4
		Total	2,619	100

Discussion

R-factor

Mean annual rainfall and rainfall erosivity have a direct relationship based on the empirical equation for R-factor calculation and the computed values. The catchment's northern and southern reaches had lower R-values, indicating that they were less prone to soil erodibility. The higher the R-values were in the eastern parts, which were more prone to soil erodibility than the other parts. The medium R-values were mostly found in the catchment's center. According to the R-factor values, the susceptibility of soil erosion increases from the southern and northern parts of the watershed to the central, and then, to the eastern parts.

K-factor

The lower the K-factor value, the greater the soil erodibility, and vice versa. This means that as the K-factor value approaches zero, the soil has a high resistance to erosion; as the K-factor value approaches one, the soil has a lower resistance to erosion. Approximately 49.6% of the catchment was very susceptible to soil erosion. Cambisols soil was vulnerable to erosion and sediment yield due to uncontrolled agricultural activities and poor land management. Regosols are very deep, unconsolidated mineral soils with very weakly developed mineral soils. They are widespread in eroding lands, particularly in arid and semi-arid regions and mountain ranges. Nitosols are most common at higher elevations. Because of their high nutrient content and deep, permeable structure, they are the most naturally fertile of tropical soils and are widely used for plantation agriculture. The third category included chromic vertisols and luvisols, which accounted for approximately 20.27% of the catchment. Luvisols hold soils are distinguished by pronounced textural differentiation within the soil profile, a clay-depleted surface horizon, and clay accumulation in a subsurface argic horizon. Although most chromic luvisols drain well, shallow groundwater may occur in luvisols in depression areas. Luvisols are fertile soils that can be used for a variety of agricultural purposes when managed properly.

LS-factor

The LS factor has a significant impact on RUSLE's prediction of soil loss. Higher LS values in mountain and hilly areas result in greater soil erosion from the catchment. According to the LS-values, the south-western and central parts of the study area had higher soil loss, while the south-center and partially northern parts had less soil erosion.

C-factor

Water bodies, swamp area grasslands, and wooded open land with lower C-values resulted in less soil erosion in the central part of the catchment. According to the LULC and C-values, the majority of the catchment was under agricultural practice, which was easily exposed to runoff during the heavy rainy season under uncontrolled conditions. As a result, high soil erosion can be expected in these areas when compared to others. The western, south-western, and central northern regions were all affected. As a result, best management practice should begin with these areas and work its way down.

P-factor

The catchment's management practice was contour farming, with different *P* values depending on the slope. As a result, the steepest area has the highest P-factor value. As the results show, most parts of the catchments, particularly the upper and lower parts, have higher *P* values, resulting in greater soil loss. The P-value was reduced with lower soil erosion when the proposed management practice with terracing techniques was implemented.

The status of spatial soil losses of the catchment

Soil loss tolerance refers to the maximum soil loss that can occur on a given land without leading to degradation of the soil and is estimated to be 5–11 t ha^{-1} yr^{-1}. According to the results, the majority of the central and south-eastern parts of the watershed, which account for approximately 63.36% of the total area, exhibit soil loss tolerance. In comparison, this area is less likely to experience soil erosion. According to the results, 15.86% of the watershed had a very high soil loss rate, indicating that there was land degradation in the study area. This condition was mostly found in the middle of the watershed, in the north corner, and in the southwestern corner.

The majority of the catchment was affected by a severe soil loss rate, which covered approximately 1.96% of the catchment, and only slightly in the central part of the catchment.

In general, more than 36.64% of the watershed exceeded the maximum allowable soil loss rates. This demonstrated that the outcome was caused by agricultural activities and poor watershed management practices in the study area. Based on the findings, the soil loss rate and spatial patterns of the study area are comparable to previous studies in some Ethiopian basins.

According to a previous research, annual soil rates in the Agew Mariayam watershed, northern Ethiopia, range from 0 to 897 t ha^{-1} yr^{-1}, with an average value of 25 t ha^{-1} yr^{-1} (14). Another study (17) estimated annual soil loss rates in steep slope areas as high as 187.47 t ha^{-1} yr^{-1}, with a mean annual soil loss of 38.9 t ha^{-1} yr^{-1} in the Chereti watershed in northern Ethiopia. According to the result shown in Anka-shashara watershed, Southern Ethiopia, the mean annual soil loss was 15.22 t $ha^{-1}yr^{-1}$ (35). According to the study of Mustefa et al (36), the amount of soil loss in Hangar River watershed, Ethiopia ranges from 1 to 500 t ha^{-1} yr^{-1} with an average annual soil loss rate of 32 t ha^{-1} yr^{-1} using RUSLE. In Gilgel Gibe-1 Catchment, South West Ethiopia, the mean annual soil loss of the catchment is 62.98 t ha^{-1} yr^{-1} (37) and estimated annual mean soil loss rate was found to be 37 t ha^{-1} yr^{-1} in the Beshillo Catchment of the Blue Nile Basin, Ethiopia (38).

According to these studies, variations in results within the same basin are caused by the following factors: catchment size, specific data used, catchment topography, land use, land cover, and watershed management practice in the area.

This study aimed to estimate average annual soil loss rates, identify prone areas, and assess the impact of terracing with contour ploughing technique on soil erosion rate. As a result, best watershed management practices can be implemented by decision-makers and other interested parties. Rainfall data were collected from four stations for this study, and missing data were filled in before the current LULC was used. As a result, the accuracy of the result is increased, and it differs from previous studies.

As shown in Figure 6, the soil erosion risk map, almost the entire watershed requires the implementation of best watershed management practices. Due to resource availability and implementation techniques, it may be difficult to implement for the entire catchment at once and instead focus on the vulnerable even with limited resources, best conservation practices implemented in prone areas can reduce total soil loss from the watershed.

Conclusion

Creating a soil erosion susceptibility map is critical for identifying prone areas at the sub-watershed level and deciding on the best watershed management practice. In this study, ArcGIS 10.4 was used to delineate the watershed and create RUSLE parameters for soil loss prediction in the catchment based on topography, soil type, land use, and existing water and soil conservation in the watershed. Topographic (LS) values have the greatest influence on soil loss prediction using RUSLE of the five parameters, with land use (land cover) coming in the second.

According to the results of the soil loss spatial distributions in the catchment, more than half of the catchment was under good conditions based on the soil loss tolerance levels in the central and south-eastern parts of the watershed. The remaining percentage was above the maximum allowable level, indicating that there is significant soil loss in the catchment. The main causes for high soil erosion in this watershed were because of agricultural activities and topographical situation. The findings can provide basic information for any concerned body in the case of best watershed management practice, and also, interested researcher.

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Ethical Issues

The authors of this manuscript certify that all information collected for the study are as presented in this paper, and no data have been or will be published elsewhere independently.

Competing interests

The authors declare no conflict of interests.

Authors' Contribution

Conceptualization: Seifu Kebede Debela, Fekadu Fufa Feyessa.
Data curation: Seifu Kebede Debela.
Formal analysis: Seifu Kebede Debela, Fekadu Fufa Feyessa.
Funding acquisition: Seifu Kebede Debela.
Investigation: Seifu Kebede Debela.
Methodology: Seifu Kebede Debela.
Project administration: Seifu Kebede Debela.
Resources: Seifu Kebede Debela.
Software: Seifu Kebede Debela.
Supervision: Seifu Kebede Debela, Fekadu Fufa Feyessa.
Validation: Seifu Kebede Debela.
Visualization: Seifu Kebede Debela.
Writing – original draft: Seifu Kebede Debela.
Writing – review & editing: Seifu Kebede Debela, and Fekadu Fufa Feyessa.

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References

1. Yang X. Digital mapping of RUSLE slope length and steepness factor across New South Wales, Australia. Soil Res. 2015;53(2):216-25. doi: 10.1071/SR14208.
2. Chen J, Chen JZ, Tan MZ, Gong ZT. Soil degradation: a global problem endangering sustainable development. J Geogr Sci. 2002;12(2):243-52. doi: 10.1007/BF02837480.
3. Lal R, Wagner A, Greenland DJ, Quine T, Billing DW, Evans R, et al. Degradation and resilience of soils [and discussion]. Philosophical Transactions: Biological Sciences. 1997;352(1356):997-1010.
4. Costa RT, Gonçalves CF, Fushita AT, dos Santos JE. Land use/cover and naturalness changes for watershed environmental management (Southeastern Brazil). J Geosci Environ Prot. 2017;5(11):1-14. doi: 10.4236/gep.2017.511001.
5. Gebreselassie S, Kirui OK, Mirzabaev A. Economics of land degradation and improvement in Ethiopia. In: Nkonya E, Mirzabaev A, von Braun J, eds. Economics of Land Degradation and Improvement–A Global Assessment for Sustainable Development. Cham: Springer; 2016. p. 401-30. doi: 10.1007/978-3-319-19168-3_14.
6. Hurni H. Degradation and conservation of the resources in the Ethiopian highlands. Mt Res Dev. 1988;8(2-3):123-30. doi: 10.2307/3673438.
7. Lanckriet S, Derudder B, Naudts J, Bauer H, Deckers J, Haile M, et al. A political ecology perspective of land degradation in the north Ethiopian highlands. Land Degrad Dev. 2015;26(5):521-30. doi: 10.1002/ldr.2278.
8. Yang D, Kanae S, Oki T, Koike T, Musiake K. Global potential soil erosion with reference to land use and climate changes. Hydrol Process. 2003;17(14):2913-28. doi: 10.1002/hyp.1441.
9. Tiruneh G, Ayalew M. Soil loss estimation using geographic information system in Enfraz watershed for soil conservation planning in highlands of Ethiopia. Int J Agric Res Innov Technol. 2015;5(2):21-30. doi: 10.3329/ijarit.v5i2.26265.
10. Betrie GD, Mohamed YA, van Griensven A, Srinivasan R. Sediment management modelling in the Blue Nile basin using SWAT model. Hydrol Earth Syst Sci. 2011;15(3):807-18. doi: 10.5194/hess-15-807-2011.
11. Tefera B, Sterk G. Land management, erosion problems and soil and water conservation in Fincha'a watershed, western Ethiopia. Land Use Policy. 2010;27(4):1027-37. doi: 10.1016/j.landusepol.2010.01.005.
12. Bewket W, Teferi E. Assessment of soil erosion hazard and prioritization for treatment at the watershed level: case study in the Chemoga watershed, Blue Nile basin, Ethiopia. Land Degrad Dev. 2009;20(6):609-22. doi: 10.1002/ldr.944.
13. Gashaw T, Tulu T, Argaw M. Erosion risk assessment for prioritization of conservation measures in Geleda watershed, Blue Nile basin, Ethiopia. Environ Syst Res. 2017;6(1):1. doi: 10.1186/s40068-016-0078-x.
14. Girmay G, Moges A, Muluneh A. Estimation of soil loss rate using the USLE model for Agewmariayam watershed, northern Ethiopia. Agric Food Secur. 2020;9(1):9. doi: 10.1186/s40066-020-00262-w.
15. Gelagay HS, Minale AS. Soil loss estimation using GIS and Remote sensing techniques: a case of Koga watershed, northwestern Ethiopia. Int. Soil Water Conserv Res. 2016;4(2):126-36. doi: 10.1016/j.iswcr.2016.01.002.
16. Hussain F, Nabi G, Wu RS, Hussain B, Abbas T. Parameter evaluation for soil erosion estimation on small watersheds using SWAT model. Int J Agric Biol Eng. 2019;12(1):96-108. doi: 10.25165/j.ijabe.20191201.3769.
17. Negese A, Fekadu E, Getnet H. Potential soil loss estimation and erosion-prone area prioritization using RUSLE, GIS, and remote sensing in Chereti watershed, northeastern Ethiopia. Air Soil Water Res. 2021;14:1-17. doi: 10.1177/1178622120985814.
18. Ostovari Y, Ghorbani-Dashtaki S, Bahrami HA, Naderi M,

Dematte JAM. Soil loss estimation using RUSLE model, GIS and remote sensing techniques: a case study from the Dembecha watershed, northwestern Ethiopia. Geoderma Regional. 2017;11:28-36. doi: 10.1016/j.geodrs.2017.06.003.
19. Panditharathne DL, Abeysingha NS, Nirmanee KG, Mallawatantri A. Application of revised universal soil loss equation (Rusle) model to assess soil erosion in "Kalu Ganga" River Basin in Sri Lanka. Appl Environ Soil Sci. 2019;2019:4037379. doi: 10.1155/2019/4037379.
20. Sekyi-Annan E, Gaisie E, Issaka RN, Quansah GW, Adams S, Bessah E. Estimating soil loss for sustainable crop production in the semi-deciduous forest zone of Ghana. Front Sustain Food Syst. 2021;5:674816. doi: 10.3389/fsufs.2021.674816.
21. Tamene L, Vlek PL. Soil erosion studies in northern Ethiopia. In: Braimoh AK, Vlek PL, eds. Land Use and Soil Resources. Dordrecht: Springer; 2008. p. 73-100. doi: 10.1007/978-1-4020-6778-5_5.
22. Hernando D, Romana MG. Estimating the rainfall erosivity factor from monthly precipitation data in the Madrid region (Spain). J Hydrol Hydromech. 2015;63(1):55-62. doi: 10.1515/johh-2015-0003.
23. Panagos P, Meusburger K, Ballabio C, Borrelli P, Alewell C. Soil erodibility in Europe: a high-resolution dataset based on LUCAS. Sci Total Environ. 2014;479-480:189-200. doi: 10.1016/j.scitotenv.2014.02.010.
24. Wang J, He Q, Zhou P, Gong Q. Test of the RUSLE and key influencing factors using GIS and probability methods: a case study in Nanling National Nature Reserve, South China. Adv Civ Eng. 2019;2019:7129639. doi: 10.1155/2019/7129639.
25. Cassol EA, da Silva TS, Eltz FL, Levien R. Soil erodibility under natural rainfall conditions as the K factor of the universal soil loss equation and application of the nomograph for a subtropical Ultisol. Rev Bras Ciênc Solo. 2018;42:e0170262. doi: 10.1590/18069657rbcs20170262.
26. Das S, Bora PK, Das R. Estimation of slope length gradient (LS) factor for the sub-watershed areas of Juri River in Tripura. Model Earth Syst Environ. 2022;8(1):1171-7. doi: 10.1007/s40808-021-01153-0.
27. Schmidt S, Tresch S, Meusburger K. Modification of the RUSLE slope length and steepness factor (LS-factor) based on rainfall experiments at steep alpine grasslands. MethodsX. 2019;6:219-29. doi: 10.1016/j.mex.2019.01.004.
28. Zhang HM, Yang QK, Li SQ, Wang ML, Ying M, Lang H, et al. Design and implementation of regional LS factor computing tool based on GIS and array operation. Appl Mech Mater. 2013;394:509-14. doi: 10.4028/www.scientific.net/AMM.394.509.
29. Zhang H, Wei W, Chen L, Wang L. Effects of terracing on soil water and canopy transpiration of Chinese pine plantation in the Loess Plateau, China. Hydrol Earth Syst Sci Discuss. 2016;2016:1-30. doi: 10.5194/hess-2016-223.
30. Kebede B, Tsunekawa A, Haregeweyn N, Adgo E, Ebabu K, Meshesha DT, et al. Determining C- and P-factors of RUSLE for different land uses and management practices across agro-ecologies: case studies from the Upper Blue Nile basin, Ethiopia. Phys Geogr. 2021;42(2):160-82. doi: 10.1080/02723646.2020.1762831.
31. Vatandaşlar C, Yavuz M. Modeling cover management factor of RUSLE using very high-resolution satellite imagery in a semiarid watershed. Environ Earth Sci. 2017;76(2):65. doi: 10.1007/s12665-017-6388-0.
32. Adimassu Z, Mekonnen K, Yirga C, Kessler A. Effect of soil bunds on runoff, soil and nutrient losses, and crop yield in the central highlands of Ethiopia. Land Degrad Dev. 2014;25(6):554-64. doi: 10.1002/ldr.2182.
33. Belayneh M, Yirgu T, Tsegaye D. Effects of soil and water conservation practices on soil physicochemical properties in Gumara watershed, Upper Blue Nile basin, Ethiopia. Ecol Process. 2019;8(1):36. doi: 10.1186/s13717-019-0188-2.
34. Mekuriaw A, Heinimann A, Zeleke G, Hurni H. Factors influencing the adoption of physical soil and water conservation practices in the Ethiopian highlands. Int Soil Water Conserv Res. 2018;6(1):23-30. doi: 10.1016/j.iswcr.2017.12.006.
35. Bekele M. Geographic information system (GIS) based soil loss estimation using RUSLE model for soil and water conservation planning in Anka-shashara watershed, southern Ethiopia. Int J Hydrol. 2021;5(1):9-21. doi: 10.15406/ijh.2021.05.00260.
36. Mustefa M, Fufa F, Takala W. GIS estimation of annual average soil loss rate from Hangar River watershed using RUSLE. J Water Clim Chang. 2020;11(2):529-39. doi: 10.2166/wcc.2019.181.
37. Tesfaye G, Tibebe D. Soil erosion modeling using GIS-based RUSEL model in Gilgel Gibe-1 catchment, South West Ethiopia. Int J Environ Sci Nat Resour. 2018;15(5):555923. doi: 10.19080/ijesnr.2018.15.555923.
38. Yesuph AY, Dagnew AB. Soil erosion mapping and severity analysis based on RUSLE model and local perception in the Beshillo catchment of the Blue Nile basin, Ethiopia. Environ Syst Res. 2019;8(1):17. doi: 10.1186/s40068-019-0145-1.