Vol. 11(8), pp. 143-158, October-December 2019
DOI: 10.5897/IJWREE2018.0820
Article Number: 584CEAF62204
ISSN: 2141-6613

http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Geographic Information System (GIS) based soil loss estimation using Universal Soil Loss Equation Model (USLE) for soil conservation planning in Karesa Watershed, Dawuro Zone, South West Ethiopia

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Received 29 October, 2018; Accepted 15 February, 2019

Soil erosion is the most challenging and continuous environmental problems resulting in both on-site and off-site effects in the world particularly in Ethiopia. Karesa watershed is one of the most erosion-prone watersheds which received little soil conservation attention. This study was conducted to estimate average annual soil loss rate using Geographic Information System and Universal Soil Loss Equation Model adapted to Ethiopian condition. The following datasets were obtained from different sources for estimating annual soil loss such as 15 years mean annual rainfall data for estimating erosivity factor, digital soil map for estimating soil erodibility factor, 30 m × 30 m resolution Digital Elevation Model for estimating slope length and slope steepness (LS) factor, Landsat6ETM+ images with 30 m × 30 m resolution for detecting vegetation cover and conservation practice factor. The result reveals that 42,413.72 ton per year soil loss from 9939 ha entire watershed or 4.27 tons per hectare per year average annual soil loss rate was observed. The mean annual soil loss rate was classified into four erosion severity classes as very less, less, moderate and high. The result also implies that 94.4% (9383.07 ha) of the watershed areas contributes 81.13% of the total soil loss which were observed from two slope classes (0-15% and 15-30%) and categorized under very less to less soil loss (0-6.25 tons $ha^{-1}yr^{-1}$). On the other hand, moderate to high soil loss (6.25-25 tons $ha^{-1}yr^{-1}$) was obtained on slope classes of >30% which covers 555.93 ha (5.6%) of the watershed areas and contributes 18.82% of the total soil loss indicating the maximum share of slope mainly due to cultivation of marginal land,intensive cultivation, poor vegetation cover during critical rainfall period. Moreover, about 2,184.93 ha of the watershed area requires integrated soil and water conservation measures.

Key words: Conservation priority, soil erosion, Universal Soil Loss Equation Model (USLE), geographic information system (GIS), Karesa watershed

INTRODUCTION

Soil erosion is the process of wearing a way of top productive soil which mostly occurred since the end of World War II, causing a 17% reduction in crop productivity (Angima et al., 2003). Its extent and distribution is widespread in Africa and Asia, due to high population pressure, land shortage and critical lack of resources for conservation by subsistence small holder farmers (Blanco and lal, 2008). Its effects are also recognized to be severe threats to the national economy of Ethiopia due to cultivation on steep slopes, clearing of vegetation and over grazing (Tamene, 2005).

The impact of soil erosion has results both in on-site nutrient loss and off-site sedimentation of water resources in arid and semi-arid areas like Ethiopia. Farmers are highly dependent on intrinsic land properties and unable to improve soil fertility through application of purchased inputs (Emrah et al., 2007). Studies made in different parts of Ethiopia reported that annual soil loss show spatial and temporal variations. Based on the modeling, Soil Conservation Research Project (SCRP) estimated that about 1.5 billion tons of soil is eroded every year from the Ethiopian highlands (Hurni, 1984; Kruger, 1995). In the past, FAO (1984) and Hurni (1993) reported annual soil loss from Ethiopian highlands to be 200-300 tons $ha^{-1}yr^{-1}$. Similarly, Hurni et al. (2008) estimated that soil loss due to erosion of cultivated fields in Ethiopia amounts to about 42 tons $ha^{-1}yr^{-1}$. The average crop yield from a piece of land in Ethiopia is very low mainly due to soil fertility decline associated with removal of topsoil by erosion (Sertu, 2000). As a result of soil erosion, Ethiopia losses USD 1 billion yr^{-1} (Sonneveld, 2002) and is still affecting 50% of the agricultural area and 88% of the total population of the country (Sonneveld et al., 1999). Erosion could also generate deposition of soil materials in the reservoirs, irrigation schemes and waterways downstream (Cerda and Doerr, 2008). Gibe-3, downstream of Gibe-1 and 2 are currently constructed by Ethiopian Government which will generate the power capacity of 1,860 MW after completion of its life span (EEPCo, 2009); however, the storage volume of this reservoir is threatened by the soil erosion from the upstream of Karesa watershed.

To reverse soil degradation problems, there should be effective policy interventions and integrated soil and water conservation treatments. The intervention requires understanding of the rates of onsite erosion processes and its controlling factors that enhance or retard these processes. However, direct measurements of soil erosion are costly, labor intensive, and time consuming, spatial soil erosion model plays a vital role in the design of these interventions (Mirco et al., 2003). Erosion prediction involves the use of process based, empirical and conceptual models. However, their large data requirements as well as the applications of process based models are not practical in Ethiopia and other developing countries (Sonneveld et al., 1999).

To minimize the erosion problem, Ethiopian government initiated soil conservation effort since the mid 1970‟s and 80‟s (Wogayehu and Darke, 2003). The large scale implementation of soil and water conservation started since 1975 land reform and the establishment of peasant association. The reform provides lands for farmers to implement soil conservation and played instrumental role for labor mobilization (Woldeamlak, 2007). In the late 1960s and 1970s, survey on soil erosion and its outcomes was reported (Ware-Austin, 1970) which led to the initiation of SWC Programs. These initiatives include Food-for-Work (FFW) (1973–2002). The initiatives was started in the form of food aid and gradually shifted in the 1980s to a development oriented program through engaging the community in rehabilitation of degraded lands (Devereux et al., 2009). Biological and physical soil and water conservation practices started in different parts of Ethiopia. Among physical measures, the traditional terraces in Konso (more than 400 years) (Beshah, 2003) and the development of terraces under traditional agriculture in the Tigray Highlands and in the Chercher Highlands (Virgo and Munro, 1977) are one of the interventions. Despite the many initiatives or approaches designed and implemented, the problem of land degradation by soil erosion is still a major issue that needs large scale implementation of watershed based soil and water conservation technologies.

Soil erosion is measured using different techniques. From empirical erosion prediction models, Universal Soil Loss Equation was used for this study because of its preferences to complex physical based models that can be implemented in situations with limited data and parameters (Merritt et al., 2003).

Though various studies have been conducted on soil erosion at Omo Gibe *III* Basin (Gerawork, 2014), none of them have assessed soil erosion rate from specific watershed at woreda level for conservation planning. Therefore, the objectives of this study were to estimate values of soil erosion factors, to estimate the average annual soil loss rate and to classify and prioritize critical erosion prone areas for conservation planning using Universal Soil Loss Equation Model (USLE) by integrating GIS and remote sensing technology.

MATERIALS AND METHODS

Study area description

Karesa watershed is located in Loma Woreda of Dawro Zone of Southern Nation Nationalities and People's Region (SNNPR). It is located 282 km Southwest, Hawassa and 470 km Southwest, Addis Ababa. It is geographically located between 6°51'30'' N - 7° 01' 00' N latitude and 37° 15' 0'' E - 37° 19' 0'' E longitude. The watershed' covers 9939 ha as shown in Figure 1.

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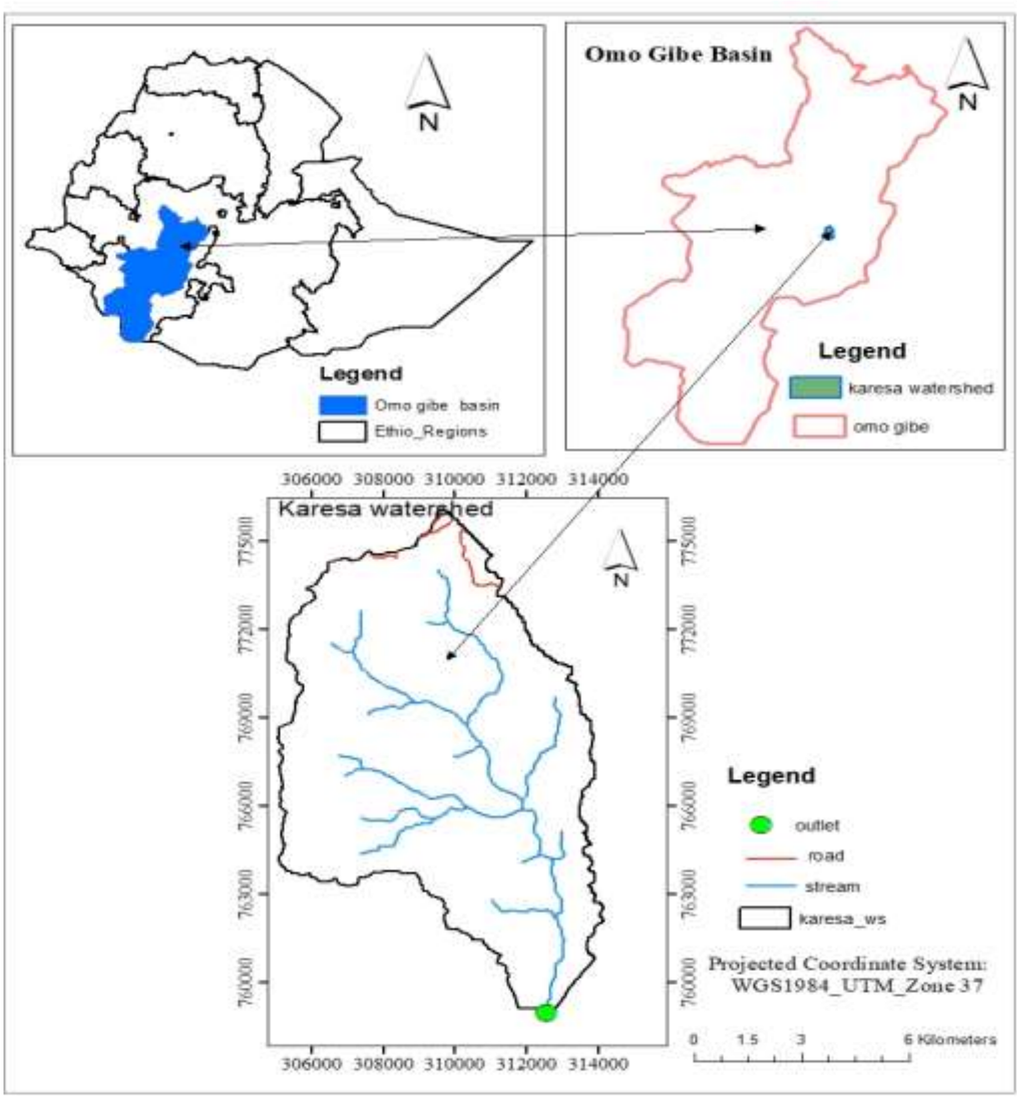

Figure 1. Location map of the study area.

The major physiographic units of the catchment are characterized by undulating, rugged, hilly topography with altitude ranging from 678 m.a.s.l (meter above sea level) around the Gibe III dam site (Southern edge) to 2489 m.a.s.l in the Northern ridge

There are no meteorological stations within the watershed but in the nearby there are three meteorological stations outside the watershed. Based on the data obtained from three meteorological stations (Gessa Chere, Tercha and Halale), the annual rainfall of the study area ranges from 1636.49 to 1783.92 mm. The 15 years (2002-2016) average annual precipitation of the area is 1728.79 mm. The rainfall is unimodal type with one long rainy season. March, April, May, June, July, August, September and October receive >100 mm average annual rainfall and among three stations, Gessa Chere station receives peak rainfall in August. The mean annual temperature varies from 14.2 to 26.6°C (Figures 2 and 3).

According to FAO soil classification (2012), Karesa watershed is covered by three major soil types which are Leptosols, Cambisols, and Alisols covering 8096.40, 1118.94 and 723.66 ha, respectively. Leptosols are the dominant soil types in the watershed. The major crops grown in both upper and lower watershed are maize, sorghum, and barely, teff, field pea and faba bean.

The major land use/land cover units of the watershed area include cultivated land, shrub land, forest, grass land and water bodies. Cultivated land is situated on the steep and undulating slope and in most parts of this land use, there is no conservation measures implemented. The farming system of the watershed is mixed farming with dominantly cereal crop production. The major crops grown in both upper and lower watershed are maize, sorghum, and barely, teff, field pea, and faba bean. Besides this, vegetation cover of the study watershed is dominated by forest, bush and shrub, in the western and southern parts while some *Juniperus procera, Gravilia robusta,* and *Eucalyptus* plantations are in the upper watershed. Much of the natural vegetation, especially, mountainous area of *Atso* forest has been destroyed due to uncontrolled felling and excessive cultivation (Field observation by the author and key informant interviews, 2017*).* Steepness of the land, intensive cultivation, and absence of conservation structures as well as deforestation are factors for soil erosion in the study area. As a result of these factors, there are visible erosion features like sheet and rill (very shallow channels formed by the

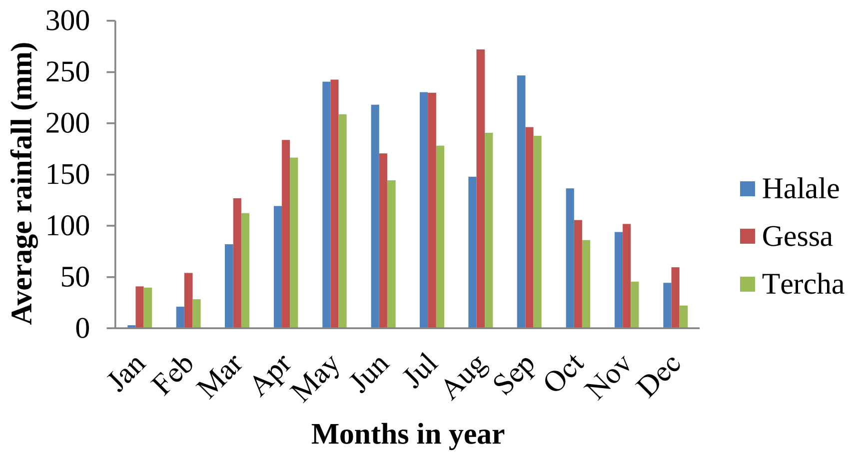

Figure 2. 15Years Mean Monthly Rainfall of the stations (2002-2016).

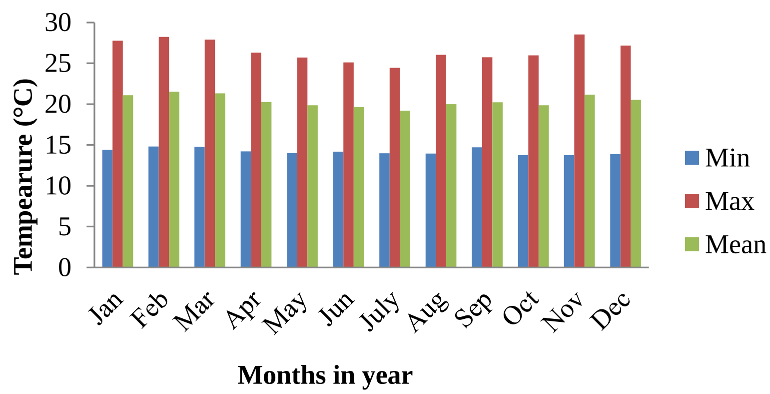

Figure 3. 15 Years Mean Monthly temperature of the stations (2002-2016).

concentration of surface run-off) at upper catchment parts of the watershed, both erosion and deposition at the middle part of the watershed and deposition at lower catchment (Field observation by the author, 2017). According to Loma Woreda Farm and Natural Resource Development Office (LWFNRDO) (2013), the total population of Karesa watershed is estimated at 24,954 (10,800 in the upper, and 14,154 in the lower watershed.

Data sources and materials

Primary and secondary data was used as data sources. Primary data was collected by topographic transect walk and field observation. During transect walk, vegetation types, major LULC and land management practices including improved and local soil and water conservation measures implemented under different slope classes on agricultural land use in the study watershed were collected. Secondary data such as Landsat6 ETM+ image with spatial resolution of 30 × 30 m resolution acquired at March 5, 2016 from Ethiopian Mapping Agency for land use land cover classification, 30 m × 30 m resolution of FAO digital soil map, 30 m × 30 m resolution DEM, time series climatic data, particularly rainfall and temperature (2002-2016 GC) from National Meteorology Agency, Hawassa Sub-meteorological Service Center and Soil Conservation and Farm Management Information from Woreda Agriculture and Natural Resource Development Office was collected. Meanwhile, materials like ERDAS Imagine 9.2 for satellite image processing and Arc GIS 10.1 were used for DEM processing, watershed delineation, and soil loss analysis, GPS to collect ground truth information of land use/land cover and clinometers.

Methods of determining USLE factors

The techniques for prediction of soil loss have been evolved over the years. The most widely used equation soil loss prediction of the entire catchment is Universal Soil Loss Equation (USLE) which uses five parameters and each parameter values were computed using the following chart as indicated in the Figure 4.

Determination of rainfall erosivity (R_ factor)

The erosivity factor for the erosive power of rainfall is related to the amount and intensity of rainfall over the year. Typically, rainfall erosivity (R) is computed as total storm energy multiplied by the maximum 30 min intensity, Renard et al. (1997). However, the data on rainfall kinetic energy and rainfall intensity is limited in Ethiopia to compute rainfall erosivity. Rainfall data of three stations Gessa Chere, Tercha and Halale were used for this study. Mean annual

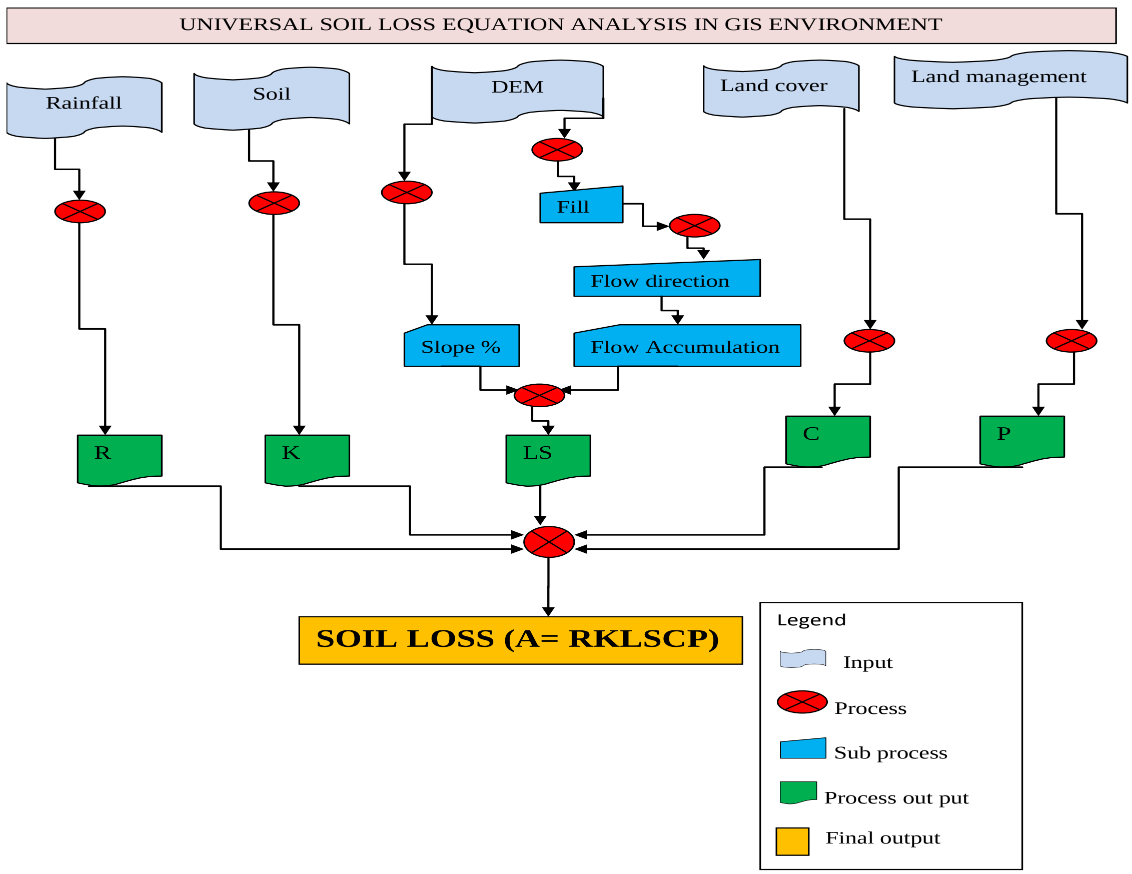

Figure 4. Flow chart of USLE model to estimate soil loss rate in Arc GIS environment.

rainfall data of 15 years (2002 to 2016 GC) were used for this study. Some missing meteorological station data were filled using nearest neighborhood interpolation technique. R_factor was calculated for each station using mean annual rainfall data from regression equation developed by Kaltenrieder (2007) to Ethiopian conditions as shown in Equation 1 using inverse distance weighted (IDW) interpolation, with 12 neighborhoods in spatial analyst tool.

$$R = 0.36 \times p + 47.6 \quad (1)$$

Where R is the rainfall erosivity factor in MJmm ha^{-1} yr^{-1} and P is the mean annual rainfall (mm).

Determination of soil erodibility (K_ factor)

It is an expression of inherent resistance to particle detachment and transport by rainfall and determined by the cohesive force between the soil particles, which may vary depending on the presence or absence of plant cover, the soil's water content and the development of its structure (Wischmeier and Smith, 1978); and depends on the amount of organic matter in the soil, the texture of the soil, the structure of the surface horizon and permeability (Robert and Hilborn, 2000). But, for this study, FAO digital soil map was collected from Ministry of Agriculture (MoA) to derive soil map of the study watershed. Hence, the soil erodibility (K) factor for the watershed was estimated based on soil colors referred from FAO (2012) soil database adapted to Ethiopia by Hurni (1985) and Hellden (1987) as shown in the Table 1. Once the dominant soil type's map of the study area is clipped in the ArcGIS environment, each soil characteristic particularly their color was obtained from FAO digital soil map.

Determination of conservation practice (P-value) factor

It is the specific soil and water conservation practices implemented to reduce run-off speed and increase infiltration, ultimately lowering soil loss and sediment delivery (Renard and Foster, 1983). Topographic transect walk in two directions to obtain valuable watershed information from east to west and South to north was employed to assess major LULC and types of the existing soil and water conservation measures in agricultural land. According to woreda information, Karesa Watershed area was treated with different physical soil and water conservation measures by Meret project, Sustainable Land Management (SLM), safety net and agricultural extension program. There is no improved permanent conservation measures practiced under different slope classes. Drainage ditch are the traditional conservation measures practiced to drain excess run-off during rainstorm in the farm land. The agricultural lands were classified into six slope categories. The raster land use and slope map (%) were combined using spatial analyst tool 'local' extension to get combined land use-slope map of the study area and the attribute table opened. Because of no permanent soil and water conservation measures implemented to control runoff, the corresponding P-value for the study watershed were collected from similar techniques used in Wischmeier and Smith (1978) indicated in Table 2 was assigned for each land use.

Table 1. Soil erodibility value estimated based on soil color.

Soil color	Black	Brown	Red	Yellow
K-factor	0.15	0.2	0.25	0.3

Hurni (1985).

Table 2. Estimated Support Practice(P-Factor) values.

Land use type	Slope(percent)	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 use type	Water body	-
	All	1.00

Source: Wischmeier and Smith(1978); Gerawork (2014).

Table 3. Estimated C_factor values for Land use/Land cover classes.

Land use/cover type	C-factor	Sources
Forest	0.01	Hurni (1985)
Cultivated land(cereals/pulses)	0.15	Morgan (2005)
Grass land	0.05	Morgan (2005)
Shrubs	0.014	Gelagay and Minale (2016)

Finally, the assigned P_ factor value were looked up in spatial Analyst tool extension Re-class, converted into grid format with a cell size of 30 × 30 m and finally, reclassified using 'reclass' method in arc GIS 10.1 Environment.

Determination of topographic (LS_factor)

In USLE, the LS factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 22 m plot (Robert and Hilborn, 2000). Slope steepness factors of the study watershed in degree are generated from digital elevation model of 30 m × 30 m spatial resolution using 'Slope' from Spatial Analyst Tool in arc GIS 10.1 environment. Topographic (LS factor) were computed using the equation developed by Wischmeier and Smith (1978) as shown in Equation 2. The values of exponents for m ranges from 0.2 - 0.6 and n= 1.0 - 1.3, where the lower values are used for prevailing sheet flow and higher values are used for prevailing rill flow. In the current study, due to the concentrated rill flow in the watershed we have used upslope contributing area factor (m= 0.4) and slope steepness factor (n=1.3).

$$LS = (\text{Flow accumulation} \times \text{Cell size} / (22.13))^{0.4} \times (\text{Local sin slope (degree)}/0.0896)^{1.3} \quad (2)$$

Where: Cell size represents the resolution of the grid (30 m), 22.13 is the length of the research field plot, and flow accumulation is the number cells contributing flow in to a given cell.

Determination of crop and management cover (C_factor)

The cover management factor (C-values) reflects the effect of cropping and management practices on the soil erosion rate (Renard et al., 1997). Landsat6 ETM+ image with spatial resolution 30 m × 30 m resolution acquired on March 5, 2016 was used to derive Land use/land cover map of the study watershed. Based on the information collected from field, five land use land covers were identified from the study watershed, these are forest, cultivation, grass land, water body and shrub land. C_factor for the study area was estimated from the similar literature conducted. However, during C_factor estimation for cultivated lands, the average C_factor values of the dominant crop types were used as shown in Table 3.

Data analysis

For image pre-processing and classification under remote sensing data, all data collected from different sources may have different projections, spatial resolutions and data quality which produce

Table 4. Stations mean annual rainfall and erosivity factor result.

Stations	Location			Available data	Average annual precipitation (mm)	No of years	Erosivityv(R)
	Longitude	Latitude	Altitude (m)	Duration			
Gessa chere	37.283	7.024	2251	2002-2016	1784.06	15	689.86
Tercha	37.068	7.148	1335	2002-2016	1410.91	15	555.53
Halale	37.337	6.750	1854	2009-2015	1584.35	7	617.97

errors on the final soil loss. All the data was geo-referenced into Universal Transverse Mercator (UTM) and datum WGS-1984 Zone 37. Using signature editor of unsupervised classes, supervised image classification technique was employed to classify the current land use land cover map using Erdas Imagine 9.2 software. 108 ground truth points on the major types of LULC from field using Global Positioning System (GPS) for the year 2017 GC was collected and the Pixels of LULC classes having similar spectral classes was defined. Maximum likelihood image classification was utilized for the supervised image classification.

Soil loss analysis

Both quantitative and qualitative data analysis techniques were used. GIS layers were formed in raster format for both Environmental (RKLS) and management factors (C and P) as input for the USLE model. Each factor were converted in to grid with a cell size of 30 x 30 m and multiplied by their respective values in arc GIS 10.1 using raster calculator from command of spatial analyst. The output map was converted to hectare basis to obtain the annual soil loss per hectare per year. In order to minimize errors on soil loss, all the USLE factor layers were projected to WGS 1984 UTM Zone 37N. The following formula was used to generate the factor grids and produce the soil loss potential of the study watershed in the arc GIS environment.

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

Where: A = Annual soil loss in ton/ha/yr, R = Rainfall erosivity factor in MJ $mm.ha^{-1}.yr^{-1}$ K= Soil erodibility factor in t.h. MJ^{-1}. mm^{-1}, LS = Slope Steepness and Slope length factor (dimensionless), C = Cover factor (dimensionless), p=conservation practice factor(dimensionless).

RESULTS AND DISCUSSION

Estimation of soil erosion factor values

Factors contributing soil erosion was computed from different sources and approaches (Table 4).

Rainfall erosivity (R_ Factor)

The distribution of average annual rainfall of the study area for 15 years period is different from place to place in the watershed. The result depicted that about 75.65% of the study watershed areas have R_values greater than 666.71 MJmm ha^{-1} yr^{-1} with the maximum R_value of 689.8 MJmm ha^{-1} yr^{-1}. The remaining 24.34% of R_values fall within the range from 654.22 to 666.71 MJmm ha^{-1} yr^{-1} as shown in the Figure 5. The average R-factor value in the watershed was 669.96 MJmm ha^{-1} yr^{-1}, which are within the ranges of Amsalu and Mengaw (2014) estimated erosivity factor value for Jabi Tehinan Woreda, ANRS, and Ethiopia from 441.5 to 1166.4 MJmm ha^{-1} yr^{-1}.

Soil erodibility (K_Factor)

Three major soil types were identified from the study watershed including Alisols, Cambisols, and Leptosols. The erodibility values and their proportion from the total area are Alisols- 0.28(7.28%), Cambisols- 0.2(11.26%), and Leptosols- 0.2(81.46%). The soils of the study area contain two distinctive erodibility values which range from 0.20 to 0.28. Higher value indicates more susceptibility while lower value indicates less susceptibility to erosion. The soil in the study area is dominated by *Leptosols* having > 80% coarse fragment. According to Mati et al. (2000), soils high in sand content were poorly aggregated and structurally weak which contribute to easy soil disintegration. Therefore, they were easily detached and transported by runoff (Figure 6).

Topographic (LS_Factor)

Interaction of angle and length of slope has an effect on the magnitude of erosion. As a result of this interaction, the effect of slope length and degree of slope should always be considered together (Edwards, 1987). The result depicted that, the LS factors of the study area ranges from 0 in flat areas to 154.6 steeper and longer slope area of the watershed. The increments of LS factors from 0 to 154.6 shows that the potential erosion increases as the slope steepness increases. 51.15% of the study area have slope gradient <30% (Flat to moderately steep), 48.85% of the study area have slope gradient >30% (steep slope). This clearly shows that the landform of the study area contributes to high soil loss rate. The steeper and longer slopes are combined in

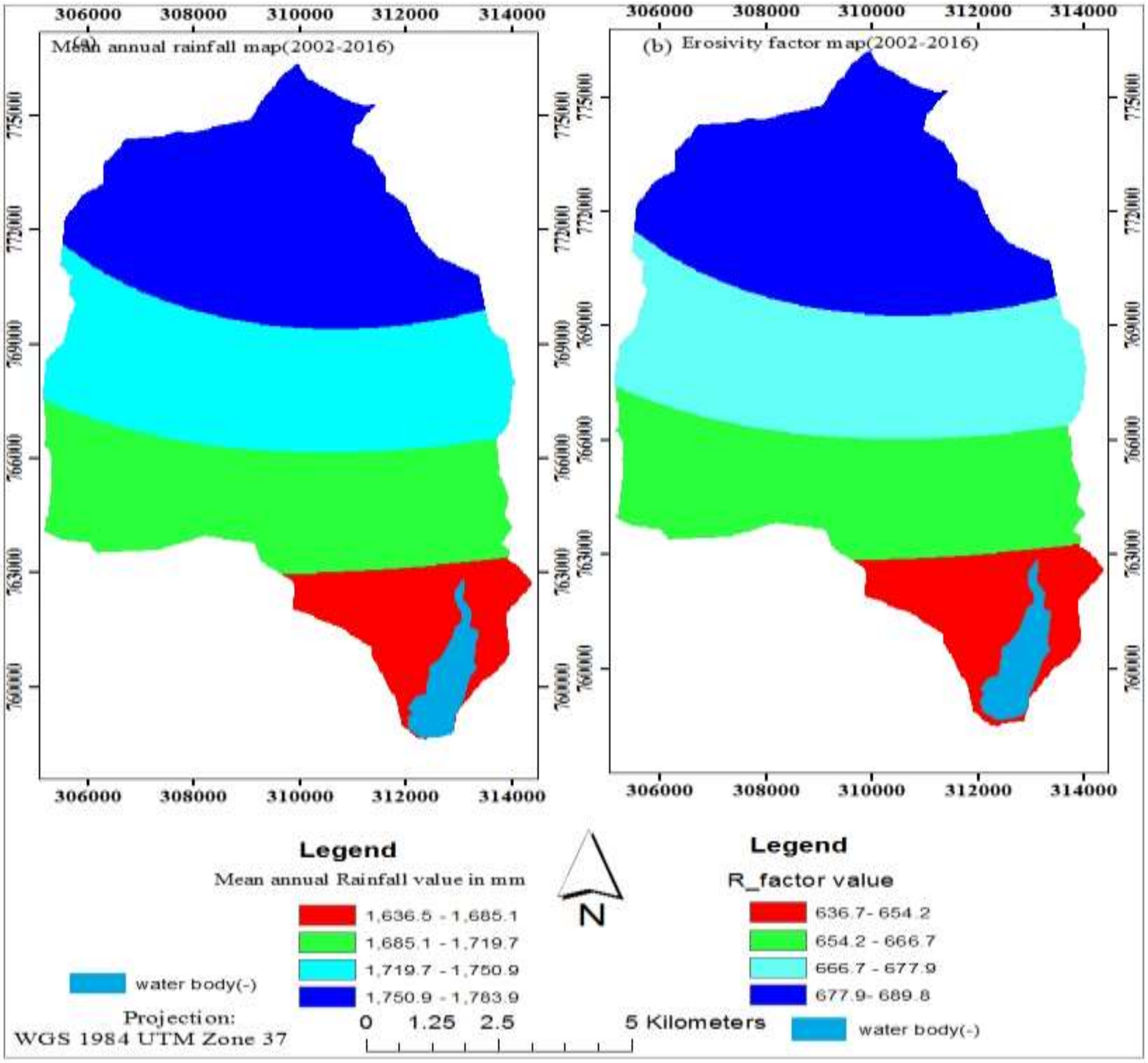

Figure 5. (a) Mean Annual rainfall Map and (b) Erosivity(R-factor) Map of the study area.

48.85% of the area resulting to higher runoff velocities and, therefore, greater potential for erosion. Longer, steeper slopes especially those without adequate vegetative cover are more susceptible to very high rates of erosion during heavy rains than shorter, less steep slopes (Blanco-Canqui and Lal, 2008). The data shows that factors taking into account the topography (LS factor) are affecting in a stronger way the erosion process (Adediji et al., 2010) (Figure 7).

Cover and management (C _Factor)

Based on the analysis, the study watershed LULC was classified into five classes namely cultivated land, forest, bush and shrubs, grass land and water body. Cultivated land is the dominant land use type in the study area which covers 41.21% of the total study area, while other land use covers 58.79% as shown in the Table 5.

The C-factor result for the study watershed ranges from 0.01 for the area covered by natural vegetation to 0.15 cultivated land, which is similar with the finding of Gizachew and Yihenew (2015) who reported that crop management C_factor values of the Guang watershed ranged from 0.01 to 0.15. Based on the study area LULC result, there is variation on C-factor value. Thus, cultivated land has maximum C-value. This condition results to higher soil erosion rate. The study shows that finely tilled, ridged surfaces produce much run-off, leaving it susceptible to rill erosion (Vander et al., 2000) (Figure 8).

Conservation practice (P- Factor)

From 41.21% of cultivated land most of the area was

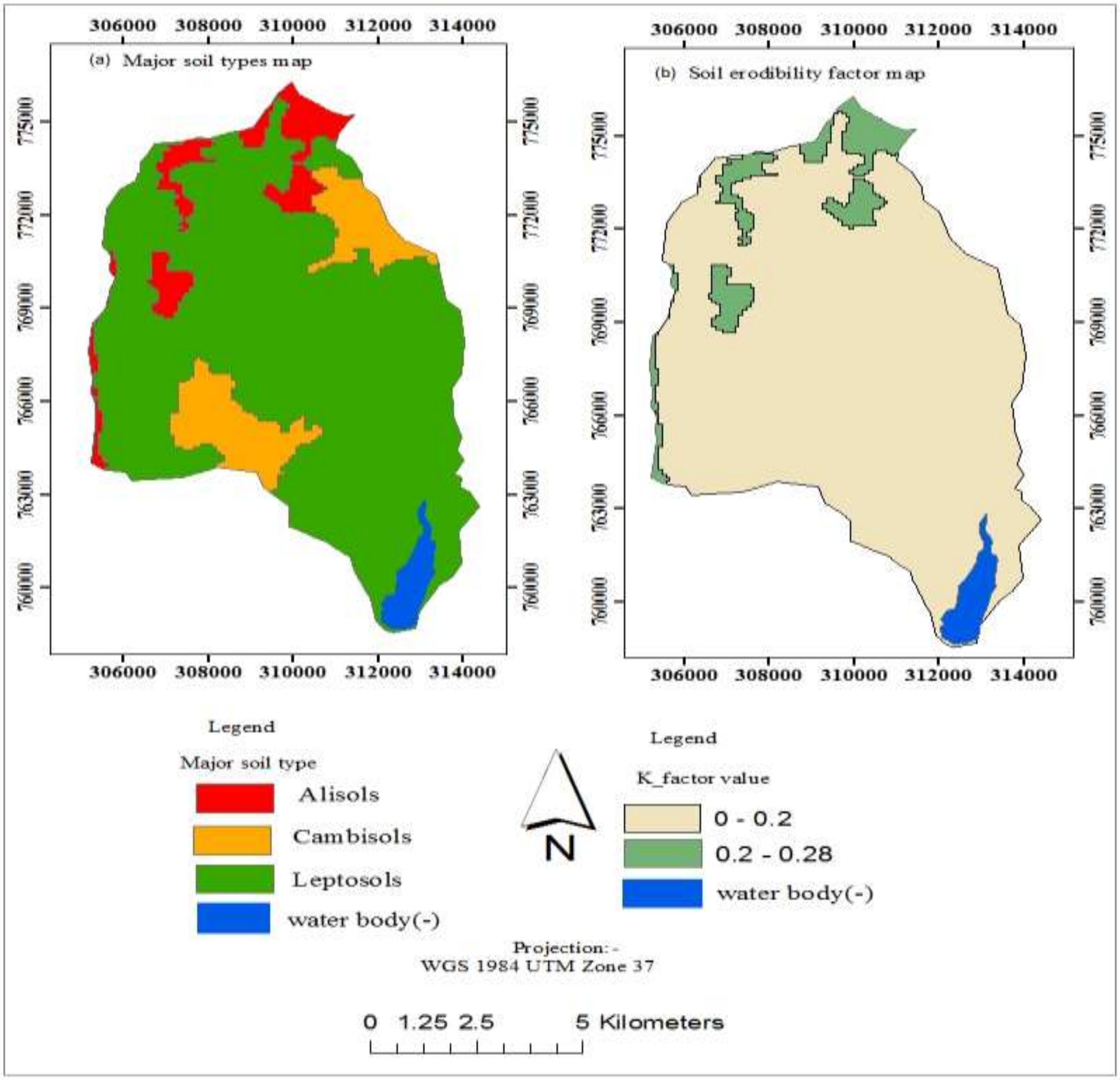

Figure 6. (a) Major soil types (b) Soil Erodibility (K_factor) map of the study area.

covered by cereal cultivation whereas 58.79% was covered by other land use which has P value of 1. Even though, a small part of watershed area was treated by terracing, periodic maintenance of structure by land users was ignored. Such condition coupled with poor vegetation cover in watershed area has large influence on soil loss rate. Renard et al. (1997) defined conservation practice factor as an expression of supporting conservation practices such as contour farming, strip cropping, terracing, and subsurface drainage on soil loss at a particular site, which principally affect water erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the volume and rate of runoff (Figure 9).

Soil loss rate estimation

The annual soil loss rate of the study watershed was determined by a cell-by–cell analysis of each USLE factors. The mean annual soil loss rate map of the study watershed ranges from 0 tones ha^{-1} yr^{-1} in the flat areas to a little over 25 tones ha^{-1} yr^{-1} in steep slope of the watershed.The soil loss rate map of the study watershed has been divided into four classes of erosion severity and its largest categories were that of 0-3.125 tons $ha^{-1}yr^{-1}$ as shown in the Table 6.

The total and mean annual soil loss rate estimated by the USLE model for the study watershed was 42,413.72 and 4.27 tones ha^{-1} yr^{-1} from 9939 ha respectively. The

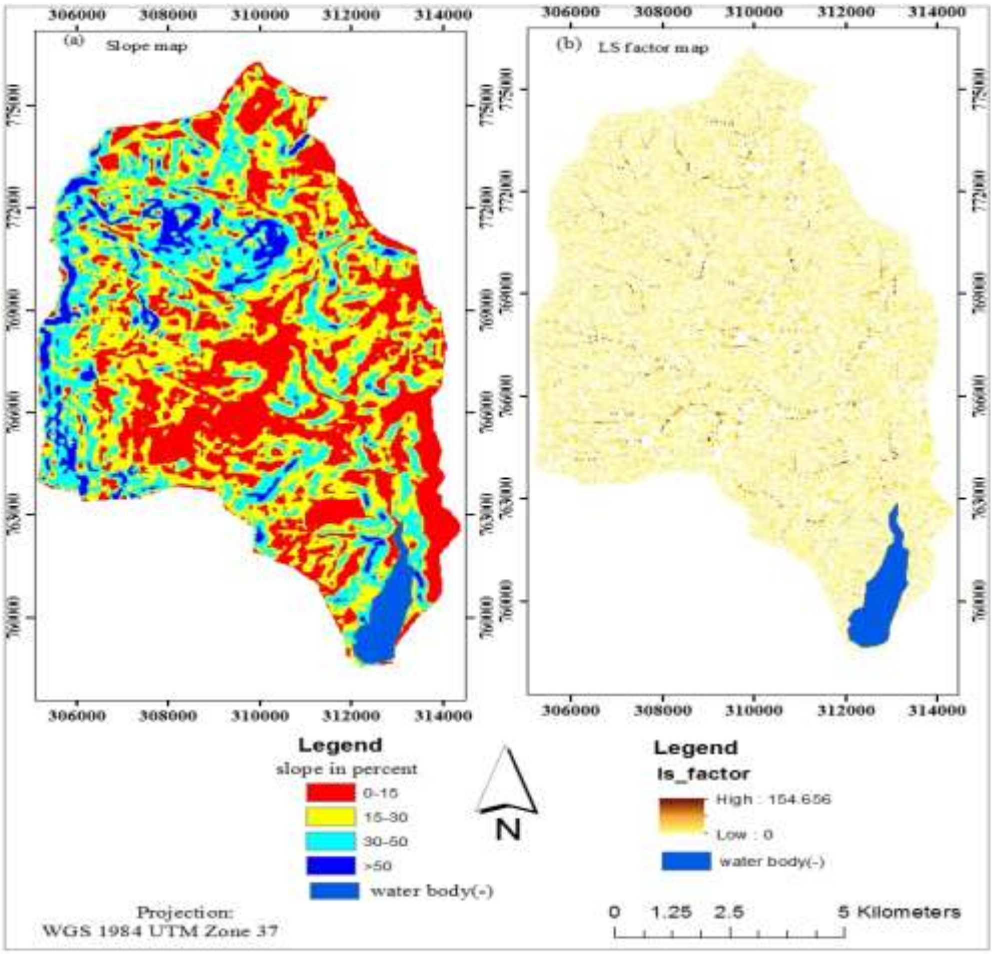

Figure 7. Topographic Factor(LS_factor) map of the study area.

Table 5. Land use types of karesa watershed.

Land cover	Area coverage	
	Hectare	Percent
Cultivated land	4095.86	41.21
Grass land	1986.33	19.99
Forest	1627.28	16.37
Shrub land	1987.14	19.99
Water bodies	242.39	2.44

Source: Landsat image ETM+ (2016)

amount of estimated annual average soil loss rate for the study watershed is low as compared to the past studies. For example, Tadesse and Abebe (2014) reported 30.4 tones ha^{-1} yr^{-1} soil loss for Jabi Tehinan woreda in the north western high land, while Gerawork (2014) estimated the soil loss from Loma woreda as 10.28 tones ha^{-1} yr^{-1}. Similarly, Gebreyesus and Kirubel (2009) estimated soil loss due to erosion of Medego watershed as 9.63 tons ha^{-1} y^{-1}; Hurni et al. (2008) estimated that soil loss due to erosion of cultivated fields in Ethiopia amounts to about 42 tones ha^{-1} yr^{-1}; and in the past, FAO (1986) reported the annual average soil loss rate for Central and Northern high land as 35 tones ha^{-1} yr^{-1}. Therefore, the relatively low estimated average annual soil loss in the current study watershed could be due to the topography, which is largely flat to moderately steep (< 30%), which accounts for 51.15% of the watershed area. The other reason could be due to the contribution

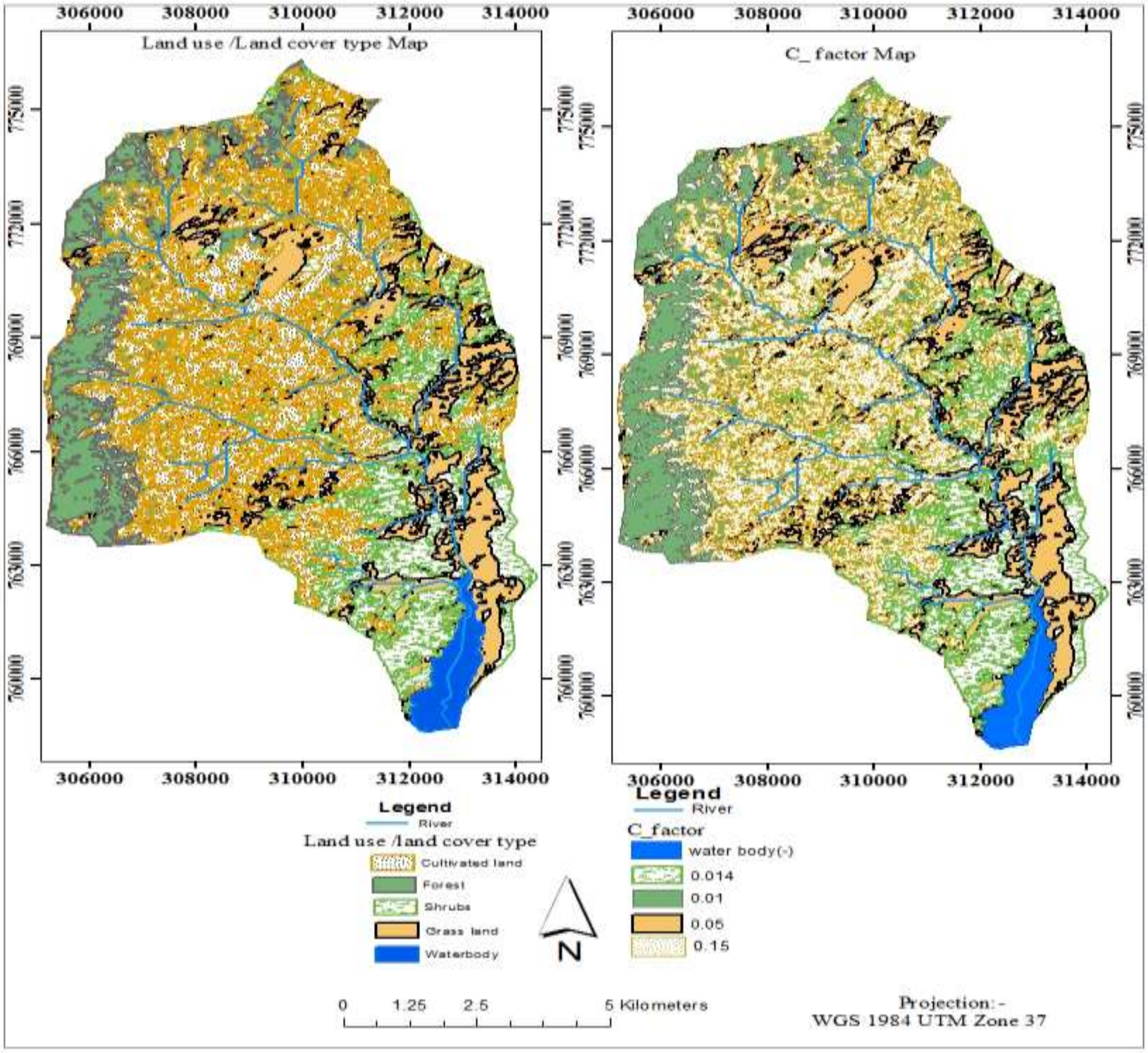

Figure 8. (a) Land use /Land cover type map (b) Cover (C_factor) Map of the study area.

of different soil conservation interventions implemented by different project and agricultural extension program for at least the last decades in the country in general and the study watershed in particular in decreasing the rate of soil loss (Figure 10).

Classification and prioritization of critical erosion prone area for conservation planning

One of the objectives of this study was to classify and prioritize critical erosion prone areas for conservation planning. Therefore, regarding delineation of micro watersheds as erosion prone areas according to the severity level of soil loss, priority is given for a targeted and cost-effective conservation planning (Kaltenrieder, 2007). According to WBISPP (2001), the mean annual soil loss potential of the study watershed (4.27 tones ha^{-1} yr^{-1}) was classified into four soil erosion severity classes (0-3.125 tones ha^{-1} yr^{-1} as very less, 3.125-6.25 tones ha^{-1} yr^{-1} less, 6.25-12.5 tones ha^{-1} yr^{-1} moderate and 12.5-25 tones ha^{-1} yr^{-1} high). The threshold for each of the risk level is presented in Table 6 and Figure 11. The final risk classes were prioritized for intervention on the bases of the maximum allowable soil loss that will sustain an economic and a high level of productivity (Wischmeier and Smith, 1978). Based on result, the mean annual soil loss rate for the entire watershed (4.27 tons ha^{-1} yr $^{-1}$) is within the tolerable soil loss of 5-11 tons ha^{-1} yr $^{-1}$ estimated for Ethiopia by Hurni (1985).

555.93 ha (5.6%) of the watershed area experiencing moderate to high erosion severity classes which was

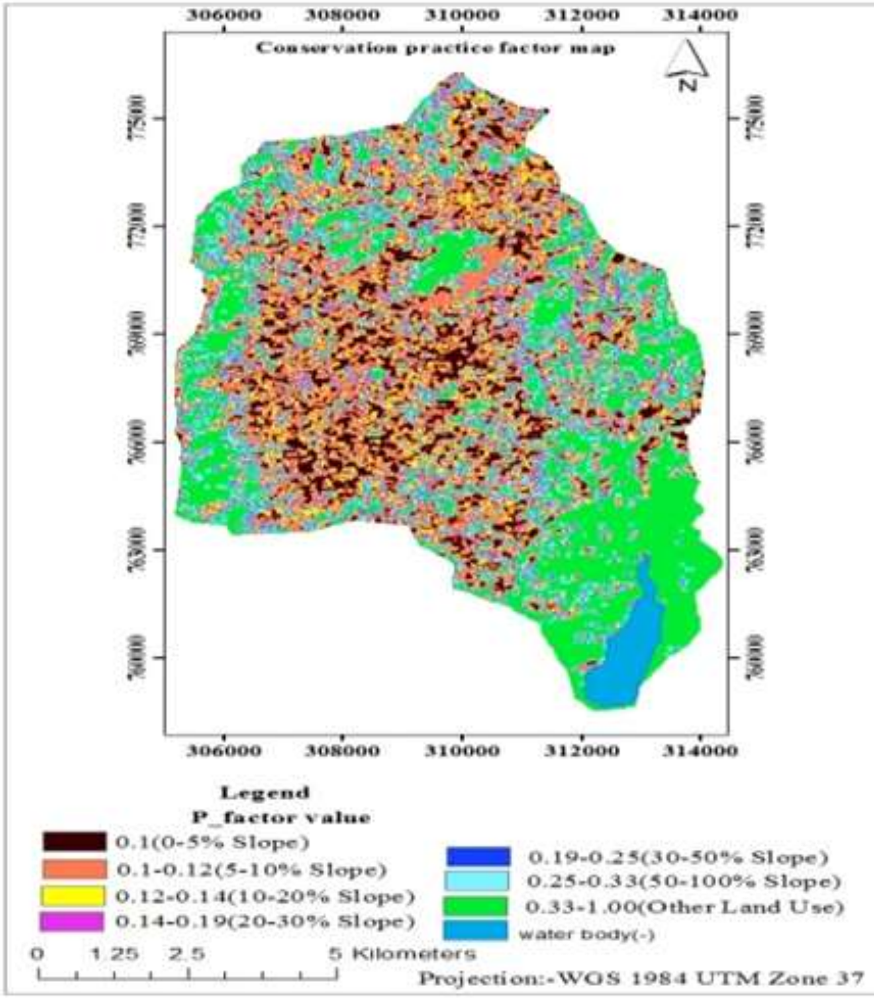

Figure 9. Conservation practice (P_ factor) Map of the study area.

Table 6. Annual soil loss rates, Severity classes and conservation priority of the study area.

Soil loss rate(t/ha/yr)	Equivalent top soil removal (mm)	Severity classes	Priority	Area coverage (ha)	Proportion of total area(percent)	Total annual soil loss (tone per year)	Proportion of total soil loss(percent)
0-3.125	0-0.25	Very less	4	7754.07	78.01	24231.47	57.13
3.125-6.25	0.25-0.5	Less	3	1629	16.39	10181.25	24.00
6.25-12.5	0.5-1	moderate	2	471.78	4.75	5897.25	13.91
12.5-25	1-2	High	1	84.15	0.85	2103.75	4.96
		Total		9939	100	42413.72	100

estimated from steep slope watershed classes (>30%) and representing 18.82% of the total soil loss (more than 0.5 mm of topsoil removal per annum) which requires the conservation priority of first and second order. These areas in the watershed were highly affected by erosion, with soil loss rate higher than SLT, greater than 6.25 tons ha^{-1} yr^{-1}. Our current result clearly shows that as slope steepness increases, the severity of erosion increases. Several studies shows that from the relationship between the slope of the watershed and the erosion rate, the higher the slope, the higher the erosion risk (Hoyos, 2005). The main causes of high soil erosion on steeper bank of the watershed area could be due to inappropriate land management practices like deforestation, cultivation

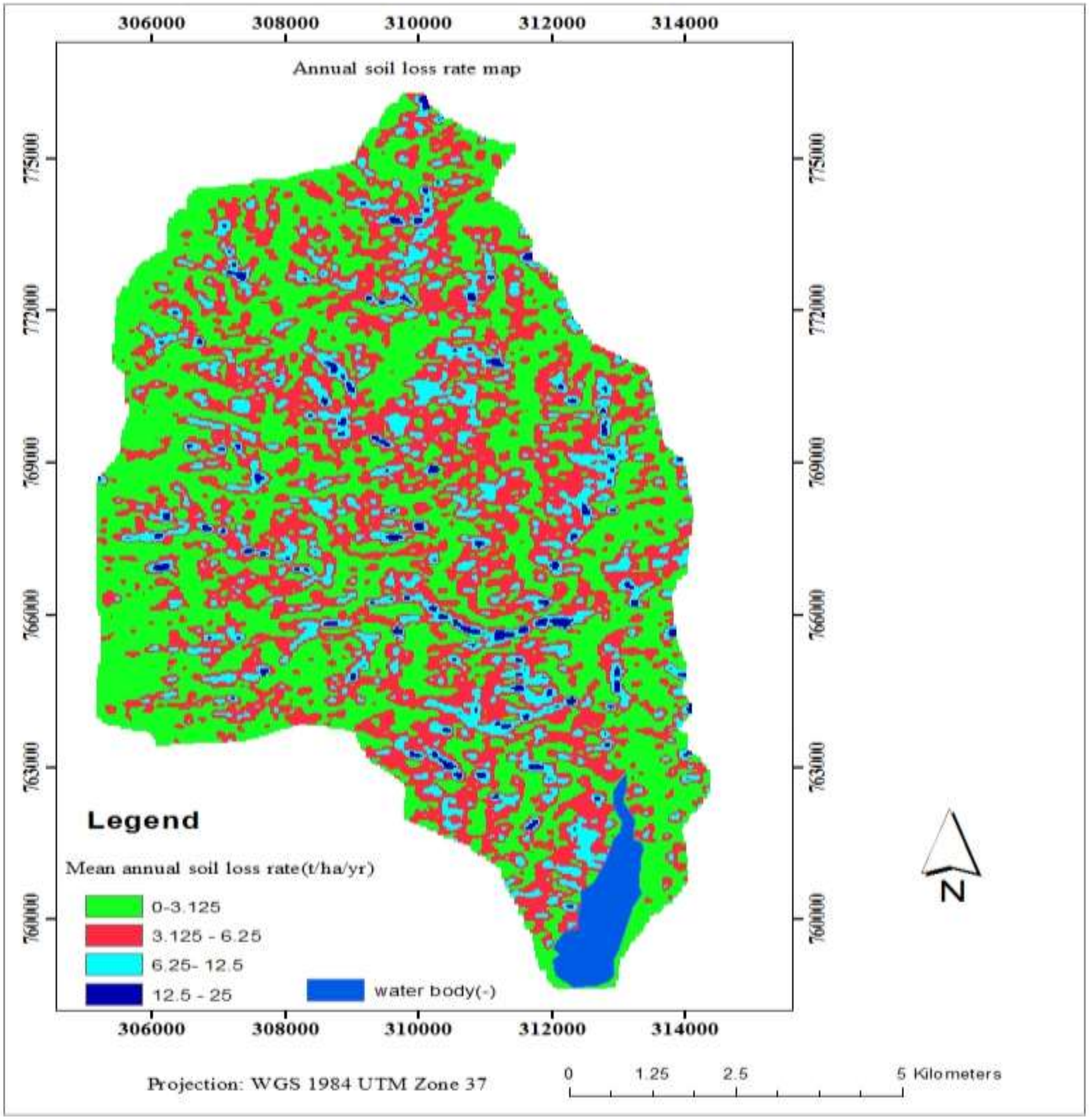

Figure 10. Soil loss rate map of the study area.

of marginal land, intensive cultivation, and poor vegetation during critical rainfall period. In our study area watershed slope classes, the largest soil loss rate could be mainly due to high erosivity (R_factor) value from heavy rainfall, erodibility (K_factor), high LS value especially slope steepness, soils without support practice factors (P=1, which accounts for 58.79%).

Flat to moderately steep (0-30%) watershed slope classes experiencing very less to less erosion severity classes accounts for 9383.07 ha (94.4%) of the watershed areas and represents 81.13% of the total soil loss. These areas remove less than 0.5 mm topsoil per annum and requires third and fourth conservation priority. The soil loss rate in this flat to moderately steep parts of watershed area are low as compared to steep slope (>30%) due to the forest, bush and shrub, sesal plantation integrated with stone bund and banana plantation in the Western and southern parts of watershed and *Junipers procera, Gravilia robusta,* and *Eucalyptus* plantations in upper parts of watershed.

Field observation report depicted that, the steeper parts of the land slope lack vegetative cover coupled with

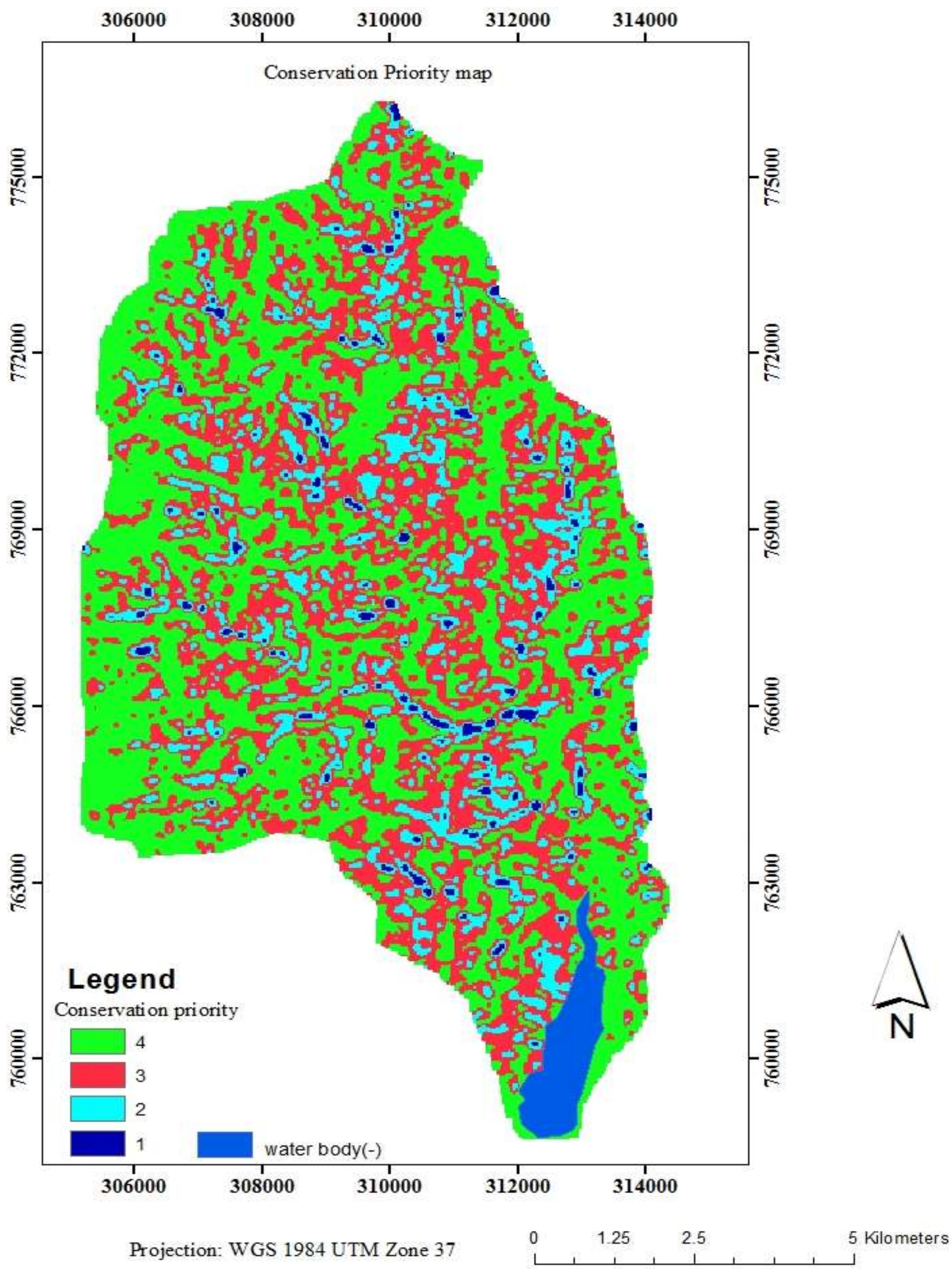

Figure 11. Conservation priority map.

intensive tillage operation, inadequate soil and water conservation measures; also, ignorance of land users to periodically maintain structures such as removing sediment from the channel and repairing the embankment was the major problems identified and resulted to high soil loss potential in this area. In general, 2,184.93 ha (21.99%) of the watershed area was affected by erosion which contributes 18,182.25 tones yr^{-1} total soil loss that accounts for above 0.25 mm top soil removal. According to Pimentel and Burgess (1995), nature takes 200–400 years to build up 1 cm of top soil; however, thousand tons of soil is lost in a season from a watershed, which calls for sustainable soil and water conservation strategies for the study area.

CONCLUSION AND RECOMMENDATIONS

In order to identify erosion risk areas, both environmental (RKLS) and management factors (C and P) grid were established in GIS layer and each factors value was estimated and mapped. Therefore, from the empirical erosion models, USLE integrated with geographical information systems and remote sensing technology is an effective tool to provide information for decision makers, land use planner and natural resource managers to formulate and implement effective soil conservation strategies.

The total and average annual soil loss estimated in Karesa watershed were 42,413.72 and 4.27 tons $ha^{-1}yr^{-1}$ from 9939 ha respectively. Of the four erosion severity classes, two erosion severity classes (6.25 - 12.5 tons $ha^{-1}yr^{-1}$ and 12.5 - 25 tons $ha^{-1}yr^{-1}$) which account for 5.6% of the total watershed area are experiencing annual average soil loss rate greater than the watershed average of 4.27 tons $ha^{-1}yr^{-1}$ whereas the other two erosion severity classes (0 - 3.125 tons $ha^{-1}yr^{-1}$ and 3.125 - 6.25 tons $ha^{-1}yr^{-1}$) represent 94.4% of the total watershed area at which annual soil losses were within the range of annual average. Moderate to high soil loss in the study watershed is aggravated by topographic factor especially slope steepness factor, high erosivity (R_factor) from heavy rainfall, high erodibility (k-factor) and poor conservation practice factors which could finally cause changes in the hydrological, biological, and geochemical cycles, resulting to lack of services that the soil offers to human beings. This influences annual crop production and land productivity impacting local farmer's food. The erosion severity may also have off-site sedimentation in the Gibe-3 dam.

To decrease the amount of soil loss in the study area, the following watershed rehabilitation measures should be recommended. Moderate to high erosion risk watershed slope classes requires various soil and water conservation activities that intercept runoff by decreasing the transport capacity of flow and improving soil infiltration in the steep slope using terracing, contouring, and strip cropping, reducing the intensity of tillage and growing cover crops.

Leptosols in the area exhibiting shallow depth soil characteristics in most parts of the watershed have low water holding capacity. The rainfall is directly converted into runoff due to low soil infiltration rate; therefore, deep tillage should be practiced in the study area to reduce the runoff amount and its velocity. Enclosing denuded hill slope areas, especially Atso Mountain from human and livestock interferences and rehabilitating it with different indigenous and exotic tree species should be embarked upon by participating farmers in conservation strategies from plan preparation to implementation. During field observation, the increased practices of sesal plantation integrated with stone bund at the lower catchment, some *Juniperus procera, Gravilia robusta,* and *Eucalyptus* plantations practiced in upper watershed area played a great role in reducing soil erosion rate and should be maintained and scaled up. Finally, the combination of GIS and USLE model is an important tool to map and estimate soil erosion rate. Therefore, the input parameter values contributing to soil erosion need to be calibrated to the specific watershed.

ABBREVIATIONS

DEM, Digital Elevation Model; **EEPCo,** Ethiopian Electric Power Corporation; **ENMA,** Ethiopian National Meteorology Agency; **ETM+,** Enhanced Thematic Mapper plus; **FAO,** Food and Agricultural Organization; **GIS,** Geographical Information System; **GPS,** Global Positioning System; **IDW,** Inverse Distance Weight; **LS,** Slope Length and Steepness; **LULC,** Land Use Land Cover; **RS,** Remote Sensing; **SCRP,** Soil Conservation Research Project; **SLM,** Sustainable Land Management; **SNNPR,** Southern Nations Nationalities and People's Region; **SLT,** Soil Loss Tolerance; **USLE,** Universal Soil Loss Equation; **WGS,** World Geodetic System.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

Special gratitude goes to South Agricultural Research Institute (SARI) for the financial support. The authors also thank Ethiopian National Meteorological Agency (ENMA), Ethiopian Mapping Agency (EMA), Ethiopian Ministry of Agriculture (MoA), Loma Woreda Farm and Natural Resource Department (LWFNRD), Gerawork Belayneh, Miki Berehane, and Dr. Negash Wagesho for the respective assistance rendered.

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