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# Remote Sensing and GIS-Based Soil Loss Estimation Using RUSLE in Bahir Dar Zuria District, Ethiopia

*Nurhussen Ahmed Mohammed and Desale Kidane Asmamaw*

## Abstract

The severity of soil loss in the Ethiopian highlands has been increased from time to time. Hence, the assessment of soil erosion using models is very important for planning successful and sustainable soil management. This study was conducted in Bahir Dar Zuria district, Ethiopia with aiming to quantify the amount of soil loss using the GIS-based RUSLE (Revised Universal Soil Loss Equation) model. Based on the study, the most pronounced RUSLE factor that increases soil erosion was the slope length (L) and slope steepness (S). Compared with other land uses, bare land and cropland in the higher slopes were more vulnerable to erosion. As expected slope and soil losses have a direct relationship. About 80% of the study area experienced annual soil loss of less than 1.2 ton/ha/yr. Conversely, soil loss was very high for slopes greater than 30%. This indicated that slope has a great impact on regulating soil loss. The annual soil loss for cropland, vegetation, grassland, and degraded land was 19.05, 8.78, 8.82, and 71.16 ton/ha/yr., respectively. This is to mean that land use land cover have a strong relationship with the amount of soil loss. The same land cover with different slopes have different soil loss amount. It was found that lack of vegetative cover during the critical period of rainfall, expansion of croplands, and absence of support practices increase soil erosion. Thus, the application of stone lines, contour tillage, terraces, and grass strip barriers are suggested to break the slope length into shorter distances, reducing overland flow velocity and soil erosion. Moreover, improving the awareness of society to reduce the illegal cutting of trees and apply conservation practices to reduce soil erosion in their farmland is very essential.

**Keywords:** Ethiopia, GIS, land use cover change, RUSLE, soil loss, slope

## 1. Introduction

Land degradation has been one of the major global environment and sustainable development challenges in the 21st Century. The expansion of agriculture and the clearance of natural habitats over the past decades aggravated the magnitude of land degradation in Ethiopia [1, 2]. Land degradation is mainly manifested by soil erosion [3].

Soil erosion is a serious problem in the Ethiopian highlands that increased sedimentation of reservoirs and lakes [4, 5]. Sediment export rates in the Ethiopian highlands are characterized by important changes in sediment supply [2, 6–9]. FAO [10] reported that soil erosion in Ethiopia is nearly 10 times greater than the rate of soil regeneration, and the country has among the highest estimated rates of soil nutrient depletion in Sub-Saharan Africa. Such land degradation reduces average agricultural productivity. It also increases farmers' vulnerability to drought by reducing soil fertility and water-holding capacity. Thus, land degradation in the form of soil erosion and declining soil quality is a serious challenge to agricultural productivity and economic growth in these highlands [11].

Soil erosion is a hazard traditionally associated with agriculture in different parts of the world and is important for its long-term effects on soil productivity and sustainable agriculture [1, 5, 11]. It is, however, a problem of wider significance occurring additionally on land devoted to forestry, transport, and recreation. Hence, it is important to identify estimated locations where soil erosion occurs to prevent substantial soil loss. In the most erodible situations, soil loss or sediment yield is limited by the transport capacity of the runoff. As the runoff flows through a watershed, changes in topography, vegetation, and soil characteristics often reduce this transport capacity [12–15].

Severe soil erosion not only leads to the impoverishment of cultivated land and poverty of the local people, but also to desertification that destroys the conditions crucial for human survival. It leads to the reduction of land/soil quality, loss of topsoil, and decrease in the content of soil organic matter and thereby to the loss in crop yield as it relates to high runoff rates and low soil permeability which in turn resulted in a decrease in infiltration and less water availability for the crops [16].

Degradation of land indicates undesirable changes that destroy the potentialities of regeneration, growth, and survival of plants. It is one of the most serious environmental problems causing great concern. Degradation is a cumulative effect of various factors acting singly or in combination [1]. Addressing land degradation would, therefore, could contribute significantly to reducing poverty and ensuring environmental sustainability.

The importance of studying soil erosion among global issues is enhanced because of its impact on world food security and the quality of the environment. The severity of the land degradation process makes large areas unsuitable for agricultural production because of the removal of topsoil and even part of the subsoil in some areas, and stones or bare rock are left at the surface [17]. Thus, there is a growing global awareness that land degradation is as much a threat to environmental well-being as more obvious forms of damage, such as air and water pollution.

To restore the productivity of the soil and to prevent further damage, planning, conservation, and management of the watersheds are vital. The watershed prioritization and formulation of proper watershed management programs for sustainable development require information on watershed sediment yield [18]. However, due to the complexity of the variables involved in the erosion process, it becomes difficult to measure or predict the soil loss in a precise manner [19]. Conversely, remote sensing data provide accurately, and near-real-time information on the various aspects of the watershed such as land use/land cover, physiographic, soil distribution, drainage characteristics, etc. [19]. It also assists in the identification of the existing or potential erosion-prone areas and provides data inputs to many of the soil erosion and runoff models [20].

To quantify the sediment yield (soil loss), several empirical models based on the biophysical parameters were developed in the past [7]. Among other models, Sediment Yield Index (SYI) [17] and Universal Soil Loss Equation (USLE) [10]

are extensively used. For instance, the USLE model has been widely applied at the watershed scale based on the lumped approach [17, 21] to the catchment scale [21]. However, various modifications in the models were often applied for the estimation of soil loss using GIS and remote sensing [22]. The Revised Universal Soil Loss Equation (RUSLE) uses the same empirical principles as USLE, however, it includes numerous improvements, such as monthly factors, incorporation of the influence of profile convexity/concavity using segmentation of irregular slopes, and improved empirical equations for the computation of LS factor [23, 24].

So far traditional soil erosion monitoring has been undertaken using field-based sampling methods utilizing discrete spatial intervals. These methods are unable to provide spatially distributed information on land conditions due to the high processing demands and effort involved in analyzing the relevant land properties [25]. However, Remote Sensing and GIS applications are often considered as cost-effective techniques [26] for the collection of data over large areas that would otherwise require a very large input of human and material resources. It can potentially provide spatial products for use in the assessment of soil condition and it has long been recognized [27] as a highly capable method for discriminating soil properties. A field study confirmed that satellite Remote Sensing data can be rapidly processed with computers provides further opportunities for the analysis and interpretation of data, resulting in the acquisition of valuable information over large areas for policy formulation, planning, and management decisions [25]. Moreover, remote sensing offers an important but as of yet underutilized set of tools to manage the transition towards sustainable land usage [28].

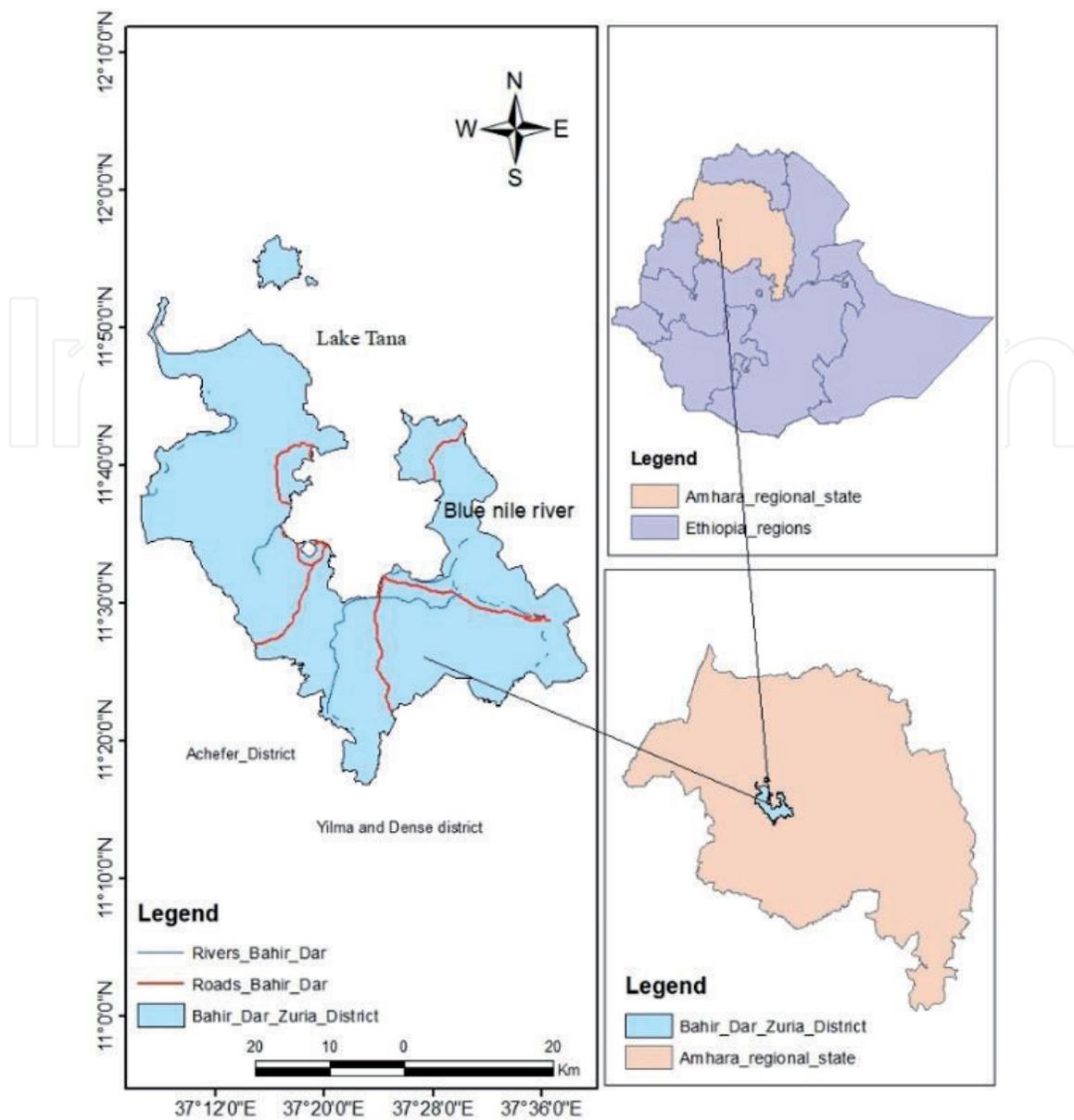
Many soil and water conservation efforts have been implemented by the Ethiopian government and charitable organizations in the past decades in northern Ethiopia, but still, soil erosion becomes major problem; and the severity of the problem is increasing from time to time [1, 11]. Evaluating the implemented technologies and land use systems on soil erosion/soil loss effect using modern appropriate tools is paramount important for future soil management issues. This paper estimated the effect of the applied conservation practices and existed land use dynamics on soil loss by the RUSLE model using Remote Sensing and GIS.

## 2. Materials and method

### 2.1 Characterization of the study area

Bahir Dar Zuria district is located within  $29^{\circ} 27' 34''$ ,  $35^{\circ} 58' 40''$  East of longitude and  $13^{\circ} 38' 19''$ ,  $12^{\circ} 1' 37''$  North of latitude (**Figure 1**). It is about 578 km northwest of Addis Ababa. The district has 32 peasant associations and covers a total area of 128,360.48 ha. It is located in the Amhara region, Ethiopia. It is bounded by Lake Tana, Yilma and Dense Wereda in South, Metcha, and Achefer Wereda in the West and river Abay in the East.

The study area has four major soil types (**Figure 2**). Vertisols, Nitosol, Luvisols, and Cambisols. Vertisols cover 85,394.9 ha (67.7%); Cambisols cover 13,901.5 ha (11%); Nitosols cover 26,313.5 ha (20.8%); and Luvisols cover 496.5 ha (0.5%) of the total area [29]. The distribution of the Vertisols is observed mostly in the plain. Luvisols have a little share when it is compared with the other types of soil. The area around Lake Tana basin is dominated by three geological events: Quaternary Basalts, Oligocene to Miocene basalts, and Quaternary Alluvial and lacustrine deposits. Also, Basaltic lavas of the Aden volcanic series formed the plateau during the Quaternary period of the Cenozoic era. Lake Tana is considered to have been created by the barrier of extended lava of this series.



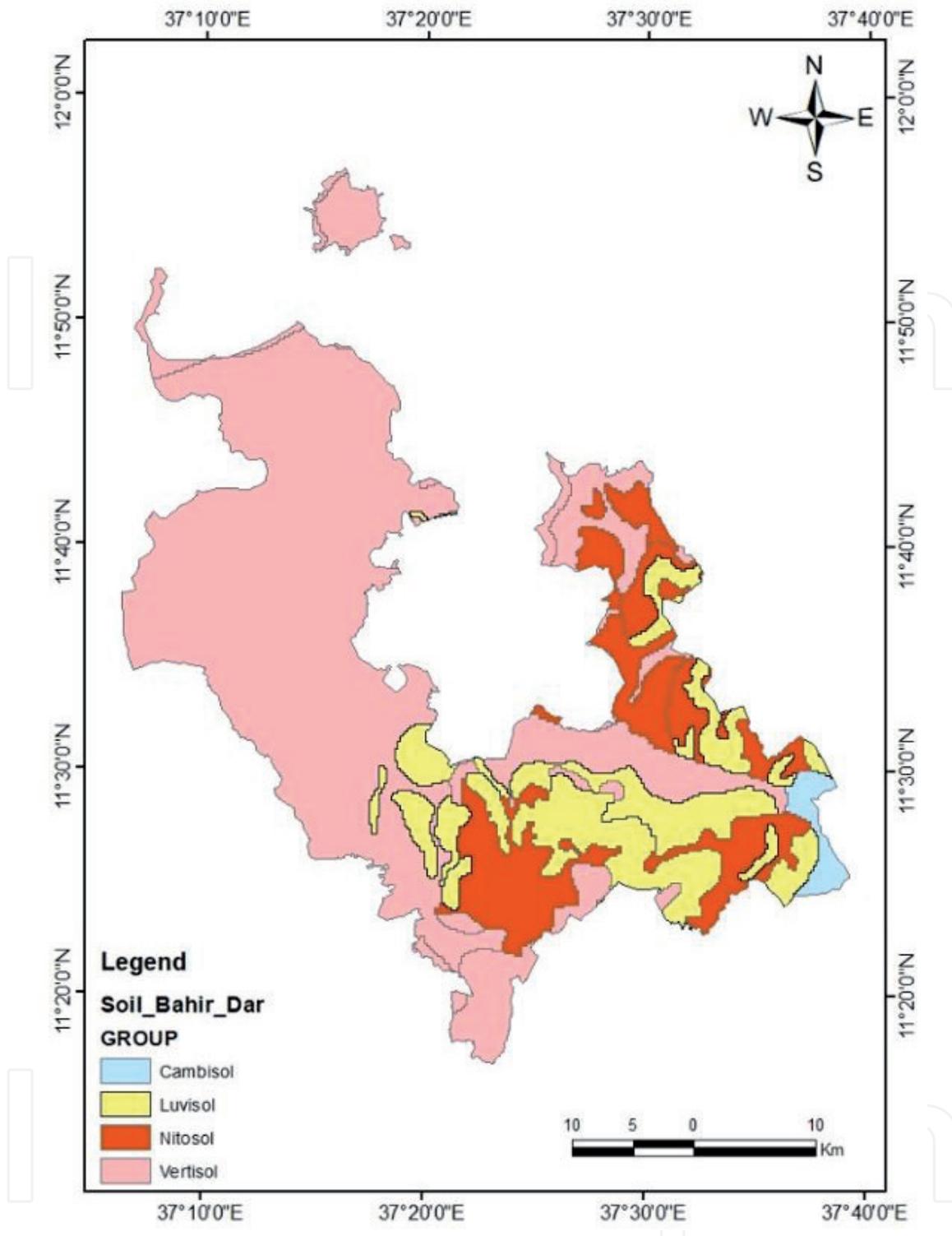
**Figure 1.**  
Map of the study area.

The area lies within the central highland of Ethiopia. About 79% of the total area is found in the slope < 5% and 9.8% is found between 5 and 10%. The remaining area is found in the slope > 10% (**Figure 3**).

The area receives a mean annual rainfall of 1447 mm ranging from a maximum of 2036 mm to a minimum of 895 mm (Amhara region meteorological agency 2018). The study area receives maximum rainfall in summer (June–August). The districts experienced a warm temperature climate, with an average temperature of 21.3 °c. The highest temperature is recorded from February to March and the lowest temperature is observed in January and December (**Figure 4**).

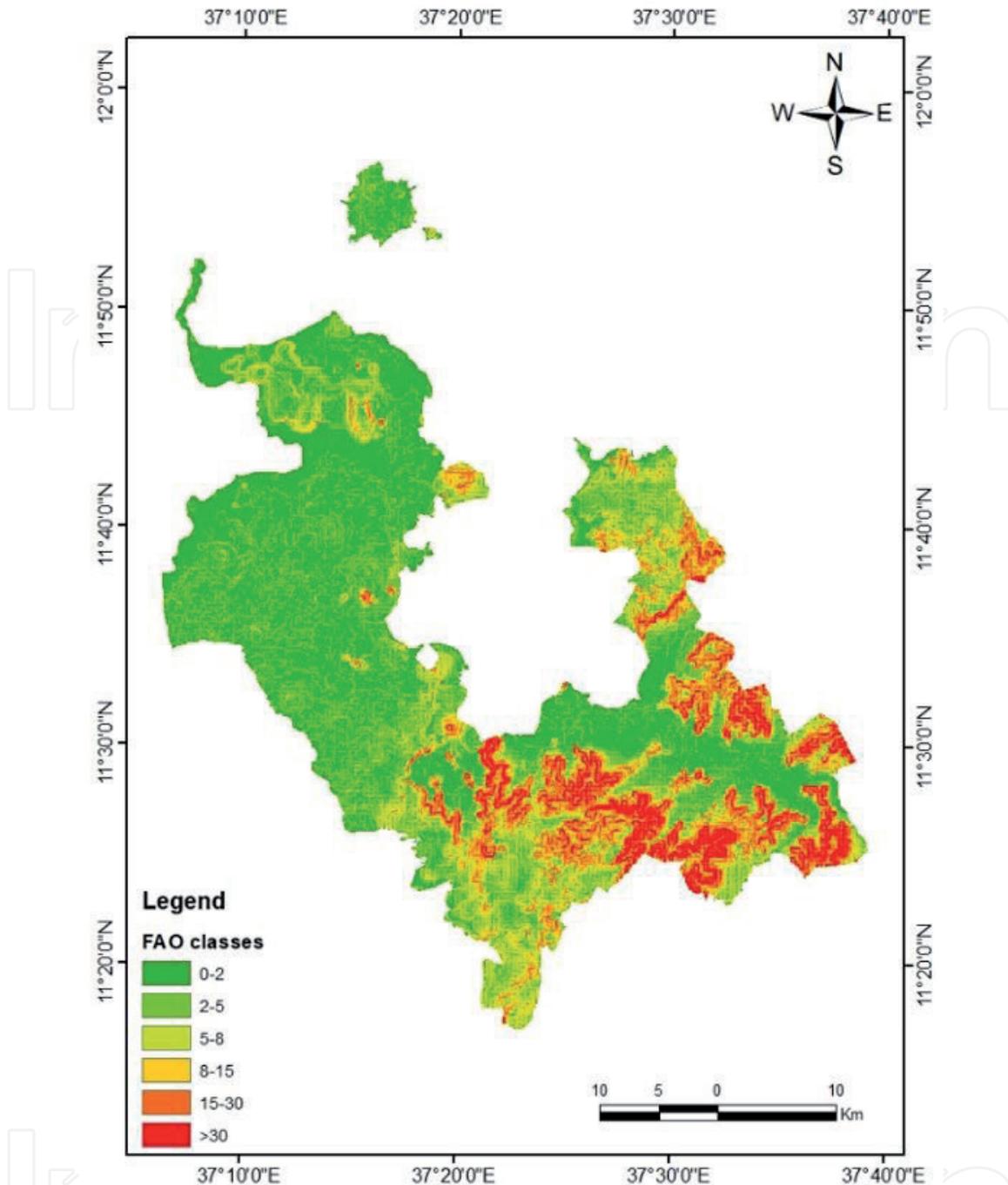
## 2.2 Data collection and preparation

Using different tools such as Arc GIS 10.3, USA, Erdas Imagine 14.0.0.166, USA, and Garmin 64 handheld GPS, elevation, latitude, longitude, slope, and land use data were collected. To geo-reference the satellite images and digitizes the different features in the image, the topographic map of the study district (1:250,000 scale) was taken from the GIS team of the Amhara region [Amhara region GIS team, 2018].



**Figure 2.**  
*Soil distribution of Bahir Dar Zuria district.*

To calculate the K-factor and produce a soil type map which can be used in the Revised Universal Soil Loss Equation (RUSLE) model, soil map of the study areas was taken from the same sources [Amhara region GIS team, 2018]. The DEM and slopes were generated from the SRTM (Shuttle Radar Topographic Mission) which had been also taken from the same sources [Amhara region GIS team, 2018]. To calculate the RUSLE, R-factor, and to observe the effect of rainfall on soil erosion 19 years of rainfall data of four major rainfall stations were collected from the department of the meteorology of the Amhara region (Amhara region meteorology, 2018). To calculate the C-factor of the RUSLE model satellite images of 2018 had been downloaded from the internet (date accessed:13/02/2018). To calculate the LS factor of the RUSLE



**Figure 3.**  
Slope distribution of Bahir Dar Zuria districts.

model, Digital Elevation Model (DEM) was converted from the SRTM resolution of 30 m data.

Field surveys on different land use/land cover dynamics, slope steepness, and soil erosion conservation practices were made. Moreover, field observation of vegetation and biodiversity under certain land use/management practices and ground points were taken.

The RUSLE is a model that can predict the long-term average annual rate of soil erosion on a field slope as a result of rainfall patterns, soil type, topography, crop system, and management practices [30]. The strength of this model permits an all-inclusive analysis by breaking down soil erosion into elements. Rainfall, soil, slope, land use/land cover data, and management practice were collected and hence, used for the estimation of soil loss using the formula.

The equation is presented as

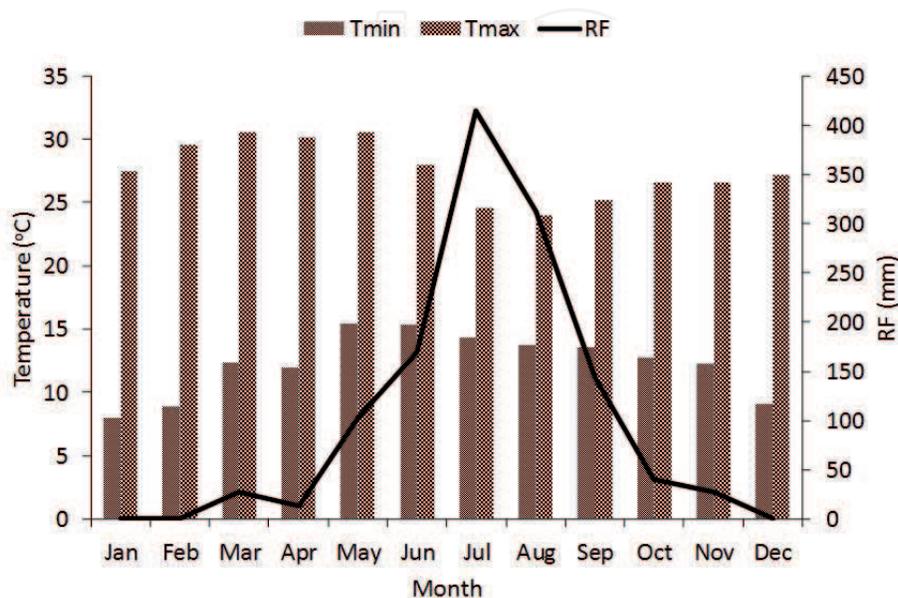
$$A = R * K * LS * C * P, \quad (1)$$

Where: **A**- represents soil loss in tons/ha/yr., **R**- Rainfall erosivity is a term used to describe the degree of soil loss due to rainfall effect when other factors of erosion are held constant. It is an index that characterizes the effect of raindrop impact and the rate of runoff associated with a rainstorm. The erosivity index, **R**, depends upon the amount and intensity of rainfall. It is very high where frequent heavy storms occur and declines as the amount of rainfall and intensity of storms diminish. **R** is calculated from long-term rainfall data. A high correlation  $r = 0.88$  for monthly precipitation and monthly erosivity was found together with the following regression equation:

$$R = -8.12 + 0.562 * P \quad (2)$$

Where **P** is the mean monthly precipitation in millimeter.

**K**- The **K**-factor is defined as the rate of soil loss per unit of **R**-factor on a unit plot [31]. The **K**-factor also defines as the resistance of the soil to both detachment and transport, the unit depending upon the amount of soil occurring per unit of erosivity and under specified conditions. The inherent properties of the soil would have more influence on being liable to erosion than other factors. RUSLE **K**-factor depends on a combination of soil and climatic parameters developed under specific conditions in the USA, which might not be suitable to different conditions in other parts of the world, such as in the Ethiopian condition. For the Ethiopian case according to Hurni [8], the determination of the **K**-factor was simplified by giving the soil color representing a major soil type a specific value. Hence to calculate the **K** factor soil data was obtained from woody biomass and the value for different soil was given according to Hurni [8] adaptation to the Ethiopian condition. The spatial variation of the **K**-factor was determined using the soil maps produced by the Woody Biomass [29]: using GIS attribute table level editing which was adapted to Ethiopian conditions by Hurni [8]. The resulting shapefile was changed to a grid file using convert feature to raster.



**Figure 4.**  
 Monthly rainfall, minimum and maximum temperature of the study area.

**L & S** - the topographic factor, is divided into 2 components: S is the slope grade expressed as a percentage and L is the length of the slope. Slope grade affects mainly the speed of runoff. Slope length affects mainly the amount of runoff. In assessing the effects of slope length it is necessary to take into account the total length of the slope over which runoff occurs, not just the length of the field in question. Hurni [8] calculated the L and S factor depending on its slope length. For the calculation of the L-factor, there should be slope data. The slope length and steepness (LS-factor) were derived from the DEM of 90-meter resolution. The DEM was converted into fill sinks and flow direction grid using a hydrological extension of Arc GIS version 10.3. Secondly, a flow accumulation grid was created using the flow direction grid in the same technique. The third step was to calculate the LS-factor using the flow-accumulation grid and the slope grid using the same method. Generally, the DEM was used to generate slope, fill sinks, flow direction, flow accumulation, and LS maps using the Arc Hydro extension.

**C**- Cropping practices have a strong influence on erosion by their effect on the amount of protective coverage that crops and crop residues provide. The C-factor is defined as the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow [30]. The RUSLE C-factor is a measure of the cropping and management practices' effect on soil erosion [31]. The more of the soil that is left uncovered the greatest the risk of soil erosion by either wind or water and vice versa. To calculate the C-factor land use/ land cover for image 2018 was collected and the resulting data was substitute with the value given by Hurni [8] for different land cover types. Hence the C-value for vegetation is considered as  $C = 0.02$  and for grazing land is  $C = 0.03$  and for degraded land is  $C = 0.2$  and for cropland is  $C = 0.16$ .

**P**- is the support practice factor. It reflects the impact of support practices on the average annual erosion rate. It indicates the fractional amount of erosion that occurs when any special practices are used compared with what would occur without them. The P-factor gives the ratio between the soil loss expected for a certain soil conservation practice to that with up-and down-slope plowing [30]. Special conservation practices have the effect of reducing erosion. The support practice factor is the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to soil loss with straight-row farming up and down the slope. Hence the different support practices methods that are observed in the study area were collected and their values are substituted with the value given by Hurni [8] for different management practices in the adaptation of RUSLE to the Ethiopian condition.

## 2.3 Methodology

To assess and analyze the effect of different variables on a single area, the weighted overlay method was conducted on the RUSLE variables (**Figure 5**).

### **Digital Image processing**

Digital image processing involves numerous procedures including formatting and correcting of the data, digital enhancement to facilitate better visual interpretation, had been carried out [32]. The common image processing functions available in image analyses like radiometric correction, geometric correction, image mosaic, subsetting, and image enhancement had been made accordingly.

### **Image Classification**

Image classification is defined as the process of sorting pixels into a finite number of individual classes, or categories of data, based on their data file values [32]. If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that corresponds to those criteria. This process is also referred to as image segmentation. Depending on the type of information you want to extract from the original

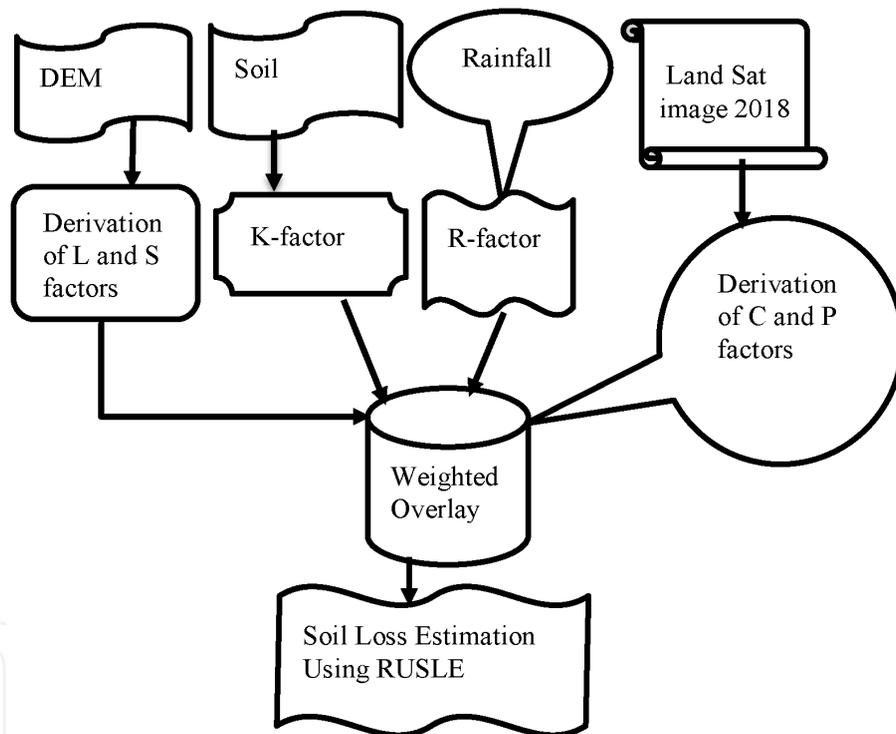
data, classes may be associated with known features on the ground or may simply represent areas that look different to the computer. An example of a classified image is a land cover map, showing vegetation, bare land, pasture, etc. [33].

To classify the images, ground truth points were collected from different land use land cover types, and hence supervised image classification technique was applied. Supervised training is closely controlled by the analyst. The sample ground truth points taken during the field time help a lot to identify the land use/land cover on the image by using supervised classification and hence the computer can automatically classify the image based on the given sample ground truth points.

### Rainfall Erosivity Factor

The erosivity factor  $R$  was calculated according to the equation given by Hurni [8], for Ethiopian conditions based on the easily available mean annual rainfall ( $P$ ).  $R = -8.12 + 0.562 * P$ ; Where  $P$  is mean annual rainfall in mm. The correspondence  $R$  values of the four stations were calculated as follows in **Table 1**.

The above data with their location were used to generate a rainfall erosivity map using Arc GIS 10.3 Spatial Analyst, IDW Interpolation. The  $R$ -map was simply generated from the mean annual rainfall data.



**Figure 5.** Methodology flow chart of soil loss estimation using RUSLE. Variables like soil, rainfall, and slope, which have a great relationship with land degradation were analyzed at the same time to assess land degradation.

Station's name	Mean annual rainfall	R-value
Bahir Dar	1503.8	837.1
Meshenti	1280.5	711.5
Tis Abay	1968.3	1098.1
Zege	1470.5	818.3

**Table 1.** RUSLE,  $R$ -factor.

**Soil Erodibility Factor (K)**

The K-factor is defined as the rate of soil loss per unit of R-factor on a unit plot [31]. Hurni [8] in the adaptation of RUSLE to Ethiopian conditions considered the soil color to calculate the K-value. The resultant soil color and their K-value are presented in **Table 2**.

The spatial variation of the K-factor was determined using the soil maps produced by the Woody Biomass [29]: using GIS attribute table level editing which was adapted to Ethiopian conditions by Hurni [8].

**Topographic (LS) Factor**

The analyzed LS factor with the slope ranges is presented in **Table 3**. After generating the flow accumulation the topographic factor (LS) factor in the GIS environment was used [30].

$$LS = (\text{Flow accumulation} * \text{Cell size} / 22.13)^{0.4} * (\sin(\text{slope} / 0.0896))^{1.3} \tag{3}$$

Where flow accumulation refers to the number of cells contributing to flow into a given cell and cell size is the size of the cells being used in the grid-based representation of the landscape [30, 34] (**Figure 6**).

**Crop Management (C) Factor**

The C-factor was given based on the estimated value that was developed by [8]. The mean value of different crops (C = 0.16) had been taken for the C - value for croplands. Besides, the C-value for vegetation was considered as C = 0.02 and for grazing land was C = 0.03 and for degraded land was C = 0.2. Thus, the C-value was applied to the land use map of the 2018 land sat image. After generating the classified land sat image of 2018, the format was changed into a vector and a corresponding C-value was assigned to each land use type using the editing menu of Arc GIS 10.3 from the C-value adopted by Hurni [8] for the RUSLE model.

**Conservation Support Practice (P) Factor**

The data related to management practices were collected during the fieldwork. Values for this factor were assigned considering local management practices and

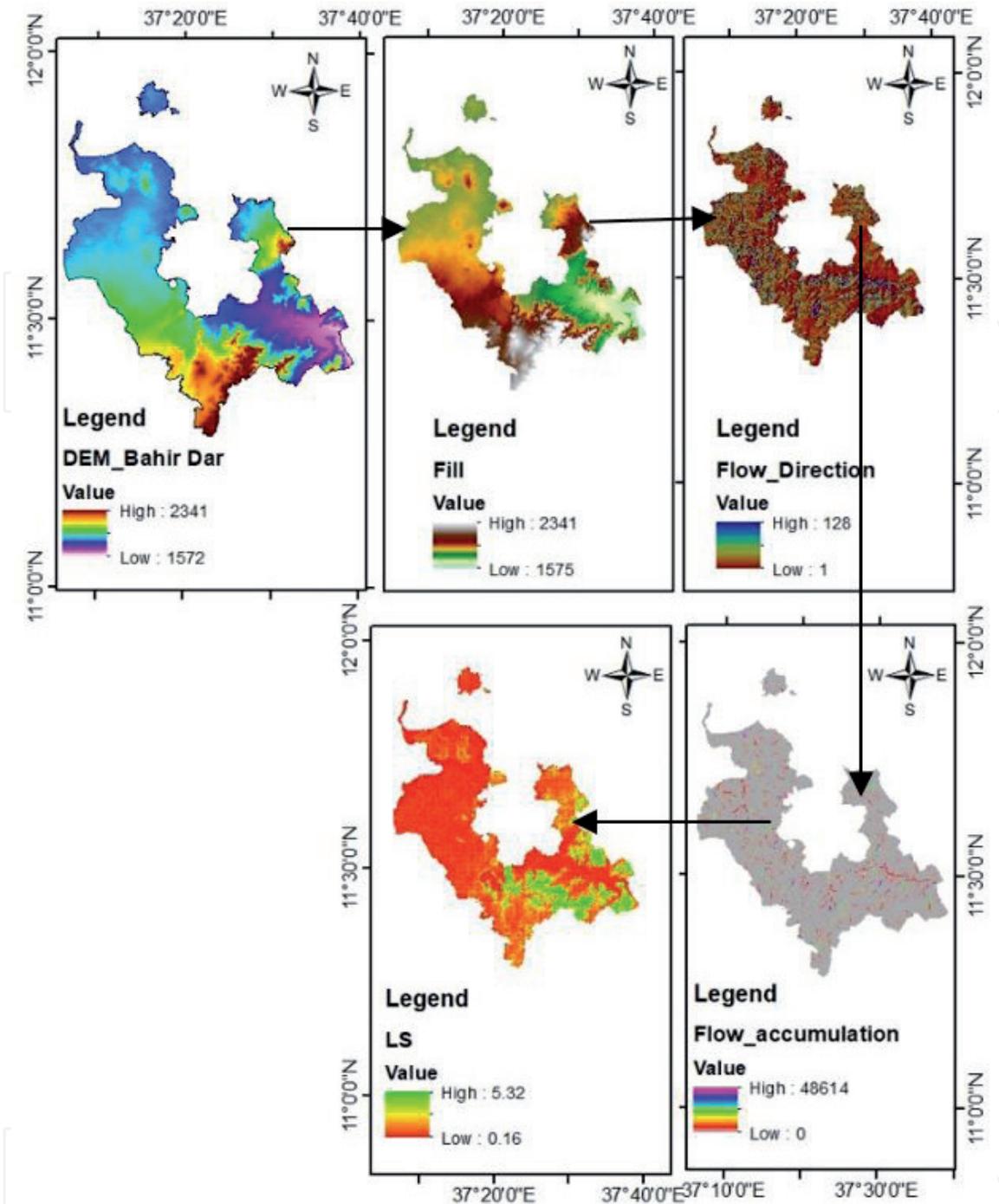
Soil color	K-value	Soil type
Black	0.15	Vertisols
Brown	0.20	Luvisols and Cambisols
Red	0.25	Nitisols

*Source: [8].*

**Table 2.**  
*K-values of soil colors in the study areas.*

Slope class %	0–5	5–10	10–20	20–30	>30
Area (ha)	102,242	12,544.5	9062.3	3350.2	1161.5
L-factor	0.4	0.7	1.0	1.2	1.4
S-factor	0.4	1.0	1.9	3.0	3.8
LS-factors	0.16	0.7	1.9	3.6	5.32

**Table 3.**  
*RUSLE LS factor.*



**Figure 6.**  
 Flow chart of LS factor.

based on values suggested in Hurni [8]. The result land cover map and the associated P-factors were used to generate a grid surface for the P-factor, utilizing Arc GIS 10.3 spatial analyst. Soil bund, bench terrace, grassed waterways, grassed strips, and area closure are the dominant management practices. The bench terraces and area closures are mainly found at the higher elevation, whereas soil bund and grassed waterways are distributed in the low laying areas.

#### Overlay

The RUSLE is an index method that includes factors that represent how land cover, climate, soil, topography, and land use affect soil erosion caused by raindrop impact and surface runoff. To assess the effect of these parameters at the same time, the overlay of all factors in a single scene was made. This was done utilizing Arc GIS software (Figure 7).

### 3. Results and discussion

#### 3.1 Revised universal soil loss estimation (RUSLE)

##### 3.1.1 Rainfall erosivity (R-factor)

The analysis of the monthly average rainfall erosivity revealed that more rainfall occurs during summer (**Figure 7**). During this period, the height of agricultural production is small, which leaves the soil surface unprotected against raindrop impacts, resulting in a high risk of erosion in areas of cultivation. This indicates that when other erosion parameters are held constant, areas with the highest rainfall have high R-values (**Table 1**) and are exposed to erosion. As it is presented in **Figure 8**, the Northern and Eastern parts are more exposed to erosion than many other areas in the study area when other parameters remaining constant. In principle the greater the R-value the greater the soil loss is and the opposite is also true. When other soil loss factors are remaining constant, greater soil loss is observed in areas where high R-values were registered.

Using the R-value, rainfall distribution throughout the study area was interpolated. This method was designed in a GIS environment with the principle of things found to be close to one another are more alike than those that are farther apart. Different findings reported that rainfall erosivity has been one of the leading factors for soil erosion. Among them, Outhman *et al.* [25] concluded that rainfall erosivity increase soil erosion especially when the heights of the agricultural lands are short. Also [6, 7, 35] reported that rainfall erosivity has a great role in aggravating soil erosion and soil loss.

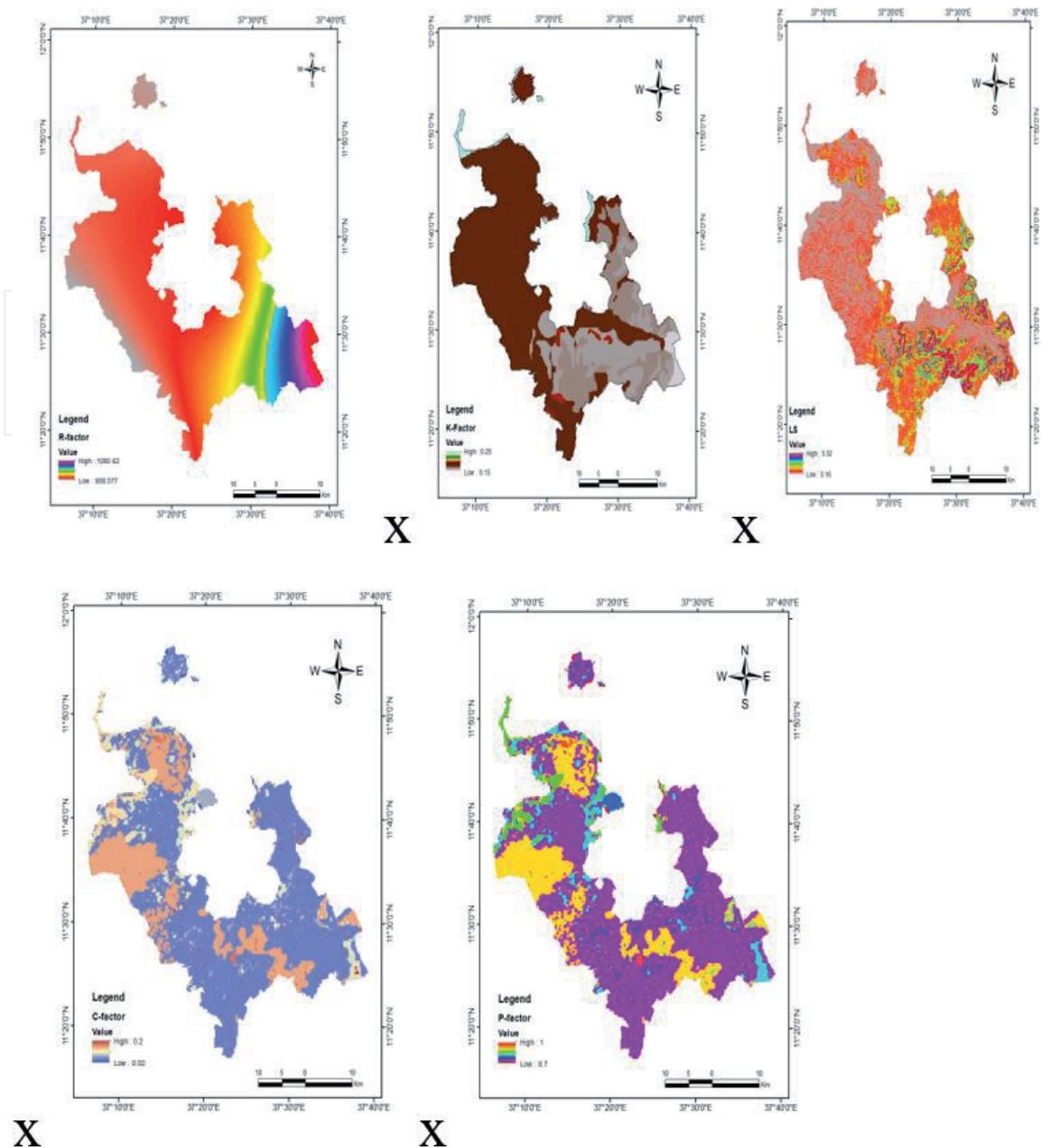
##### 3.1.2 Soil erodibility (K-factor)

The K-value for Vertisols, Luvisols, and Cambisols and Nitosols are 0.15, 0.2, and 0.25 respectively (**Figure 9**). This is to mean that as the K-value increases the erodibility of the soil also increases and vice versa. In this case, the Nitosols for example are more erodible than vertisols. In the same way areas with Nitosols are more vulnerable to erosion than areas with Vertisols. Vertisols, Nitosols, Cambisols, and Luvisols had the first, the second, and the third share in the study areas respectively. The Nitosols in the study area is observed in the higher slopes i.e. slope > 10% and covers 10.6% of the study area, whereas the Vertisols are observed in lower slopes i.e. slope < 5% and covers 79.6 percent. The remaining part of the study area has been covered by Nitosols and Vertisols. Soil type has a great role in soil erosion because some soils are more erodible than others. In this case, considering the soil erodibility factor in RUSLE parameters helps to see its effect on soil erosion.

Different researchers noted that soil erodibility is one of the leading factors to soil erosion. For instance, Assen [36] reported that Nitosols and Cambisols are more erodible to soil erosion than other soil types. Hurni [8] also founded similar findings.

##### 3.1.3 Topographic (LS) factor

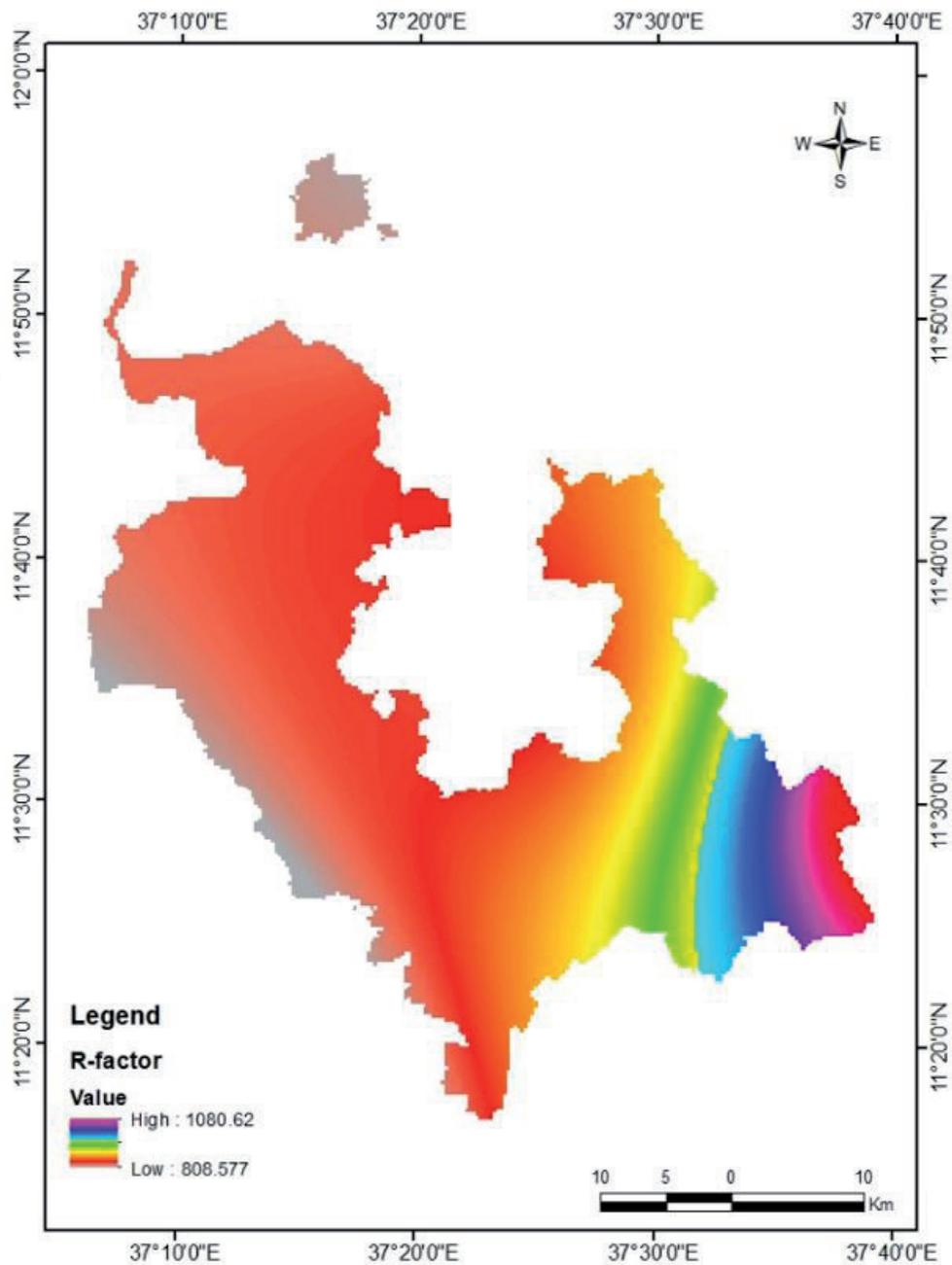
The LS-factor value represents the relative erodibility of the particular slope length and steepness (**Figure 10**). The LS factors have a great impact on erosion. Higher slopes have higher LS value and lower slopes have lower LS value. In the same way, high LS values indicate that higher soil erosion and the opposite being



**Figure 7.**  
 Overlay of RUSLE parameters.

other factors of erosion remaining constant. As it is presented in **Figure 10**, a higher LS factor value (LS = 5.32) is observed in the Central and South margin of the study area. On the contrary, a lower LS factor value (LS = 0.16) was observed in the plains of the North and northwest part of the study area. Therefore, other factors remaining constant in the Central and -south margins of the study (where LS-factor is greater) area are at high risk of soil erosion than any other area. Various findings confirmed that the LS factor have a great impact than any other RUSLE parameters. For instance, Outhman *et al.* [25] Palestine reported that the LS factors are the two major factors of soil erosion than any other factors.

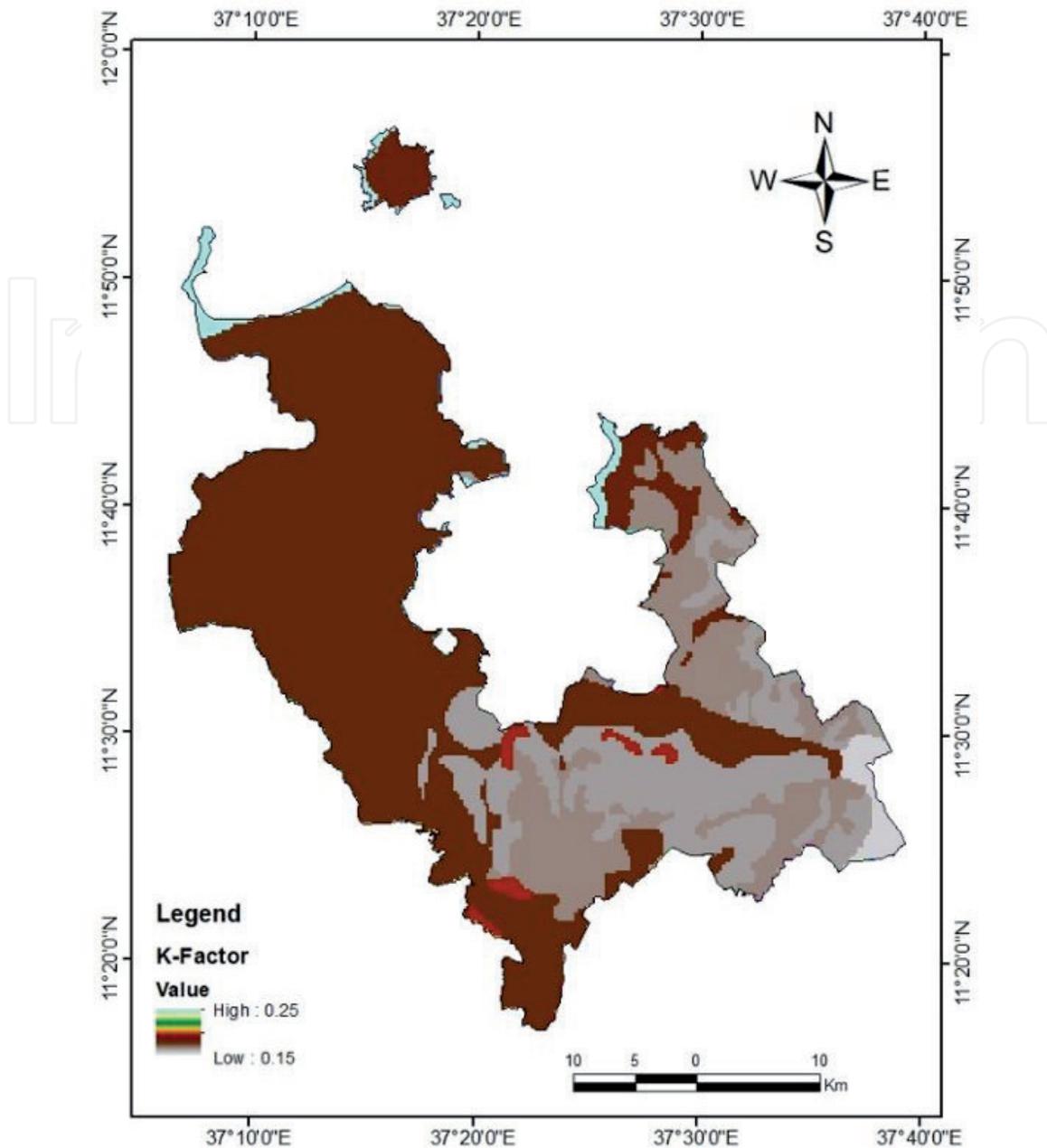
Yitafaru [35] also presented the effect of the slope in soil erosion separately from the other parameters [37]. This indicates that the slope has a great impact on soil erosion than any other parameter. Besides, the report by [6, 7, 38] showed that soil erosion increase as the slope increases. Generally, as the slope increase, the soil loss also increases unless a special soil loss conservation mechanism is applied in the higher slopes.



**Figure 8.**  
Rainfall erosivity map.

### 3.1.4 Land cover (C-factor)

The C-values for agriculture, vegetation, grassland, and degraded land were 0.16, 0.025, 0.03, and 0.2, respectively (**Figure 11**). This means that as the value for the C-factor increases the capacity of the area to resist erosion decreases and vice versa. For example, the degraded lands are more vulnerable to erosion than vegetation areas because the C-value for degraded land and vegetation are 0.2 and 0.025, respectively. It is true that soil erosion increases, if there is no cover or if the cover is not resistant to erosion. For instance, [9] reported that differences in the vegetative cover have been mainly responsible for the variation in erosion rates in the Ethiopian highlands. Morgan [39] also reported the differences in erosion rates caused by different land use practices on the same soil are much greater than the corresponding changes from different soils under the same land use. From this

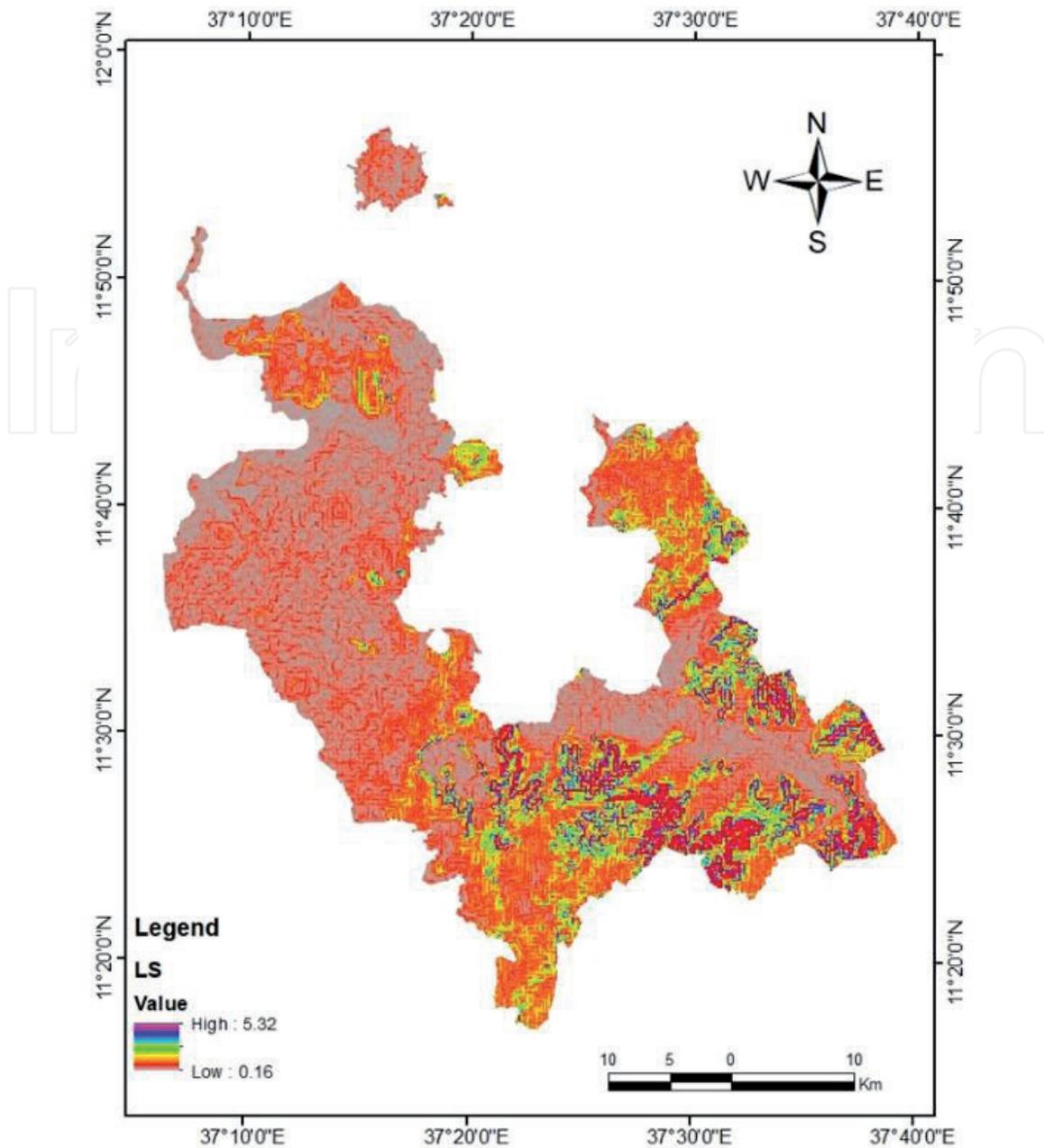


**Figure 9.**  
*Soil erodibility factor map.*

study, we can understand that areas having a higher value of C-factor have a higher capacity for soil loss resistance. This is to mean that areas with vegetations or any other cover types have less soil loss than areas with barren land.

### 3.1.5 Conservation support practice (P) factor

The support practice factor (P) reflects the impact of support practices on the average annual soil loss rate. It indicates the amount of soil loss that occurs when any special practices are used compared with what would occur without management. According to our study, the P-value for agriculture, bareland, vegetation, and grasslands were 0.9, 0.7, 0.8, and 1, respectively (**Figure 12**). This is to mean that areas having conservation practice have the lowest erosion than areas with no conservation practice because, in areas where there is conservation practice, runoff speed could be reduced.



**Figure 10.**  
*Topographic factor map.*

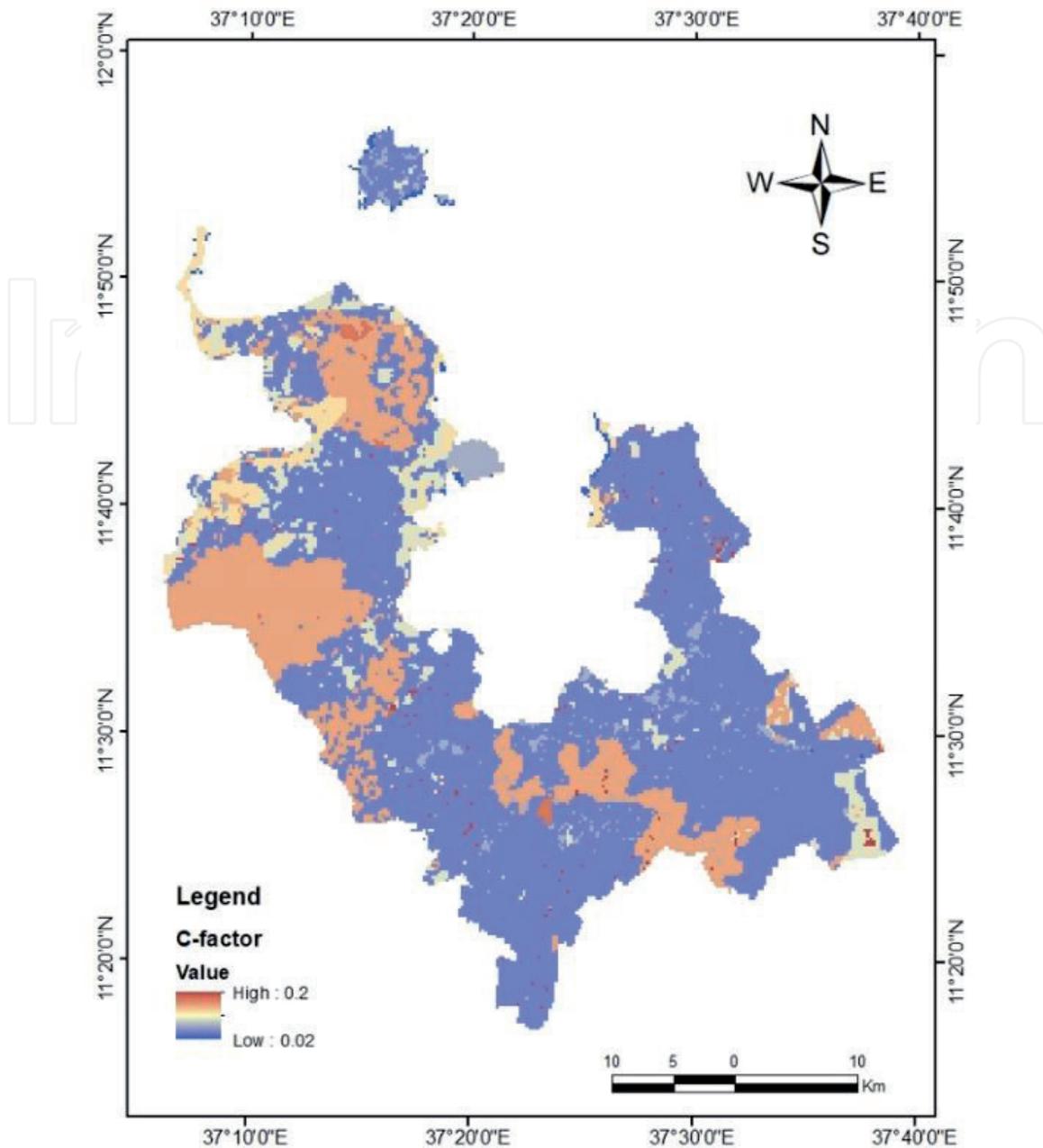
To reduce soil erosion, conservation practices have been implemented in the study areas. Many researchers confirmed that conservation practice have a significant role to reduce soil erosion [6, 11, 25, 35].

### 3.1.6 Annual soil loss

To ease the presentation of the output data, the result considers three main categories such as annual soil loss based on slope gradient, annual soil loss based on land use/land cover type, and annual soil loss based on slope and land cover.

#### 3.1.6.1 Annual soil loss based on slope gradient

The slope has a major role in the RUSLE model since it determines the direction and velocity of the water movement. It also determines the processes of detachment, transport, and accumulation of soil particles. We have found that as the



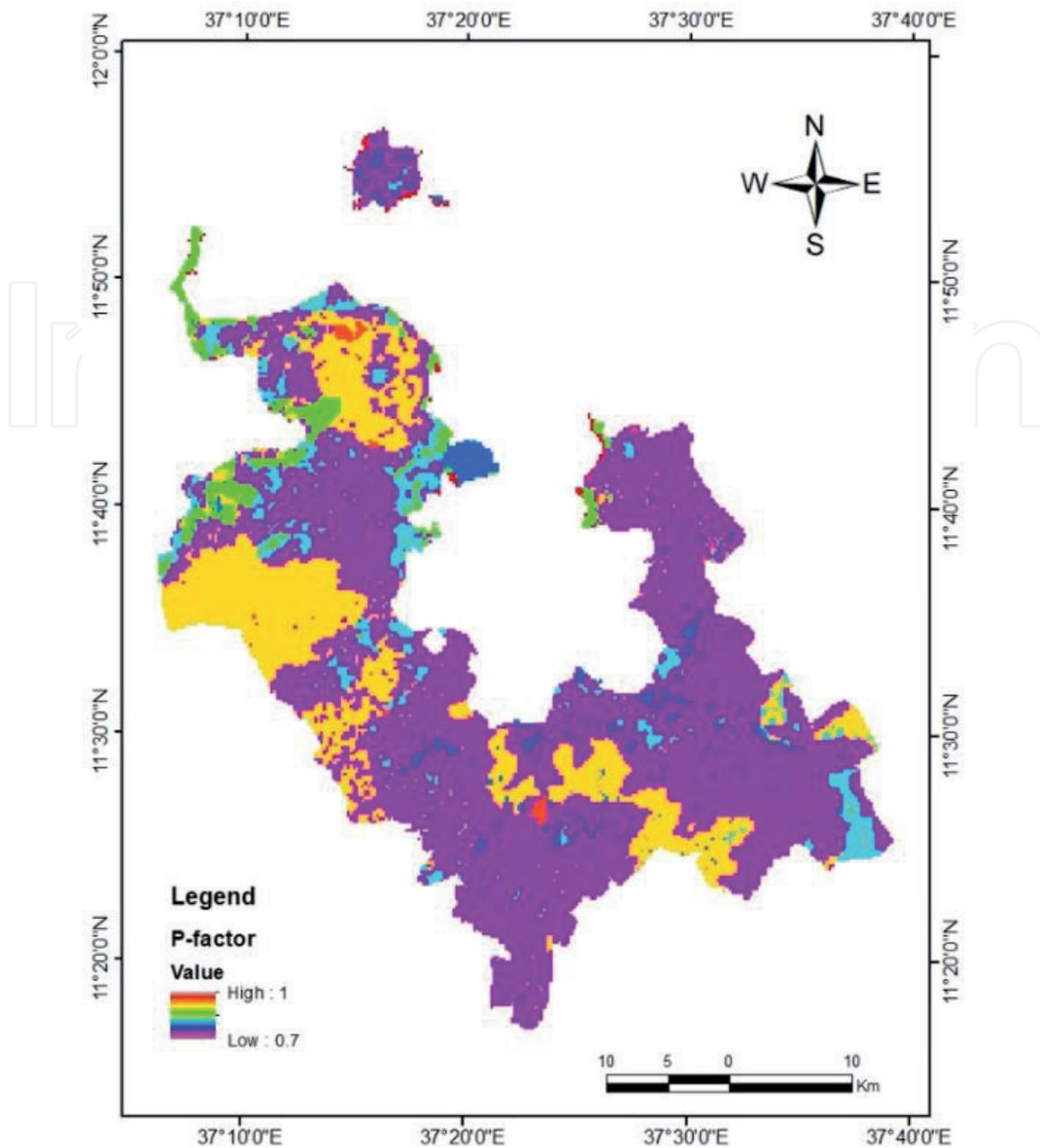
**Figure 11.**  
*Cropping practice map.*

slope increases the amount of soil loss also increases (**Table 4, Figure 13**). This is because higher slopes increase the speed of water and transport of soil particles. Slope and soil losses have a direct relationship i.e. as the slope increases the annual soil loss also increases. A relatively small amount of soil loss per hectare of land was recorded around the low slope areas whereas a high amount of soil loss per hectare had been obtained at sloppy lands. As it is observed in **Figure 13**, 79.65% of the study area experiences low soil loss which is  $<1.2$  ton/ha/yr. This indicated that most of the area is situated in the plains and have low soil loss.

Conversely, soil loss is very high for slopes  $>30\%$ . This indicates that slope has a great impact on regulating soil loss.

### 3.1.6.2 Annual soil loss based on land cover type

The type of land cover has a great impact on soil loss estimation and various scientists tried to relate the RUSLE soil loss estimation model with the land use

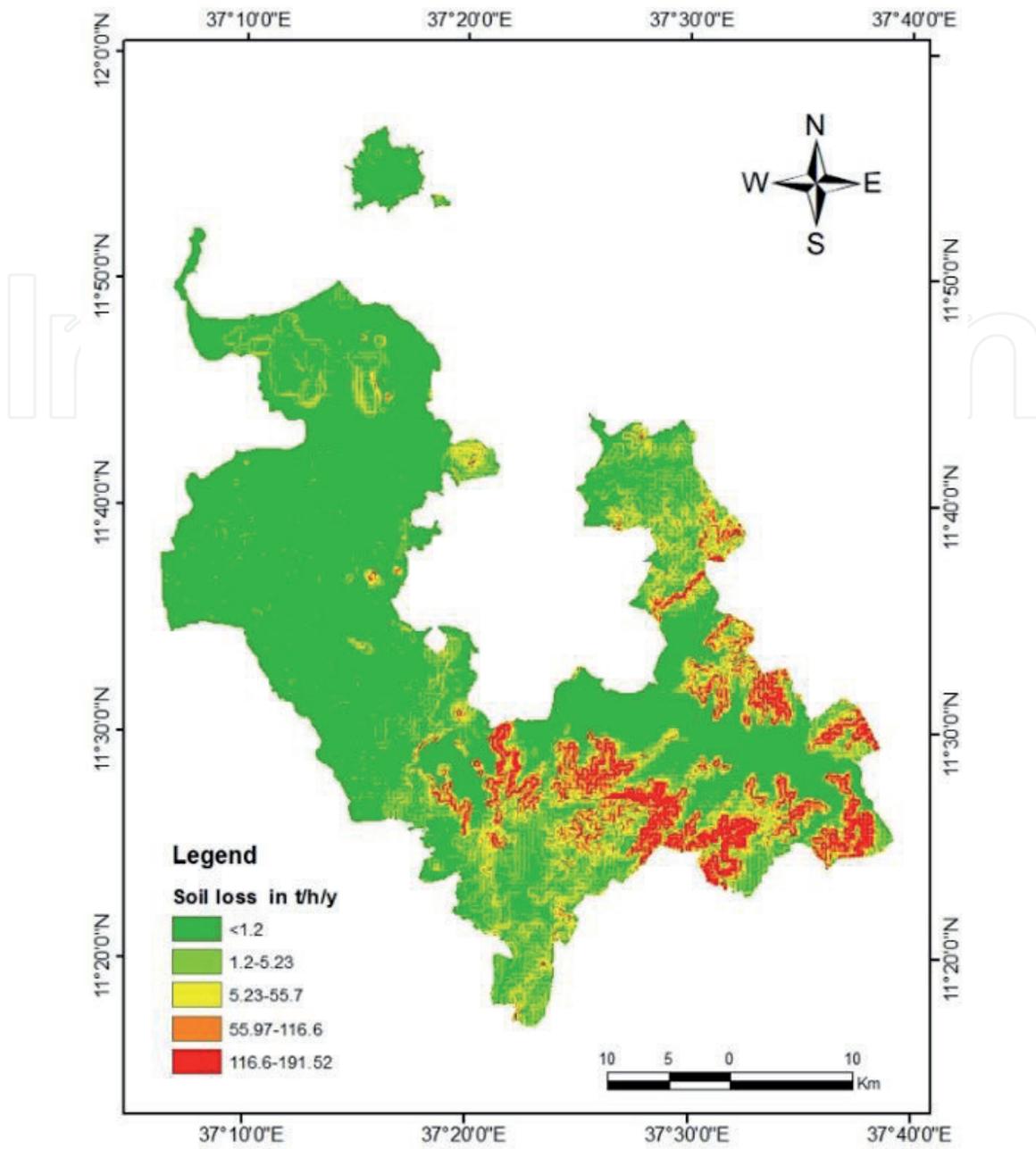


**Figure 12.**  
Conservation support practice factor map.

Slope %	Area (ha)	%	Soil loss in ton/ha/year
0–5	102,242	79.7	< 1.2
5–10	12,544.5	9.8	1.2–5.2
10–20	9062.3	7.1	5.2–6
20–30	3350.2	2.6	56–12
>30	1161.5	0.9	117–192

**Table 4.**  
Soil loss estimation based on the slope.

dynamics. As is presented in **Table 5** and **Figure 14**, the annual soil loss for cropland, vegetation, grassland, and degraded land was 19.05, 8.78, 8.82, and 71.16 ton/ha/yr., respectively. This means that the type of land cover has great relationships with the amount of soil loss. For example, the soil loss under cropland



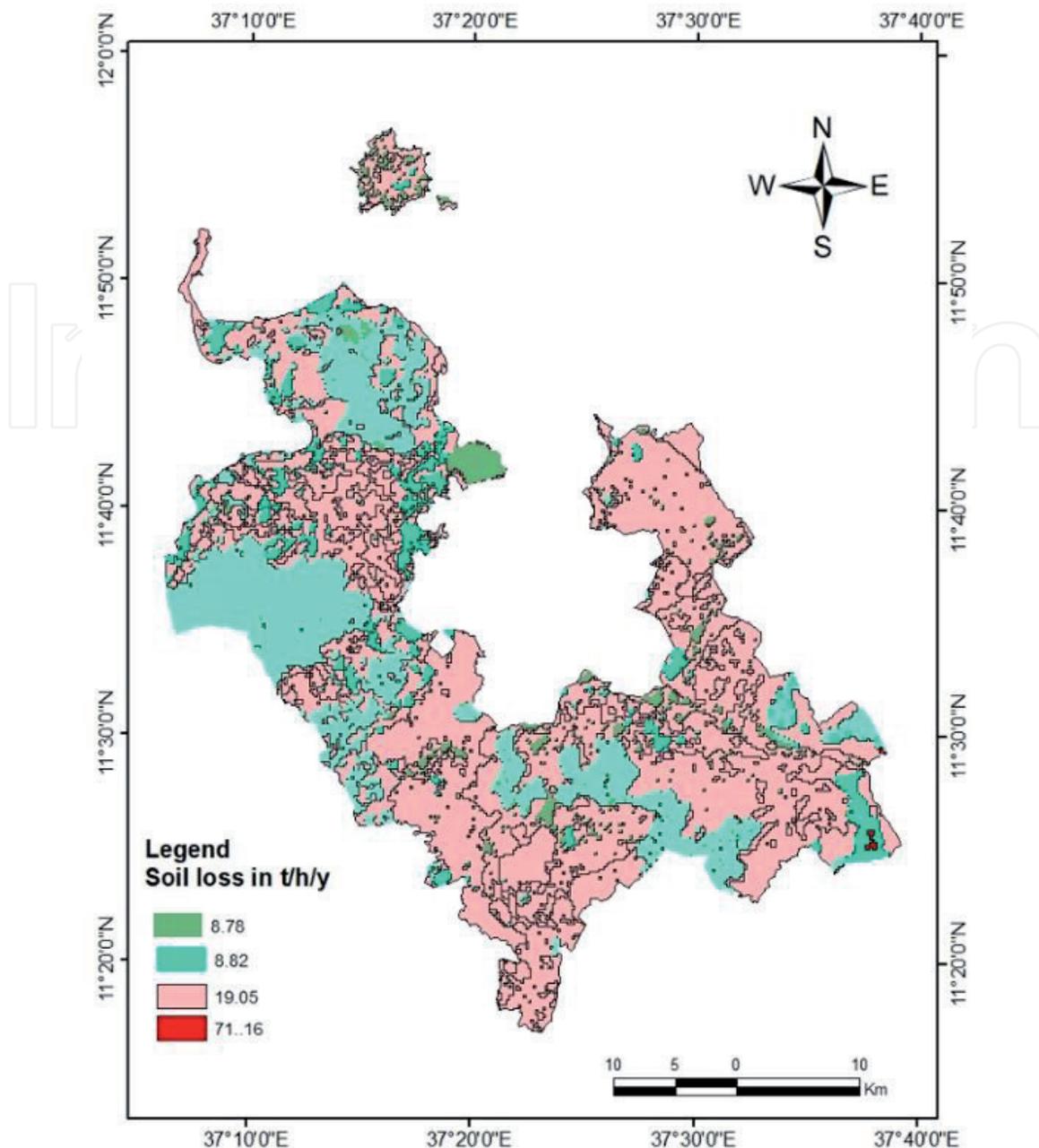
**Figure 13.**  
 Soil loss based on slope gradient.

Land use/land cover	Area (ha)	%	Annual soil loss in t/h/y
Crop land	68,218.6	53.15	19.05
Vegetation	11,861.2	9.24	8.78
Grass land	29,774.3	23.2	8.82
Degraded	17,315.4	13.49	71.16

**Table 5.**  
 Annual soil loss estimation for different land cover.

was more than the soil loss for vegetation and this means that areas covered with vegetations have less vulnerable to erosion than areas covered with crops.

Similarly, the soil loss for degraded land was greater than the grasslands, vegetation, and crops. On the contrary, vegetation cover and grasslands were more erosion resistant than croplands and degraded land.



**Figure 14.**  
Soil loss of some land cover types.

Our result agreed with the finding of Hurni [40] who studied the effect of different land use/land cover types on soil loss in Ethiopia. According to his report, the soil loss for cropland, grassland, totally degraded land, and bushland was 42, 5, 70, and 5 ton/ha/yr., respectively. Assen [36] reported that severely deforested and cultivated lands are more vulnerable to erosion, 18 ha of land was exposed to soil erosion every year and 95% of the gullies were also observed in cultivated land confirming the susceptibility of the area to water erosion in general.

Hurni [8] also reported that in Ethiopia cultivated land followed by severely deforested landform the major source of soil erosion. Moreover, Hurni [9] noted that differences in vegetation cover have been mainly responsible for the variation in erosion rates in the Ethiopian highlands. Morgan [39] reported that the differences in erosion rates caused by different land use practices on the same soil are much greater than the corresponding changes from different soils under the same land use.

Slope	Cropland		Vegetation		Grassland		Degraded land	
	Area (ha)	Soil loss in t/ha/y	Area (ha)	Soil loss in t/h/y	Area (ha)	Soil loss in t/ha/y	Area (ha)	Soil loss in t/ha/y
0–5	59373.2	<0.12	8255.1	<0.01	21526.9	<0.08	12605.7	<2.35
5–10	4999.9	0.12–0.8	1144.6	0.01–0.15	4198.2	0.08–0.5	2268.4	2.35–10
10–20	2460.7	0.8–4.97	1340.7	0.15–0.7	3513.4	0.5–1.6	1714.3	10–38
20–30	1090.3	4.97–13.77	761.5	0.7–2.6	119.1	1.6–5.2	588.7	38–111
>30	294.7	13.77–35.91	359.3	2.6–6.7	416.8	5.2–11	138.6	111–219

**Table 6.**  
Average annual soil loss based on slope and land cover.

### 3.1.6.3 Annual soil loss based on slope and land cover

The soil loss with the slope gradient can simply explain the effect of slope in soil erosion by taking the average value of other factors; even though, different land covers at different slope have a great impact on soil erosion [38]. In this study different land covers situated on different slopes with their relative area have been analyzed using Arc GIS 10.

As it is presented in **Table 6**, the same land cover but different slopes have different soil loss amount. For example, the amount of soil loss for cropland in different slopes (0–5 and > 30) varies between 0.117 and 35.91 ton/ha/yr., respectively. This indicated that land cover type can be greatly determined by slope difference.

In an experiment conducted in 2005 and 2006 cropping seasons in northern Ethiopia, a significant difference ( $p < 0.05$ ) in soil loss in wheat and *tef* cropped field was observed [41]. The soil loss reduction at wheat crop was 76% in permanent bed (PB) while 61% in Terwah (TERW) as compared to traditional tillage (TT). Therefore, land cover and slopes can determine the amount of soil loss in a particular area.

## 4. Conclusion and recommendations

This study assessed soil loss using a GIS-based RUSLE equation. The GIS-based RUSLE equation well estimated the amount of soil loss in our study areas, which resulted in comparable findings with other findings. The annual soil loss increased at LS and S factors compared with the other RUSLE factors. Compared with other land uses, barelands and croplands that found at the higher elevations generated more soil loss. It is found that lack of vegetative cover during the critical period of rainfall, expansion of croplands, and lack of support practices also increase soil erosion. The application of soil bund, area closure, contour tillage, terraces, and grass strip barriers are suggested to break the slope length into shorter distances, reducing overland flow velocity and soil erosion.

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