Estimating Landscape Vulnerability to Soil Erosion by RUSLE Model Using GIS and Remote Sensing: A Case of Zariema watershed, Northern Ethiopia

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Research

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ABSTRACT

***Background*:**

Zariema watershed located in the Tekeze basin Northern highlands of Ethiopia has been a subject to serious problem of soil erosion. Soil degradation due to soil erosion is one of the key environmental and socioeconomic case which threats soil nutrient depletion and food security in northern Ethiopian highlands. This study was conducted to estimate the soil loss rate and identify hotspot areas using RUSLE model in the Zariema watershed, Tekeze basin, Ethiopia.

Methods:

The rainfall – runoff erosivity(R) factor was determined from mean annual rainfall, soil erodibility(K) factor from soil map, Topographic factor (Ls) were generated from DEM, Crop management factor (C) and Conservation support practice factor(P) obtained from land use/land cover map. Finally, the factors were integrated with Arc GIS 10.3 tools to estimate soil loss rates and landscape vulnerability to soil erosion of the study watershed.

***Results*:**

Annual Soil losses rates were estimated to be between 0 ton ha^{-1} year^{-1} in plain areas and 989 ton ha^{-1} year^{-1} in steep slope areas of the study watershed. The total annual soil loss from the entire watershed area of 2239.33Sq. Km was about 3,603,895.23 tons. About 31.41% of the study areas were affected through the soil loss hazard which is above acceptable soil loss rate 11 ton ha^{-1} year^{-1}. The spatial hazard classification rate was 68.59% of the watershed area categorized as slight (0 – 11 ton ha^{-1} year^{-1}), 8.03% moderate (12 – 18 ton ha^{-1} year^{-1}), 7.64% high (19 – 30 ton ha^{-1} year^{-1}), 6.65% very high (31 – 50 ton ha^{-1} year^{-1}) and 9.09% severe (>51 ton ha^{-1} year^{-1}).

***Conclusion*:**

As a result, In the cultivation land around steep slope the soil loss rate was in sever condition. To mitigate the severity of the soil erosion in the identified prone area which accounts for about 31.41% *of the total watershed area immediate action of soil and water conservation required.*

***Keywords*:** *Soil loss, RUSLE, Zariema watershed, Tekeze, Ethiopia*

1. INTRODUCTION

Soil erosion has been considered as the most critical problems resulting in both onsite and offsite effects across the world [3, 46]. Soil erosion may arise due to human and natural activities, such as poor land use practice, poor soil conservation practice, overgrazing, high rainstorm, and steep slopes topography. These incidents resulted in harsh land degradation problems in the highlands of Ethiopia [7]. The worldwide annual rate of soil erosion from cultivated land ranges from 22 to 100 ton ha^{-1} and declines in crop yield as much as 15–30% annually [21, 29]. According to Morgan RP [29], soil erosion costs the US economy between US$30 billion and US$44 billion annually related to on-site which is the price of crop yield and crop land loss and off-site such as contamination and sedimentation of downstream water resources development and sources are affected by soil erosion.

Ethiopia ware threatened with soil erosion caused by water for continuous decades [10, 23, 24]. As Hurni 1985 [22], about 18 ton ha^{-1} year^{-1} soil loss's averagely each year. This problem is severe in the Ethiopian highlands [10, 14, 34]. 16-300 ton ha^{-1} year^{-1} soil was detached from the cultivation lands in the highlands of Ethiopia [23]. As a result of 1.9-3.5 billion tons of topsoil in Ethiopian highlands was lost due to severe soil erosion about 20,000–30,000 ha of agricultural land was taken out of production [11]. Due to soil erosion, poverty and, food insecurity are intense in rural areas [27]. Thus, consecutively to achieve food security, poverty reduction and environmental sustainability in the country reversing soil erosion is a high priority [2, 10].

Understanding of the soil erosion process and their interaction information on soil loss is very essential for planning and prioritizing of treatments of the watershed. Soil erosion assessment and mapping of soil erosion vulnerable area identification is helpful to understand soil conservation and ecosystem management methods in the study watershed. The mean annual soil loss information per unit land area could be determined by employing Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) [40]. While the USLE model Wischmeier & Smith, 1978 [42] was initially developed only for gentle sloping cropland situations; successive research's has lead to the RUSLE model [32], to incorporate soil loss assessment for variety of land use types and slope ranges like forest land, disturbed sites, and steep slopes. And that's increase the applicability of the models.

2. MATERIAL AND METHODS

Study area

Zariema watershed is found in the Tekeze basin and geographically located between 13°9′–13°52′N latitude and 37°22′–38°3′ E longitude). The watershed covers 2239.33Sq.Km area, with elevation ranging from 743 to 3292 m above sea level (Figure 1). Based on a dataset from five meteorological stations for the period from 2009 to 2017 (Table 3), the mean annual rainfall in the study region varied between 1137.8 mm in Debarik and 1606.4 mm in Ketema nigus.

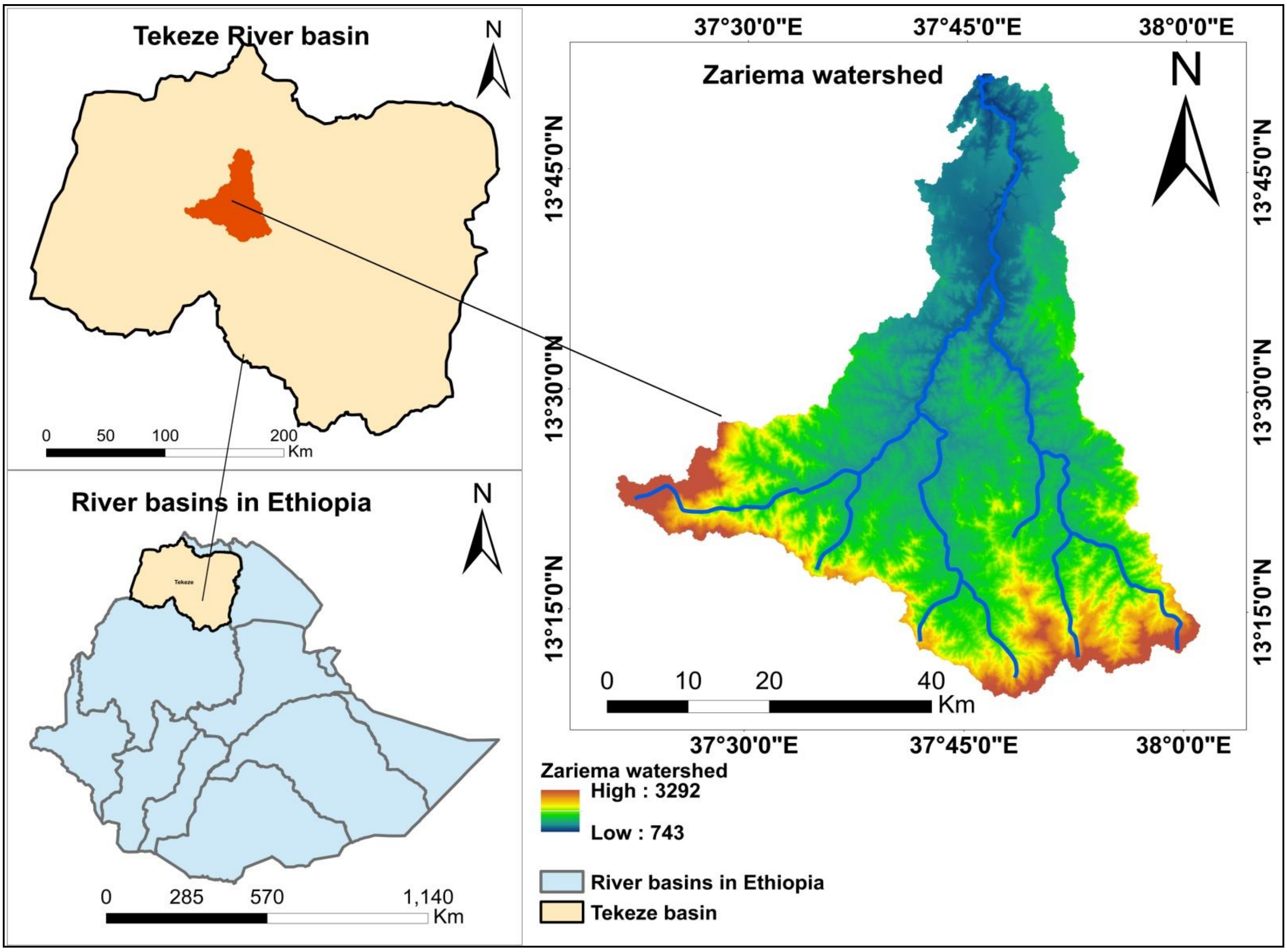

Figure 1 Location of Zariema Watershed

Data sources

The RUSLE model variables are estimated from different sources. Rainfall erosivity factor (R–value) was derived from annual rainfall data from the five meteorology station round the study watershed (Table 3). Soil erodibility factor (K–value) determined from FAO DSMW soil map. Slope length and slope gradient factor (LS–value) were obtained from the analysis of SRTMDEM with 20 m resolution. The crop factor (C) and conservation practice factor (P) are estimated by analyzing Land sat image and DEM (Figure 6, Figure 7).

Data collection and processing

Due to the present local condition mainly biophysical and land management variables, the extent of soil loss rate is varied for a given specific watershed [29, 33, 42]. The essential idea is the collection of spatial data is critical [26]. To the current study, the subsequent datasets were collected from different sources and processed using the predictable methods in ArcGIS 10.3 environment. The average yearly soil loss (ton ha^{-1} yr^{-1}) was estimated on a grid cell basis by multiplying the individual RUSLE factor values (R, K, LS, C, and P) interactively using the "Spatial Analyst Tool Map Algebra Raster Calculator" in Arc GIS environment.

$$A = R * K * LS * C * P \text{ .... (Eq. 1)}$$

Where A is the annual soil loss (ton ha^{-1} $year^{-1}$); R is the rainfall erosivity factor (MJ mm h^{-1} ha^{-1} $year^{-1}$); K is soil erodibility factor [Mg ha^{-1} MJ^{-1} mm^{-1}]; LS = slope length factor (dimensionless); C is management factor (dimensionless); and P is conservation practice factor (dimensionless).

Rainfall erosivity (R) factor

The rainfall erosivity factor measures the effect of rainfall impact and also reflects the quantity and rate of runoff likely to be related to rainfall events [43]. As Foster et al. 2003 [16] denoted, rainfall amount and intensity are considered because they are the most vital precipitation attributes and has greater annual variations too. R-correlation established by Hurni, 1985 [22] for Ethiopia (Eq.2) was adopted to compute R-factor value in ArcGIS raster calculator [5, 7, 19, 38]. R factor is calculated based on the available mean annual rainfall data (P) where:

$$R = -8.12 + (0.562 * P) \text{ .... (Eq. 2)}$$

The mean annual rainfall of the five stations obtained from the National Meteorological Agency was interpolated by inverse distance weighted (IDW) method to generate continuous rain fall data for every grid cell in Arc GIS10.3 environment. From the collected rainfall data from the stations around watershed, the R -value of every grid cell was calculated using (Eq. 2), and raster calculator geo–processing tool.

Soil erodibility factor (K)

As Wischmeier and Smith, 1978 [42] Soil erodibility (K), is the susceptibility of soil towards erosion, is extremely smitten by the natural properties of the soil. The K–factor is empirically determined for a specific soil type and reflects the physical and chemical properties of the soil, which contribute to its erodibility potential [6]. Soil map, in vector format, collected from Ethiopian Ministry of Water, Irrigation and Energy (MoWIE) was converted in to raster map using the Feature to Raster tool in ArcGIS 10.3. The K–factor value was then estimated by using a formula below (Eq. 4) adapted from Williams, 1995 [41] as follows in raster calculator:

$$K_{RUSLE} = f_{csand} * f_{cl-si} * f_{orgC} * f_{hisand} \text{ .... (Eq. 3)}$$

Where:

- fcsand is that the factor that gives low soil erodibility factors for soils with high coarse-sand contents and high values for soils with little sand,
- fcl-si is that the a factor that gives low soil erodibility factors for soils with high clay to silt ratios,
- forgC is that the a factor that reduces soil erodibility for soils with high organic carbon content and;
- fhisand is that the a factor that reduces soil erodibility for soils with extremely high sand contents. The factors are calculated as be (Eq. 4 – 7) [21, 30]:

$$f_{csand} = \left(0.2 + 0.3 * Exp\left[-0.256 * ms * \left(1 + \frac{m_{silt}}{100}\right)\right]\right) \text{ .... (Eq. 4)}$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} \text{ .... (Eq. 5)}$$

$$f_{orgC} = \left(1 - \frac{0.256 * 0rgC}{orgC + Exp[3.72 - 2.95 * orgC]}\right) \text{ .... (Eq. 6)}$$

$$f_{hisand} = \left(1 - \frac{0.7 * \left(1 - \frac{ms}{100}\right)}{\left(1 - \frac{ms}{100}\right) + Exp\left[5.51 + 22.9\left(1 - \frac{ms}{100}\right)\right]}\right) \text{ .... (Eq. 7)}$$

Where:
ms is that the percent sand content (0.05–2.00 mm diameter particles),
msilt is that the percent silt content (0.002- 0.05 mm diameter particles),
mc is that the percent clay content (< 0.002 mm diameter particles), and orgC is that the percent organic carbon content of the layer (%).

Topographic factor (LS)

In a particular area, the effect of topography on wearing away is represented by its slope length and steepness condition. In step with Wischmeier and Smith (1978) and Schmidt et al (2019) [35, 42], considering the 2 factors as one topographic factor, LS, is more convenient. The LS-factor is taken into account within the soil loss equation model because both the length and also the steepness of the slope significantly influence the speed of wearing away by water. The speed of abrasion by water is higher when the slope is steeper and longer, because of the greater accumulation of runoff [4, 37, 42].

$$L = (\boldsymbol{Flow\ Accumulation} * \boldsymbol{cell\ size}/22.1)^{m} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 8)}$$

$$S = (0..065 + 0.045s + 0.0065s^{2}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq. 9)}$$

In this study, the slope length (L) (Eq. 8) and slope steepness (S) (Eq. 9) factors were used to calculate and map the LS-factor (Eq. 8,

Figure 5) as has been applied by other studies like Shiferaw A. (2011) and Kamaludin et al. (2013) [25, 36]. The slope length and steepness values were drawn from the Digital elevation model (20 m resolution) using the ArcGIS Spatial analyst tool.

$$LS = (\boldsymbol{Flow\ Accumulation} * \boldsymbol{cell\ size}/22.1)^{m} * (0..065 + 0.045s + 0.0065s^{2}) \ldots\ldots \text{(Eq. 10)}$$

Where Flow accumulation is that the a grid theme of flow accumulation expressed as a number of grid cells while cell size is the length of a cell side in meter (i.e., 20 m), m is a fan that depends on slope steepness (Table 1) and S is slope gradient in percent.

Table 1 m – Values for a range of slope classes [42]

Slope class in percent	m - value
<1	0.2
1 - 3	0.3
3 - 5	0.4
>5	0.5

Cover (C) factor

The C-factor represents the effect of cropping and management practices on erosion rate. It has a close relation to land use/land cover types and is a reduction factor in soil erosion susceptibility. It is expressed as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled, continuous fallow. The vegetation type, stage of growth, and canopy percentage conditions are mainly affect the value of C factor.

The C-factor remains the foremost significant of the factors to reduce the threat of erosion on the landform. According to the case the techniques of cultivation and plant cover are the main factors depending directly in the human activity that might speed up or reduce erosion in step with the case. The corresponding C-values were allocated to every land use and land cover classes using reclassify tools in ArcGIS 10.3 environment. Finally, C-factors raster layer of the study area was created by assigning adapted C-value for every land use and land cover classes.

Support practice (P) factor

The erosion support practice factor is the ratio linking the soil losses estimated for a specific conservation practice to it of up and down slope plowing [42]. Thus, the P-factor for RUSLE can be mapped through by collecting data from field observations [10]. However, for the study area of Zariema watershed, there were no conservation measures, as data were lacking on permanent management practice and there were no management practices it is preferable to use the P-factor suggested by Wischmeier & Smith (1978) [42]. This method has also been employed in the highlands of Ethiopia by other researchers [21, 28, 39]. This method categorizes land covers into cultivated land, shrub land, and other land. P value was assigned 0.8 and 1 irrespective of their slope for shrub and other land use types. However, P-value for agricultural land was given cherish with respect to its slope, so sub-divided into six classes 0-5, 5-10, 10-20, 20-30, and > 50% [8, 20, 42, 44].

Table 2 Conservation practices factor (P-value) for the Zariema watershed

LULC	Slope in percent	P-Values	References
Cultivated land	0_5	0.1	[8, 20, 42, 44]
	5_10	0.12	
	10_20	0.14	
	20_30	0.19	
	30_50	0.25	
	>50	0.33	
Shrub land	All	0.8	
Other land		1	

Creation of soil erosion severity map

For the purpose of identifying priority areas, soil loss potential of the basin was categorized into five different severity classes as low (0 – 11 t $ha^{-1}year^{-1}$), moderate (12 – 18 t $ha^{-1}year^{-1}$), high (19 – 30 t $ha^{-1}year^{-1}$), very high (31 – 50 t ha^{-1} $year^{-1}$), sever (>51 t ha^{-1} $year^{-1}$) [18]. This classification is used to identify the priority of conserving the land against erosion hazard.

3. RESULTS AND DISCUSSION

RUSLE factor estimation and map derivation in this study, the RUSLE was integrated with GIS and remote sensing techniques to conduct cell-by-cell calculation of mean annual soil loss rate (ton $ha^{-1}year^{-1}$) and to identify and map soil erosion vulnerable areas in the watershed of Zariema maps of each RUSLE parameter derived from different data sources were developed and discussed as follows (Figure 2).

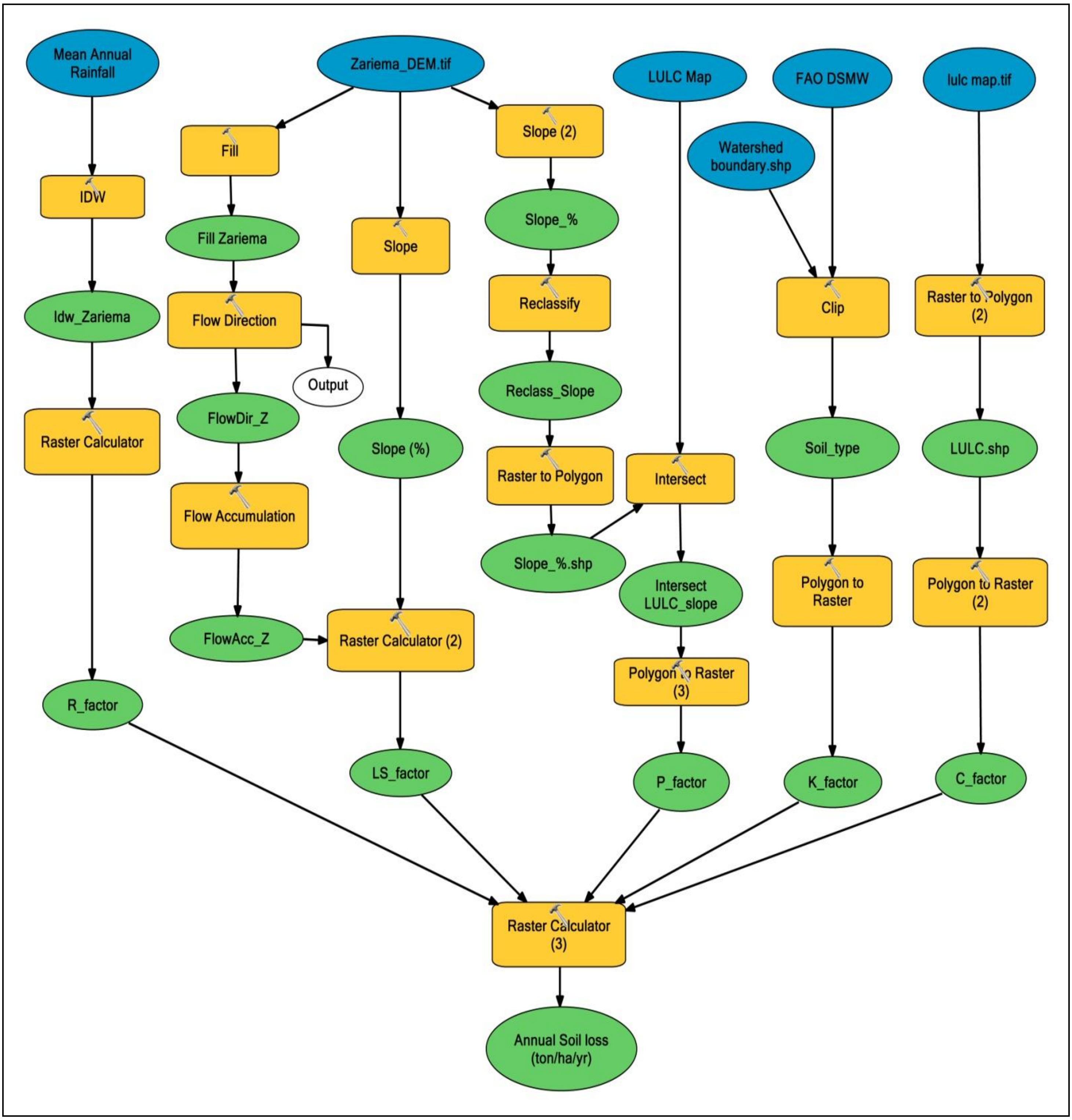

Figure 2 Summary of methods employed to estimate soil loss by RUSLE model of Zariema watershed

Rainfall erosivity (R) factor

The R-factor measures the impact of rainfall on erosion in MJ mm ha^{-1} h^{-1} $year^{-1}$. By the application of the inverse distance weighted (IDW) method in Arc-GIS 10.3 software, the R-factor values calculated for the five rain gauge stations have been used to produce the rainfall-runoff erosivity map of the study area. As (Table 3, Figure 3) the R-factor values obtained for the study watershed area varied from 634.25 MJ mm ha^{-1} h^{-1} $year^{-1}$, in the South western part of the watershed, 894.67 MJ mm ha^{-1} h^{-1} $year^{-1}$, in the eastern part of the watershed.

Table 3 Mean annual rainfall and R-factors of the five meteorological stations around Zariema watershed

Station	Location		Altitude	Mean annual rainfall(mm) (2009-2017)	R-factor
	Longitude	Latitude			
Zariema	378321.670	1475365.040	1227.0	1144.8	635.26
Adi Arkay	389641.715	1487430.059	1548.0	1225.2	680.44
Debark	380438.350	1453139.990	2836.0	1137.8	631.32
Ketema Nigus	327098.240	1481503.380	2868.0	1606.4	894.68
Adi Remets	317917.178	1520635.334	2013.8	1364.6	758.79

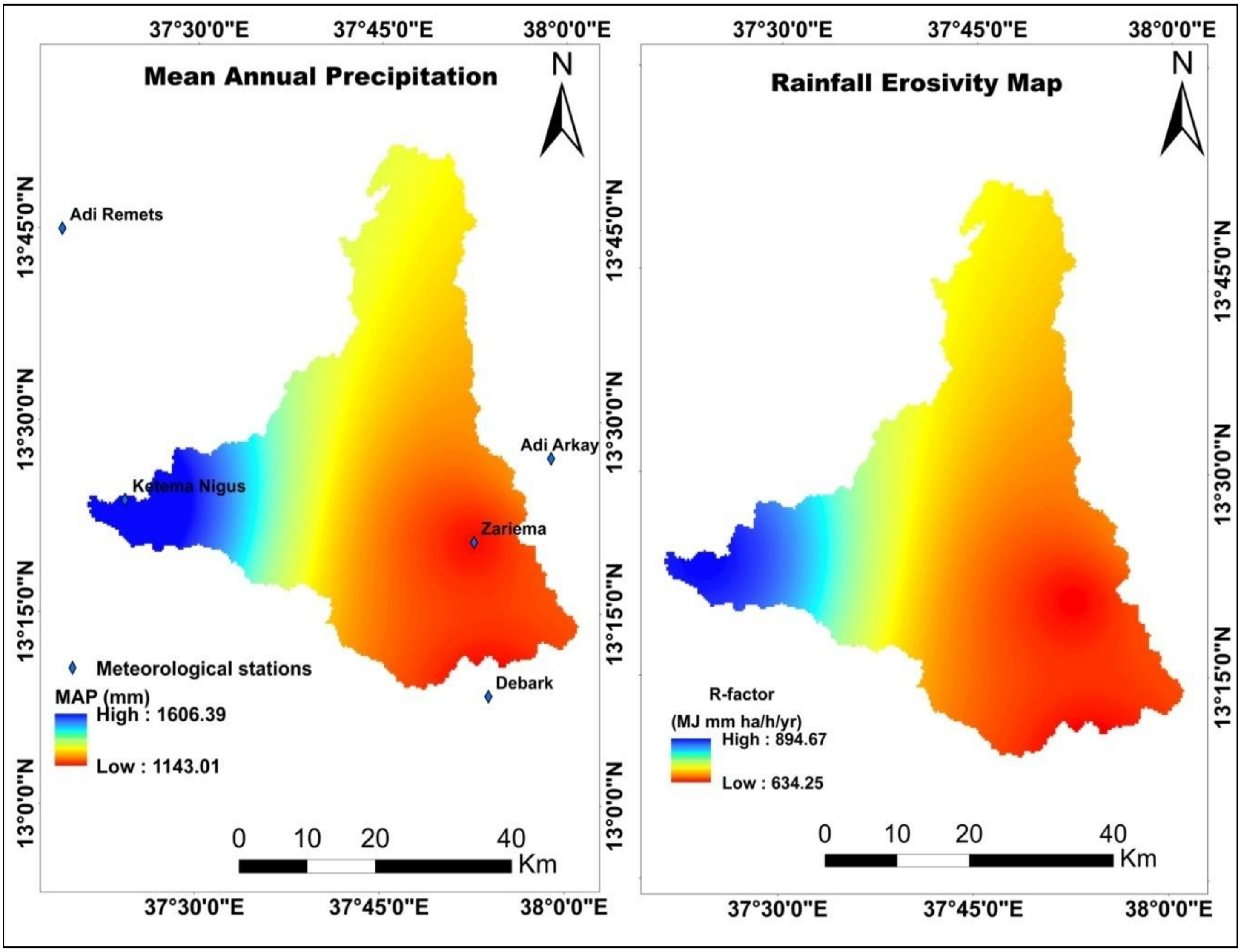

Figure 3 Mean annual precipitation and R-factor value

Soil Erodibility (K) factor

The main effect of soil detachment and transportation by the water is the physico-chemical properties of the soil**.** The K value in Zariema watershed ranged from 0.127 to 0.168 t ha $MJ^{-1}mm^{-1}$ (Figure 4). Most of the central part of the basin was dominated by Haplic Luvisols soil and characterized with high K value ranging from 0.162 to 0.168 t hr $MJ^{-1}mm^{-1}$; hence these soils are highly affected by water erosion. On the other hand, the left and right-down part is more of Dystric Leptosols and Humic Nitisols. These soils have a low to moderate K value ranging from 0.127 to 0.155 t hr $MJ^{-1}mm^{-1}$.

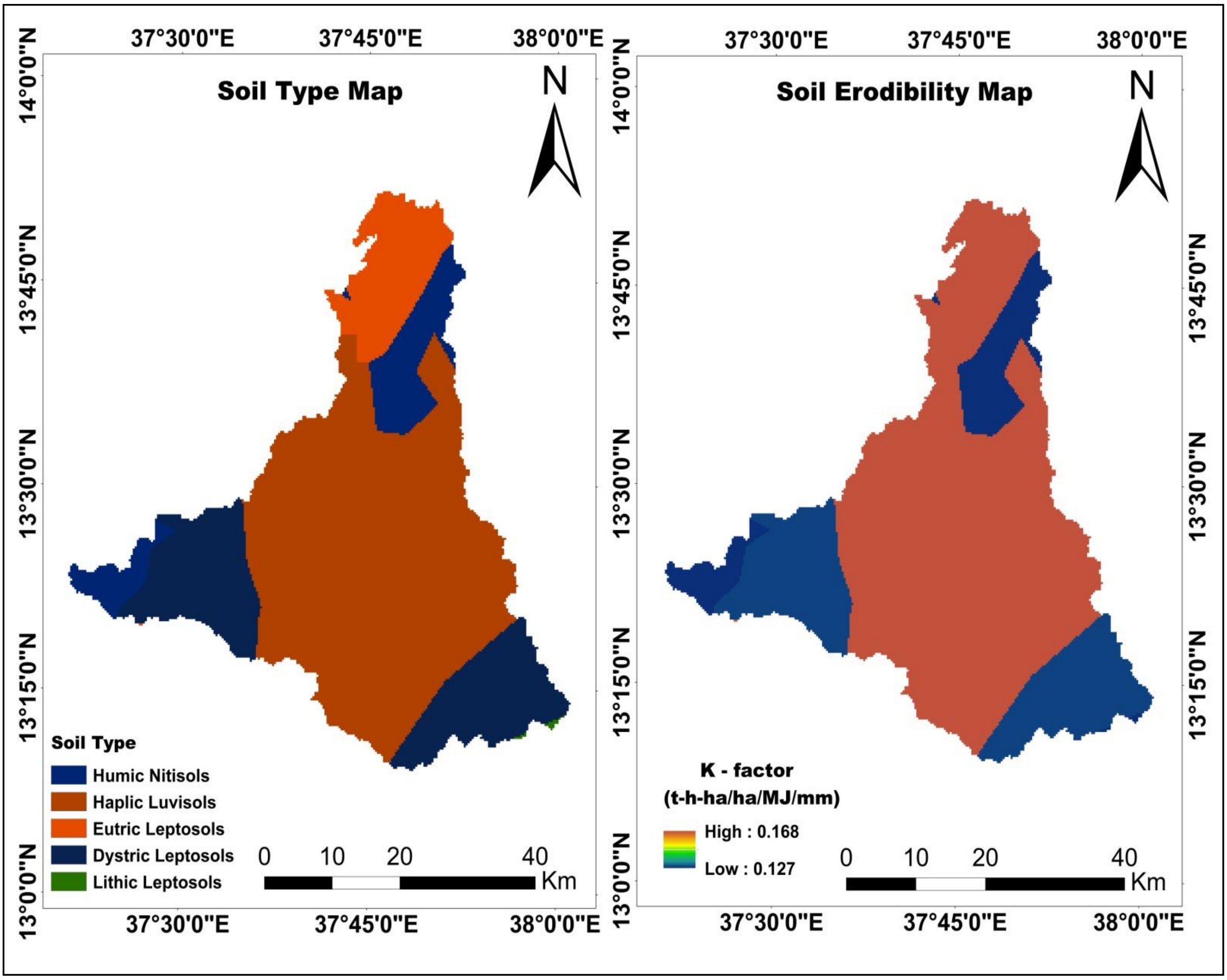

Figure 4 Soil type and soil erodibility (K) map

Topographic factor (LS)

The topographic factor represents that the consequence of slope length value and slope steepness value on soil loss process. LS factor was calculated by considering the flow accumulation and slope in percentage as an input. From the analysis, it’s observed that the value of topographic factor increases in an exceedingly range of 0 to 337.09 because the flow accumulation and slope increases (

Figure **5**). Mapping of m was undertaken by classifying the slope of the watershed in step with the m values presented in (Table 1) to run the equation. The resulting m map (

Figure **5** upper left side) designated that values of m vary from 0.2 in some parts of the watershed in Northern part to 0.5 in the majority parts of the watershed. The resulting slope length (L) map indicated that the slope length varied from 0 to 21.95 (

Figure **5** upper right side). The slope steepness (S) map demonstrate that the slope gradient ranged from 0to 22.58 in most part of the watershed and upper sloppy part of the watershed, respectively (

Figure **5** lower left side). Values for the combined LS-factor varied between 0 and 337.09 (

Figure **5** lower right side).

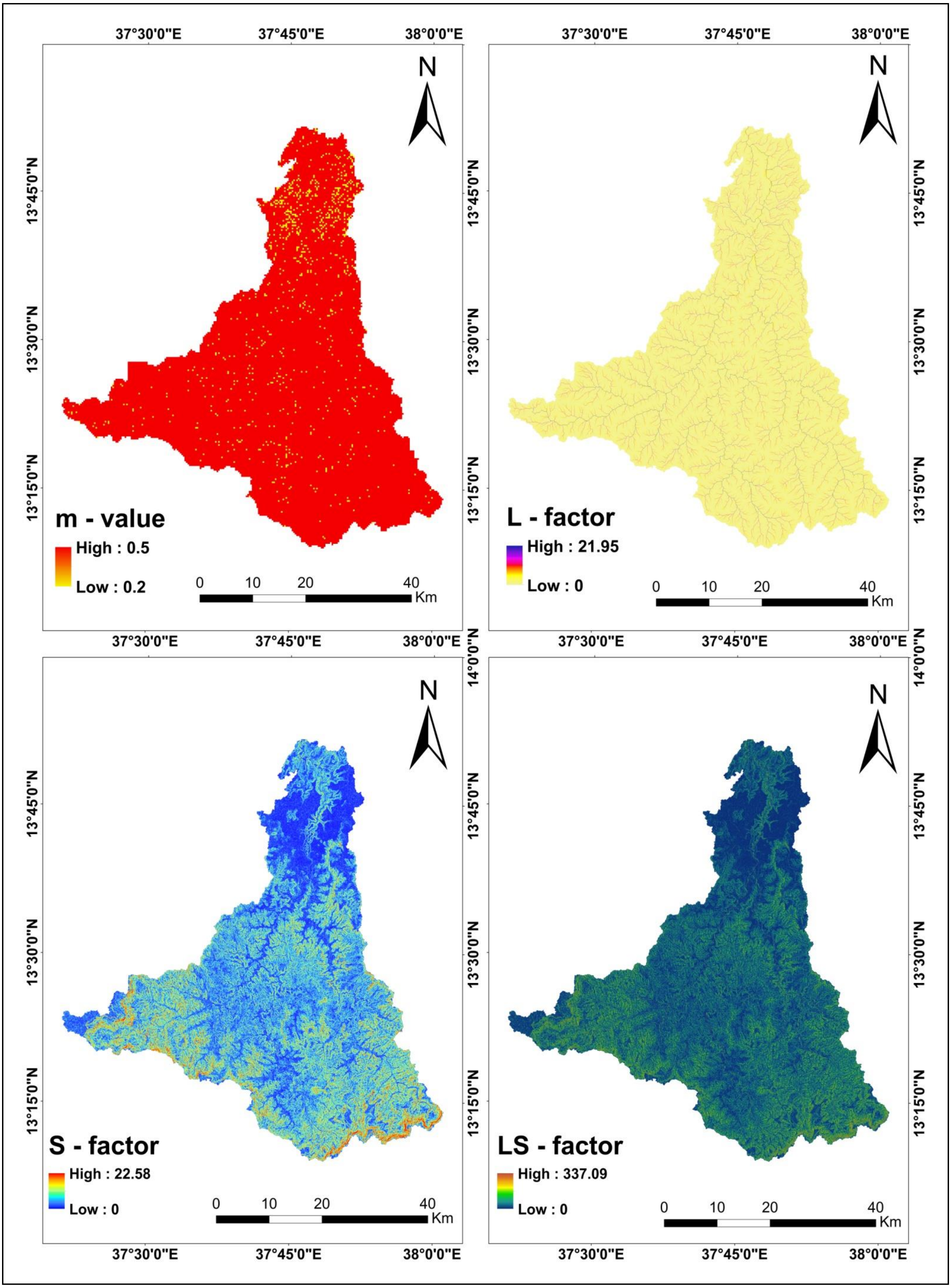

Figure 5- The m, L-factor, S-factor, and LS-factor maps of Zariema watershed

Land Cover (C) factor

Information onto land use permits a much better understanding of the land utilization aspects of cropping pattern, fallow land, forest, wasteland and surface water bodies, which are vital for developmental planning/erosion studies. Remote sensing and GIS technique has a potential to generate a thematic layer of land use-land cover of a watershed. The study area has been classified into six land use classes as forest land (291.48sq.Km), grassland (476.55sq.Km), shrub land (819.48sq.Km), tilled land (637.50sq.Km), water body (0.58sq.Km) and bare soil (13.73sq.Km). Crop management factor was assigned to different land use patterns using the values given in (Table 4). Using land use-land cover map and C factor value, the C factor map was prepared (Figure 6).

Table 4 Land cover classes and their distribution and C values for the Zariema watershed

LULC	Area (sq. Km)	C-Values	References
Forest land	291.48	0.001	[12, 22]
Grassland	476.55	0.05	[1, 10, 22, 29, 45]
Shrub land	819.48	0.014	[1, 18, 42]
Cultivated land	637.50	0.15	[10, 22]
Water body	0.58	0	[13, 31, 17]
Bare soil	13.73	1	[12, 20]
Total	2239.33		

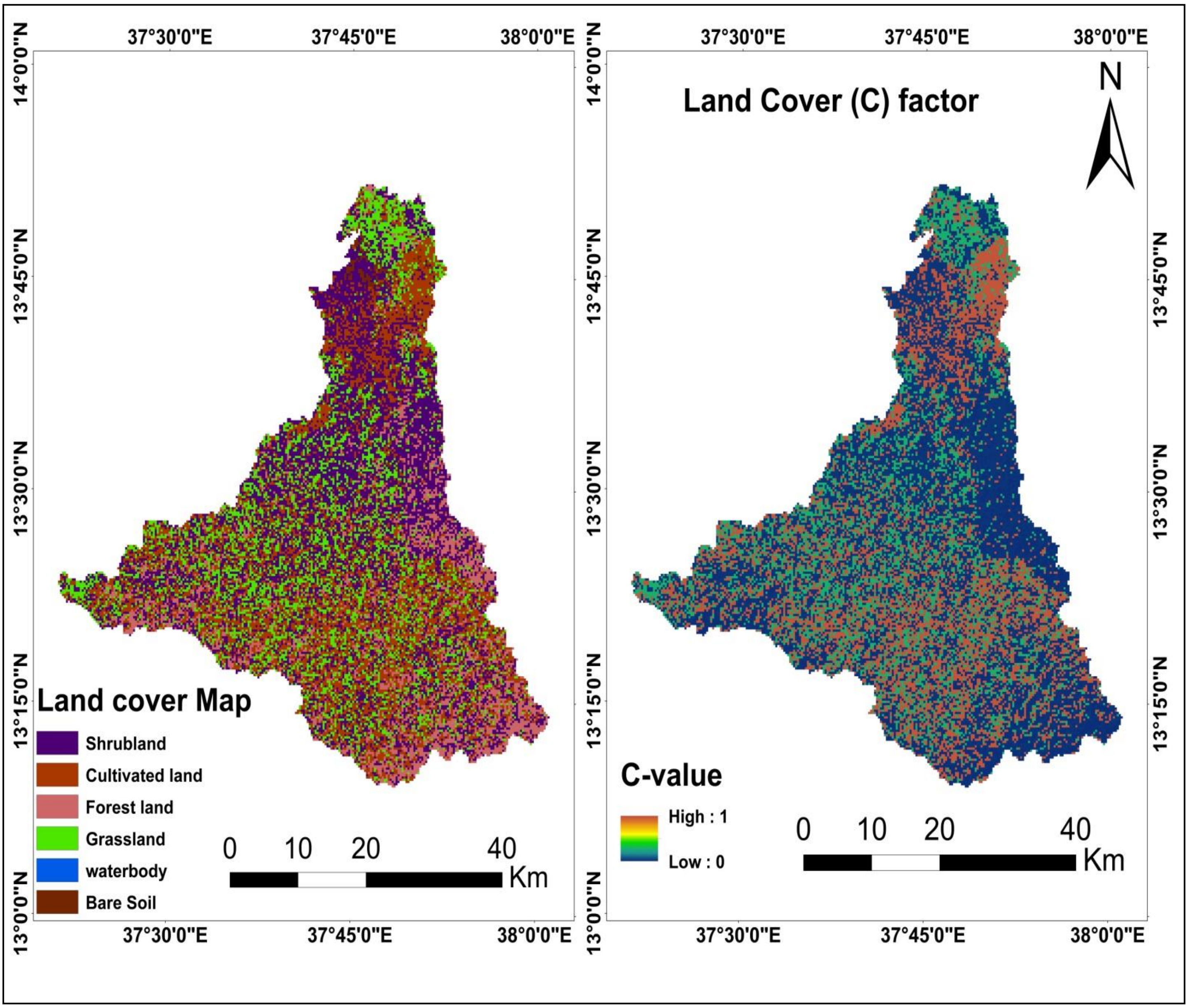

Figure 6 Land cover map and corresponding C-factor map of the Zariema watershed

Support practice (P) factor

The entire Land use/Land cover (LULC) of Zariema watershed was clustered in to Agricultural land where further classified into six slope class and given P-values, for shrub lands the P-value is given as 0.8 and land uses classified under forest, water body, grass land and bare land were clustered as other land uses given the P-value of 1(Table 2). The value of P factor for the current study is ranging from 0.1 to 1 as obtained from the correlation between the slope in percent and LULC. As the image seen below in (Figure 7), P value of 1 is observed in most of the watershed. On the positive hand, lesser P-value 0.1 is distributed on part the lower and central part of the watershed. The higher the P value, the more the realm is dominated by grass cover, shrub land and forest land where erosion management practice weren't implemented [**20**].

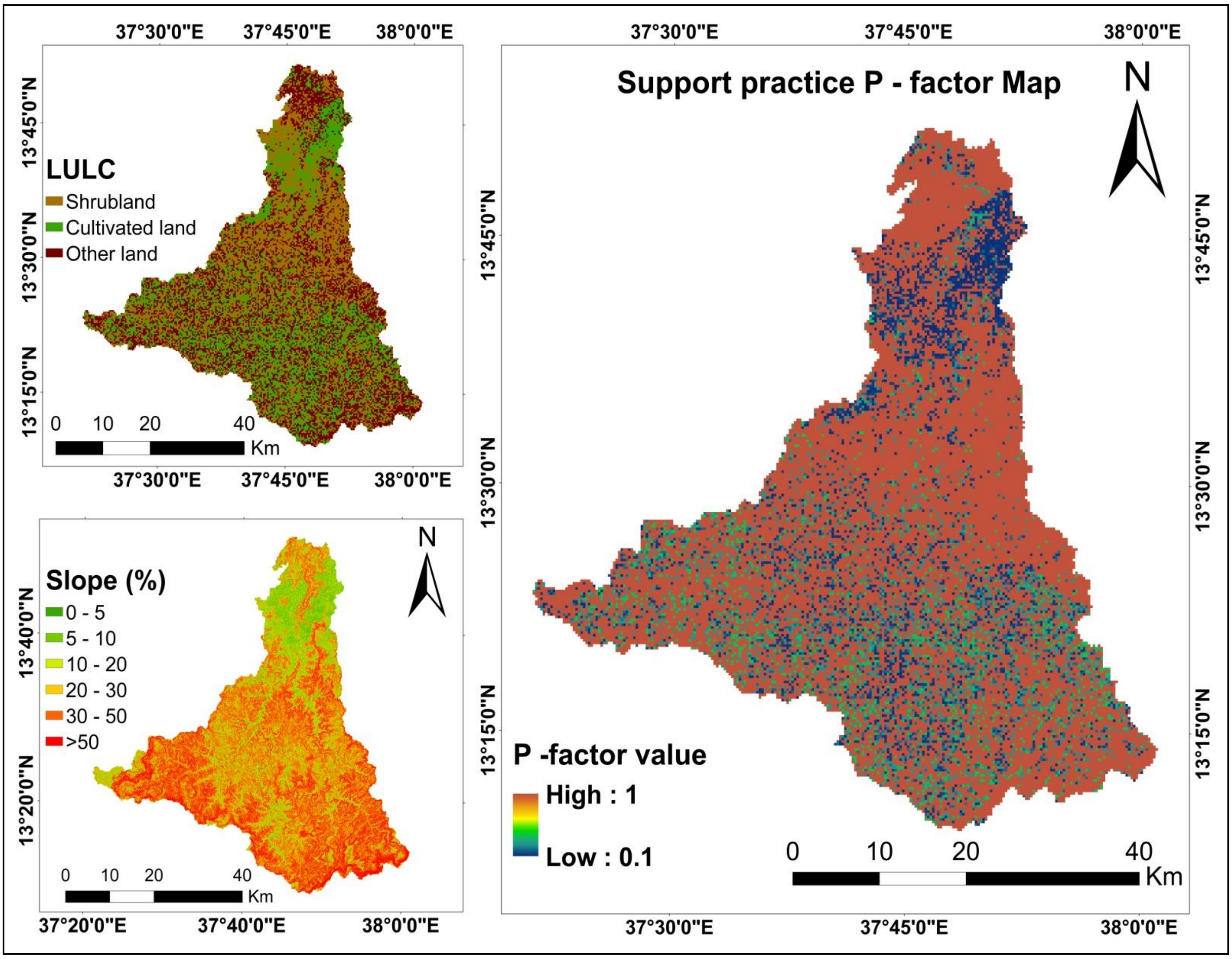

Figure 7 Reclassified (LULC and Slope (in percent)) and P-factor maps of the Zariema watershed

Soil erosion rate at the watershed scale

The factors of RUSLE were analyzed in ArcGIS 10.3 spatial analysis tool to calculate the spatiotemporal annual soil loss rate for the study watershed (Figure 2). The annual soil loss rate ranges between <11 ton ha^{-1} yr^{-1} to >51 ton ha^{-1} yr^{-1} (Figure 8 and Table 5). The estimated soil loss rate was divided into five severity class, which were adapted from [**18, 21**] like low (0 - 11 ton ha^{-1} yr^{-1}), moderate (12 - 18 ton ha^{-1} yr^{-1}), high (19 - 30 ton ha^{-1} yr^{-1}), very high (31 - 50 ton ha^{-1} yr^{-1}), sever (>50 ton ha^{-1} yr^{-1}).

Table 5 Annual soil loss rate, severity class, and annual soil loss and priority classes in the Zariema watershed

Soil loss rates (ton ha^{-1}yr^{-1})	Severity classes	area (km^2)	Percent of total	Estimated annual soil loss (ton)	Percent of total	Priority class for conservation
<11	Slight	1536.00	68.59	285738.2	7.93	V
12 to 18	Moderate	179.72	8.03	265882.2	7.38	IV
19 to 30	High	170.98	7.64	406388.0	11.28	III
31 to 50	Very high	149.03	6.65	583469.0	16.19	II
>51	Severe	203.61	9.09	2062417.9	57.23	I
Total		2239.33	100	3603895.2	100	

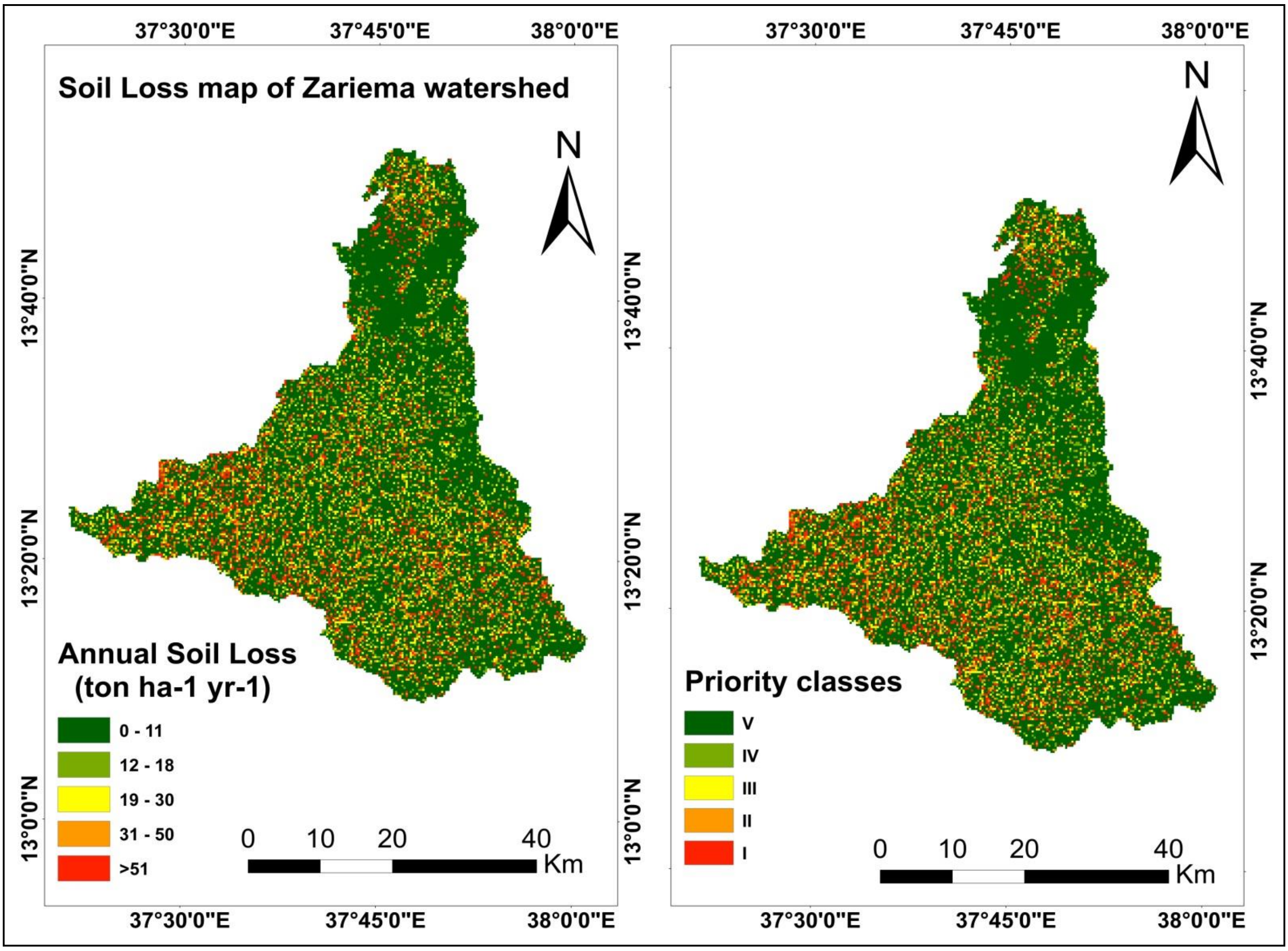

Figure 8 Annual soil loss and soil conservation priority classes map of Zariema watershed

The GIS-RUSLE based assessment shows that the annual soil loss value ranging from 0 in flat landscape to 989t ha^{-1} year^{-1} in the hilly landscape central area of the watershed and the extended southern part of the watershed (see Figure 8). The total annual soil loss from the entire watershed area of 2239.33ha was about 3,603,895.23tons. Regarding of the coverage to the risk of erosion, about 68.59% of the watershed is characterized low soil erosion rate, which is considered as slight risk areas. The remaining areas are grouped as moderate risk areas (8.03%), high risk areas (7.64%), very high risk areas (6.65%) and severely affected areas (9.09%) as presented in (Table 5). The mean annual soil loss rate projected for total watershed of 2239.33 Sq. Km area was 16.09 ton ha^{-1} yr^{-1} which is equivalent to other findings by Hurni [22] for the highland of Ethiopia (20 ton ha^{-1} yr^{-1}); by Amsalu and Mengaw (2014) [5] for the JabiTehinan watershed in the Northwestern Highlands (30.4 ton ha^{-1} yr^{-1}); by Ayalew and Selassie (2015) [9] for the Guang watershed in the Northwestern Ethiopia (24.95 ton ha^{-1} yr^{-1}); by L. Tamene et al. (2017) [38] for the Laelaywukro catchment in the Northern Highlands (20.8 ton ha^{-1} yr^{-1}); by Gashaw et al. (2017) [18] for the Geleda Watershed in the Northwestern Ethiopia (23.7 ton ha^{-1} yr^{-1}) and by Girmay et al. (2020) [21] for the Agewmariam watershed in the Northern Highlands (25 ton ha^{-1} yr^{-1}). Considering the tolerance limit of 10 t ha^{-1} yr^{-1}, the total area with a soil erosion risk higher than the soil loss tolerance was 31.41% of the watershed area which 703.33 Sq. km (see Table 5).

But, it is obvious that the decision on the tolerable level is depend on the local condition and in particular land use/land cover condition, the type and depth of soil, topographic feature and amount, intensity and duration of precipitation [15]. Due to the above causes similar studies undertaken in different parts of the northern highlands of Ethiopia reported that a higher average soil loss rates than the current Zariema watershed finding. For example, For the year 2013, 84 ton ha^{-1} yr^{-1} by Yihenew and yihenew [45] in Northwestern Ethiopia; 47 ton ha^{-1} yr^{-1} mean soil losses was recorded in Koga watershed, Northwestern Ethiopia ranged from 0 to 265 ton ha^{-1} yr^{-1} H.S. Gelagay, A.S. Minale, (2016) [19]; L. Tamene et al. (2017) [38], reported that the mean annual soil loss of 56, 44 and 20.8 ton ha^{-1} yr^{-1} in the northern Ethiopia (Adikenafiz, Gerebmihiz and Laelaywukro catchments); 37 ton ha^{-1} yr^{-1} by Yesuph and Dagnew (2019) [44] in Beshillo Catchment of the Blue Nile Basin; and 69 ton ha^{-1} yr^{-1} mean annual soil loss was recorded for e Omo-Gibe basin in the southern Ethiopia by Girma and Gebre (2020) [20]. So the estimated mean annual soil loss value for Zariema watershed and its spatial distribution is reasonable compared with the findings in the northern highlands of Ethiopia by applying similar analysis.

In the current study of Zariema watershed, high soil loss rates were recorded in the steeper slope areas of the watershed (Figure 8). The slope ranges from 0 to 584%. High erosion rates on steep slopes were also reported in other similar studies such as in Agewmariam watershed where the slope ranged between 0 to greater than 50% [21]. So, high soil loss was observed in high slope areas and sloppy cultivated land. Soil loss is high and the top layer of land surface gets eroded and transported simply due to the steepness of the land slope. This study result also conformed to similar results reported by Gashaw et al. 2017; Yesuph and Dagnew, 2019; Girmay et al. 2020) [18, 21, 44].

Approaches for validation of model results

The numerical data outputs of similar research works in the Ethiopian highlands were used to validate the model output because of there is no case studies to the specific area. As Table 6 below the estimated mean annual soil loss value for Zariema watershed which is 16.09ton ha^{-1} yr^{-1} is reasonable comparatively with other studies finding by applying similar analysis method in the Ethiopian highlands.

Table 6 relative table showing Estimated Soil Loss values from similar regions using similar method of soil loss analysis technique

Location	Soil Erosion Model Applied	Estimated Mean Annual Soil Loss (ton ha-1yr-1	References
Highlands of Ethiopia	RUSLE	20	[22]
JabiTehinan watershed	RUSLE	30.4	[5]
Guang watershed	USLE	24.95	[9]
Laelaywukro catchment	RUSLE-3D	20.8	[38]
Geleda watershed	RUSLE	23.7	[18]
Agewmariam watershed	USLE	25	[21]

4. CONCLUSIONS

In this study, the RUSLE model with GIS and remote sensing techniques is adopted for estimating the annual average soil loss in the Zariema watershed provided satisfactory results, and can be effectively used for estimating soil erosion in other similar watersheds. Annual Soil losses rates were estimated to be between 0 ton ha^{-1} year^{-1} in plain areas and 989 ton ha^{-1} year^{-1} in steep slope areas of the study watershed. The mean soil loss from the entire watershed was 16.09 ton ha^{-1} year^{-1} which is above the tolerable limit. High soil erosion rate is attributed in the cultivation land areas around steep slope and the soil loss rate was in severing condition. To mitigate the severity of the soil erosion in the identified prone area which accounts for about 31.41% of the total watershed area immediate action of soil and water conservation required. The watershed map of soil erosion hazard generated in this study gives reasonable estimations of annual soil loss in the Zariema watershed of the Tekeze Basin, which is useful for applying more efficient and successful soil and water conservation measures in general. Finally, the study confirmed that using RUSLE linking with GIS and remote sensing technique are crucial approaches to better estimate soil loss values, categorize and delineate erosion vulnerable areas of the study watershed, and prioritize the areas for successful planning of sustainable land management based on erosion severity levels in the watersheds.

Abbreviations

DEM: digital elevation model; FAO: Food and Agricultural Organization; GIS: Geographical Information Systems; ha: hectare; IDW: Inverse distance weighted; LULC: Land use land cover; RUSLE: Revised Universal soil loss equation; USLE: ton: tone; Universal soil loss equation; yr: year.

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Availability of relevant data and materials

All the required data utilized for analysis are incorporated in the manuscript. If the datasets used in the manuscript are not clear, the author is ready to clarify and even to send the data on request.

Competing interests

The author declares that have no competing interests with anyone else.

REFERENCES

1. Abate S. (2011). Estimating soil loss rates for soil conservation planning in the Borena woreda of South Wollo highlands. Ethiopia J Sustain Dev Afr 13(3):87–106

2. Teka, A.H., Tolosa, A.T, et al. (2018). Erosion Sensitivity Mapping Using GIS and Multi-Criteria Decision Approach in Ribb Watershed Upper Blue Nile, Ethiopia. International Journal of Energy and Environmental Science. Vol. 3, No. 6, 2018, pp. 99-111. https://doi.org/10.11648/j.ijees.2018.0306.11

3. Aiello A, Adamo M, Canora F (2015) Remote sensing and GIS to assess soil erosion with RUSLE3D and USPED at River Basin Scale in Southern Italy. CATENA 131:174–185. https://doi.org/10.1016/j.catena.2015.04.003

4. Alexakis DD, Hadjimitsis DG, Agapiou A. (2013). Integrated use of remote sensing, GIS, and precipitation data for the assessment of soil erosion rate in the catchment area of "Yialias" in Cyprus. Atmos Res. 2013;1(131):108–24.

5. Amsalu T, Mengaw A (2014) GIS based soil loss estimation using RUSLE model: the case of Jabi Tehinan Woreda, ANRS, Ethiopia. Nat Res 5:616–626. https://doi.org/10.4236/nr.2014.51105 4

6. Animka, S., Tirkey, P., & Nathawat, S. (2013). Use of satellite data, GIS and RUSLE for estimation of average annual soil loss in Daltonganj watershed of Jharkhand (India). Journal of Remote Sensing Technology, 1,1.

7. Andualem, T.G., Hagos, Y.G., Kefale, A. et al. (2020). Soil erosion-prone area identification using multi-criteria decision analysis in Ethiopian highlands. Model. Earth Syst. and Environ. 6, 1407–1418 (2020). https://doi.org/10.1007/s40808-00757-2

8. Asmamaw LB, Mohammed AA. (2019). Identification of soil erosion hotspot areas for sustainable land management in the Gerado catchment, North-eastern Ethiopia. Rem Sens Appl. 2019; 1(13):306–17.

9.Ayalew G, Selassie YG. (2015). Soil loss estimation for soil conservation planning using geographic information system in Guang atershed, Blue Nile basin. J Environ Earth Sci. 2015;5:126–34.

10. Bewket W, Teferi E (2009). 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 20:609–622

11. EFAP (Ethiopian Forestry Action Program) (1993) Ethiopian Forestry Action Program: the challenge for development, vol 2. Ministry of Natural Resources Development and Environmental Protection, Addis Ababa

12. El Jazouli, A., Barakat, A., Ghafiri, A. et al. (2017). Soil erosion modeled with USLE, GIS, and remote sensing: a case study of Ikkour watershed in Middle Atlas (Morocco). Geosci. Lett. 4, 25(2017). https://doi.org/10.1186/s40562-017-0091-6

13. Erdogan E, Erpul G, Bayramin I (2006). Use of USLE/GIS methodology for predicting soil loss in a semiarid agricultural watershed. Environ Monit Assess 131:153–161

14. FAO (1986) Ethiopian highlands reclamation study, Ethiopia. Final Report, Rome, FAO

15. Foster GR, Yoder DC, Weesies GA, McCool DK, McGregor KC, Bringer RL (2002) User's guide-revised universal soil loss equation version 2 (RUSLE 2). USDA-Agricultural Research Services, Washington, DC

16. Foster IDL, Chapman AS, Hodgkinson RM, Jones AR, Lees JA, Turner SE, Scott M (2003) Changing suspended sediment and particulate phosphorus loads and pathways in undertrained lowland agricultural catchments; Herefordshire and Worcestershire, U.K. In: Kronvang B (ed) The interactions between sediments and water. Developments in hydrobiology, vol 169. Springer, Dordrecht, pp 119–126 10.1007/978-94-017-3366-3_17

17. Ganasri BP, Ramesh H (2015) Assessment of soil erosion by RUSLE model using remote sensing and GIS—a case study of Nethravathi Basin. Geosci Front. doi:10.1016/j.gsf.2015.10.007

18. Gashaw T, Taffa T, Mekuria A (2017) Erosion risk assessment for prioritization of conservation measures in Geleda watershed Blue Nile basin, Ethiopia. Environ Syst Res. https://doi.org/10.1186/s40068-016-0078-x

19. Gelagay HS, Minale AS (2016) Soil loss estimation using GIS and remote sensing techniques: a case of Koga watershed international soil and water conservation research Northwestern Ethiopia. Int Soil Water Conserv Res. 4(2):126–136

20. Girma, R., Gebre, E. (2020). Spatial modeling of erosion hotspots using GIS-RUSLE interference in Omo-Gibe river basin, Southern Ethiopia: implication for soil and water conservation planning. Environ Syst Res 9, 19 (2020). https://doi.org/10.1186/s40068-020-00180-7

21. Girmay, G., Moges, A. & Muluneh, A. (2020). Estimation of soil loss rate using the USLE model for Agewmariam watershed, northern Ethiopia. Agric & Food Secur 9, 9 (2020). https://doi.org/10.1186/s40066-020-00262-w

22. Hurni H (1985) Erosion-productivity-conservation systems in Ethiopia. In: Proceedings of paper presented at the 4th international conference on soil conservation, Maracay, Venezuela, pp 654-674

23. Hurni H (1988) Degradation and conservation of the resources in the Ethiopian Highlands. Mt Res Dev 8:123–130

24. Kebede W, Habitamu T, Efrem G, Fantaw Y (2015) Soil erosion risk assessment in the Chaleleka wetland watershed, Central rift valley of Ethiopia. Environ Syst Res 4(5):1–12

25. Kamaludin H, Lihan T, Rahman Z, Mustapha M, Idris W, Rahim S (2013) Integration of remote sensing, RUSLE and GIS to model potential soil loss and sediment yield (SY). Hydrol Earth Syst Sci Discuss 10:4567–4596

26. Lulseged T, Zenebe A, Ermias A, Tesfaye Y (2017) Estimating landscape susceptibility to soil erosion using a GIS-based approach in Northern Ethiopia. Int Soil Water Conserv Res 5:221–230. https://doi.org/10.1016/j.iswcr .2017.05.002

27. Ministry of Agriculture and Rural Development (MoARD) (2010) Ethiopia's Agricultural Sector Policy and Investment Framework (PIF) 2010–2020. Draft Final Report, p 39

28. Molla T, Sisheber B. (2017). Estimating soil erosion risk and evaluating erosion control measures for soil conservation planning at Koga watershed in the highlands of Ethiopia. Solid Earth. 2017;8(1):13

29. Morgan RPC (2005). Soil erosion and conservation, 3rd edn. Hoboken, Black-well Publishing Company

30. Neitsch SL et al (2002). Soil and water assessment tool (SWAT) user's manual, version 2000, Grassland Soil and Water Research Laboratory. Blackland Research Center, Texas Agricultural Experiment Station, Texas Water Resources Institute, Texas Water Resources Institute, College Station, Texas

31. Prasannakumar V, Vijith H, Abinod S, Geetha N (2012). Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. Geosci Front 3(2):209–215

32. Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC (1996). Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). United States Department of Agriculture, Handbook No. 703, p 384

33. Renard, K., Foster, G., Weesies, G., McCool, D., Yoder, D., (1997). Predicting Soil Erosion by Water: a Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). US Government Printing Office, Washington, DC.

34. Reusing M, Schneider T, Ammer U (2000). Modeling soil loss rates in the Ethiopian highlands by integration of high resolution MOMS-02/D2-stereo-data in a GIS. Int J Remote Sensing 21(9):1885–1896

35. Schmidt S, Tresch S, Meusburgere K (2019). Modification of the RUSLE slope length and steepness factor (LS-factor) based on rainfall experiments at steep alpine grasslands. MethodsX 6:219–229. https://doi.org/10.1016/j.mex.2019.01.004

36. Shiferaw A. (2011). Estimating soil loss rates for soil conservation planning in the Borena Woreda of South Wollo Highlands, Ethiopia. J Sustain Develop Africa. 2011;13(3):87–106.

37. Tadesse A, Abebe M (2014). GIS based soil loss estimation using RUSLE model: the case of Jabi Tehinan Woreda ANRS, and Ethiopia. Nat Res 5:616–626

38. Tamene L, Adimassu Z, Aynekulu E, Yaekob T (2017). Estimating landscape susceptibility to soil erosion using a GIS-based approach in Northern Ethiopia. Int Soil Water Conserv Res 5(3):221-230. https://doi.org/10.1016/j.iswcr.2017.05.002

39. Tiruneh G, Ayalew M. (2015). Soil loss estimation using geographic information system in enfraz watershed for soil conservation planning in highlands of Ethiopia. Int J Agric Res Innovat Technol. 2015; 5(2):21–30.

40. Van Remortel, R., Hamilton, M., & Hickey, R. (2001). Estimating the LS factor for RUSLE through iterative slope length processing of digital elevation data. Journal of Cartography, 30(1), 27–35.

41. Williams JR (1995). Chapter 25. The EPIC model. In computer models of watershed hydrology. Water Resources Publications, Highlands Ranch, pp 909–1000

42. Wischmeier WH, Smith DD (1978). Predicting rainfall erosion losses: a guide to conservation planning. United States Department of Agriculture, Handbook No. 537, p 58

43. Xu, Y., Shao, X., Kong, X., Peng, J., & Cai, Y. (2008). Adapting the RUSLE and GIS to model soil erosion risk in a mountains karst watershed, Guizhou Province, China. Environmental Monitoring and Assessment, 141, 275–286.

44. Yesuph, A.Y., Dagnew, A.B. (2019). Soil erosion mapping and severity analysis based on RUSLE model and local perception in the Bashillo Catchment of the Blue Nile Basin, Ethiopia. Environ Syst Res 8, 17 (2019). https://doi.org/10.1186/s40068-019-0145-1

45. Yihenew G, Yihenew B (2013). Costs of nutrient losses in priceless soils eroded from the highlands of Northwestern Ethiopia. J Agric Sci 5(7):1916–9752

46. Zhou W, Wu B (2008). Assessment of soil erosion and sediment delivery ratio using remote sensing and GIS: a case study of upstream Chaobaihe River catchment, north China. Int J Sedim Res 23:167–173

Figures

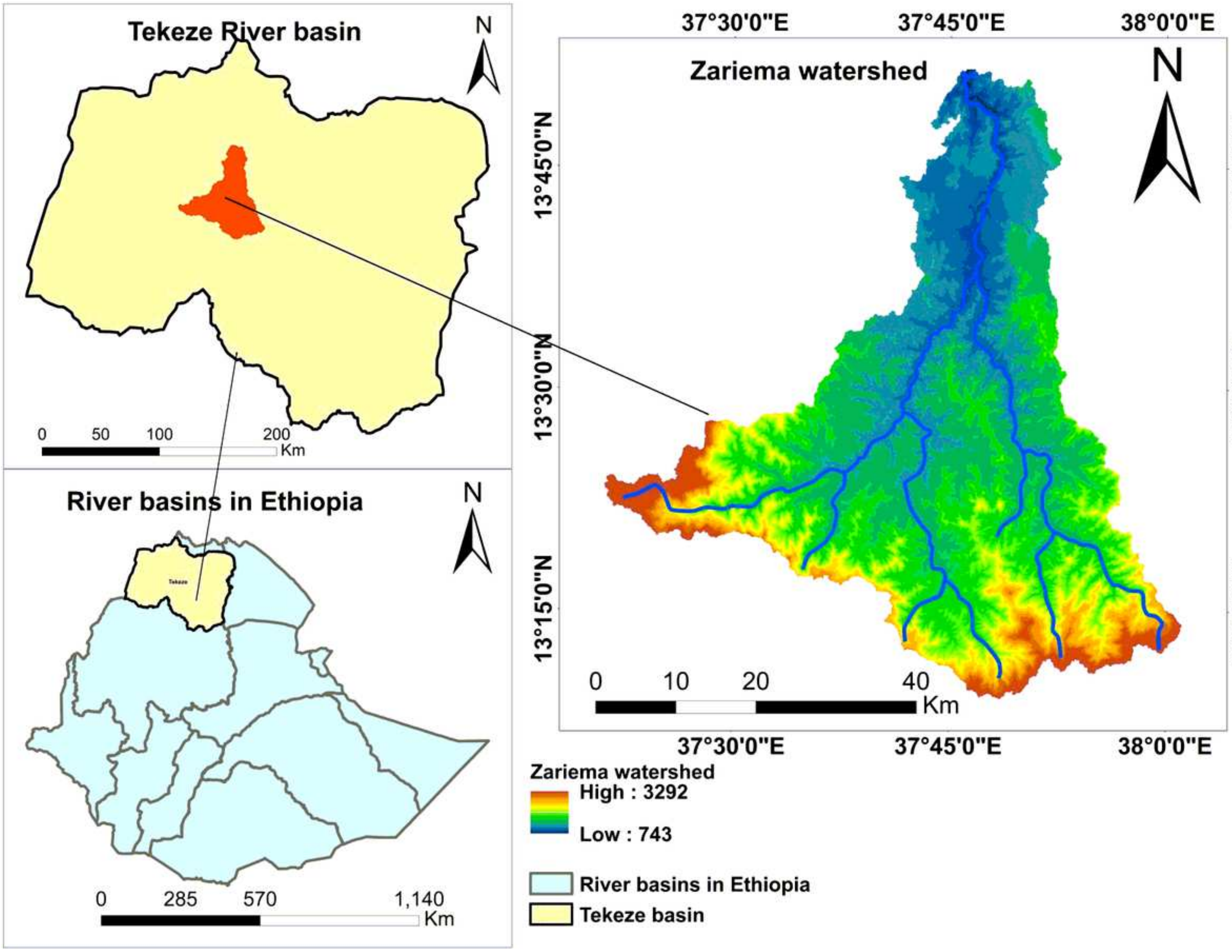

Figure 1

Location of Zariema Watershed Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

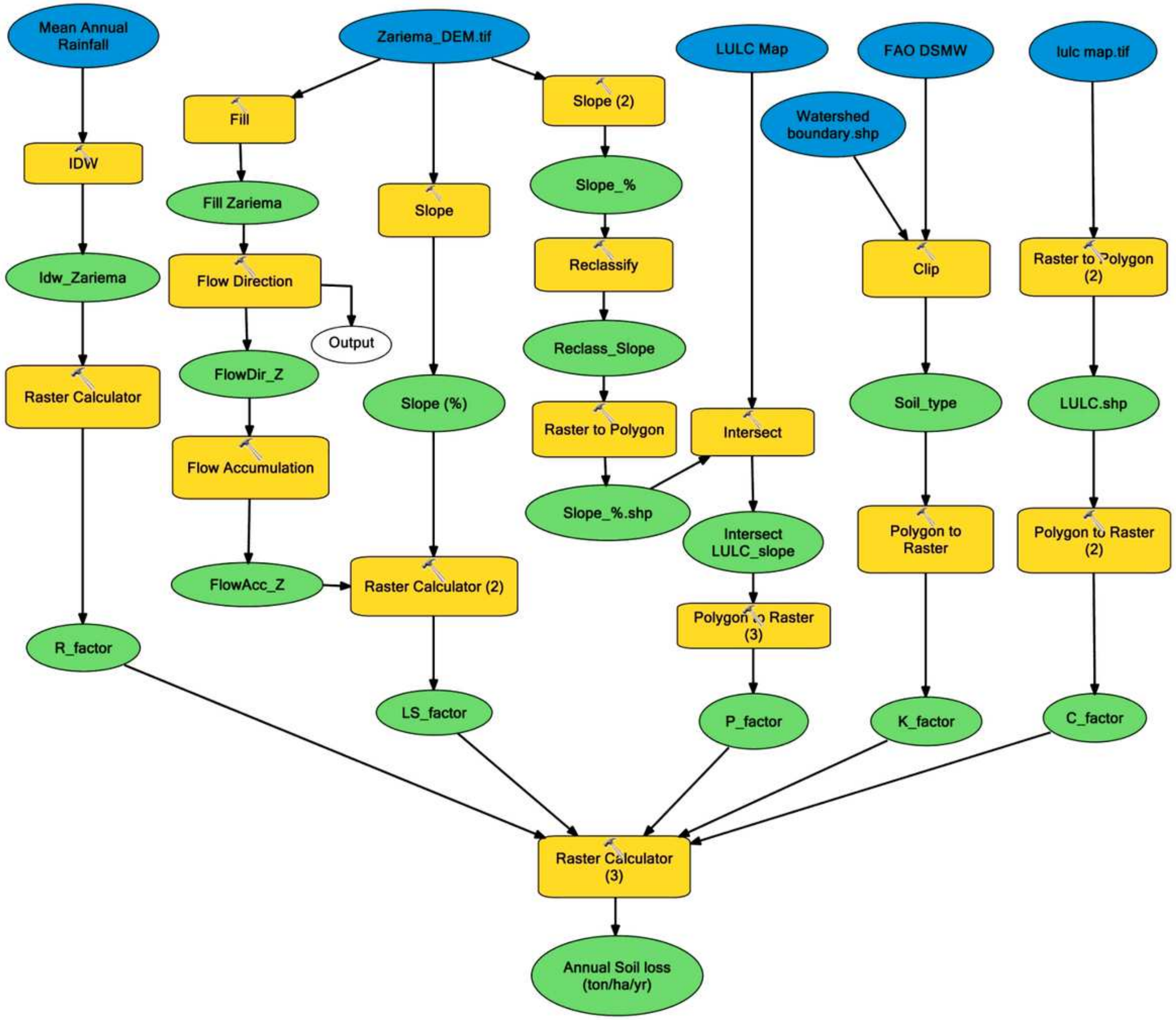

Figure 2

Summary of methods employed to estimate soil loss by RUSLE model of Zariema watershed

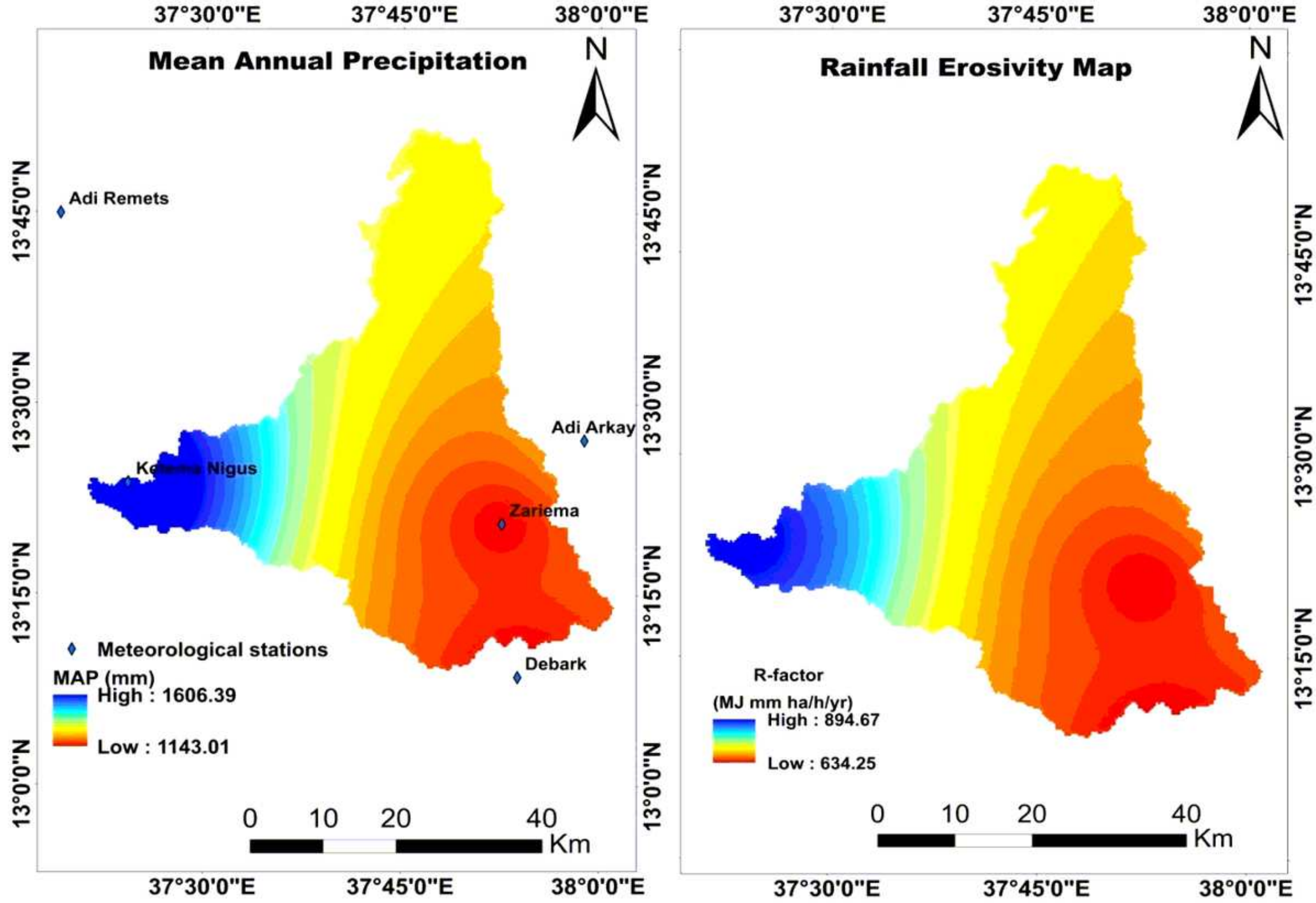

Figure 3

Mean annual precipitation and R-factor value Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

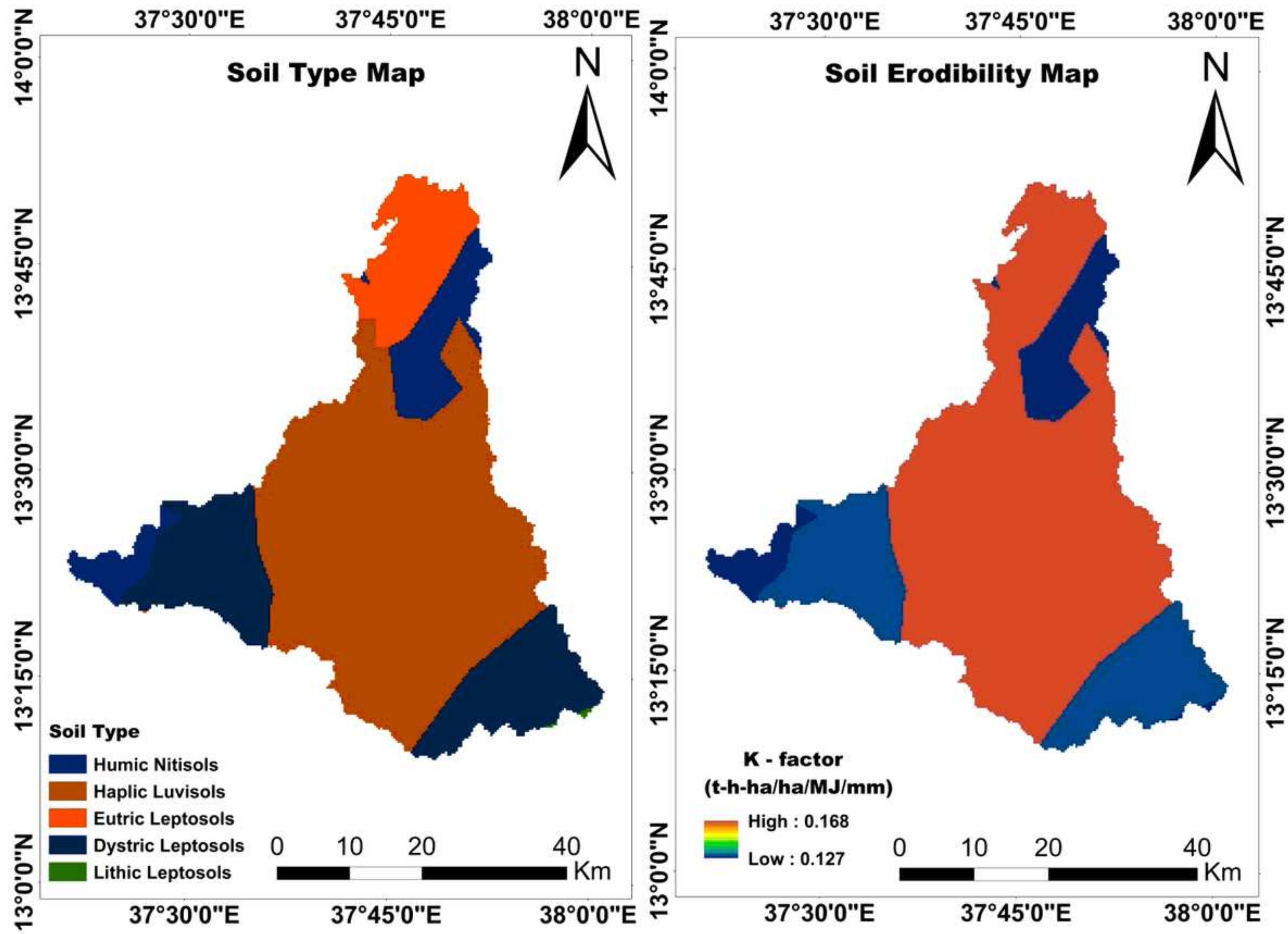

Figure 4

Soil type and soil erodibility (K) map Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

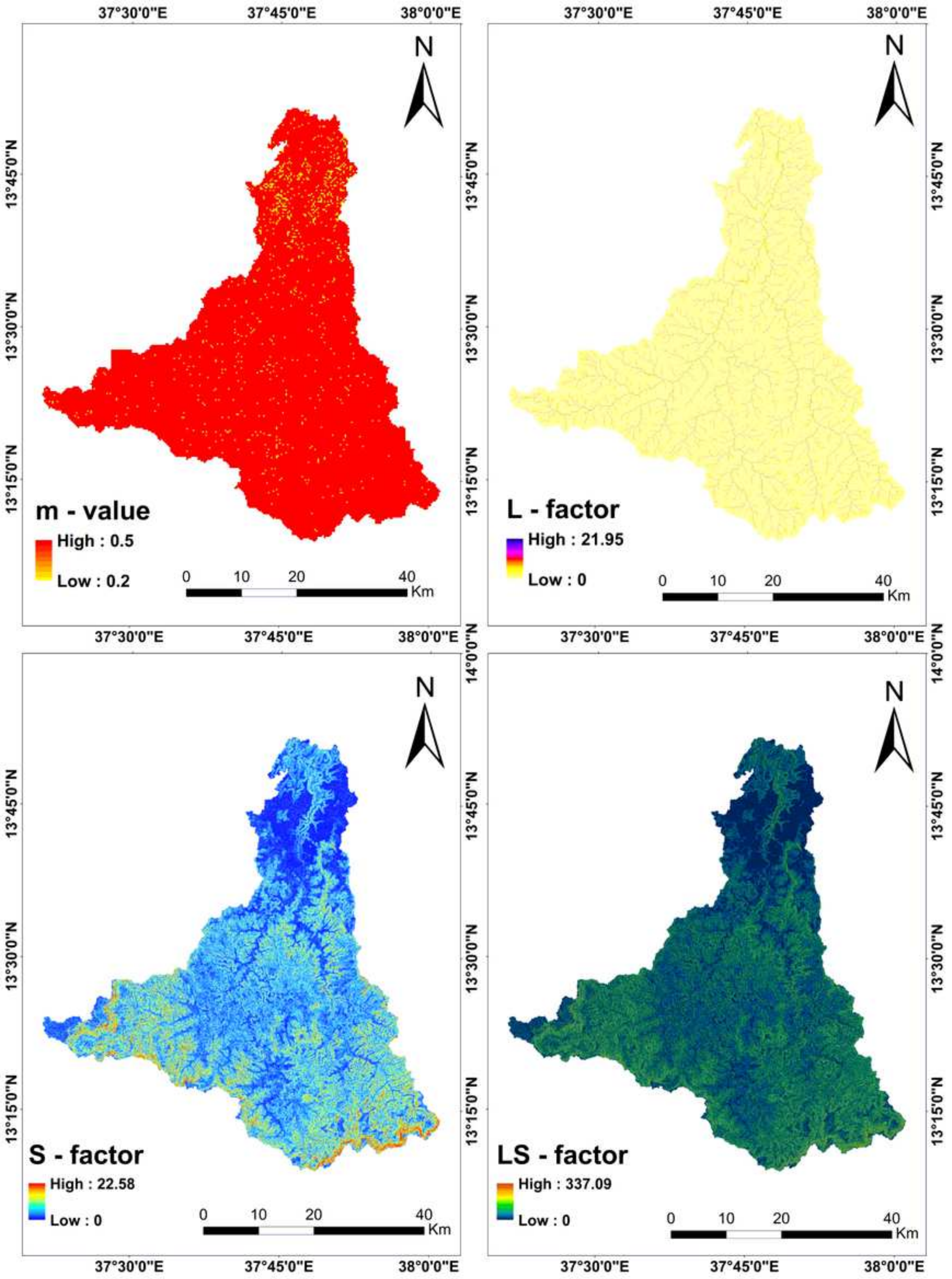

Figure 5

The m, L-factor, S-factor, and LS-factor maps of Zariema watershed Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

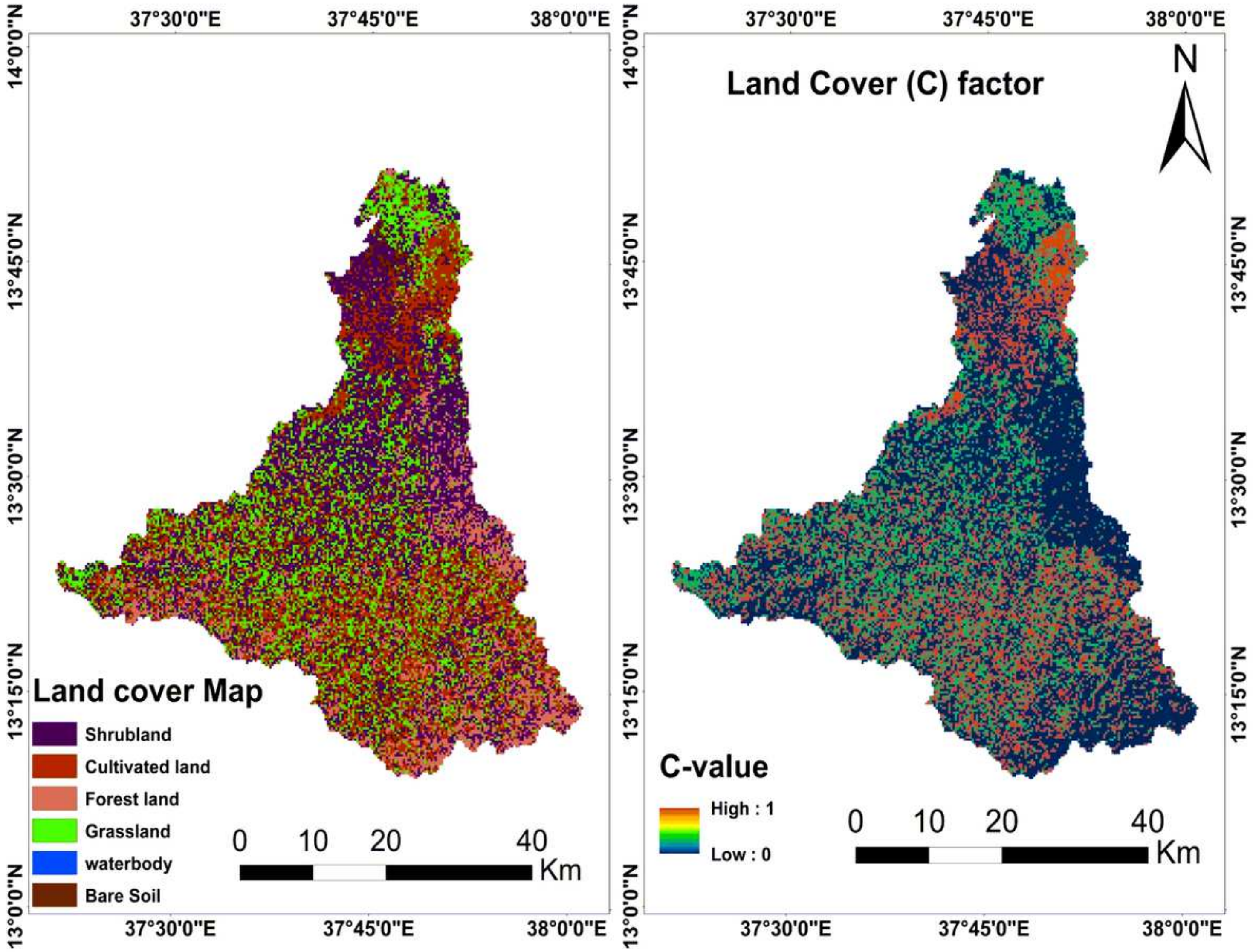

Figure 6

Land cover map and corresponding C-factor map of the Zariema watershed Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

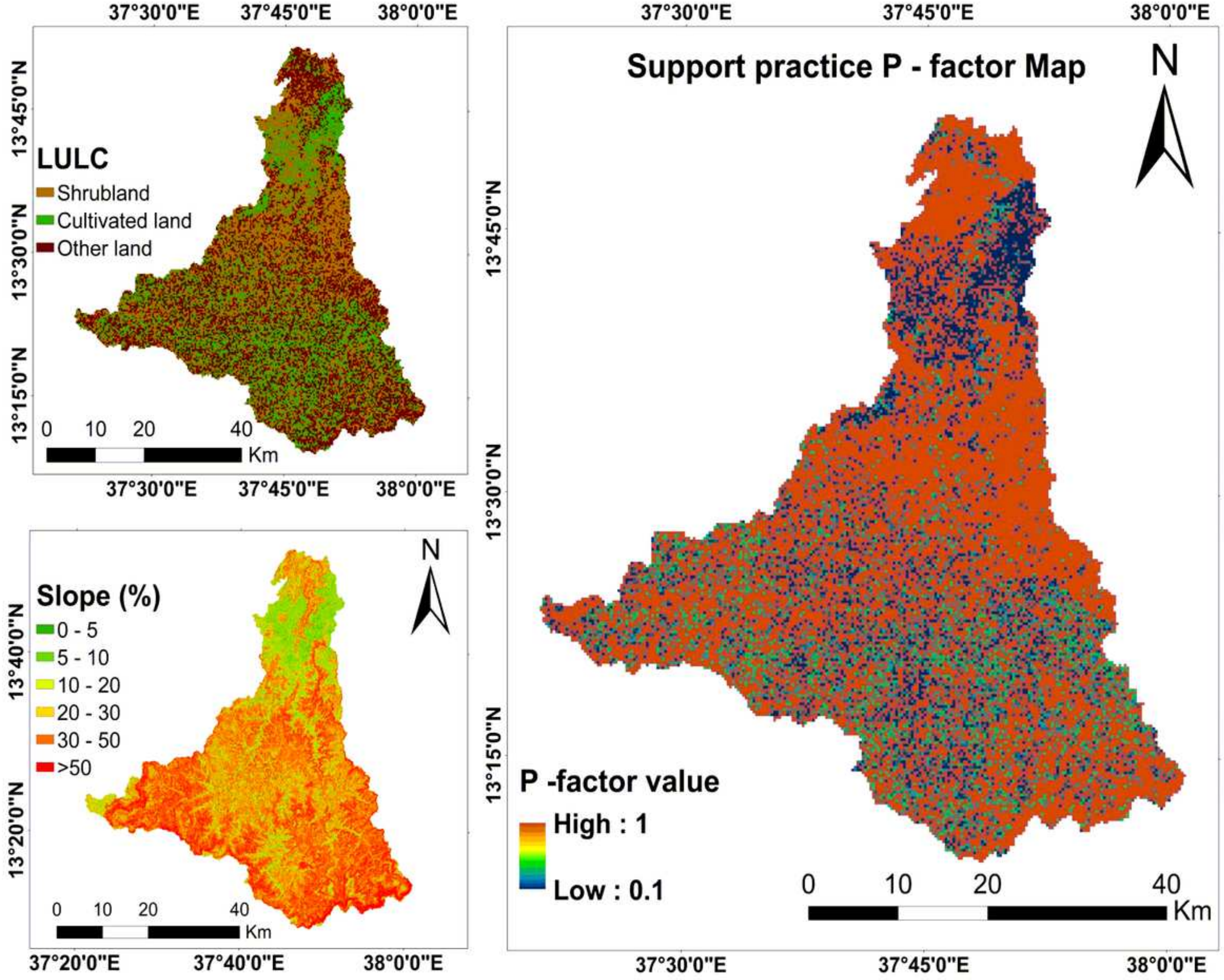

Figure 7

Reclassified (LULC and Slope (in percent)) and P-factor maps of the Zariema watershed Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

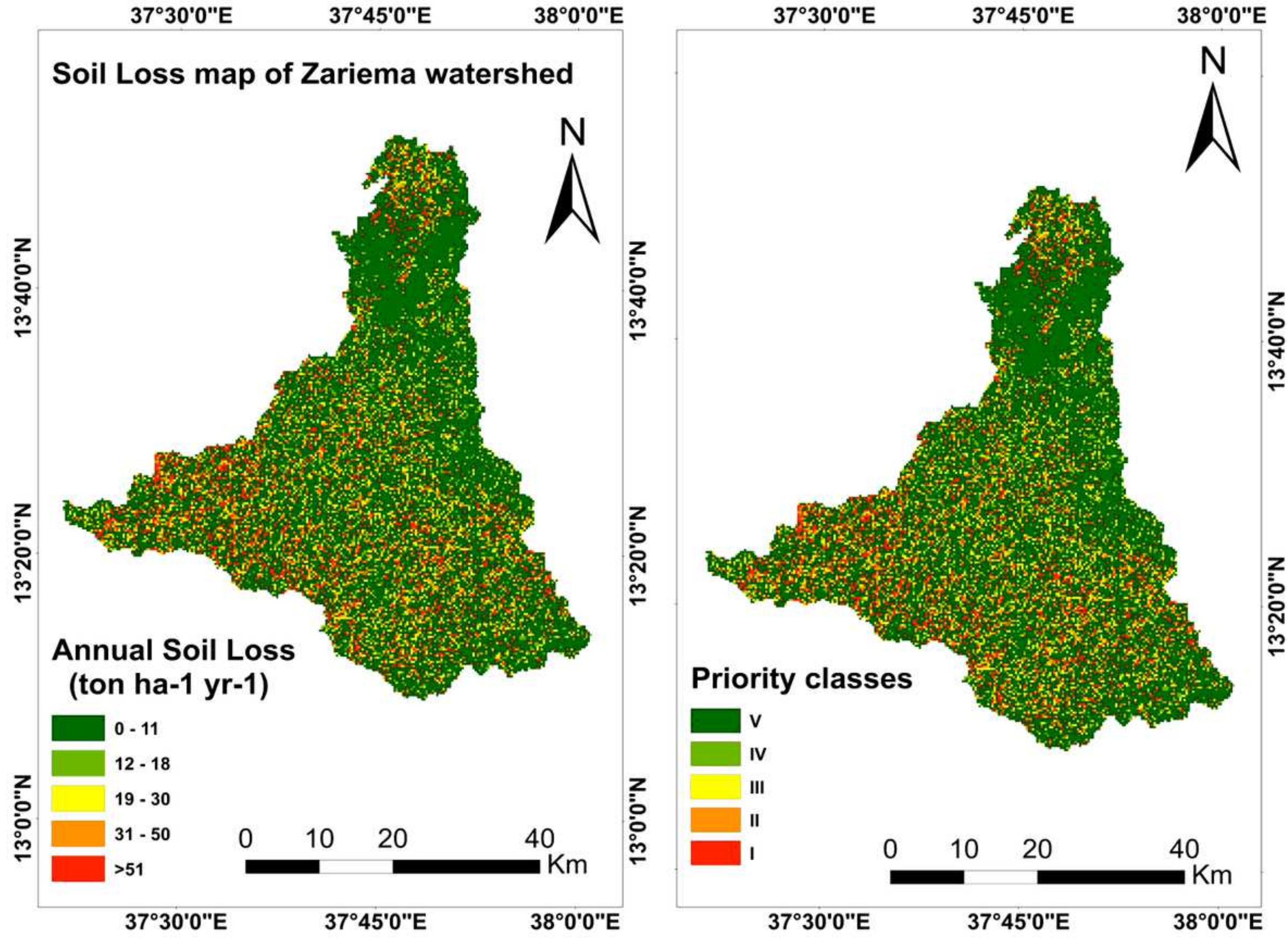

Figure 8

Annual soil loss and soil conservation priority classes map of Zariema watershed Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.