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ORIGINAL ARTICLE

Integration of geospatial technologies with RUSLE for analysis of land use/cover change impact on soil erosion: case study in Rib watershed, north-western highland Ethiopia

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Abstract In recent times, soil erosion interlocked with land use and land cover (LULC) changes has become one of the most important environmental issues in developing countries. Evaluation of this complex interaction between LULC change and soil erosion is indispensable in land use planning and conservation works. This paper analysed the impact of LULC change on soil erosion in the north-western highland Ethiopia over the period 1986–2016. Rib watershed, the area with dynamic LULC change and severe soil erosion problem, was selected as a case study site. Integrated approach that combined geospatial technologies with revised universal soil loss equation model was utilized to evaluate the spatio-temporal dynamics of soil loss over the study period. Pixel-based overlay of soil erosion intensity maps with LULC maps was carried out to understand the change in soil loss due to LULC change. Results showed that the annual soil loss in the study area varied from 0 to 236.5 t ha^{-1} $year^{-1}$ (tons per hectare per year) in 1986 and 0–807 t ha^{-1} $year^{-1}$ in 2016. The average annual soil loss for the entire watershed was estimated about 40 t ha^{-1} $year^{-1}$ in 1986 comparing with 68 t ha^{-1} $year^{-1}$ in 2016, a formidable increase. Soil erosion potential that was estimated to exceed the average soil loss tolerance level increased from 34.5% in 1986 to 66.8% in 2016. Expansion of agricultural land at the expense of grassland and shrubland was the most detrimental factor for severe soil erosion in the watershed. The most noticeable change in soil erosion intensity was observed from cropland with mean annual soil loss amount increased to 41.38 t ha^{-1} $year^{-1}$ in 2016 from 26.60 in 1986. Moreover, the most successive erosion problems were detected in eastern, south-eastern and northern parts of the watershed. Therefore, the results of this study can help identify the soil erosion hot spots and conservation priority areas at local and regional levels.

Keywords Soil erosion · Land use/cover change · RUSLE · GIS · Remote sensing · Ethiopia

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Introduction

Land degradation caused by soil erosion is one of the most widespread and critical environmental problems in the world (Zuazo and Pleguezuelo 2008; Ganasri and Ramesh 2016; FAO and ITPS 2015; Li et al. 2014; Sharma et al. 2011). At a time when agricultural efforts are focused on increasing food production, soil erosion is worldwide increasing (Pimentel 1993). It is estimated that about 75 billion tons of soil is removed from the world's terrestrial ecosystem due to erosion (Dabral et al. 2008), which is approximately one-sixth of the world's total land size (Hurni et al. 2010). The rate and extent of soil erosion is severe in the world's agricultural regions (Pimentel 1993) where soil is being washed 10–40 times faster than it is being replenished (Pradhan et al. 2012).

The fact that soil is almost non-renewable resource over the human time-scale makes soil erosion a critical problem (Bewket and Teferi 2009). It requires at least 500 years for the formation of 2.5 cm of topsoil under tropical and temperate agricultural conditions (Pimentel 1993). As a result, soil erosion assessment has gained a great attention in twentyfirst century due to its importance as a base for developing effective soil conservation plans (Ali and Hagos 2016). Soil erosion is considered to be one of the greatest environmental problems in Ethiopia where subsistence rainfed agriculture constitutes the basis of the economy (Reusing et al. 2000; Amsalu and de Graaff 2007). Its severity is more pronounced in the highland areas which are characterized by steep slopes, intensive rainfall, high population, and livestock densities (Kidane 2016; Abate 2011; Shiferaw and Holden 1999; Hailu et al. 2015; Subhatu et al. 2017; Moges and Taye 2017).

The annual rate of soil loss in Ethiopia is estimated at 1.5 billion tons (FAO 1986; Hurni 1993), of which more than 50% occurs in cropland (Assefa and Bork 2015) and 10% of it crosses the national boundary (Ali and Hagos 2016). Many studies have been conducted in the area of soil erosion in Ethiopian highlands and revealed the alarming rate of the problem. For instance, the study by FAO (1986) showed the estimated average annual soil loss of 100 t ha^{-1} $year^{-1}$ from the cultivated lands. The average annual soil loss rate of 42 t ha^{-1} $year^{-1}$ was also estimated by Hurni (1993). Moreover, recent studies in north-western highland Ethiopia by Bewket and Teferi (2009) and Gelagay and Minale (2016) presented the estimated mean annual soil loss rate of 93 and 47 t ha^{-1} $year^{-1}$, respectively. Such excessive rate of soil erosion constitutes a real threat to economic and ecological sustainability in Ethiopia.

The problem of soil erosion in Ethiopia is often the product of complex interactions between human and the ecosystem (Nyssen et al. 2004; Pimentel 1993). The LULU change, which is the result of intended or unintended decisions and the subsequent actions, is one of the easiest indicators of nature–human interaction (Kindu et al. 2015; Teferi et al. 2016). The LULC change in combination with climatic and geomorphologic conditions of the given area has an accelerated impact on environmental degradation in the form of soil erosion, nutrient leaching, soil acidification and organic matter depletion (Sharma et al. 2011). Many researches (Tamene and Vlek 2007; Garedew et al. 2009; Minale and Rao 2012; Kindu et al. 2015; Meshesha et al. 2014; Kidane et al. 2014; Mengistu and Waktola 2016; Teferi et al. 2016) have been conducted in Ethiopia to analyse LULC changes and their consequences. However, only few studies (Mengistu and Melesse 2011; Ciampalini et al. 2012; Tadesse et al. 2017; Tesfaye et al. 2016) have been carried out on the impacts of LULC change on soil erosion, and the knowledge of spatio-temporal interaction between LULC change and soil erosion is limited, particularly in the Rib watershed. Therefore, estimation and mapping of soil loss caused by LULC change is very crucial in the study area to provide scientific basis for land use planning and soil conservation decisions.

Estimation of soil loss is often a difficult task due to the complex interplay of biophysical and socioeconomic components. Therefore, effective estimation of soil loss needs approaches capable of integrating and addressing these components and their spatial and temporal variability. In recent decades, integration of geospatial technologies, primarily remote sensing and geographic information system (GIS), with erosion estimation models has made soil erosion assessment and its spatial distribution attainable at a high accuracy and low cost (Wang et al. 2003). Several models have been developed to estimate soil losses worldwide. For instance, universal soil loss equation (USLE) (Wischmeier and Smith 1965, 1978), revised universal soil loss equation (RUSLE) (Renard et al. 1997), Soil and Water Assessment Tool (SWAT) (Arnold et al. 1998), Water Erosion Prediction Project (WEPP) (Nearing et al. 1989), Chemical Runoff and Erosion for Agricultural Management System (CREAMS) (Knisel 1980), and European Soil Erosion Model (EuroSEM) (Morgan et al. 1998) are some of the models which have been developed and utilized for decades.

Among these prediction models, RUSLE in combination with remote sensing and GIS has been frequently used by several researchers worldwide (Kavian et al. 2017; Shit et al. 2015; Jabbar 2003; Bagherzadeh 2014; Farhan and Nawaiseh 2015; Tanyas et al. 2015; Fagnano et al. 2012; Fu et al. 2005; Ganasri and Ramesh 2016; Kumar et al. 2014). The RUSLE is an empirical model designed to predict annual soil loss carried by runoff from slopes with specified cropping and management conditions (Renard et al. 1997; Le Roux et al. 2005). Even though RUSLE is the blind model in prediction of erosion caused by gullies (Renard et al. 1997), it has been recognized as the most effective empirical model to assess the average annual rate of soil erosion caused by raindrop impact and surface runoff (rill and sheet erosion) (Kouli et al. 2009). Compared to other process-based erosion estimation models, RUSLE model is characterized by numerous benefits. It is more flexible, easy to implement, and compatible with geospatial information technologies (Bhandari et al. 2015; Mhangara et al. 2012). The data required to run RUSLE model are not complex and are easily accessible (Farhan and Nawaiseh 2015; Yue-Qing et al. 2008).

Moreover, RUSLE model enables the researchers to predict erosion rates of ungauged watersheds by using knowledge of the watershed characteristics and local hydroclimatic conditions (Yue-Qing et al. 2008). Unlike models that predict soil losses based on small experimental sites, RUSLE model provides better accurate results for watershed and regional level studies (Prasannakumar et al. 2012). This model also makes soil erosion estimation and observation results feasible at a reasonable cost (Farhan and Nawaiseh 2015). Based on these and other various merits, RUSLE model was selected and used in present study in integration with GIS and remote sensing to analyse the effect of LULC change on soil erosion in the Rib watershed, north-western highland Ethiopia, over the period 1986–2016. The specific objectives of this study were: (1) to examine the spatio-temporal dynamics of LULC changes and soil erosion; (2) to examine the effect of LULC change on soil erosion in the study area.

Materials and methods

Description of the case study site: the Rib watershed

The Rib watershed is located in the north-western highland Ethiopia which extends from the top of Mount Guna to the eastern part of Lake Tana, forming the headwater source of Blue Nile River. It lies between 11°40′N–12°20′N latitude and 37°30′E–38°20′E longitude (Fig. 1) and covers a total area of 1975 square kilometres. In administrative terms, it is located in South Gondar Zone, Amhara Regional State. Its elevation ranges from 1758 m (around Lake Tana, outlet) to 4104 m (at the top, Guna Mountain). The watershed is the main source of water for Lake Tana, which together with Gumara, Megech and Gilgel Abay contributes more than 90% of inflow water (Setegn et al. 2009; Dile et al. 2013). The topography of the study area is generally increasing in elevation from the downstream to upstream (Fig. 1). A mountainous and hilly dissected terrain with steep slopes characterizes significant parts of the watershed. The most elevated areas are found in the south-eastern and some northern parts of the watershed, and it declines towards west and south-west.

The climate condition of Ethiopia generally ranges from equatorial rainforest in the south and south-west parts of the country to the desert areas of the northeast, east and southeast lowlands (Awange et al. 2014). Based on traditional classification system, it can be classified into five agro-climatic zones (Hurni 1998; Dejene 2003): *Bereha* (hot arid), *Kolla* (warm semi-arid), *Woyna-Dega* (cool subhumid), *Dega* (cool and humid) and *Wurch* (Alphine). The climate of the study area is dominantly humid (*Dega*) with some areas undergoing sub-humid and Alphine climate. The average annual rainfall and temperature in the study area (1986–2016) was 1503.43 mm and 15.62 °C, respectively. During the study period, about 80.24% of the annual rainfall had occurred between June and September (Fig. 2), which refers to the main rainy season (locally known as *Kiremt*). The minor rainy season or autumn (locally known as *Belg*) is

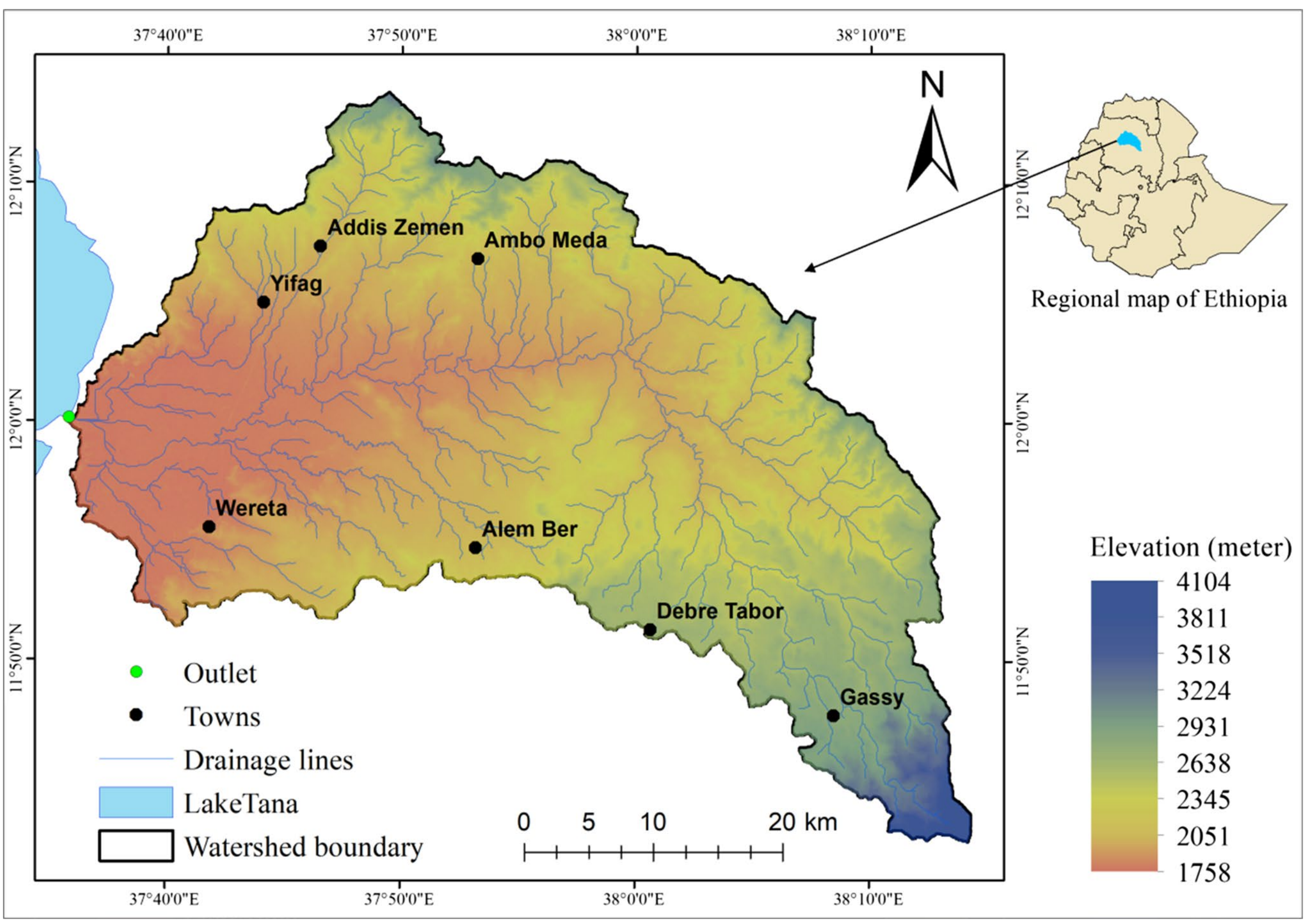

Fig. 1 Location map of the study area

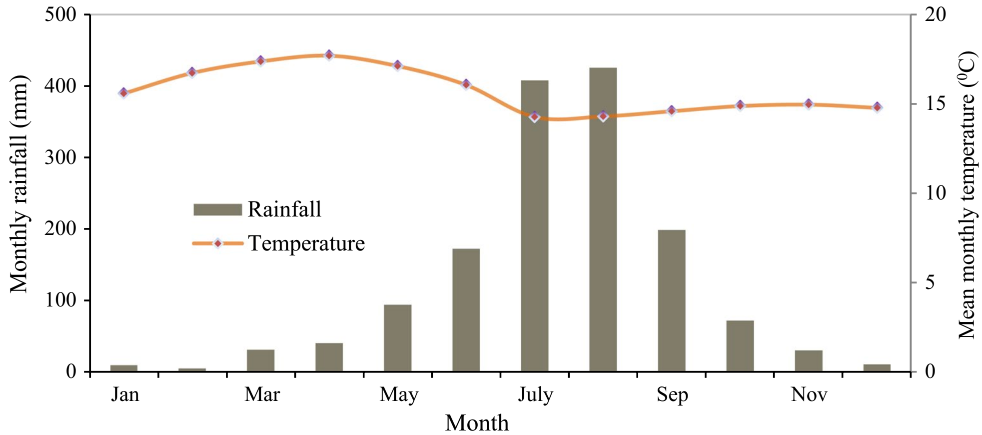

Fig. 2 Mean monthly temperature and rainfall in Rib watershed (1986–2016)

also an important season for the farming system of the area. This season usually ranges from March to May.

According to the population and housing census result obtained from the Ethiopian Central Statistical Authority (CSA 2007), the total population of the watershed was 376,256 with corresponding population density of 190 people per square kilometre. More than 85% of the population lives in rural areas where farming is the main source of food and income. The agriculture in this area is characterized by rain-fed and mixed crop-livestock production with an average farm size of not more than 1 ha. The major crops grown in the watershed include maize (*Zea mays L.*), barley (*Hordeum vulgare*), teff (*Ergarostis teff Zucc*), wheat (*Triticum vulgare*), beans (*Phaseolus vulgaris L.*), rice (*Oryza galberrima*), and Potato (*Solanum tuberosum*). The common livestock types raised in the area include cattle, equine, and poultry. It is rare to find farmers who are not raising at least one livestock of any kind.

Based on USDA soil taxonomy, eight different soil groups were identified in the study area, which include Alisols, Cambisols, Ferrasols, Fluvisols, Leptosols, Luvisols, Regosols, and Vertisols. Luvisols (30%), Vertisols (23%), and Leptosols (21%) were the dominant soil types. The major LULC types identified in the watershed include cropland, grassland, shrubland, forestland, built-up land, and waterbody. Cropland was the dominant LULC type covering 88% of the total size followed by grassland.

The Rib watershed is endowed with diverse vegetation types due to its location in the highland area combined with topographic variations. Some of indigenous and high value tree species observed in the watershed include *Millettia ferruginea* (locally known as *Birbera*), *Strychnos spinose (Dokma), Rosa abyssinica (Kega), Hagenia abyssinica (Kosso), Acacia bussei (Girar), Cordia Africana (Wanza), Olea africana (Weira),* and *Ficus sp. (Warka*). However, the coverage of these plant species has indicated significant and continuous reduction in the past few decades mainly due to the expansion of cropland and exotic pant species, for example eucalyptus. Plantation of eucalyptus, usually by removing the natural forests, is the common practice in the watershed because of its fast growing nature for immediate household purpose and better performance in area with limited water and soil fertility.

The RUSLE model

The soil erosion risk in present study was estimated for 1986 and 2016 using RUSLE model. This model predicts the long-term average annual rate of soil erosion on a field slope based on five input factors in raster data format: rainfall erosivity (*R*); soil erodibility (*K*); slope length and steepness (*LS*); cover management (*C*); and support practice (*P*). These input data were obtained from the meteorological stations; available soil map, and satellite images (Fig. 3) with intensive field observation. The RUSLE equation is expressed as (Renard et al. 1997):

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

where A is average soil loss (t ha^{-1} year^{-1}); R is rainfall-runoff erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}); K is soil erodibility factor (t h MJ^{-1} mm^{-1}), LS is slope length and steepness factor (dimensionless), C is crop and management factor (dimensionless) and P is conservation practice factor (dimensionless).

Rainfall-runoff erosivity factor (R)

The R factor is the ability of rainfall and runoff to detach and transport soil at a particular area (Renard et al. 1997). An increase in the intensity and amount of rainfall results an increase in the values of R. In the original equation of RUSLE, the value of R measures the kinetic energy of the

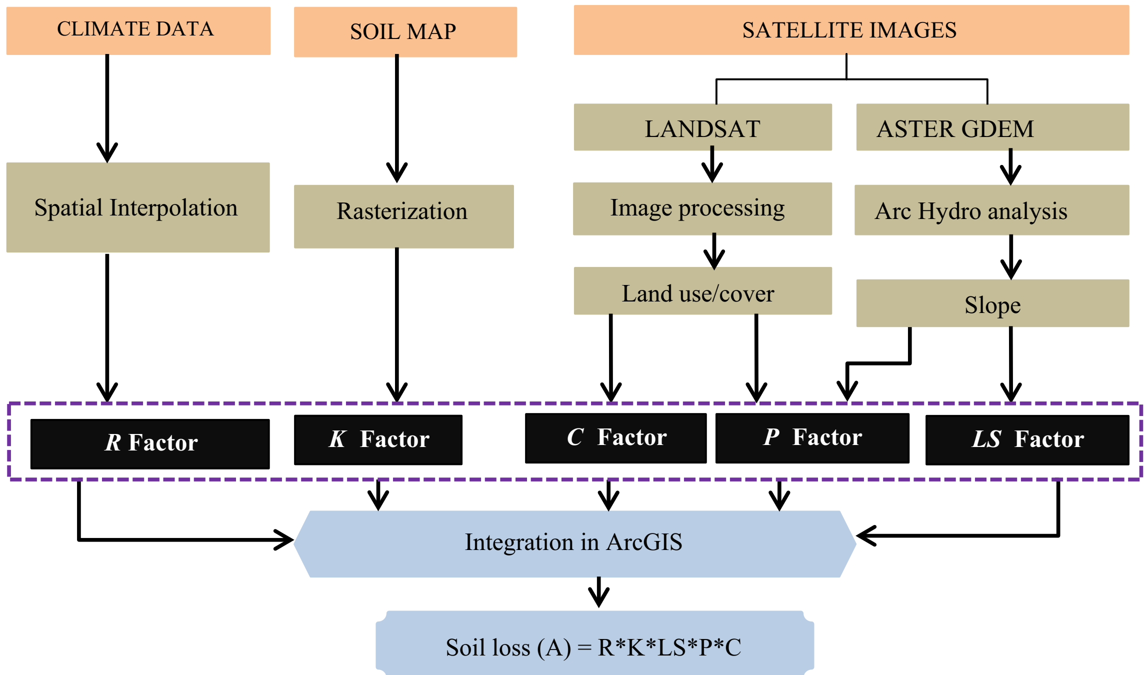

Fig. 3 Flowchart of approach used to assess soil erosion risk

rain, and it requires measuring the rainfall intensity with autographic records continuously. However, due to lack of recorded rainfall intensity data in the study area, the empirical equation developed by Hurni (1985) for Ethiopian conditions was used to estimate *R* factor value. It depends on the easily available mean annual rainfall and given by the regression equation:

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

where *R* is the erosivity factor and *P* is the mean annual rainfall in mm.

Daily rainfall data series for 12 stations in and around the Rib watershed were obtained from the National Meteorological Agency (NMA) of Ethiopia. Rainfall data qualities such as data completeness, length and homogeneity were checked for each station over the period 1986–2016. Table 1 summarizes the name and location of selected stations, elevation, and average annual rainfall during the study period. Kriging interpolation in ArcGIS 10.3 was utilized to compute *R* factor values and develop the *R* factor map (Fig. 4a).

Table 1 Summary of meteorological stations in and around the Rib watershed (1986–2016)

Station name	Latitude	Longitude	Elevation (m)	Mean annual rainfall (mm)
Debere Tabor	37.99 E	11.87 N	2602	1468
Kimir Dingay	11.81 E	38.21 N	2987	1307
Yifag	12.08 E	37.73 N	1850	1047
Leway	11.72 E	38.07 N	2713	1574
Ebinat	12.12 E	38.05 N	2201	913
Wolela Bahir	11.63 E	38.25 N	3170	1045
Wanzay	11.78 E	37.67 N	1823	1364
Alem Ber	11.91 E	37.88 N	2043	1301
Gassay	11.79 E	38.14 N	2787	1448
Woreta	11.92 E	37.69 N	1831	1200
Addis Zemen	12.11 E	37.77 N	1931	1243
Agere Genet	11.80 E	38.29 N	3010	1597

Soil erodibility factor (K)

The *K* factor expresses inherent erodibility of the soil or surface materials (Demirci and Karaburun 2012). It shows an average long-term soil and soil profile responses to the impact of raindrop on the soil surface. Soil erodibility basically depends on spoil physical and chemical properties such as soil texture, aggregate stability, shear strength, infiltration capacity, organic content, and several chemical compositions. However, in conditions where there is unavailability of such detail data of soil properties, different researchers (Hellden 1987; Bewket and Teferi 2009) suggested to use soil colours as the base for *K* factor determination in Ethiopia. A similar method was applied to obtain *K* values in this study. The soil map of the watershed was extracted from the soil map of Ethiopia (FAO/UNESCO), and the *K* values were assigned for each extracted soil types based on their respective colours, as suggested by Amsalu and Mengaw

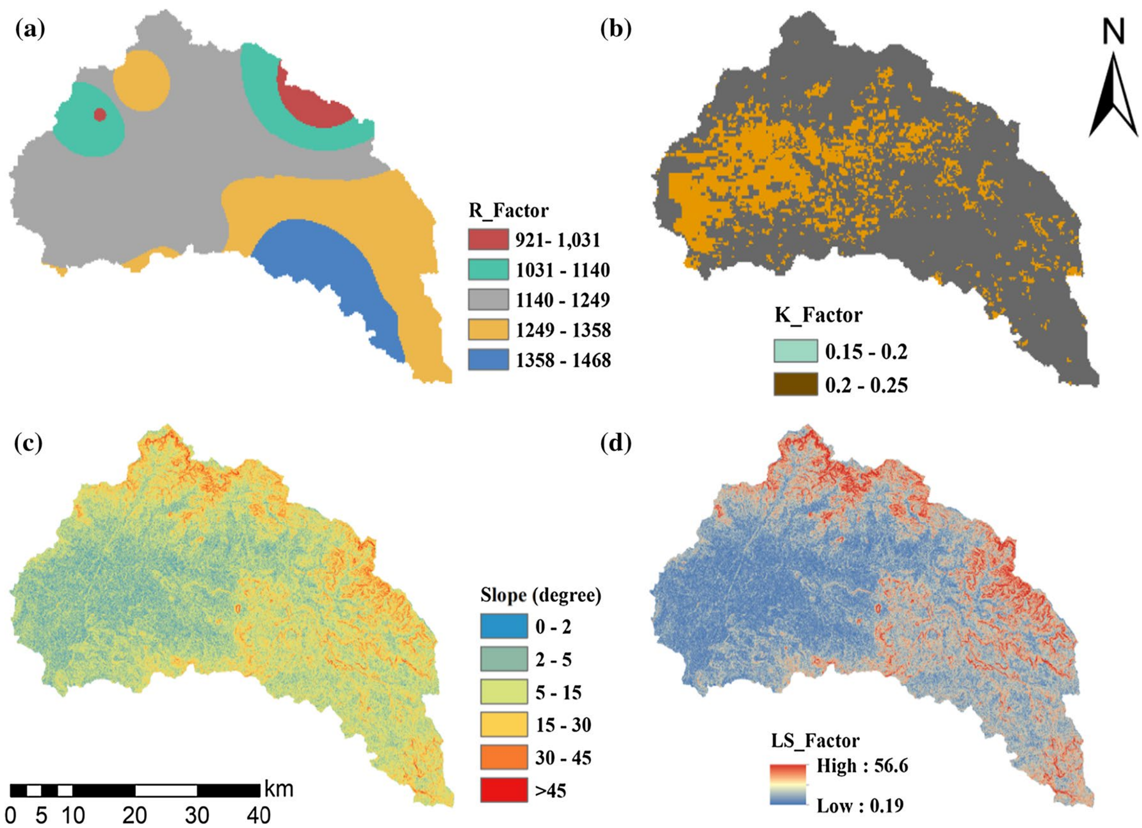

Fig. 4 Spatial distribution of RUSLE factors: rainfall-runoff erosivity factor (**a**), soil erodibility factor (**b**), slope (**c**), and topography factor (**d**)

Table 2 *K* factor values (t h MJ^{-1} mm^{-1}) of different soil types

Soil type	Area		Soil colour	*K* value
	km^2	Percentage		
Alisols	133	6.73	Red	0.25
Cambisols	62	3.14	Brown	0.2
Ferrasols	42	2.13	Red	0.25
Fluvisols	86	4.35	Brown	0.2
Leptosols	422	21.37	Red	0.25
Luvisols	590	29.87	Brown	0.2
Regosols	190	9.62	Brown	0.2
Vertisols	450	22.78	Black	0.15

(2014), Bewket and Teferi (2009), and Brhane and Mekonen (2009) (Table 2). The identification of soil colours was also supported by field survey results. The *K* factor map is indicated in Fig. 4b.

Topography factor (*LS*)

The *LS* factor describes the effect of both steepness and slope length of the field on soil erosion (Renard et al. 1997). Slope length (*L*) defines the distance from the point of origin of the overland flow to the place where either the slope gradient decreases enough that deposition begins or the runoff water enters a well-defined channel that may be part of a drainage network (Smith and Wischmeier 1957), whereas slope steepness (*S*) refers to the rise or fall of the land surface. In many studies, these variables have been considered as most important parameters of RUSLE model, and they are commonly combined in a single index as *LS* refer to topography. The *LS* factor of the study area was estimated by using the following equation (Prasannakumar et al. 2012; Pradeep et al. 2015; Demirci and Karaburun 2012; Lee 2004):

$$LS = (\text{Fac} * \text{cell resolution}/2.13)^{0.4} * (\sin \text{slope}/0.0896)^{1.3} \quad (3)$$

where Fac (flow accumulation) is the number of cells contributing to flow into a given cell and derived from the ASTER GDEM after conducting fill, flow direction and flow accumulation processes, cell resolution is the size of the grid cells (for this study 30 m), and sin slope is the sin of slope angle in degree. The slope map of study area (in degree) and the *LS* factor grid map are shown in Fig. 4c, d, respectively.

Crop and soil management factor (*C*)

The *C* factor reflects the effect of cropping and management practices on the soil erosion rate (Wischmeier and

Smith 1978). It is the effect of soil-disturbing activities, vegetation, crop sequence, soil cover and subsurface biomass on soil erosion (Prasannakumar et al. 2012). Vegetation cover protects the soil by dissipating the raindrop energy before it reaches the soil surface (Demirci and Karaburun 2012; Bhandari et al. 2015). The *C* factor for the present study was computed from LULC map of the watershed. The LULC map was generated from Landsat satellite image through supervised image classification technique. Finally, reclassification technique was applied to identify six LULC classes and to assign the corresponding *C* factor values (Table 3). The suggestions of different studies (Bewket and Teferi 2009; Amsalu and Mengaw 2014; Hurni 1985; Ganasri and Ramesh 2016; Balasubramani et al. 2015) were considered to assign the *C* factor values. The *C* factor maps of 1986 and 2016 are shown in Fig. 5a, b, respectively.

Conservation practices factor (*P*)

The *P* factor is the soil loss ratio with a specific support practice to the corresponding soil loss with up and down slope tillage (Renard et al. 1997). The type of soil management practice, such as terracing, contour tillage, and permanent barriers or strips, reduces the overall amount of erosion (Demirci and Karaburun 2012). The value of *P* ranges from 0 to 1, in which the highest value is assigned to areas with no conservation practices. A detail field survey was conducted, and there were no organized data available for identifying soil and water conservation

Table 3 *C* factor values of different land use/cover classes

LULC	General description	*C* value
Forestland	Areas covered with dense growth of both natural and man-made trees	0.010
Cropland	Areas used for crop cultivation, both annual and perennials	0.150
Grassland	Grassy areas predominantly covered with grasses	0.010
Shrubland	Areas covered by scattered small trees, shrubs, bushes & mixed with grass	0.014
Built-up land	Urban areas and other man-made structures	0.050
Waterbody	Area covered by water (like ponds, lakes, and rivers)	0.000

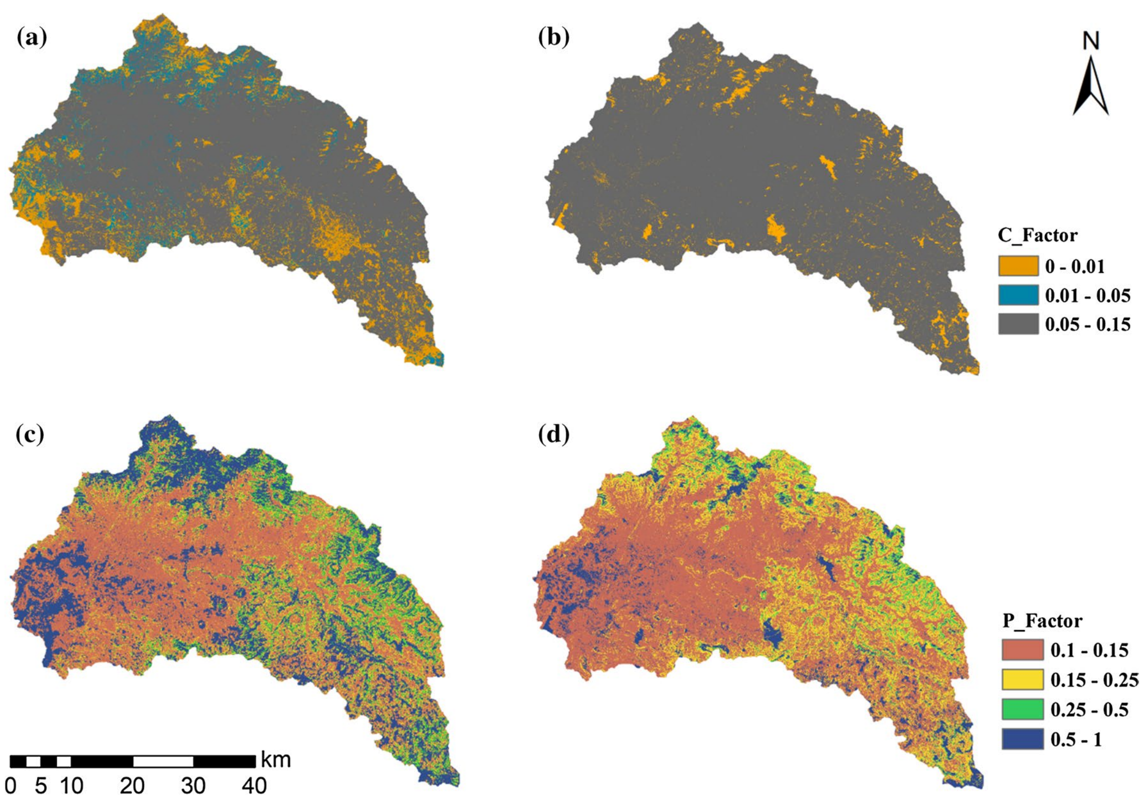

Fig. 5 Spatial distribution of RUSLE factors: *C* factor for 1986 (**a**), *C* factor for 2016 (**b**), *P* factor for 1986 (**c**), and *P* factor for 2016 (**d**)

practices in the study area. Only small areas have been treated with poorly designed stone terraces, bunds and check dams. The existing conservation measures were also not well maintained. Therefore, the *P* factor values of the present study were computed by combining the LULC classes with slope categories, as suggested by Wischmeier and Smith (1978). The entire watershed was classified into two broad classes: agricultural land (including both crop and pasture land) and other land (non-agricultural land). The agricultural land was further subdivided into six slope classes by superimposing land use and slope maps using ArcGIS 10.3 software. Finally, the *P* factor value for each class was assigned (Table 4). The *P* factor maps of 1986 and 2016 are shown in Fig. 5c, d, respectively.

The average annual soil loss was calculated using a cell-by-cell multiplication of these five parameter layers (*R*, *K*, *LS*, *P*, and *C*) in ArcGIS 10.3 software. To evaluate the effect of LULC change on soil erosion, the RUSLE was run for 1986 and 2016 separately. While running the model, the three inputs (*R*, *K* and *LS*) remained constant and the two inputs (*C* and *P*) were changed to the respective year, due to LULC change. The rainfall interpolation in this study was done by using the 30 years precipitation data (1986–2016). As a result, the same *R* factor values was used to calculate the annual soil loss of initial (1986) and final (2016) years. As well, the changes in soil erodibility and topography in the study area were insignificant over the period 1986–2016, and the same *K* and *LS* factor values were used to calculate the soil loss of both years.

Results and discussion

Land use/cover change

The major LULC classes identified in the Rib watershed include cropland, grassland, shrubland, forestland, built-up land and waterbody. Cropland was the dominant LULC type in the watershed, covering 77.6 and 88% of the total area in 1986 and 2016, respectively. Table 5 indicates the statistical summary of different LULC classes in the study area in 1986 and 2016. The spatial distribution of LULC types in 1986 and 2016 are indicated in Fig. 6a, b, respectively. The LULC change analysis result revealed that grassland and shrubland were significantly converted into cropland and built-up land during the study period (Table 5). This might be attributed to rapid population growth and advancement in living standard of the society, which has created a high competition on land for agriculture, residence, infrastructure, and urban expansion.

Slight increment in forestland (1.11% per year) was observed in the watershed over the period 1986–2016. This change was basically due to the expansion of eucalyptus plantation as a means of livelihood of the community. Waterbody also considerably increased from 0.7 km^2 in 1986 to 6.5 km^2 in 2016 (27.62% increase per year). The construction of Rib dam (in the eastern part of the watershed, Fig. 6b) has played a significant role for this drastic increase of waterbody during the study period. Moreover, the regeneration of upslope vegetation might be another reason for

Table 4 Adopted values of *P* factor in different land use/cover classes

LULC class	Slope (%)	Area (1986)		Area (2016)		*P* value
		km^2	%	km^2	%	
Agricultural land	0–5	204	10.33	208	10.53	0.1
	5–10	366.5	18.56	391	19.8	0.12
	10–20	498	25.22	561	28.41	0.14
	20–30	213	10.78	261.6	13.25	0.19
	30–50	181	9.16	221.9	11.24	0.25
	> 50	69.5	3.52	93	4.71	0.33
Other land	All	443	22.43	238.5	12.08	1

Table 5 Land use and land cover change analysis (1986–2016)

LULC class	Area (1986)		Area (2016)		Change (1986–2016)		Annual rate of change	
	km^2	%	km^2	%	km^2	%	km^2	%
Cropland	1532	77.57	1737	87.95	205	13.38	6.83	0.45
Grassland	242	12.25	118	5.97	− 124	− 51.24	− 4.13	− 1.71
Shrubland	142	7.19	25	1.27	− 117	− 82.39	− 3.9	− 2.75
Forestland	51	2.58	68	3.44	17	33.33	0.57	1.11
Built-up land	8	0.41	21	1.06	13	162.50	0.43	5.42
Waterbody	0.7	0.04	6.5	0.33	5.8	828.57	0.19	27.62

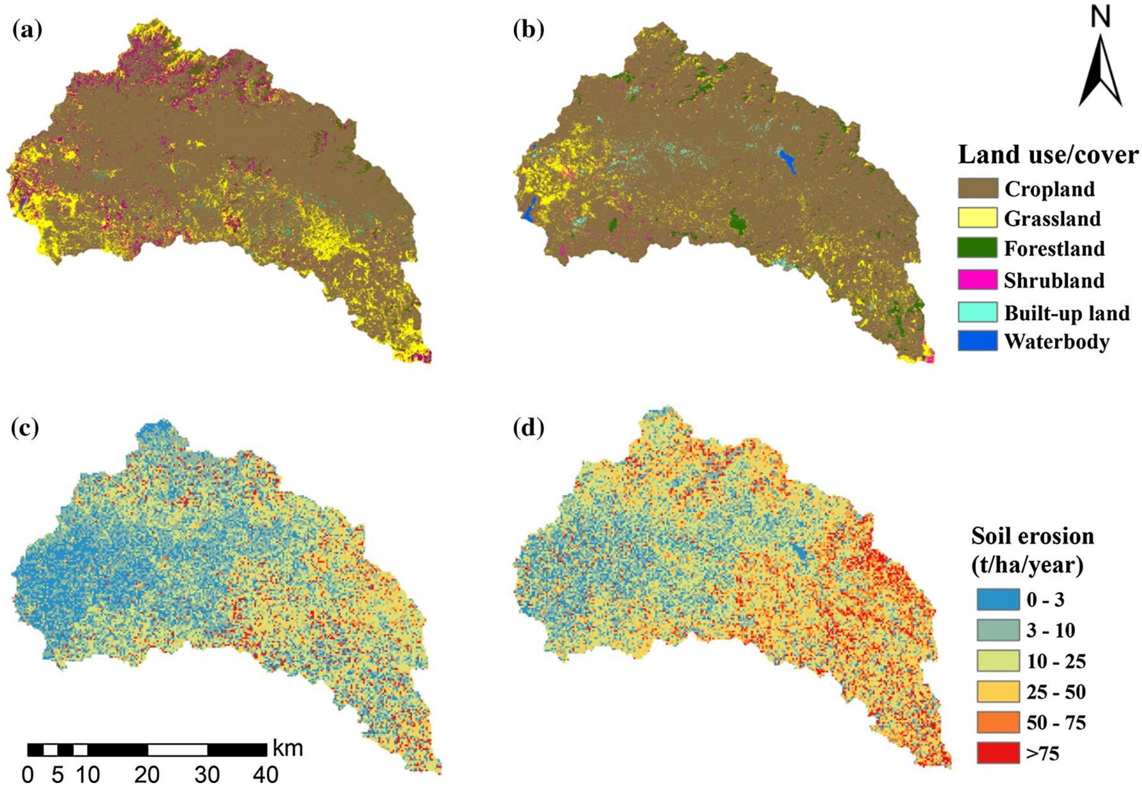

Fig. 6 Spatial distribution of land use/cover for 1986 (**a**), land use/cover for 2016 (**b**), soil erosion for 1986 (**c**), and soil erosion for 2016 (**d**)

expansion of water at downstream areas. This result is in agreement with the findings of Nyssen et al. (2009) and Descheemaeker et al. (2006), which indicated the increasing availability of water at downstream area when the upslope landscape becomes revegetated.

Soil erosion change

The input layers of RUSLE model were converted into grid cells of 30 x 30 m in a uniform coordinate system and multiplied to estimate the annual soil erosion and to recognize its spatial distribution in the watershed. The estimated annual soil erosion (A) was finally classified into six severity categories by using soil erosion rate standards suggested by Morgan (2005) and Gemechu (2016). These categories include very slight erosion for $A < 3$ t ha^{-1} year^{-1}, slight for $3 \leq A < 10$ t ha^{-1} year^{-1}, moderate for $10 \leq A < 25$ t ha^{-1} year^{-1}, high for $25 \leq A < 50$ t ha^{-1} year^{-1}, very high for $50 \leq A < 75$ t ha^{-1} year^{-1}, severe for $A \geq 75$ t ha^{-1} year^{-1}. Table 6 and Fig. 6 illustrate the statistical summary of soil erosion and its spatial distribution in the study area in 1986 and 2016.

The annual soil loss in the watershed ranged from 0 to 236.5 t ha^{-1} year^{-1} in 1986 and 0 to 807 t ha^{-1} year^{-1} in 2016. The average annual soil loss for the entire watershed was estimated at 40 and 68 t ha^{-1} year^{-1} in 1986 and 2016, respectively, a substantial increase. As shown in Table 6, the areas under very slight, slight, and moderate erosion categories diminished from ~ 93% in 1986 to 58% in 2016. On the other hand, the areas under high,

Table 6 Summary of soil erosion categories and their changes (1986–2016)

Erosion categories	Soil loss (t ha^{-1} year^{-1})	Area (1986)		Area (2016)		Change area (km^2)
		km^2	%	km^2	%	
Very slight	0–3	626.03	31.70	220.07	11.14	– 406.00
Slight	3–10	615.88	31.18	365.43	18.50	– 250.50
Moderate	10–25	589.40	29.84	566.24	28.67	– 23.16
High	25–50	26.51	1.34	488.02	24.71	461.50
Very high	50–75	26.74	1.35	182.39	9.23	155.65
Severe	> 75	91.4	4.63	152.73	7.73	61.33

very high and severe erosion categories increased from 7% in 1986 to 42% in 2016. The implication of this result is that the parts of watershed with minimum soil erosion intensity in 1986, which were mostly found in the western and central part of the watershed (Fig. 6c), were changed into the next higher erosion categories in 2016 (Fig. 6d). This shift in erosion intensity was basically due to human intervention on natural environment. The areas with soil erosion categories from high to severe were mostly located in the eastern, south-eastern, and some northern parts of the watershed where frequent cultivation of steep and marginal lands has been a common practice.

In Rib watershed, soil erosion potential that was estimated to exceed the average soil loss tolerance level of 11 t ha^{-1} year^{-1} (Bewket and Teferi 2009; Hudson 1981) increased from 34.5% in 1986 to 66.8% in 2016. Soil loss tolerance level is the maximum rate of soil erosion that may occur and still permits a high productivity in a given land (Wischmeier and Smith 1978). For proper decision and effective conservation, tolerance level should be determined scientifically and rationally based on real situation of a given area, like soil depth and topography. Bewket and Teferi (2009), furthermore, suggested the concept of critical soil loss and its importance in conservation and land use planning decisions. Critical soil loss is the level where reducing soil erosion is no more possible regardless of the effectiveness of conservation measures used. Therefore, these two points, i.e., soil loss tolerance and critical soil loss level, can be used as indispensable indicators to recognise the degree of soil erosion and decide on erosion intervention issues.

Areas with critical soil erosion level in the study area were observed in the eastern part of the watershed (Fig. 6d) where the maximum amount of soil loss (807 t ha^{-1} year^{-1}) was detected. Based on the above suggestion, in such critical soil loss areas, the natural resource conservationists and local communities should focus on changing or modifying the current LULC type to another ecologically friendly type, rather than investing on soil and water conservation programs.

Impact of land use/cover change on soil erosion

The results of present study showed that there was complex change in soil erosion associated with dynamic LULC changes over the study period. As depicted in Fig. 6a, the western, northern, and south-eastern parts of the watershed were densely covered with grassland and shrubland in 1986. However, this LULC classes were significantly converted into cropland and built-up land in 2016. This conversion, in turn, has directly caused the shift in soil loss rate from very slight, slight, and moderate levels in 1986 (Fig. 6c) to the next higher erosion levels in 2016 (Fig. 6d). The detail cause–effect relationship between LULC dynamics and subsequent changes in soil erosion potential was analysed by superimposing soil erosion intensity maps with LULC change maps. Table 7 provides the detail of change in area of different soil erosion intensity classes due to LULC change over the study period.

As seen in Table 7, the cropland under very slight and slight erosion categories decreased from 953 km^2 in 1986 to 495 km^2 in 2016, while the areas of other erosion categories from moderate to severe showed significant increase from 578 km^2 in 1986 to 1241 km^2 in 2016. The implication is that large part of cropland which was under minimum state of soil erosion in 1986 has been changed into the next higher erosion categories in 2016. The main factors for this increase in soil erosion severity might be highly attributed to clearing of vegetation, frequent cultivation, overgrazing, cultivation of marginal lands, and removal of crop residues from the farm lands. As indicated in Table 4 and confirmed during filed observation, more than 65% of cropland was located in areas where slope is exceeding 10 percent, and natural resource conservation practices in these areas were also not satisfactory. Therefore, cultivation of steep slopes with poor conservation practices might be another contributing factor for higher potential of soil erosion in croplands. Waterbody and built-up land also showed obvious increase at all erosion intensity classes due to extensive increase in land use area.

The effect of LULC change on soil erosion can be also analysed by calculating mean annual soil loss amount of different LULC types (Table 8). The most noticeable change in soil erosion intensity was observed from cropland with mean

Table 7 Areas of different soil erosion categories for each LULC types (km^2) (1986–2016)

LULC	Very slight		Slight		Moderate		High		Very high		Severe	
	1986	2016	1986	2016	1986	2016	1986	2016	1986	2016	1986	2016
Cropland	479.7	184	473	311	475	516	20.2	440	20.1	160.3	62.9	125
Forestland	13.12	6.52	18.6	17	13.2	11.2	1.0	13.5	1.11	8.29	4.46	10.3
Shrubland	44.14	3.05	48.3	5.4	37.7	5.3	2.0	6.2	2.01	2.67	8.5	3.1
Grassland	87.8	18.4	73.7	25	59.2	27	3.2	24.6	3.41	10.1	15.1	13.3
Built-upland	1.1	3.97	2.0	6.1	4.1	6.15	0.11	3.43	0.11	0.99	0.4	1.12
Waterbody	0.17	4.63	0.28	0.3	0.2	1.03	0.0	0.17	0.0	0.12	0.04	0.06

Table 8 Statistical results of soil loss intensity in 1986 and 2016 per various LULC types

LULC	Estimated soil loss in 1986 ($t\ ha^{-1}\ year^{-1}$)			Estimated soil loss in 2016 ($t\ ha^{-1}\ year^{-1}$)		
	Maximum	Mean	SD	Maximum	Mean	SD
Cropland	276.95	26.6	36.42	393.77	41.38	46.75
Grassland	236.26	13.18	26.16	301.61	33.87	44.17
Shrubland	120.46	10.67	13.84	253.93	24.19	30.83
Forestland	153.33	17.27	24.48	127.4	33.18	37.82
Built-up land	86.63	5.71	6.67	218.14	23.75	39.68
Waterbody	32.78	17.23	13.23	62.4	6.23	12.00

annual soil loss amount increased to 41.38 $t\ ha^{-1}\ year^{-1}$ in 2016 from 26.60 in 1986. The second largest change in soil erosion amount was seen in grassland, with mean annual soil loss amount increased from 13.18 $t\ ha^{-1}\ year^{-1}$ in 1986 to 33.87 $t\ ha^{-1}\ year^{-1}$ in 2016. The dramatic increase in soil losses from cropland and grassland could be highly attributed to increasing human activities to meet the demand of ever-growing population in the study area.

Although forestland was expected to have low soil erosion intensity, the result showed that the mean annual soil erosion potential had undergone a great degree of change from 17.27 $t\ ha^{-1}\ year^{-1}$ in 1986 to 33 $t\ ha^{-1}\ year^{-1}$ 2016. The highest potential of soil loss in forestland might be due to poor coverage of trees in the forest and persistent removal of trees (most likely eucalyptus trees planted adjacent to natural forests) for different livelihood purposes. Significant part of forestland was confined to hillside areas of the watershed. So, highly slopping areas are most likely to facilitate runoff and reduce infiltration and finally increase soil erosion in forestland.

Validation of the model used to predict soil erosion is essential to ascertain the quality of results and test the usefulness of the model. However, the absence of measured sediment yield data in the study area constrained comparison of predicted erosion values with field derived values. Field observation and image analysis were used to validate only the presence and absence of soil erosion in the study area. Previous studies in the north-western highland Ethiopia (Nurelegn and Amare 2014; Estifanos 2014; Sewnet 2015) were used to crosscheck the consistency of predicted results and effectiveness of the model. Therefore, the estimated soil loss rate and spatial distribution of erosion classes in our watershed are more realistic when compared with results of field observation and previous studies.

Conclusion

This study successfully employed a GIS-based RUSLE model to evaluate the soil erosion induced by LULC change in Rib watershed, north-western highland Ethiopia. The spatio-temporal variation and distribution of LULC change and soil erosion were predicted over the period 1986–2016. The highest mean annual soil loss was observed in croplands followed by grasslands, which are highly subjected to frequent human intervention. The annual soil loss for the entire watershed ranged from 0 to 236.5 $t\ ha^{-1}\ year^{-1}$ in 1986, with an average annual loss estimated at 40 $t\ ha^{-1}\ year^{-1}$ and 0–807 $t\ ha^{-1}\ year^{-1}$ in 2016, with an average annual loss estimated at 68 $t\ ha^{-1}\ year^{-1}$. About 70% of the watershed suffered from moderate to severe soil loss rates in 2016, and only the remaining 30% of the watershed had undergone slight and very slight soil erosion categories. At present, the eastern, south-eastern and some northern parts of the watershed are the areas with the most serious soil erosion problem. Therefore, these areas can be considered as high-priority areas for soil and water conservation activities to reduce soil losses. Since croplands were the dominant LULC type with severe erosion problem, plot level agronomic and biological soil conservation practices could help minimize the problem. Further studies by using the same approach but high-resolution satellite data, process-based models, and sediment yield could also suggest more reliable management methods in the watershed.

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References

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

Ali SA, Hagos H (2016) Estimation of soil erosion using USLE and GIS in Awassa Catchment, Rift valley, Central Ethiopia. Geoderma Reg 7(2):159–166. https://doi.org/10.1016/j.geodrs.2016.03.005

Amsalu A, de Graaff J (2007) Determinants of adoption and continued use of stone terraces for soil and water conservation in an Ethiopian highland watershed. Ecol Econ 61(2–3):294–302. https://doi.org/10.1016/j.ecolecon.2006.01.014

Amsalu T, Mengaw A (2014) GIS based soil loss estimation using RUSLE model: the case of Jabi Tehinan Woreda, ANRS, Ethiopia. Nat Resour 05(11):616–626. https://doi.org/10.4236/nr.2014.511054

Arnold JG, Srinivasan R, Muttiah RS, Williams JR (1998) Large area hydrological modelling and assessment part I: model development. J Am Water Resour Assoc 34(1):73–89

Assefa E, Bork HR (2015) Farmers' perception of land degradation and traditional knowledge in Southern Ethiopia—resilience and stability. Land Degrad Dev. https://doi.org/10.1002/ldr.2364

Awange JL, Gebremichael M, Forootan E, Wakbulcho G, Anyah R, Ferreira VG, Alemayehu T (2014) Characterization of Ethiopian mega hydrogeological regimes using GRACE, TRMM and GLDAS datasets. Adv Water Resour 74:64–78. https://doi.org/10.1016/j.advwatres.2014.07.012

Bagherzadeh A (2014) Estimation of soil losses by USLE model using GIS at Mashhad plain, Northeast of Iran. Arab J Geosci 7(1):211–220. https://doi.org/10.1007/s12517-012-0730-3

Balasubramani K, Veena M, Kumaraswamy K, Saravanabavan V (2015) Estimation of soil erosion in a semi-arid watershed of Tamil Nadu (India) using revised universal soil loss equation (rusle) model through GIS. Model Earth Syst Environ 1(3):1–17. https://doi.org/10.1007/s40808-015-0015-4

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(6):609–622. https://doi.org/10.1002/ldr.944

Bhandari KP, Aryal J, Darnsawasdi R (2015) A geospatial approach to assessing soil erosion in a watershed by integrating socio-economic determinants and the RUSLE model. Nat Hazards 75(1):321–342. https://doi.org/10.1007/s11069-014-1321-2

Brhane G, Mekonen K (2009) Estimating soil loss using Universal Soil Loss Equation (USLE) for soil conservation planning at Medego watershed, Northern Ethiopia. J Am Sci 5(1):58–69

Central Statistical Authority (CSA) (2007) Summary and statistical report of the 2007 population and housing census. Addis Ababa

Ciampalini R, Billi P, Ferrari G, Borselli L, Follain S (2012) Soil erosion induced by land use changes as determined by plough marks and field evidence in the Aksum area (Ethiopia). Agric Ecosyst Environ 146(1):197–208. https://doi.org/10.1016/j.agee.2011.11.006

Dabral PP, Baithuri N, Pandey A (2008) Soil erosion assessment in a hilly catchment of North Eastern India using USLE, GIS and remote sensing. Water Resour Manag 22(12):1783–1798. https://doi.org/10.1007/s11269-008-9253-9

Dejene A (2003) Integrated natural resources management to enhance food security. The Case for community-based approaches in Ethiopia. Working paper no. 16, Environment and Natural Resources Service, Food and Agriculture Organization of the UN, Rome

Demirci A, Karaburun A (2012) Estimation of soil erosion using RUSLE in a GIS framework: a case study in the Buyukcekmece Lake watershed, northwest Turkey. Environ Earth Sci 66(3):903–913. https://doi.org/10.1007/s12665-011-1300-9

Descheemaeker K, Nyssen J, Poesen J, Raes D, Mitiku H, Muys B, Deckers S (2006) Runoff on slopes with restoring vegetation: a case study from the Tigray highlands, Ethiopia. J Hydrol 331:219–241

Dile YT, Berndtsson R, Setegn SG (2013) Hydrological response to climate change for Gilgel Abay River, in the Lake Tana Basin—Upper Blue Nile Basin of Ethiopia. PLoS ONE 8(10):e79296. https://doi.org/10.1371/journal.pone.0079296

Estifanos A (2014) Assessment of micro-watershed vulnerability for soil erosion in Ribb watershed using GIS and remote sensing. M.Sc. thesis, Mekelle University of Ethiopia

Fagnano M, Diodato N, Alberico I, Fiorentino N (2012) An overview of soil erosion modelling compatible with RUSLE approach. Rend Lincei 23(1):69–80. https://doi.org/10.1007/s12210-011-0159-8

FAO (1986) Ethiopian highlands reclamation study, Ethiopia, final report, FAO, Rome

FAO, ITPS (2015) Status of the world's soil resources (SWSR)—technical summary. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy

Farhan Y, Nawaiseh S (2015) Spatial assessment of soil erosion risk using RUSLE and GIS techniques. Environ Earth Sci 74(6):4649–4669. https://doi.org/10.1007/s12665-015-4430-7

Fu BJ, Zhao WW, Chen LD, Zhang QJ, Lü YH, Gulinck H, Poesen J (2005) Assessment of soil erosion at large watershed scale using RUSLE and GIS: a case study in the Loess Plateau of China. Land Degrad Dev 16(1):73–85. https://doi.org/10.1002/ldr.646

Ganasri BP, Ramesh H (2016) Assessment of soil erosion by RUSLE model using remote sensing and GIS—a case study of Nethravathi Basin. Geosci Front 7(6):953–961. https://doi.org/10.1016/j.gsf.2015.10.007

Garedew E, Sandewall M, Söderberg U, Campbell BM (2009) Land-use and land-cover dynamics in the central rift valley of Ethiopia. Environ Manag 44(4):683–694. https://doi.org/10.1007/s00267-009-9355-z

Gelagay HS, Minale AS (2016) Soil loss estimation using GIS and Remote sensing techniques: a case of Koga watershed, Northwestern Ethiopia. Int Soil Water Conserv Res 4(2016):126–136

Gemechu A (2016) Estimation of soil loss using revised universal soil loss equation and determinants of soil loss in Tiro Afeta and Dedo Districts of Jimma Zone, Oromiya National Regional State, Ethiopia. Trends Agric Econ 9(1):1–12. https://doi.org/10.3923/tae.2016

Hailu H, Mamo T, Keskinen R, Karltun E, Gebrekidan H, Bekele T (2015) Soil fertility status and wheat nutrient content in Vertisol cropping systems of central highlands of Ethiopia. Agric Food Secur. https://doi.org/10.1186/s40066-015-0038-0

Hellden U (1987) An assessment of woody biomass, community forests, land use and soil erosion in Ethiopia. Lund University Press, Lund

Hudson NW (1981) Soil conservation, 2nd edn. Batsford, London

Hurni H (1985) Erosion-productivity conservation systems in Ethiopia. In: 4th ISCO conference, Venezuala, pp 654–674

Hurni H (1993) Land degradation, famine, and land resource scenarios in Ethiopia. Cambridge University Press, Cambridge, pp 27–62

Hurni H (1998) Agroecological belts of Ethiopia: explanatory notes on three maps at a scale of 1:1,000,000. Addis Ababa

Hurni H, Abate S, Bantider A, Debele B, Ludi E, Portner B, Yitaferu B, Zeleke G (2010) Land degradation and sustainable land management in the highlands of Ethiopia. Geographica Bernesia. University of Bern, pp 187–207

Jabbar MT (2003) Application of GIS to estimate soil erosion using RUSLE. Geo-Spat Inf Sci 6(1):34–37

Kavian A, Hoseinpoor S, Solaimani K, Jafari B (2017) Simulating the effects of land use changes on soil erosion using RUSLE model. Geocarto Int 32(1):97–111. https://doi.org/10.1080/10106049.2015.1130083

Kidane W (2016) Identification and prioritization of subwatersheds for land and water management in Tekeze dam watershed, Northern Ethiopia. Int Soil Water Conserv Res 4:30–38

Kidane T, Beshah T, Aklilu A (2014) Determinants of physical soil and water conservation practices in Ethiopia's semi-arid tropics: the case of Bati District. Soc Basic Sci Res Rev 2:525–541

Kindu M, Schneider T, Teketay D, Knoke T (2015) Drivers of land use/land cover changes in Munessa-Shashemene landscape of the south-central highlands of Ethiopia. Environ Monit Assess. https://doi.org/10.1007/s10661-015-4671-7

Knisel WG (1980) CREAMS: a field model for chemical, runoff, and erosion from agricultural management system. USDA, Science and Education Administration, conservation report no. 26, Washington

Kouli M, Soupios P, Vallianatos F (2009) Soil erosion prediction using the revised universal soil loss equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. Environ Geol 57(3):483–497. https://doi.org/10.1007/s00254-008-1318-9

Kumar A, Devi M, Deshmukh B (2014) Integrated remote sensing and geographic information system based RUSLE modelling for estimation of soil loss in western Himalaya, India. Water Resour Manag 28(10):3307–3317. https://doi.org/10.1007/s11269-014-0680-5

Le Roux JJ, Sumner PD, Rughooputh SD (2005) Erosion modelling and soil loss prediction under changing land use for a catchment on Mauritius. South Afr Geogr J 87(2):129–140. https://doi.org/10.1080/03736245.2005.9713836

Lee S (2004) Soil erosion assessment and its verification using the universal soil loss equation and geographic information system: a case study at Boun, Korea. Environ Geol 45(4):457–465. https://doi.org/10.1007/s00254-003-0897-8

Li J, Feng P, Chen F (2014) Effects of land use change on flood characteristics in mountainous area of Daqinghe watershed, China. Nat Hazards 70(1):593–607. https://doi.org/10.1007/s11069-013-0830-8

Mengistu BD, Melesse AM (2011) Field scale investigation of the effect of land use on sediment yield and runoff using runoff plot data and models in the Mara river basin, Kenya. Catena 89:54–64

Mengistu DA, Waktola DK (2016) Monitoring land use/land cover change impacts on soils in data scarce environments: a case of south-central Ethiopia. J Land Use Sci 11(1):96–112. https://doi.org/10.1080/1747423X.2014.927011

Meshesha DT, Tsunekawa A, Tsubo M, Ali SA, Haregeweyn N (2014) Land-use change and its socio-environmental impact in Eastern Ethiopia's highland. Reg Environ Change 14(2):757–768. https://doi.org/10.1007/s10113-013-0535-2

Mhangara P, Kakembo V, Lim KJ (2012) Soil erosion risk assessment of the Keiskamma catchment, South Africa using GIS and remote sensing. Environ Earth Sci 65(7):2087–2102. https://doi.org/10.1007/s12665-011-1190-x

Minale AS, Rao KK (2012) Impacts of land cover/use dynamics of Gilgel Abbay catchment of Lake Tana on climate variability, Northwestern Ethiopia. Appl Geomat 4(3):155–162. https://doi.org/10.1007/s12518-012-0092-2

Moges DM, Taye AA (2017) Determinants of farmers? Perception to invest in soil and water conservation technologies in the North-Western Highlands of Ethiopia. Int Soil Water Conserv Res 5(1):56–61. https://doi.org/10.1016/j.iswcr.2017.02.003

Morgan RPC (2005) Soil erosion and conservation, 3rd edn. Wiley, Malden

Morgan RPC, Quinton JN, Smith RE, Govers G, Poesen JWA, Auerswald K, Chisci G, Torri D, Styczen ME (1998) The European Soil Erosion Model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. Earth Surf Process Landf 23:527–544

Nearing MA, Foster GR, Lane LJ, Finkner SC (1989) A process-based soil erosion model for USDA water erosion prediction project technology. Trans ASAE 32(5):1587–1593

Nurelegn M, Amare S (2014) Land use/cover dynamics in Ribb watershed, North Western, Ethiopia. J Nat Sci 4(16):9–16

Nyssen J, Poesen J, Moeyersons J, Deckers J, Haile M, Lang A (2004) Human impact on the environment in the Ethiopian and Eritrean highlands—a state of the art. Earth Sci Rev 64:273–320

Nyssen J, Simegn G, Taha N (2009) An upland farming system under transformation: proximate causes of land use change in Bela-Welleh catchment (Wag, Northern Ethiopian Highlands). Soil Tillage Res 103(2):231–238. https://doi.org/10.1016/j.still.2008.05.020

Pimentel D (ed) (1993) World soil erosion and conservation. Cambridge University Press, Cambridge

Pradeep GS, Krishnan MVN, Vijith H (2015) Identification of critical soil erosion prone areas and annual average soil loss in an upland agricultural watershed of Western Ghats, using analytical hierarchy process (AHP) and RUSLE techniques. Arab J Geosci 8(6):3697–3711. https://doi.org/10.1007/s12517-014-1460-5

Pradhan B, Chaudhari A, Adinarayana J, Buchroithner MF (2012) Soil erosion assessment and its correlation with landslide events using remote sensing data and GIS: a case study at Penang Island, Malaysia. Environ Monit Assess 184(2):715–727. https://doi.org/10.1007/s10661-011-1996-8

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. https://doi.org/10.1016/j.gsf.2011.11.003

Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC (1997) Predicting soil erosion by water—a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture handbook no. 703, USDA-ARS, p 56

Reusing M, Schneider T, Ammer U (2000) Modelling soil loss rates in the Ethiopian Highlands by integration of high resolution MOMS-02/D2-stereo-data in a GIS. Int J Remote Sens 21(9):1885–1896. https://doi.org/10.1080/014311600209797

Setegn SG, Srinivasan R, Dargahi B, Melesse AM (2009) Spatial delineation of soil erosion vulnerability in the Lake Tana Basin, Ethiopia. Hydrol Process. https://doi.org/10.1002/hyp.7476

Sewnet A (2015) Land use/cover change at Infraz watershed by using GIS and remote sensing techniques, northwestern Ethiopia. Int J River Basin Manag 14(2):133–142. https://doi.org/10.1080/15715124.2015.1095199

Sharma A, Tiwari KN, Bhadoria PBS (2011) Effect of land use land cover change on soil erosion potential in an agricultural watershed. Environ Monit Assess 173(1–4):789–801. https://doi.org/10.1007/s10661-010-1423-6

Shiferaw B, Holden S (1999) Soil erosion and smallholders' conservation decisions in the highlands of Ethiopia. World Dev 27(4):739–752

Shit PK, Nandi AS, Bhunia GS (2015) Soil erosion risk mapping using RUSLE model on jhargram sub-division at West Bengal in India. Model Earth Syst Environ. https://doi.org/10.1007/s40808-015-0032-3

Smith DD, Wischmeier WH (1957) Factors affecting sheet and rill erosion. Am Geophys Union Trans 38:889–896

Subhatu A, Lemann T, Hurni K, Portner B, Kassawmar T, Zeleke G, Hurni H (2017) Deposition of eroded soil on terraced croplands in Minchet catchment, Ethiopian Highlands. Int Soil Water Conserv Res. https://doi.org/10.1016/j.iswcr.2017.05.008

Tadesse L, Suryabhagavan KV, Sridhar G, Legesse G (2017) Land use and land cover changes and Soil erosion in Yezat Watershed, North Western Ethiopia. Int Soil Water Conserv Res 5(2):85–94. https://doi.org/10.1016/j.iswcr.2017.05.004

Tamene L, Vlek PLG (2007) Assessing the potential of changing land use for reducing soil erosion and sediment yield of catchments: a case study in the highlands of northern Ethiopia. Soil Use Manag 23(1):82–91. https://doi.org/10.1111/j.1475-2743.2006.00066.x

Tanyas H, Kolat C, Suzen ML (2015) A new approach to estimate cover-managemnt factor of RUSLE and validation of RUSLE model in the watershed of Kartalkaya Dam. J Hydrol 528:584–598. https://doi.org/10.1016/j.jhydrol.2015.06.048

Teferi E, Bewket W, Simane B (2016) Effects of land use and land cover on selected soil quality indicators in the headwater area of

the Blue Nile basin of Ethiopia. Environ Monit Assess. https://doi.org/10.1007/s10661-015-5086-1
Tesfaye MA, Bravo F, Ruiz-Peinado R, Pando V, Bravo-Oviedo A (2016) Impact of changes in land use, species and elevation on soil organic carbon and total nitrogen in Ethiopian Central Highlands. Geoderma 261:70–79. https://doi.org/10.1016/j.geoderma.2015.06.022
Wang G, Gertner G, Fang S, Anderson AB (2003) Mapping multiple variables for predicting soil loss by geostatistical methods with TM images and a slope map. Photogramm Eng Remote Sens 69(8):889–898
Wischmeier WH, Smith DD (1965) Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. Guide for selection of practices for soil and water conservation, vol 282. US Government Printing Office, Washington
Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses: a guide to conservation planning. Agriculture handbook no. 537, US Department of Agriculture Science and Education Administration, Washington, p 163
Yue-Qing X, Xiao-Mei S, Xiang-Bin K, Jian P, Yun-Long C (2008) Adapting the RUSLE and GIS to model soil erosion risk in a mountains karst watershed, Guizhou Province, China. Environ Monit Assess 141(1–3):275–286. https://doi.org/10.1007/s10661-007-9894-9
Zuazo VHD, Pleguezuelo CRR (2008) Soil-erosion and runoff prevention by plant covers: a review. Agron Sustain Dev 28(1):65–86. https://doi.org/10.1051/agro:2007062