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Original Research Article

Soil loss estimation using GIS and Remote sensing techniques: A case of Koga watershed, Northwestern Ethiopia

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ABSTRACT

Soil loss by runoff is a severe and continuous ecological problem in Koga watershed. Deforestation, improper cultivation and uncontrolled grazing have resulted in accelerated soil erosion. Information on soil loss is essential to support agricultural productivity and natural resource management. Thus, this study was aimed to estimate and map the mean annual soil loss by using GIS and Remote sensing techniques. The soil loss was estimated by using Revised Universal Soil Equation (RUSLE) model. Topographic map of 1:50,000 scale, Aster Digital Elevation Model (DEM) of 20 m spatial resolution, digital soil map of 1:250,000 scale, thirteen years rainfall records of four stations, and land sat imagery (TM) with spatial resolution of 30 m was used to derive RUSLE's soil loss variables. The RUSLE parameters were analyzed and integrated using raster calculator in the geo-processing tools in ArcGIS 10.1 environment to estimate and map the annual soil loss of the study area. The result revealed that the annual soil loss of the watershed extends from none in the lower and middle part of the watershed to 265 t ha^{-1} $year^{-1}$ in the steeper slope part of the watershed with a mean annual soil loss of 47 t ha^{-1} $year^{-1}$. The total annual soil loss in the watershed was 255283 t, of these, 181801 (71%) tones cover about 6691 (24%) hectare of land. Most of these soil erosion affected areas are spatially situated in the upper steepest slope part (inlet) of the watershed. These are areas where Nitosols and Alisols with higher soil erodibility character (0.25) values are dominant. Hence, Slope gradient and length followed by soil erodibility factors were found to be the main factors of soil erosion. Thus, sustainable soil and water conservation practices should be adopted in steepest upper part of the study area by respecting and recognizing watershed logic, people and watershed potentials.

1. Introduction

Soil loss by runoff is a severe ecological problem occupying 56% of the world wide area. Soil loss is accelerated by human-induced soil degradation (Bai, Dent, Olsson, & Schaepman, 2008). There are varieties of soil erosion, and rill and inter-rill erosion are the recurrent types of water erosion, involving detachment, transport, and accumulation of soil particles to a new depositional area, deteriorating soil quality as well as diminishing the productivity of vulnerable lands (Fernandez, Cool, & Stockle, 2003).

Despite the fact that soil erosion can be caused by geomorphologic process, accelerated soil erosion is principally favored by human activities. Rapid population growth, deforestation, unsuitable land cultivation, uncontrolled and overgrazing have resulted in accelerated soil erosion in the world principally in developing countries like Ethiopia (Reusing, Schneider, & Ammer, 2000; Tamene & Vlek, 2006; Zemenu & Minale, 2014). Speedy land use alteration because of exhaustive agronomic practices in the Ethiopian high lands upshots intensifying rates of soil erosion (Aster, 2004; Zemenu & Minale, 2014). Soil loss is also activated by an amalgamation of factors such as slope length-steepness, climate change, land cover patterns and the intrinsic properties of a soil, which makes the soil particles more prone to erosion.

The economic effect of soil loss is more in unindustrialized countries like Ethiopia because of lack of capability to withstand it and also to replace the nutrients (Tamene & Vlek, 2006). These countries have been characterized by high population growth which leads to exaggerated use of already harassed resources and proliferation of production to marginal and fragile lands. Such process aggravates erosion and productivity declines, resulting in population-poverty-land deterioration cycle.

The Ethiopian countryside environment has been affected by

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an accelerated deforestation leading to lessening soil fertility. This has accelerated soil loss, intensified the severity of the impact of drought, and a decrease in the capacity to produce food and other biological resources (Bekele & Drake, 2002). Soil loss and the consequent sedimentation still distress 50% of the agricultural area, and 88% of the total population of the country (Sonneveld, Keyzer, & Albersen, 2011). Young (1998) stated that the world's most severe erosion is found in Ethiopia. At national level, the overall soil loss from the whole land is estimated about 1.5 billion tons per year (FAO, 1986; Tamene & Vlek, 2006) with a mean of 42 t ha^{-1} accompanied with land loss of 25,000 ha $year^{-1}$, of which 45% initiated from cultivated land solely. On the other hand, soil loss in the high lands of Ethiopia was estimated about 200–300 t ha^{-1} $year^{-1}$ which makes a total soil loss of 23,400 million ton per year (Bewket, 2003). The annual rate of soil loss (over 1.5 billion tons) in the nation is much greater than the rate of soil formation in annual basis (1.5 million tons) Tamene & Vlek (2006) with an associated cost close to one billion Ethiopian birr each year by Alemu (2005), and 1.0 billion US$ by FAO (1986).

Koga watershed (KW), which is a part of Lake Tana sub basin, is characterized by the above mentioned problems. Gebreyohannis, Taye, and Bishop (2009) also stipulated that loss of top fertile soil and dissection of grazing and farm land by gullies are the major problems in KW. If the current trends in soil erosion in the watershed persist, the farmer's agricultural production in Koga irrigation development will decline.

Information on soil loss is therefore essential to plan and prioritize treatments of the watershed, and to understand the erosion process and their interaction. Soil erosion evaluation and mapping of soil loss susceptible area also helps to understand soil conservation and ecosystem system management mechanisms in the watershed. The mean annual soil loss information per unit land area could be ascertained by employing Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) (Van Remortel, Hamilton, & Hickey, 2001). Since the USLE model (Wischmeier & Smith, 1978) was initially developed only for gentle sloping cropland situations; successive research has lead to the RUSLE model (Renard, Foster, Weesies, McCool, & Yoder, 1996) to broaden the applicability of the models to incorporate soil loss estimation for range land, forest land, disturbed sites, and steep slopes. Therefore, the revised form of USLE (RUSLE) fits the most for this research in Koga watershed.

Koga watershed, where soil loss information and evaluation of risk of potential soil erosion was very few and not assisted with GIS and Remote sensing techniques was preferred for this study. Thus, an attempt was made to estimate and map the spatial pattern of annual soil loss rate by water using Revised Universal Soil Loss Equation (RUSLE) simulated by GIS and Remote sensing techniques. Therefore, this research has given answers to four core research questions; how much of soil is lost per unit area of land annually in Koga watershed? How is the spatial distribution of soil loss rate in Koga watershed? Does the estimated soil loss rate exceed the tolerable limit of soil erosion set by FAO? And where are erosion hotspot areas located for conservation prioritization? It was also supportive to evaluate the effectiveness of soil and water conservation measures implemented so far in the KW. The result of this study will serves as a baseline for further research and ecosystem management.

2. Research methods

2.1. Study area description

The geographic location of the Koga watershed extends from 11.16°N to 11.41°N Latitude and 37.03°E to 37.28°E longitude. A total area of the watershed is about 28,000 ha (Fig. 1) Topography of the area exhibits distinct variation and contains flat low – laying plains (0% slope) surrounded by steep hills (70% slopes) and rugged land features. Thus, Koga catchment can be divided into a narrow steep upper catchment draining the flanks of Mount Adama range, and the remainder on relatively flat plateau sloping

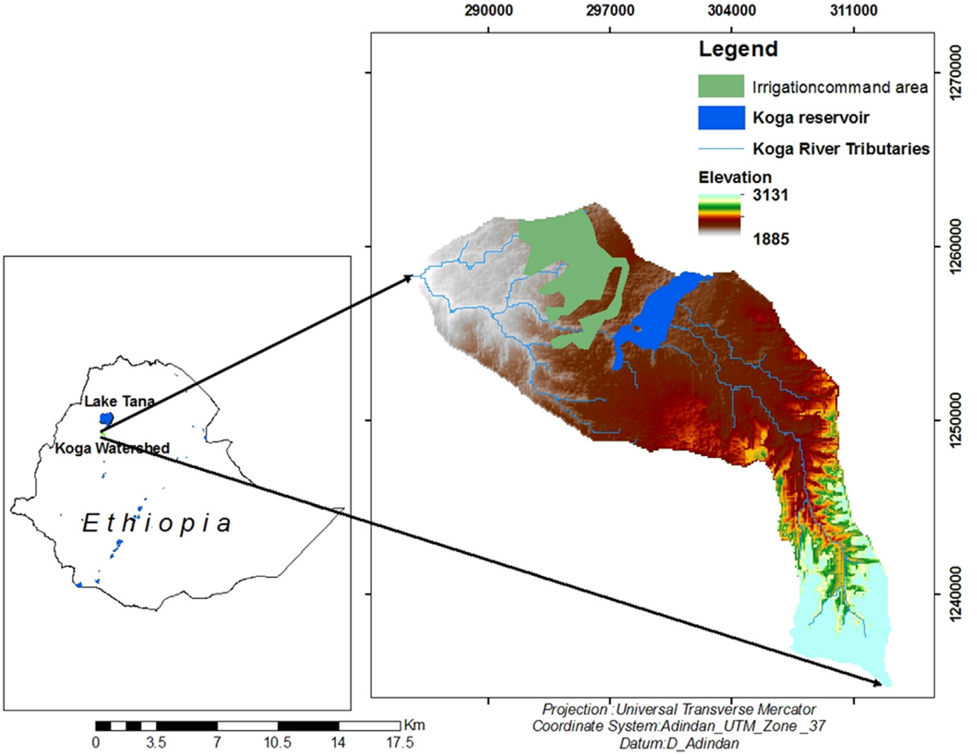

Fig. 1. Study area map.

gently west wards.The altitude ranges from 1885 to 3131 m.a.s.l. The nature of the topographical features has made the area very liable to heavy gully formation and extensive soil erosion. The Koga River is a tributary of the Gilgel Abay River in the head water of the Blue Nile catchment. The Gilgel Abay flows in to Lake Tana. The river is 64 km long flowing into Gilgel Abay River. Koga irrigation and fish reservoir is located in the North Western confluence point of the watershed (Amare, 2013b).

There are about seventeen kebeles (smaller administrative unit) in the watershed. The total population of the watershed excluding the local capital Merawi town was about 57,155 (33475 male and 23627 female) (CSA, 2007). Majority of the population is engaged in agriculture. Koga large scale irrigation and watershed development project has been implemented in watershed since 2009. The Koga irrigation and watershed development project covered about 7000 ha of the irrigable land in the watershed. It is only 1000 ha of the irrigation command area that is located within the watershed.

The mean annual precipitation of Koga watershed was 1628.2 mm, and its minimum and maximum temperature was 17.10 °C and 28.4 °C, respectively. The area experiences the main rainy season '*meher*' *which* commences in June and extends to September (Fig. 2).

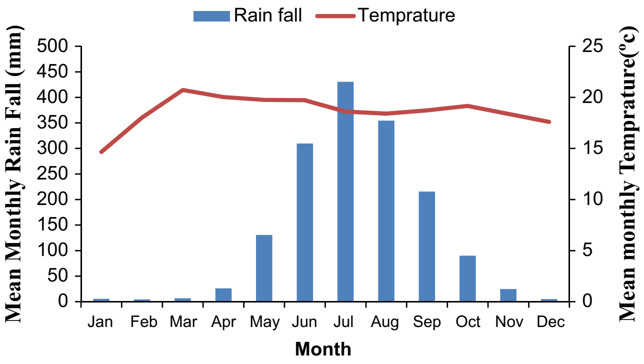

Fig. 2. Mean monthly rainfall and temperature of KW.

2.2. *Sources and techniques of data collection*

Primary and secondary data sources were used for this study. Primary data were collected via field survey and/or ground truth authentication and observation using Global positioning system (GPS) instruments. This gives actual information about what is going on the study area. The watershed was stratified into upper catchment, middle catchment and lower catchment depending on their relative altitude above sea level. Intensive field observation using Global positioning system (GPS) in each stratum of the watershed for each major land use or land cover types were carried out to generate principal information vis-à-vis ground truth so as to train the image using supervised image classification and to produce thematic land use and land cover map. Ground control points (GCPs) for each major land use/cover types were also collected for accuracy validation. Secondary data such as the soil map (1:250,000) taken from Nile river basin master plan,from which, dominant soil type map of Koga watershed associated with their tabular database were identified; Aster Digital Elevation Model (30*30 m) downloaded from Global land cover facility (www.landcover.org) which was resampled to 20*20 m spatial resolution, from which slope length–steepness (LS) factor was derived; Thematic Mapper (TM) multi-spectral image with spatial resolution of 30 m (land use/land cover map) of the year 2013 taken from Ethiopian mapping authority, topographic map (1:50,000) taken from Bureau of Agriculture, from which drainage of the study area were delineated, and thirteen years (2000–2013) rainfall records from four rain gauge stations (Merawi, Meshenti and Bahir Dar and Durbetie) obtained from National Meteorological Agency were used to estimate the annual soil loss of KW. A resampled DEM was employed to discretize and organize each layer of the RUSLE parameters to the cell size of the DEM (20*20) to obtain fine grid based soil loss result as well as to derive detailed slope length–steepness factor value. The Google earth image was also used to digitize and produce water body (Koga reservoir) map of the study area. Other than the aforementioned secondary data, published and unpublished materials such as research reports, census reports, and journal obtained from different sources were used.

2.3. *Method of data analysis*

2.3.1. *Soil loss estimation*

The Revised Universal Soil Loss Equation (RUSLE) framed with GIS and Remote sensing technique was used to estimate the mean annual soil loss occurred in KW. The Revised Universal Soil Loss Equation (RUSLE) is an empirical model developed by Renard et al. (1996) to estimate soil loss from fields. Laflen and Molden (2003) confirmed its applicability on every continent on earth where soil loss by water is a problem. Therefore, Hurni (1985a) made the first attempt to adapt the USLE to the Ethiopian–Eritrean highland conditions using the data available at that time. But, an attempt made by Hurni (1985a) was faced with certain critical puzzles. Firstly, USLE (Wischmeier & Smith, 1978) was best adapted to the condition in United States of America (USA), where it was primarily developed. Thus, it did not account the spatial dynamics of erosion process at different regional scale. Secondly, USLE can be applied only for specific situation, for agricultural field 'not for other kinds of fields' and it cannot be even applied for topographically intricate land scape units by which a country like Ethiopia is characterized. Because USLE assumed little slope curvature and no deposition.

On examining the above mentioned facts, Nyssen et al. (2006) examined the application of the (R) USLE after Hurni (1985a) in the Ethiopian highlands (Tigray Region). However, RUSLE can be applied in many circumstances even on steep and undulating terrain in this study; flow convergence and divergence in a complex terrain were not considered. Again it was conducted at regional scale, hence it did not consider the spatial variability of soil loss process at catchment or watershed level. Zhang et al. (2013) and Van Remortel, Maichle, and Hickey (2004) confirmed that the USLE and RUSLE method of soil loss estimation at regional scale has a limitation in extracting slope length and gradient (LS) factor. Thus, in this study, RUSLE was applied at watershed or catchment level by incorporating the advanced LS factor estimation approach. The Revised Universal Soil Loss Equation (RUSLE) is empirically expressed as:

$$A\left(\text{metric tons ha}^{-1}\ \text{year}^{-1}\right) = R{*}K{*}LS{*}C{*}P\ldots\ldots\ldots \quad (1)$$

where A is the mean annual soil loss (metric tons ha^{-1} year^{-1}); R is the rain fall erosivity factor [MJ mm h^{-1} ha^{-1} year^{-1}]; K is the soil erodibility factor [metric tons ha^{-1} MJ^{-1} mm^{-1}]; LS is the slope length–steepness factor (dimensionless); C is the cover and management factor (dimensionless, ranges from zero to one); and P is the erosion support practice or land management factor (dimensionless, and ranges from zero to one). The RUSLE model was simulated by GIS and Remote sensing techniques as shown in the Fig. 3 below.

To recognize the spatial pattern of the potential soil loss rate in the study area, all the considered erosion factors (R, K, LS, C and P) had been surveyed and calculated depending on the recommendations of Hurni (1985a) to Ethiopian context and other

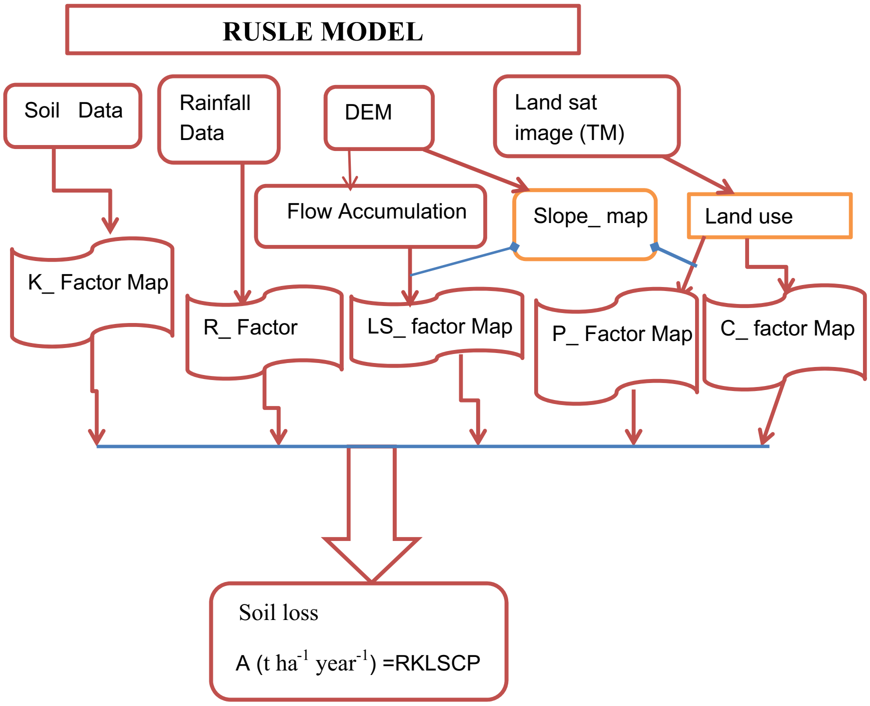

Fig. 3. Conceptual frame work of Soil loss analysis by RUSLE model.

related studies. For the estimation and mapping of the spatial distribution of soil loss in the study area, all the five parameter maps (having the same coordinate system) were discretized to grid with 20 m × 20 m cell size. The layers were then overlaid and multiplied pixel by pixel, using Eq. (1) and raster calculator geoprocessing tool in Arc GIS 10.1 environment.

2.3.1.1. Rainfall erosivity (R) factor. The rainfall erosivity factor quantifies the effect of rainfall impact and also reflects the amount and rate of runoff likely to be associated with precipitation events (Xu, Shao, Kong, Peng, & Cai, 2008*)*.

Erosivity can be predicted by a suitable regression equation in a case of insufficient rainfall records (FES, 2009). Hence, since the rainfall kinetic energy and intensity data were not available in KW, the erosivity factor R was calculated according to the equation given by Hurni (1985a), derived from a spatial regression analysis (Hellden, 1987) for Ethiopian conditions. The model adapted by Hurni (1985a, 1985b) for Ethiopian condition is based on the available mean annual rainfall data (P) where

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

The mean annual rainfall of the four stations obtained from the National Meteorological Agency was interpolated by inverse distance weighted method to produce uninterrupted rain fall data for each grid cell in Arc GIS10.1 environment. From this continuous rainfall data, the R-value of each grid cell was calculated using Eq. (2), and raster calculator geoprocessing tool (Table 1).

2.3.1.2. Soil erodibility (K) factor. Soil erodibility is the manifestation of the inherent resistance of soil particles for the detaching and transporting power of rain fall (Wischmeier & Smith, 1978). This factor quantifies the cohesive character of a soil type and its resistance to dislodging and transport due to raindrop impact and overland flow shear forces. The K-factor is empirically determined for a particular soil type and reflects the physical and chemical properties of the soil, which contribute to its erodibility potential (Animka, Tirkey & Nathawat, 2013). Hurni (1985a) and Hellden (1987) recommended the K values based on easily observable soil color as an indicator for the erodibility of the soil in the highlands of Ethiopia. Thus, the soil types of KW were classified based on their color by referring the soil data base of Blue Nile river master plan. Besides the Blue Nile River master plan soil data base, the Google earth map was used to digitize and produce water body (Koga reservoir) map of the study area. Thus, the vector format of Koga soil map was dissolved with vector format water body map. The original vector format soil map was converted into grid (raster) format. The grid format was then reclassified based on K-factor value for each soil class in Arc GIS 10.1 using reclassification geo processing tools. Provided that the reclassification of the raster soil map was done according to the soil color class given by Hurni (1985a) and Hellden (1987) (Table 2).

Table 1
Rain gauge stations around the study area.
Source: National Meteorological Agency (2014) (computed).

No.	Station name	Location		Altitude	Mean annual rainfall (mm)
		Latitude (Y)	Longitude(X)		
1	Bahir Dar	11.59	37.388	1800	1371.743
2	Merawi	11.411	37.164	2000	1570.87
3	Meshenti	11.5	37.3	1969	1287.74
4	Durbetie	11.359	36.956	1984	1696.74

Table 2
Estimated K values for some soils in Ethiopia.

Soil color	Name/class	Estimated K value [metric tons ha^{-1} MJ $^{-1}$ mm^{-1}]
Black	Andosols,Vertisols…etc.	0.15
Brown	Cambisols, Phaeozems, Regososl, Luvisols…etc.	0.20
Red	Lixisols, Nitosols, Alisols…etc.	0.25
Yellow	Fluvisols, Xerosols….etc.	0.3

2.3.1.3. Slope length–steepness (LS) factor. The (LS) factor is the ratio of soil loss per unit area from afield slopes to that from a 22.13 m length of uniform 9% slope under otherwise identical conditions (Wischmeier & Smith, 1978). Slope length (L sub-factor) in this case represents the distance between the source and culmination of inter rill process. The culmination is either the point where slope decreases and the resultant depositional process begins or the point where concentration of flow into rill or other constructed channel such as a terrace or diversion (Wischmeier & Smith, 1978; Renard et al., 1996).

Deriving slope by geographic information system (GIS) benefits a wide range of environmental models because slope attributes are frequently needed as input for landslides, land planning and construction, and others (Dunn & Hickey, 1998). The shortcomings of slope length calculation can be solved by using the cumulative uphill length from each cell which accounts for convergent flow paths and depositional areas during the use of the Universal Soil Loss Equation (Hickey, 2000). Similarly, LS factor in the RUSLE are measures of the sediment transport capacity of the flow (Moore & Wilson, 1992).

In USLE and RUSLE, the method of slope length calculation was with the notion that the longer the slope, the higher the soil loss without considering the three dimensional complex nature of terrain (Robert & Hilborn, 2000). However, other researchers' claimed that soil loss does not depend on slope length for three dimensional complex terrain where there is flow convergence and divergence, instead it is influenced by upslope contributing area. Thus, it should be substituted by upslope contributing area (Desmet & Govers, 1996a; Moore & Burch, 1986a, 1986b; Mitas & Mitasova, 1996; Simms, Woodroffe, & Jones, 2003). Thus, it is helpful to consider the three dimensional complex terrain geometry as well the upslope contributing area to better comprehend the spatial distribution of soil erosion and deposition process. This study therefore employed the following advanced LS factor computation method based on up slope contributing area suggested by (Desmet & Govers, 1996a; Moore & Burch, 1985, 1986, 1992; Mitasova & Mitas, 1999; Simms et al., 2003).

$$LS = (As/22.13)^{0.6}(\sin B/0.0896)1.3\ldots\ldots\ldots \tag{3}$$

where LS is slope steepness–length factor, As is the specific catchment area, i.e. the upslope contributing area per unit width of contour drains to a specific point (flow accumulation*cell size), and B is the slope angel. LS-factor was computed in Arc GIS raster calculator using the map algebra expression in Eq. (4) suggested by Mitasova and Mitas (1999) and Simms et al. (2003).

$$\text{POW}\ \ ([\text{flow accumulation}]*\ \text{cell size}\ /22.13,\ \ 0.6)*\ \text{POW}\ \ (\sin\ ([\text{slope}]*\ 0.01745)/0.0896,\ \ 1.3)\ldots\ldots\ldots \tag{4}$$

This study therefore used the above mentioned modified and advanced approach of determining slope length and gradient (LS) factor. The values of *S* were directly derived from 20 m resolution DEM. Similarly, flow accumulation was derived from the DEM after conducting fill and flow direction processes in Arc GIS 10.1 in line with Arc Hydro tool. Flaw accumulation grid represents number of grid cells that are contributing for down ward flow and cell size represents 20 m*20 m contributing area.

2.3.1.4. Support practice (P) factor. Erosion control practice factor (*P*-factor) is the ratio of soil loss with a specific support practice to the corresponding loss with up slope and down slope cultivation (Wischmeier & Smith, 1978). The *P*-factor map generated is used for understanding the conservation practices being taken up in the study area. This factor considers the control practices which reduce the eroding power of rainfall and runoff by their impact on drainage patterns, runoff concentration, and runoff velocity. The supporting mechanical practices include the effects of contouring, strip cropping, or terracing (Hyeon & Pierre, 2006). Wischmeier and Smith (1978) assigned the *P*-factor value by categorizing the land into agricultural and other land major kinds of land use types. They then sub-divided the agricultural land in to six slope classes and assigned *p*-value for each respective slope class as many management activities are highly dependent on slope of the area. In this study, this method of combining general land use type and slope was therefore adopted. Values for this factor were therefore assigned considering local management practices along with values suggested in Wischmeier & Smith (1978) (Table 3).

Table 3
P-value (Wischmeier & Smith, 1978).

Land use type	Slope (%)	*P*-factor
Agricultural land (cultivated land)	0–5	0.1
	5–10	0.12
	10–20	0.14
	20–30	0.19
	30–50	0.25
	50–100	0.33
Other land	All	1.00

Hence, in this study the lands with water body, shrubs, and forest and the land used for grazing were classified as other lands given the *P*-value regardless of the slope class they have, whereas the cultivated land was classified into six slope class and given *P*-values as discussed by Wischmeier and Smith (1978). Finally, the classified LULC and slope thematic map format has been changed to vector format and the corresponding *p* values were assigned to the combination of each land use/land cover and slope classes,and raster map of *p* factor was produced.

2.3.1.5. Cover and management (C) factor. The cover and management (C) factor represents the ratio of soil loss from land with specific vegetation to the corresponding soil loss from a continuous fallow (Wischmeier & Smith, 1978; Morgan, 2005). It is the single factor most easily changed and is the factor most often considered in developing a conservation plan. Primarily, unsupervised classification was conducted to acquire the major land use land cover types in the watershed. Based on this information, supervised classification by the help of GCPs was used to produce thematic land cover maps. The thematic land use and land cover raster map of KW was then converted to vector format to assign the corresponding cover and management factor value obtained from different studies. Finally, raster map of *C*-factor was produced.

3. Result and discussion

3.1. Soil loss rate assessment

In this study, (RUSLE) model was integrated with GIS and Remote sensing techniques to conduct cell by cell calculation of mean annual soil loss rate (t ha^{-1} year^{-1}), and to identify and map soil erosion risk areas in KW. Raster map of each RUSLE parameters derived from different data source were produced and discussed as follows.

3.1.1. Rain fall erosivity (R) factor

The erosivity factor estimated by Eq. (2) ranges from 715.58 (Meshenti station) to 945.4 (Durbetie station). The *R*-value of Merawi station which is quite close to the study watershed is 874.7, thus this value has great weight to the *R*-value of the watershed see table (below) (Table 4).

Table 4
Mean annual rain fall and the corresponding *R*-factor value.
Source: National Meteorological Agency (2014) (Computed).

Station name	Mean annual rain fall	*R*-factor [MJ mm h^{-1} ha^{-1} $year^{-1}$]
Bahirdar	1371.742857	762.79
Merawi	1570.871429	874.70
Meshenti	1287.74	715.58
Durbetie	1696.74	945.4

As discussed in Section 2, the point rainfall data obtained from four stations were interpolated by inverse distance weighted (IDW) method so as to estimate the *R*-value of each grid cells. Therefore, the result of this interpolation gives you an idea that there is no significant variation of erosivity value in the watershed (Fig. 4).

3.1.2. Soil erodibility (K) factor

The *K*-factor values of KW comprises three dissimilar soil color types, but five soil class. Eutric Vertisols (black), Eutric Regososl and Haplic Luvisols (brown), and Haplic Nitosols and Alisols (Red) were the dominant soil class in KW. Thus, the *K*-factor value was assigned for each soil class with special reference to their color as recommended by Hurni (1985a, 1985b). Accordingly, the *K* value of 0.15, 0.20, and 0.25 was assigned for Eutric Vertisols (Black), Eutric Regososl and Haplic Luvisols (Brown), and Haplic Nitosols and Alisols (Red) respectively. Water bodies have no estimated erodibility value (Erdogan, Erpul & Bayramin, 2006). So that, the impounded water of Koga reservoir was assigned a *K*-value of zero (0). Therefore, we can understand that Haplic Nitosols and Alisols have high *K*-value (0.25); hence these soils are highly affected by erosion followed by Regosoils and Haplic Luvisols with *K*-value of 0.2. These soils are intrinsically susceptible to the erosive force of rain fall. On the contrary, Eutric Vertisols has low soil erodibility factor (0.15); it is therefore less susceptible to the detaching power of rain drop. Most of the upper part of Koga watershed is dominated by Haplic Nitosols and Alisols which are intrinsically less resistant to the eroding power of rain fall. Whereas, Eutric vertisol with high-resistance to rain fall force is situated in the middle, and a little bit around the outlet of the watershed. Most of the lower and middle part of the watershed is dominated by moderately erodible Haplic Luvisols see Fig. 5 below.

3.1.3. Slope length and steepness (LS) factor

The topographic component of RUSLE was computed using Eq. (3) suggested by Moore and Bruch (1985); Mitasova and Mitas (1999); and Simms et al. (2003). Slope length was substituted by upslope contributing area so as to take in to account the flow convergence, and divergence in a three dimensional complex terrain condition. Thus, the upstream contributing factor and slope angle were considered in the aforementioned method of slope length and gradient factor estimation. As shown in Fig. 6 (upper-left), the slope length is high in the lower part of the watershed duet to high-flow accumulation (upstream contributing area), and low in the upper (inlet) and ridge part of the watershed due to the little or no flow contributing pixel upstream of the ridge. On the other hand, slope gradient is high (70%) in the upper part (inlet) of the watershed, and vice versa in the outlet (lowest elevation) of the watershed (Fig. 6, lower-left).

As expressed above, slope length (*L*-sub factor) and gradient (*S*-sub factor) could not be informative soil loss parameters autonomously. Hence,the combined LS factor was computed as shown in Fig. 6 (right). As a result, the LS factor of RUSLE extends from 0 in the lower part of the watershed to 109 in the steepest slope upper part of the watershed. This implies that the influence of the combined slope length–steepness (LS) factor for soil loss is significant in the upper part of the watershed. On the contrary, the topographic (slope length–steepness) factor contributes insignificantly for soil erosion in the lower and middle part of the watershed (Fig. 6).

3.1.4. Erosion management (support) practice (P) factor

Field observation and the report of Merawi office of agriculture confirmed that different supporting cropland and other land practices in the study area were conducted around the reservoir, in the middle and lower part of the watershed. These are contour tillage, area closure, terrace, stream bank stabilization, forest

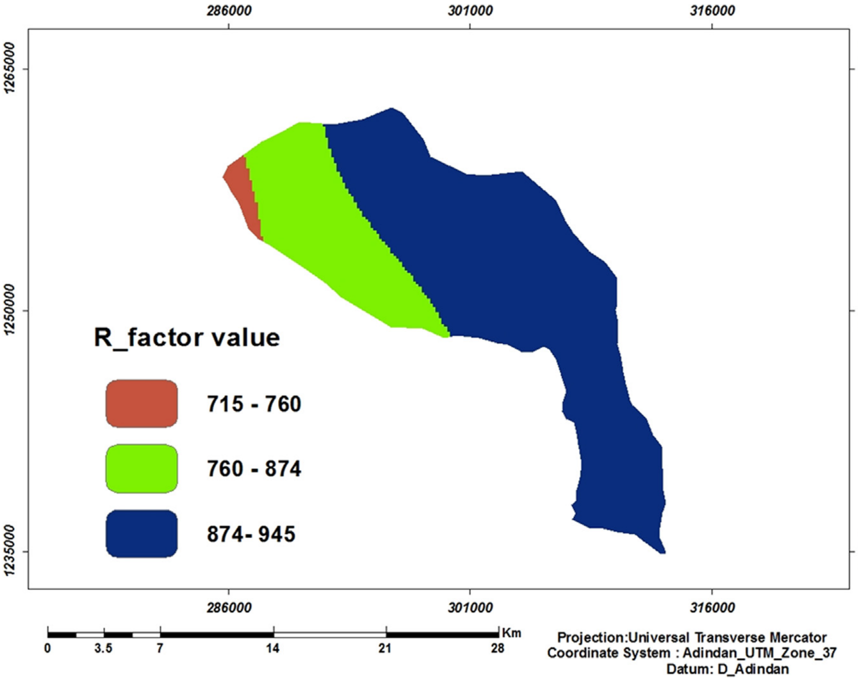

Fig. 4. *R*-factor map.

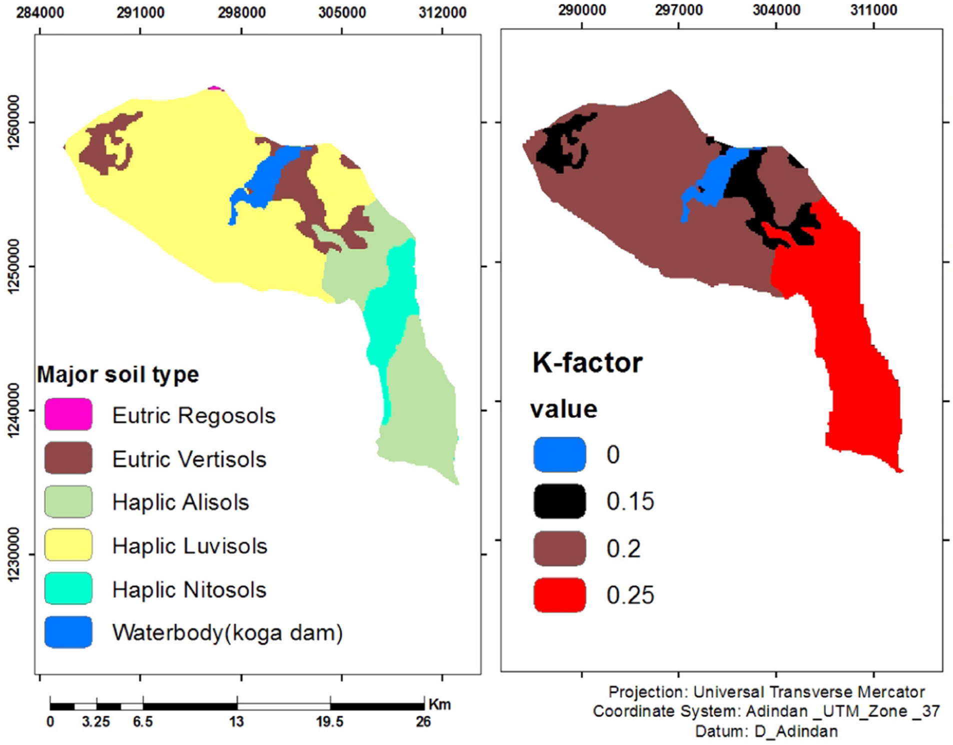

Fig. 5. Major soil type (left) and *K*-factor (right) map.

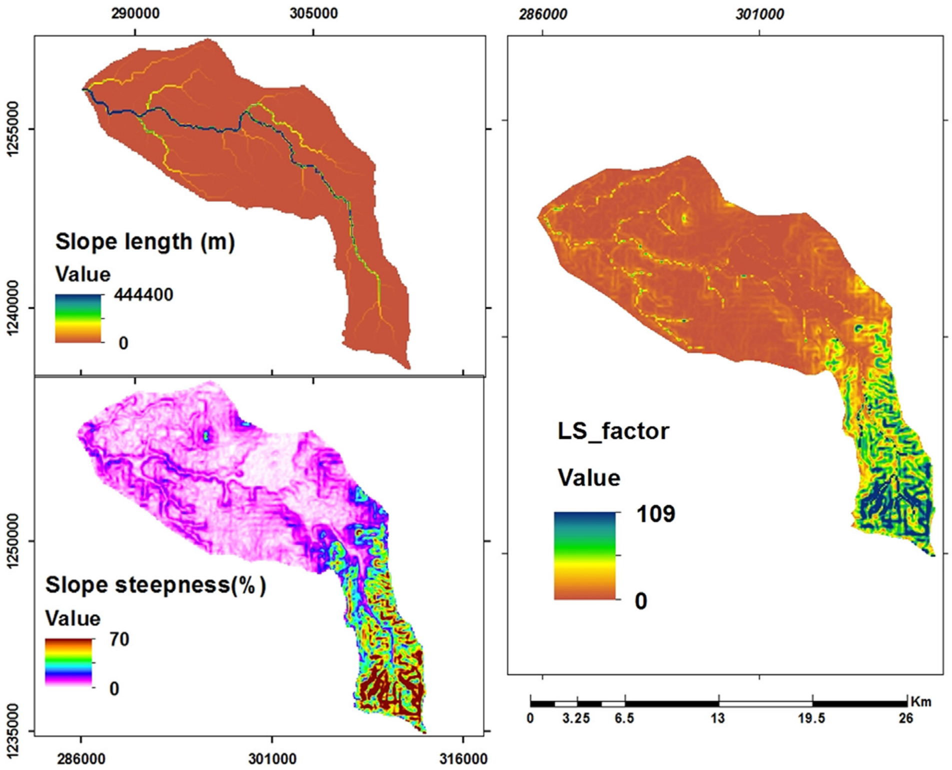

Fig. 6. Slope gradient and slope length (left), and LS-factor (right) map.

development, and grass strip development. Stabilized water ways for the disposal of excess rainfall are also a necessary part of each of this practice. As explained in detail in Section 2, Wischmeier & Smith (1978) method of calculating the *P*-value was used. Therefore, in this study lands containing water body, shrub, and forest and lands used for grazing were assigned as other lands given the *P*-value of 1.00 regardless of their slope class whereas the cultivated land was classified in to six slope class and given *P*-values. Lastly, the thematic land use and land cover and slope map of the watershed were changed to vector format to assign the *P*-value, and raster map of *P*-factor was produced. As illustrated in Fig. 7 below, most of the upper catchment and some of the north eastern middle part of the watershed exhibits *P*-value of 1. On the contrary, most of the lower part of the watershed has the *P*-value

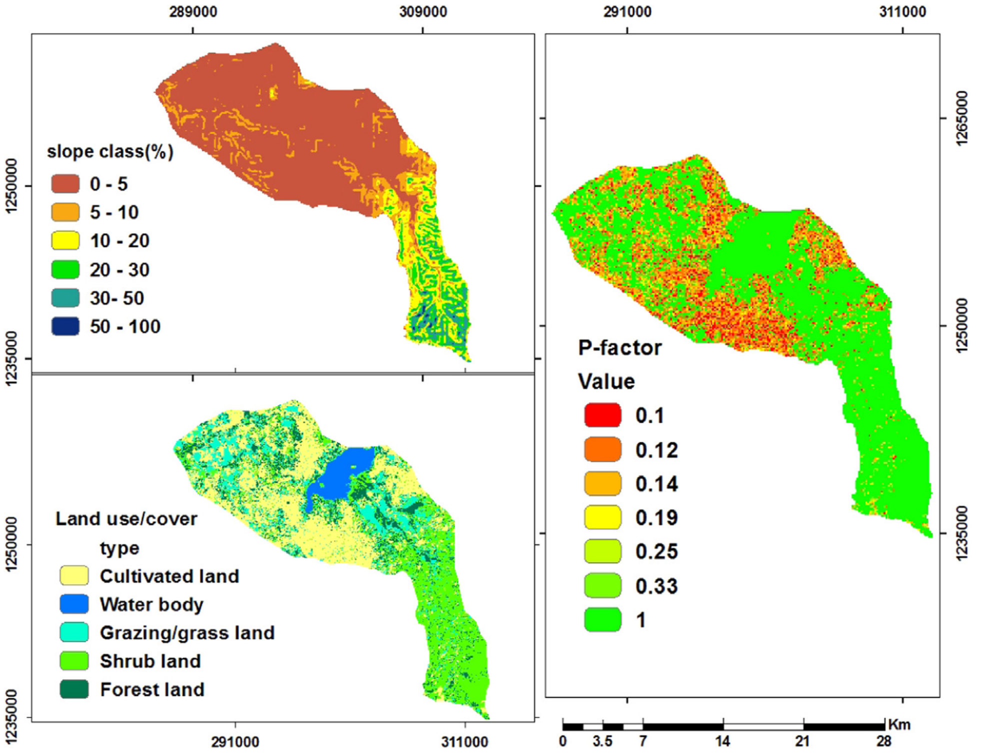

Fig. 7. Land use land cover and slope class (left), and *P*-factor (right).

of nearly 0.1. This implies that the upper catchment of the watershed where erosion management practice were not yet conducted, shrub and grass/grazing lands are dominated as well the highest slope classes are dominant have a significant contribution for erosion (see the following figure).

3.1.5. Cover and management (C) factor

The major land use/covers of the watershed identified by supervised image classification were forest land, shrub land, grazing land, water body, and cultivated land. Maize and Millet were found as a dominant crop covers in Koga watershed. Most of the corresponding land cover factor was obtained from different studies (Table 5).

Most of the lower catchment of the watershed is covered by crop land (millet and maize) so that this part of the watershed has highest *C*-factor value (0.1).This is because annual crops like millet and maize do not reduce the direct impact of rainfall on soil resources unlike forest land. Whereas most of the upper catchment of the watershed is dominated by scattered shrub land and assigned the *C*-value of 0.014 which has less *C*-factor value next to forest land. Therefore we conclude that the contribution of crop and management factor for soil erosion model is higher in case of cultivated land followed by grazing land (Fig. 8).

Thus, the final map that shows the potential annual soil loss of the watershed was produced by overlaying the above five parameters (*K*, *R*, LS, *C*, and *P*) using Eq. (1), and raster calculator geo-processing tools in Arc GIS 10.1 environment (Fig. 9). Each layer was organized in a grid format with a resampled cell size (20 × 20 m) of the DEM. Furthermore, the statistical tool has been used to estimate the amount of soil loss potential and to classify the level of the soil loss risk in the study watershed. For the matter of management prioritization, soil erosion map of the watershed was classified in to six classes as shown in Table 6 and Fig. 9 below.

Table 5
C-factor values for the catchment taken from different studies.

Land use land cover	*C*-factor	References
Water body	0.00	Erdogan et al. (2006)
Cultivated land (Millet Maize)	0.1	Hurni (1985a, 1985b)
Forest land	0.01	Hurni (1985a, 1985b)
Shrub land	0.014	Wischmeier & Smith (1978)
Grazing land	0.05	Hurni (1985a, 1985b), Yihenew and Yihenew (2013)

As shown in Fig. 9, the annual soil loss of KW extends from 0 (the lower and middle part,specifically on koga reservoir) to 265 metric ton ha^{-1} year^{-1} (the narrow steep slope upper catchment) with a mean annual soil loss rate of 47.4 metric ton ha^{-1} year^{-1}. The total annual soil loss in the watershed is 255283 t; of this, 181801 (71%) tone which covers 6691 (24%) ha of land is lost at a rate much greater than the tolerable soil loss rate (Table 6). Tolerable soil loss rate is the maximum allowable soil loss rate that will sustain high-level productivity and an economy (FAO, 1984). Since, most of the major soil types of KW have soil depth ranges from deep to very deep (BCEOM, 2006), the soil loss rate in the study area is far beyond FAO (1994) tolerable soil loss rate of 4.2–7.2 t ha^{-1} year^{-1} for deep and very deep soil depth respectively. This implies that the farmers' agricultural production in general and Koga irrigation development in particular is at severe risk which consequently makes the people insecure for food. Moreover, the life supporting system may be deteriorated and eventually reach in an irreversible condition.

As illustrated in Table 5, soil erosion risk classes of very high (25–45 t ha^{-1} year^{-1}), severe (45–60 t ha^{-1} year^{-1}), and very severe ($>$60 t ha^{-1} year^{-1}) jointly covers 6% of the entire study watershed area, and 42% of the total soil lost in the watershed. Most of these soil erosion affected areas are spatially situated in the narrow steep slope part of the upper catchment (inlet) of the watershed. The severity of soil loss in this part could be (I) the absence of any support practice (high *P*-factor value), and (II) the dominance of Haplic Nitosols and Alisols (K=0.25) which are naturally less resistant to the eroding power of rain fall, and the

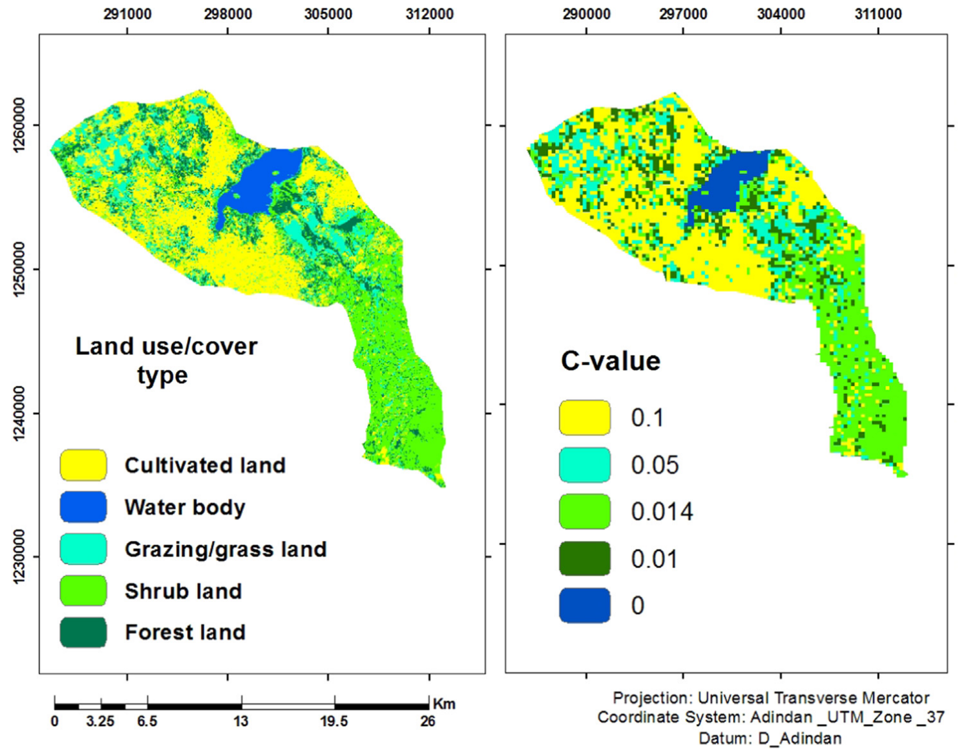

Fig. 8. Land use/cover (left), and *C*-factor (right) map.

steepness of the slope. This part is therefore the primary erosion hot spot area which requires principal conservation measures. While, soil erosion risk classes of moderate (7–15 t ha^{-1} year^{-1}) and high (15–25 t ha^{-1} year^{-1}) which covers 17% of the whole study watershed and 28% of the total soil lost are located a little bit in the lower, and dominantly in the moderate slope upper catchment of the watershed. The reason for these two soil loss classes could be also the prevailing of erosion susceptible soil type (Nitosols and Alisols) together with the undulating nature of the topography. This area is therefore the second conservation priority area and requires considerable soil conservation measures. Whereas the low erosion risk class (0–7 t ha^{-1} year^{-1}) which covers 75.8% of the total study area, and 28.8% of the total soil loss is spatially distributed in the lower and middle part of the watershed surrounding Koga irrigation reservoir. The soil loss rate in this part is lower than the tolerable soil loss rate stipulated by FAO (1984). This could be (I) different supporting croplands and other land practices such as contour tillage, area closure, terrace, stream bank stabilization, forest development, and grass strip development, and stabilized water ways were constructed at the

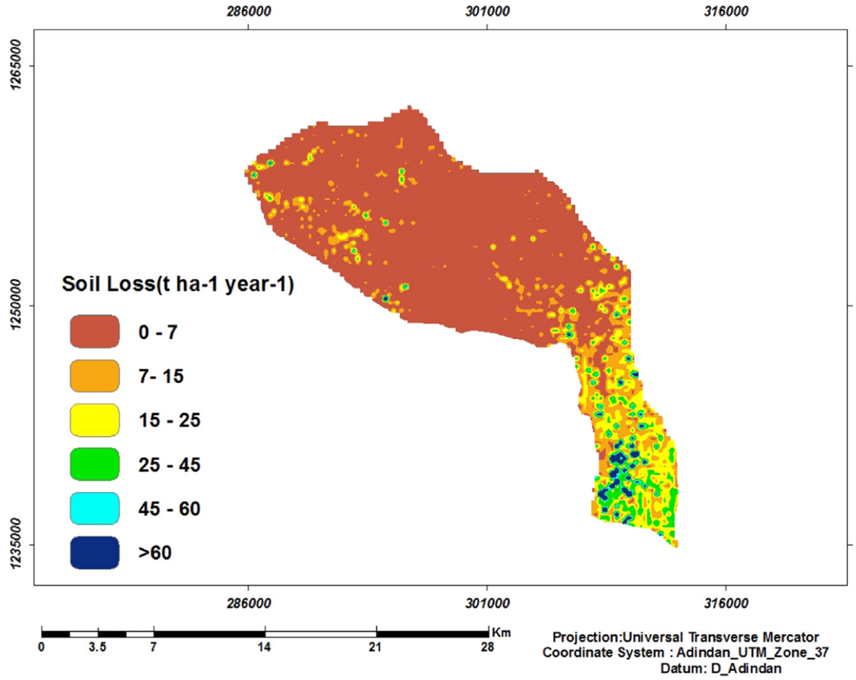

Fig. 9. Soil loss rate map.

Table 6
Numeric soil loss range, area coverage, and severity class.

Numeric range of soil loss (t ha^{-1} year^{-1})	Soil erosion risk class	Area (ha)	Percent of total area	Annual soil loss (tone)	Percent of total soil loss
0–7	Low	20995	75.8	73482.5	28.8
7–15	Moderate	3046	11	33506	13.12
15–25	High	1991	7	39820	15.5
25–45	Very high	1108	4	38780	15.19
45–60	Severe	173	0.6	9082.5	3.6
>60	Very severe	373	1.35	60612.5	23.7

circumference of the reservoir and the lower irrigated part of the watershed with the immediate aspiration of protecting the reservoir and irrigated land since 2009; (II) this part is dominated by flat and/or gentle slope, and intrinsically erosion resistant Vertisols and Luvisols. Zero soil loss was also estimated in this part specifically in Koga reservoir. This is because *K*-factor value is zero in the water body Erdogan et al. (2006), hence the overlay result of RUSLE factor was found to be zero in this point.

The result of RUSLE parameter analysis gives you an idea that slope length and gradient (LS) factor are the primary influential RUSLE parameters followed by soil erodibility (K) factor. This is because Nitosols and Alisols with higher soil erodibility (0.25) values are dominant in the steeper upper part of the watershed.

The estimate of this study (a mean of 47.4 t ha^{-1} year^{-1}) was found to be lower than 131–171 t ha^{-1} year^{-1} estimated by Anjeni research unit of SCRP(Kefeni, 1995), 243 t ha^{-1} year^{-1} by Gete (2000) and a weighted mean of 84 t ha^{-1} year^{-1} estimated by Yihenew & Yihenew (2013). Thus, the variation with the previous findings conducted in North western highlands of Ethiopia could be due to soil and water conservation investment conducted in the last decades in the country in general, and in KW (by Koga watershed development project since 2001) in particular. This indicates that watershed based soil and water conservation investment conducted by Koga watershed development project reduces soil loss rate of the study area specifically in in the middle and lower part. However, the estimate of this study indicated that the watershed is still affected by moderate to very severe erosion rate, thus it needs great attention.

The estimate of this study was close to 30.6 t ha^{-1} year^{-1} by Amsalu and Mengaw (2014), and 39.8 t ha^{-1} year^{-1} by Estifanos (2014). According to the analysis and estimations of FAO (1986), Abate (2011), and Amsalu and Mengaw (2014), the Northern Highlands of Ethiopia comprising the study area has been affected by moderate to very severe erosion. Thus, the finding of this study is authentic based on the aforementioned previous findings.

4. Conclusion and recommendation

Quantitative and spatial soil loss information obtained through simulation of RUSLE parameters by GIS and Remote sensing techniques in an intermediate watershed like Koga watershed guarantees the handling of spatially variable data and inaccessible area easily and efficiently where ground based observation is difficult. The method can therefore be replicated in other parts of Lake Tana sub-basin in particular and in Ethiopia in general for the assessment and delineation of erosion-prone areas, conservation prioritization, and for the evaluation of the effectiveness of different land management practices.

The finding of this study incorporates spatially distributed soil loss rate, and erosion risk map of Koga watershed. The annual soil loss of the watershed extends from 0 (at Koga reservoir) to 265 t ha^{-1} year^{-1} in the narrower steep slope part of the watershed with a mean annual soil loss of 47 t ha^{-1} year^{-1}. Very severe soil loss was observed in the narrower steep slope upper part of the watershed at a rate that exceeds the tolerable soil loss limit. This could be due to the steepness of the slope, and the dominance of intrinsically less resistant soil type (Nitosols and Alisols) to the eroding power of rain fall coupled with the absence of supporting practice. It is therefore observed that this area could be a threat to agricultural productivity, and it extends its offsite effect of sedimentation on Koga irrigation reservoir and irrigated lower part of the watershed. On the reverse, tolerable soil loss rate was estimated in most of the lower parts of the watershed. This is due to the huge investment on soil and water conservation at the near perimeter of the reservoir, flatness of the slope, and the presence of erosion resistant soil type (Vertisols and Luvisols). In this study, therefore, slope length and gradient (LS) factor was the primary influential RUSLE parameter followed by soil erodibility (*K*) factor.

Substantial investment on soil and water conservation measure had been made in the middle and lower part of the watershed irrespective of the watershed logic (conservation measures should be started at upper part of the watershed). Thus, planners should modify their soil and water conservation measures implementation strategies by investing at the upper part of the watershed first and then progressively to the lower part to avert the influence of runoff at its initiation point. Huge investment should be made on biophysical soil and water conservation measures at narrower steep slope upper part of the watershed where severe to very severe erosion rates were estimated. Strong awareness has to be created both for lower land users who intensively engage in irrigation farming and for the upper land users whose soil and water conservation investment has multiplier effect and the strategies to bring them together for land management practice needs to be designed to protect this sensitive watershed (Koga). Moreover, RUSLE does not consider gully erosion which now seriously dissects and fragments grazing and farm lands, and threatens irrigation canals in Koga watershed. Thus, further study on gully erosion estimation and sedimentation is recommended.

References

Abate, S. (2011). Estimating soil loss rates for soil conservation planning in the Borena woreda of South Wollo high lands, Ethiopia. *Journal of Sustainable Development in Africa*, *13*(3), 1520–5509.

Alemu, M. (2005). *Green accounting puts price on Ethiopian soil erosion and deforestation*. Environment for development. ⟨http://www.efdinitiative.org/our-work/policy-interactions/green-accounting-puts-price-ethiopian-soil-erosion-and-deforestation⟩.

Amare, S. (2013b). Retrospective analysis of land cover and use dynamics in Gilgel Abbay Watershed by using GIS and remote sensing techniques, Northwestern Ethiopia. *International Journal of Geosciences*, *4*(7), 1003–1008. http://dx.doi.org/10.4236/ijg.2013.47093.

Amsalu, T., & Mengaw, A. (2014). GIS based soil loss estimation using RUSLE model: the case of JabiTenan Woreda, ANRS, Ethiopia. *Natural Resource*, *5*, 616–626.

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.

Aster, D. (2004). Use of geospatial technologies for environmental protection in Ethiopia. Environmental Protection Authority. United Nations/European Space Agency/Sudan. In *Proceedings of Remote Sensing Workshop on the Use of Space Technology for Natural Resources Management Environmental Monitoring and Disaster Management*. April 4–8, 2004 Sudan, Khartoum.

Bai, Z. G., Dent, D. L., Olsson, L., & Schaepman, M. E. (2008). Proxy global assessment of land degradation. *Soil Use and Management*, *24*, 223–234.

BCEOM (2006). Abay river basin integrated development master plan project. *Data collection and site investigation survey and analysis on environment and soil conservation*. Sectorial studies Section II, Phase 2. Vol. XIII.

Bekele, W., & Drake, L. (2003). Soil and water conservation decision behavior of subsistence farmers in the Eastern Highlands of Ethiopia: a case study of the Hunde-Lafto area. *Ecological Economics*, *46*, 437–451. http://dx.doi.org/10.1016/S0921-8009(03)00166-6.

Bewket W. (2003). Land degradation and farmers' acceptance and adoption of conservation technologies in the Digil Watershed, Northwestern highlands, Ethiopia. Social Science Research Report Series-no. 29. Addis Ababa: OSSERA.

Central Statistical Agency of Ethiopia (CSA) (2007). *Statistical abstract of Ethiopia*. Addis Ababa: CSA.

Desmet, P. J. J., & Govers, G. (1996a). A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. *Journal of Soil and Water Conservation*, *51*, 427–433.

Dunn, M., & Hickey, R. (1998). The effect of slope algorithm on slope estimates with in a GIS. *Journal of Cartography*, *27*(1), 9–15.

Erdogan, H. E., Erpul, G., & Bayramin, I. (2006). *Use of USLE/GIS methodology for predicting soil loss in a semiarid agricultural watershed*. Turkey: Department of Soil Science, University of Ankara.

Estifanos, A. (2014). *Assessment of micro watershed vulnerability for soil erosion using GIS and remote sensing; master of science in GIS and remote sensing*. Ethiopia: Mekele University.

FAO (1986). Ethiopian highlands reclamation study. Vols. 1 and 2. Rome.

FAO (1984). Ethiopian highland reclamation study. Final Report, Vol 1–2. Rome.

Fernandez, C., Wu, Q., McCool, D. K., & Stockle, C. O. (2003). Estimating water erosion and sediment yield with GIS, RUSLE, and SEDD. *Journal of Soil and Water Conservation*, *58*(3), 128 Community Perception. Royal Swedish Academy of Sciences..

FES (2009). Assessment of soil erosion in selected micro-watersheds in Koraput district, Orissa. Anand, India: Foundation for Ecological Security Report.

Gebreyohannis, G., Taye, A., & Bishop, K. (2009). *Forest cover and stream flow in a headwater of the blue nile: complementing observational data analysis with community perception*. Sweden: Royal Swedish Academy of Sciences.

Gete, Z. (2000). *Landscape dynamics and soil erosion process modelling in the North Western Ethiopia highlands. African studies series*. Switzerland: Univesity of Berne.

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

Hickey, R. (2000). Slope angle and slope length solutions for GIS. *Journal of Cartography*, *29*(1), 1–8.

Hurni, H. (1985a). *Soil conservation manual for Ethiopia*. Addis Ababa: Ministry of Agriculture.

Hurni H. (1985b). Erosion–productivity–conservation systems in Ethiopia. In *Proceedings of paper presented at the 4th international conference on soil conservation*, 3–9 November 1985. Maracay, Venezuela.

Hyeon, S. K., & Pierre, Y. J. (2006). Soil erosion modeling using RUSLE and GIS on the IMHA watershed. *Water Engineering Research*, *7*(1).

Kefeni, K. (1995). Soil erosion and conservation in Ethiopia. In *Proceedings of paper presented at the workshop on coffee and other crops in coffee growing areas*. Addis Ababa.

Laflen, J. M., & Moldenhauer, W. C. (2003). *Pioneering soil erosion prediction: the USLE story* (p. 54) Beijing, China: World Association of Soil and Water Conservation.

Mitasova, H., & Mitas, Z. (1999). *Modeling soil detachment with RUSLE 3D using GIS*. IL, USA: University of Illinois at Urbana –Champaign.

Mitas, Z., & Mitasova, H. (1996). Modelling topographic potential for erosion and deposition using GIS. *International Journal of GIS*, *10*, 629–641.

Moore, I. D., & Burch, G. J. (1986a). Physical basis of the length-slope factor in the universal soil loss equation. *Soil Science Society of America Journal*, *50*(5), 1294–1298.

Moore, I. D., & Burch, G. J. (1986b). Modeling erosion and deposition: topographic effects. *Transactions of the Asae*, *26*, 1624–1630.

Moore, I. D., & Bruch, G. J. (1985). Physical basis of the length–slope factor in the universal soil loss equation. *Journal of Soilless Science of American Journal*, *50*, 1294–1298.

Moore, D., & Wilson, J. P. (1992). Length–slope factors for the revised universal soil loss equation: simplified method of estimation. *Journal of Soil and Water Conservation*, *47*(5), 423–428.

Morgan, R. P. C. (2005). *Soil erosion and conservation* ((3rd Edn). Oxford: Blackwell Publishing.

NMA (2014). National Meteorological Agency, Bahir Dar branch, Bahir Dar.

Nyssen, J., Veyret-Picot, M., Poesen, J., Moeyersons, J., Haile, M., Deckers, J., & Govers, G. (2006). The effectiveness of loose rock check dams for gully control in Tigray, northern Ethiopia. *Soil Use and Management*, *20*, 55–64.

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K. & Yoder, D. C. (1996). Predicting soil erosion by water: a guide to conservation planning with the revised universal soil loss equation (RUSLE). Hand book. no. 703. Washington DC: USDA, Agricultural.

Reusing, M., Schneider, T., & Ammer, U. (2000). Modeling Soil loss rates in the Ethiopian highlands by integration of high resolution MOMS-02/D2-Streao-data in a GIS. *International Journal of Remote Sensing*, *21*(9).

Robert, P. S. & Hilborn, D. (2000). Factsheet: universal soil loss equation (USLE). Queen's printer for Ontario.

Simms, A. D., Woodroffe, C. D. & Jones, B. G. (2003). Application of RUSLE for erosion management in a coastal catchment, Southern NSW. In *Proceedings of the international congress on modeling and simulation: integrative modeling of biophysical, social and economic systems for resource management solutions* (pp. 678–683). July 14–17, 2003. Townsville, Australia.

Sonneveld, B. G. J. S., Keyzer, M. A. & Albersen, P. J. (2011). A non-parametric analysis of qualitative and quantitative data for erosion modeling: a case study for Ethiopia.

Tamene, L., & Vlek, P. L. G. (2006). Analysis of factors determining sediment yield variability in the highlands of Northern Ethiopia. *Geomorphology*, *76*, 76–91.

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.

Van Remortel, R. D., Maichle, R. W., & Hickey, R. J. (2004). Computing the LS factor for the revised universal soil loss equation through array-based slope processing of digital elevation data using a C++ executable. *Journal of Computers Geosciences*, *30*(9–10), 1043–1053.

Wieschmeier, W. H., & Smith, D. D. (1978). *Predicting rainfall erosion losses – a guide to conservation planning. Series: agriculture handbook* (pp. 3–4)Washington DC: USDA.

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.

Yihenew, G., & Yihenew, B. (2013). Costs of nutrient losses in priceless soils eroded from the highlands of Northwestern Ethiopia. *Journal of Agricultural Science*, *5* (7), 1916–9752.

Young, A. (1998). *Land resources: now and for the future* (p. 332) Cambridge, UK: Cambridge University Press.

Zemenu, D., & Minale, A. S. (2014). *Adoption of soil conservation practices in North Achefer District, Northwest Ethiopia, Chinese*. *Journal of Population Resources and Environment*, 12. http://dx.doi.org/10.1080/10042857.2014.934953.

Zhang, H. M., Yang, Q. K., Li, R., Lir, Q. R., Moore, D., He, P., Ritsema, C. J., & Geissen, V. (2013). Extension of a GIS procedure for calculating the RUSLE equation LS factor. *Journal of Computers Geosciences*, *52*, 177–188.