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Estimating soil erosion risk and evaluating erosion control measures for soil conservation planning at Koga watershed in the highlands of Ethiopia

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Abstract. Soil erosion is one of the major factors affecting sustainability of agricultural production in Ethiopia. The objective of this paper is to estimate soil erosion using the universal soil loss equation (RUSLE) model and to evaluate soil conservation practices in a data-scarce watershed region. For this purpose, soil data, rainfall, erosion control practices, satellite images and topographic maps were collected to determine the RUSLE factors. In addition, measurements of randomly selected soil and water conservation structures were done at three sub-watersheds (Asanat, Debreyakob and Rim). This study was conducted in Koga watershed at upper part of the Blue Nile basin which is affected by high soil erosion rates. The area is characterized by undulating topography caused by intensive agricultural practices with poor soil conservation practices. The soil loss rates were determined and conservation strategies have been evaluated under different slope classes and land uses. The results showed that the watershed is affected by high soil erosion rates (on average $42\,\mathrm{t\,ha^{-1}\,yr^{-1}}$), greater than the maximum tolerable soil loss ($18\,\mathrm{t\,ha^{-1}\,yr^{-1}}$). The highest soil loss ($456\,\mathrm{t\,ha^{-1}\,yr^{-1}}$) estimated from the upper watershed occurred on cultivated lands of steep slopes. As a result, soil erosion is mainly aggravated by land-use conflicts and topographic factors and the rugged topographic land forms of the area. The study also demonstrated that the contribution of existing soil conservation structures to erosion control is very small due to incorrect design and poor management. About 35 % out of the existing structures can reduce soil loss significantly since they were constructed correctly. Most of the existing structures were demolished due to the sediment overload, vulnerability to livestock damage and intense rainfall. Therefore, appropriate and standardized soil and water conservation measures for different erosion-prone land uses and land forms need to be implemented in Koga watershed.

1 Introduction

The livelihoods of human kind are closely linked to soil resources. Soil provides food, clean water and air and is a major carrier for biodiversity (Katsuyuki, 2009; Keesstra et al., 2016). Nowadays, most of the people in the world remain heavily dependent on soil resources as their main livelihood source, what leads to soil degradation. Soil erosion is a worldwide environmental problem that reduces the productivity of all natural ecosystems and agriculture, which threatens the lives of most smallholder farmers (Dai et al., 2015; Erkossa et al., 2015; Gessesse et al., 2015; Ochoa-Cueva et al., 2015; Taguas et al., 2015; Prosdocimi et al., 2016). Soil erosion by water is the greatest factor limiting agricultural productivity in the humid tropical regions (Sunday et al., 2012). The high erosion rates are mainly affecting the developing countries due to intensive cultivation, deforestation, plowing of marginal lands and extreme climate hazards (Biswas et al., 2015; Colazo and Buschiazzo, 2015; Ligonja and Shrestha, 2015). Soil erosion is further aggravated by environmental land-use conflicts (ELUCs), as recently recognized by Pacheco et al. (2014) and Valle et al. (2014). ELUCs in developing countries have been reported to cause a decline in soil fertility (Valera et al., 2016). Soil erosion rates beyond

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the tolerable limits cause changes in the hydrological, biological and geomorphic processes and geochemical cycles, which reduces services that the soil offers to the human beings (Berendse et al., 2015; Brevik et al., 2015; Decock et al., 2015; Smith et al., 2015). On cultivated lands, appropriate soil conservation mechanisms supported with vegetation are efficient strategies to control soil loss (Cerdà et al., 2016; Zhao et al., 2015). About 80 % of the current agricultural land degradation is caused by soil erosion globally (Angima et al., 2003; Rodrigo et al., 2015). Sustainable agricultural practices are challenged by severe soil erosion, as it reduces on-farm soil productivity and causes food insecurity (Sonneveld et al., 2003; Moges and Holden, 2006; Bewket, 2007). In most developing countries, including Ethiopia, anthropogenic activities trigger soil erosion (Belyaev et al., 2004; Hurni et al., 2005).

With the present Ethiopian population of 90 million and a growth rate of 2.7 % (CSA, 2015), about 80 % of the population depends on agricultural practices, leading to very high population pressure on the land. Studies conducted in Ethiopian highlands show that soil erosion is seen as a direct result of the historical human settlement in the highlands because of its favorable climatic conditions, political factors and soil fertility (Hurni, 1993; Keesstra et al., 2016). Inappropriate land use, poor farming practices and removal of the natural vegetation aggravate soil erosion and so productivity declines, resulting in food insecurity for smallholding farmers (Adimassu et al., 2014; Angassa, 2014; Bravo-Espinosa et al., 2014). Soil erosion is one of the biggest problems resulting in both on-site and off-site effects. The direct on-site effect is related to farming practices (Hurni, 1993) which is often linked to loss of agricultural soil by runoff. Annually, Ethiopia loses over 1493 million tones of topsoil from the highlands due to erosion, which could add about 1.5 million tons of grain to the country's harvest (Hurni, 1993; Lulseged et al., 2008; Yitbarek et al., 2012; Erkossa et al., 2015). Further, about 43 % (537 000 km^2) of the total highland areas of Ethiopia are highly affected by soil erosion with an estimated average of 20 $t\,ha^{-1}\,yr^{-1}$ and measured amounts of more than 300 $t\,ha^{-1}\,yr^{-1}$ on specific plots (Hurni, 1990; Paulos, 2001; USAID CRSPT, 2000). As a consequence of soil erosion, it is estimated that more than 30 000 ha of the country's cropland will be out of production annually (Erkossa et al., 2015). According to Betrie et al. (2011), the Blue Nile basin lost fertile soils with a rate of 131 million $t\,yr^{-1}$ soil due to poor land-use management.

Quantifying the effects of the soil loss helps to substantiate investment in sustainable land management for the benefits to land users. Appropriate soil conservation measures bring economic advantages to the land users, but farmers resist adopting improved erosion control measures due to lack of awareness on the immediate impacts of soil loss for livelihood, and low skills for construction of soil conservation structures (Telles et al., 2013). The amount of soil loss and the status of the existing soil conservation measures can be realistic for farmers and policy makers if expressed in terms of understandable value. The main objective of this study was to estimate soil erosion risk and to evaluate erosion control measures for soil conservation planning at Koga watershed. Specifically, the study was designed to model soil erosion with the revised universal soil loss equation (RUSLE) and to assess soil and water conservation (SWC) structures according to the national guidelines. The adapted RUSLE model was therefore selected for its low number of required data and for its ease as a tool for field application by technicians.

2 Materials and methods

2.1 Description of the study site

The study was conducted at the Koga watershed which is one of the major watersheds at the source of river Blue Nile River, in north-western Ethiopia (Fig. 1). It is located in the central highland eco-climatic zone of Ethiopia between 11°10′06″ to 11°24′22″ N and 37°2′48″ to 37°17′41″ E surrounded by high mountains (maximum elevation is 3100 m a.s.l.) which serves as the main source of water streaming in the rivers that feeds the Koga irrigation dam. Lowlands are gently sloped, with elevation 1880 m a.s.l.

In the upper catchment of the study area, more than 60 % of the land is under intensive cultivation, predominantly rainfed. In the lower catchment, more than 80 % of the area is under cultivation and 20 % of the watershed is considered too degraded for agricultural production. The upper watershed is covered by very shallow Leptosols which have reasonable potential for conservation agriculture. Over 90 % of the area in the downstream part of the watershed is covered by Haplic Alisols, which are suitable for irrigation. The remaining soils, Vertisols and Gleysols, are constrained by poor drainage. The area is included in the tepid moist midhighland agro-climatic zone, which is affected by the position of the north–south oscillation of the inter-tropical convergence zone characterized by high annual rainfall variability. The rainfall of the Koga watershed is of the monsoon type, with mean annual rainfall of 1640 mm, of which 94 % occurs in the months between May and October.

2.2 Research methods

2.2.1 Sources and use of data

The distribution of the average annual rainfall distribution of the Koga watershed was computed from the record of the last 15 years. Long-term mean monthly rainfall data were collected from six meteorological stations (Meshenti, Adet, Merawi, Tissabay, Durbete, and Dangla) from the years 2000 to 2015. The monthly values were converted to mean annual rainfall and interpolated using the ordinary kriging method for the entire watershed. Then, the R factor map was determined using the following regression Eq. (1) as calibrated by

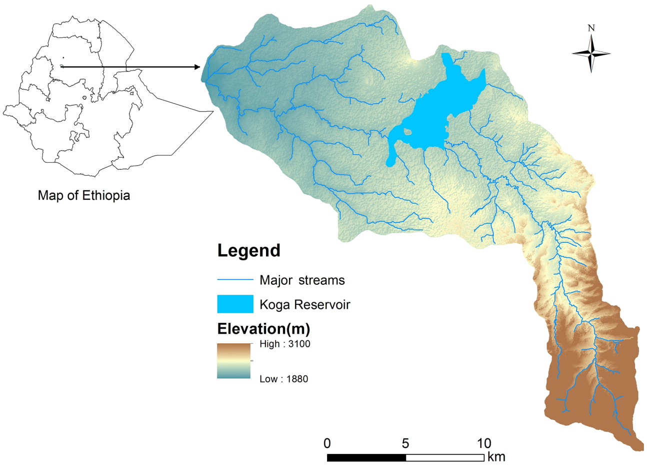

Figure 1. Location map of the Koga watershed showing an elevation range.

Kaltenrieder (2007) for Ethiopian highlands.

$$R = 0.55x - 4.7, \tag{1}$$

where R is rainfall erosivity ($\mathrm{MJ\,mm\,h^{-1}\,ha^{-1}\,yr^{-1}}$) and x is mean annual rainfall (mm).

The soil data were collected from a combination of two different sources. The digital soil map produced by Ministry of Water Resources of Ethiopia using the FAO–UNESCO–ISRIC soil classification system and the Koga irrigation project pre-visibility study (ACRES, 2006). Soil data were digitized and integrated to get a more accurate and detailed soil map. In different parts of the watershed, 29 auger-holes to a depth of 3 m and 128 test pits to a depth between 2 and 4.5 m were carried out in order to determine the soil properties. Based on these data, which is supported by the field soil survey, K factor was determined by giving it the value according to the soil type map of the watershed based on the Kaltenrieder (2007) and Andersson (2010) studies for Ethiopian conditions.

The digital elevation model (DEM) with 30 m resolution obtained from the Shuttle Radar Topographic Mission (SRTM) and a 1 : 50 000 scale contour map produced by the Ethiopian Mapping Agency in 1984 were used as a source of elevation data. The final DEM of the study area was interpolated at 20 m vertical interval and 0.01 m vertical resolution using the spline method of ArcGIS spatial analysis to compute the spatial variability of the slope length and steepness factors using the following Eq. (2) (Renard et al., 1997; Kaltenrieder, 2007):

$$L = \left(\frac{\lambda}{22.31}\right)^{m}, \tag{2}$$

where

$$m = \frac{\beta}{(1+\beta)}, \quad \beta = \frac{\left(\frac{\sin\theta}{0.0896}\right)}{\left[3(\sin\theta)^{0.8} + 0.56\right]}, \tag{3}$$

λ is the horizontal projection (m) and θ is the slope angle.

In this study, the LS factor was calculated considering the watershed conditions with the standard slope steepness of 9 % and slope length of a 22 m plot. The steepness factor derived from the slope map of the study area was calculated for high (> 9 %) and low slope land (< 9 %), as shown below (Wischmeier and Smith, 1978; Renard et al., 1997; Robert and Hilborn, 2000).

$$S = 16.8\sin\theta - 0.5 \text{ (for slope ange } \theta \geq 9\,\%)$$
$$S = 10.8\sin\theta + 0.3 \text{ (for slope ange } \theta \leq 9\,\%)$$

The C (crop cover and management) and P (supporting practice) factors, qualitative properties of a specific plot, were quantified in order to be able to calculate soil loss by the RUSLE. Information concerning crop cover types for different time span was collected from database archives of the Soil Conservation Research Project (SCRP 2000a-f, 2002) database files and reports (SCRP 1982, 1983, 1984, 1986, 1988, 1991, 2000, 2002). The crop type datasets and the land-cover classes (SPOT image with 2.5 × 2.5 m resolution) were averaged to determine the mean C factor map. Due to missing information on permanent erosion control support practices (e.g., terracing, strip cropping, mulching, stone cover), P values were analyzed based on the land-use map for different slope classes.

2.2.2 Estimation of soil loss rate

Soil loss rate at watershed level is determined by the interplay of physical, hydrological and land management practices. Therefore a mixed approach of field investigation and adopted RUSLE modeling was used for soil erosion assessment, based on the fact that RUSLE is used to compute long-time average soil losses from sheet and rill erosion. The model does not account for soil loss events caused by gully erosion or mass movements. Determination of the RUSLE model parameters was based on the adapted and validated equations to the Ethiopian Highlands by different researchers (Hurni, 1985; SCRP, 2002; Erdogan et al., 2007; Kaltenrieder, 2007; Andersson, 2010) using 6 to 14 years of data measured in seven soil conservation research programs (SCRPs) established in representative geographical sites. The annual soil loss rate was calculated by a cell-by-cell multiplication of the raster map of the six parameters following Eq. (4) (Wischmeier and Smith, 1978; Renard et al., 1997):

$$A = R \times K \times L \times S \times C \times P, \tag{4}$$

where A is the annual soil loss ($\mathrm{t\,ha^{-1}\,yr^{-1}}$) resulting from sheet and rill erosion. R is rainfall erosivity in $\mathrm{MJ\,mm\,h^{-1}\,ha^{-1}\,yr^{-1}}$ and K is soil erodibility ($\mathrm{t\,h\,MJ^{-1}\,mm^{-1}}$); the other dimensionless factors are LS as they are topographic factors for slope length and steepness, whereas C is cover management and P is conservation practice factor. Figure 2 shows the detailed process of the methodology.

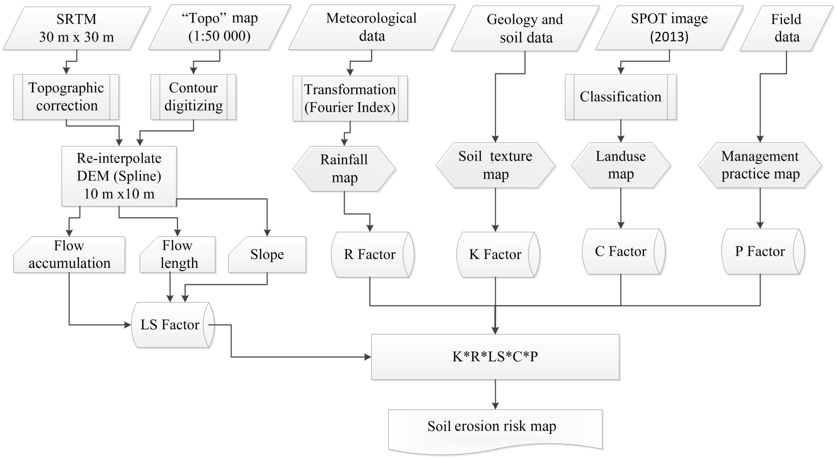

Figure 2. Conceptual framework of the research methodology to estimate the soil erosion rate using the RUSLE model.

2.2.3 Evaluating the physical soil conservation structures

In addition to RUSLE, the status of soil conservation measures provides information about the backgrounds of erosion symptoms for designing appropriate solutions to the problem. For this study, 27 sample plots (7 in the upper part, 8 in the middle, and 12 at the bottom) were randomly selected at the watershed. From these plots, slope (%), soil depth (cm) and type of soil conservation practice(s) were measured to evaluate the environmental land-use conflict based on the national land capability classification. In order to evaluate the quality of physical erosion control structures, 21 farm bund structures and 16 check dam structures were randomly selected at each land-use plot of the watershed. The major design parameters measured were horizontal spacing, vertical interval, bund gradient and foundation.

3 Results

3.1 Rainfall erosivity (*R* factor)

The long-term mean annual rainfall varies between 1500 and 2000 mm at the study area (Fig. 3). The highland areas of the watershed get relatively high rainfall. The rainfall distribution has been influenced by topographic characteristics of the watershed. The highland areas receive relatively high rainfall than the plain of the lower watershed. Considering topographic variation, the R factor was determined from average long-term rainfall data interpolated from six stations. The R factor value ranges between 810 ± 900 and 1030 ± 46 MJ mm h^{-1} ha^{-1} yr^{-1}. The effect of rainfall on soil erosion is high at the upper part of the watershed, with a mean erosivity value of 970 MJ mm h^{-1} ha^{-1} yr^{-1}. On the other hand, the erosion potential of rainfall gradually decreases from the central plain to the lower part of the watershed. Therefore, the mean R values determined for the study watershed are reliable with an average erosivity validated from SCRP experiments from the same agro-ecological zone.

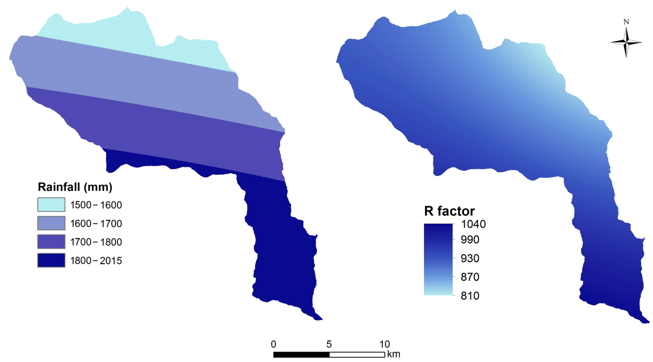

Figure 3. Map of mean annual rainfall (left) and rainfall erosivity (right) distribution of the study site.

The effect of rainfall on soil erosion is high at the southern part of the Koga watershed, with higher elevation, reaching a maximum erosivity value of 1030 MJ mm h^{-1} ha^{-1} yr^{-1}. On the other hand, the erosivity of rainfall gradually decreases from central plain to northern part of the watershed.

3.2 Soil erodibility (*K* factor)

The K factor reflects the combined effect of soil properties, showing the general proneness of a particular soil type to erosion. In general ten types of soil classes were identified for the study area (Table 1). The dominant soil type, Haplic Alisol, covers 10 500 ha of the watershed. The soil types constituting 32 % of the area, mostly in the upstream, are characterized by poor to moderate drainage and stony and shallow soil type having moderate infiltration rates; altogether this results in a high erodibility.

Table 1. General description of the soil types and detailed characteristics of the soil units and their area coverage in Koga watershed.

Soil	Soil units	Soil type	Characteristics	Area (ha)
Pd/v	Eutric Vertisols	Cracking heavy clay	Poorly to very poorly drained, very deep, very dark when dry, friable, cracking heavy clay	1160.2
Pd/g	Eutric Gleysols	Sandy clay loam to clay	Very poorly drained, very deep, friable, acid	2824.5
UpA	Haplic Alisols	Very friable to friable clay loam to clay	well drained, very deep, strongly acid	10 502.5
Upb	Haplic Alisols	Very friable to friable Clay loam to clay	as in UpA, but with complex 2 to 5 % slope	5547.3
Mr	Lithic Leptosols	Extremely rocky silty clay loam to silty clay	Excessively drained, very shallow soil	87.2
Upc	Haplic Alisols	Very friable to friable clay loam to clay	as in UpA, but with simple slopes of 5 to 15 %	1355.2
Pf/t	Gleyic and Chromic Cambisols	Silty clay loam to silty clay	Moderately well to imperfectly drained, very deep, acidic	196.8
Pd/gd	Eutric Gleysols	Sandy clay loam to clay	Same as in Pd/g, but with a better drainage during the dry periods due to proximity to incised Koga river	784.4
Pd/gb	Eutric Gleysols	Sandy clay loam to clay	Same as in Pd/g, but with complex 2 to 5 % slope	316.3
Md	Luvic Phaeozems and Chromic Cambisols	Friable sandy clay loam to clay	Well drained, moderately deep to very deep, in places stony to very stony	6270.8

The K factor, indicating the rate of soil loss per erosion index unit following Wischmeier and Smith (1978) and Andersson (2010), was assigned to each soil type considering the soil characteristics based on the detailed soil map (Fig. 4).

K values of different soil types that have similar characteristics were averaged and the mean value was used for further analysis. The erodibility map shows that Lithic Leptosols and Eutric Gleysols are highly susceptible to soil erosion, with K values of 0.32 and 0.31 respectively. Soils of the highlands such as Luvic Phaeozems and Chromic Cambisols have moderate K values.

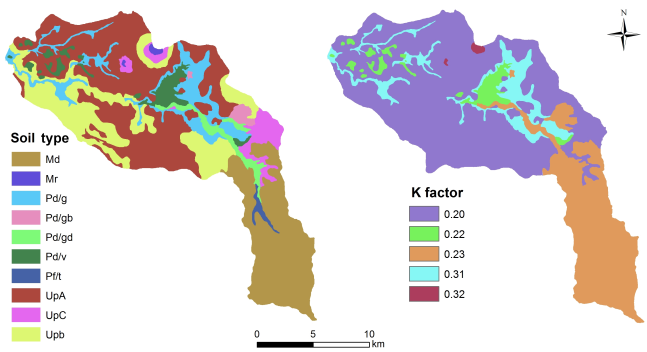

Figure 4. Calculated mean K values map (right) based on data from the soil type map (left) of the study site.

3.3 Slope length and steepness (LS) factor

The combined LS factor indicates the effect of slope length and slope steepness on soil loss. The combined LS factor value was calculated for every segment and the result varies from 0 to 200 (Fig. 5).

Most of the upper and central plains of the Koga watershed, covering 68 % of the study area, have relatively low LS values (0–10). In this study, high LS values (20–200) were mostly determined for the mountainous and hilly region of the upper Koga watershed and along the sides of the main streams that covered 23 % of the area.

3.4 Crop cover and management (C factor)

The C factor represents the effect of plants, crop sequence and other soil cover surface on soil erosion. The C factor is dimensionless with values between 0 and 1. As shown in Fig. 6, six representative land-cover classes were identified for the study area that consists mainly of agricultural lands. Finally, land-cover classes were used to calculate the mean C factor values by averaging each record for a particular land use. C values for finger millet and teff (0.25), maize

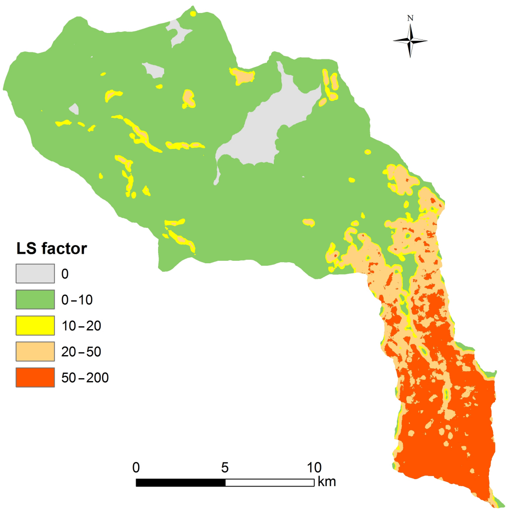

Figure 5. Map of slope length and steepness (LS) factor generated from the DEM and topographic map of the study site.

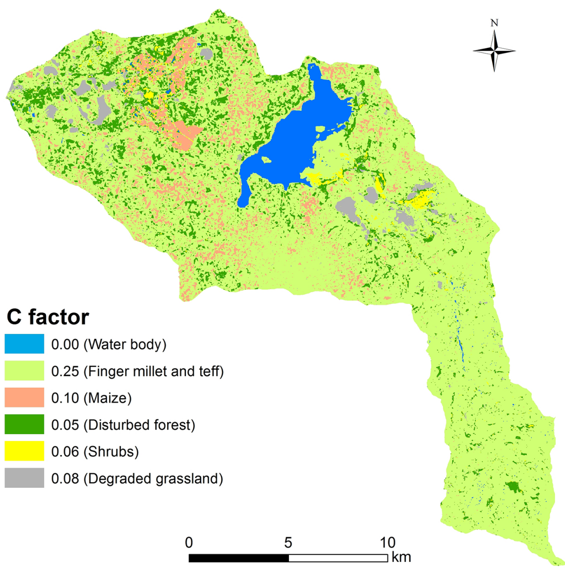

Figure 6. Map of C values quantified from land-cover classes based on different files of the Soil Conservation Research Program (SCRP) database and different SCRP publications (after Hurni, 1985; Wischmeier and Smith, 1978).

(0.10), degraded grass (0.08), shrub (0.06) and disturbed forest (0.05) were determined following Hurni (1985) and Wischmeier and Smith (1978). Finger millet and teff were given the C values which indicates that these crops show slightly similar characteristics.

3.5 Erosion management practice (P factor)

The P factor reflects the impact of specific erosion management practices on the corresponding erosion rate with values between 0 and 1. No soil or water conservation measures are applied to the study area, except temporary terracing, strip cropping, mulching and stone cover treatments in a small area. P values are assigned by delineating the land into arable, forest, grass and shrub land-use classes (Fig. 7).

Table 2. Resulting P values using records of supporting Practices and land uses, 6 categories of agricultural lands based on slopes.

ID	Land-use type	Slope	P factor
1	Cultivated land 1	0–2 %	0.10
2	Cultivated land 2	2–5 %	0.12
3	Cultivated land 3	5–8 %	0.14
4	Cultivated land 4	8–15 %	0.19
5	Cultivated land 5	15–30 %	0.25
6	Cultivated land 6	> 30 %	0.33
7	Forest	all	1.00
8	Grassland	all	0.80
9	Shrub	all	0.80
10	Water body	all	0.00

The management activities vary on the slopes of the cultivated lands. Therefore, the arable land is also sub-divided in to six classes based on the slope percentage, to assign different P value for each slope class (0–2, 2–5, 5–8, 8–15, 15–30, and > 30 %) (Table 2). High P values are determined from cultivated land practiced on slope classes greater than 30 %.

3.6 Annual soil loss estimation within Koga watershed

According to FAO (1986) and Gebreyesus and Kirubel (2009), there are six categories of soil loss risk in the study area (Fig. 8), ranging from low (0–5 t ha^{-1} yr^{-1}) to extreme (150–716 t ha^{-1} yr^{-1}). On average, the rate of annual soil loss in the Koga watershed was predicted to be 42 t ha^{-1} with a specific spot at the upper part of the watershed exhibiting maximum losses of 716 t ha^{-1}. The highest erosion rates are found at the upper hill parts of the study site and near channels of rivers. This situation was severe in mountainous lands where farming is common and the soil loss rates from these areas were above 50 t ha^{-1} yr^{-1}. The estimated soil loss was relatively much lower on plain sites compared to the hill slope lands.

The long-term average annual soil loss rate increased with the slope conditions (Table 3); on average, 1.3 million tons of soil eroded from 4924.3 ha of land due to cultivation of steep slopes and climate extremes.

Most parts of the lower watershed (62 %) lie within the low-severity class that contributes only 6 % of the total annual loss estimated. 5 % of the study area is classified as high and very high potential erosion zones (Table 3). The steep slope and rugged mountains region of the southern part of the watershed falls under severe (100 to 150 t ha^{-1} yr^{-1}) and extremely severe (150 to 716 t ha^{-1} yr^{-1}) erosion classes. These sites contribute about 83 % of the potential soil loss and cover 21 % of the entire area.

Table 3. Area and amount of annual soil loss for each severity class and the corresponding average slope (%), measured mean LS and *R* values of the study site.

Soil loss ($t\,ha^{-1}\,yr^{-1}$)	Severity class	Area (ha)	Area (%)	Total annual soil loss (t)	Average slope (%)
0–5	Low	18 400	62	57 180	3
5–20	Moderate	3300	12	33 242	6
20–50	High	940	3	19 864	10
50–100	Very high	650	2	98 360	12
100–150	Severe	1560	5	228 670	17
150–716	Extreme	4650	16	807 764	26

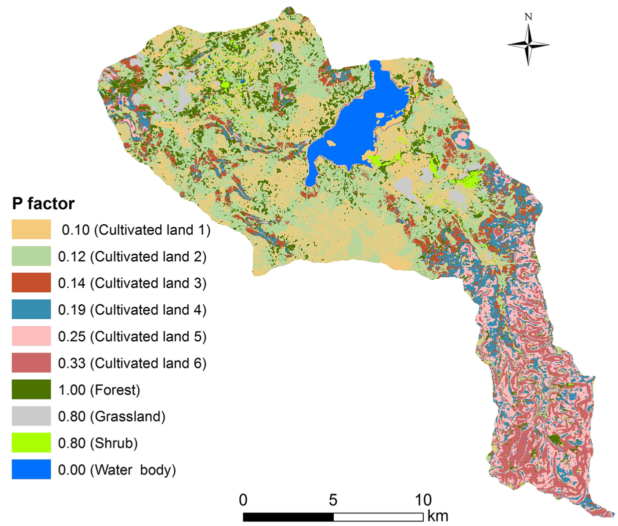

Figure 7. Spatial distribution of calculated *P* values using basing on SCRP database and other publications on the study site (following Wischmeier and Smith, 1978; Shi et al., 2002; Bewket and Teferi, 2009).

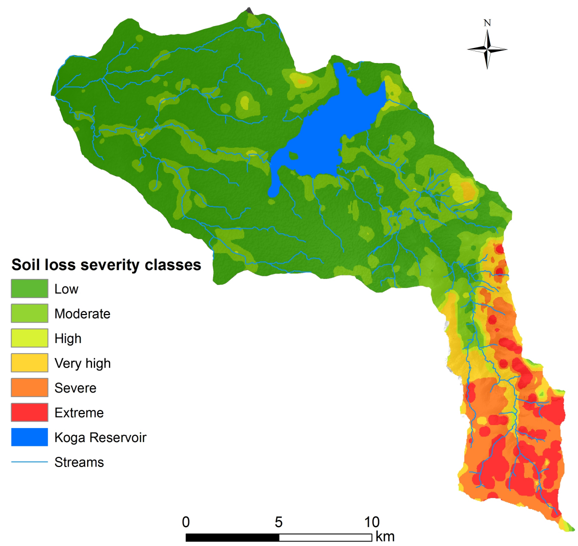

Figure 8. Spatial distribution of soil loss severity classes of the study watershed.

3.7 Evaluation of soil conservation structures

Soil depth, slope (%) and existing soil conservation practices were measured on 27 farm plots with dimensions of 100 m × 100 m at every 200 m spacing, as presented in Table 4. It can be seen that there is high (65 %) mismatch between the existing and the recommended soil conservation practices in the study site. The farmers practice only contour cultivation and use stone terraces which are damaged and ineffective for erosion control.

The result revealed that only 35 % (standard deviation of 29 %) average performance of the existing implemented soil conservation practices fit with the national technical standards. Better matches with recommended standards are observed at the middle part of the watershed.

3.8 Evaluation of farm terraces and check dam conservation structures

As Table 5 showed, the vertical intervals and horizontal distance of only 21 erosion control structures (34 %) were constructed based on the standardized package set on the national guidelines of the country. The remaining 42 terraces do not meet the standardized vertical interval (VI) and horizontal distance (HD) structural requirements.

The result revealed that the vertical interval (height) of terraces is wider than the recommended value in which huge amount of runoff has been accumulated on the terraces. The distance between consecutive terraces is also wider than the recommended dimensions. Among the measured terraces, 30 dismantled terraces were observed during the field work.

Additionally, the existing spacing and foundation of 16 check dams was measured to evaluate the status of the structure along different slope classes in the watershed. The average check dam spacing measured in 2015 is 9.42 m. As depicted in Table 6, the average spacing between consecu-

Table 4. Evaluation of the status of existing soil conservation practices (ESCP) based on the national recommended soil conservation practices (ReSCP), considering the soil depth and slope value of selected farm plots during the study period.

Plot no.	Soil depth (cm)	Slope (%)	ESCP	ReSCP (MoARD, 2005)	Rating fitness of ESCP vs. ReSCP (%)
1	22	26	Stone face soil bund and vegetative barrier	Contour cultivation, strip cropping, vegetative barrier and road-based terraces	50
2	52	12	Contour cultivation and damaged stone terrace	Contour cultivation, strip cropping, vegetative barrier, broad-based terraces	41
3	12	23	No conservation structures	Bench terracing, or terracing	0
4	28	11	Contour cultivation, stone face soil bund and vegetative barrier	Contour cultivation, strip cropping, vegetative barrier and broad-based terraces	75
5	6	55	No conservation structures	Tree plantation	0
6	11	34	No soil conservation structures	Bench terracing and hill side ditching	0
7	9	35	No soil conservation structures	Terracing and hill side ditching	0
8	38	10	Contour cultivation and stone terraces	Contour cultivation, strip cropping, vegetative barrier and broad-based terraces	50
9	76	10	Contour cultivation, stone face soil bund and vegetative barrier	Contour cultivation, strip cropping, vegetative barrier and broad-based terraces	75
10	30	16	No conservation structures	Bench terracing or terracing	0
11	20	17	Contour cultivation and damaged stone terrace	Bench terracing or terracing	70
12	71	9	Contour cultivation and stone face soil bund	Contour cultivation, strip cropping, vegetative barrier and broad-based terraces	50
13	45	11	Damaged stone bund and contour cultivation	Contour cultivation, strip cropping, vegetative barrier, broad-based terraces	45
14	14	18	Contour cultivation, stone face soil bund and vegetative barrier	Bench terracing, or terracing	100
15	77	7	No soil conservation structures	Contour cultivation, strip cropping, vegetative and rock barrier	0
16	52	12	Contour cultivation and damaged stone face soil bund	Bench terracing, or terracing	50
17	66	11	Stone face soil bund and contour cultivation	Contour cultivation, strip cropping, vegetative barrier and broad-based terraces	50
18	10	19	Contour cultivation and terraces	Bench terracing, or terracing	50
19	12	18	No soil conservation structures	Bench terracing	0
20	130	4.5	Stone face soil bund and contour cultivation	Contour cultivation, strip cropping, vegetative barrier and broad-based terraces	50
21	55	13	Damaged stone face soil bund and contour cultivation	Bench terracing, or terracing	50
22	84	7	Vegetative barrier and contour cultivation	Contour cultivation, strip cropping, vegetative barrier and broad-based terraces	50
23	120	5.5	Contour cultivation	Contour cultivation, strip cropping, vegetative barrier and broad-based terraces	25
24	155	4	No soil conservation measure	Contour cultivation, strip cropping, vegetative barrier and broad-based terraces	0
25	134	4.5	No soil conservation structures	Contour cultivation, strip cropping, vegetative barrier and broad-based terraces	0
26	110	10	Contour cultivation	Contour cultivation, strip cropping, vegetative barrier and broad-based terraces	25
27	15	17	Damaged stone face soil bund	Bench terracing, or terracing	50
Average performance					35 %

Table 5. Comparison of measured terrace structure parameters (VI, HD, gradient) based on the national terrace dimensions for different slope classes at selected farm plots of the study site.

			Status of measured terraces				Recommended dimensions of terraces (MoARD, 2005)		
Plot No.	Slope (%)	No. of terraces measured	VI (m)	HD (m)	Terrace gradient	No. of terraces dismantled	VI (m)	HD (m)	Terrace gradient
1	3	3	1	33	1	0	1	33	0.5–1
2	4	3	1.2	26	1	3	1	25	0.5–1
3	5	3	1.34	26	0.5	2	1	20	0.5–1
4	6	3	1	18	0.7	1	1	17	0.5–1
5	7	3	1.21	25	0.6	3	1	14	0.5–1
6	8	3	1	12	0.8	0	1	12	0.5–1
7	9	3	1.3	12	1	1	1	11	0.5–1
8	10	3	1.3	14	0.6	3	1	10	0.5–1
9	11	3	1.11	10	0.8	1	1.1	10	0.5–1
10	12	3	1.6	12	0.6	3	1.1	9	0.5–1
11	13	3	1.2	9	0.8	0	1.2	9	0.5–1
12	14	3	1.70	10	0.8	0	1.2	8	0.5–1
13	15	3	1.2	8	1	1	1.2	8	0.5–1
14	16	3	1.8	11	1	2	1.3	8	0.5–1
15	17	3	1.9	10	0.5	2	1.3	8	0.5–1
16	18	3	2	11	1	3	1.3	7	0.5–1
17	19	3	2	11	0.5	2	1.3	7	0.5–1
18	20	3	1.82	12	1	1	1.4	7	0.5–1
19	21	3	1.54	7	1	1	1.4	6	0.5–1
20	22	3	1.42	6	0.6	0	1.4	6	0.5–1
21	23	3	1.41	6	0.8	1	1.4	6	0.5–1
Total		63				30			

Table 6. Average size of measured and recommended check dam spacing and measured and recommended check dam foundations per plot during the measurement period at the study site.

Plot No.	Slope (%)	Existing spacing (m)	Recommended spacing (m)	Existing foundation (m)	Recommended foundation (m)
1	8	11	15	0	0.5
2	10	11.98	12	0.5	0.5
3	10	5	12	0.22	0.5
4	11	15.3	10.9	0	0.5
5	10	12	12	0.5	0.5
6	12	12.3	10	0	0.5
7	14	8.5	8.6	0.6	0.6
8	14	7	8.6	0.45	0.6
9	15	7	8	0.5	0.6
10	18	6.8	6.7	0.6	0.6
11	21	10	5.7	0.5	0.6
12	20	9.3	6	0	0.6
13	25	10.7	4.8	0.14	0.7
14	23	6	5.2	0.27	0.7
15	25	5.5	4.8	0.24	0.7
16	21	12.4	5.7	0.54	0.7

tive check dams is by far less than the national recommended spacing. Most of the existing check dams failed to fit the standard spacing whereas only four check dams were constructed correctly. In addition, the bottom foundation of four check dams fulfilled the technical standard set by the Ministry of Agriculture.

4 Discussion

Soil erosion is the most serious cause of land degradation in the Ethiopian highlands, which causes farmers to increase agricultural production and reduce food insecurity. Soil erosion is caused by soil erodibility, rainfall erosivity, slope steepness, poor land cover, improper land management and inadequate farmer income and knowledge. During this study, spatial soil loss rates were determined using the RUSLE model and the status of the soil conservation structures was evaluated based on the standard guidelines of Ethiopia. The RUSLE is one of the critical tools for the assessment of the situation concerning erosion in a specific area. The factors help give information about the soil erosion symptoms. With this method, the spatial distribution of annual soil loss calculated using the RUSLE model ranges from $12\,\mathrm{t\,ha^{-1}}$ at the outlet to $456\,\mathrm{t\,ha^{-1}}$ at the upper part of the study area, which is above the tolerable soil loss (2 to $18\,\mathrm{t\,ha^{-1}\,yr^{-1}}$) determined by Hurni (1985) for Ethiopian highland conditions. On higher slopes of the watershed, very high rates of soil losses were observed. This research result has the same pattern as previous researches conducted on similar agroecological zones. For instance, FAO estimated $100\,\mathrm{t\,ha^{-1}\,yr^{-1}}$ soil loss from cropped lands in the highlands of Ethiopia in which the Koga watershed is included. The Soil Conservation Research Program (SCRP) also conducted a study at Anjeni research station which showed the annual soil loss rate to be 131 to $170\,\mathrm{t\,ha^{-1}}$ (SCRP, 1996; Betrie et al., 2011). As described in the result, average soil loss due to rill and sheet erosion was estimated at $42\,\mathrm{t\,ha^{-1}\,yr^{-1}}$, which is equivalent to $3\,\mathrm{mm\,yr^{-1}}$ as Morgan (1996) and Tadesse (2001) computed that $1\,\mathrm{t\,ha^{-1}\,yr^{-1}}$ was equivalent to $0.1\,\mathrm{mm\,yr^{-1}}$. Assuming the mean soil loss tolerance be $10\,\mathrm{t\,ha^{-1}}$ (Hurni, 1985; Morgan, 1996; Mwendera et al., 1997; Tadesse, 2001), then the soil loss rate obtained from this study increased by 76 %. According to Morgan (1996)'s average worldwide soil formation rate (0.1 to $7.7\,\mathrm{mm\,yr^{-1}}$), the soil erosion rate of the study watershed is greater by 85 % than the soil formation rate.

Soil loss in the study watershed is influenced by erosion factors differently. Ordinary least-square regression analysis on 13 077 hill-slope locations of the entire watershed indicated that soil loss has high correlation with land use and topographic factors. The overall coefficient of determination (R^2) is 92 and 89 % for the land use and topographic factors respectively. The highest annual erosion rate was found at upper-slope fields and cultivated lands. As Table 7 depicts, about 90 % of the total soil loss was observed from cultivated land, followed by 6 % erosion risk from grassland. In addition, the friable soil is highly susceptible to transport on the steeper topography of the upper watershed. From field observation it was also found that there is cultivation on the steep slope side of the mountains and hills. Uncontrolled free grazing in the communally owned grassland is also a common practice which can trigger high soil loss.

Table 7. Area coverage and amount of annual soil loss of each class and the corresponding average slope (%) values of the study site.

Land use type	Area (ha)	Area (%)	Total annual soil loss (t)	Total annual soil loss (%)
Water body	1720	6	–	–
Wetland	380	1	156	0.1
Forest	300	1	3479	0.3
Shrub	2900	10	50 075	4.1
Grassland	7500	25	72 770	6.0
Cultivated	16 700	56	1 118 600	89.5

The pattern and spatial distribution of erosion risk classes implies that sediment is transported from the southern highlands of the catchment to the center where the Koga irrigation reservoir is situated and then to the mouth of the river. This creates a siltation trait to the water source that irrigates 7004 ha of land inside and outside the study area.

Large-scale SWC practices have been implemented in the past 15 years in the Koga watershed. The basis for the implementation of the SWC interventions on a large scale was the 1975 land reform. After analyzing the risks of land degradation, the government of the Federal Democratic Republic of Ethiopia (FDRE) has intensively launched the natural resource development work through public mobilization since 2010 (Badege, 2001; MoARD, 2010). However, sustainable land resource management is not yet attained due to failure of SWC measures (Herweg and Ludi, 1999; Ludi, 2004; Tadesse, 2010). Similarly, the assessment result of SWC activities indicates that about 35 % of the existing SWC structures were effective for soil erosion control strategies. In the study watershed, the SWC activities were carried out using food aid in the form of food-for-work through which the farmers develop livelihood dependency. As the results of farm terraces and check dam conservation measures showed, the structures built existed in place for a short period of time. Some were dismantled in response, to reconstruct them in another round in order to get incentives for their livelihood. The structures require frequent maintenance due to their sediment-trapping characteristics, vulnerability to livestock damage and to intensive rainfall (Shiferaw and Holden, 1999; Bewket, 2007; Moges and Holden, 2006). As a result, terraces and check dams constructed were dismantled due to poor foundation and lack of proper prone and spill ways. In addition, most farmers perceived that constructing bunds in narrow spacing may create difficulty in plowing activities and large numbers of bunds reduce farm size while at the same time needing much labor force to implement.

In general, poorly designed soil conservation structures, over-grazing, deforestation and land-use conflict are the main causes of soil erosion. Therefore, for landforms and land uses that have large soil losses, integrated soil conservation measures that decrease soil erosion and improve food productivity should be selected based on the consent of farmers and participation of stakeholders at the Koga watershed.

5 Conclusions

Remotely sensed data and a GIS-based approach are effective techniques to estimate watershed-based soil loss rate in data-scarce conditions. The model predicted very high soil erosion rates with an average soil loss rate indicating 42 $t\,ha^{-1}\,yr^{-1}$, and the total soil loss of 1.3 million tons was estimated in the whole study area. This study showed that high erosion in the watershed is caused by the following: topographic factors shaping basin morphology; cultivation and over grazing on erosion sensitive locations such as on steep slope hills and mountains terrain units; and banks of the river where the soil is fragile and easily worn away. The common forms of erosion in the watershed are rill and sheet erosion coming from hillsides, steep-slope mountains and because of over-cultivation.

Soil loss depends on the land use and the type of soil and water conservation structures. In general, only 35 % of the different soil conservation practices were effective and fulfilled the national recommended standard of conservation structures during the study period at the Koga watershed. Governmental organizations and international and local NGOs have paid strong attention to building the conservation structures, partially sticking to recommended design and specification. In addition, the constructed conservation structures were not even managed properly. Therefore, to minimize erosion risk in the study watershed, standardized conservation measures considering local topographic variation have been constructed to sustain agricultural productivity. Furthermore, land-use plans should be practiced for the management and utilization of fragile and marginal areas. SWC should be implemented in integrated distributions based on participatory watershed management logic, starting from high erosion risk uphill areas and progressing down towards the watershed outlet.

6 Data availability

The study brought together field and existing raw data obtained upon request from a number of different sources. Full details on how these data were obtained are available at locations cited in the methodological section.

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