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Soil erosion assessment and control in Northeast Wollega, Ethiopia

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Abstract

Soil erosion is the main driver of land degradation in Ethiopia, and in the whole region of East Africa. This study was conducted at the Northeast Wollega in West Ethiopia to estimate the soil losses by means of the Revised Universal Soil Loss Equation (RUSLE). The purpose of this paper is to identify erosion spot areas and target locations for appropriate development of soil and water conservation measures. Fieldwork and household survey were conducted to identify major determinants of soil erosion control. Six principal factors were used to calculate soil loss per year, such as rainfallerosivity, soil erodiblity, slope length, slope steepness, crop management and erosion-control practices. The soil losses have shown spatio-temporal variations that range from 4.5 Mg ha^{-1} yr^{-1} in forest to 65.9 Mg ha^{-1} yr^{-1} in cropland. Results from the analysis of stepwise multiple linear regression show that sustainable soil erosion control are determined byknowledge of farmers about soil conservation, land tenure security and off-farm income at community level. Thus, policy aim at keeping land productivity will need to focus on terracing, inter-cropping and improved agro-forestry practices.

1 Introduction

Soil is a key component of the Earth System that control the bio-geo-chemical and hydrological cycles and also offers to the human societies many resources, goods and services (Keesstra et al., 2012; Berendse et al., 2015). Land degradation is the major problem in many regions of the world (Bisaro et al., 2014; Hueso-Gonzalez et al., 2014; Lieskovský and Kenderessy, 2014; Srinivasarao et al., 2014), specially in East Africa, where Ethiopia show the highest erosion rates (de Mûelenaereet al., 2014; Gessesse et al., 2014; Lanckriet et al., 2014), and where the agriculture, particularly the highlands, is facing new strategies to combat desertification (Mekonnen et al., 2015). Land degradation manifests itself through soil erosion, nutrient depletion and loss of organic matter, acidification and salination (Bewket and Teferi, 2009; Haile and Fetene, 2012). The soil loss rate by water ranges from 16 to over 300 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ in Ethiopia, mainly depending on the degree of slope gradient, intensity and type of land cover and nature of rainfall intensities (Tamrie, 1995; Tesfaye et al., 2014). Studies made in different parts of Ethiopia also reported that annual soil loss show spatial and temporal variations. Based on field assessment of rill and inter-rill erosion, Bewket and Teferi (2009) estimated annual soil loss 93 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ for the entire Chemago watershed. Haile and Fetene (2012) estimated that about 97.04 % of Kilie catchment, East Shoa, have 0–10 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ erosion rate. In Borena district of south Wello, the rate of soil loss estimated between 10 Mg and 80 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ (Abate, 2011). Approximately, 75 % of the total area of the Gerado catchment, Northeastern Ethiopia, was found to have rates of soil losses which were above 25 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$. Berhan and Mekonnen (2009) estimates that the highest soil loss at Medego watershed was recorded at the landform-steep mountains (slope 30–50 %), which is 35.4 $\mathrm{Mg\,h^{-1}\,yr^{-1}}$. All exceeded both the suggested soil loss tolerance of 18 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ (Hurni, 1983a) and the estimated soil formation rate ranging from 2 to 22 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ (Hurni, 1983b).

Studies suggested that high rates of soil erosion in Ethiopia is mainly caused by extensive deforestation due to the prevalence of high demand for fuel wood collection and grazing into steep land areas (Amsalu et al., 2007; Haile and Fetene, 2013). Ethiopia is a country of great geographical diversity with high and rugged mountains, flat-topped plateau, deep gorges, incised river valleys, rolling plains, a wide range of temperature and rainfall regimes, a variety of agricultural crops and land uses (Mutua et al., 2006; Tesfahunegn, 2015). About 43 % of the country is classified as highland (above 1500 m a.s.l.), where most of the populations (about 88 %) carry out mixed crop-livestock agriculture (Bewket and Teferi, 2009). Deforestation, population growth, overgrazing and use of marginal lands intensify erosion, and the intensification of the agriculture production also results in high erosion rates (Cerdà et al., 2009).

The prediction of erosion and/or degradation typically involves the use of empirical models (Leh et al., 2013). The Revised Universal Soil Loss Equation (RUSLE) is

SED
7, 3511–3540, 2015

one of the most commonly applied models (Erol et al., 2015). The available data on modeling soil erosion with the RUSLE have shown that the model is applicable for specified conditions (Mati and Veihe, 2001). This model reveals that soil erosion is greatest on cultivated land (Hurni, 1993; Gimenez-Morera et al., 2010). As a result of soil erosion Ethiopia losses USD 1 billion yr^{-1} (Sonneveld, 2002). Erosion could also generate deposition of soil materials in the reservoirs, irrigation schemes and waterways downstream (Cerda and Doerr, 2008).

If no proper measures are taken to protect the soil, intensive agriculture to meet the increasing demand for food will accelerate soil erosion in the country (Gelaw et al., 2013). Therefore, erosion control is a necessity under virtually every type of land use adopting efficient conservation measures (Kropfl et al., 2013; Ligonja and Shrestha, 2015). Distinguished the effects of soil erosion, the Government of Ethiopia and non-governmental organizations have commenced soil conservation measures since 1970s (Mekonnen et al., 2013). However, a number of previous studies have pointed out that such schemes were unsuccessful and incompatible in prompting voluntary implementation of soil conservation practices among the small holder farmers (Bizoza, 2014; Ndah et al., 2015). The major determinants could be land tenure systems (SIDA, 2003), education/experience (Erenstein, 2003), pressure on the land (Cerdà and Doerr, 2005; Bolligeret al., 2006), institutional control (Giller et al., 2009), economic incentives (Fan et al., 2004), political stability and social status (Ligonja and Shrestha, 2015). This study, therefore, estimated soil loss under different land cover types and other erosion prone areas in Northeast Wollega, Ethiopia. The soil loss prediction procedures presented in this paper adopt methodologies that combine research information from different sources. This approach allows selecting soil erosion control practices best suits to the particular requirements of each site and land-users. Therefore, the purpose of this study was to estimate the amount of soil loss in different land uses using USLE and identify determinants of soil erosion control.

2 Materials and methods

2.1 The case study site: Northeast Wollega

Northeast Wollega lies within 9°45′–10°00′ N and 37°00′–37°15′ E and covers a total area of 14 979 ha. It belongs to northwestern highland of Ethiopia and it is distinguish by a diverse topographic conditions. The elevation ranges from 1800 till 2657 m. It is mountainous and dissected terrain with steep angle slope (> 20 %). The climatic condition is humid. The mean annual rainfall is 1875 mm that mainly falls between June and September. The mean annual temperature is 24 °C. Subsistence farming is the basis of livelihood to the residents in the study area. Both crop cultivation and livestock herding provide about 90 % of the livelihood of the local community in the study area. In the 2013 *Meher* (the main cropping season in Ethiopia), cereal production accounts 85 % of the cultivated land. Teff (*Eragrostis tef*), barley (*Hordeum vulgare*) and maize (*Zea mays*) were the main cereal crops of the study area. These crops are mainly grown for subsistence. Approximately the total livestock population of the study area was estimated to have 169 333 tropical livestock units in 2013 (DoA, 2013). Livestock provide an important source of power for crop cultivation and threshing, some types of livestock such as horse, mule and donkey are essential means of mode of traditional transport for people and agricultural products to market centres. Livestock as well give certain degree of security during crop failure, and their dung is source of manure to improve soil fertility in the farmyards. Northeast Wollega was selected as the site for this study because of two reasons. First, it belongs to northwestern highland of Ethiopia where topography, soils, climate and socioeconomic circumstances are spatially varied. Second, the area is a constituent of the highlands that was acknowledged to be excess producing parts of the country, but currently exposed to land degradation and imminent food insecurity.

SED
7, 3511–3540, 2015

2.2 Field work

Multi-stage systematic random sampling technique was employed to collect primary data from the households. First, the sampled *kebeles* (the smallest administrative structure in Ethiopia) were purposefully selected such as *Sombokumi*, *Sombowato*, *Harolego, Iero* and *Tulunono*. Second, a total of 200 (10.4 %) sample households had been selected from the households' lists of each kebele administration office through systematic random sampling technique. Such sample size was selected because of the similarity of livelihood of households in the area. Third, the randomly selected households were taken proportional to size of the population to ensure representation.The fieldwork was undertaken in July and September 2014 for atotal of 60 days. Perhaps, the two moths were selected because June–September is the main rainy period when erosion incidence will be high in the area. This study employed questionnaire, key informant interview and focus group discussions as well as non-participant observation to collect data from household heads. Questionnaire was administered to gather information on household circumstances such as age, education, family size, land holding size, opinion on level of soil erosion, land management, right to use extension services, access to markets, forest products and livestock. Soil protection procedures and triumph as well as challenges that farmers faced during implementation were collected through key informant interview with group of village elders and councils. Direct observations were also carried out to identify land cover types, which is crucial for visual interpretation of Landsat images of the area.

2.3 Landsat image processing

A map of land cover of the study area was prepared through on screen digitization in Arc-GIS software. Remotely sensed (ETM+ sensor) Landsat image scenes of path 181 and row 63 taken during the month of February were downloaded from the Global Land Cover Facilities (GLCF) website.The image has 30 m^2 resolution. Digital Elevation Model (DEM) was also produced from this image, which is important to generate slope

SED
7, 3511–3540, 2015

gradient (%). Land cover classification was carried out with respective percentage of canopy cover: (1) forest land labeled as forest with 70–100 %, (2) shrub land 40–50 %, (3) grassland 20–30 %, (4) cropland 36–45 % and (5) built up area 60 %.

2.4 Modeling of soil erosion

Modeling of soil erosion and estimation of soil loss was predicted using Universal Soil Loss Equation (USLE). This method presents the possible soil loss as results of splash, sheet and rill erosions (Welle et al., 2007; Hui et al., 2010). According to Wall et al. (2002), USLE calculate the average annual soil loss anticipated on certain spot (A) by multiplying a number of issues collectively, which includes: rainfall (R) factor in $\mathrm{Mg\,mm\,ha^{-1}\,h^{-1}}$; soilerodibility ($K$) factor in ($\mathrm{t\,h\,MJ^{-1}\,mm^{-1}}$); slope length and steepness (LS); crop management factor (C) and support practice factors (P) (Eq. 1). The estimated amount of soil erosion is given in $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$, which is also important to compare with the "tolerable soil loss limits" (Wall et al., 2002).

$$A = R \times K \times L \times S \times C \times P \tag{1}$$

2.4.1 Rainfall erosivity factor (R)

Monthly rainfall report from Shambu meteorological covering the period 1993–2007 were applied to calculate the erosivity index. In USLE, the value for "R" measures the kinetic energy of the rain and it necessitates measurements of rainfall intensity with autographic recorders; however, intensity data do not normally exist in the study area. Different empirical equations have been developed that estimate "R" values from rainfall totals, which is easily available. In the study area, there is no intensity data. Hence, an empirical equation developed by Hurni (1985a) that estimates "R" factor value from annual total rainfall was used. It is given as:

$$R = -8.12 + 0.562P \tag{2}$$

SED
7, 3511–3540, 2015

where R is the rainfall erosivity factor and P is the mean annual rainfall (mm). Similar methods of determining R factor values from rainfall totals have been used in previous studies from different countries (Morgan, 2005).

2.4.2 Soil erodibilityfactor (K)

"K" is the resistance of soil to erosion and often represents soil loss per unit of R; therefore, "K" is given in $\mathrm{Mg\,ha^{-1}}$ for one unit of metric "R" (Veihe, 2002). Different soil types have different pace of erosion caused by detachment and transportation (Morgan, 2005). "K" can be calculated using key soil parameters such as texture, organic matter, structure and permeability (Wischemeier and Smith, 1978). Soil maps in Ethiopia often do not contain detailed information about these soil parameters because soil survey laid emphasis on classifications ystem rather than interpretation of soils in terms of land evaluation. This limits prediction of "K" factor in the study area. However, K factor was generated on the basis of soil texture and organic matter content described in the soil survey report of the study area in the top soil (0–20 cm). The values were consigned according to "K" value ranges given inthe literature (Wall et al., 2002).

2.4.3 Topographic factors (L and S)

Slope length (L), which is the distance between the start of runoff to a position where deposition happen, was taken from field measurements among the land cover types. Representative slope lengths from each land cover types and in various topographical terrains was measured and recorded during fieldwork: (1) 160 m slope length was measured in cropland, (2) 80 m in grassland, (3) 150 m in shrubland, (4) 210 m in forestland.

$$L = (X/22)^{0.5} \tag{3}$$

where X is the slope length taken from field measurements.

SED
7, 3511–3540, 2015

On the other hand, slope angle (S) was computed from DEM using 3-D analyst extension in the Arc-GIS, which was downloaded from thewebsite of GLCF. Then, slope angle S in percentage was calculated by Eq. (4).

$$S = 0.0138 + 0.0097s + 0.00138s^2 \quad (4)$$

where S is the general accustomed slope angle and s is the slope angle in percent.

Therefore, the topographical factor combines "L" and "S" factors computed by Eqs. (3) and (4). In addition, the slope map of the study area was shown in Fig. 2.

2.4.4 Cropping and land-cover factor (C)

The C factor is used to corroborate the virtual efficacy of soil and crop management methods in terms of preventing or reducing soil loss. A "C" value is a ratio contrasting the soil eroded beneath a specific crop and management system to continuous fallow conditions. A land cover map of the study area was produced from a Landsat ETM+ imagery obtained on 15 February 2005 (path 181/row 63) (Fig. 3). Supervised digital image classification procedures complemented with field surveys that provided on-the-ground information about the types of land-cover classes was employed. Four land-cover classes were identified, and the subsequent C factor values were specified. These were forestland, shrubland, grassland and cultivated land (Fig. 3). The C factor for those land-cover types was used in the present study as suggested in previous literature (Table 4). The C factor showed annual variation under cultivated land as crop cultivated on the field varies annually. The dominant crops in the study area remain the same, however, and these are tef, barely, maize and wheat. Hence, a value of 0.15 was used for all cultivated areas.

2.4.5 The support practice factor (P)

The P factor refers effectiveness of support practices that will diminish the amount and rate of soil erosion. In this perspective, soil erosion can be reduced by adjusting the flow pattern, grade, or direction of surface runoff and "*P*" also supports the *C* factor in land management system. A support practice is most successful when it causes eroded sediments to be deposited on the upslope, very close to their source than close to the end of the slope. However, the effectiveness of *P* factor is influenced by a range of activities functional on the farm such as cross slope cultivation, contour farming, strip cropping and terracing. The lesser the *P* factor, the more effectively the practice facilitates deposition to take place close to the source. In the study area, contour plowing is the dominant soil erosion control practices among the farmers in cultivated lands as observed during field visits, augmented by the construction of soil and stone bunds in some parts. Thus, in assigning *P* factor values for the study area, 0.9 was given for cultivated lands and the other land cover types were given 0.8 based on Hurni (1985a), as shown in Table 4.

2.5 Determinants of soil erosion control

From various attributes of farmers, perception on soil erosion (X_1), knowledge of conservation measures (X_2), land tenure security (X_3), off-farm income (X_4), availability of land (X_5), age of farmers (X_6), educational level (X_7) and existence of public support (X_8) were some of the main determinants of soil erosion control. Different models can be used to ascertain the association between the possible determinants of soil erosion control like linear regression, logistic regression, ridge regression, lasso regression and ecologic regression. In this study multiple linear regression models is applied using Eq. (5). Bivariate correlation was run to establish the association between dependent and independent variables. This also helps to skip independent variable that does not associate with dependent variable before computing stepwise linear regressions analysis.

SED
7, 3511–3540, 2015

3 Results and discussion

3.1 Soil erosion assessment in Northeast Wollega

The rainfall erosivity R factor was 1045.63 $\mathrm{MJ\,mm\,ha^{-1}\,h^{-1}\,yr^{-1}}$ given the mean annual rainfall is 1875 mm. K factor (Table 1), L factor (Table 2), S factor (Table 3), C and P factors (Table 4) vary with land cover types. Soil loss of the study area, therefore, was estimated based on values given in the tables mentioned above. The annual rate of soil erosion (A) is in the range of 4.5–65.9 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$. It was 4.5 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ in forestland, 37.6 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ in shrubland, 22 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ in grassland, and cropland 65.9 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$. As expected, soil loss is maximum on cropland land and minimum on forestland. Perhaps, the annual soil erosion rate in cropland is very highly severe (50–80 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$). This land use was hence assigned the first priorities, in order of mention, for conservation planning-account for about 69 % of the total soil loss from the study area (Table 5). This is in agreement with research results elsewhere (Tripathi et al., 2003). This suggests that soils covered with forest and grasses are less vulnerable to erosion than cropland. Further, the result of this study clearly shows that nearly the whole study area needs execution of different types of soil and water conservation measures for a sustainable land use (Angima et al., 2003). In resource constraint areas, carrying out land management measures in only chosen hotspots of erosion can significantly decrease total soil loss (Berhan and Mekonnen, 2009). Studies have also shown that spatial variations in land cover are responsible for disproportionate loss of soils (Angima et al., 2003; Tripathi et al., 2003; Bewket and Teferi, 2009). Thus, it is indispensable and tactical to prioritize land cover for curing with proper soil and water conservation technologies. Prioritizing land cover means grading different land covers according to the category in which they ought to be taken up for curing with conservation technologies (Bewket and Teferi, 2009).

Furthermore, the result of this study implies that soil erosion is the most urgent agricultural problems, which present a major jeopardy to land productivity in the study area. In the face of escalating population pressure, the land is constantly cultivated

SED
7, 3511–3540, 2015

with cereal crops such as maize, wheat, tef and barley. Croplands are characterized by lack of comprehensive land management practices, which can contribute to high erosion hazard. Farmers in the study area practiced complete tillage, while minimum or zero tillage was completely abandoned. Minimum or zero tillage is an important soil conservation technology in Sub-Saharan African countries as it reduces soil erodibility (Ndah et al., 2015). This form of tillage results in long-term maintenance of the soil structure and an increase in water retention and hydraulic conductivity.

The farming system of the study area is rotational mono-cropping, not intercropping. According to Kangalawe et al. (2008) intercropping and/or mixed cropping practiced by farmers is an essential approach that farmers utilize to adapt to soil degradation and unfavorable climatic conditions because these practices involve growing more than two crops in the same field. These practices also spread the risks of crop failure and maximize the use of available cultivable land (Gowing and Palmer, 2008). Croplands are characterized by poor cover, associated with over cultivation, which can be ascribed to a lack of well-structured cropland management practices. The management system on cropland is carried out individually, which made the degree of success of land rehabilitation considerably vary among the land cover; even, there are cases in which some farmers abandoned land management technologies. According to Ndah et al. (2015) exploitation of agricultural land without commencement of land management can easily results in soil degradation, mainly due to loss of organic matter, leading to reduced rainwater infilterability and lowered water holding capacity.

On the other hand, cultivation using contour ridges is common in the study area as a component of the regular land-preparation practices. The cultivation ridges are used along the contours to control surface runoff. However, the ridges were not planted with crops or grasses. This may reduce the ability of the ridges to arrest surface runoff. As noted in Gowing and Palmer (2008), if ridges are covered with crops, farmers will take the advantage of accumulated soil fertility-being broken down for cultivation. The current study as well as other studies carried out elsewhere reveals that undertaking cropland management appears to be more personal responsibility and demands a long-term perspective on maintaining land productivity. Another explanation for severity of soil erosion on cultivated land could be diminished application of manure and compost in the study area. Spreading of domestic wastes (including animal waste) on to cultivated land is an age-long traditional farming practice. It is a source of nutrient as well as an ameliorative material for degraded soils (Nigonja and Shrestha, 2015). Results from a study by Bizoza (2014) showed that soil amendments through animal wastes reduce bulk density and compaction, increase pore spaces and infiltration capacity, which ultimately reduce runoff and soil erosion. However, as informed by respondents during discussions, application of manure in the cultivated land is inadequate as most of them either have no cattle or have insufficient manure.

Next to cropland, in grassland extensive grazing has accelerated soil erosion. Ndah et al. (2015) suggested deduction of livestock as a conservation device that possibly reduces runoff and erosion in the grassland. As a result, more land will be vacant for cultivation. This seems unfeasible in the study area may be related to the roles livestock played in sustaining livelihood of local communities. Livestock is the source of lobour, power, income, prestige and transport system. Furthermore, demand for wood as source of energy and construction material may instigate deforestation, which is likely to have triggered erosion in shrubland and forestland.

3.2 Determinants of soil erosion control

Results from household survey demonstrated that 68 % of farmers understood soil erosion is severe and 30 % demonstrated the intensity of soil erosion was moderate in cropland. This entails inventiveness to manage soil erosion through sustainable land management technologies and involvements of local communities as well as backing from additional stakeholders have not considerably controlled soil loss. From 8 determinates of soil erosion control tested bystepwise multiple linear regression analysis, only three of them appeared to have significant relationship with soil erosion

SED
7, 3511–3540, 2015

control as shown in Eq. (5) and Table 6.

$$Y = 0.066 + 0.003X_2 + 0.009X_3 + 0.033X_4 \quad (5)$$

where, Y initiative to control soil erosion; X_2 knowledge of conservation measure; X_3 land tenure security; X_4 off-farm income. All independent variables were significant at 0.01 confidence level. Multiple correlation coefficients (R^2) of 0.45 signify that there is reasonable relationship between predictor variables and reduction of soil erosion rate.

The results of multiple linear regression analysis shows that knowledge of farmers conservation technologies was significant at $P < 0.005$, the coefficient was positive implying that knowledge of conservation measures positively affects efforts to control soil erosion by water. Knowledge and skill are important to appropriately install modern soil conservation technologies that will control soil erosion on their farms. These skills can be proper planting of trees and grass seedlings on degraded land as well building cut-off drains, drainage channels and contour bunds. The rate of adoption may be influenced by age of land users where aged farmers might have knowledge of soil conservation impacted to them compared to younger farmers (Fan, 2004; Lal, 2007; Ligonja and Shrestha, 2015). Key informants suggested stated that farmers should acquire funding, communication skills and technical training through extension services and education to advance their ability to arrest soil loss. The presence of support from concerned bodies (government, non-government, researchers and other conservationists) increased the number of adopters elsewhere in Ethiopia (Tadesse and Belay, 2004).

Land tenure security has positive relation with methods of erosion control. This implies that if farmers don't have secure land rights, they will have few incentives to engage in sustainable soil erosion control measures. According to Tsue et al. (2014), tenure security can also influence the long-term environmental impact of over-exploitation of the land's nutrients. Land tenure system in the study area was predominantly using family land. However, the constitution of the country prohibits private ownership of arable land, which may decrease credit access, investment and environmental conservation opportunities. Tsue et al. (2014) asserted that land tenure was a key factor that influences adoption of controls of soil erosion since it conferred property rights and defined access to and control over land assets, including natural resources that existed on the land. In addition, according to Lal (2015), land tenure conferred rights in relation to the manner in which people own, occupy and transact land. Tenure security affects choices of people such as which crops to grow and whether crops are grown for subsistence or commercial purposes (Oyekale, 2012). Lack of secure land tenure, therefore, exacerbates the loss of soil by erosion. Degraded lands can be regenerated, managed and protected when people have secure land tenure, for example, through community forestry and leased forestry (Lal, 2015).

Another determinant of soil erosion control in the study area is off-farm income. Majority (about 63 %) of the respondents had no non-farm employment (DoA, 2013). The low engagement in off-farm employment could hinder farmers from owning and operating large farm sizes and investing in both farm and environmental protection (Angima et al., 2003). Access to credit was generally low in the study area. This situation is likely to decrease farmers' efficiency by limiting investment and adoption of modern technologies and farming practices that would increase land productivity. The result of this study agreed with Okekale (2012) and Tsue et al. (2014) who stated access to formal credit as a major constraint of farmers in controlling soil erosion hazard.

4 Conclusions

This study was designed to assess soil erosion hazard in northeast Wollega, western Ethiopia, by employing Revised Universal Soil Loss Equation along with remote sensing and GIS techniques. The results are valuable tools to estimate erosion risk over certain areas for land restoration. The result of the USLE showed that the annual rate of soil loss is in the range of 4.5 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$ in forestland and 65.9 $\mathrm{Mg\,ha^{-1}\,yr^{-1}}$

SED
7, 3511–3540, 2015

in cropland. The rate of soil loss in the cropland, which accounts for about 69 % of the total soil loss in the study area, is very highly severe. This clearly shows that cropland should be prioritized to carry out land management practices such as minimum or zero tillage, intercropping, mulching, planting crops or grasses along contour ridges, use of manure/compost and spreading domestic waste on to cropland land. Results from multiple linear regression analysis showed these practices are influenced by knowledge of conservation measures, land tenure security and off-farm income. The findings of this study have revealed that there is need to address issues of farmers' education, secure land rights and access to credit in order to control soil loss from cultivated land.

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SED
7, 3511–3540, 2015

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SED
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SED
7, 3511–3540, 2015

Table 1. Soil texture, organic matter content and estimated values of soil erodiblity (K) factor of the Northeast Wollega, Ethiopia.

Land use type	Topsoil texture class	Organic matter (%)	K value
Forestland	Sandy loam	9.0	0.19
Shrubland	Very fine sand	2.8	0.36
Grassland	Clay loam	7.3	0.21
Cropland	Clay loam	4.6	0.21

SED
7, 3511–3540, 2015

Table 2. Slope length and its factors of Northeast Wollega, Ethiopia.

Slope length (m)	*L* factor
< 50	1.2
50–200	2.5
> 200	3.8

SED
7, 3511–3540, 2015

Table 3. Slope class, gradient (%) and S factor of Northeast Wollega, Ethiopia.

Class	Slope gradient (%)	S factor
1	0–1	0.1
2	1–2	0.1
3	2–4	0.2
4	4–6	0.35
5	6–8	0.6
6	8–13	1

SED
7, 3511–3540, 2015

Table 4. *C* factor and *P* factor values for the respective land use and land cover classes of Northeast Wollega, Ethiopia.

Land-use and land-cover classes	*C* factor	*P* factor
Forestland	0.01	0.9
Grassland	0.05	0.8
Shrubland	0.05	0.8
Cropland	0.15	0.8

SED
7, 3511–3540, 2015
Soil erosion assessment and control, Ethiopia
A. Adugna et al.

Table 5. Annual soil erosion rate and severity classes among different land uses in Northeast Wollega, Ethiopia.

LULC	Soil loss ($Mg\,ha^{-1}\,yr^{-1}$)	Severity class	Area (ha)	% of total
Cropland	65.87	Very high	10 363.3	69.18
Shrubland	37.64	High	21.51	0.14
Grassland	21.95	Moderate	952.0	6.36
Forestland	4.47	Low	3164.5	21.13

SED
7, 3511–3540, 2015

Table 6. Linear regression model summary coefficients*.

Model	Unstandardized coefficients		Standardized coefficients		
	B	Coefficients	Beta	*t*	Sig.
(Constant)	0.056	0.099	–	0.676	0.511
Knowledge of conservation measures	0.300	0.099	0.187	3.012	0.002
Land tenure security	0.143	0.050	0.178	3.628	0.007
Off-farm income	0.222	0.105	0.216	2.157	0.003

* Dependent variable-initiative to control soil erosion.

SED
7, 3511–3540, 2015
Soil erosion assessment and control, Ethiopia
A. Adugna et al.

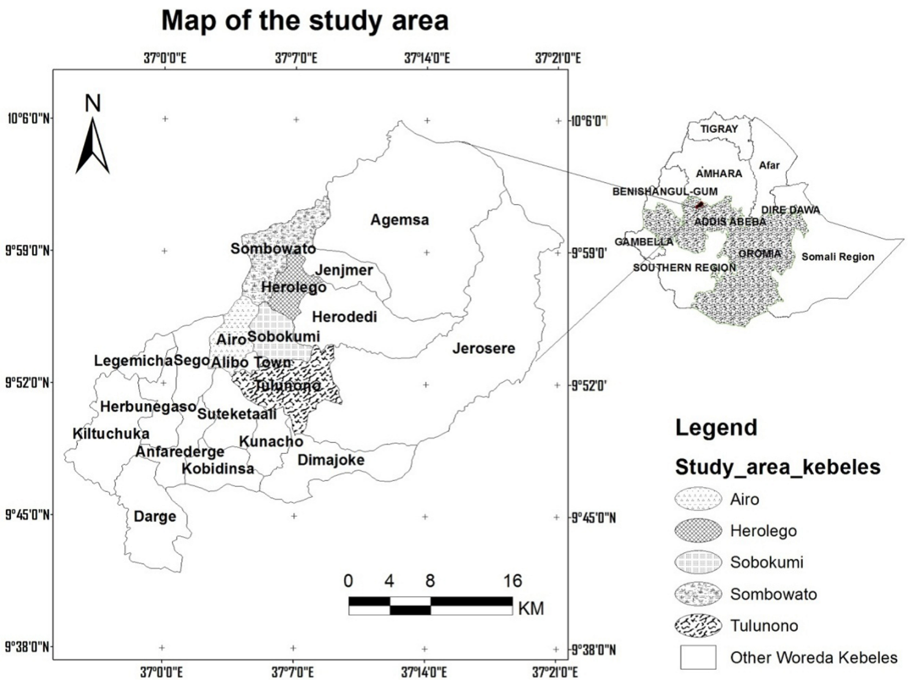

Figure 1. The location map of Northeast Wollega, Ethiopia.

SED
7, 3511–3540, 2015

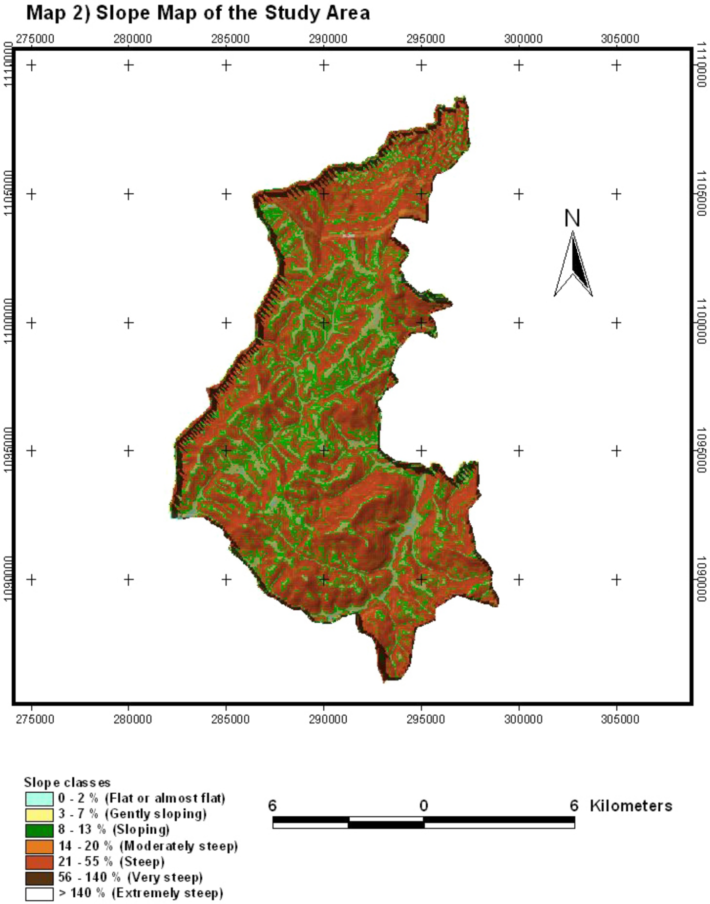

Figure 2. Slope map of Northeast Wollega, Ethiopia.

SED
7, 3511–3540, 2015

Title Page
Abstract | Introduction
Conclusions | References
Tables | Figures
◀| |▶
◀ ▶
Back | Close
Full Screen / Esc
Printer-friendly Version
Interactive Discussion

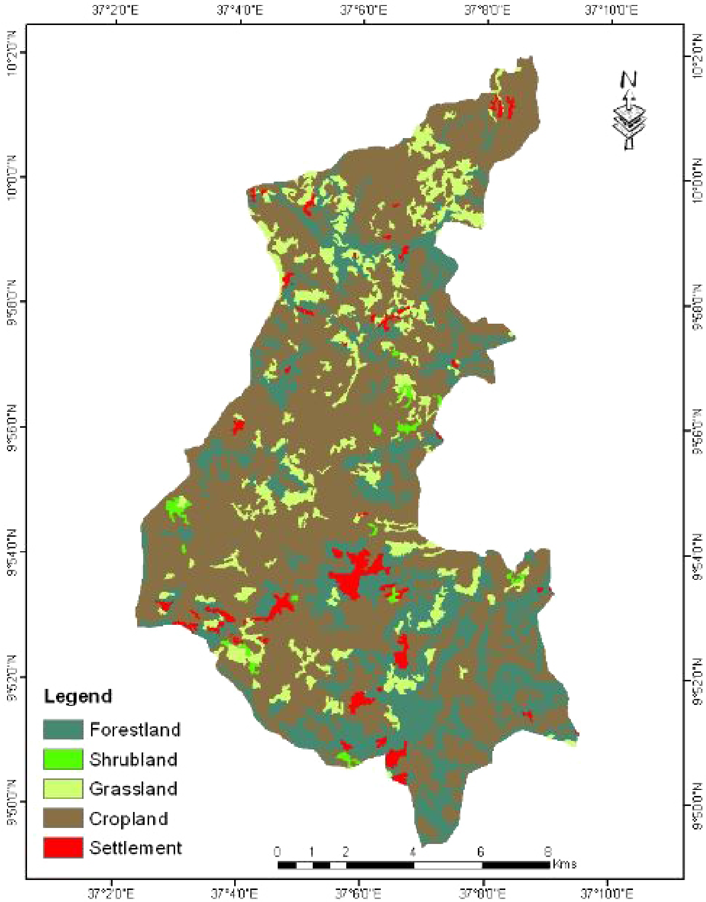

Figure 3. Land-use and land cover map of Northeast Wollega, Ethiopia.

SED
7, 3511–3540, 2015