# Estimating Soil Loss Rates For Soil Conservation Planning in Borena Woreda Of South Wollo Highlands of Ethiopia: The Case from the Legemara Watershed

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## Abstract

The rate of soil erosion is pervasive in the highlands of Ethiopia. Soil conservation is thus crucial in these areas to tackle the prevailing soil erosion. This area is mainly in the steeper slope banks of tributaries where steep lands are cultivated or overgrazed. The objective of this study is to estimate the rate of soil loss in Legemara watershed in Borena *Woreda* of South Wollo Administrative Zone in the Amhara Regional State. The study also recommends possible ways of curbing the problem.The study uses the Revised Universal Soil Loss Equation (RUSLE), integrated with satellite remote sensing and the Geographical Information System (GIS) as useful tools for conservation planning. Monthly precipitation, a soil map, a 30m-digital-elevation model, a land-cover map, land-use types and slope-length steepness were used to determine the RUSLE values. Based on the level of soil erosion rates, the study area was divided into five priority categories for conservation interventions. The results show that, 2,344.57 ha (42.97 %) of the total area and 130,102.35 tons $ha^{-1}yr^{-1}$ (77.19 %) of the total soil loss have ranges of the erosion severity classes of very severe and severe, in which case, conservation priorities of first and second order are suggested. Moreover, the total soil loss in the study area was168, 521 metric tons per year from 5456.5 ha, and the average annual soil loss for the entire watershed was estimated at 30.88 metric tons $ha^{-1}yr^{-1}$.

*Keywords: Soil Erosion; RUSLE; GIS; Conservation; Watershed; Ethiopia*

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## Acronyms

| | |
|---|---|
| CREAM: | Chemical Runoff and Erosion from Agricultural Management |
| DEM: | Digital Evaluation Model |
| EPIC: | Erosion Productivity Impact Calculator |
| EUROSEM | European Soli Erosion Model |
| FAO: | United Nations Food and Africultutr Organization |
| GIS: | Geographic Information System |
| GLCF: | Global Land Cover Facility |
| OM: | Organic Mater |
| RUSLE; | The Revised Universal Soil Loss Equation |
| SLT: | Soil Loss Tolerance |
| UNEP: | United Nations Environment Program |
| USDA; | United States Department of Agriculture |
| USLE: | Universal Soil Loss Equation |
| WEPP: | Water Prediction Program |

## Introduction

Soil erosion is one of the biggest global environmental problems resulting in both on-site and off-site effects. Soil erosion has accelerated in most parts of the world, especially in developing countries, due to different socio-economic and demographic factors and limited resources (Bayramin et al., 2003). For instance, Reusing *et al.* (2000) mentioned that increasing population, deforestation, intensive land cultivation, uncontrolled grazing and higher demand for firewood often cause soil erosion. Soil erosion is generally more acute in tropical areas where rainfall is more intense and the soil is highly erodible due to the relatively shallow depth and low structural stability (Eaton, 1996).

Soil erosion is a complex process that depends on soil properties, ground slope, vegetation, and rainfall amount and intensity. Changes in land use are widely recognized as capable of greatly accelerating soil erosion (Hooke, 2000) and it has long been the case that erosion in excess of soil formation eventually results in decreased potential of agricultural productivity. Although soil fertility generally declines with accelerated erosion, soil fertility is itself a function of an agricultural method and site conditions such as soil type, nutrient, and organic matter content.

Soil erosion is a common phenomenon in the East African highlands where it causes widespread soil degradation (Edwards, 1979; Gachene, 1995; Tiffen et al., 1994). Rapid population growth, cultivation on steep slopes, clearing of vegetation, and overgrazing are the main causes for accelerated soil erosion in Ethiopia. Such unsustainable and exploitative land use practices due to an increasing demand for food, fiber and fodder by the growing human and livestock populations are responsible for accelerated soil erosion in many parts of Ethiopia. These practices diminish the protective plant cover thereby exposing the soil surface to the destructive impact of high-intensity rainfall (Aregay and Chadokar, 1993). In the study area, high population growth, which leads to intensified use of stressed resources and expansion of agricultural land towards marginal and fragile lands, is very common. These situations aggravate soil erosion and decline of productivity resulting in a population-poverty-land degradation cycle.

The impact of soil erosion can be most problematic in the developing countries where farmers are highly dependent on intrinsic land proprieties and are unable to improve soil fertility through application of purchased inputs (Lulseged and Vlek, 2008). In the Ethiopian highlands only, the annual rate of soil loss reaches to 200 - 300 tons $ha^{-1}yr^{-1}$, while the soil loss can reach to 23400 million metric tons per year (FAO, 1984; Hurni, 1993). Hurni (1988) and Hurni et al. (2008) estimated that soil loss due to erosion of cultivated fields in Ethiopia amounts to about 42 metric tons $ha^{-1}yr^{-1}$. In Ethiopian highlands, soil erosion rates measured on test plots amount to 130 to 170 metric tons $ha^{-1}yr^{-1}$ on cultivated land (Hurni et al., 2008). The impact of this loss of fertile soil in Ethiopia is multifaceted. It affects 50 percent of the agricultural area and 88 percent of the total population of the country (Sonneveld et al., 1999). The average crop yield from a piece of land in Ethiopia is very low by international standards mainly due to the decline of soil fertility associated with removal of topsoil by erosion (Sertu, 2000). This removal of the upper part of the soil always entails loss of nutrient and water by runoff, reduction of rooting depth and water and nutrient storage capacity resulting, sooner or later, in reduced crop production. In relation to this, (Belay, 1992) found a very high correlation (r=0.96) between soil productivity and erosion in southern Ethiopia. Taddese (2001) indicated that Ethiopia loses over $1.5 \times 10^6$ metric tons of soil each year from the highlands by erosion resulting in the reduction of about $1.5\times10^6$ metric tons of grain from the country's annual harvest.

Considering the severity of soil erosion and its impacts in the study area, it is necessary that appropriate management measures be taken. A sound knowledge of spatial variations in soil erosion is also mandatory when planning conservation efforts (Lulseged et al., 2006). Given the high costs of conservation and the competing production objectives, such as population increase, infrastructure development, and land degradation, there is a need to target responses and resources to areas of high risk, hereafter referred to as 'hotspots', rather than spreading them equally across the landscape (Adinarayana et al., 1998). Different management and land use planning scenarios can then be implemented to address the various land degradation problems taking into account the biophysical and socioeconomic conditions of the respective sites.

The early and widely accepted soil erosion models consist of relatively simple responses function that was calibrated to fit limited numbers of statistical observations-the Universal Soil Loss Equation (USLE). The current trend is towards replacing these models by the far more elaborated process based models (Sonneveld et al., 1999). Among these models, the Water Prediction Program (WEPP) of the United States Department of Agriculture (USDA), the Erosion Productivity Impact Calculator (EPIC), the Chemical, Runoff and Erosion from Agricultural Management Systems (CREAMS) and the European Soil Erosion Model (EUROSEM) can be listed as examples. However, (Sonneveld et al., 1999) urges that in case of Ethiopia and many other developing countries, the application of these process-based models is not practical due to their large data requirement. In countries like Ethiopia where soil degradation is extremely severe, application of basic soil erosion models that require less data and thus best fit to the available resources becomes imperative. Such models, integrated in a GIS environment, could conveniently be used to estimate soil loss and simulate conservation options (Bayramin, et al., 2003). Soil erosion models integrated in GIS provide a good opportunity to assess the spatial distribution of soil loss, identify areas of concern and simulate possible management scenarios (Mellerowicz et al., 1994; Renard et al., 1994 &1997; Stillhardt et al., 2002; Nyssen et al., 2004; Kaltenrieder, 2007; Woldeamlak and Ermias, 2009). The Revised Universal Soil Loss Equation (RUSLE) is now the most accepted and frequently used method as it can be applied in many situations, even on topographically complex landscape units, such as steep slopes and rugged terrain (Desmet & Govers, 1996a). Moreover, this model can be supported by GIS because it will be helpful to map the RUSLE factor layers.

Despite the severity of soil erosion and its associated consequences in the study area, there have been few studies at regional level to quantify erosion rates and less understanding of spatial dynamics of erosion processes at local or catchment scale (Nyssen et al., 2004; Kaltenrieder ,2007; Woldeamlak and Ermias, 2009). Since different portions of the landscape vary in sensitivity to erosion due to differences in their geomorphologic and land cover attributes, it is necessary to identify high erosion-risk areas in order to prioritize areas for specific soil conservation plan. The objective of this study is thus to assess the rates of soil loss and develop a soil loss intensity map of the study area using

RUSLE within a GIS environment, and delineate areas that require prior soil conservation measures.

Within a raster-based GIS, the RUSLE model can predict erosion potential on a cell-by-cell basis. This has distinct advantages when identifying the spatial patterns of soil loss present within a larger region. The GIS can then be used to isolate and query these locations to provide vital information on the role of individual variables in contributing to the observed erosion potential value.

Agricultural and livestock production as well as deforestation rapidly expanded in the area and gradually removed the natural land cover resulting in serious water-induced soil erosion. With the loss of topsoil, soil fertility deteriorated dramatically contributing to lower grain yields. Farmers had to expand their cultivated hill land area for crop production to maintain the food supply thus causing more soil loss. This cycle evolved with time and continues to date.

## MATERIALS AND METHODS

### . Description of the study area

The study encompasses the Legemara watershed of Borena Woreda located in the north-central highlands of Ethiopia and forms part of South Wollo Administration Zone of the Amhara Regional State (Figure 1). The watershed lies between $10^{0}$39’N and $10^{0}$47’N and $38^{0}$41’ E and $38^{0}$46’E covering a total area of $52km^{2}$ .Its relative location as road distance is about 580 km north of Addis Ababa and 180 south west of Dessie town.

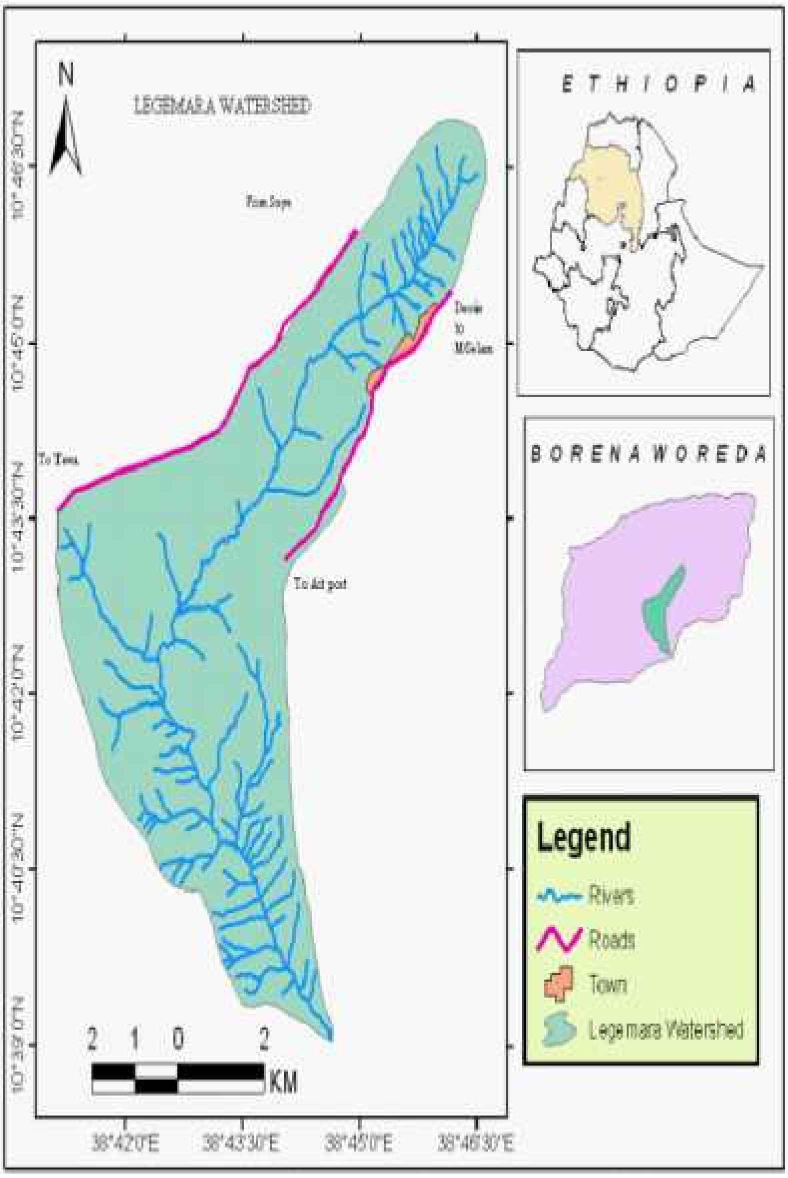



Figure 1: Location map of Legemara watershed

Computed from raw data of Mekane Selam station, which is shown in Figure 2, the total annual rainfall per year varies from 889 to 1500 mm. The highest rainfall is during the summer season, which starts in June and ends in September. Relatively less rainfall occurs during the spring season, which lasts from March to May. The mean annual temperature of the region varies from $14^0$c to $19^0$c. The absolute maximum temperature occurs from March to May with maximum of all in May. The absolute minimum temperature occurs in December, July and August, and the lowest occurs in July (Figure 2).

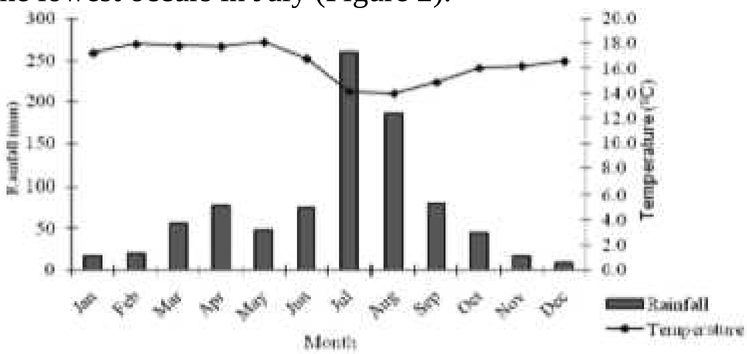



Figure 2: The mean monthly rainfall and temperature of Mekane Selam station in the study area, (1993-2005)

**2.2. Data sources and methods in determining RUSLE factor values**

Since the erosion process is gradual, there are difficulties in differentiating between the natural and accelerated rate of erosion, and the physical measurement of soil erosion is made worse by the complexities of temporal and spatial variations (Lal, 1990; Eaton, 1996). To overcome this, statistical modeling of the process of erosion was developed. This can be used to estimate soil loss based on the climate, topography, soil properties, and land use conditions of an area. The Universal Soil Loss Equation (USLE) has been the most widely used erosion model for decades (Wischmeier and Smith, 1978). It is an empirical equation model developed to predict soil erosion rates from agricultural fields in the United States of America (Wischmeier and Smith, 1978). It has, however, been used widely all over the world either in its original or modified form (Mellerowicz et al., 1994), including in Ethiopia (Hurni, 1985a, b; Hurni, 1988; Hellden, 1987; Renard *et al.*, 1994; BCEOM, 1998; Stillhardt *et al.*, 2002), in Eretria with the same geological and geomorphologic with Ethiopia (Nyssen et al., 2004; Kaltenrieder, 2007; Woldeamlak and Ermias, 2009) because of its simplicity and limited data requirement. Simple models have limited data requirements and thus can be practical for large watersheds in developing countries, where availability of adequate data is a problem (Millward and Mersey, 1999; Kinnell, 2001; Fistikoglu and Harmancioglu, 2002; Renschler and Harbor, 2002). The parameter values of the factors are location-specific and need to be calibrated to the specific area to enable reasonable prediction of the rate of soil loss. Numerous variations and local calibrations of these factors have made this equation to be the most widely used tool in the prediction of erosion (Fistikoglu and Harmancioglu, 2002; Angima et al., 2003; Lee, 2004). The advent of the Geographical Information System (GIS) technology has allowed the equation to be used in a spatially distributed manner because each cell in a raster image comes to represent a field-level unit.

Even though the equation was originally meant for predicting soil erosion at the field scale, its use for large areas in a GIS platform has produced satisfactory results (Mellerowicz et al., 1994; Renard *et al.*, 1994). By delineating micro-watersheds as erosion-prone areas according to the severity level of soil loss, priority is given for a targeted and cost-effective conservation planning (Kaltenrieder, 2007; Woldeamlak and Ermias, 2009). For this purpose, the Universal Soil Loss Equation (USLE) has been modified into a Revised Universal Soil Loss Equation (RUSLE) by introducing improved means of computing the soil erosion factors (Kaltenrieder, 2007; Woldeamlak and Ermias, 2009).

In this study, the modified form of RUSLE model has been applied.

The equation is given as:

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

Where $A$ is the annual soil loss (metric tons $ha^{-1}yr^{-1}$); $R$ is the rainfall erosivity factor [MJ mm $h^{-1}$ $ha^{-1}$ $yr^{-1}$]; $K$ *is* soil erodibility factor [metric tons $ha^{-1}$ $MJ^{-1}$ $mm^{-1}$]; LS = slope length factor (dimensionless); C is land cover and management factor (dimensionless, ranging between 0 and 1); and P is conservation practice factor (dimensionless, ranging between 0 and 1).

Individual GIS files relevant for the RUSLE were built for each factor and combined on a cell- by-cell grid modeling procedure in ArcGIS 9.3, to predict soil loss in a spatial domain. Each factor grid had a cell size of 30 m, although actual resolution (of the lowest resolution data source) is approximately 250 $m^2$. This resampling was done to incorporate the greater precision of the precipitation and topographic interpolations. All layers were projected with UTM Zone 37N using the WGS 1984 datum. These correspond to the standards used by the Ethiopian Mapping

Agency. For this study, therefore, the following methodology was used to generate these factors as grids. Figure 3 shows the general framework followed.

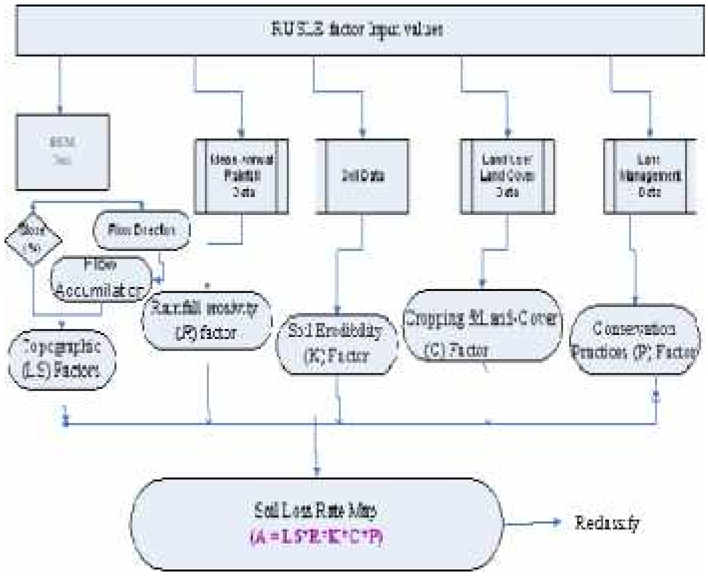



Figure 3: Framework to manipulate Soil erosion rate map using RUSLE model.

### *Topographic (L and S) factors*

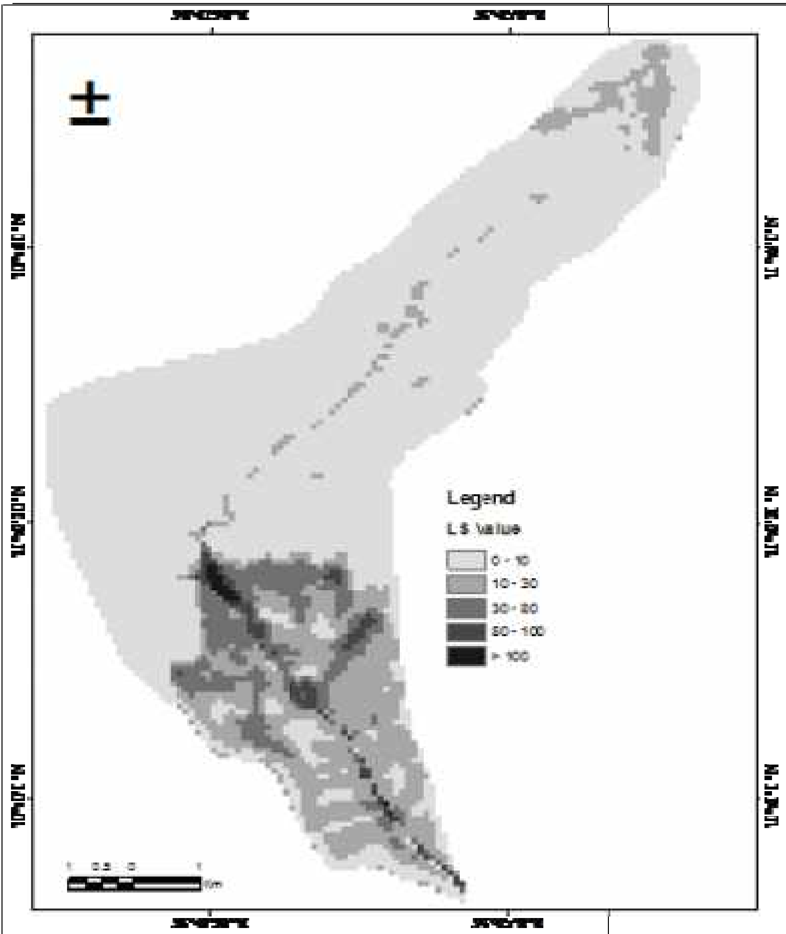
Terrain geometry and characteristic (slope, aspect, and curvatures), have significant impact on the spatial distribution of erosion/deposition (Moore and Burch, 1986b; Desmet and Govers, 1996a). It is, therefore, essential to take account of the three-dimensional complex terrain through a landscape-based approach to fully capture the spatial distribution of erosion/deposition processes.

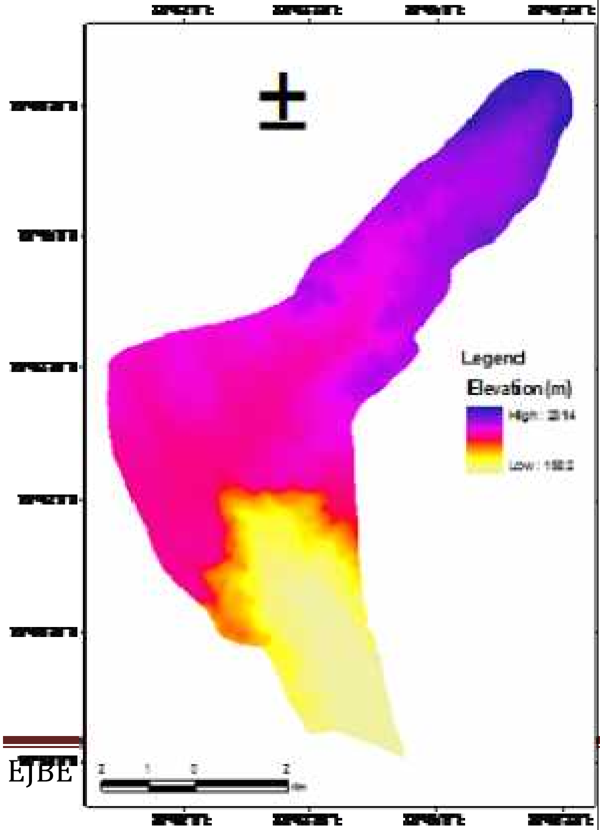
The influence of topography on erosion is complex. Local slope gradient (S sub-factor) influences flow velocity and thus, the rate of erosion. Slope length (L sub-factor) is a concept used to describe the distance between the origin and termination of inter-rill processes. Termination is either the result of the initiation of depositional processes or the concentration of flow into rills (Wischmeier and Smith, 1978; Renard et al., 1997). In RUSLE, the LS-factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 22 m plot (Robert and Hilborn, 2000). The steeper, and the longer, the slope, the higher the erosion.

Some researchers have argued that upslope drainage area is a better parameter to use when describing the influence of slope length on erosion, not slope length (Desmet and Govers, 1996a; Moore et al., 1993; Mitas and Mitasova, 1996). The upslope drainage area for each cell in a Digital Elevation Model (DEM) was calculated with multiple flow algorithms. Multiple flow algorithms can divide flow between several output cells (Desmet and Govers, 1996b and 2000). Depressions in the DEM are problematic for most flow routing algorithms and must be eliminated before calculating flow accumulation (Martz and Garbrecht, 1998; Rieger, 1998). In ArcView 9.3, the hydrology extension uses a single flow routing algorithm and raises the internal cells to remove depressions (Jenson and Domingue, 1988; ESRI, 2005c). A 30 m resolution was preprocessed to drive the LSfactor after appropriate size of the study area was clipped. The LS- factor grid was estimated with the following equation proposed by (Moore and Burch, 1986a and b; Engel, 2005).

$$LS = ([\text{Flow Accumulation}] * [\text{cell size}] / 22.13)^{0.4} * (\sin[\text{local Slope gradient (degrees)}] / 0.0896)^{1.3} \quad \ldots\ldots 2$$

Where LS is slope steepness- length factor and cell size is 30m by 30 m contributing area.






a)

**Figure 3.** DEM (a) and topographic (LS) factors (b) in the Legemara watershed

### *Precipitation and rainfall erosivity (R) factor*

Soil loss is closely related to rainfall through partly, the detaching power of raindrops striking the soil surface and, partly, through the contribution of rain to runoff (Morgan, 1994). Rainfall erosivity is a term used to describe the potential for soil to wash off the disturbed and de-vegetated areas into surface waters of the state during storms. In the original equation of USLE, the value for R measures the kinetic energy of the rain, and it requires measuring the rainfall intensity with autographic recorders. The energy of a given storm depends upon all the intensities at which the rain occurred, and the amount of precipitation that is associated with each particular intensity value. Within the RUSLE, rainfall erosivity is estimated using the EI30 measurement (Renard *et al*., 1997). That means $R$ is the average annual sum of the event rainfall-runoff (erosivity) factor when this factor is given by the product of the kinetic energy of the rainstorm $E$ and the maximum 30 minutes rainfall intensity $I30$. However, rainfall intensity data is usually unavailable, mostly in the data-scarce remote regions of developing countries. There is, thus, a tendency to use intensity values available in roughly similar environments to estimate for locations where relevant data is available. However, as several authors have shown, there are problems in determining adequate rainfall erosivity index for areas outside of those for which the USLE was developed. In line with this, different empirical equations have been developed that estimate R-values from rainfall totals, which is easily available (Hurni, 1985a; Renard et al., 1994). Similar methods of determining R– values from rainfall totals have been used in previous studies on different countries (Morgan, 2005; Angima et al., 2003; Woldeamlak and Ermias, 2009). Mekane Selam rainfall station, located in the middle of the watershed, was used in this study. The monthly amount of precipitation for this station was collected over years by the National Meteorological Agency. Monthly rainfall records from this meteorological station (Mekane Selam) covering the period 1970-2007 were used to calculate the rainfall erosivity factor (R-value). In this study, Hurni's empirical equation (Hurni, 1985a), which estimates R-value for the Ethiopian highlands from annual total rainfall, was used.

$$R = -8.12 + 0.562P \qquad \ldots (3)$$

Where R is the rainfall erosivity factor and P is the mean annual rainfall (mm). The mean annual rainfall was 891.92 mm, and the R Value was found to be 493. 139 mm to all cells.

### *Soil and soil erodibility (K) factor*

The erodibility of soil is an expression of its inherent resistance to particle detachment and transport by rainfall. Erodibility is determined by the cohesive force between the soil particles, which may vary depending on the presence or absence of plant cover, by the soil's moisture content, and by the development of its structure (Wischmeier and Smith, 1978). Erodibility depends essentially on the amount of organic matter in the soil, the texture of the soil, especially on sand of 100-2000 µ and silt of 2-100 µ, the profile, the structure of the surface horizon and permeability (Robert and Hilborn, 2000). Texture is the principal factor affecting K-values. Structure, organic matter, and permeability are also important contributors (Robert and Hilborn, 2000). In Africa, (Robert and Hilborn,2000) have found K-values from 0.12 for ferralitic soils on granite, 0.2 for ferralitic soils on schist, and up to 0.4 if the ferralitic soils are covered by volcanic deposits of schist. The researchers found 0.2-0.3 on tropical ferruginous soils; 0.01-0.1 on vertisols according to the 2006 world soil resource-based classification of FAO; and 0.01-0.05 on soils which were gravelly even on the surface. In this study, K-value estimates by (Robert and Hilborn, 2000) for similar environments to our study areas were used. The K-factor is defined as the rate of soil loss per unit of R on a unit plot (Renard et al., 1997). The rate of soil loss depends on the relative easiness of the soil for detaching and transporting forces. Soil erodibility is mainly a function of texture, organic matter (OM) content, structure, and permeability (Wischmeier et al., 1978). Texture and OM can be determined using laboratory measurements. Once these data are available, the following equation can be used to derive the K- factor (Renard et al., 1997):

$$100K = \left[2.1M^{1.14}\left(10^{-4}\right)\left(12 - OM\right) + 3.25(s-2) + 2.5(p-3)\right] / 7.59$$
………………4

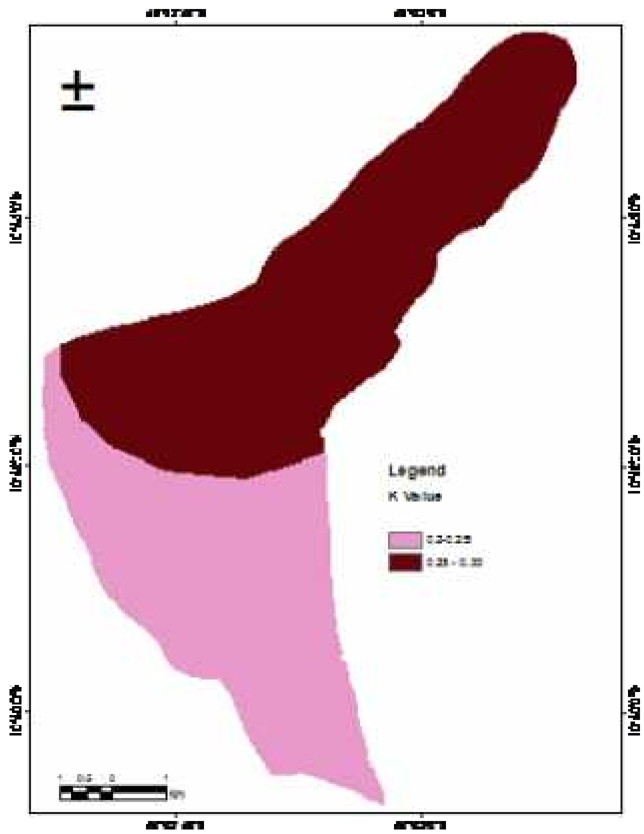
Where K = erodibility factor, in t/ ha (ha MJ mm)$^{-1}$; M = particle size parameter = (%silt + %sand)* 100 - %clay); OM is percent organic matter; s = soil structure code; p = permeability class. The division by 7.59 is to get values expressed in SI units of t/ ha (ha MJ mm)$^{-1}$ (Renard et al., 1997).

Soil samples for texture, structure, permeability and OM analysis were collected from soil pits located at different land mapping units in the catchments, mainly considering slope, land use, and land cover and soil texture classes' attributes. The samples were collected from representative samples of the watershed, and erodibility values were extrapolated to the whole of the watershed based on equation 4 (Table 1). Table 4 shows the average values of the K-factors of the sample for each land mapping units as well as the minimum, which is <2% and maximum range, which is >2% among the sample points based on equation 4. Figure 4 shows the resulting K-values map of Legemara watershed based on the extrapolated average values.

Table 1: K value based on the soil texture content

| Soil Types | Textural class | K value | | |
|---|---|---|---|---|
| | | Average | <2% | >2% |
| Cambic Arenosols | Sand | 0.02 | 0.03 | 0.01 |
| Eutric Cambisols | Sandyloam,clay,clayloam | 0.13 | 0.14 | 0.12 |
| Eutric Leptosols | Clayloam | 0.30 | 0.33 | 0.28 |
| Rendacize Leptosols | Sandyloam,Loam,clayloam | 0.30 | 0.33 | 0.28 |
| Vertic Cambisols | Clay | 0.22 | 0.24 | 0.21 |
| Rock surface (Regosols) | Coarse Sandy | 0.07 | - | 0.07 |

Source: Adapted from Robert and Hilborn (2000)




***Land use, and cover and crop management (C-values) factor***

The C factor is defined as the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow (Wischmeier and Smith, 1978). The crop management factor represents the ratio of soil loss under a given crop to that of the base soil (Morgan, 1994). The cover management factor (C-values), reflects the effect of cropping and management practices on the soil erosion rate (Renard *et al*., 1997). It is used to determine the relative effectiveness of soil and crop

**Figure 4.** Soil erodibility (K-Values) map.

management systems in terms of preventing soil loss. The C-value is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land. In order to account for the influence of surface cover on erosion rates and spatial patterns, Landsat7 ETM+ satellite image of 30 m resolution was used to derive land-use and land-cover map of the study area, which were acquired on 10 October 2005 from GLCF (Figure 5a). Supervised digital image classification technique was employed, using ERDAS EMAGINE 9.1 software which was complemented with field surveys that provided on-the-ground information about the types of land-use and land-cover classes. Four land-use and land-cover classes were recognized.

These include shrub or bush, grassland, agricultural and bare land (Figure 5a). A field checking effort was made in order to collect ground truth information. Since the introduction of the USLE, experimental studies have suggested different values for different cover types and management practices (Wischmeier and Smith, 1978; Renard et al., 1997**).** It is, however, difficult to apply those values to other environmental settings. For this study, C-factor values suggested by different researchers for different crop and surface cover types in Ethiopia were employed (Table 2). Based on the land cover classification map, the analysis of crop management factor (C-values) was made by changing the coverage to grid. A corresponding C- value was assigned to each land-use classes using the "reclass" method in a GIS (figure 5b). In the case of cultivated fields, the C- value varies annually where the cover of the fields varies. However, the dominant crops such as *teff* (*Eragrostis tef* -Zucc.), wheat, and pulses in the study area, remain the same, year after year, as substitutes tone another through crop rotation and hence, C- value of 0.17 was used for all cultivated fields.

Table 2: Cropping and land-cover C- values used in different studies

| Land-use and land-cover type | C factor value | References |
|---|---|---|
| Forest | 0.02 | Hurni (1988) |

| | | |
|---|---|---|
| Grassland | 0.01 | Eweg and van Lammeren (1996) |
| Cultivated land (cereals/pulses) | 0.17 | Hurni (1988) |
| Bare land | 0.6 | BCEOM (1998) |
| Shrub | 0.014 | Woldeamlak and Ermias, 2009 |

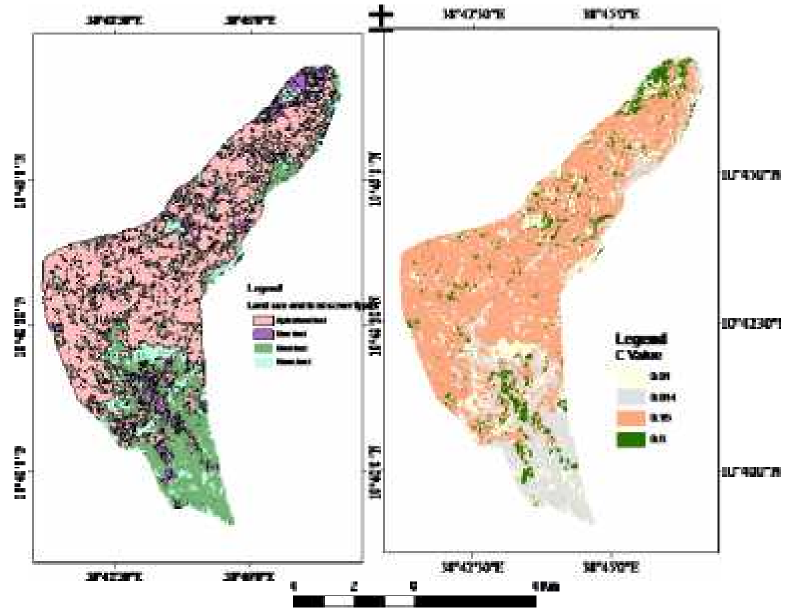



**Figure 5.** The Land-use and land-cover types (a) and the cover factor (C) values (b) in the Legemara watershed

***Determining conservation practices (P-Values)***

The P-factor gives the ratio between the soil losses expected for a certain soil conservation practice to the one with up-and-down-slope plaughing (Wischmeier and Smith, 1978). Specific cultivation practices affect erosion by modifying the flow pattern and the direction of runoff and, by reducing the amount of runoff (Renard et al., 1994). The conservation practices factor (p-values) reflects the effects of practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. It depends on the type of conservation measures implemented, and requires mapping of conserved areas for it to be quantified. In areas where there is terracing, runoff speed could be reduced with increased infiltration, ultimately resulting in lower soil loss. The P-value ranges from 0 to 1 depending on the soil management activities employed in the specific plot of land. Values for this factor were assigned considering local management practices. Most of the data related to management practices were collected during field visits to the watershed made from January to March, 2003. In the study area, there is only a small area that has been treated with terracing under the agricultural extension programme of the Ethiopian Government. But this is poorly maintained in the area under discussion as the participatory approach was not used in the implementation of the project. The traditional conservation method widely used in the study area is the drainage ditch, which is used to safely drain excess runoff from croplands during rainstorms. The entire study area is therefore not treated with improved permanent soil and water conservation measures. Considering the lack of data in the area on permanent management factors, and an absence of soil management practices, the P-values, suggested by Wischmeier and Smith (1978) and Shi et al. (2002); Woldeamlak and Ermias (2009) that consider only two types of land uses (agricultural and non-agricultural) and land slopes, were used in this study. Thus, the agricultural lands were classified into six slope categories and assigned P-values, while all non-agricultural lands were assigned a P-value of 1.00 (Table 3). A corresponding P-value was assigned to each land-use type using the “reclass” method in GIS (figure 6).

Table 3: Conservation practices factor (P-Value)

| Land use type | Slope (%) | P factor |
|---|---|---|
| Agricultural land | 0-5 | 0.11 |
| | 5-10 | 0.12 |
| | 10-20 | 0.14 |
| | 20-30 | 0.22 |
| | 30-50 | 0.31 |
| | 50-100 | 0.43 |
| Other land | All | 1.00 |

Source: Adapted from Wischmeier & Smith (1978); Shi et al. (2002) & Woldeamlak and Ermias (2009).

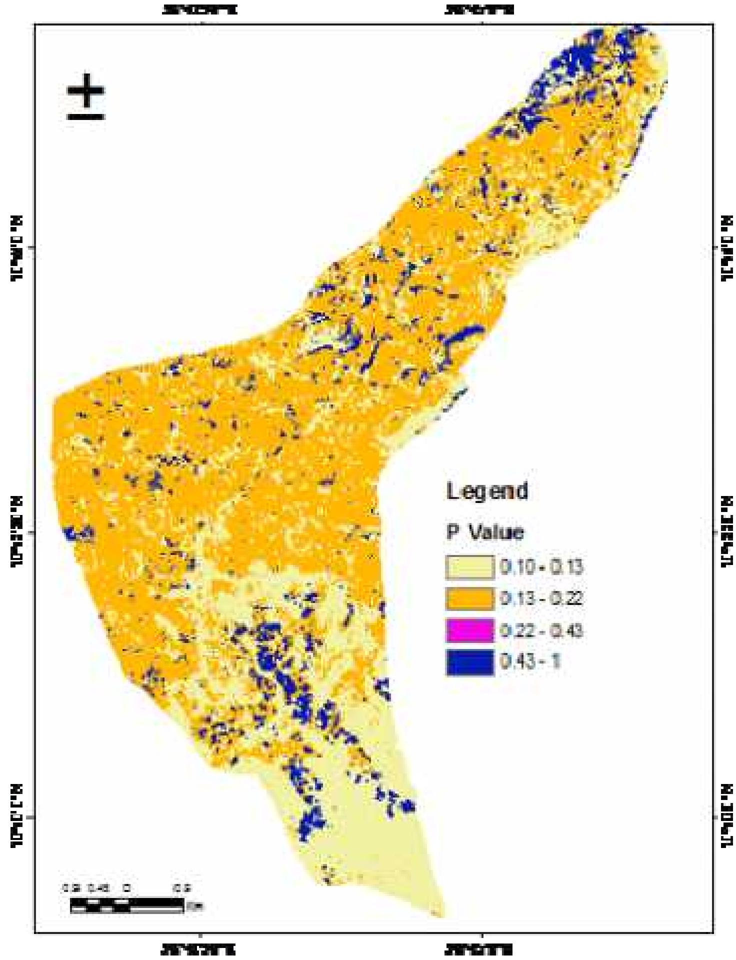



**Figure 6**. Conservation practices (P-value) factor values map of Legemara Watershed

## 3. RESULTS AND DISCUSSION

### *3.1. Assessment of soil loss rates*

The annual soil loss rate was determined by a cell-by-cell analysis of the soil-loss surface by multiplying the respective RUSLE factor values interactively by using ArcGIS 9.3.1 software using Equation (1) in section 3.2.4,which resulted in the rate of soil-loss shown in the map (Figure 7a.) In order to ease the presentation of the output data, the map shows five main categories (Figure 7a and Table 4).

**Table 4.** Annual soil loss rates and severity classes in the study area

| Soil loss (t ha_1 yr_1) | Severity classes | Area (ha) | Per cent of total area | Annual soil loss (tone) | % of total soil loss |
|---|---|---|---|---|---|
| 0-10 | Low | 1329.92 | 24.38 | 6649.60 | 3.95 |
| 10-20 | Moderate | 1278.14 | 23.43 | 19172.09 | 11.38 |
| 20-30 | High | 503.88 | 9.24 | 12596.96 | 7.48 |
| 30-50 | Sever | 528.58 | 9.69 | 21143.05 | 12.55 |
| >50 | Very severe | 1815.99 | 33.28 | 108959.30 | 64.64 |

Annual soil loss ranged from 0 in the plain area of the study watershed to over 50 metric tons $ha^{-1}yr^{-1}$ in much of the steeper slope banks of tributaries, and to well over 154 metric tons $ha^{-1}yr^{-1}$ in some areas (Figure 7a). The total soil loss in the study area was 168,521 metric tons per year from 5456.5 ha. The largest size among the soil-loss categories was >50 metric tons $ha^{-1}yr^{-1}$ (Figure 7a). Average annual soil loss for the entire watershed was estimated at 30.88 metric tons $ha^{-1}yr^{-1}$.

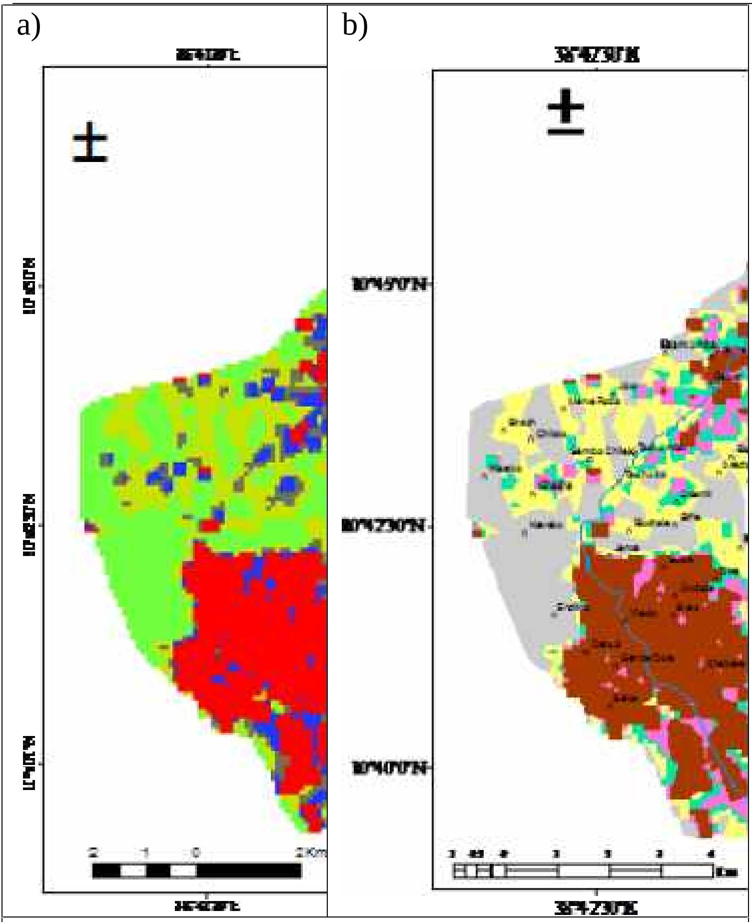



**Figure 7.** Soil erosion hazard (a) and, Soil erosion hotspots and sub areas for conservation planning practices (b) in the Legemara watershed

### *3.2 Prioritization for soil conservation planning*

In this study, the categorization of different erosion potentials was done following the FAO basic classification of desertification (FAO, 1986) method, with some modification to suit to the unique features of the study area. Soil-loss tolerance (SLT) is a commonly used term in soil erosion studies. SLT denotes the maximum allowable soil-loss that will sustain an economic and a high level of productivity (Wischmeier and Smith, 1978; Gebreyesus and Kirubel, 2009; FAO and UNEP,1984). The normal SLT values range from 5 to 11 tons $ha^{-1}yr^{-1}$ (Renard et al., 1996; Foster et al., 2002). The assignment of a range depended on the judgment of how much erosion would be harmful to the soil. Areas with higher soil-loss potential than the SLT are shown in Figure 7a and b.

The total area with a soil-loss potential higher than the SLT was 4126.59 ha (Table 5), covering 75.64% of the total study area. This area can be subdivided into five severity classes as shown in Table 4.

**Table 5.** Prioritization areas of the Legemara watershed

| Soil loss (t $ha^{-1}$ $y^{-1}$) | Priority classes | Priority sub area | Area (ha) | Per cent of total area | Annual Soil loss (tone) | % of total soil loss |
|---|---|---|---|---|---|---|
| >50 | I | SW_1 | 1815.99 | 33.28 | 108959.30 | 64.64 |
| 30-50 | II | SW_2 | 528.58 | 9.69 | 21143.05 | 12.55 |
| 20-30 | III | SW_3 | 503.88 | 9.24 | 12596.96 | 7.48 |
| 10-20 | IV | SW_4 | 1278.14 | 23.43 | 19172.09 | 11.38 |
| 0-10 | V | SW_5 | 1329.92 | 24.38 | 6649.60 | 3.95 |

As shown in Table 5, the spatial locations of the highly affected spots by soil erosion in the study area are the steeper slope banks of tributaries which, combined, cover about 2344.57 ha (42.97 %) of the total area and 130102.35 tons $ha^{-1}yr^{-1}$ (77.19 %) of the total soil loss. These areas have ranges of the erosion severity classes of very severe and severe, in which cases, the first and second conservation priority orders are needed, respectively. A detailed investigation showed that the most pronounced RUSLE-factors that worsened soil erosion and caused high soil loss rate were the slope length (L) and steepness (S) factors (Figure 3). Other high soil erosion areas are dispersed throughout the study areas which together cover 1782.02 ha (32.67%) of the total area and account for 31769.05 tons $ha^{-1}yr^{-1}$(18.86%) of the total soil loss. Their topographic ruggedness and poor vegetation cover contribute to the high rate of soil erosion in these areas. They are typically associated with high erosion potential land uses, and these areas have ranges of severity classes of high and moderate, in which case the third and fourth conservation priority orders is needed, respectively. The main reasons for the higher soil loss in these areas could be (i) the prevailing tillage and management practices where crop cultivation operations are carried out when it rains intensively, resulting in a weak soil surface with readily available through plow and loose soil particles for erosion and (ii) absence of tree covers, leaving areas exposed to direct impact of the rainfall.

The plane parts of the study area, which account for 1329.92 ha (24.38 %) of the total area and 6649.60 tons $ha^{-1}yr^{-1}$ (3.95 %) of the total soil loss, show to be the least vulnerable areas to soil erosion, compared with other areas, as they have a severity class of low, in which case, the fifth conservation priority is needed.

**DISCUSSIONS**

The estimated rate of soil loss and the spatial patterns are generally realistic compared to what can be observed in the field as well as from the results of previous studies. For instance, Mati *et al.* (2000) estimated average soil loss from croplands in the highlands of Ethiopia at 100 metric tons $ha^{-1}yr^{-1}$. In the Highlands of Ethiopia and Eritrea, soil losses are extremely high with an estimated average of 20 metric tons $ha^{-1}yr^{-1}$ (Hurni, 1985a) and measured amounts of more than 300 metric tons $ha^{-1}yr^{-1}$on specific plots. Accounting for re-deposition of mobilized sediments, Hurni (1993) estimated mean soil-loss from cultivated fields as 42 metric tons $ha^{-1}yr^{-1.}$ . The average annual soil-loss estimated by USLE from the entire Medego watershed of northern Ethiopia was also 9.63 metric tons $ha^{-1}yr^{-1}$ (Tripathi and Raghuwanshi, 2003) and the average annual soil-loss for the entire Chemoga watershed in the Blue Nile Basin, Ethiopia, was estimated at 93 metric tons $ha^{-1}yr^{-1}$ (Woldeamlak and Ermias, 2009).

Therefore, the RUSLE model was critically applied using an integrated GIS approach in a raster environment so as to obtain maps for each RUSLE factor. RUSLE is an empirically based model, which has been developed for both natural and simulated runoff plots. Its simplicity and statistical relationships between input and output variables make it adaptable to other environments (Morgan, 1986 and Soil and Water Conservation Society, 1994). The recent advancements in GIS technology have made the derivation of some RUSLE factors easier, more accurate and less time-consuming, specifically for those related to slope-length and steepness-factor (Desmet and Govers, 1996a&b;

Nearing, M.A., 1997). The RUSLE equation was run using the different grid surfaces created by ArcGIS 9.3.1 spatial analyst.

The soil-loss rate map, Figure 7a and b, and Tables 4 and 5, clearly show that, nearly 96.05% of the total study area requires implementation of different types of soil and water conservation measures for a sustainable land use. Farmers' understanding of soil-loss or practicability of participatory conservation measures may, however, limit implementation of soil and water conservation technologies to a few priority areas only. Where there is limited resources to implement conservation measures, giving priority to only selected areas that are highly affected can significantly reduce heavy soil-loss in the study area. Thus, it is necessary to prioritize highly affected areas for treatment with appropriate soil and water conservation measures.

## CONCLUSION AND POLICY IMPLICATIONS

The modeling of soil erosion potential for the Legemara watershed provided several insights, for instance, as to which area must first be conserved based on the severity level of soil loss with the interactions among erosion factors in a highland environment like Ethiopia. The use of GIS strengthens conservation planning and analysis of multi-layer data spatially and quantitatively within the study area. This study provides ways of collecting representative data needed for the RUSLE, and demonstrates its usefulness for predicting soil-loss and soil conservation planning. The results of the study include a soil loss level map of the Legemara watershed and the prioritization of areas for conservation.

The study demonstrates that the RUSLE together with satellite remote sensing and geographical information systems is a useful tool to estimate soil loss over areas and to facilitate sustainable land management through conservation planning. The method can thus be applied in other parts of Ethiopia for assessment and delineation of erosion-prone areas for prioritization of areas for conservation. The method is an efficient tool in situations with limited resources.

Generally, the practice of removing plant residues and plowing the land several times should be avoided in the areas exposed to high soil loses. Similarly, lack of vegetative cover during the critical period of rainfall with high erosivity and the lack of support practices (contour planting, strip cropping and other vegetative barriers) which could reduce the effect of runoff on steep areas have been identified in this assessment as major causes of soil loss.

Therefore, this study forwards the following policy implications and recommendations:

- The study area is one with high level of land degradation. Therefore, sustainable soil conservation strategies need to be formulated and implemented;
- As indicated in the land use and land cover analysis, the vegetation cover of the land should be improved to act as speed breaker for the unchecked flow of water thereby reduce the removal of soil organic matters;
- As the top soil of the watershed is lost by water erosion and the underlying bare rock is exposed, the water-holding capacity and nutrient availability of the soil should be increased by applying biological and agronomic conservation schemes to help increase agricultural productivity and minimize los of biodiversity in the area;
- Conservation efforts need to involve farmers and members of the communities as active participants.

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