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ESTIMATING SOIL LOSS RATES FOR SOIL CONSERVATION PLANNING IN THE BORENA WOREDA OF SOUTH WOLLO HIGHLANDS, ETHIOPIA

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ABSTRACT

The rate of soil erosion is severe in the highlands of Ethiopia. Soil conservation is critically required in these areas to tackle soil erosion. The objective of this study was to estimate soil loss rates in the Borena Woreda of South Wollo Highlands. The Revised Universal Soil Loss Equation (RUSLE) integrated with satellite remote sensing and geographical information systems (GIS) as a useful tool for conservation planning was used. Monthly precipitation, soil map, a 30 m digital elevation model, land-cover map, land use types and slope steepness were used to determine the RUSLE values. Based on the level of soil erosion rates, the study area was divided into seven priority categories for conservation interventions. The results show that 15.72 per cent of total area suffer from a severe or very severe to extremely severe erosion risk (>80 metric tons $ha^{-1}yr^{-1}$), mainly in the steeper slope banks of tributaries where steep lands are cultivated or overgrazed. Moreover, the total soil loss in the study area was 2,661,888 metric tons per year from 102,756 hectares.

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

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, Dengiz, Baskan, and Parlak, 2003). For instance, Reusing, Schneider and Ammer, 2000) state 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 soils are highly erodible due to the relatively shallow depth and low structural stability (Eaton, 1996).

Soil erosion is a common phenomenon in the East African highlands, where it causes widespread soil degradation (Edwards, 1979; Gachene, 1995; Tiffen, Mortimore, and Gichuki, 1994). Rapid population growth, cultivation on steep slopes, clearing of vegetation and overgrazing are the main factors that accelerate soil erosion in Ethiopia. Such unsustainable and exploitative land use practices due to an increasing demand for food, fibre and fodder by the growing human and livestock populations are responsible for accelerated soil erosion in many parts of Ethiopia. Those practices reduce 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 productivity declines, resulting in a population-poverty-land degradation cycle.

The impact of soil erosion can be most problematical in the developing countries where farmers are highly dependent on intrinsic land ownership (Lulseged. & Vlek, 2008) and unable to improve soil fertility through application of purchased inputs (Lulseged. & Vlek, 2008). In the Ethiopian highlands only, an annual soil loss reaches 200 - 300 tons $ha^{-1}yr^{-1}$, and can be as much as 23.4 X 10^9 metric tons per year Food and Agricultural Organization(FAO,1984); Hurni, 1993). Hurni, 1988, and Hurni, Herweg, Portner, and Liniger, 2008), estimates that soil loss due to erosion of cultivated fields in Ethiopia amounts to about 42 metric tons $ha^{-1}yr^{-1}$. In the Ethiopian highlands soil erosion rates measured on test plots amount to 130 to 170 metric tons $ha^{-1}yr^{-1}$ on cultivated land (Hurni, Herweg, Portner, and Liniger, 2008).There are many consequences to this loss of fertile soil in Ethiopia. It affects 50 percent of the agricultural area and 88 percent of the total population of the country (Sonneveld, Keyzer and Albersen, 1999). The average crop yield from a piece of land in Ethiopia is very low according to international standards mainly due to soil fertility decline associated with removal of topsoil by erosion (Sertu, 2000). This upper part of the soil removal always implies nutrient loss, loss of water by runoff, reduction of rooting depth, and water and nutrient storage capacity and sooner or later 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 1.5×10^6 metric tons of soil each year from the highlands by erosion resulting in the reduction of about 1.5×10^6 metric tons of grain from the country’s annual harvest.

Considering the severity of soil erosion and its impacts, it is necessary that appropriate management measures be undertaken. To achieve this, a sound knowledge of spatial variations in soil erosion is necessary when planning conservation efforts (Tamene, Park, Dikau and Vlek, 2006). Because of the high cost 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 (‘hotspots’), rather than spreading them equally across the landscape (Adinarayana, Gopalrao, Ramakrishna, Venkatachalam & Suri,1998). Different management and land use planning scenarios can then be implemented to deal with the various land degradation problems. These attempts must take into consideration the biophysical and socioeconomic conditions of the respective sites.

The widely accepted soil erosion models consist of relatively simple responses functions calibrated to fit limited numbers of statistical observations; Universal Soil Loss Equation (USLE). The current trend is towards replacing these by far more elaborated process based models (Sonneveld, Keyzer and Albersen, 1999). Among these models are the Water Prediction Program (WEPP) of the United States Department of Agriculture (USDA), the Erosion Productivity Impact Calculator (EPIC), Chemical, Runoff and Erosion from Agricultural Management Systems (CREAMS), and European Soil Erosion Model (EUROSEM). Sonneveld, Keyzer and Albersen (1999) urge that for 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, it is imperative to apply basic soil erosion models that require less data and thus that best fit with available resources. Such models integrated in a GIS environment could conveniently be used to estimate soil loss and simulate conservation options (Bayramin, Dengiz, Baskan, and Parlak, 2003). Soil erosion models integrated in GIS are a means to assess the spatial distribution of soil loss, identify areas of concern and simulate possible management scenarios (Mellerowicz, Ress, Chow and Ghanem, 1994; Renard, Foster,Wessies and Porter, 1994 &1997*;* Stillhardt, Herweg and Hurni, 2002; Nyssen, Veyret-Picot, Poesen, Moeyersons, Haile, Deckers and Govers, 2004; Kaltenrieder, 2007; Bewket & Teferi, 2009).The Revised Universal Soil Loss Equation (RUSLE) is now the most 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, 1996) and can be supported by GIS because it is helpful to map the RUSLE factor layers.

Despite the severity of soil erosion and its consequences in the study area, there have been few studies at regional level to quantify erosion rates and the spatial dynamics of erosion processes at local or catchment scale do not appear to be well understood (Nyssen -Picot, Poesen, Moeyersons, Haile, Deckers and Govers, 2004; Kaltenrieder, 2007; Bewket & Teferi, 2009). Since different portions of the landscape vary in sensitivity to erosion through differences in their geomorphological and land cover attributes, it is necessary to identify high risk areas and so to prioritize areas for specific soil conservation plans. The objectives of this study are thus to: (1) assess rates of soil loss and develop a soil loss intensity map of the study area using RUSLE within a GIS environment and (2) 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 attempting to identify the spatial patterns of soil loss present within a large region. The GIS can then be used to isolate and query these locations to yield vital information about the role of individual variables in contributing to the observed erosion potential value.

MATERIALS AND METHODS

Description of the study area

The study area in Borena Woreda is located in the north-central highlands of Ethiopia (Figure 1). This is within the administrative zone of South Wollo in the Amhara Regional State. It lies between $10^0$34'N to $10^0$53'N and $38^0$28' E to $38^0$54'E. The Woreda covers a total area of 937km^2 and is inhabited by about 158,920 people CSA (2008). It is characterized by diverse topographic conditions having four agro-climatic zones ranging from 1000 to 4000m above sea level Watershed Development and Land Use Department (WDLUD, 1995). These are Kolla (tropical) which refers to lowlands between 500 and1, 500 m; Woina Dega (subtropical) which refers to highlands between 1,500 and 2,300 m; Dega (temperate) which refers to highlands between 2,300 and 3,200 m; and Wurch (Alpine) which refers to highlands between 3,200 and 3,700 m (Figure 1). A mountainous and highly dissected terrain with steep slopes characterizes the upstream part, but the downstream part has undulating topography and relatively gentle slopes.

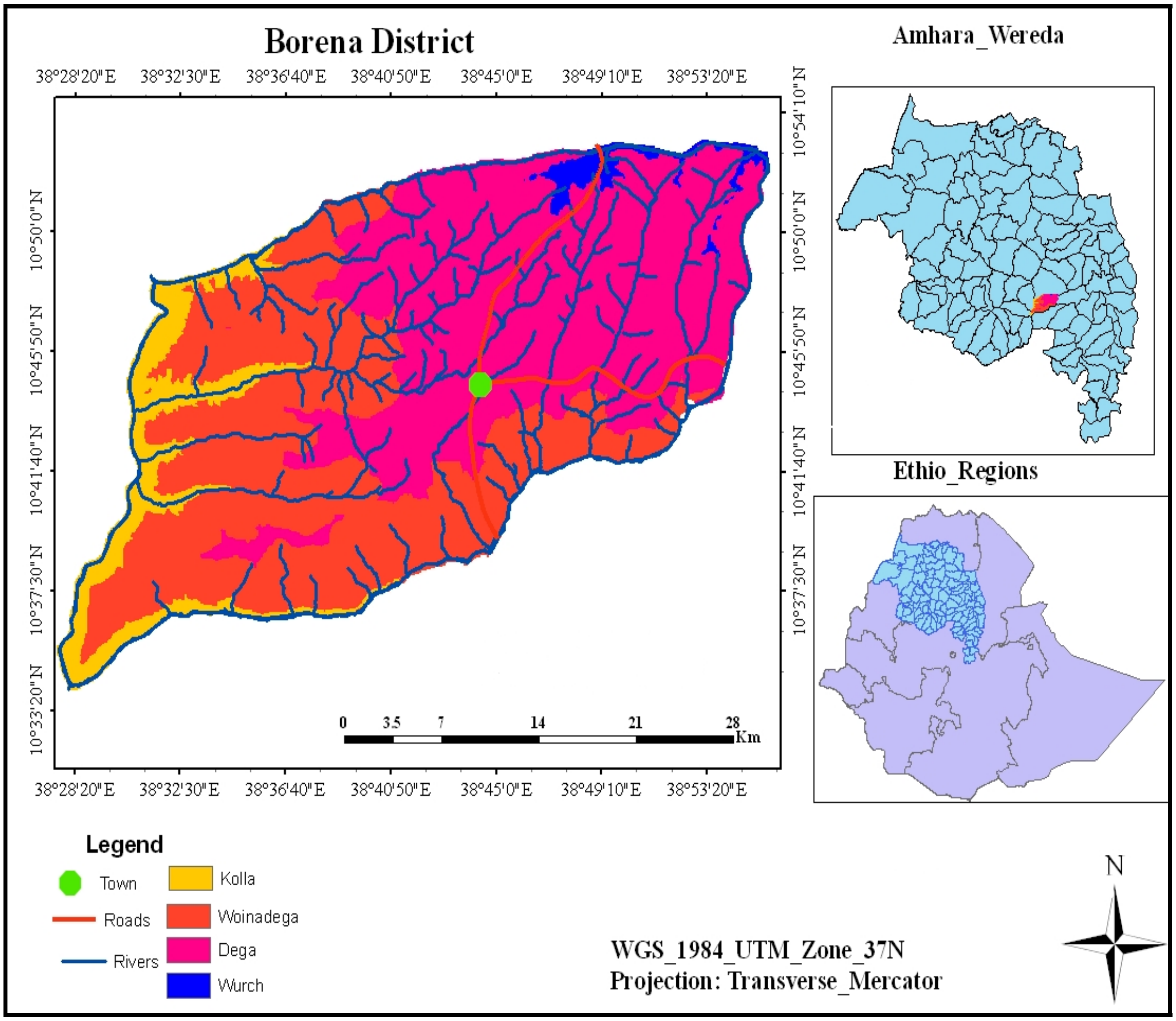

Figure 1: Location map of Borena Woreda

The total annual rainfall varies from 889 mm to 1500 mm yr^{-1}. The highest rainfall occurs during summer, which starts in June and ends in September. There is a short rainy season in spring, 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 and the absolute minimum temperature occurs in December, July and August. The upper North Western part of the Woreda is known for its minimum temperature and the wurch type of climate. The South Western part of the Woreda has the highest temperature, with the kolla climate.

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 these, statistical modelling 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 (Wischmeier & Smith, 1978) for decades. The USLE is an empirical equation that was developed to predict soil erosion rates from agricultural fields in the United States of America (Wischmeier & Smith, 1978). It has, however, been used widely all over the world either in the original or modified form (Mellerowicz, Ress, Chow and Ghanem, , 1994),, including in Ethiopia (Hurni, 1985a,b; Hurni ,1988; Helden, 1987; Renard, Foster,Wessies and Porter, 1994; BCEOM, 1998; Stillhardt, Herweg and Hurni, 2002; Nyssen-Picot, Poesen, Moeyersons, Haile, Deckers and Govers, 2004; Kaltenrieder, 2007; Bewket & Teferi, 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 data may be lacking (Millward & Mersey, 1999; Kinnell, 2001; Fistikoglu & Harmancioglu, 2002; Renschler & 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 the most widely used tool in the prediction of erosion (Fistikoglu & Harmancioglu 2002; Angima, Stott, Neill, Kong and Weesies, 2003; Lee, 2004). The advent of 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, Ress, Chow and Ghanem, 1994; Renard, Foster,Wessies and Porter, 1994). By delineation of 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; Bewket & Teferi, 2009). For this purpose the Universal Soil Loss Equation (USLE) has modified into a Revised Universal Soil Loss Equation (RUSLE) by introducing improved means of computing the soil erosion factors (Kaltenrieder, 2007 and Bewket and Teferi, 2009).

In this study, the RUSLE modified by [21] has been applied. The equation is given as:

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

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 and combined on a cell by cell-grid modelling 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 re-sampling 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 standards used by the Ethiopia Mapping Agency. The following methodology was used to generate the factor grids. Figure 2 show the general framework followed.

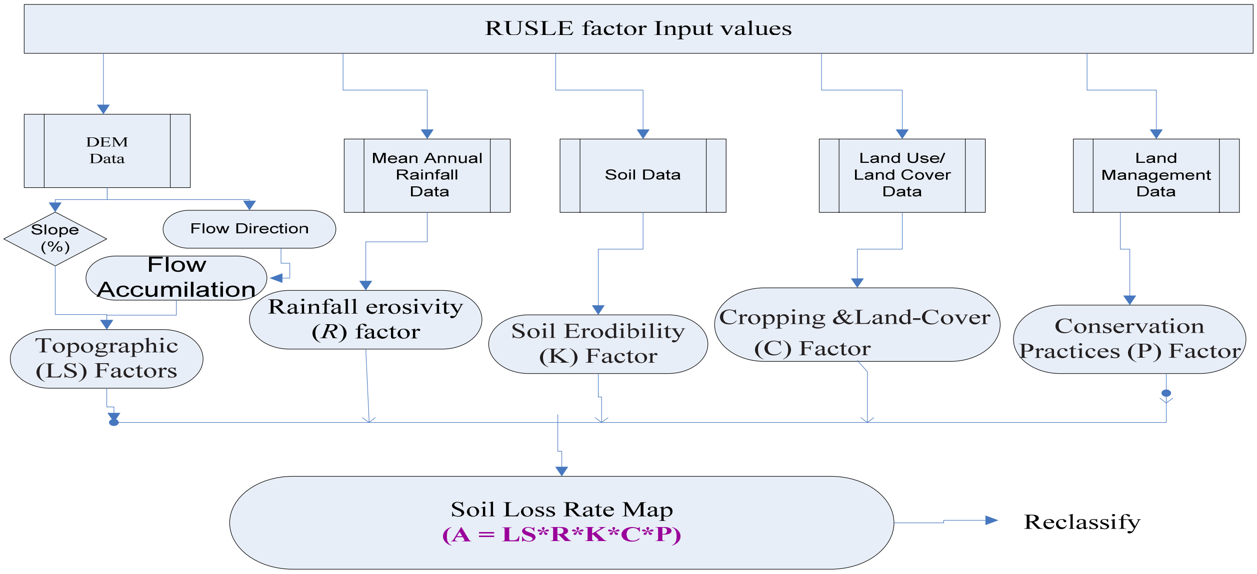

Figure 2: Framework to manipulate Soil Erosion rate map using RUSLE model.

Topographic (L and S) Factors

The influence of topography on erosion is complex. The local slope gradient (S sub-factor) influences flow velocity and thus the rate of erosion. Slope length (L sub-factor) describes 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, Foster, Weesies, McCool and Yoder, 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 & Hilborn, 2000). The steeper and longer the slope, the higher is the erosion.

Some researchers have argued that upslope drainage area is a better parameter when describing the influence of slope length on erosion, not slope length (Desmet & Govers, 1996a; Moore, Turner, Wilson, Jenson and Band, 1993; Mitas & 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 & Govers, 1996b and 2000). Depressions in the DEM are problematic for most flow routing algorithms and must be eliminated before calculating flow accumulation (Martz & 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 pre-processed to drive the LS factor 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).

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

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

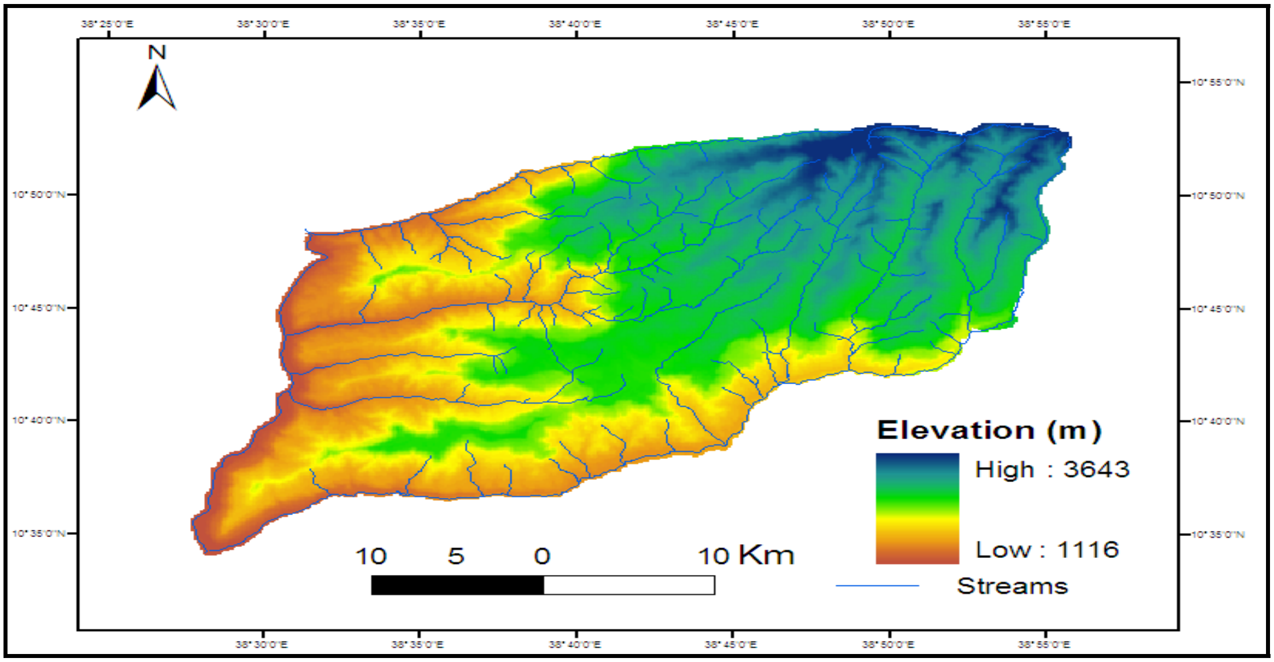

Figure 3: DEM showing elevation of the study area

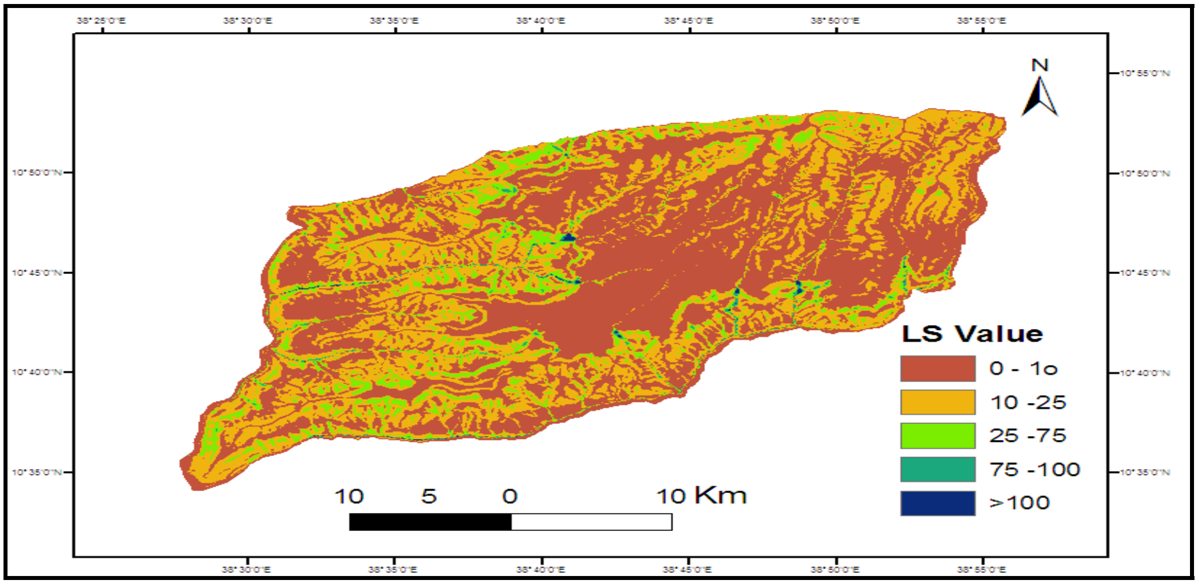

Figure 4: The topographic (LS) factors map of the study area

Precipitation Data and Rainfall Erosivity (*R*) factor

Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff (Morgan, 1994). Six rainfall stations randomly distributed within and around the study area (Table 1) were used in this study. The monthly amounts of precipitation for these stations were collected over 33 years by the National Meteorological Agency. Monthly rainfall records from these six meteorological stations (Mekane Selam, Wegdi, Amba mariam, Yeduha, Debre Work, Merto Lemariam) covering the period 1970-2007 were used to calculate the rainfall erosivity Factor (R-value). The monthly precipitation surface was interpolated to determine the value of each cell based on the values of nearby cells. “Nearby” is determined by setting a search radius that should lead, on average, to 6 control points being found. If fewer than 4 control points are found, the search radius is temporarily increased until a sufficient number are found.

Table 1: Mean annual rainfall (38-year average) for 6 stations

Station Mean	**Annual Rainfall (mm)**
M/selam	891.92
Wegdi	886.69
Amba mariam	1221.29
Yeduha	957.9
Debre Work	962.47
Merto Lemariam	1132.53

Source: National Meteorological Agency, 2007 (Computed)

Rainfall erosivity is a term that is used to describe the potential for soil to wash off disturbed, de-vegetated areas and into surface waters during storms. In the original equation of USLE, the value for R measures the kinetic energy of the rain and it requires measurements of 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 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 *I*30. Rainfall intensity data are not commonly available in data-scarce developing and remote regions. There is, thus, a tendency to use intensity values available in roughly similar environments to estimate for locations where those data are available. Several authors have shown the problems of determining an adequate rainfall erosivity index for areas outside of those for which the USLE was developed. Therefore, different empirical equations have been developed that estimate R- values from rainfall totals, which are easily available (Hurni, 1985a; Renard, Foster,Wessies and Porter, 1994). In this study, Hurni’s empirical equation (Hurni, 1985a) that estimates R-value for the Ethiopian highlands from annual total rainfall was used. It is given as:

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

Where R is the rainfall erosivity factor and P is the mean annual rainfall (mm). Similar methods of determining R– values from rainfall totals have been used in previous studies from different countries (Morgan, 2005; Angima, Stott, Neill, Kong and Weesies, 2003; Bewket & Teferi, 2009). The mean annual rainfall available from the National Meteorological Services Agency (Table 1) was first interpolated to generate continuous rainfall data for each grid cell. The R-value of each cell was then calculated using Equation 3 (Figure 5).

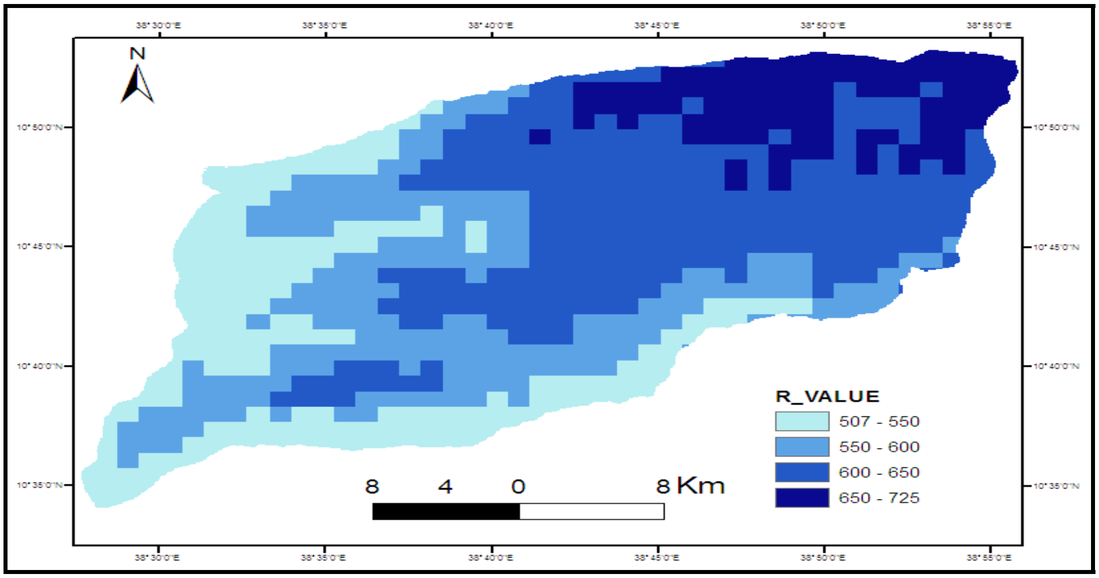

Figure 5: Rainfall erosivity distribution in the study area

Soil Data and Soil Erodibility (K) Factor

The soil data for this study are obtained from the soil map of the master plan of the Blue Nile river basin (scale 1:250,000). This map was used for analysing the soil erodability factor (K-value). The erodibility of a soil is an expression of its inherent resistance to particle detachment and transport by rainfall. It is determined by the cohesive force between the soil particles, and may vary depending on the presence or absence of plant cover, the soil's water content and 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 sand of 100-2000 µ and silt of 2-100 µ, the profile, the structure of the surface horizon and permeability (Robert & Hilborn, 2000). Texture is the principal factor affecting K- values; structure, organic matter and permeability are also important contributors (Robert & 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. They found 0.2-0.3 on tropical ferruginous soils, 0.01-0.1 on vertisols according to the World Soil resource based 2006 classification of FAO (2006) and 0.01-0.05 on soils which were gravelly even on the surface. In this study, K- values estimated by Robert and Hilborn (2000) for similar environments to our study areas was used. The vector data were first rasterized and each raster (grid-cell) was assigned K-values (Table 2). Figure 6 shows the resulting K- values map.

Table 2: K value based on the soil texture and organic matter content

Soil Types	K value			
	Textural class	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).

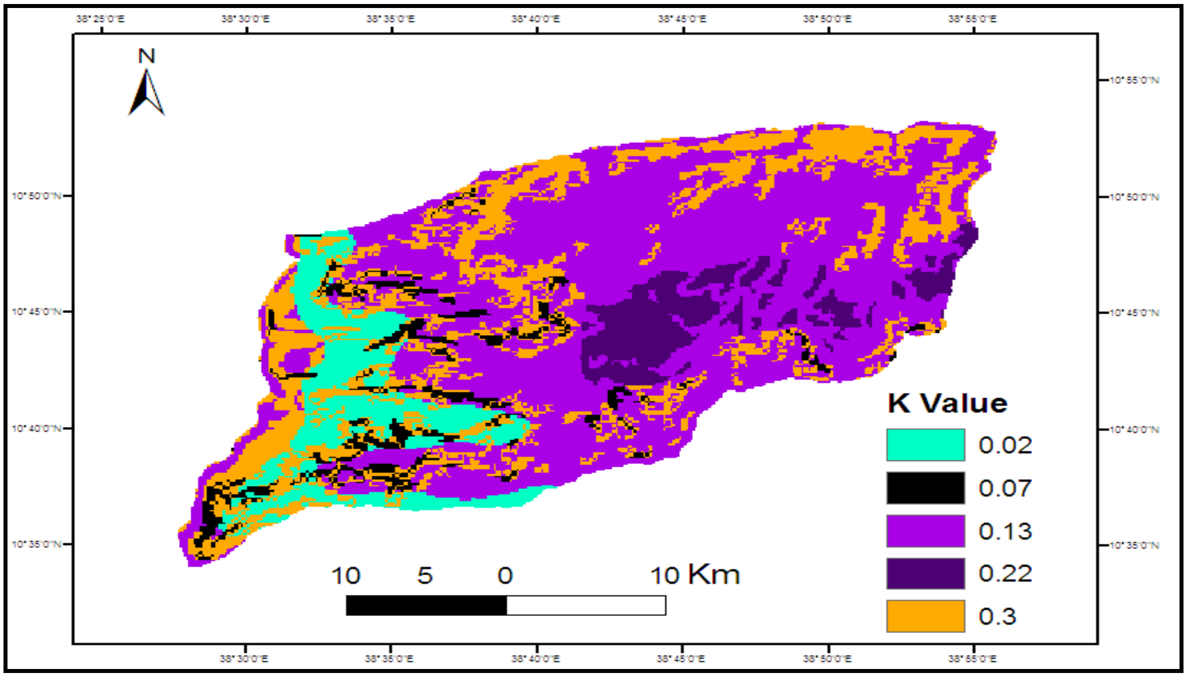

Figure 6: Soil erodibility (K- values) map of the study area

Land Use/Cover Data and Crop Management (C-values) Factor

A land-use and land-cover map of the study area was prepared from Landsat ETM+ imagery acquired on 12 February 2003 from Global Land Cover Facility (GLCF) (Figure 7). 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. Five land-use and land-cover classes were recognized. These include forest, shrub or bush, grass, agricultural and bare land. A field checking effort was made in order to collect ground truth information. Based on the land cover classification map, the analysis of crop management factor (C-value) was made.

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, Foster, Weesies, McCool, and Yoder, 1997). It is used to determine the relative effectiveness of soil and crop management systems in 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. To determine the C-values a land-use/ land-cover map of the study area was used. The crop and management factor (C- value) corresponding to each crop/vegetation cover was estimated from RUSLE guide (Table 3). After changing the coverage to grid, a corresponding C-value was assigned to each land use class using the "reclass" method in a GIS (figure 8). In the case of cultivated fields, the C- value varies annually where the cover of the fields varies. But, the dominant crops such as teff (*Eragrostis tef* (Zucc.), wheat, barley, sorghum and pulses in the study area remain the same year after year and hence a C-value of 0.17 was used for all cultivated fields. Teff which grows for its seed and straw is used to make *injera*, porridge, bread and traditional beers in Ethiopia.

Table 3: 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	Wischmeier and Smith (1978)

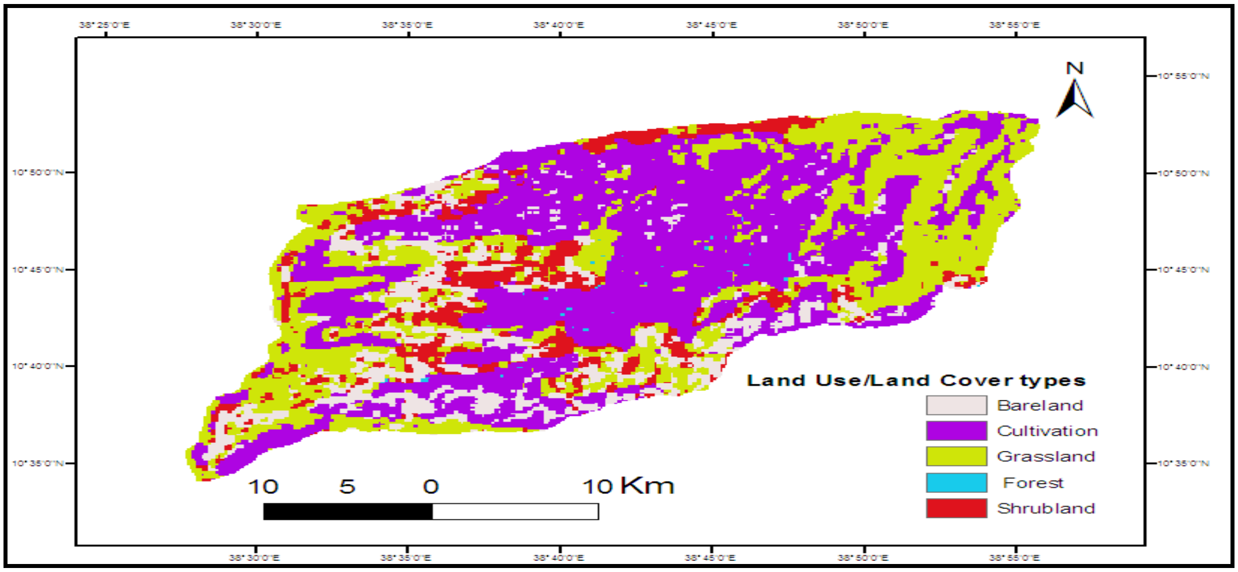

Figure 7: Land-use and land-cover types of the study area.

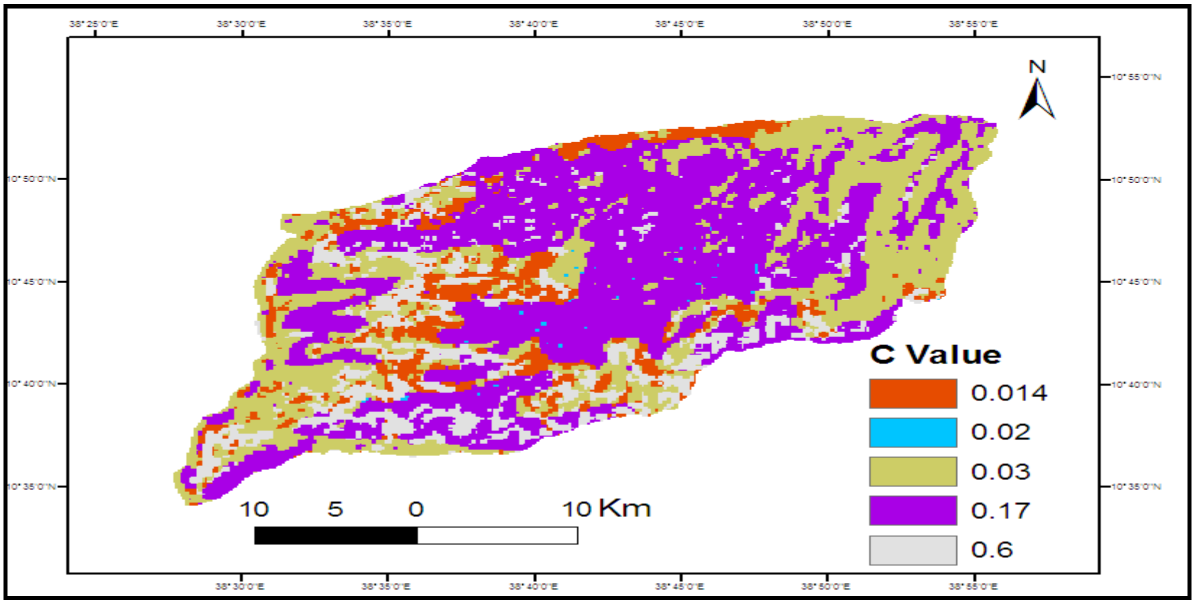

Figure 8: The cover factor C-values in the study area

Determining Conservation Practices (*P*-Values)

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. The P-value ranges from 0 to 1 depending on the soil management activities employed in the specific plot of land. In the study area, there is only a small area that has been treated with terracing through the agricultural extension programme of the government, and these are poorly maintained as implementation was performed without participation of the local people. The traditional conservation measure is a drainage ditch which is meant to drain excess runoff from croplands during rainstorms. The entire study area is therefore not treated with improved permanent soil and water conservation measures. As data were lacking on permanent management factors and there were no management practices, we used the P-values suggested by Bewket and Teferi (2009), Wischmeir and Smith (1978) , and Shi, Cai, Ding, Li, Wang and Sun (2002); that consider only two types of land uses (agricultural and non-agricultural) and land slopes. Thus, the agricultural lands are classified into six slope categories and assigned P-values; while all non-agricultural lands are assigned a P-value of 1.00 (Table 4). A corresponding P-value was assigned to each land use type using the re-class method in GIS (figure 9).

Table 4: 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) & Bewket and Tefer 2009)

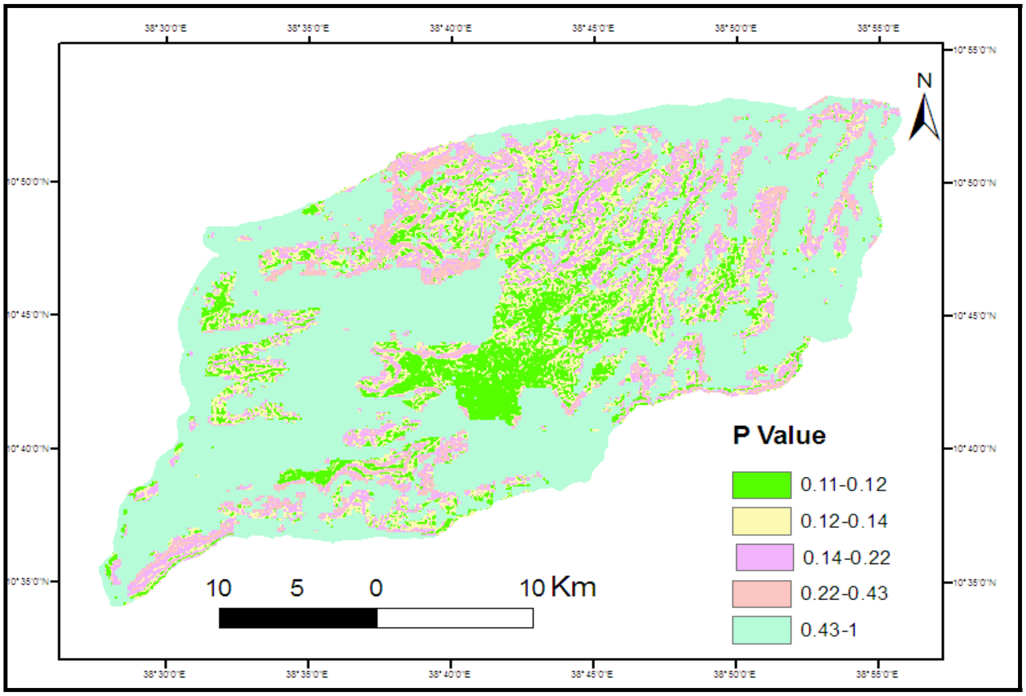

Figure 9: Conservation practices (P-value) factor values in the study area.

RESULTS

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 in ArcGIS 9.3 using Equation (1). Figure 10 shows the resulting soil loss rate map. In order to ease the presentation of the output data, the map showed seven main categories (Figure 10 and Table 5). Annual soil loss ranged from 0 in the plain area of the studied Woreda area to over 80 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 10). The total soil loss in the study area was 2,661,888 metric tons per year from 102,756 ha. The largest size among soil loss categories was that of 30-45 metric tons ha^{-1}yr^{-1} (Figure 10). Average annual soil loss for the entire Woreda was estimated at 27 metric tons ha^{-1}yr^{-1}.

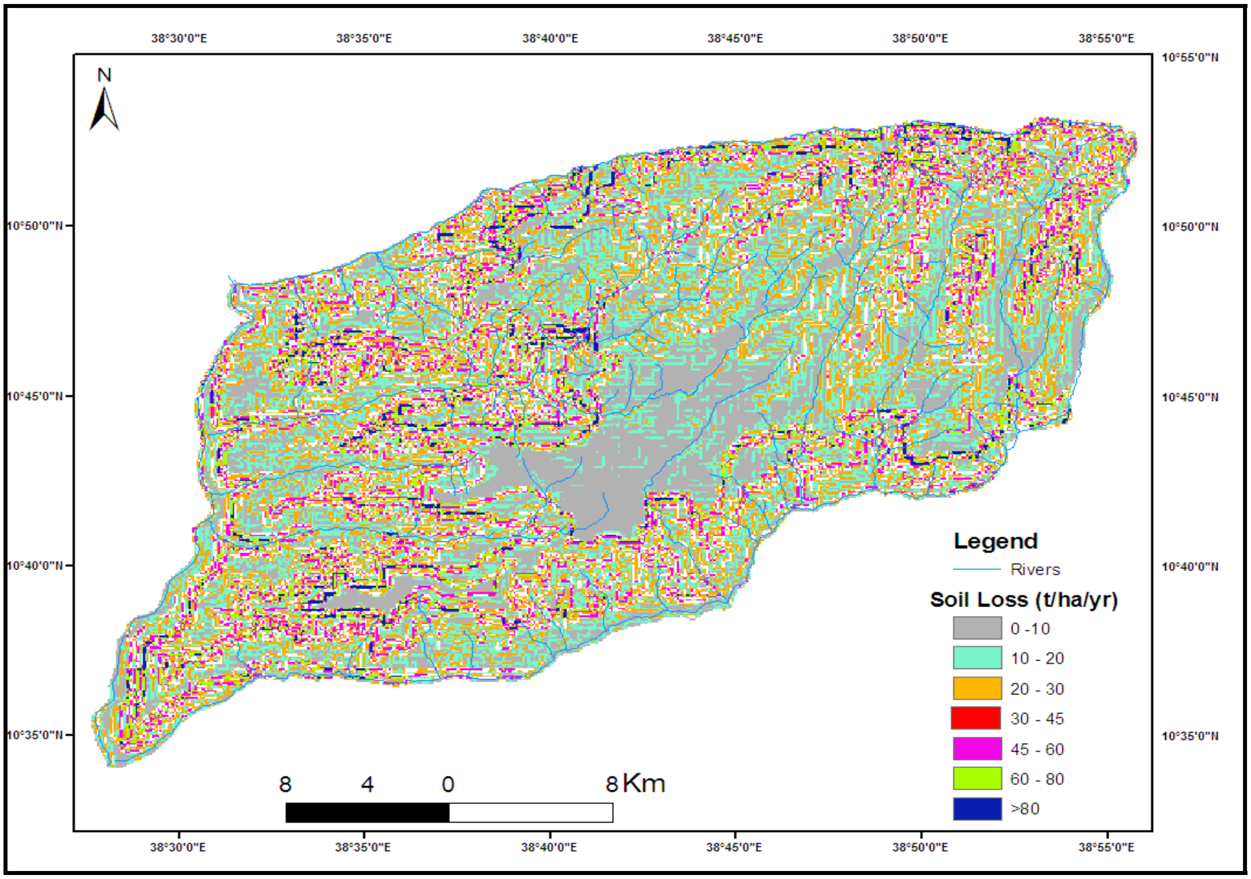

Figure 10: Soil Loss rate map in the Borena Woreda

Prioritization for Soil Conservation Planning

Categorization of different erosion potentials followed the FAO basic classification of desertification FAO (1986) with some modification to suit the features of the study area (Table 5). Soil loss tolerance (SLT) denotes the maximum allowable soil loss that will sustain an economic and a high level of productivity (Wischmeier & Smith, 1978; Gebreyesus & Kirubel, 2009; FAO & UNEP., 1984).The normal SLT values range from 5 to 11 tons ha^{-1}yr^{-1} (Renard, Foster, Weesies, McCool and Yoder, 1996) The assignment of a range depended on the judgment of how much erosion would be harmful to the soil. Figure 10 shows areas with higher soil loss potential than the SLT.

The total area with a soil loss potential higher than the SLT was 79336 ha (Table 5 and Figure 10), comprising 77% of the total study area. This area can be subdivided into six severity classes (Table 5).

Table 5: Annual soil loss rates and severity classes with their conservation priority in the study area

Soil loss ($t\ ha^{-1}\ y^{-1}$)	Severity Classes	Priority classes	Area (ha)	Per cent of total area	Annual Soil loss (tone)	Per cent of total soil loss
0-10	Low	VII	23420.34	22.79	117101.7	4.4
10-20	Moderate	VI	26951.13	26.23	404266.95	15.19
20-30	High	V	21707.19	21.13	542679.75	20.39
30-45	Very High	IV	14521.68	14.13	544563	20.46
45-60	Sever	III	9178.92	8.93	481893.3	18.10
60-80	Very severe	II	5205.87	5.07	364410.9	13.69
>80	Extremely sever	I	1770.66	1.72	206972.45	7.78

As shown in Table 5, the spatial locations of the areas highly affected by soil erosion in the study area are the steeper slope banks of tributaries where they together cover about 16 percent of the total area and 39 percent of the total soil loss. These areas have ranges of the erosion severity classes of severe, very severe and extremely severe, where conservation priorities of the first, second and third order are needed. A detailed investigation showed that the most pronounced RUSLE factor that worsened soil erosion and caused high soil loss rate was the slope length (L) and steepness (S) factors (Figure 4). Other high soil erosion areas are dispersed throughout the study areas which together cover 35 percent of the total area and account for 41 percent 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 have ranges of severity classes of high and very high in which the fourth and fifth conservation priorities order are needed. The main reasons for the higher soil loss in these areas could be (i) the prevailing tillage and management practices, where crop cultivation operations were being performed with intense rainfall events, resulting in a weak soil surface cased by ploughing and loose soil particles for erosion and (ii) absence of tree cover, leaving areas exposed to direct rainfall impact.

The plane or flat parts of the study area, which account for 49 percent of the total area and 20 percent of the total soil loss, show as the least vulnerable to soil erosion compared with other areas, as they have a severity class of low and moderate in which case the sixth and seventh conservation priorities are needed. Generally, the practice of removing plant residues, and ploughing the land several times, should be avoided in the high soil loss potential areas. Similarly, a 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.

The soil loss rate map (Figure 10) clearly shows that nearly 80 percent of the total study area requires implementation of different types of soil and water conservation measures for a sustainable land use. The lack of understanding among farmers of soil loss or their lack of participation in conservation measures may, however, limit implementation of soil and water conservation technologies to a few priority areas only. Where resources are limited, implementing conservation measures in only selected areas that are highly affected can significantly reduce great soil loss in the study area. Thus, it is necessary to prioritize highly affected areas for treatment with appropriate soil and water conservation measures. Prioritization of these areas means ranking in terms of urgency.

DISCUSSION

The estimated soil loss rate and the spatial patterns are generally realistic, compared to what can be observed in the field as well as results from previous studies. For instance, Mati, Morgan, Gichuki, Quinton, Brewer and Liniger (2000) estimated average soil loss from croplands in the highlands of Ethiopia as a whole at 100 metric tons $ha^{-1}yr^{-1}$. This is not a realistic estimate. 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 & Raghuwanshi,2003) and average annual soil loss for the entire Chemoga watershed in the Blue Nile Basin, Ethiopia was estimated at 93 metric tons $ha^{-1}yr^{-1}$ (Bewket & Teferi, 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 advancement in GIS technology has made the derivation of some RUSLE factors easier, more accurate and less time consuming, specifically for those related to the 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 spatial analyst.

CONCLUSION AND POLICY IMPLICATIONS

The modelling of soil erosion potential for the Borena Woreda provided several insights such as which area is first 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 Woreda and the prioritization of areas for conservation.

The study demonstrates that the RUSLE together with satellite remote sensing and geographical information systems are useful tools to estimate soil loss over areas and 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 use of limited resources. Therefore, this study has the following policy implications

- Because of accelerated land degradation, there must be sustainable soil conservation strategies in the area
- The vegetation cover of the land should be improved to reduce the removal of soil organic matter
- The water-holding capacity and nutrient availability of the soil should be increased by applying biological and agronomic conservation schemes to increase agricultural productivity and minimize biodiversity loss in the area
- The farmers should be included in all such schemes as active participants.

REFFERENCES

Adinarayana, J., Gopalrao, K., Ramakrishna, N., Venkatachalam, P., & Suri, K.J. (1998). A site-specific systems-approach model for soil erosion and silt yield studies for hilly watershed management: *Modelling Soil Erosion, Sediment Transport and Closely Related Hydrological Processes.* Proceedings of, a symposium held at Vienna, IAHS, 249.

Angima, S.D., Stott, D.E., O'Neill, M., Kong, C.K., Weesies, G.A. (2003). Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agriculture, Ecosystems and Environment*, 97, 295–308. Elsevier

Aregay, B.W. & Chadokar, P.A. (1993). Soil conservation: An Ethiopian experience. In

N.W. Hudson and R.J. Cheatle (eds.) *Working with farmers for better land husbandry* (p. 23-25).

Soil and Water Conservation Society, Ankeny, Iowa.

BCEOM. 1998. Abbay River Basin Integrated Development Master Plan, Main Report. Ministry of Water Resources: Addis Ababa.

Bayramin, I., O.Dengiz., O.Baskan, M. Parlak. 2003. *Soil Erosion Risk Assessment with ICONA Model; Case Study: Beypazari Area*. Turk Journal of Agriculture and Forestry 27(2003).

Belay,T. 1992. Erosion. Its effect on properties and productivity of eutric nitosols in Gununo area, Southern Ethiopia, and some techniques of its control.Berne:Geographica Bernensa African Studies Series A9.

Bewket,W. and Teferi, E. 2009. Assessment of soil erosion hazard and prioritization

for treat, ment at the watershed level: case study in the Chemoga watershed, Blue Nile basin, Ethiopia. Land degradation & development. Published online in Wiley InterScience

(www.interscience.wiley.com) DOI: **10**.1002/ldr.944

Bork, H.-R., Frielinghaus, M. 1997. Zur Tolerierbarkeit von Bodenabtrag. Mitt. Dtsch. Bodenkdl. Ges. 83, 83– 86.

CSA. 2008. Ethiopian Population and Housing Census results, CSA, Ethiopia.

Desmet, P.J.J. and G. Govers, 1996a. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. Journal of Soil and Water Conservation. 51.5:427-433.

Desmet, P.J.J., and G. Govers. 1996b. Comparisons of routing algorithms for digital elevation models and their implications for predicting ephemeral gullies. International Journal of Geographical Information Systems. 10.3:311-331.

Desmet, P. J. and Govers, G. 2000. USLE2D.EXE (Release 4.1): User documentation.

Experimental Lab of Geomorphology, Catholic University of Leuven, Leuven.

Eaton, D. 1996. "The Economics of Soil Erosion: A Model of Farm Decision-Making," Discussion Papers 24134, International Institute for Environment and Development, Environmental Economics Programme.

Edwards, K.A. 1979. Regional contrasts in rates of soil erosion and their significance with respect to agricultural development in Kenya. In: Lai, R and D.J. Green land (eds.); Soil physical properties and crop production in the tropics.

Engel, B. 2005. Personal Communication (via email) Regarding: .Estimating Soil Erosion Using RUSLE (Revised Universal Soil Loss Equation) Using ArcView. Unpublished.

ESRI , 2005c. ArcView. [GIS software]. Version 3.3. Help Files: *Flow Direction Description* and *Flow Accumulation Description.*

Eweg HPA, van Lammeren R. 1996. The application of geographic information system at the rehabilitation of degraded and degrading areas of Tigray, Ethiopia. Research Report, Wageningen Agricultural University, Wageningen.

FAO.1984. Ethiopian Highland reclamation Study (EHRS). Final Report, Vol **1-2**.Rome.

FAO. 1986. Ethiopian Hihgland Reclamation Study: Report prepared for the government of Ethiopia by FAo, Rome .Vol.I

FAO and UNEP. 1984. Provisional Methodology for Assessment and Mapping of Desertification. FAO, Rome, Italy.

Fistikoglu, O., and Harmancioglu, N.B. 2002. Integration of GIS with USLE in assessment of soil erosion. Water Resources Management, 16: 447-469.

Gachene, C.C.K. 1995. Evaluation and mapping of soil erosion susceptibility: an example from Kenya. Soil Use and Management **11:** 1-4.

Gebreyesus, B. and Kirubel, M. 2009. Estimating Soil Loss Using Universal Soil Loss Equation (USLE) for Soil Conservation planning at Medego Watershed, Northern Ethiopia .Journal of American Science 2009: 5(1), 58-69. Marsland Press

Hellden, U. 1987. An Assessment of Woody Biomass, Community Forests, Land Use and Soil Erosion in Ethiopia, Lund University Press,Lund.

Hudson N. 1995. Soil Conservation, 3rd edn. Batsford: London, 391 pp.

Hurni H. 1985a. Soil Conservation Manual for Ethiopia. Ministry of Agriculture: Addis Ababa. Hurni H. 1985b. Erosion–productivity–conservation systems in Ethiopia. Paper Presented at the 4th International Conference on Soil Conservation, 3–9 November 1985, Maracacy, Venezuela.

Hurni, H. 1988. Degradation and conservation of the resources in the Ethiopian highlands. Mountain Research and Development, 8 (2/3): 123-130.

Hurni H. 1993. Land degradation, famine, and land resource scenarios in Ethiopia. In World Soil Erosion and Conservation, Pimentel D (ed.).Cambridge University Press: Cambridge; 27–62.

Hurni H, Cook MG, Sombatpanit S. 1996. Soil conservation extension—Aworld perspective. In Soil Conservation Extension from Concepts to Adoption. Sombatpanit S, Zobisch MA, Sanders DW, Cook MG (eds). Science Publishers: Enfield, USA; 3–18.

Hurni,H.;Herweg,K;Portner,B. and Liniger,H. 2008. Soil Erosion and Conservation in Global Agriculture. Springer Science+Business Media B.V.

Jenson, S.K. and J.O. Domingue, 1988. Extracting topographic structure from digital elevation data for geographic information system analysis. Photogrammetric Engineering and Remote Sensing. 54.11: 1593-1600.

Kaltenrieder,J. 2007. Adaptation and Validation of the Universal Soil Loss Equation (USLE) for the Ethiopian-Eritrean Highlands.MSc Thesis, University of Berne,Centre for Development and Environment Geographisches Institut.

Kinnell, P.I.A. 2001. Slope length factor for applying the USLE-M to erosion in grid cells. Soil and Tillage Research. 58:11-17.

Lal,R. 1990. Soil Erosion in the Tropics: Principles and Management, New York: McGraw Hill.

Lee, S. 2004. Soil erosion assessment and its verification using the Universal Soil Loss Equation and Geographic Information System: a case study at Boun, Korea. Environmental Geology. 45:457-465.

Lulseged,T. and Vlek,G.L.P. 2008. Soil Erosion Studies in Northern Ethiopia. Springer Science+Business Media B.V.

Martz, L. and J. Garbrecht, 1998. The treatment of flat areas and depressions in automated drainage analysis of raster digital elevation models. Hydrological Processes. 12: 843 . 855.

Mati BM, Morgan RPC, Gichuki FN, Quinton JN, Brewer TR, Liniger HP. 2000. Assessment of erosion hazard with the USLE and GIS: A case study of the Upper Ewaso Ng'iro North basin of Kenya. International Journal of Applied Earth Observation and Geoinformation 2: 1–9.

Mellerowicz KT, RessHW, Chow TL, Ghanem I. 1994. Soil conservation planning at the watershed level using the Universal Soil Loss Equation with GIS and microcomputer technologies: A case study. Journal of Soil and Water Conservation 49: 194–200.

Millward, A. and J. Mersey. 1999. Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. Catena 38: 109-129.

Moore, I.D. and G.J. Burch. 1986a. Physical basis of the length-slope factor in the universal soil loss equation. Soil Science Society of America Journal. 50: 1294-1298.

Moore, I.D. and G.J. Burch. 1986b. Modeling erosion and deposition: topographic effects. Transactions of the ASAE.26.6: 1624-1630.

Moore, I. D., Turner, A. K., Wilson, J. P., Jenson, S. K. and Band, L. E. 1993. `GIS and land-surface-subsurface process modelling', in Goodchild, M. F., Parks, B. O. and Steyaert, L. T. (eds), Environmental modelling with GIS. pp. 213-230.

Morgan R.P.C. 1986. Soil Erosion and Conservation. Longman Scientific and Technical Group Ltd: Hongkong; 111–210.

Morgan, R.P.C. 1994. Soil Erosion and Conservation. Silsoe College, Cranfield University.

Morgan, R.P.C. 1995. Soil Erosion and Conservation. Addison-Wesley Longman, Edinburgh. Morgan RPC. 2005. Soil Erosion and Conservation (3rd edn). Blackwell Science: Oxford.

Natural Resources Conservation Service (NRCS), 1999c. National Soil Survey Handbook—Title 430-VI, http://www.statlab.iastate. edu/soils/nssh/.National Soil Erosion

Nearing, M.A. 1997. A single, continuous function for slope steepness influence on soil loss. Soil Sci. Soc. Am. J. 61:917-919.

Nyssen, J., M. Veyret-Picot, J. Poesen, J. Moeyersons, M. Haile, J. Deckers and G. Govers. 2004. The effectiveness of loose rock check dams for gully control in Tigray, northern Ethiopia.

Pimentel D, Allen J, Beers A, Guinand L, Hawkins A, Linder R, McLaughlin P, Meer B, Musonda D, Perdue D, Poisson S, Salazar R, Siebert S, Stoner K. 1993. Soil erosion and agricultural productivity. In World Soil Erosion and Conservation, Pimentel D (ed.). Cambridge University Press: Cambridge, UK; 277–292.

Renard K, Foster GR,Wessies GA, Porter JP. 1994. RUSLE-Revised universal soil loss equation. Journal of Soil and Water Conservation 46:30–33.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. and Yoder, D.C. 1996. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA, Washington, DC.

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., Yoder, D.C.1997. Predicting soil erosion by water—a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). United States Department of Agriculture, Agricultural Research Service (USDA-ARS) Handbook No. 703. United States Government Printing Office, Washington, DC.

Renschler, C.S. and J. Harbor, 2002. Soil erosion assessment tools from point to regional scales. the role of geomorphologists in land management research and implementation. Geomorphology. 47: 189-209.

Reusing,M., T. Schneider and U. Ammer. 2000. *Modelling Soil Loss rates In the Ethiopian Highlands by Integratation of High Resolution MOMS-02/D2-Streao-data in a GIS.* Int. Journal of Remote Sensing. **Vol.21** (9).

Rieger, W. 1998. A phenomenon-based approach to upslope contributing area and depressions in DEMs. Hydrological Processes. 12: 857-872.

Robert P. S. and Hilborn, D. 2000. Factsheet: Universal Soil Loss Equation (USLE).Index No-572/751,Queen,s printer for Ontario.

Sertu,S. 2000. Degraded Soil of Ethiopia and their management.Proceeding of FAO/ISCW expert consultation on management of degraded soils in Southern and East Africa. 2nd network meeting, 18-22 September 2000. Pretoria.

Shi, Z.H., Cai, C.F., Ding, S.W., Li, Z.X., Wang, T.W. and Sun, Z.C.2002. Assessment of

Erosion Risk with the Rusle and Gis in the Middle and Lower Reaches of Hanjiang River.

12th ISCO Conference, Huazhong Agricultural University, Wuhan, 430070, Beijing.

Soil and Water Conservation Society. 1994 Soil Erosion Research Methods. St. Lucie Press, Ankeny, IA.

Sonneveld, B.G.J.S., M.A. Keyzer and P.J.Albersen. 1999. A non-parametric Analysis of Qualitative and Quantitative Data for Erosion Modeling: A case Study for Ethiopia.

Stillhardt, B.,Herweg, K., Hurni, H. 2002. Long-term Monitoring of Soil Erosion and Soil and Water Conservation in Afdeyu, Eritrea (1984-1998),Centre for Development and Environment, Berne.

Taddese,G.2001. Land Degradation. A challenge to Ethiopia. Environmental Management,27,815-824.

Tamene,L.,Park,S.,Dikau,R.and Vlek,P.L.G.2006. Analysis of factors determining sedment yield variability in the highlands of Ethiopia. Geomorphology, 76, 76-91.

Tiffen, M., M. Mortimore and F. Gichuki. 1994. More people, less erosion: Environmental

recovery in Kenya. Wiley, Chichester, U.K.

Tripathi M. P. and Raghuwanshi N.S. 2003. Identification and prioritization of critical sub-

watersheds for soil conservation management using the SWAT model.

Biosystems Engineering 85: 365–379.

Wischmeier W.H. and Smith D. 1978. Predicting rainfall erosion losses: a guide to conservation planning. *USDA-ARS Agriculture Handbook* N° 537, Washington DC. 58 p.

WDLUD. 1995.Guidelines for Development Agents on Soil Conservation in Ethiopia, Switzerland. Global Agriculture. Springer Science+Business Media B.V.