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Soil Loss Estimation for Soil Conservation Planning using Geographic Information System in Guang Watershed, Blue Nile Basin

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Abstract
This research was carried out to spatially predict the soil loss rate of Guang watershed with a Geographic Information System (GIS) and Remote Sensing (RS). Revised Universal Soil Loss Equation (RUSLE) adapted to Ethiopian conditions was used to estimate potential soil losses by utilizing information on rainfall erosivity (R) using interpolation of rainfall data, soil erodibility (K) using soil map, vegetation cover (C) using satellite images, topography (LS) using Digital Elevation Model (DEM) and conservation practices (P) using satellite images. Based on the analysis, the mean and total annual soil loss potential of the study watershed was 24.95 tons ha^{-1} $year^{-1}$ and 8,732.5 tons ha^{-1} $year^{-1}$, respectively. About 147.9 ha (64%) of the watershed was categorized none to slight class which under soil loss tolerance (SLT) values ranging from 5 to 11 tons ha^{-1} $year^{-1}$ whereas moderate to high soil loss potential covered about 202.1 ha (36%) about several times the maximum tolerable soil loss (11 tons ha^{-1} $year^{-1}$). The study demonstrates that the RUSLE using GIS and RS provides great advantage to spatially analyze multi-layer of data. The predicted amount of soil loss and its spatial distribution could facilitate sustainable land use and management.
Keywords: soil erosion; RUSLE; GIS; Guang watershed; Ethiopia

1. INTRODUCTION

Agriculture is the mainstay of Ethiopia economy, which supports more than 85% of the country's population (FDREPCC, 2008). It accounts for the employment of 90 percent of its population, over 50% of the country's gross domestic product (GDP) and over 90% of foreign exchange earnings (ECACC, 2002). However, low productivity characterizes the country's agriculture. The low productivity of the agricultural sector has made it difficult to attain food self-sufficiency at a national level.

Land degradation in Ethiopia accounts for 8% of the global total (Tekalign M., 2008). The most serious problem concerning country's land resources, however, is the removal of fertile topsoil by water. This is much more severe in the highlands where, 85% of the human and 77% of livestock population are living and agriculture is intensive (Gete Z., 2000). As estimates from national level studies indicate, more than 2 million ha of Ethiopia's highlands have been degraded beyond rehabilitation, and an additional 14 million hectares severely degraded, which is reflected in cereal yield reduction averaging less than 1.2 tons per hectare in most of the highlands (FAO/WFP, 2005). In the Ethiopian highlands only, an annual soil loss reaches 200-300 tons ha^{-1} $year^{-1}$ (FAO, 1984; Hurni, 1993). It has been estimated that out of the estimated 60 million ha of agriculturally productive land, about 27 million ha are significantly eroded, 14 million ha are seriously eroded and 2 million ha have reached the point of no return, with an estimated total loss of 2 billion cubic meters of top soil per annum (Fikru, 1990). The average crop yield from a piece of land in Ethiopia is very low mainly due to soil fertility decline associated with removal of topsoil by erosion (Sertu, 2000).

Despite the severity of soil erosion and its consequences in the study watershed, there have been few studies carried out to quantify erosion rates. In addition, the soil loss estimated by different researchers could vary for the same environment. This implies that there is a need to have watershed specific information on soil erosion to support timely information for decision makers and land managers that plan the correct soil conservation planning. As different portions of the landscape vary in sensitivity to erosion through differences in their slope, soil and land use and cover attributes, it was necessary to estimate rates of soil loss and develop a soil loss intensity map of the study watershed using RUSLE within a GIS environment, identify severity areas and prioritize areas for specific soil conservation plans.

2. MATERIALS AND METHODS

2.1 Description of the Study Watershed

Guang watershed is located in North Gondar Zone of Amhara National Regional State at about 597 km northwestern of Addis Ababa, capital city of Ethiopia. The watershed lies within $11^0 35'59''$ to $13^0 49'12''$ latitude and $35^0 09'45''$ to $37^0 46'42''$ longitude (Figure 1) with the total area of 2,500 ha. Agro-ecologically, 51% and 49% of the watershed is found to be warm and hot zones, respectively. Rainfall in the watershed is ranging from 720 to 1253.2 mm. Temperature extends from 12.8 to $30.15^{0}{}_{C}$. Altitude is ranging from 511 to 3043 m.a.s.l. The watershed exhibited a slope range of flat to very steep slopes with many tributaries. Major soil units of the study watershed identified by DSA and SCI (2006) were Chromic Cambisols (30%), Chromic Vertisols (28%), Eutric Cambisols (18%), Eutric Nitisols (12%), Orthic Luvisols (6%), Dystric Cambisols (4%), Chromic Cambisols (1%) and Eutric Fluvisols (1%).

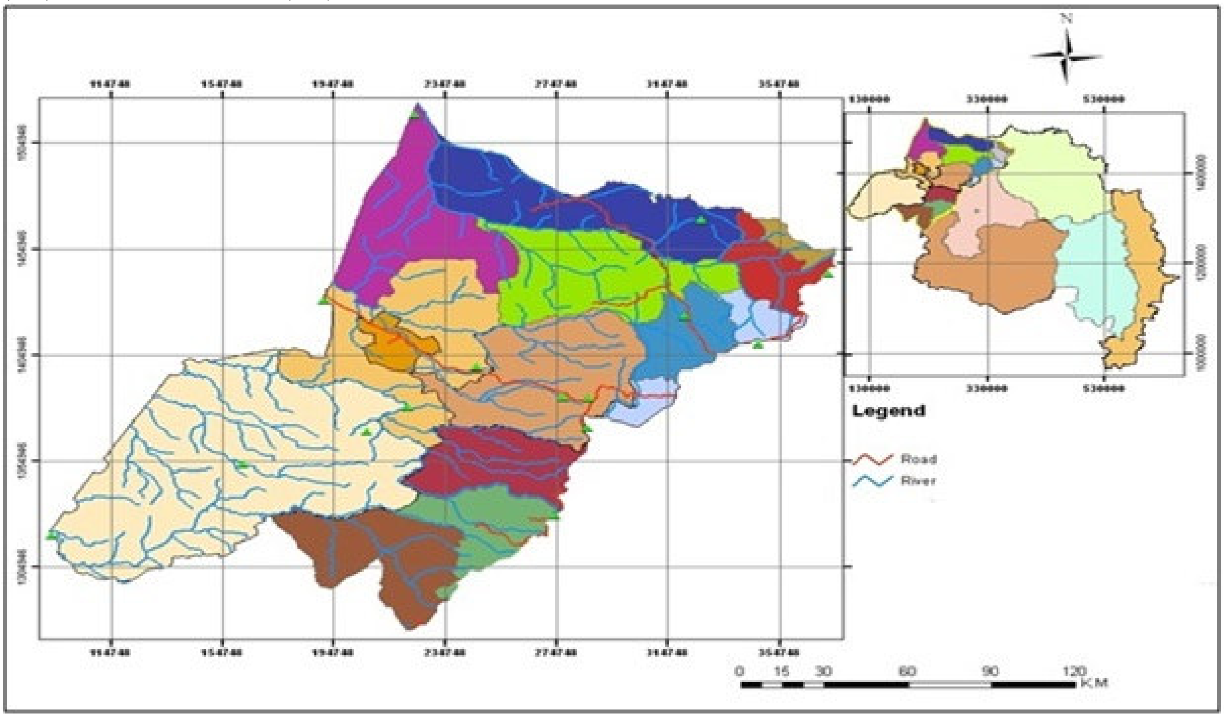

Figure 9: Location map of study watershed

2.2 Methods

2.2.1 Determination of Soil Loss factors

Rainfall Erosivity Factor

Seven rainfall stations randomly distributed within the study watershed were used in this study. The monthly amounts of precipitation for these stations were collected over 15 years by the Amhara Regional Meteorological Agency. Monthly rainfall records from these meteorological stations covering the period 1998-2012 were used to calculate the rainfall erosivity Factor (R-value).

Different empirical equations have been developed that estimate R-values from rainfall totals which are easily available (Hurni, 1985; Renard, Foster,Wessies and Porter, 1994). In this study, Hurni’s empirical equation (Hurni, 1985) that estimates R-value for the Ethiopian highlands from annual total rainfall was used and shown in equation 1. The mean annual rainfall was first interpolated to generate continuous rainfall data for each grid cell by “3D Analyst Tools Raster Kriging Interpolation” in ArcGIS environment. Then, the R-value corresponds to the mean annual rainfall of the watershed was found using the R-correlation established in Hurni (1985) to Ethiopia condition.

$R = -8.12 + 0.562P$…… ……………………………..…………………..………… Equation (1)

Where R is the rainfall erosivity factor and P is the mean annual rainfall (mm).

Soil Erodibility Factor

“Spatial Analyst Tool Extract by Mask” in GIS environment was used to obtain soil unit’s map of the study watershed from Amhara regional digital soil (DSA and SCI, 2006) map at 1:50,000 scales. The soil erodibility (K) factor for the watershed was estimated based on soil unit types referred from FAO (1989) soil database adapted to Ethiopia by Hurni (1985) and Hellden (1987). Finally, the resulting shape file was changed to raster with a cell size of 30x30 m. The raster map was then reclassified based on their erodibility value.

Slope Length and Slope Steepness

The 30 m spatial resolutions DEM (digital elevation model) was used to generate slope as shown Figure 2 by using “Spatial Analyst Tool Surface Slope” in ArcGIS 10.1 environment. The flow accumulation and slope steepness were computed from the DEM using ArcGIS. Flow Accumulation was derived from hydrologically corrected DEM after conducting FILL and Flow Direction processes by ArcHydro tools, GIS soft ware. Flow accumulation and slope maps were multiplied by using “Spatial Analyst Tool Map Algebra Raster Calculator” in Arc GIS to calculate and map the slope length (LS factor) as shown in equation (2) and defined by Wischmeier and Smith (1978).

LS = (Flow Accumulation*Cell size/22.13)$^{0.4}$ *(Sin slope/0.896)$^{1.3}$……………….………....Equation (2)

Where cell size represents the field slope length and 22.13 is the length of the research field plot.

Land Use/Cover Data and Crop Management Factor

A land-use and land-cover map of the study area was prepared from LANDSAT satellite image acquired on 2013 and supervised digital image classification technique was employed using ENVI 5.0 software. The image has 30*30 meter resolutions. In addition, ground truth data were used as a vital reference for supervised classification, accuracy assessment and validation of the result. In supervised image classifications technique, land use and land cover types were classified so as to use the classified images as inputs for generating crop management (C) factor and support practice (P) factor. Based on the land cover classification map, a corresponding C value obtained from Hurni (1985) was assigned in a GIS environment.

Erosion Management Practice Factor (P-value)

The P-factor was assessed using major land cover and slope interaction adopted by Wischmeier and Smith (1978) for Ethiopia condition. The data related to management practices of the study watershed were collected during the field work. Therefore, values for this factor were assigned considering local management practices and taken the weighed value for similar land use types.

2.2.2 Soil Loss Analysis

The overall methodology involved the use of the RUSLE in a GIS environment with factors obtained from meteorological stations, soil map, topographic map, Satellite Images and DEM as shown in equation 4, Figure 2. Individual GIS layers were built for each factor in the RUSLE and combined by cell-grid modeling procedures in ArcGIS to predict soil loss in a spatial domain (Eastman, 1999). Annual soil loss rate was determined by multiplying the respective RUSLE factor values interactively using "Spatial Analyst Tool Map Algebra Raster Calculator" in ArcGIS 10.1 environment as shown equation (3) adopted from the recommendations of Hurni (1985) and Gebreselassie (1996). Soil loss potential of the watershed was then categorized into different severity classes following FAO & UEP (1984) guide line.

A= LS* R* K* C* P ……………………………………………………………….…….. Equation (3)

Where A is the annual soil loss (metric tons ha^{-1} year^{-1}); R is the rainfall erosivity factor [MJ mm h^{-1} ha^{-1} year^{-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) and P is conservation practice factor (dimensionless). Selected GPS points were used for checking and validation of results. All the maps were geo-referenced with Universal Transverse Mercator (UTM) coordinate system.

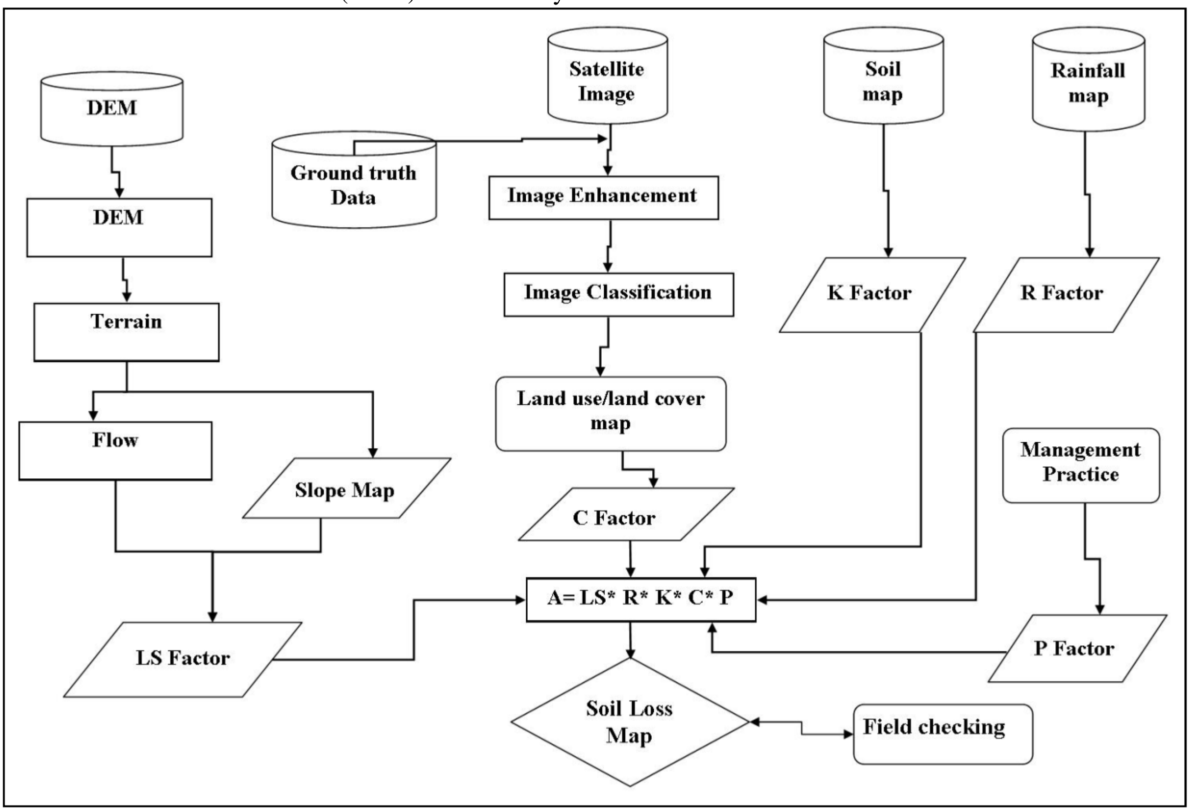

Figure 10: Flowchart showing the GIS based soil loss estimation

3. RESULTS AND DISCUSSION

3.1 Determination of Soil Loss Factors

3.1.1 Rainfall Erosivity 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). The average annual rainfall of the watershed is approximately 990.88 mm. As indicated in Figure 2, R-factor value in the watershed ranged 413.38 to 681.454 MJmm ha^{-1} $year^{-1}$.

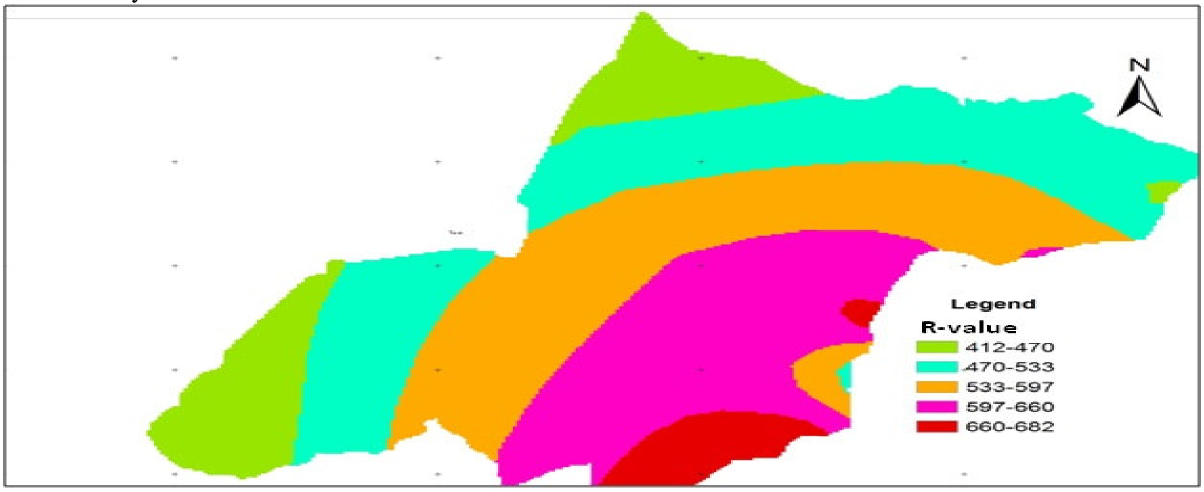

Figure 11: Map of erosivity (R) value

3.1.2 Soil Erodibility Factor

The soil erodibility factor (K) represents the effect of soil properties and soil profile characteristics on soil loss (Renard *et al*., 1997). Erodibility depends essentially on the amount of organic matter in the soil, the texture of the soil, the structure of the surface horizon and permeability (Robert & Hilborn, 2000). The results indicated that soil erodibility value in the study watershed ranged from 0.15 Mgh MJ^{-1} mm^{-1} to 0.20 Mgh MJ^{-1} mm^{-1} (Figure 4).

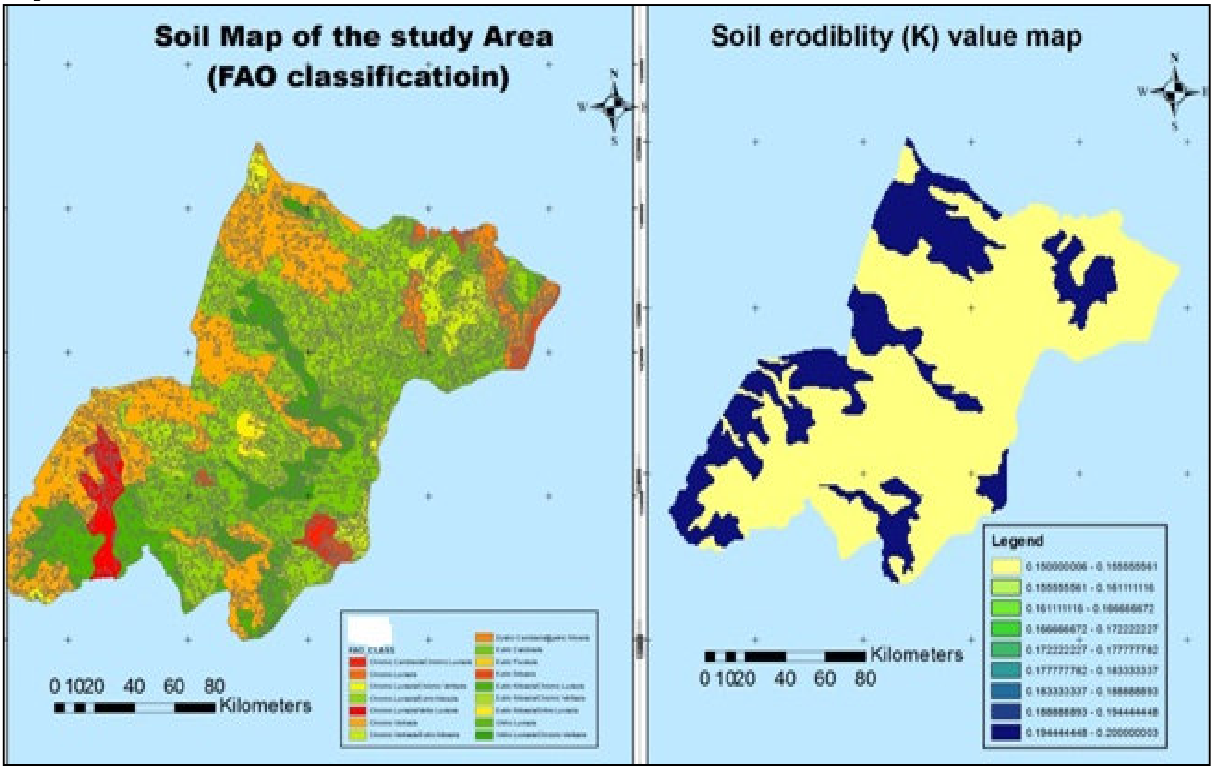

Figure 12: Soil units and their erodability factor map

3.1.3 Slope Length and Slope Steepness Factor

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, 1996).The upslope drainage area for each cell in a DEM was calculated with multiple flow algorithms. The LS-factor value in the study watershed varies from 0 to 4.22. The majority of the watershed has LS value less than 4.22 (Figure 5).

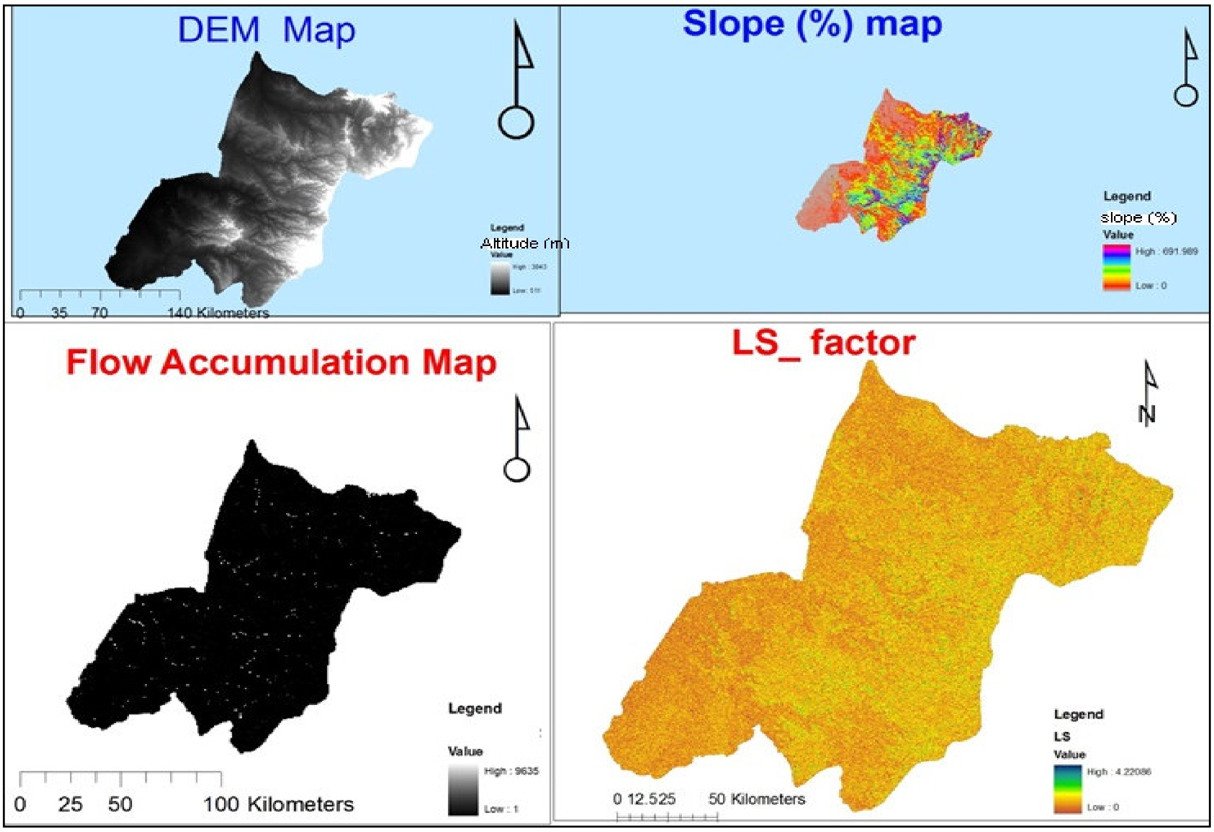

Figure 13: LS Factor map

3.1.4 Land Use and Land Cover and Crop Management Factor

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. It represents the ratio of soil loss under a given crop to that of the base soil (Morgan, 1994). It also reflects the effect of cropping and management practices on the soil erosion rate (Renard, Foster, Weesies, McCool and Yoder, 1997). As shown in Figure 6, six land-use and land-cover classes were recognized in the watershed, dominantly by woodland (40%) and crop cultivation (26%). These include built-up area, cultivated land, forest land, woodland, grass land and rockout crop. Crop management C factor values of the study watershed were ranging from 0.01 to 0.15 similar with the work of Morgan (2005).

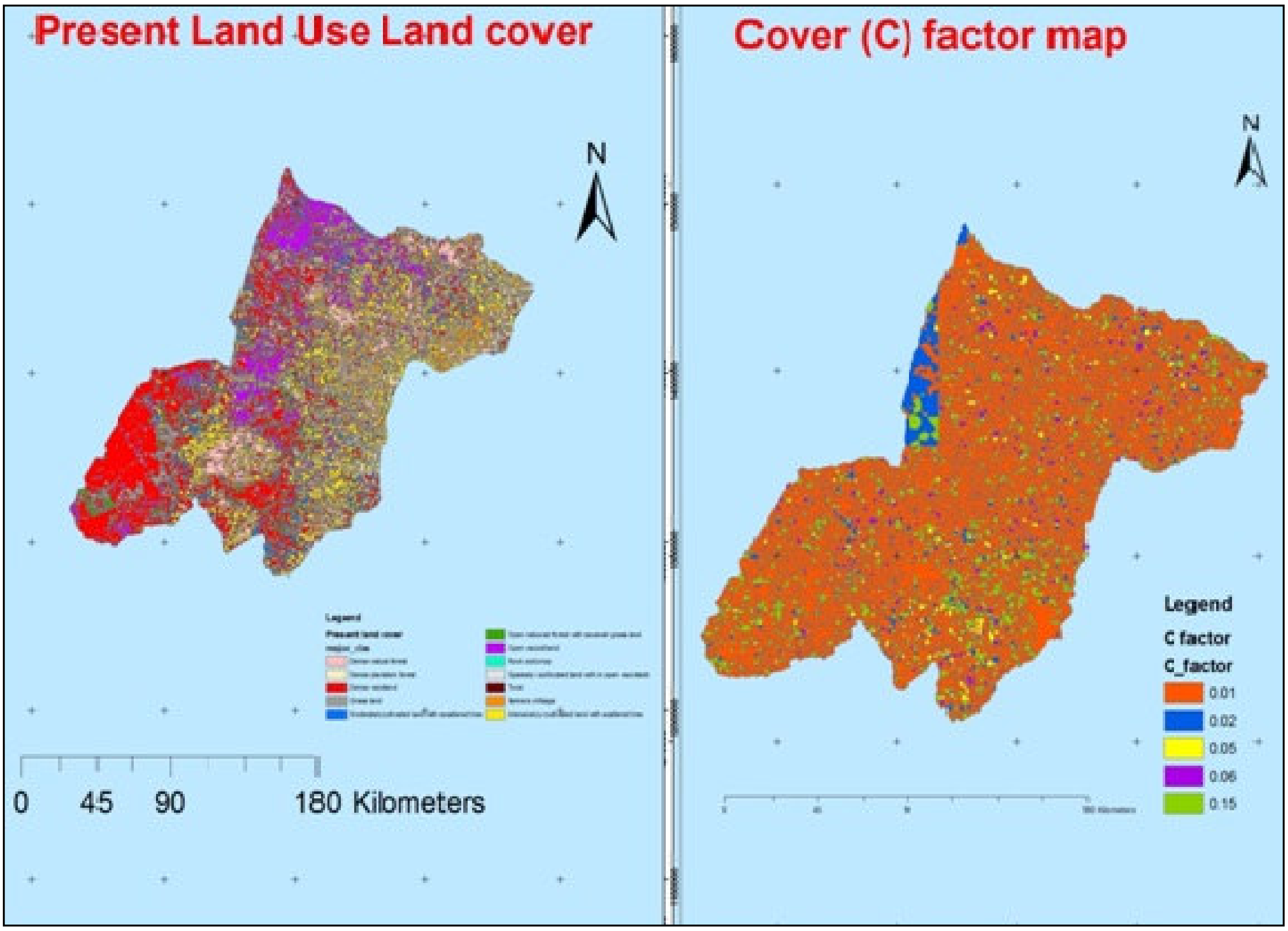

Figure 14: Crop management (C) factor values of the watershed

3.1.5 Management Practice Factor

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. 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); 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 were classified into six slope categories and assigned P-values while all non-agricultural lands are assigned a P-value of 1 (Figure 9). Results indicated that most of the watershed was covered by wood land and crop cultivation.

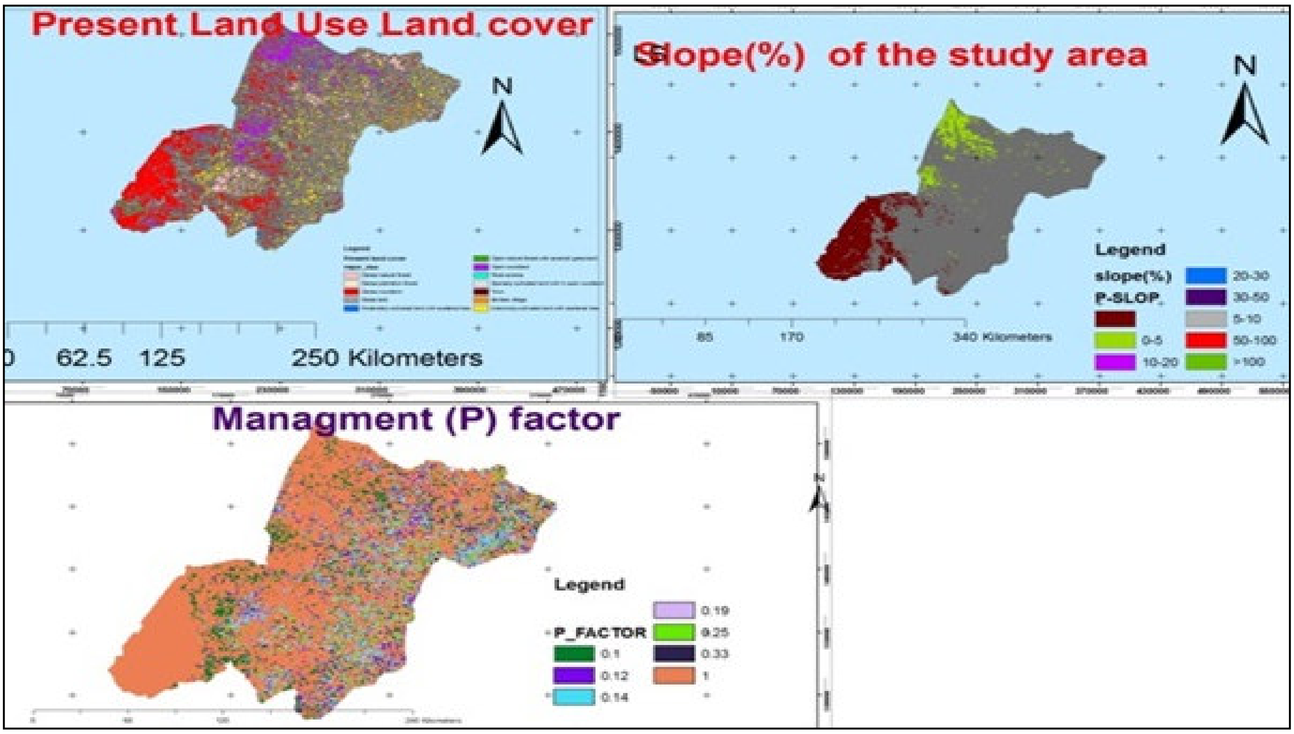

Figure 15: Derivation of management (P) factor

3.2 Soil Loss Estimation and Prioritization for Soil Conservation Planning

The Revised Universal Soil Loss Equation (RUSLE) has been used widely all over the world (Mellerowicz, Ress, Chow and Ghanem, 1994) including Ethiopia (Kaltenrieder, 2007; Bewket and Teferi, 2009) because of its simplicity and limited data requirement. 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).

Based on the analysis, the mean annual soil loss potential of the study watershed was 24.95 tons ha^{-1} $year^{-1}$. About 64% (147.9 ha) of the watershed was categorized none to slight class which under SLT values ranging from 5 to 11 tons ha^{-1} $year^{-1}$ (Renard, Foster, Weesies, McCool and Yoder, 1996). The remaining 36% (202.1 ha) of land was classified under moderate to high class about several times the maximum tolerable soil loss (11 tons ha^{-1} $year^{-1}$) (Table 1 and Figure 8). 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} $year^{-1}$. In the highlands of Ethiopia and Eritrea soil losses are extremely high with an estimated average of 20 metric tons ha^{-1} $year^{-1}$ (Hurni, 1985). The average annual soil loss estimated by USLE from the entire Guang watershed, northwestern Ethiopia was 24.95 tons ha^{-1} $year^{-1}$. Thus, the estimated soil loss rate was generally realistic as compared to results from previous studies.

Table 3: Soil loss class of the watershed

	Soil loss							
No.	Tons ha^{-1} $year^{-1}$	mm/yr	ha	%	Severity classes	Priority classes	ha	%
1	0-5	0-0.5	147	42	None to slight	4	147.9	64
2	5-15	0.5-1	80.5	23				
3	15-30	1-2.5	45.5	13	Moderate	3	14.7	21
4	30-50	2.5-4	24.5	7				
5	50-100	4-6.5	24.5	7	High	2	5.04	12
6	100-200	6.5-16.5	17.5	5				
7	200-300	16.5-25	7	2	Very high	1	0.315	3
8	>300	>25	3.5	1				

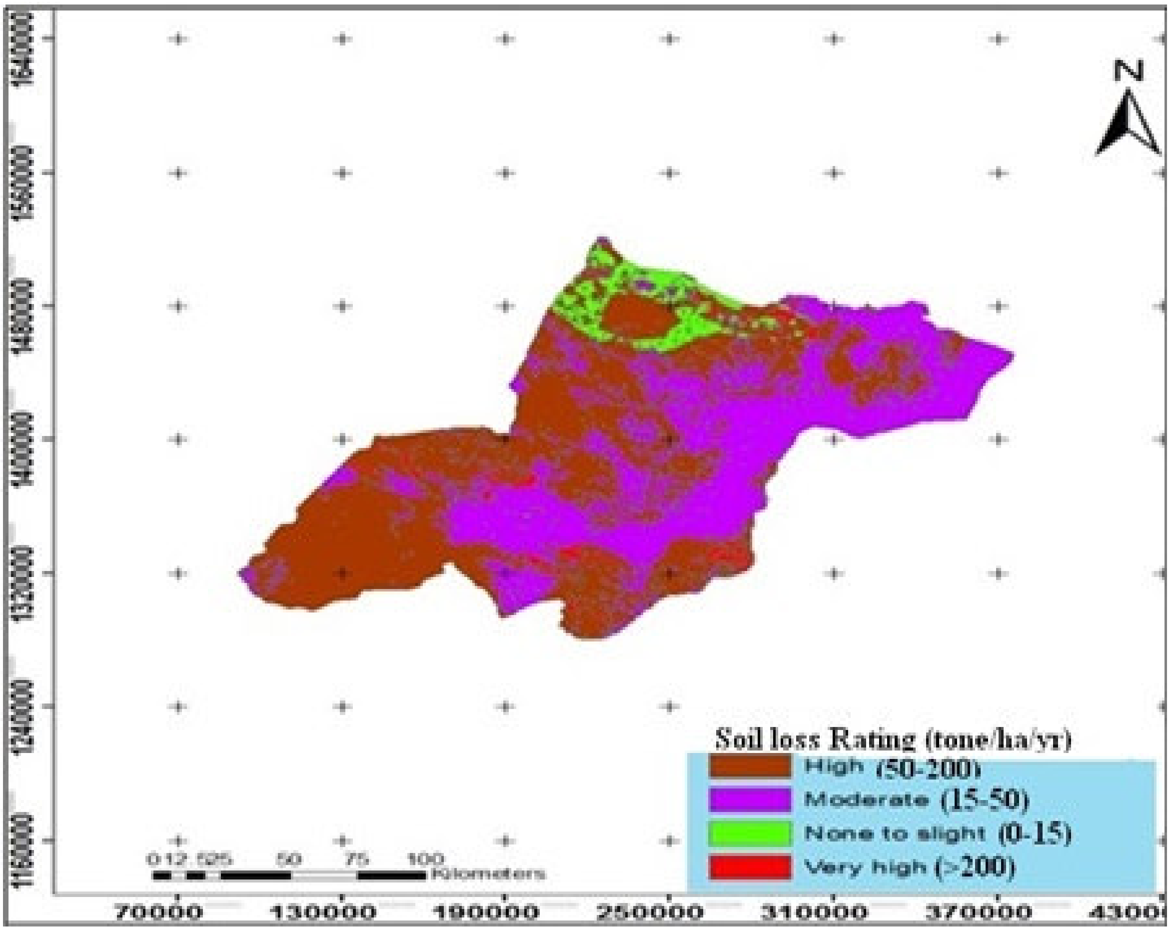

Figure 16: Soil loss severity map of the study watershed

4. CONCLUSIONS AND RECOMMENDATIONS

The study demonstrates that the RUSLE together with GIS and RS provides great advantage to analyze multi-layer of data spatially and estimates soil loss rate over large areas. The predicted amount of soil loss and its spatial distribution could facilitate sustainable land use and management for the watershed and the method can also be applied in similar watershed of the country. However, the accuracy of results obtained is largely a function of the accuracy of the different input data such as topography (LS factor), support practices (P factor) and cover parameters (C factor) which are location specific and need to be calibrated. Areas characterized by high to very high soil loss should be given special priority to reduce or control the rate of soil erosion by means of conservation planning.

6. REFERENCES

Bewket, W., and Teferi, E. (2009). Assessment of soil erosion hazard and prioritization for treatment at the watershed level: case study in the Chemoga watershed, Blue Nile basin, Ethiopia. Land degradation and development. Published online in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/ldr.944).

Desmet, P.J.J., and G., Govers. (1996). 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.

DSA (Development Studies Associates) and SCI (Shawel Consult International).(2006). *Potential Survey, Identification of Opportunities and Preparations of Projects Profiles and Feasibility Studies*. Addis Ababa, Ethiopia.

Eastman, J.R. (1999). Idrisi 32: User's Guide. Worcester, MA: Clark University.

Ethiopian Central Agricultural Census Commission (ECACC). (2002). Report on Preliminary Results of Area, Production and Yield of Temporary Crops (Meher Season Private Peasant Holding), Part II, on Ethiopian Agricultural Sample Enumeration, Addis Ababa, Ethiopia.

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

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

FAO. (1989). Reconnaissance Physical Land Evaluation in Ethiopia. Addis Ababa, Ethiopia.

FAO/WFP (Food and Agricultural Organization/ World Food Program). (2005). Report on the Cost-benefit Analysis and Impact Evaluation of Soil and Water Conservation and Forestry Measures in MERET Project. WFP, Addis Ababa, Ethiopia (Unpublished).176p.

Federal Democratic Republic of Ethiopia Population Census Commission (FDREPCC). (2008). Summary of statistical report of the 2007 population and housing census. Addis Ababa, Ethiopia

Fikru, A. (1990). The role of land use planning in the improvement of natural resources management: In National Conservation Strategy Conference. Vol. 3.

Gebreselasie, E.D. (1996). Soil erosion hazard assessment for land evaluation. Soil Conservation Research Program, University of Bern, Switzerland and the Ministry of Agriculture, Ethiopia. MSc Thesis, 1996:68-82.

Gete, Z. (2000). Landscape Dynamics and Soil Erosion Process Modeling in the Northwestern Ethiopian Highlands. African Studies Series A16. University of Berne Switzerland. Geographica Bernensia.

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

Hurni, H. (1985).Erosion-Productivity-Conservation Systems in Ethiopia. Proceedings 4th International Conference on Soil Conservation, Maracay, Venezuela, 654-674.

Hurni, H. (1993). Land degradation, famine, and land resource scenarios in Ethiopia. In: Pimentel D. (ed.) World soil erosion and conservation. Cambridge University. Press, 89-97.

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.

Mati, B.M., Morgan, R.P.C., Gichuki, F.N., Quinton, J.N, Brewer, T.R., and Liniger, H.P., (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, K.T., Ress, H.W., Chow, T.L., and 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.

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

Morgan, R.P.C. (2005). Soil Erosion and Conservation (3rd edn). Blackwell Science: Oxford.

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., and Yoder, D.C. (1997). Predicting soil erosion by water-a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE).

Renard, K., Foster, G.R., Wessies, G.A., and Porter, J.P. (1994). Revised Universal Soil Loss Equation (RUSLE). Journal of Soil and Water Conservation, 46, 30-33.

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.

Sutcliff, J.P. (1993). Economic assessment of land degradation in the Ethiopian highlands: A case study. National conservation strategy secretariat, Ministry of planning and economic development, Addis Ababa, Ethiopia.

Tamene, L. (2005).Reservoir siltation in the drylands of northern Ethiopia: causes, source areas and management options. PhD Thesis, Ecology and Development Series 30, Center for Development Research, University of Bonn. 84-138.

Tekalign, M. (2008). Opening Address to the 9th Annual Conference of the Ethiopian Society of Soil Science.

Wischmeier, W.H., and Smith, D.D. (1978). Predicting Rainfall Erosion Losses-A Guide to Conservation. Agricultural Handbook 537. US Department of Agriculture: Washington, DC.