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A GEOGRAPHIC INFORMATION SYSTEM BASED SOIL LOSS ESTIMATION IN LALEN WATERSHED FOR SOIL CONSERVATION PLANNING, HIGHLANDS OF ETHIOPIA

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ABSTRACT

This study was carried out to spatially predict the soil loss rate of Lalen 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, about 95% (2495.09 ha) of the watershed was categorized none to slight class which under soil loss tolerance (SLT) values ranging from 5 to 11 tons ha^{-1} $year^{-1}$. The remaining 5% (114.65 ha) of land was classified under moderate to high class about several times the maximum tolerable soil loss. The total and an average amount of soil loss estimated by RUSLE from the watershed was 8213.25 tons $year^{-1}$and 3.15 tons ha^{-} $year^{-1}$, respectively. 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: Ethiopia; GIS; Lalen watershed; RUSLE; soil erosion

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1. Introduction

Soil erosion is one of the biggest global environmental problems resulting in both on-site and off-site effects. It has most accelerated in developing countries due to different socio-economic and demographic factors. In the Ethiopian highlands, 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).

There have been few studies carried out to quantify erosion rates in Lalen watershed. In addition, the soil loss estimated by different researchers varied for the watershed. 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

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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

Lalen watershed is located in Amhara National Regional State (Dangla and Fagita Lokoma districts) at about 450 km northwestern of Addis Ababa, capital city of Ethiopia. The watershed lies within 1225597.83 to 1231286.92 meters North and 243544.85 to 253710.59 m East and altitude ranging from 1820 to 2415 m.a.s.l. (Figure 1) with the total area of 2610.3 ha. The average annual rainfall of the watershed is 1350 mm. Temperature extends from 36.65 to 36.75$^{0}{}_{C}$.

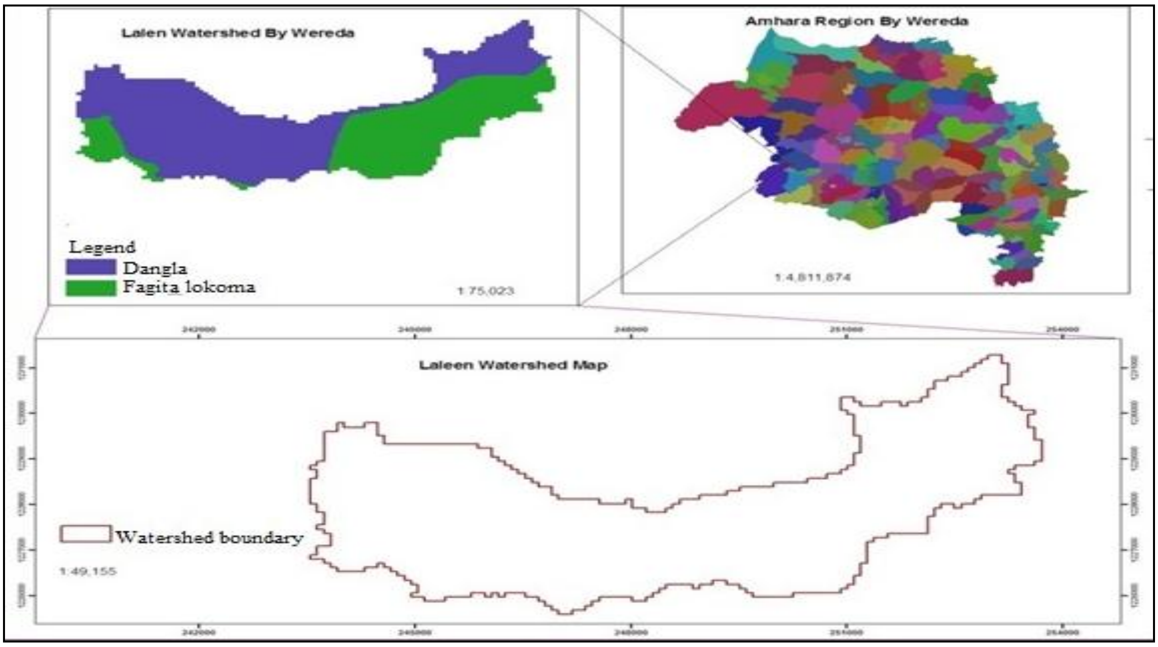

FIGURE 1: LOCATION MAP OF LALEN WATERSHED

2.2. Methods

The input thematic data included rainfall, soil units, slopes and land use/cover and determined as follow.

2.2.1 Rainfall Erosivity Factor

The monthly amounts of rainfall for the watershed 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). 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) from a spatial regression analysis (Hellden, 1987) for Ethiopian conditions to Ethiopia condition.

$$R = -8.12 + 0.562P \qquad \text{Equation (1)}$$

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

2.2.2 Soil Erodibility Factor

“Spatial Analyst Tool Extract by Mask” in GIS environment was used to obtain soil units map of the study watershed from Amhara Regional digital soil map at 1:50,000 scale developed by DSA and SCI (2006).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 as shown in Table 1.

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2.2.3 Slope Length and Slope Steepness

The 30 m spatial resolution DEM (digital elevation model) was used to generate slope as shown in 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 and slope maps were multiplied by using "Spatial Analyst Tool Map Algebra Raster Calculator" in Arc GIS 10.1 environment to calculate and map the slope length (LS factor) as shown in Equation (2) and Equation (3).

$$L = 0.799 + 0.0101*\text{Flow Accumulation} \quad \text{Equation (2)}$$

$$S = 0.344 + 0.0798*\text{Slope} \quad \text{Equation (3)}$$

Where, L and S stand for slope length and steepness factor

2.2.4 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 2014 and supervised digital image classification technique was employed using ENVI 5.0 software. A field checking effort also was made in order to collect ground truth information. The LAND SAT satellite image acquired on 2014 was used to classify the current land use and land cover map of the watershed. Digital image processing operations were carried out using ENVI 5.0 software. 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.

2.2.5 Erosion Management Practice Factor

The P-factor was assessed using major land cover and slope interaction adopted by Hurni (1985) for Ethiopia condition. The data related to management or support practices of the watershed were collected during the field work. Therefore, values for this factor were assigned considering local management practices and it was taken the weighed value for similar land use types. The corresponding P values were assigned to each land use/land cover classes and slope classes and the P factor map was produced.

2.2.6 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 and Figure 2. Annual soil loss rate was determined by a cell-by-cell analysis of the soil loss surface by superimposing and multiplying the respective RUSLE factor values (R, K, LS, C and P) interactively by using "Spatial Analyst Tool Map Algebra Raster Calculator" in ArcGIS 10.1 environment as shown equation (4) adopted from the recommendations of Hurni (1985) and Gebreselasie (1996). For the purpose of identifying priority areas for conservation planning, soil loss potential of the study area was first categorized into different severity classes following FAO's basis of classification (FAO & UEP, 1984).

$$A = LS * R * K * C * P \quad \text{Equation (4)}$$

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). Ground truth data selected across slope classes and collected by GPS were used for checking and validation of results (Figure 2 and 3).

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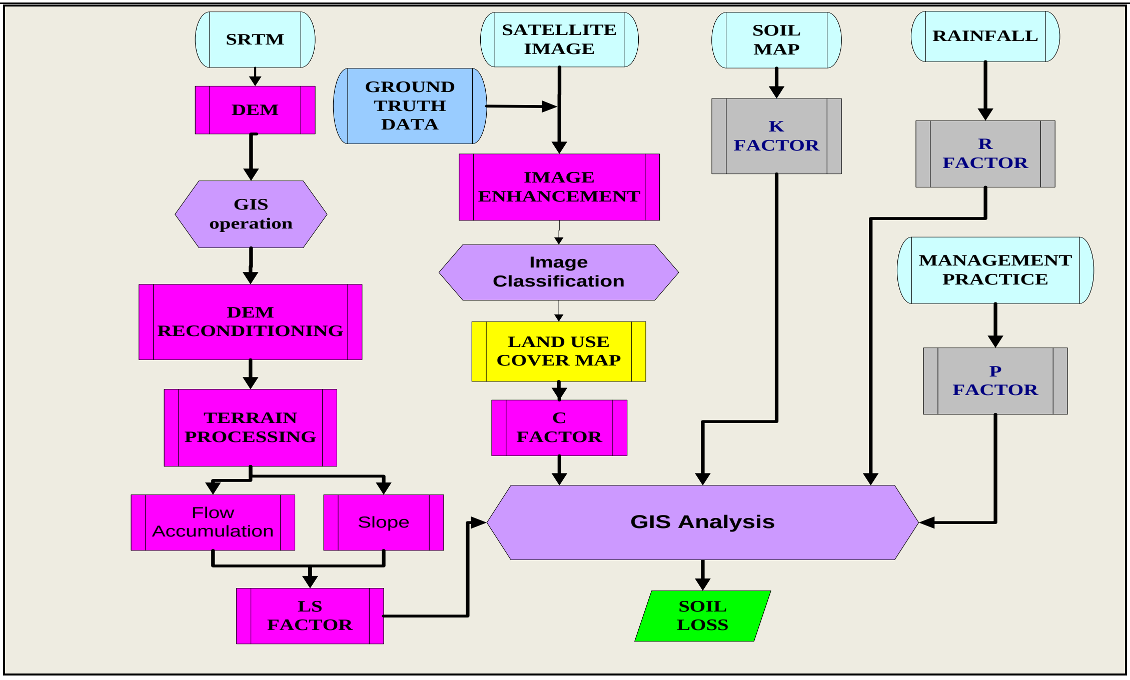

Figure 2: Procedures of RUSLE Implementation in GIS

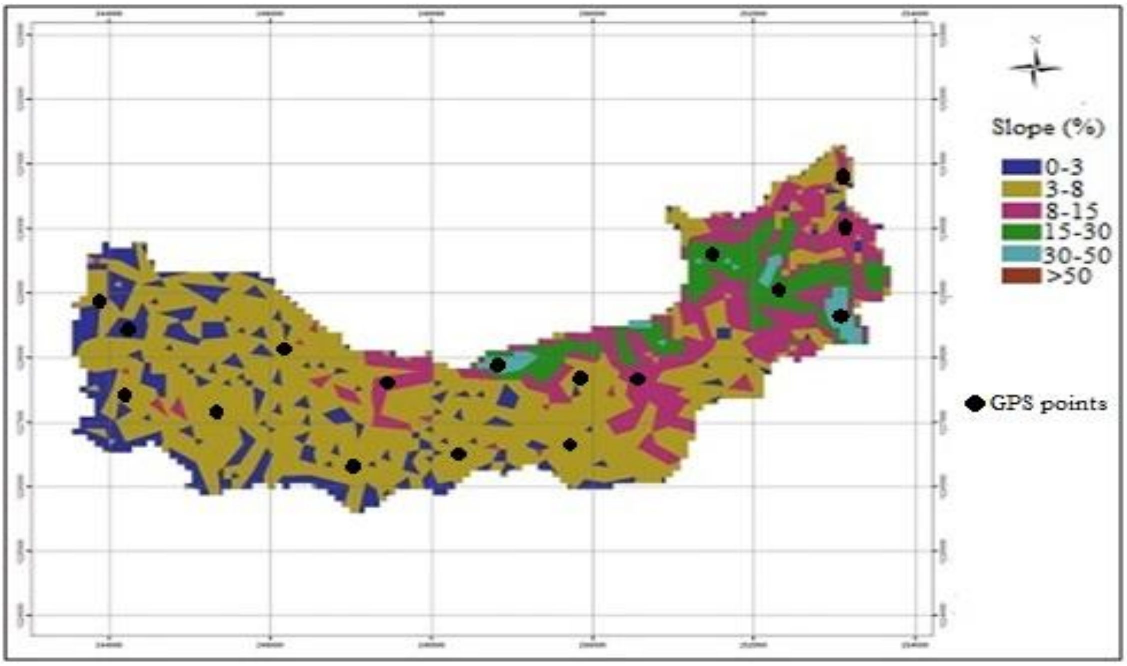

Figure 3: Slope map of Lalen watershed

3. Results and Discussion

3.1. 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 soil loss is closely related to rainfall partly through the detaching power of raindrop striking the soil surface and partly through the contribution of rain to runoff. The annual rainfall of the watershed is ranging 1350 mm. The result showed that the average R-factor value in the watershed was 750.58 MJmmha^{-1} year^{-1}with higher values occurring in the watershed.

3.2. Soil Erodibility Factor

"The erodibility of a soil is an expression of its inherent resistance to particle detachment and transport by

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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. 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 and Hilborn, 2000). The results indicated that soil erodibility value in the study watershed was 0.15 Mgh MJ^{-1} mm^{-1} (Table 1).

Table 1: Soil type and erodibility coverage

No	Soil Type	Erodibility (K Factor)	Area Coverage	
			Hectare (ha)	Percent (%)
1	Dystric Gleysols	0.15	198.40	7.60
2	Dystric Nitosols	0.15	1256.77	48.15
3	Eutric Nitosols	0.15	593.79	22.75
4	Orthic Luvisols	0.15	561.35	21.51
Total			2610.31	10

3.3. Slope Length and Slope Steepness

The L and S factors in RUSLE reflected the effect of topography on erosion. The slope ranged from 0% in the flat areas to 50.16% on the steep slopes of the watershed. The slope length and steepness factor were ranged from 0.8 to 31 m and 0.344 to 4.34 (Figure 4 and 5).

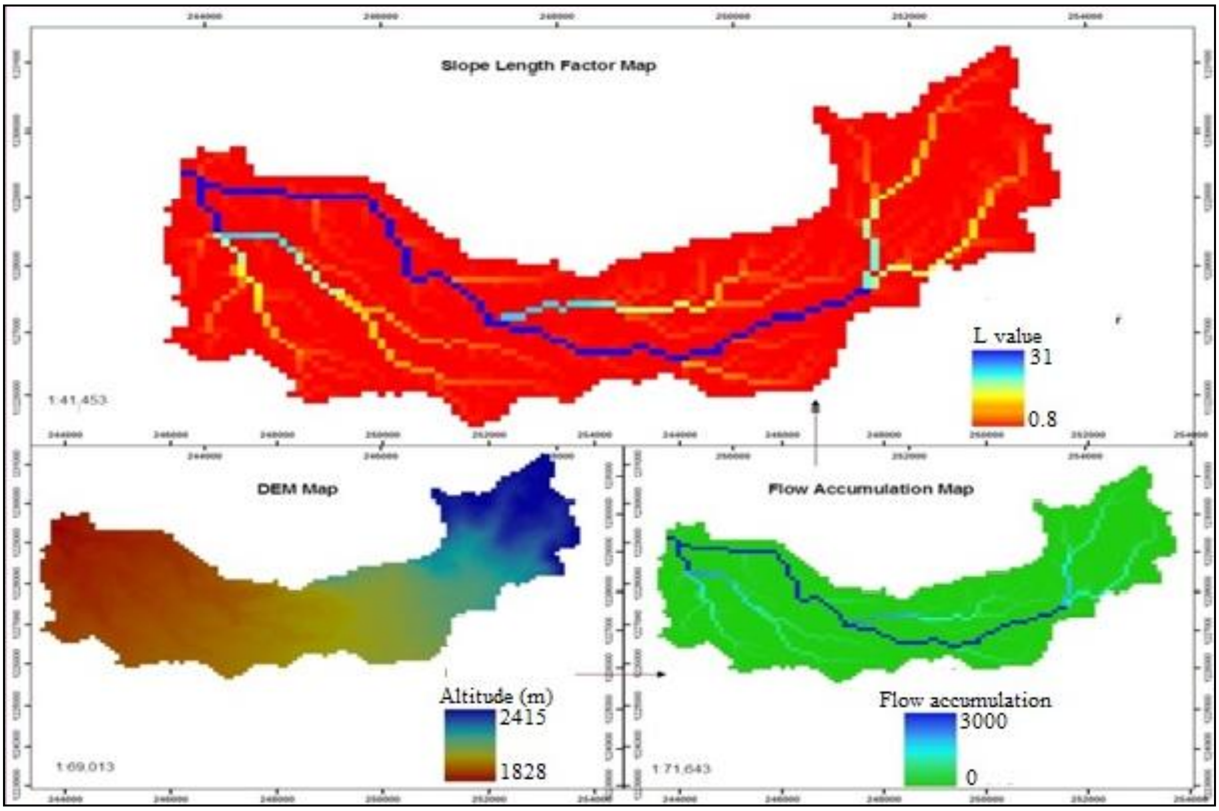

Figure 4: Derivation of slope length (L) factor from flow accumulation and slope data

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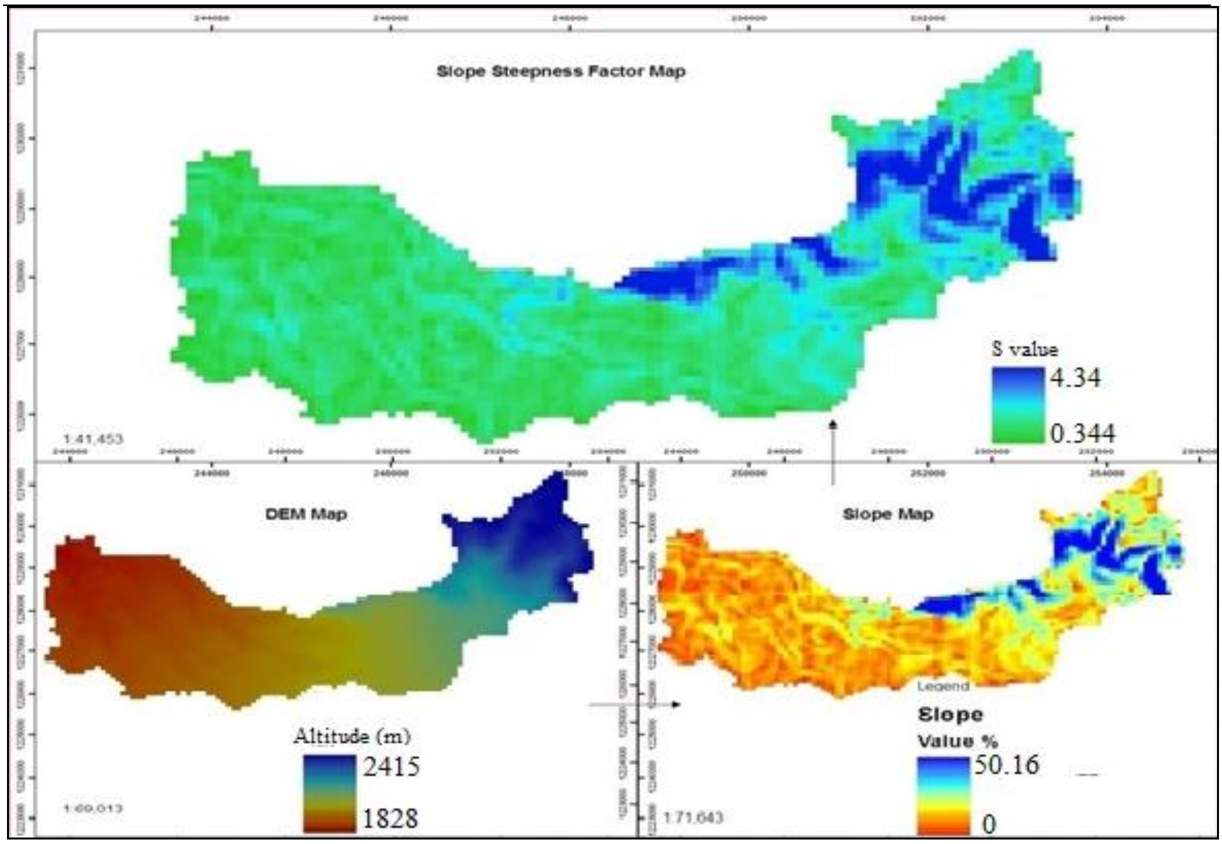

Figure 5: Derivation of steepness factor (S) from slope map

3.4. Land Use and Land Cover and Crop Management Factor

The cover management factor (C) represents the ratio of soil loss under a given crop to that of the base soil (Morgan, 1994). The C-value measures the combined effect of cropping and management practices in agricultural system and the effect of ground cover, tree canopy and grass covers in reducing soil loss in non-agricultural condition. It also reflects the effect of cropping and management practices on the soil erosion rate (Renard *et al*, 1997). The results indicated that six land-use and land-cover classes were recognized in the watershed, dominantly by cultivated land (90.57%) (Figure 6). Crop management C factor values of the study watershed were ranging from 0.01 to 0.20 similar with the work of Morgan (2005).

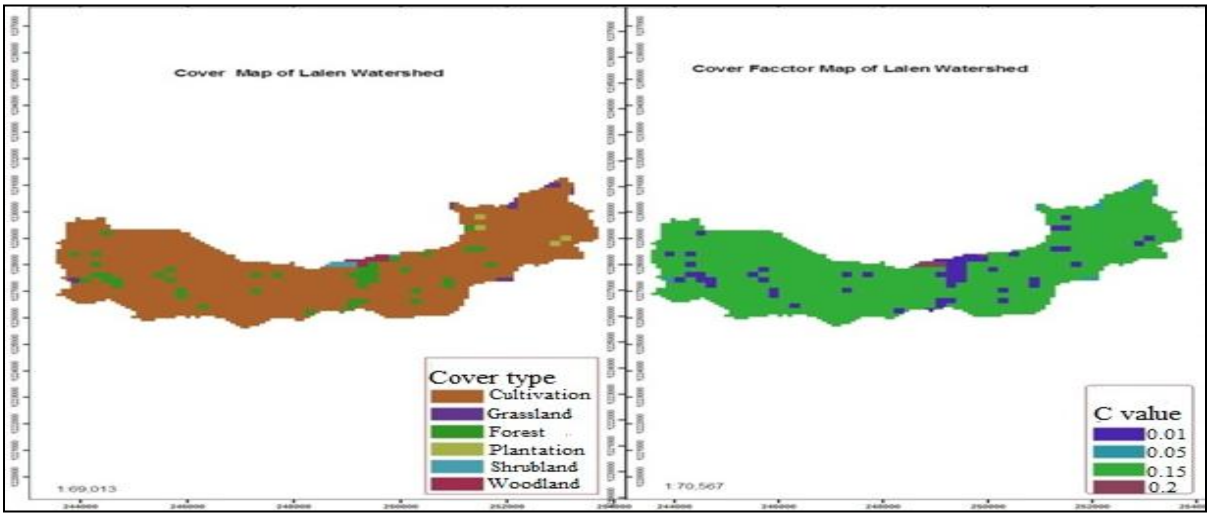

Figure 6: Derivation of cover factor from cover type

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3.5. Erosion Practice Factor 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. 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. As data were lacking on permanent management factors and there were no management practices, the P-values suggested in Bewket and Teferi (2009) were used. 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 (Figure 7).

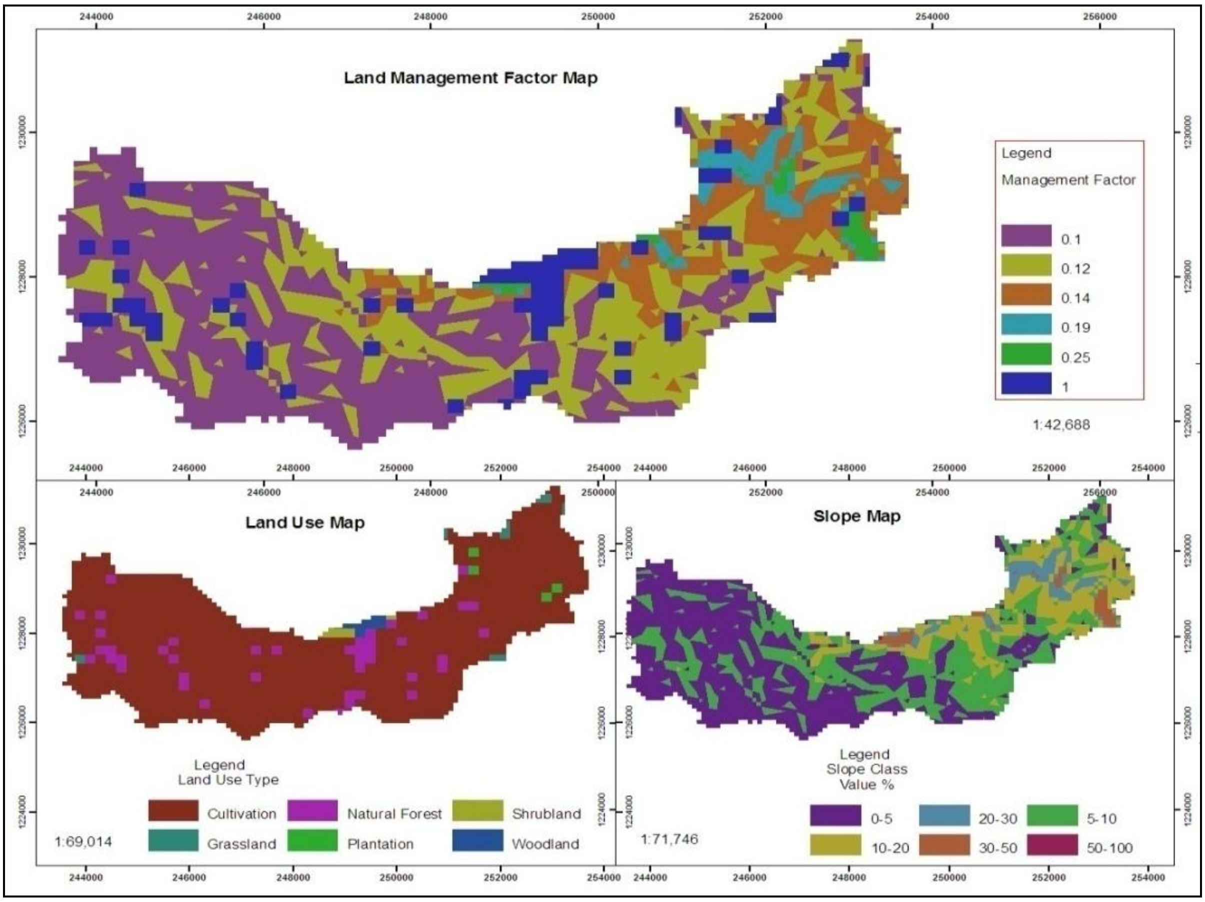

Figure 7: Derivative of management factor from land cover and slope

3.6. 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 *et al* (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 *et al*, 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).

Based on the analysis, 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 *et al,* 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 2 and Figure 8). The total and an average amount of soil loss estimated by RUSLE from the entire

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Lalen watershed, northwestern Ethiopia was 8213.25 tons $year^{-1}$ and 3.15 tons $ha^{-1}year^{-1}$, respectively. As compared to the soil loss estimated for Ethiopia as 42 tons ha-1 y-1 from cultivated fields by Hurni (1993) in Tigray region, northern Ethiopia, the soil loss estimated on this study in 2007/08 is by far the smallest. The results of the present study as compare to past findings indicate that the amount of soil loss from a given unit of land is low. This could be due to the contribution of the different soil conservation interventions implemented for at least the last decades in the country in general and the study watershed in particular. The implication is the contribution of the implemented soil water conservation measures in decreasing the rate of soil erosion is encourageable as compared to the results related to high soil loss estimated in the past studies. However, the present value indicates still a need for cost-effective conservation planning (Kaltenrieder, 2007; Bewket & Teferi, 2009) that decreases the amount of soil loss in the watershed.

Table 2: Soil loss summary of the watershed

Soil Loss Rating				Area Coverage		
Class	Tons $ha^{-1}year^{-1}$	mm $year^{-1}$	Descriptions	ha	%	Priority for Intervention
I	0-5	0-0.5	Non to slight	2280.02	87.35	6
II	5-15	0.5-1	Non to slight	215.07	8.24	5
Sub total				2495.09	95	
III	16-30	1-2.5	Moderate	73.77	2.83	4
IV	31-50	2.5-4	Moderate	27.83	1.08	3
V	51-100	4-6.5	High	10.44	0.40	2
VI	101-200	6.5-16.5	High	2.61	0.10	1
Sub total				114.65	5	

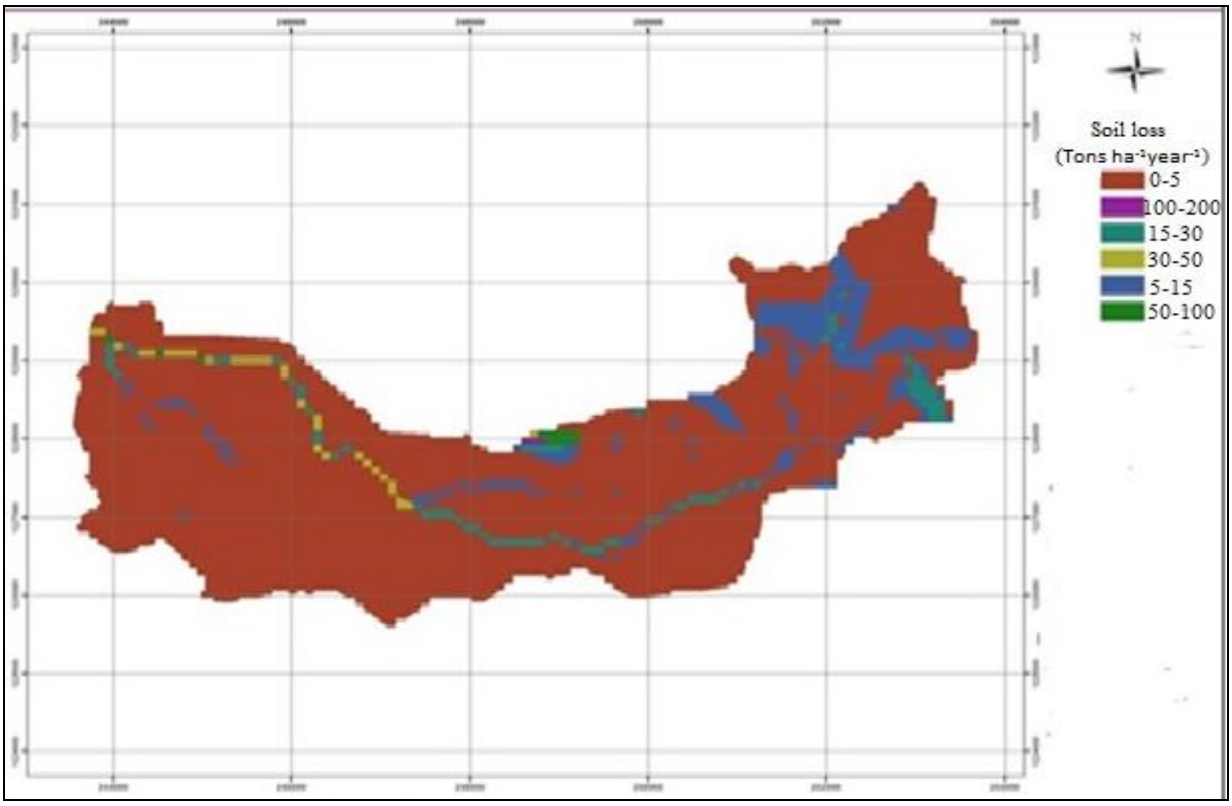

Figure 8 : Soil loss map of the watershed

4. CONCLUSIONS

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.

5. ACKNOWLEDGEMENTS

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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).

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.

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.

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.

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.

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.

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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).

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.