Application of GIS for Modeling Soil loss rate in Awash River Basin, Ethiopia

Atesmachew Bizuwerk (abizuwerk@cgiar.org)
Girma Taddese(g.taddesse@cgiar.org)
Yasin Getahun (yagetahun@cgiar.org)
International Livestock Research Institute (ILRI), P.o.Box 5689. Addis Ababa, Ethiopia.

Abstract

Soil erosion is one of the major factors affecting sustainability of agricultural production. In most developing countries, like Ethiopia, anthropological or accelerated erosion, which is mainly favored by human activities, is the major trigger factor for the loss of soil and water resources. To facilitate the urgent policy intervention that targeted soil degradation, study the amount of soil loss is inevitable. In this paper, a GIS simulating model using a universal soil loss equation (USLE) was applied to analyze the amount of soil loss in Awash basin of Ethiopia. The result of the analysis depicted that the amount of soil loss in the Awash basin ranges from 0 to 330414.5 t/ha/year. Moreover the total soil movement in the basin was 37684000 ton per year from 11.2 million hectare.

Key words: USLE, Soil erosion, GIS, Awash basin.

Introduction

The major factor affecting the sustainability of agricultural production is land degradation. Soil erosion is the major threat, among others, to the conservation of the soil and water resources. Even though soil erosion can be caused by geomorphological processes, anthropological or accelerated erosion, which is mainly favored by human activities, is the major trigger factor for the loss of soil and water resources. Soil erosion has accelerated on most of the world, especially in developing countries, due to different socio-economic, demographic factors and limited resources (Bayramin et.al, 2002). For instance, Reusing et.al (2000) mentioned that increasing population, deforestation, land cultivation, uncontrolled grazing and higher demand for fire often cause soil erosion.

The impact of soil erosion can be worst in the developing countries where farmers are highly dependent on intrinsic land proprieties and unable to improve soil fertility through application of purchased inputs. In Ethiopian highlands only, an annual soil loss reaches to 200 - 300 ton per hectare, while the soil loss movement can reach to 23400 million ton per year (FAO, 1984; Hurni, 1993). These highlands account 43 % of the countries and dominated by high soil fertility that covers 95 percent of the cultivated land. The impact of this loss of fertile soil in Ethiopia is multifaceted. It is still affecting 50 percent of the agricultural area and 88 percent of the total population of the country (Sonneveld et.al, 1999). Hence there is an urgent need for policy interventions and soil conservation practices to alleviate soil degradation in these areas. Even if it is unlikely to measure and experiment with soil erosion measures at every degraded areas in the country, spatial soil erosion model provides a vital tools in the design of these interventions.

The early and widely accepted soil erosion models consist of relatively simple responses function that was calibrated to fit limited numbers of statistical observations (eg. USLE, SLEMA). The current trend is towards replacing these by far more elaborated process based models (Sonneveld, et.al, 1999). Among these models, WEPP (water prediction program) of the USDA, EPIC (the erosion productivity impact calculator), CREAMS (chemical, runoff and erosion from agricultural management systems), and EUROSEM (European soil erosion model) can be listed as an example. However, Sonneveld et.al (1999) urges that in case of Ethiopia and many other developing countries the application of these process-based models is not practically applicable due to their large data requirement. In contradiction with it, the issue and the impact of soil erosion in Ethiopia is still extremely severe, an assessment on the basic soil erosion model that best fit with the available resource is imperative.

Simulation models are the most effect way to predict soil erosion processes and their effect by using GIS (Geographic Information System) and RS (Remote Sensing) (Bayramin, et.al, 2002). GIS and RS analysis could help analyze soil erosion in speedy and accurate way. The objective of this study is, therefore, to apply GIS method for analyzing spatial soil erosion using USLE and to predict the amount of soil loss at Awash River basin.

Material and Method

Study Area

The study area is located in eastern part of Ethiopia with a location of 7^0 53’ - 12^0 4’ N and $38^0$2’ - $43^0$16 E. The Awash basin comprised about 11 million ha in size and consists of various topographical features (flat to mountainous). Elevation ranges from 210 to 4195 meter above sea level (m.a.s.l). The average mean annual rainfall of the area ranges from 135-1372mm. The basin also comprised with different soil types dominated by Leptosol. Agro-climatically the basin is dominated by ‘dry kola’.

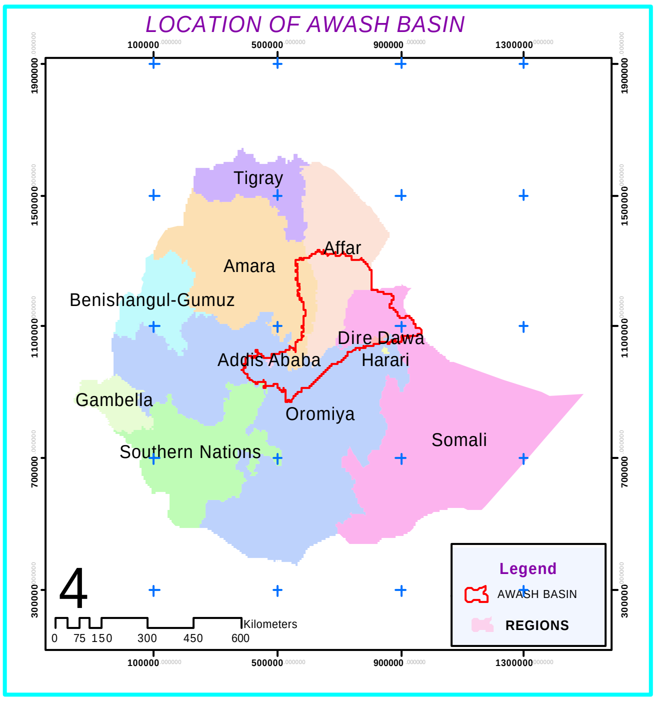

Figure1. Location of the Study area

Data Sources

Different data source were refereed to analyze the soil loss in the study area. A digital elevation model (DEM) with 90-meter resolution developed by NASA was implemented for analyzing the slope length and slope gradient of the study area. The land cover classification map, which was developed by WBISPP, was used for the analysis of crop management factor (C-value). A

Soil map made by FAO was also used for analyzing the soil erodability factor (K-value). Analysis of soil erosivity factor (R-value) was derived from Annual rainfall data from World Climate.

Method

The universal soil loss equation was employed to assess the amount of soil loss existed in the Awash basin. The universal soil loss equation is an empirical model developed by Wischmeir and Smith (1978) to estimate soil erosion from fields. Mathematically the equation is denoted as:

$$\mathbf{A} \text{ (tons/ha/year)} = \mathbf{R * K * L * S * C * P}$$

Where A is the mean annual soil loss, R is the rainfall erosivity factor, K is the soil erodability factor, L is the slope length factor, S is the slope steepness factor, C is the crop management factor and P is the erosion control practice or land management factor. The USLE was applied in GIS based on the flow chart as shown in figure 2.

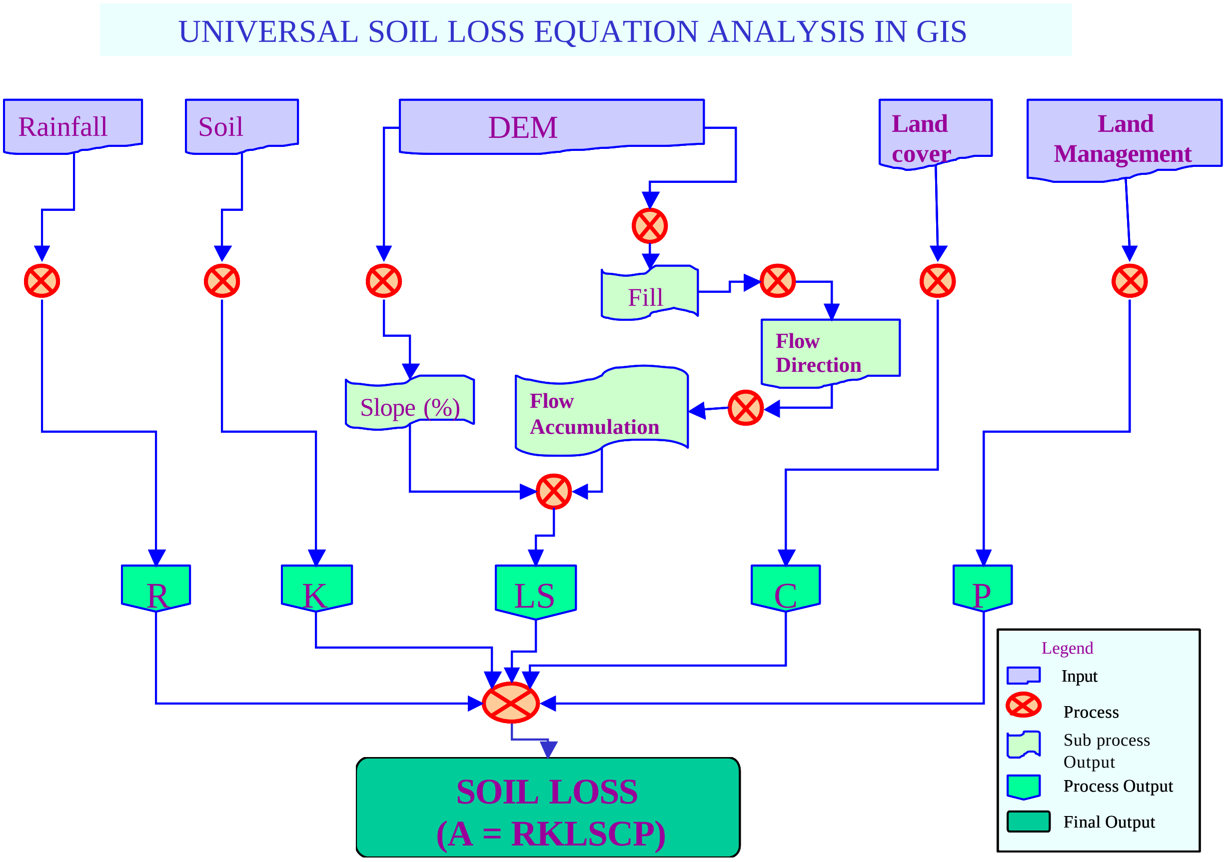

Figure 2. Flow chart showing analysis of soil loss based on GIS application

In this paper the analysis of each process factors was derived as follow:

1. Rainfall Erosivity Factor (R)

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 (Morgan, 1994).

The most suitable expression of the erosivity of rainfall is an index based on kinetic energy of the rain. There are different ways of analyzing the R factor. For instance,

(i) $R = 9.28 * P - 8838$. Mean annual erosivity ($KE > 25$) where P is mean annual precipitation [Morgan (1974) cited in Morgan (1994)]

(ii) $R = 0.276 * P * I_{30}$. Mean annual EI_{30}, where P is mean annual precipitation [Foster et.al (1981) cited in Morgan (1994)]

(iii) $R = 0.5 * P$ (in US unit) and $R = 0.5 * P * 1.73$ (in Metric unit). [Roose (1975) cited in Morgan (1994)]

These formulas have been applied in different parts of the world. The first equation appears to work well for Peninsular Malaysia, where as the application for other countries is less satisfactory. Especially with the annual rainfall below 900mm, like part of the study area, the equation yields estimates of erosivity, which are obviously meaning less (Morgan, 1994). In line with this, the second equation needs the value of I_{30} for calculating of erosivity factor, which is difficult to get in context of the study area. Therefore, in this study, we preferred to use the third equation for the determination of R-value. Hence each grid cells of mean annual rainfall were calculated based on third equation to get the R-value using GIS software, ArcGIS 9 (Fig.3).

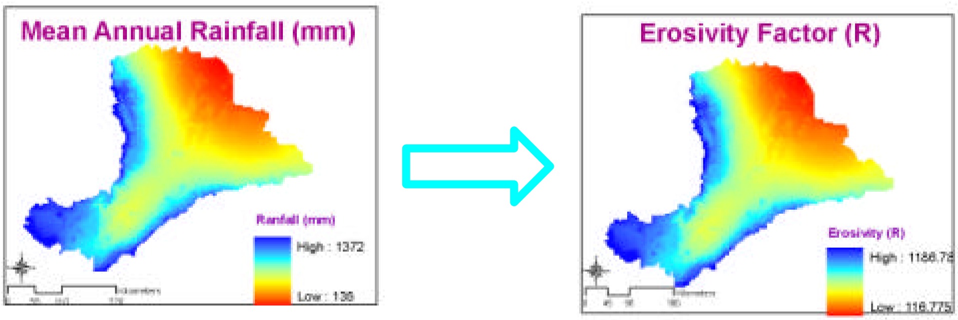

Figure 3. Derivation of Erosivity factor (R)

2. Soil Erodability Factor (K)

Soil Erodability Factor (K) defines as mean annual rainfall soil loss per unit of R for a standard condition of bare soil, recently tilled up-and-down with slope with no conservation practices and on a slope of 5^0 and 22 m length (Morgan, 1994). The value of K ranges from 0 to 1. Hellden (1987) developed a USLE for Ethiopian condition by adapting different sources and proposed the K values of the soil based on their color (see table1).

Table 1. Soil Erodability factor (Hellden, 1987)

Soil color	Black	Brown	Red	Yellow
K factor	0.15	0.2	0.25	0.3

However, the soil data of the study area were in their geomorphological names not in their color. An attempt was made to classify the soil types of the study area based on their color by referring the FAO soil database. Besides Hellden (1987) soil color classification, in the study area, two additional soil colors, white and gray, were found. Thus a value of 0.40 and 0.35 were given to these soil types respectively. Accordingly the K value of the study area was consists of six different soil color types as shown in table 2.

Table 2. Soil Erodability factor (Modified from Hellden, 1987)

Soil color	Black	Brown	Red	Yellow	Grey	White
K factor	0.15	0.2	0.25	0.3	0.35	0.40

Moreover, the basic soil data set was found in vector format. After changing the vector format in to grid, the grid data set was reclassified based on K-value of for each soil class in ArcGIS 9 (see fig 4).

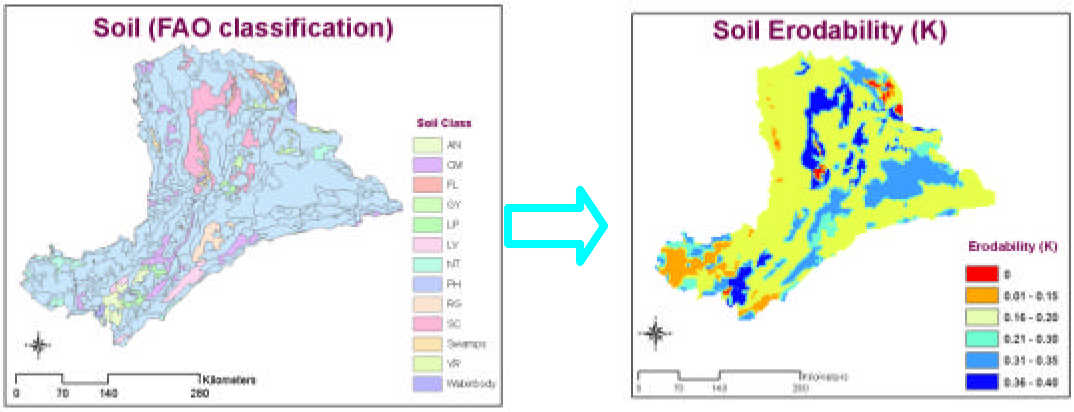

Figure 4. Derivation of Soil Erodability factor

3. Slope length and Slope steepness (LS)

The slope length and slope steepness can be used in a single index, which expresses the ratio of soil loss as defined by (Wischmeier and Smith 1978)

$$LS = (X/22.1)^{m} (0.065 + 0.045 S + 0.0065 S^{2})$$

Where X = slope length (m) and S = slope gradient (%)

The values of X and S were derived from DEM. To calculate the X value, Flow Accumulation was derived from the DEM after conducting FILL and Flow Direction processes in ArcGIS 9.

$$X = (\text{Flow accumulation} * \text{Cell value})$$

By substituting X value, LS equation will be:

$$LS = (\text{Flow accumulation} * \text{Cell value} /22.1)^{m} (0.065 + 0.045 s + 0.0065 s^{2})$$

Moreover slope (%) also directly derived from the DEM using the same software. The value of m varies from 0.2 –0.5 depending of the slope as shown in table 3 (Wischmeier and Smith 1978). The result of the analysis is shown in figure 5.

Table 3. m-value

m-value	Slope (%)
0.5	> 5
0.4	3-5
0.3	1-3
0.2	<1

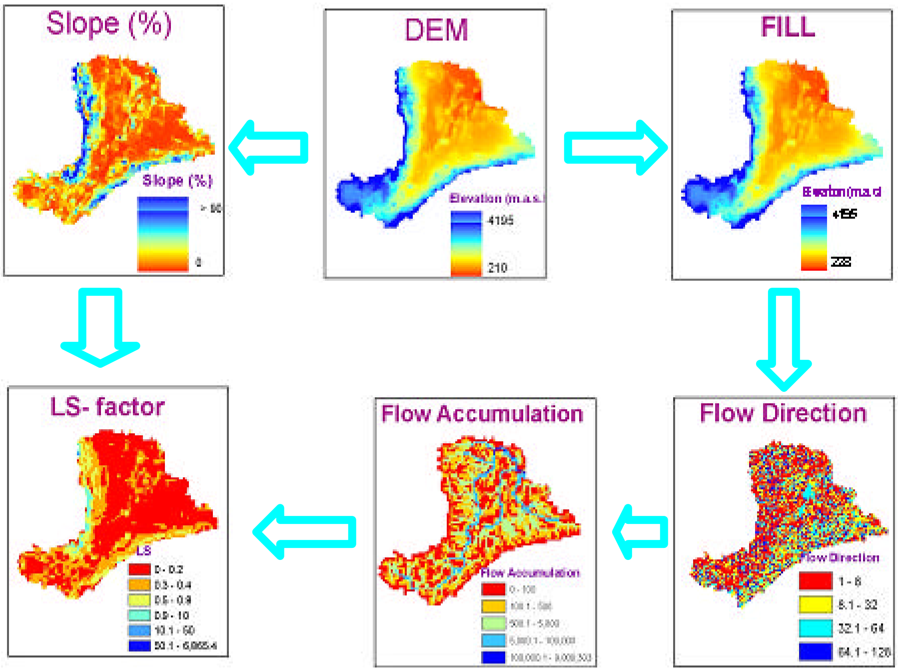

Figure 5. Derivation of slope gradient and slope length (LS)

4. Crop Management factor (C)

The crop management factor represents the ratio of soil loss under a given crop to that of the base soil (Morgan, 1994). The land use map (Fig 6) was used for analyzing the c-value. After changing the coverage to grid, a corresponding C-value was assigned to each land use classes using Reclass method in ArcINFO 9 as given by (Wischmeier and Smith 1978).

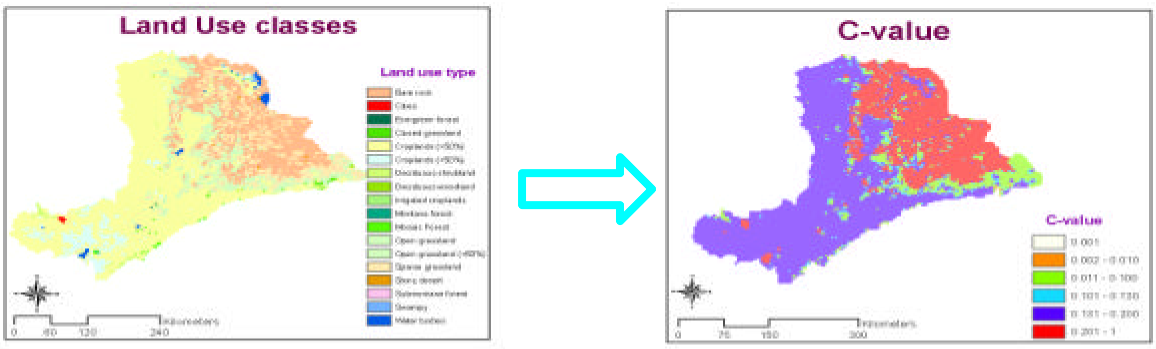

Figure 6. Derivation of Crop management factor (C-value)

5. Erosion Management Practice Factor (P-value)

The erosion management practice, P value, is also one factor that governs the soil erosion rate. The P-value ranges from 0-1 depending on the soil management activities employed in the specific plot of land. These management activities are highly depends on the slope of the area. Wischmeier and Smith (1978) calculated the P-value by delineating the land in to two major land uses, agricultural land and other land. The agricultural land sub-divided in to six classes based on the slope percent to assign different P-value (see table 4). In this study, we employed this same technique to assign the P-value of the basin (Fig 7).

Table 4. P-value (Wischmeier and Smith (1978)

Land use type	Slope (%)	P-factor
Agricultural land	0-5	0.1
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
Other Land	All	1.00

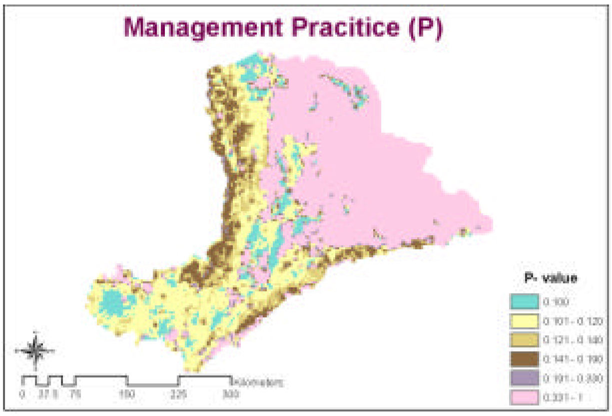

Figure 7. Derivation of P-value

Result and Discussion

Based on the analysis, the amount of soil loss in the Awash basin is about 37684000 ton per year from 11.2 million hectare. As shown in the figure 8, the amount of soil loss of each parcel of land in the basin ranges from 0 to 330414.5 t/ha/year. The mean annual soil loss of the Awash basin is 28.84 t/ha/year. The result of study falls within the ranges of the findings of FAO (1984). According to the estimate of FAO (1984), the annual soil loss of the highlands of Ethiopia ranges from 1248 – 23400 million ton per year from 78 million of hectare of pasture, ranges and cultivated fields through out Ethiopia.

The spatial locations of the high spot area for soil erosion in the study revealed that the potential soil loss is typically greater along the steeper slope banks of tributaries. Other high soil erosion areas are dispersed through out the basin and are typically associated with high erosion potential land uses. The plain area of the basin shows the least vulnerable to soil erosion.

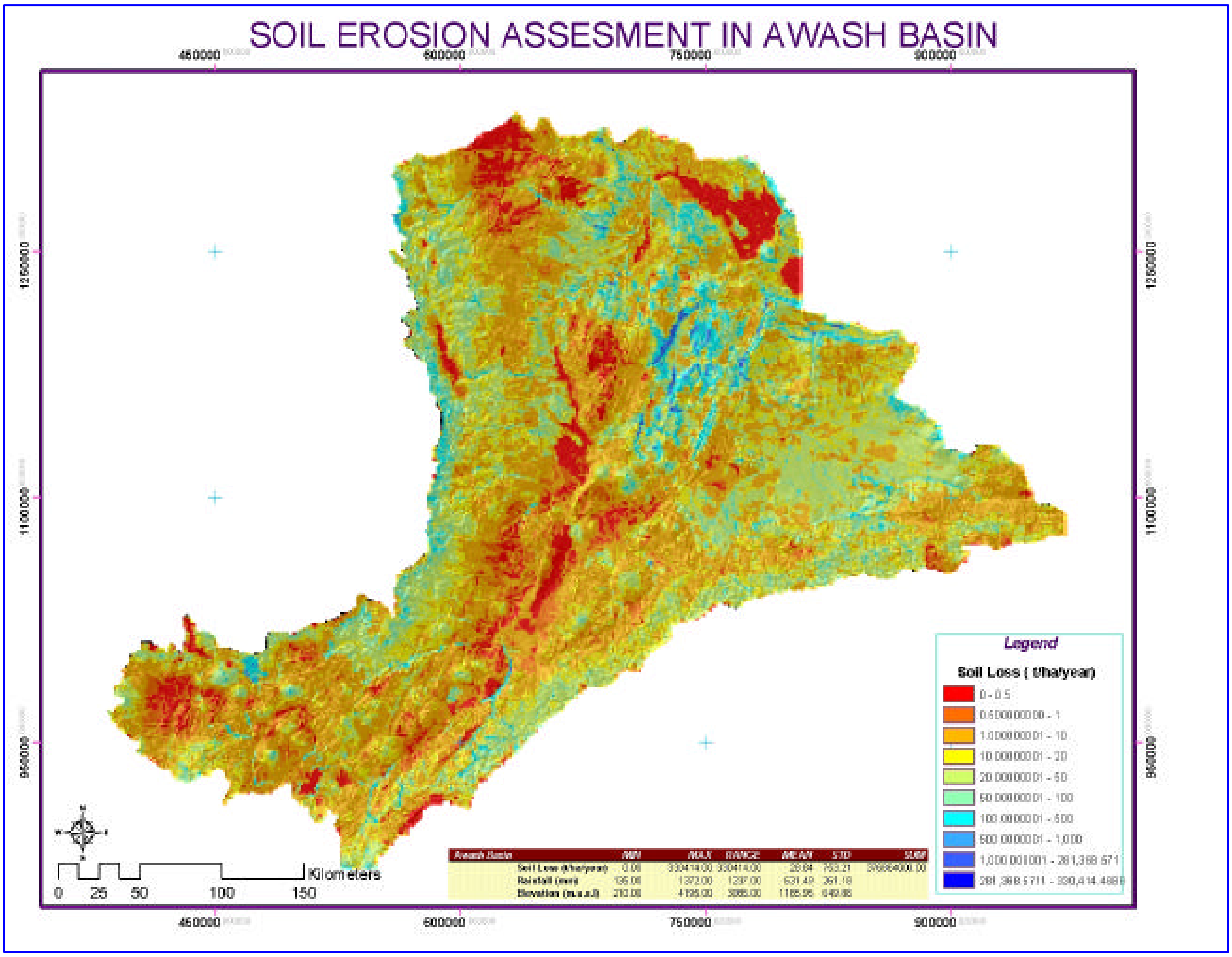

Figure 8. Amount of soil loss in Awash basin

Since the basin consists of about 130 woredas of 6 regions, an attempt was also made to see which of these woreda has highly affected by soil erosion. As shown in the figure 9 and figure 10, Erer, Gewane, Shinile, Mile, Ayesha, Dubti and Dembel are the most highly affected areas. Besides their area coverage, the topographic ruggedness and poor vegetation coverage contributes to the high rate of soil erosion in the above-mentioned woredas.

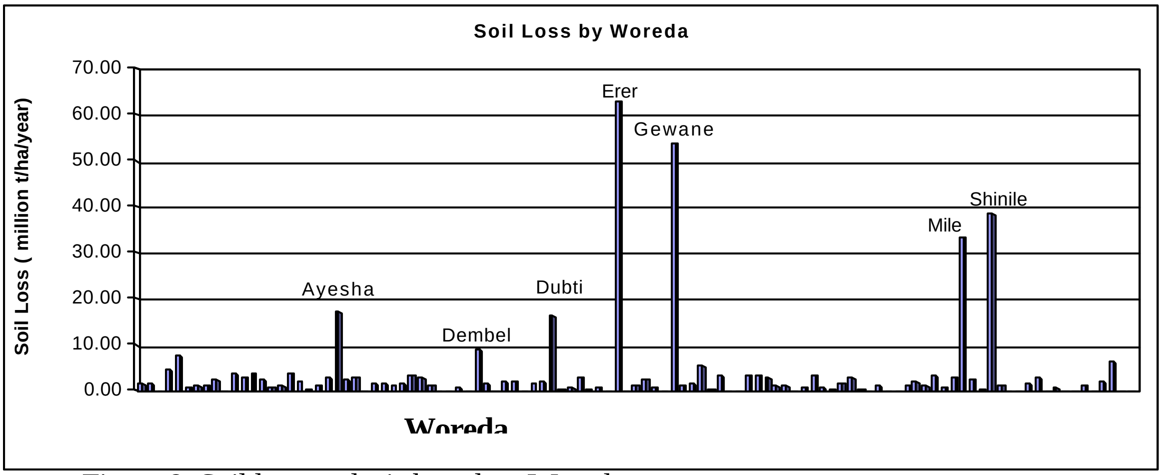

Figure 9. Soil loss analysis based on Woreda

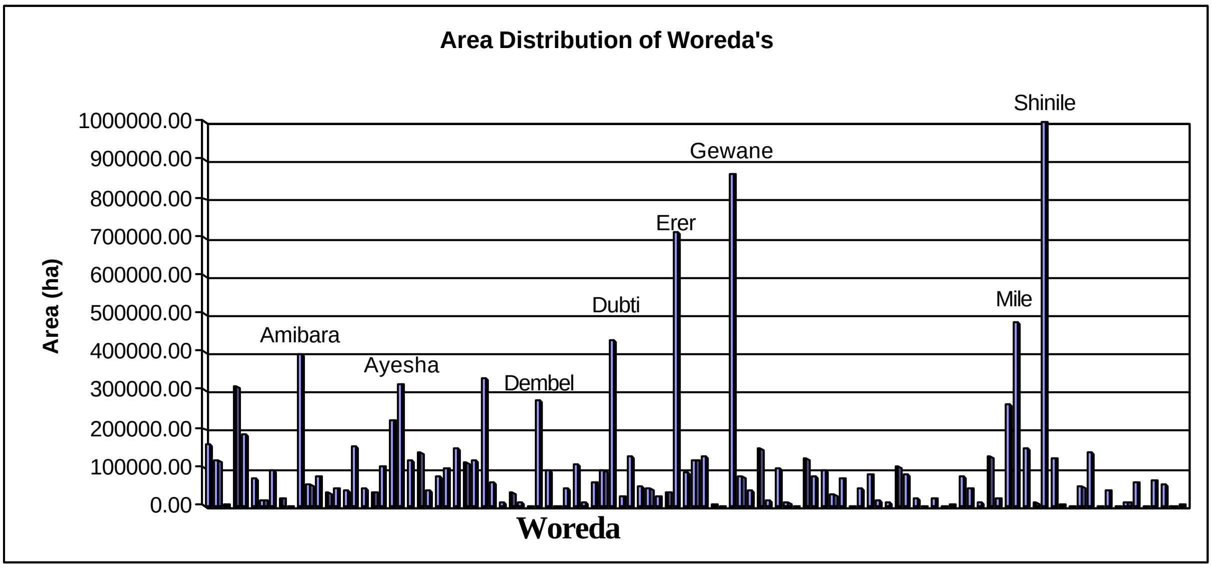

Figure 10. Area distribution of Woreda's in Awash basin

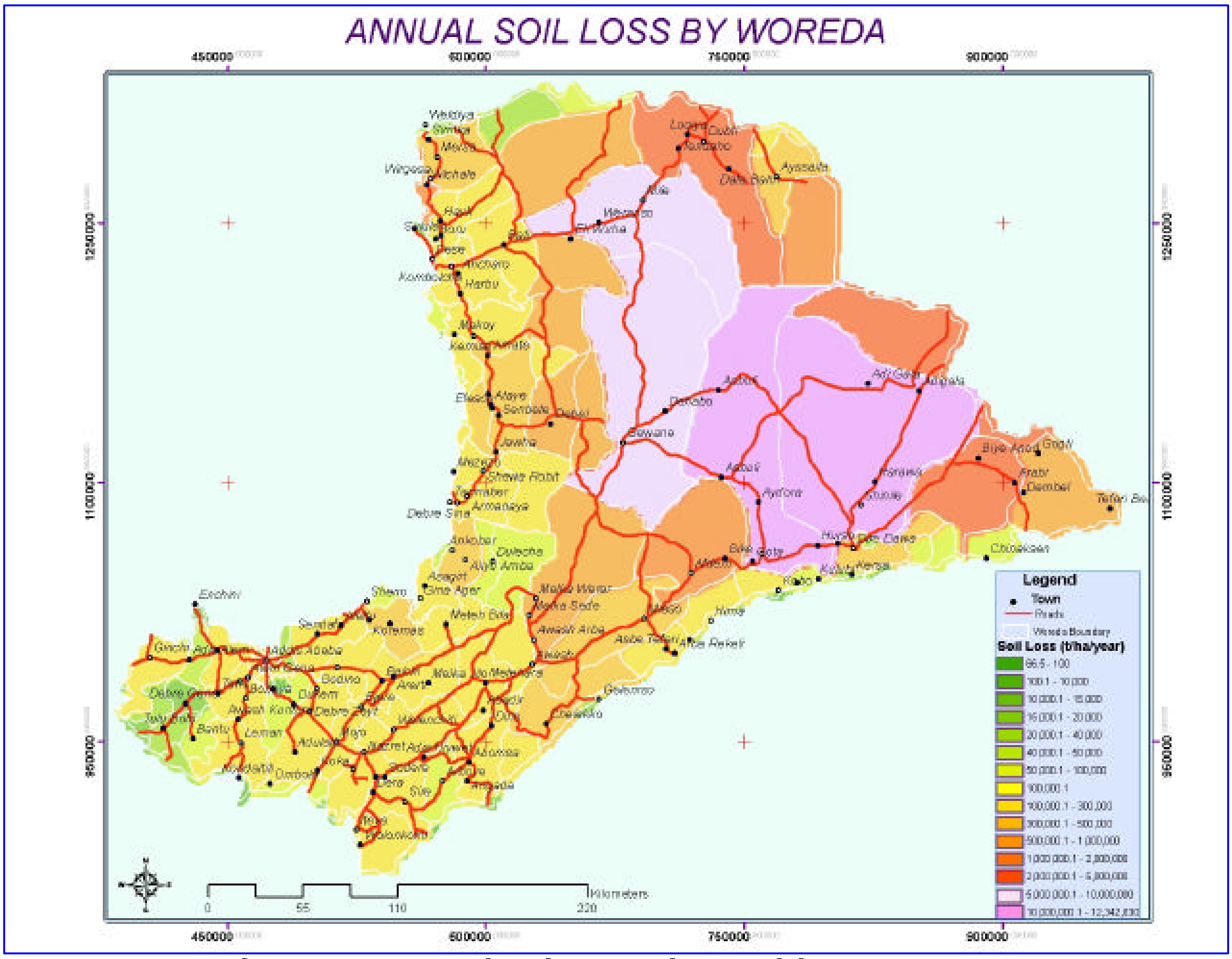

Figure 11. Soil Loss assessment in based on Woreda'sAwash basin

Conclusion

GIS provides a great advantage to analyze multi-layer of data spatially and quantitatively within the basin. The estimation of soil loss in the basin using GIS is also in the ranges of other studies. GIS not only provides accurate results but also provides cost and time effective ways of analysis.

References

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).

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

Foster, G.R, L.J. Lane.1981. Simulation of erosion and sediment yield from field-sized areas. In Tropical agricultural hydrology, ed. R. Lal and E. W. Russell. Chichester, Wiley: 375-94.

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

Hurni, H. 1993. Land Degradation, famine and resource scenarios in Ethiopia. In World Soil Erosion and Conservation, ed. D. Pimentel. Cambridge University press, Cambridge.

Hurni,H. 1988. *Degradation and Conservation of the Resources in the Ethiopian Highlands.* Mountain research and Development 8(2/3).

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

Morgan, R.P.C. 1974. Estimating regional variation in soil erosion hazard in Peninsular, Malaysia. Malayan Nature Journal 28: 94-106.

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).

Roose, E.J. 1975. *Erosion et ruisellement en Afrique de l'ouest: vingt annies de measures en petites parcelles experimentales. Cyclo. ORSTOM, Adiopodoume, Ivory Coast*.

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.

Wischmeier W.H., D.D.Smith.1978. Predicting Rainfall erosion Loss. USDA. Agricultural research Service Handbook 537.

Data Sources

FAO Soil Classification

NASA Shuttle Radar Topographic Model (SRTM) 90m. http//:srtm.csi.cgiar.org

WBISPP. Woody Biomass Inventory and Strategic Planning project in Ethiopia.
World Climate.

Software
ArcGIS 9.0X. ESRI

Appendix 1. Soil classification of Awash River Basin