CHAPTER 3

PREDICTION OF SOIL LOSS USING SOIL EROSION MODELS

3.1 Introduction

Ethiopia is one of the most ecologically sensitive regions of the world for accelerated erosion (Lal and Pierce, 1991). The Harerge region of eastern Ethiopia, especially the highlands (with altitudes greater than 1500m) are among the highly affected areas by land degradation due to erosion. This is why the Soil Conservation Research Project (SCRP) selected one of its representative sites at Hunde Lafto (West Harerge) and established soil erosion experimental plots to evaluate the effect of various soil conservation measures. Despite many efforts made to quantify the extent of soil loss in the country, the available information at this stage is inadequate as it was mainly based on results obtained from selected agro-climatic regions. Therefore, more detailed and extensive work is required to assess the spatial variability and extent of soil erosion within a given region.

This study was initiated to this effect, to estimate soil loss in some areas of Harerge, eastern Ethiopia using two empirical soil loss models namely Soil Loss Estimator for Southern Africa (SLEMSA) and the Universal Soil Loss Equation (USLE). These two models were selected mainly due to the limited amount of information they require and the relative simplicity of collecting the required input data to run the models because of the limited data available for the study areas.

One of the purposes of predicting soil erosion hazards and factors responsible for the same is to get information for planning of appropriate soil management systems based on the severity of erosion in specific areas. Sustainable soil management systems should be developed to reduce further degradation and restore the productivity of the eroded land. The aims of this study were therefore,

1. To estimate extent of soil loss at different areas in the Harerge region using SLEMSA and USLE models so that planning of management techniques can be suggested in order to reduce further degradation,

2. To analyze the sensitivity of the above models to their input variables and evaluate their applicability to these areas for further study and

3. To estimate the tolerable soil loss as well as soil life for the study sites under the current management situations.

3.2 Soil loss estimation using SLEMSA

3.2.1 Introduction

Soil Loss Estimation Model for Southern Africa (SLEMSA) was initially developed for Zimbabwean conditions by Elwell (1978) to predict long term average annual soil losses by sheet and rill erosion from small scale farming areas for specific combination of physical and management conditions (Schulze, 1979). Since then, it has been widely used to predict soil loss in African environments (Elwell and Stocking, 1982). Among others, it was used for assessing areas of high silt discharge into Richards Bay in South Africa (Schulze, 1979), for assessing rates of soil erosion in Botswana (Abel and Stocking, 1987), to develop erosion hazard map for the SADC (Southern African Development Community) region (Stocking et al., 1988), for erosion hazard assessment in Malawi (Paris, 1990), to predict soil losses from small scale farming areas in Zimbabwe (Grohs and Elwell, 1993) and to predict soil loss in the Lesotho Highlands Water Project (Smith et al., 1997).

The SLEMSA model is neither meant for estimation of sediment yields to rivers or dams nor soil deposition in depressions. It is essentially a model for soil removal (Schulze, 1979). However, it can be regarded as a useful model in differentiating areas of high and low erosion potential (Schulze, 1979).

In this study, it has been envisaged that SLEMSA could be used to the conditions of eastern Ethiopia since the equation employed represents the major factors affecting erosion (Foster and Meyer, 1977 as quoted by Smith, 1999) and it only requires determination of appropriate values for the different factors.

3.2.2 Materials and methods

The study sites are the same as those indicated in chapter 2. However, some of the sites do not have weather stations and lack rainfall data. For such sites, the rainfall data of the nearest study site with a complete data set was used to comply with the input requirements of the models.

The major erosion control variables that have been identified and expressed numerically (Elwell, 1977 cited by Schulze, 1979) in the SLEMSA model include: rainfall kinetic energy (E), percent effective vegetal cover (i), soil erodibility index (F), percent slope steepness (S) and slope length (L). These variables were combined into three factors namely, a factor that describes soil loss from bare plot (K), a canopy cover factor (C), and a topographic factor (X).

The above three factors were combined into the general SLEMSA model as follows:

$$Z = K X C \qquad (3.1)$$

(Department of Agricultural Technical Services, 1976; Schulze, 1979; Morgan, 1995)
Where

Z = Predicted mean annual soil loss (t $ha^{-1}yr^{-1}$),

K = Mean annual soil loss (t $ha^{-1}yr^{-1}$) from a standard field plot of 30m long, 10m wide, 2.5° slope for a soil of known erodibility F under a weed free bare fallow,

X = Dimensionless combined slope length and steepness factor which is the ratio of soil loss from a plot of length L and slope percent S, to that lost from the standard plot and

C = dimensionless crop management factor which is the ratio of soil loss from a cropped plot to that lost from the bare fallow

3.2.2.1 Estimation of K for SLEMSA

Field observation of the research sites and laboratory soil analysis were the main sources of input data used. The soil erodibility index F (see equations 3.4 to 3.6) was estimated based on the soil textural classes and other relevant soil surface and subsurface conditions that directly or indirectly affect the soil's inherent sensitivity to erosion including percent clay content in the B horizon, ridging, self mulching, drainage, surface crusting, previous erosion damage, tillage techniques, moisture retention capacity, and dominance of sands and silts (Appendices 1.4A and 1.4B).

Weather data were obtained from the weather bureau of the region where the respective research site is located. Due to the absence of weather stations at some of the sites considered in this study, the data of the nearest weather station was used. Accordingly, weather data of Alemaya University was used for AU Regosol, AU vertisol, AU Alluvial (all of which are located in Alemaya University campus), Adele and Hamaressa. Similarly, weather data of Chiro (Asebe Teferi) was used for Hirna. For the three sites in the Somali region namely, Amadle, Dugda Hidi (Chinaksen) and Karamara, data from a single weather station (i.e. Jijiga) was used. Hence, most of variabilities in the estimated soil losses between the research sites that shared the same rainfall data will be mainly associated with factors other than rainfall erosivity.

Estimation of rainfall kinetic energy (E) is based on the annual rainfall data. The kinetic energy has been expressed in terms of rainfall intensity equation developed by Elwell and Stocking (1973) as quoted by Department of Agricultural and Technical Services (1976) as follows:

$$E = (29.82-127.51/I) \qquad (3.2)$$

Where,

E= Rainfall kinetic energy in $Jm^{-2}mm^{-1}$ and

I= Rainfall Intensity in mm hr^{-1}

According to the Department of Agricultural Technical Services (1976), charts from autographic rain gauges should be analysed to obtain storm, daily, monthly or annual values for E. However, owing to the lack of such detailed and consistent information for the research sites under consideration, the tabulated provisional values of rainfall energy (E) (Elwell and Stocking, 1973 as quoted in Department Agricultural Technical Services, 1976) (Appendix 1.1) based on mean annual rainfalls were used for this study. Hence, the estimated rainfall energy for the study sites based on the range of their annual rainfall is presented in Appendix 1.2.

The value of the K factor was determined by relating mean annual soil loss to mean annual rainfall energy (E) using the exponential relationships (Morgan, 1995):

$$\ln K = b \ln E + a \qquad (3.3)$$

Where E is in $Jm^{-2}mm^{-1}$ and the value of a and b are functions of the soil erodibility factor (F):

$$a = 2.884 - 8.2109F \qquad (3.4)$$

$$b = 0.4681 + 0.7663F \qquad (3.5)$$

By substituting equations 3.4 and 3.5 into equation 3.3, we get

$$K = \exp\left[(0.4681 + 0.7663F)\ln E + 2.884 - 8.1209F\right] \qquad (3.6)$$

The estimated K values based on the above sub models are presented in Table 3.1.

3.2.2.2 Assumptions and procedures used to estimate the C values for SLEMSA

The cover information for the sites was obtained through visual observation of the sites and by estimations based on the mean monthly and annual rainfall data. The types of vegetation and/ or dominant crops grown in each site were identified and the percent surface cover during a certain season of the year was estimated based on the growing season of each crop and the temporal rainfall distribution. Therefore, a year is divided into four seasons representing three months each. For most of the sites in this study, October – December are considered to be dry seasons. The same is true for January - March except for few ‘Belg’(the first rainfall season of the year) rainfall events that start in March. Even if the ‘Belg’ rainfall starts in March at the majority of the research sites, surface cover on agricultural lands during this period is very poor due to the maximum disturbance of the land by cultivation and subsequent bare soil surfaces that are prone to erosion. Hence, a relatively small percent cover value is assigned to crops during this season.

October– December are usually seasons for ripening and harvesting for many agricultural grain crops. Though harvesting reduces the percent cover (especially when the residue is removed from the land) a relatively better estimate of cover was assigned to crops during this season as compared to that of January- March. April to June is a season mainly for planting, seedling emergence and vegetative growth for most crops grown in the regions as a whole including sorghum and maize. The percent cover of the land by crops like maize and sorghum during these seasons will receive a better value than for both October-December and January –March. During July –September all crops will be in a vegetative stage and provide the maximum surface cover. Therefore maximum surface cover values for different crops were allocated for the sites during this season.

The crop management factor C, calculated from the value of soil loss from standard bare soil condition and that of a cropped field (Morgan, 1995) depends on the percentage of the rainfall energy intercepted by the crop (i). Some of the procedures followed to calculate C value for SLEMSA include (Appendix 1.5):

i. Dominant crops and vegetation for each site were identified and percent cover was estimated for each crop separately based on the expected growth stage and stand of a particular crop at a specific season.

ii. The average value of the product of the percent cover and fraction of rainfall during that season (ratio of the seasonal total rainfall to annual rainfall) for each crop was used to calculate the seasonal percent rainfall energy interception, i value.

iii. The sum of i values for the four seasons were taken as the annual rainfall interception for a given locality.

iv. For crops and natural grasslands with i<50 percent, the crop management factor C was calculated using equation 3.7.

$$C = e^{(-0.06i)} \qquad (3.7)$$

and for dense pastures and mulches when i ≥ 50 percent, it is

$$C = (2.3 - 0.01i)/30 \qquad (3.8)$$

3.2.2.3 Procedures used to estimate the topographic factor X for SLEMSA

Due to the absence of data on the relationship between slope characteristics and soil loss for the areas for which SLEMSA was developed (Elwell, 1977 as quoted by Schulze, 1979) the slope factor X of the USLE (Wischmeier and Smith, 1965) was adapted to be more representative of the conditions of the experiments during the development of the model. Hence, the topographic factor is given by

$$X = \sqrt{L}(0.76 + 0.53S + 0.076S^2)/25.65 \qquad (3.9)$$

Where

X= the ratio of soil loss from a plot of length L and slope percent S, to that lost from the standard plot

L= slope length in m

S= Slope gradient in percent.

The topographic features of the studied areas vary widely ranging from nearly level at AU Vertisol, AU Alluvial and Diredawa Toni Farm to hilly terrain in Asebe Tefri (Chiro) (Appendix 1.3). It is well known that a single value of slope gradient will not represent the topography of the whole area. For the purpose of using the model, however, a representative average slope for each site was considered. Therefore, it should be stressed that the value of S indicated for each site is a gross oversimplification of the topography of the area. No cognisance has been taken of slope convexity (which would yield greater soil loss) or concavity (yielding smaller soil losses) (Schulze, 1979). For computational purposes, all slope gradients greater than 25% were assigned the value 25% because SLEMSA has not been designed for higher slope gradients (Schulze, 1979).

According to Wischmeier and Smith (1965), effective slope length is defined as the distance from the point of origin of overland flow to the point where either the slope decreases enough that deposition begins; or runoff water enters a well-defined channel. The slope gradient and length for the study sites are presented in Appendix 1.3. The topographic factor, X was estimated for each study site using equation 3.9 and presented in Table 3.1 and Appendix 1.3.

3.2.3 Results and discussion

The values for the factors involved in the SLEMSA model and the predicted soil loss for the study sites using this model is presented in Table 3.1. Details of calculations and guidelines for estimating the input factors of SLEMSA are given in Appendix 1.1 – 1.5.

Table 3.1 Estimated input variables of SLEMSA model and calculated soil loss (t $ha^{-1}yr^{-1}$) for some sites in eastern Ethiopia

Site	F	a	b	E	K	X	C	Z (t $ha^{-1}yr^{-1}$)
Adele	5.50	-42.28	4.68	17600.00	54.38	7.53	0.058	23.81
Amadle	3.50	-25.85	3.15	12200.00	60.41	1.85	0.053	5.93
AU Aluvial	5.00	-38.17	4.30	17600.00	74.51	0.92	0.069	4.74
AU Regosol	5.00	-38.17	4.30	17600.00	74.51	5.33	0.062	24.72
AU Vertisol	5.00	-38.17	4.30	17600.00	74.51	0.75	0.055	3.09
Babile	3.50	-25.85	3.15	14000.00	93.20	7.04	0.107	70.23
Bedessa	6.00	-46.38	5.07	21000.00	97.11	2.98	0.060	17.36
Chiro	6.00	-46.38	5.07	17600.00	39.69	10.72	0.060	25.54
Dire Dawa	6.00	-46.38	5.07	14000.00	12.45	1.43	0.060	1.07
Dugda Hidi	3.50	-25.85	3.15	12200.00	60.41	2.77	0.058	9.69
Gelemso	5.00	-38.17	4.30	23000.00	235.44	7.12	0.059	98.84
Hamaresa	6.00	-46.38	5.07	17600.00	39.69	10.72	0.101	42.99
Hirna	6.50	-50.49	5.45	17600.00	28.97	6.36	0.062	11.43
Karamara	3.00	-21.75	2.77	12200.00	95.25	7.04	0.093	62.39
Lange	5.50	-42.28	4.68	19000.00	77.82	5.83	0.066	29.96

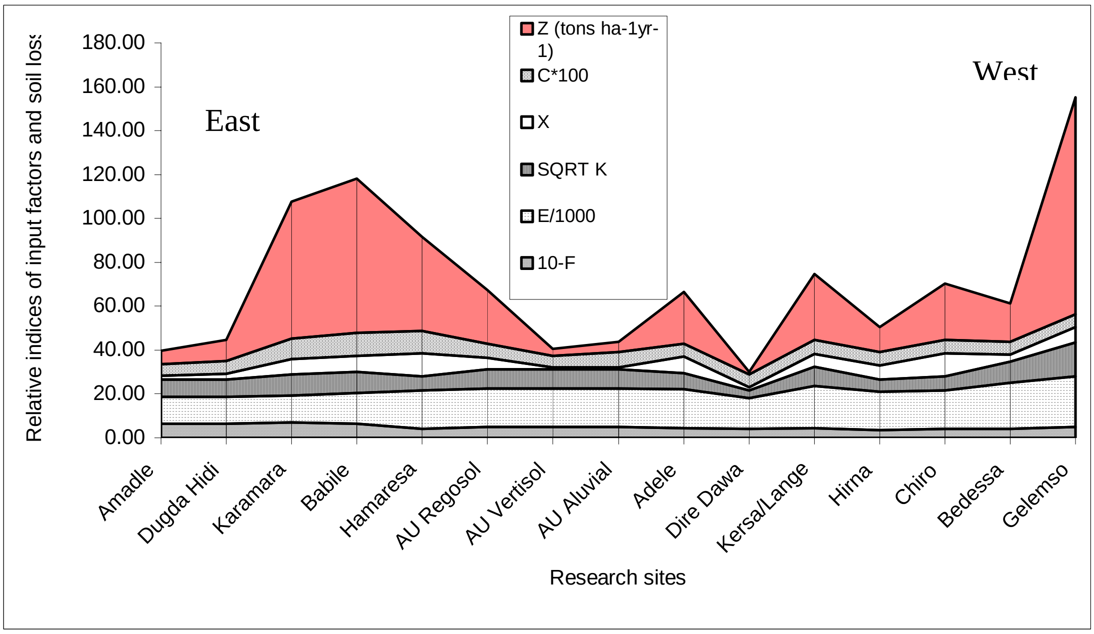
3.2.3.1 Estimated soil losses using SLEMSA

The estimated soil losses for the study sites in eastern Ethiopia ranged from 1.07 t ha^{-1} yr^{-1} for Diredawa to 98.84 t ha^{-1} yr^{-1} for Gelemso (Table 3.1). The estimated soil losses were higher at Gelemso, Babile, Karamara, and Hamaressa all of which were above 40t ha^{-1} yr^{-1}. These high soil loss values for these areas are attributed to the combined effects of the various factors affecting erosion at each site.

In some areas, a single factor may have an overwhelming effect than others leading to large differences in the estimated soil loss among the research sites. For instance, the highest soil loss estimated at Gelemso is mainly due to its highest K value (Table 3.1) which is a function of rainfall erosiviy and soil erodibility factors. This is again mainly associated with its higher mean annual rainfall (1146mm) averaged over nine years. For other sites like Karamara, Babile and Hamaressa, where relatively higher soil loss estimates were also recorded, no single factor seemed more important than any other factors in affecting the estimated soil loss values. At Babile and Karamara, all values of the three factors are relatively higher resulting in higher soil losses. The higher estimated soil loss at Hamaressa was largely due to the higher values of the topographic, X factor and crop cover, C factors than the K factor. In general, although one or two factors may be responsible for the high or low soil loss in a given area, the combined effect of the values of all three factors is most important.

Lowest estimated soil loss values were obtained for Diredawa, AU vertisol and AU Alluvial. These sites have more or less similar values for the crop cover factor with other sites where relatively high soil losses were estimated. However, their values of the K and X factors are very low. Actually these areas are relatively level lands and the topographic factors are relatively low resulting in low soil loss values.

To facilitate a comparison between the contributions of the different erosion factors on the estimated soil loss, the values for various erosion factors are transformed so as to fit into a graph that is presented in Fig 3.1. It was indicated that the estimated soil loss was relatively higher where all erosion parameters are proportionally high. The higher slope factor at Hamaressa and Chiro had a more pronounced effect on increasing estimated soil loss but the low slope factors at AU Vertisol, AU Alluvial and Diredawa had contributed a lot to reduction in estimated soil loss. According to Fig. 3.1, the effect of crop cover factor was more or less constant at most of the sites and was not the main contributor to the variation of soil loss values among the study sites. However, since the effect of any single factor on the predicted soil loss is dependent on the values of the other factors, separate evaluation of each factor is not reasonable.



*Z=Estimated soil loss (t ha^{-1}yr^{-1}); C*100= Crop cover index times 100; X= Topographic factor; SQRT K = Square root of K values; E/1000= Erosivity index divided by 1000; 10 – F= 10 minus erodibility factor F. [The study sites are arranged according to their east-west geographical locations]*

Fig. 3.1 Relationships among the indices of erosion factors and soil loss as estimated by using SLEMSA at the study sites.

3.2.3.2 Sensitivity of soil loss estimated by SLEMSA to changes in input variables

The sensitivity of the soil loss estimated by SLEMSA to changes in some of its input variables was tested by increasing or decreasing some of the factors by 20%. All other factors were fixed while the effect of one factor was tested. In this study, the response of estimated soil loss to changes in soil erodibility factor (F), slope gradient (S) and length (L), rainfall kinetic energy index (E) and percentage rainfall energy intercepted by cover (i) was evaluated. The estimated soil loss due to changes in one of its input variables while keeping the others constant, and the percentage change as compared to the original estimated soil loss is presented in Table 3.2.

Table 3.2 Response of soil loss estimated by SLEMSA to changes in some input variables.

Study site	Soil loss base value	Soil loss with 20% increase in F		Soil loss with 20% decrease in E		Soil loss with 20% decrease in S%		Soil loss with 20% decrease in slope length		Soil loss with 20% increase in i	
	$t\ ha^{-1}\ yr^{-1}$	Amount $t\ ha^{-1}yr^{-1}$	% decrease	Amount $t\ ha^{-1}yr^{-1}$	% decrease	Amount $t\ ha^{-1}yr^{-1}$	% decrease	Amount $t\ ha^{-1}yr^{-1}$)	% decrease	Amount $t\ ha^{-1}yr^{-1}$	% decrease
Adele	23.81	11.91	49.98	8.37	64.83	17.19	27.79	21.30	10.56	22.29	6.37
Amadle	5.93	3.13	47.14	2.94	50.49	4.57	22.86	5.30	10.56	6.39	-7.70
AU Aluvial	4.74	2.53	46.73	1.82	61.69	4.28	9.76	4.24	10.56	4.04	14.76
AU Regosol	24.72	13.17	46.73	9.47	61.69	17.85	27.79	22.11	10.56	23.07	6.66
AU Vertisol	3.09	1.64	46.73	1.18	61.69	2.79	9.76	2.76	10.56	3.22	-4.21
Babile	70.23	39.97	43.09	34.77	50.49	49.97	28.85	62.82	10.56	44.67	36.40
Bedessa	17.36	9.59	44.75	5.60	67.71	12.78	26.35	15.52	10.56	16.38	5.60
Chiro	25.54	11.99	53.04	8.25	67.71	17.34	32.11	22.84	10.56	24.67	3.41
Dire Dawa	1.07	0.41	61.95	0.35	67.71	0.91	15.13	0.96	10.56	1.01	6.19
Dugda Hidi	9.69	5.12	47.14	4.80	50.49	7.65	21.04	8.67	10.56	9.04	6.73
Gelemso	98.84	64.63	34.61	37.87	61.69	69.17	30.01	88.40	10.56	92.01	6.91
Hamaresa	42.99	20.19	53.04	13.88	67.71	29.19	32.11	38.45	10.56	27.06	37.06
Hirna	11.43	5.04	55.90	3.39	70.36	8.00	30.01	10.22	10.56	10.73	6.16
Karamara	62.39	36.12	42.10	33.65	46.07	44.39	28.85	55.80	10.56	38.62	38.09
Lange	29.96	15.99	46.65	10.54	64.83	21.64	27.79	26.80	10.56	26.56	11.35

†The cover factor for SLEMSA is computed using two different equations when i is less than 50 (eqn. 3.7) and when i is greater than or equals to 50 (Eqn.3.8). When the percent rainfall interception, i increase from below 50 to above 50, it results in a higher C value which yields a slightly higher soil loss contrary to the expectations.

Soil loss responded highly to change in soil erodibility factor F at all study sites. A 20% increase in the value of soil erodibility factor F halved the estimated soil loss at Adele, Chiro, Diredawa, Hamaressa and Hirna. The minimum response to change in soil erodibility factor was 34.61% which was recorded at Gelemso.

The change in soil loss due to 20% decrease in rainfall kinetic energy index (E) is directly proportional to the values of the soil erodibility factor (F) of the respective study sites. Those sites with a relatively high F value (i.e. low erodibility hazard) showed a strong response to change in E. On Hirna soils, that has the highest estimated F value, the estimated soil loss decreased by 70.36% with 20% decrease in the E value. Moreover, the estimated soil losses at 14 of the 15 study sites decreased by more than 50% due to the 20% decrease in E. The least response to 20% decrease in rainfall energy (E) was 46.07% decrease in soil loss at Karamara. This can be associated with the smaller F value for Karamara soils (see appendix 1.4).

A 20% decrease in slope gradient also reduced estimated soil loss by 9.76 - 32.11%. However, the model is generally less sensitive to slope gradient as compared to other factors. Areas having higher slope gradients showed greater responses to decrease in the gradient than those with lower slope gradients. Accordingly, for Chiro and Hamaressa that have slope gradients of greater than 25%, the estimated soil loss was reduced by 32% for a 20% reduction in slope gradient.

The percent decrease in soil loss for the 20% decrease in slope length was constantly 10.56% for all sites. It seems that SLEMSA is the least sensitive to decrease in slope length as compared to that for the other input variables except for cases where the sensitivity of the percent rainfall energy interception factor, (i) is very low especially when it is larger in magnitude representing poor cover.

The sensitivity of estimated soil loss to percent crop cover (rainfall interception factor, i) varied for the different study sites. Soils with initially poor cover (i.e higher C value) showed higher sensitivity to a 20% increase in percent cover. Soil loss decreased by more than 35% at Babile, Hamaressa and Karamara due to 20% increase in percent cover.

The sensitivity of the model is very low when the percent cover that was initially less than 50% is increased to above 50%. When i is less than 50%, an exponential equation is used to calculate the C factor but when i is greater or equals to 50%, a less sensitive linear equation is used (Fig.3.2).

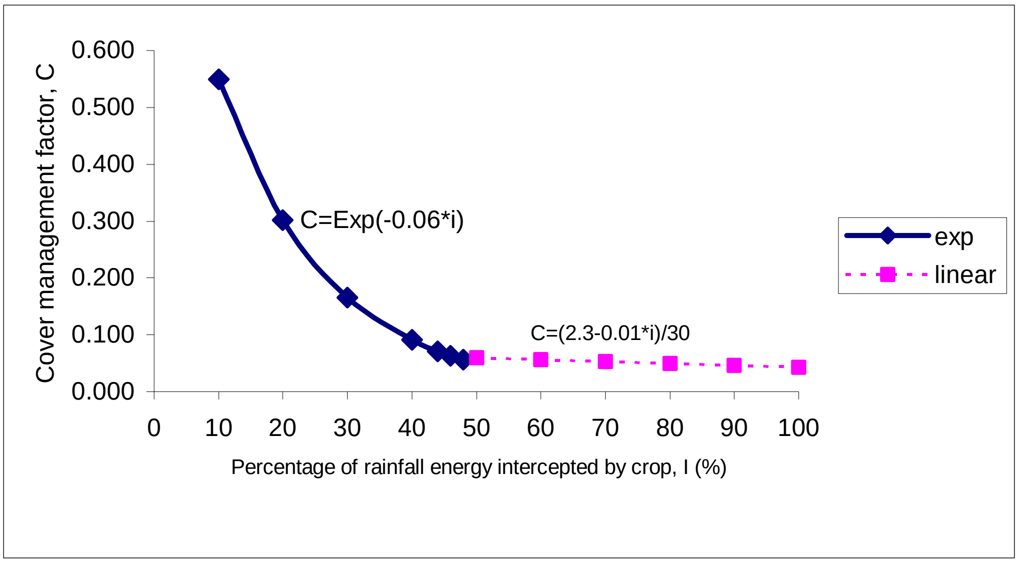


Fig.3.2 The relationship between percent rainfall energy interception (i) and the C factor for SLEMSA (Adapted from Department of Agricultural and Technical Services, 1976).

Consequently, a very small response, which was even negative at some sites, was observed for a 20% increase in i at most of the study sites. This may suggest that more research is required to modify the cover management factor and to get a reasonable output from the model.

In the case of Gelemso, it seems that soil crusting is the major factor once it had formed and increase in canopy cover as such will not improve soil protection. However, under natural conditions with more canopy cover, the soil will be better protected due to organic matter addition on the soil surface.

In general, though the response of soil loss to change in any one factor varied among the sites, the change was most sensitive to decrease in E (which is one of the major reasons for soil crusting) as compared to the other factors. For most of the study sites, the effect of the four factors can be rated as: E > F > S > i in accordance with their relative importance towards affecting the magnitude of the estimated soil loss with an equal change in these factors. Schulze (1979), working in the key area of the Drakensberg (South Africa), also indicated that SLEMSA is highly sensitive to its input variable especially to rainfall erosivity and soil erodibility. Therefore, due to the high sensitivity of the model to erosivity and erodibility factors, the input variables should be measured or estimated as accurately as possible to get more reliable soil loss estimates for the sites before making decision on conservation planning. Moreover, all assumptions considered under each factor for soil loss estimation in these study should be taken into consideration during interpretation and comparison of soil loss values at various sites.

3.3 Soil loss estimation using USLE

3.3.1 Introduction

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965, 1978) is the most widely known and used empirical soil loss model all over the world. Later in the 1980's, the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) modified the model to the Revised Universal Soil Loss Equation (RUSLE), which was an improved version of USLE for northeastern areas of the USA incorporating new approaches, new data from different locations, and corrections of the USLE limitations (Yoder and Lown, 1995; Smith, 1999). RUSLE is computer based, replaces the tables, figures, and tedious USLE calculations with simplified keyboard entry (Yoder and Lown, 1995) while maintaining the basic structure of USLE. Unfortunately, due to inadequate availability of input data for the study sites to comply with the input requirements of RUSLE, only USLE was used to estimate soil loss for the sites. The USLE computes sheet and rill erosion using values representing the four major factors affecting erosion, namely climate erosivity R, soil erodibility K, topography LS and land use and management CP (Kenneth et al., 1991). Like the SLEMSA, the USLE doesn't estimate deposition, sediment yield at a down stream location and ephemeral gully erosion and does not represent fundamental erosion processes and interactions (Kenneth et al., 1991). It is however, found to adequately represent the first order effects of the factors that affect sheet and rill erosion. The USLE involves:

$$A = R \times K \times LS \times C \times P \qquad (3.10)$$

Where A is the computed long term average annual soil loss per unit area, R is the rainfall factor, K is the soil erodibility factor, LS is the topographic factor, C is a cover management factor, and P is the support practice factor. The USLE has been used widely all over the world either in the same or modified forms (Tiwari et al., 2000). Hurni (1985) also used this model to assess soil erosion in Ethiopia. He even modified some factors of the USLE for the Ethiopian conditions. Three of the most significant modifications include R (rainfall erosivity index), C (land cover) and P (management factors) factors. This was a valuable input to the erosion and soil conservation research in Ethiopia since the 1980's. However, the available information in this regard is still a gross oversimplification of the realities in different localities. There is a need to conduct a detailed and extensive assessment of erosion hazard taking the various site-specific erosion factors into consideration.

The objective of this experiment was to assess the erosion hazard in selected areas of Hareghe using the USLE as was originally described by Wischmeier and Smith (1978) as well as taking some of the recommendations of Hurni (1985) for Ethiopian conditions into considerations. The results of this study was compared with that estimated using SLEMSA to have a general comparative overview of the erosion hazard indices in the study areas. Sensitivity analysis of the input variables were also conducted to see how a change in a given factor affects the magnitude of estimated soil loss. The soil loss values estimated by these models will help the extension agents and policy makers to recognize the relative severity of erosion in a given locality and will help to prioritise and suggest appropriate soil management strategies in accordance with the level of hazard.

3.3.2 Materials and methods

3.3.2.1 Procedures used to estimate the factors in USLE

3.3.2.1.1 The rainfall erosivity factor, R

The mean annual rainfall used for the different sites in this model is the same as that used for SLEMSA (Section 3.2.2.1). According to Wischmeier and Smith, (1978), erosivity is calculated from the kinetic energy of rainfall (which in turn is estimated from the mean annual rainfall and 30minute rainfall intensity value (Morgan, 1995).

$$R = EI_{30}/1000 \qquad (3.11)$$

Where,

R= rainfall erosivity factor in metric units

E = Rainfall kinetic energy, Jm^{-2}

I_{30} = 30 minute rainfall intensity, $mmhr^{-1}$ (Morgan, 1995).

However, rainfall kinetic energy and intensity data are not available in most cases. Therefore, the erosivity factor R that was adapted by Hurni (1985) for Ethiopian conditions based on the easily available mean annual rainfall P was used in this study. It is given by a regression equation:

$$R = -8.12 + 0.562*P \qquad (3.12)$$

Where, P is the mean annual rainfall, mm

The mean annual rainfall (P) and the calculated erosivity factors (R) for the study sites are presented in Appendix 2.1.

3.3.2.1.2 Soil erodibility factor, K for the USLE model

Soil texture, organic matter content, soil structure and permeability were the main soil properties used to estimate the soil erodibility factor K. These soil properties were used to compile a nomograph from which the K value could be read (Wischmeier et al., 1971). For the cases where the silt fraction doesn't exceed 70%, equation 3.13 (after Wischmeier and Smith, 1978) could also be used to estimate the K values for USLE. For the soils of this study, since the K values obtained from the two methods were almost similar (see appendix 2.4), equation 3.13 was used.

$$K = 0.01317\left[0.00021(12 - OM\%)M^{1.14} + 3.25(Ss - 2) + 2.5(Ps - 3)\right] \qquad (3.13)$$

Where,

OM% = per cent organic matter

Ss = Structure code (Appendix 2.3),

Ps = Permeability Code (Appendix 2.2),

M = product of the primary particle size fractions, i.e. [SS%*(SS%+Sa%)],

SS% = percent silt plus very fine sand (0.002-0.1mm size fraction) and

Sa = Per cent sand (0.1-2mm size fraction).

3.3.2.1.3 Topographic factor (LS)

This factor is estimated from the slope length and slope gradient of a given area. To obtain a realistic value for slope length is difficult because it involves considerable judgement. It could therefore be expected that this value will vary for different users. In this study, a roughly representative slope length for the study sites under consideration was recorded during the field survey and this value was used to calculate the topographic factor (LS) in conjunction with the slope gradients as indicated in equation 3.14. The estimated slope lengths and gradients as well as the calculated values of the LS factors are presented in Appendix 2.8.

$$LS = (l/22.13)^{n}\ (0.065 + 0.045S + 0.0065S^{2}) \qquad (3.14)$$

Where

l =slope length m

n= an exponent related to slope gradients (n=0.5 if S ≥ 5%; n=0.4 if 3%≤S<5%; n=0.3 if 1%≤S<3%, n=0.2 if S<1%) (Torri, 1996)

S= Slope gradient %

3.3.2.1.4 Cover and management factor (C)

The same assumptions pertaining to the percent cover of crops during the various seasons of a year that have been used for SLEMSA (section 3.2.2.2) were applied here. The cover and management factor C is dependent upon the percentage of the rainfall energy intercepted by the crop (Morgan, 1995). Therefore, a weighted C factor is calculated per season by considering the major crops growing in a particular area and the temporal rainfall distribution during the four seasons of the year (Appendix 2.6) and the sum of these values for the four seasons is considered as the mean annual C value for a particular site. The individual C-values of each period were weighed according to the percentage of the mean annual rainfall in that period and summed to obtain the annual C-value. The basic C values for various crops and the calculation procedures of these values for the study sites is presented in Appendices 2.5.1 - 2.5.3.

3.3.2.1.5 Support practice factor, P

P is defined as the ratio of soil loss with specific support practice to the corresponding loss with up and down slope tillage. The support practice affects erosion primarily by modifying the flow pattern, grade and direction of surface runoff and by reducing runoff amount and rate (Lorenz and Schulze, 1995). Cultivated land that is tilled directly up and down slope will have a P-factor of unity. Tillage and planting on the contour reduce erosion depending on the slope of the land. Estimated P values for various support practices is given in Appendix 2.7 (after Wischmeier and Smith (1978); Roose, (1977); Chan, 1981 quoted by Morgan, 1995)). Based on these, the P values of the study sites have been estimated and are presented in Table 3.3 and Appendix 2.8.

3.3.3 Results and discussion

3.3.3.1 Estimated soil loss at the study sites using USLE

The estimated values of the various soil loss factors and the amount of soil loss in tons per hectare per year are presented in Table 3.3.

The estimated soil loss among the study sites varied from 1.74t $ha^{-1}yr^{-1}$ at AU Alluvial to nearly 135 t $ha^{-1}yr^{-1}$ at Gelemso. High soil loss was also estimated for Karamara, Adele, Hamaressa, and Babile all of which are above 50 t $ha^{-1}yr^{-1}$. Some sites including AU alluvial, AU vertisol, and Diredawa have estimated soil losses of less than 10 t $ha^{-1}yr^{-1}$. These sites are characterised by low slope gradients resulting in low value of LS (topographic factors) factors and consequently low soil loss. In general, however, 80% of the studied sites have estimated soil losses of more than 10 t $ha^{-1}yr^{-1}$ which is beyond the tolerable limits given by Smith et al. (1997) for most soils.

The results indicate that all soil erosion factors are important in determining the amount of soil loss. Gelemso, where the highest estimated soil loss was recorded, is characterised by the highest rainfall erosivity factor as well as high values of other factors.

Table 3.3 Estimated values of erosion factors and soil loss estimated by using USLE for some soils of Hararge, eastern Ethiopia.

Research site	P	C	K	LS	†R	Soil loss t $ha^{-1}yr^{-1}$
Adele	0.50	0.58	0.20	3.50	459.00	92.69
Amadle	0.50	0.44	0.22	0.86	309.00	12.85
AU Alluvial	0.60	0.38	0.06	0.30	459.00	1.74
AU Regosol	0.60	0.40	0.18	2.48	459.00	47.26
AU Vertisol	0.60	0.46	0.20	0.23	459.00	5.79
Babile	0.60	0.47	0.16	3.28	378.00	57.47
Bedessa	0.30	0.41	0.12	1.38	589.00	12.35
Chiro	0.14	0.51	0.22	4.99	460.00	36.36
Dire Dawa	0.50	0.17	0.29	0.46	358.00	4.12
Dugda Hidi	0.50	0.31	0.27	0.99	309.00	12.98
Gelemso	0.60	0.53	0.20	3.31	637.00	135.04
Hamaresa	0.40	0.51	0.18	4.99	459.00	83.79
Hirna	0.14	0.43	0.22	2.96	460.00	17.94
Karamara	0.70	0.57	0.23	3.28	309.00	93.22
Lange	0.30	0.51	0.22	2.71	501.00	46.67

†R is calculated based on the adaptation of Hurni (1985) for Ethiopia (See appendix 2.9)

At Karamara, though the rainfall erosivity factor is relatively smaller than other sites, higher soil loss was estimated due to higher values of the P, C, K and LS factors. Similarly, the higher soil loss estimated for Adele and Hamaressa can be attributed among others to higher C and LS factors respectively. The estimated soil losses for the study sites are within the range of soil loss estimated for the Ethiopian highlands by the Soil Conservation Research Project (SCRP) which ranges from 0 to 300 t ha^{-1} yr^{-1} (Hurni, 1985; Nyssen et al., 2003).

3.3.3.2 Sensitivity analysis of USLE to its input variables

Changes in estimated soil losses at the study sites in response to 20% change in the input variables of USLE were estimated by altering one variable at a time. The variables were changed in such a way that the change in soil loss is less than the base value. This can be used as an indicator of the amount of soil loss reduction by an improvement in a certain management practice. Accordingly, the observed percentage surface cover was increased by 20% whereas other factors including slope gradient, slope length, mean annual rainfall and soil conservation practice factor were all reduced by 20% to evaluate the change in estimated soil loss. The soil erodibility factor (K) was not considered in this sensitivity analysis mainly because of the complication resulting from several factors affecting it.

The estimated soil losses after 20% change in the input variables and the percentage changes from the initial values are presented in Table 3.4.

The results indicate that the USLE is least sensitive to changes in slope length at all study sites as compared to other factors evaluated. Moreover, the effect of slope length was modified by slope gradient. A 20% decrease in slope length resulted in a maximum of 10.56% decrease in soil loss for all sites having slope gradients greater than 5%. The highest reduction in soil loss in response to 20% change in the input variables was due to slope gradient and percent cover. For the majority of the sites, reducing the slope gradient by 20% reduced soil loss by more than 25%. The sensitivity to slope gradient is more pronounced at higher slope gradients.

Table 3.4 Changes in soil loss with changes in input variables of USLE for soils of Harerge, eastern Ethiopia.

Study sites	†SL Base value	SL due to 20% increase in % cover		SL due to 20% decrease in P factor		SL due to 20% decrease in annual rainfall		SL due to 20% decrease in slope length		SL due to 20% decrease in slope gradient	
	t ha^{-1}yr^{-1}	Amount t ha^{-1}yr^{-1}	% Decrease	Amount t ha^{-1}yr^{-1}	% decrease	Amount t ha^{-1}yr^{-1}	% decrease	Amount t ha^{-1}yr^{-1}	% decrease	Amount t ha^{-1}yr^{-1}	% decrease
Adele	92.69	79.32	14.42	74.15	20.00	73.71	20.48	82.91	10.56	66.91	27.81
Amadle	12.85	9.62	25.15	10.28	20.00	10.23	20.39	11.50	10.56	8.72	32.17
AU Alluvial	1.47	0.99	32.63	1.17	20.00	1.17	20.48	1.41	4.00	0.69	53.20
AU Regosol	47.26	32.78	30.63	37.81	20.00	37.58	20.48	42.27	10.56	34.12	27.81
AU Vertisol	5.79	4.44	23.29	4.63	20.00	4.60	20.48	5.41	6.48	4.19	27.57
Babile	57.47	44.71	22.19	45.97	20.00	45.76	20.37	51.40	10.56	40.87	28.87
Bedessa	12.35	8.85	28.31	9.88	20.00	9.83	20.37	11.05	10.56	9.09	26.37
Chiro	36.36	29.49	18.91	29.09	20.00	28.93	20.43	32.52	10.56	24.68	32.13
Dire Dawa	3.57	0.16	95.61	2.86	20.00	2.84	20.39	3.30	7.5	3.00	16.00
Dugda Hidi	12.98	7.31	43.69	10.38	20.00	10.33	20.39	11.87	8.54	10.25	21.04
Gelemso	135.04	110.89	17.88	108.03	20.00	107.69	20.25	120.78	10.56	94.48	30.03
Hamaresa	83.79	67.69	19.22	67.03	20.00	66.63	20.48	74.94	10.56	56.87	32.13
Hirna	17.94	13.26	26.08	14.35	20.00	14.27	20.43	16.04	10.56	12.55	30.03
Karamara	93.22	79.27	14.97	74.58	20.00	74.22	20.39	83.38	10.56	66.31	28.87
Lange	46.67	37.84	18.91	37.33	20.00	37.17	20.36	41.74	10.56	33.69	27.81

†SL = Soil loss

For the study sites having slope gradients of less than 5%, the change in soil loss was higher in response to change in other input variables than to slope gradient. For instance, the change in estimated soil loss at AU Alluvial, AU Vertisol and Diredawa, all of which have slope gradients of less than 5%, showed more response to the soil conservation practise factor, annual rainfall and percent surface cover as compared to that of slope gradient.

The percentage reduction in soil loss in response to decrease in the soil conservation practice factor and mean annual rainfall was constant at all research sites due to the linear relationship between soil loss and these factors. A 20% decrease in these factors resulted in 20% decrease in soil loss for all study sites.

The effect of the changes in surface cover factor varied for different sites. A 20 percent increase in percentage surface cover reduced soil loss by a factor ranging from 14.42 % at Adele to 95.6 % at Diredawa. It was higher for areas with relatively higher initial percent cover (i.e. smaller C values). For Diredawa, Dugda Hidi, AU Alluvial, AU Regosol and Bedessa, increasing the percent cover by 20 % brought about the largest reduction in soil loss than other input variables.

In general, USLE is more sensitive to changes in slope gradients and surface cover and less so to that of slope length. The implication is that, a small deviation in estimating or measuring slope gradient and cover may lead to large errors in estimating the actual soil loss for a given area. Areas that have relatively small percent cover (C values greater than 0.50) such as Adele, Chiro, Gelemso, Hamaressa, Karamara and Lange showed less sensitivity to the 20% increase in percent cover. For these sites, soil loss was more sensitive to slope gradient, conservation practice factor and mean annual rainfall than the C factor.

The amount of error encountered in estimating soil loss due to inaccurate measurement or estimation of the input variables like conservation practice factor P and rainfall erosivity factor R is proportional to the degree of inaccuracy. That is, a 20% change in these variables results in a 20 % change in soil loss. Although the effect of slope length on soil loss is well recognized, the estimated soil loss is least affected by a change in slope length than other erosion factors.

3.4 Comparison of soil loss estimated by SLEMSA and USLE

A summary of soil loss values estimated by SLEMSA and USLE is presented in Fig. 3.3. Significant correlation (r = 0.87) was obtained between the soil loss values estimated by the SLEMSA and USLE. However, for some of the study sites, large variation was obtained between the pairs of soil loss values estimated by the two methods. Fig.3.3 indicates that soil loss estimated by SLEMSA is greater than that estimated by USLE for AU alluvial, Babile and Bedessa. For the rest of the study sites, however, the estimated values were higher using USLE than SLEMSA. The soil loss estimated by USLE as compared to SLEMSA is more than three fold for Adele and Diredawa and about twice for Amadle, AU Regosol and Hamaressa. The large differences between some of the values of soil losses estimated by the two methods can be attributed to the differences in the sensitivity of the two models to their input factors. At Adele, for instance, the F value (soil erodibility index) for SLEMSA is high indicating low erodibility (Table 3.1) and the C and LS factors of USLE for the same site are relatively high (Table 3.3). Hence, as the SLEMSA is highly sensitive to the soil erodibility factor and the USLE to the cover and topographic factors, the higher C and LS factors of USLE and the low erodibility indicator (high F value) for SLEMSA resulted in higher soil loss value for USLE than the SLEMSA model. Similarly, when the value of the factor(s) to which one of the models is highly sensitive is too high, the resulting estimated soil loss for that model will be higher and vice versa as compared to the soil loss estimated by the other model. However, as the reasons for the differences in the soil losses estimated by the two methods mainly result from combinations the effects of all factors involved in both models, no single factor is usually considered accountable for the variations.

Although the differences between the estimated soil losses using the SLEMSA and USLE is large for some sites, the majority of the study sites have nearly comparable soil loss values which are highly correlated.

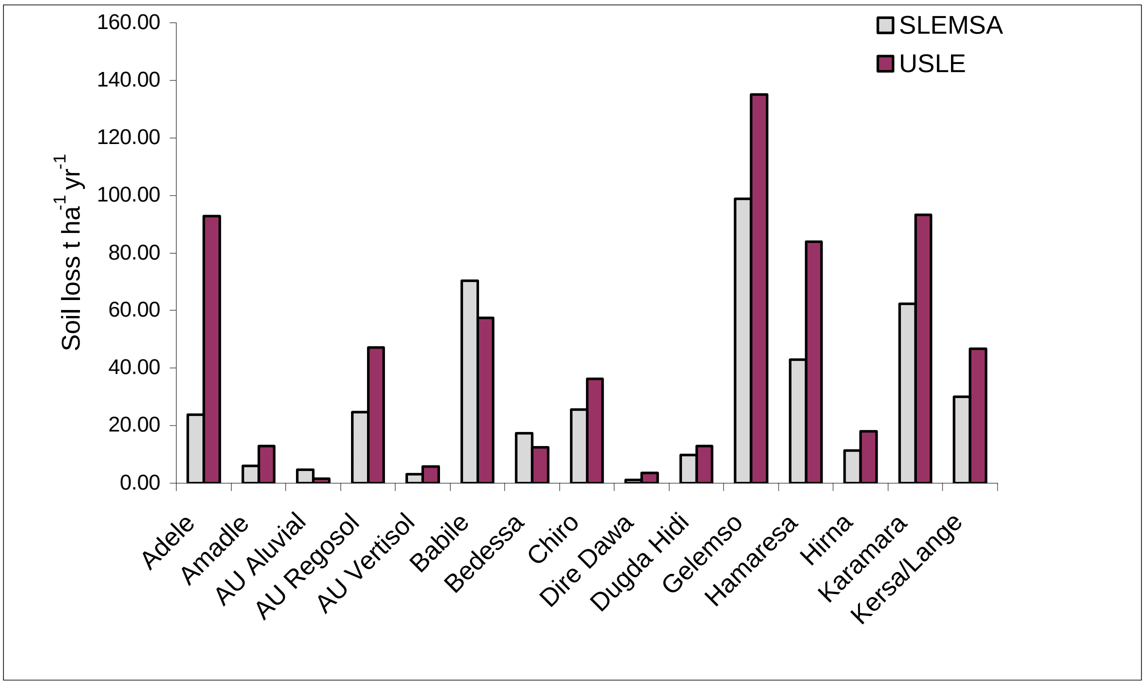


Fig. 3.3 Soil loss (t ha^{-1} yr^{-1}) estimated by SLEMSA and USLE at selected sites in Hareghe, eastern Ethiopia.

Therefore, depending on the relative ease of determination of the input variables and the level of accuracy required, either of the two methods can be used to assess the degree of severity of soil erosion under the prevailing conditions of Harerghe, east Ethiopia.

3.5 Qualitative comparison of soil erodibility indices determined in the laboratory trials and soil loss estimated using the SLEMSA and USLE models

In an attempt to validate the soil loss estimated by the USLE and SLEMSA models at different sites their values were compared to that obtained in the laboratory rainfall simulation trials. Although it could not be acceptable to compare exact figures it can be expected that tendencies should be comparable.

The 15 soils considered in this study were compared based on the amount of sediment transported by runoff from the small erosion trays in the laboratory. These values were used to rank the erodibility hazard as low, medium or high. This comparison was based only on the values of the sediment yield of the soils considered in the study and is not related to any other standard references. To simplify the comparison, the values were expressed as a percentage of the maximum value recorded for the soils in the study. Hence, those sites having percentage values of greater than 60% were considered as highly erodibile and are marked as H; 50 –60% Medium (M) and less than 50% were considered low (L).

Similarly, the erosion hazard of the research sites, where soil samples were collected for the lab trials, were also ranked based on the soil loss values estimated using the SLEMSA and USLE models. Here again, the estimated soil loss values for the different study sites were expressed as percentages of the maximum values obtained for each model. The erosion hazard was then ranked as high (when the percentage values were >20%), medium (10-20%) and low (<10%) for both cases.

The reason why different ranges of figures are used for the laboratory and model values is due to the fact that the laboratory values are relatively less dispersed indicating a minimum figure (when expressed as percentage of the maximum value) of 42% which is greater than most of the figures estimated by the soil loss models.

It should however be noted that the soil loss determined in the laboratory small trays doesn't normally represent the actual field conditions. Comparing such soil loss values with the estimated values without careful considerations to the limitations may therefore lead to wrong conclusions. In the rainfall simulation studies, the effects of many erosion factors are simplified just to obtain a relative estimate of the soil's susceptibility to erosion. Therefore, the values obtained in the laboratory should only be considered as relative indices to compare treatment effects. Examples of the limitations in the laboratory rainfall simulation experiments in this study include:

1. Difficulty to simulate the actual field topography: The erosion tray was very small and the various irregularities in the field landscape were not considered. Despite the differences in the actual topography of the study sites from where the soils were collected, all soils were subjected to 5° slope gradient for the laboratory rainfall simulation study.

2. Difficulty to simulate natural rainfall characteristics: The various study sites (from where the soils were collected) have different rainfall characteristics. However, it was difficult to simulate such variations in the laboratory. Therefore, all soils were tested at 60mm hr^{-1} of rainfall intensity that was applied for one hour.
3. No cover and management practice was taken into consideration for the laboratory studies. The simulated rainfall was applied on a bare soil surface.

On the other hand, soil loss estimation using erosion models takes almost all of these factors into consideration. Therefore, quantitative comparison of soil loss values obtained in the laboratory with those estimated using erosion models is impractical. However, to evaluate the effect of the inherent soil erodibility on the actual soil loss and assuming that all the other field specific factors are similar for the various study sites, some qualitative comparison has been made among the soils of the various study sites and are presented in Table 3.5.

Table 3.5 Comparison of soil loss values from laboratory trials and that estimated using the USLE and SLEMSA models as well as visual field observations.

Study sites	Relative erosion hazard						
	Estimated				Measured		Field observation
	SLEMSA		USLE		Lab Erodibility		Visual rating
	Value	Rating	Value	Rating	Value	Rating	
Adele	24	H	69	H	51	M	H
Amadle	6	L	10	L	52	M	L
AU Aluvial	5	L	1	L	72	H	L
AU Regosol	25	H	35	H	49	L	H
AU Vertisol	3	L	4	L	42	L	L
Babile	71	H	43	H	87	H	H
Bedessa	18	M	9	L	57	M	L
Chiro	26	H	27	H	65	H	H
Dire Dawa	1	L	3	L	60	M	L
Dugda Hidi	10	L	10	L	77	H	L
Gelemso	100	H	100	H	100	H	H
Hamaresa	44	H	62	H	45	L	H
Hirna	12	M	13	M	54	M	M
Karamara	63	H	69	H	62	H	H
Lange	30	H	35	H	49	L	H

H= High; L= Low; M= Medium
NB: The values in the table are expressed as percentages of the maximum value in each column.

As indicated in Table 3.5, qualitative assessment of the soil loss values obtained by using the SLEMSA and USLE models reveal that the values obtained by using both models agree well with the actual field observations for almost all of study sites though the actual quantitative values may differ. On the other hand, only 60% of the laboratory soil erosdibility values are in direct agreement with the estimated and observed soil erosion values. The reasons for the discrepancy may be different for the different sites. The laboratory soil erodibility for AU regosol, Hamaresa and Lange soils were low as opposed to the high erosion hazard at the sites as estimated using both models and based on field observations. In the cases where the laboratory trials indicate low erodibility (stable soils) in contrast to the higher field values, it can be concluded that the management of the field is poor. Other probabilities are inadequate simulation of the actual field topography of the sites in the laboratory that are normally more accountable for high erosion in the field. In the field, these soils occur on slopes of greater than 15% with undulating landform but all were set to slope gradients of 5° in the lab.

Some discrepancies between the estimated and measured soil loss values were also observed on some soils where the laboratory soil erodibility ranged from Medium to High (Amadle, AU Alluvial, Diredawa and Dugda Hidi) as opposed to the low estimated soil loss values. This could mean good field management or topography is again the main factor for these discrepancies. Almost all of these soils occur on a very low slope gradients (<5% slope gradient) with relatively flat landforms. Besides, most of these sites have low rainfall erosivity. Therefore, although these soils are potentially erodible as evidenced from the laboratory results, the level field topography and low natural rainfall erosivity of these sites are mainly responsible for the low soil erosion hazards.

In general, laboratory rainfall simulation studies are limited by various assumptions. Hence, these values cannot be reliably used for validation of various models. Meaningful validation of the erosion models for the study sites should be based on field based measurements of soil loss from runoff plots under natural rainfall conditions. It is however, worth mentioning that laboratory soil erodibility values provide some indications of the soils' inherent susceptibility to erosion and are valuable particularly when comparison of various treatment effects on soil erosion at a limited cost and controlled conditions are envisaged.

3.6 Estimation of tolerable soil loss and soil life for the study sites

Tolerable soil loss is defined as the maximum acceptable rate of soil erosion (Morgan, 1995). The only tolerable rate of soil loss equals the rate of soil formation. However, although the rates of soil loss can be measured, the rates of soil formation are so slow that they cannot be easily determined. The rate of soil formation throughout the world is estimated to range from 0.01 to 7.7mm y^{-1} (Buol et al., 1973) and the average is about 0.1mm y^{-1} (Zachar, 1982). In Africa, Dunne et al. (1978) estimated rates of soil formation in Kenya to range from 0.01 to 0.02 mm y^{-1} in the humid areas but fall bellow 0.01mm y^{-1} in the semi-arid areas. In Ethiopia, Hurni (1983 as quoted by Nyssen, 2003), categorized average soil formation rates based on the agro-climatic zones which are delimited based on altitude (m) and annual rainfall (mm). Accordingly, the soil formation rates ranged from 1 t ha^{-1} yr^{-1} for Berha "desert" (altitude <500m) to16 t ha^{-1} $year^{-1}$ for 'Wet Woina Dega' (altitude: 1500-2300m; annual rainfall >1400 mm) agro-climatic zones. (Appendix 5.0). The research sites in this study fall within three agroclimatic zones namely Dry Kolla, Dry Weyna Dega and Moist Weyna Dega and have soil formation rates of 3, 6 and 12 t ha^{-1} yr^{-1}.

Due to a wide variability of conditions affecting the rate of soil formation in a given locality, current values for soil loss tolerance are highly uncertain. Morgan (1995) also indicated that a better guideline to estimate tolerable soil loss is assessment of the rate of natural soil loss in the area. Assuming that the environment is stable under natural conditions, the rate of permissible soil loss will be close to the rate of new soil formation by weathering leading to tolerance values of 1 to 2 t ha^{-1} yr^{-1}. Soils with shallow root zone or other restricting characteristics are generally assigned lower tolerances (Kirkby and Morgan, 1980 quoted by Smith et al., 1997) which can be as low as 4.4 t $ha^{-1}yr^{-1}$ (El-Swaify et al., 1983 cited by Smith et al., 1997). Deep, medium textured, moderately permeable soils with subsoil characteristics favourable for plant growth are assigned tolerances of up to 11 t $ha^{-1}yr^{-1}$ (Smith et al., 1997). Soil loss tolerances of 3 to 10 t ha^{-1} yr^{-1} can therefore be considered for practical purposes.

In this experiment, the soil loss tolerance values were estimated by using the methods suggested by the Department of Agricultural Technical Services (1976) for SLEMSA model. Accordingly, the tolerable soil losses for the study sites that were estimated based on the bulk density (Table 2.3) of the soils ranged from 2 to 5 t $ha^{-1}yr^{-1}$ (Table 4.5). Based on this estimation, the soil loss estimated for all sites by SLEMSA and USLE are beyond the tolerable limit except for AU alluvial and Diredawa (compare Tables 3.1, 3.3 and 3.6). This indicates that the majority of the soils in Harerge under the current management situation are prone to severe degradation by water erosion if appropriate land management practices are not implemented to control the situation.

Estimates of the life expectancy of a soil under a given farming system, provide a basis for formulating land use practices, and where a limited soil life is envisaged, it will indicate the time available to devise means to reduce soil losses (Department of Agricultural Technical Services, 1976). It can also be used as a powerful argument in convincing farmers to adopt improved conservation practices.

To have a rough overview of the long-term erosion hazard in the study areas, the expected soil life for the top 0.15m of the productive soil surface has been estimated by using equation 3.15 and presented in Table 3.6.

$$Lf = \frac{D * M}{SL - Sf} \qquad (3.15)$$

Where, Lf = soil life (years),

D = soil depth in meters,

M = mass of soil in tones per hectare – meter ,

SL = Estimated rate of soil loss in t $ha^{-1}yr^{-1}$ and

Sf = Estimated rate of soil formation in t $ha^{-1}yr^{-1}$ (This value is considered to be insignificant and has not been considered in the calculation).

Table 3.6 indicates that, at the prevailing rate of soil erosion at most of the study sites in Harerge, the fertile top 15 cm of the soil surface will be lost and its productivity be severely affected within a period of 17 years at Gelemso and less than 40 years at Adele, Babile, Karamara and Hamaressa. In general, more than 50% of the study areas are likely to lose the top 15cm of the productive soil within a period of less than 100 years.

Table 3.6 Estimated tolerable soil loss and soil life for some sites in Harerge, eastern Ethiopia**.**

Study sites	†Estimated Soil loss t $ha^{-1}yr^{-1}$	Mass of soil t ha^{-1}-m	‡Tolerable Soil loss t $ha^{-1}yr^{-1}$	Soil mass t ha^{-1}-15 cm	No. of years to lose the top 15cm soil
Adele	58.25	12600	3	1890	32
Amadle	9.39	11000	2	1650	176
AU Aluvial	3.24	14200	4	2130	657
AU Regosol	35.99	13100	3	1965	55
AU Vertisol	4.44	9900	2	1485	335
Babile	63.85	15700	5	2355	37
Bedessa	14.85	10900	2	1635	110
Chiro	30.95	11000	2	1650	53
Dire Dawa	2.60	14800	4	2220	855
Dugda Hidi	11.34	11200	2	1680	148
Gelemso	116.94	13600	3	2040	17
Hamaresa	63.39	12200	3	1830	29
Hirna	14.68	10900	2	1635	111
Karamara	77.80	13000	3	1950	25
Lange	38.31	13000	3	1950	51

†Estimated soil loss is the average of soil loss values estimated by SLEMSA and USLE models.

‡Tolerable soil loss is estimated based on the recommendation of Department of Agricultural Technical Services (1976) for light, medium and heavy textured soils.

It should be noted however that, none of these models were meant for estimation of soil loss from steep slopes and rugged topographies like the ones dominating most of the Ethiopian highlands including Hareghe. Therefore, the actual soil loss under most of the Ethiopian conditions, where erosion is largely exacerbated by the high velocity and volume of surface flow, could more likely be greater than the estimated values resulting in much shorter soil life than the ones indicated in Table 3.6. Hence, the soil life indicated here should only be considered as rough relative estimates as the actual time required for erosion of a given depth of soil is a function of many other factors that are not taken care of in either of these models and require a detailed process based analysis (Nearing et al., 1994; Morgan, 1995).

3.7 Conclusion

The amount of estimated soil loss from rill and interill areas obtained by using SLEMSA and USLE for the study sites in Harerge, eastern Ethiopia varied among the sites. The soil loss values estimated by these methods were however, highly correlated. In both cases, the estimated soil loss was higher for Gelemso, Babile, Hamaressa and Karamara but lower for AU alluvial, AU Vertisol and Diredawa. These variations in soil loss among the study sites were functions of the interactions of the various factors affecting erosion.

Sensitivity analysis of the models to their input variables revealed that SLEMSA was highly sensitive to changes in rainfall kinetic energy (E) and soil erodibilty (F) and was less sensitive to slope length and vegetal cover. On the other hand, for the majority of the study sites, USLE was highly sensitive to slope gradient and cover but less sensitive to slope length. Considering the magnitude of percent reduction in soil loss with 20% change in the input factors, the rainfall kinetic energy factor (E) and Soil erodibility index (F) of SLEMSA brought about the largest reductions. In this respect, SLEMSA can be considered highly sensitive to changes in most of its input variables than USLE. But most of these changes are little affected by management practices.

Among the factors involved in estimating soil loss in both models the rainfall erosivity factor is not usually directly affected by different management practices. However, soil erodibility, topographic, cover and conservation practice factors can be modified through various soil and land management practices. Therefore, the fact that the USLE is more sensitive to changes in slope gradient and cover (which can be modified through improved management practices) than the SLEMSA may suggest the suitability of using the USLE especially where comparison of the effects of cover management and conservation practices on soil loss deems important.

To obtain a reasonably accurate soil loss index for a given site using either of these models, the most sensitive inputs variables should be estimated or measured as accurately as possible because slight error in measuring these input variables results in a tremendous deviation of the estimated soil loss from the actual one.