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Prediction of Soil Loss in the Northern Part of Somali Region of Ethiopia Using Empirical Soil Erosion Models

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ABSTRACT

Two empirical soil loss models, namely Universal Soil Loss Equation (USLE) and Soil Loss Estimation Model for Southern Africa (SLEMSA) were applied to assess extent of erosion hazard at 12 selected sites in the northern part of Somali region of Ethiopia. The amount of estimated soil loss for 10 out of 12 sites by using the USLE is by two to three and half times greater than that estimated by SLEMSA. The difference between the values of soil loss estimated by the two models can be attributed to the difference in the sensitivity of the models to their input factors. In general, since SLEMSA under estimate the amount of soil loss from a given site, it is recommended to use USLE to estimate soil loss in the northern part of the Somali region of Ethiopia.

The sensitivity of both models to their 20% increase or decrease in one of their input variable at a time while keeping other variables constant was analysed. The analysis indicated that USLE was highly sensitive to slope gradient factor (S), soil conservation practice factor (P) and rainfall erosivity factor (R) but less sensitive to slope length (L) and vegetal cover factor (C). Whereas, SLEMSA was highly sensitive to change in rainfall kinetic energy (E) and soil erodibility (F) and was less sensitive to slope gradient (S), slope length (L) and percent cover factor (C).

Key words: erosion model, Ethiopia, northern Somali region, soil erosion, soil loss, SLEMSA, USLE

INTRODUCTION

Soil erosion has long been a serious problem in Ethiopia, especially in the highlands. It has caused widespread ecological damage. Environmental degradation, especially soil erosion by water, has increasingly affected the Ethiopian highlands for more than 2000 years, and reached its peak with the population growth in the country, when more land had to be cultivated than ever in search of feeding more people (Hurni, 1985). The northern part of Somali region of Ethiopia, especially the highlands (with altitude greater than 1500 m above sea level) are among the highly affected areas by land degradation due to erosion.

Soil conservation activities in the region have been the concern of governmental and non-governmental organizations since 1974. Despite the considerable efforts made for controlling soil erosion, the out put was not a satisfactory. The extent of the damage is not exactly known but one can be sure from casual observation that quite a

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considerable part of the region is affected severely. The problems are related to the inappropriate assessment sequence from planning stage to implementation. One of the main reasons is lack of satisfactory tools (procedure) for predicting soil loss (Taffa, 2001). By predicting extent of soil erosion and factors responsible for it, the proper planning and implementation of soil conservation measures could be achieved. The objectives of this study were to asses the erosion hazards in the selected areas of the northern part of Somali region of Ethiopia using USLE and SLEMSA models and to know the responses of the models to their input variables.

MATERIALS AND METHODS

Description of the study sites

A survey involving visual observation and study sites characterization and soil sampling at the selected representative sites were carried out, as shown in Figure 1. Summarized description of the study sites is given in Table 1.

Selection of models for use in the present study

The USLE and SLEMSA models were considered for use in this study due to mainly their simplicity and less input requirement. Furthermore, the application USLE for Jijiga area

Table 1 Description of the study sites in the northern Somali region of Ethiopia.

Study site	Geographical location	Topography (Slope gradient %)	Copping system	Rainfall seasons	Rainfall (mm)	Major rocks	Soil texture
Amadle	N9⁰26' E43⁰01'	9	Maize, Sorghum	March-May July-October	521	Limestone Sandstones	Sandy clay loam
Awbare	N8⁰25' E44⁰15'	13	Maize, Chat Bean, Potato	March-May July-October	510	Limestone Sandstones	Sandy clay loam
Babile	N9⁰13' E42⁰37'	10	Maize, Chat Groundnut	March-May July-October	671	Granite	Sandy loam
Beyo	N4⁰22' E41⁰62'	10	Maize, Chat Bean	March-May July-October	661	Limestone Sandstones	Clay loam
Chincsan	N9⁰44' E42⁰6'	6	Maize, Chat Bean, Potato	March-May July-October	661	Limestone Sandstones	Clay
Elbehe	N7⁰82' E44⁰98'	9	Maize, Sorghum	March-May July-October	661	Limestone Sandstones	Sandy clay
Gabegabo	N7⁰26' E44⁰53'	12	Maize, Chat	March-May July-October	661	Limestone Sandstones	Silt clay
Hadaw	N9⁰35' E42⁰68'	8	Maize, Chat	March-May July-October	661	Limestone Sandstones	Sandy loam
Harshin	N3⁰64' E39⁰63'	5	Maize, Sorghum	March-May July-October	521	Limestone Sandstones	Clay loam
Kabribyah	N9⁰9' E43⁰18'	2	Maize, Sorghum	March-May July-October	521	Limestone Sandstones	Silt clay
Shinile	N9⁰67' E41⁰87'	3	Maize, Sorghum	March-May July-October	651	Granite Limestone	Loam
Tulu	N9⁰61' E42⁰75'	4	Maize, Sorghum Wheat, Potato	March-May July-October	661	Limestone Sandstones	Silt clay

is validated by comparing predicted with measured annual soil loss values from standard runoff plots and by applying measure of goodness-of-fit (Figure 2) (Sultan *et al*., 2006). Significant correlation coefficient (r=0.98) was obtained between the measured soil loss values and these predicted using USLE suggesting that if parameters in the USLE are locally established, the application of USLE can predict annual soil loss for the northern part of Somalia. Therefore, it can be used to provide first hand information for different planning purposes in data-poor situations like the northern part of Somali region. It was further used in this study to compare the values of the estimated soil loss by using it with that values estimated by using SLEMSA model. The details of the descriptions of the input factors considered, their assumptions, procedures and sensitivity analysis of the USLE and SLEMSA models are presented in the following sections.

Estimation of soil loss using USLE

For the estimation of soil erosion, Universal Soil Loss Equation (USLE) was

Figure 1 Map of northern part of Somali region of Ethiopia.

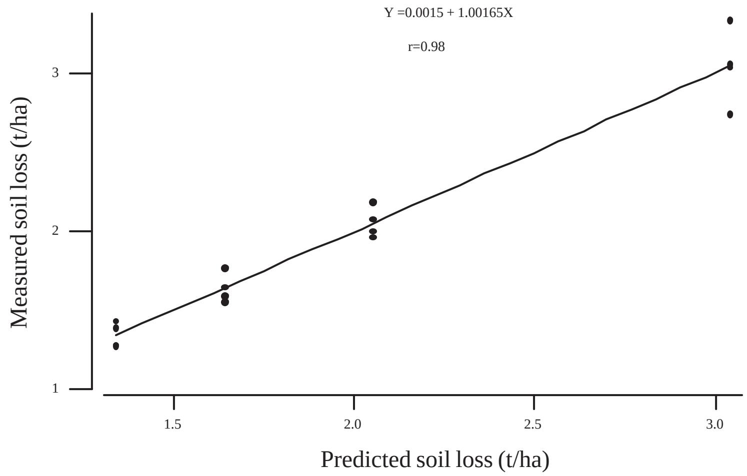

Figure 2 Correlation between measured and predicted soil loss in the Jijiga area (after Sultan *et al.*, 2006).

published by the US Agricultural Research Service (1961) and was further developed by Wischmeirer and Smith (1978). It gives the potential removal of soil from the land's surface by running water as a result of splash, sheet, and rill erosion. It enables the planners to predict the annual rate of soil erosion for alternative crop systems and managements practices (Wischmeier and Smith, 1978). The USLE involves:

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

Where, A is average annual soil loss (t $ha^{-1}yr^{-1}$), R is rainfall erosivity factor (MJ.mm $(ha\ h)^{-1}$, K is soil erodibility factor (t $ha^{-1}yr^{-1}$) and LS is topographic factor, C is crop cover factor, and P is soil conservation practice factor. The procedures used to estimate the factors in USLE are as follows.

The rainfall erosivity factor (R)

The erosivity factor R that was adopted by Hurni (1985) for the Ethiopian conditions based on the available mean annual rainfall P_r was used in this study. It is given by a regression equation:

$$R = 8.12 + 0.562 * P_r \quad (2)$$

Where, P_r is the mean annual rainfall in mm and R is the calculated erosivity in MJ mm $(ha\ h)^{-1}$ for the study sites.

Soil erodibility factor (K)

Since the silt fraction of soils of the study sites does not exceed 70%, equation (3) (after Wischmeier and Smith, 1978) was used to estimate the K values for the USLE. The laboratory analysis of particle size and organic matter content of composite soils samples of the study sites together with permeability coding for soil textural classes according to Renard *et al.* (1991) and soil structural coding according to Wischmeier *et al.* (1971) were the main sources of input data used in the equation (3).

$$K = 0.01317[0.00021(12 - OM\%)M^{1.14} + 3.25(S_s - 2) + 2.5(P_s - 3)] \quad (3)$$

Where, OM%=Percent organic matter, Ss=Structure code, Ps=Permeability code, M=Product of the primary particle size fractions, i.e., [SS%*(SS%+S)], SS%=Percent silt plus very fine sand (0.002-0.1 mm size fraction) and Sa=percent sand (0.1-2 mm size fraction)

Cover management factor (C)

The same assumptions pertaining to the percent cover of crops during the various seasons of a year that was used for SLEMSA were also 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 was 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 and the sum of these values for the four seasons was considered as the mean annual C value for a particular site. The individual C values of each period were weighted according to the percentage of the mean annual rainfall in that period and summed to obtain the annual C value.

Topographic factor (LS)

A representative slope length and slope gradient for the study sites under consideration were measured and values were recorded during the field survey. Those values were combined into a single index as indicated in equation (4) and were used to calculate the dimensionless topographic factor (LS) (Wischmeier and Smith, 1978):

$$\mathrm{LS} = \left(l/22.13\right)^{n}\left(0.065 + 0.045S + 0.0065S^{2}\right) \quad (4)$$

Where, l=slope length in m, n=an exponent related to slope gradient (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) and S=slope gradient in percent.

Erosion control practice factor (P)

Tillage and planting on contour reduce soil erosion depending on the slope of the land. A P value for different erosion control practices is given by Roose (1977) and Morgan (1995). Based on these values, the P values of the study sites were estimated.

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 conservation practice factor were all reduced by 20% to evaluate the changes in estimated soil loss. The soil erodibility factor (K) was not considered in soil sensitivity analysis mainly because of the complication resulting from several factors affecting it.

Estimation of soil loss using SLEMSA

Soil Loss Estimation Model for Southern Africa (SLEMSA) was initially developed largely from data from the Zimbabwe to evaluate the erosion resulting from different farming systems so that appropriate conservation measures could be recommended. The technique has been adopted through out the countries of Southern Africa (Elwell 1978). The SLEMSA model is essentially a model for soil removal (Schulze, 1979). It can be regarded as a useful model in differentiating areas of high and low erosion potential (Schulze, 1979). The SLEMSA involves:

$$Z = KXC \quad (5)$$

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 30 m long, 10 m wide, at 2.5^{0} slope for a soil of known erodibility (F) under a weed-free bare fallow, X= dimensionless topographic factor, and C= dimensionless crop management factor. The procedures used to estimate the factors in SLEMSA are as follows.

Estimation of soil erodibility index (F)

Field observation of the study sites and laboratory soil analysis were the main sources of input data used. The soil erodibility index F was estimated based on the soil textural classes and other relevant soil surface and subsurface conditions that directly or indirectly affected 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 (Morgan, 1995).

Estimation of K factor

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

$$\ln K = b \ln E = a \quad (6)$$

Where E is in Jm^{-2} and the values of and b are functions of the soil erodibility factor (F):

$$a = 2.884 - 8.1209F \quad (7)$$

$$b = 0.4681 + 0.7663F \quad (8)$$

By substituting equations 7 and 8 into equation 6, we get

$$K = \exp[(0.4681 + 0.7663F)\ln E + 2.884 - 8.1209] \quad (9)$$

Estimation of rainfall kinetic energy (E)

Owing to the lack of detailed daily rainfall intensity data for the study sites under consideration, the tabulated provisional values of rainfall energy (E) as quoted in US Department of Agricultural Technical Services (1976) based on the mean annual rainfall were used for this study.

Topographic factor (X)

A representative slope length (L in m) and slope gradient (S in percent) for the study sites under consideration were measured and values were recorded during the field survey. Those values were feed into equation (10) (Schulze, 1979; Morgan, 1995):

$$X = \sqrt{L}\left(0.76 + 0.53S + 0.076S^2 / 25.65\right) \quad (10)$$

Assumptions used to estimate the C values for SLEMSA

The cover information for the sites was obtained through visual observation for the sites and by estimation 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 seasons of the year was estimated based on the growing seasons of each crop and the temporal rainfall distribution. Therefore, a year was divided into four seasons representing three months each (Bobe, 2004) as follows: 1) January to March - relatively small percent cover was assigned to crop, 2) April to June – more cover that January - March 3) July to September - maximum surface cover was assigned, and 4) October to December - a relatively better estimate of cover was assigned to crop.

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 are as follows:

1. 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.

2. 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 value.

3. The sum of values for the four seasons was taken as the annual rainfall interception for given locality.

4. For crops and natural grasslands with $i<50$ percent the crop management factor C was calculated using equation 11.

$$C = (2.3 - 0.01i)/30 \quad (11)$$

Where, C is crop management factor and i is percentage of the rainfall energy intercepted by the crop.

Sensitivity analysis of SLEMSA to its input variables

The sensitivity of the soil loss estimated by SLEMSA to changes in some of its input variable was tested by increasing or decreasing one factor at a time 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.

RESULTS AND DISCUSSION

Estimated soil loss at the study sites using USLE

Estimated values of the USLE factors and the amount of soil loss in tons per hectare per year are presented in Table 2. The highest soil loss was estimated for Gabegabo 122.07 t $ha^{-1}yr^{-1}$ and Beyo 111.37 t $ha^{-1}yr^{-1}$. Both sites are characterized by the high LS and P factor values. Kabribyah, with the lowest soil loss estimate, is characterized by the lowest K and LS factor values. The estimated R, K and C factor values for Beyo site are almost equal to those estimated for Elbehe site. However, the soil loss estimated for Beyo site is 1.7 times greater than that for Elbehe site. This is mainly due to the higher topographic and conservation practices factor values estimated at Beyo. Similarly, comparably equal values of R, K and C factors was the estimated for Chinasan and Gabegabo sites. But the higher soil loss estimate recorded for the later site was due to the higher value estimated for its P and LS factors. Despite the higher values of R, K and P factors estimated for Hadaw site than for Aw-bare site, equal amount of soil loss were estimated at both sites. This was due to a relatively higher topographic factor value in the Aw-bare site. The results indicate that all the soil loss factors in USLE are important in estimating the amount of soil loss.

In general, 10 sites out of 12 study sites have estimated soil loss 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 estimated soil losses for the study sites are with in the range of soil loss estimated for the Ethiopian high lands by the Soil Conservation Research Project (SERP) which ranges from 0 to 300 t $ha^{-1}yr^{-1}$ (Hurni, 1985).

Table 2 Estimated values of erosion factors and soil loss estimated using USLE for some soils of northern part of Somali region, Ethiopia.

Research site	P	C	K	LS	R	Soil loss(t/$ha^{-1}yr^{-1}$)
Amadle	0.7	0.45293	0.18	1.89466	284.880	30.80
Aw-bare	0.45	0.48703	0.14	4.98668	278.420	42.60
Babile	0.8	0.53271	0.18	2.71285	369.150	76.82
Beyo	0.8	0.49724	0.22	3.50227	363.362	111.37
Chinasan	0.15	0.49252	0.19	0.93691	363.362	4.78
Elbehe	0.7	0.45026	0.22	2.59437	363.362	65.36
Gabegabo	0.9	0.52225	0.23	3.10766	363.362	122.07
Hadaw	0.7	0.53235	0.19	1.64822	363.362	42.40
Harshin	0.25	0.45293	0.37	1.00884	284.880	12.04
Kabribyah	0.5	0.45293	0.12	0.30787	284.880	2.38
Shinile	0.25	0.45962	0.41	0.67074	358.000	11.31
Tulu	0.5	0.49330	0.41	0.99011	363.362	36.38

Sensitivity analysis of USLE to its input variables

The estimated soil losses after 20% change in the input variables and the percentage changes as compared with the base valves are presented in Table 3.The results indicate that for USLE, the highest reduction in soil loss in response to 20% change in the input variables was due to slope gradient. Moreover, it can be seen that sensitivity of a 20% decrease in slope gradient increase on middle range slopes from 6 to 3 % and on steeper slopes from 8 to 13%. However, it is less pronounced at slope gradient of 2 %. For 10 out of the 12 study sites, the percentage reduction in soil loss in response to the 20% decrease on slope gradient can be rated as: Shinile> Harshin> Chinasan> Aw-bare> Gabegabo> Babile=Beyo> Amadle=Elbehe> Hadaw in accordance with their increasing order.

Except at Kabribyah with 2% slope gradient, reducing the slope gradient by 20% reduced soil loss by more than 21% for all the sites. Moreover, the change in estimated soil loss at Kabribyah showed more response to the soil conservation practice factor and annual rainfall as compared to that of slope gradient. The implication is that the sensitivity of slope gradient is more pronounced at slope gradients of more than 2%.

The results also indicate that the USLE is least sensitive to changes in slope length and percent surface cover at all study sites as compared to the other factors evaluated. A 20% decrease in slope length resulted in maximum of 10.56% decrease in soil loss for all sites having slope gradients greater than 5%. A 20% increase in percentage surface cover reduced soil loss by a factor ranging from 9.75 to 11.48% for all the study sites. All the sites have showed less sensitivity to 20% increase in percent cover due to the fact that they had small initial percent cover (C values greater than 0.45).

For all the study sites, a 20% decrease in the mean annual rainfall and the soil conservation practice factor resulted in 20% decreases in soil loss. This is due to the linear relationship between soil loss and these factors. This is consistent with general principle of soil loss, which holds that less soil loss generally goes with less rainfall and soil conservation practice factor. That is, the lower the rainfall amount and soil conservation practice factor (the better the soil conservation practice); the lower will be the estimated soil loss.

In general, USLE is more sensitive to change in slope gradients, soil conservation practice, rainfall erosivity factors than the slope length and the surface cover factors. This implies that the amount of error encountered in estimating or measuring these input variables may result in larger error in estimating the soil loss for the study sites.

Estimated soil losses using SLEMSA

The values for factors involved in the SLEMSA model and the predicted soil loss for the study sites using this model is presented in Table 4. The estimated soil losses for the study sites in northern Somalia region of Ethiopia ranged from 1.61 t $ha^{-1}yr^{-1}$ for Chinasan to 47.33 t $ha^{-1}yr^{-1}$ for Hadaw (Table 4). The highest soil loss estimated at Hadaw is mainly due to its highest K valve (Table 4) which is a function of rainfall erosivity and soil erodibility factors. This again mainly associated with its higher mean annual rainfall (661 mm) averaged over 53 years. The estimated soil losses were also relatively higher at Beyo, Gabegabo, Babile and Elbahe all of which were above 32 t $ha^{-1}yr^{-1}$. For these sites where relatively higher soil loss estimates were recorded have similar valves for crop cover factor with that of Hadaw's and lower K factor valves than that of the Hadaw's site. However, their X values are even higher than that of the Hadaw. In these sites, X factor together with K factor are highly contributed to estimated soil loss values.

The lowest estimated soil loss valves were obtained for Chincsan, Kabribyaha, Harshin

Table 3 Changes in soil loss with changes in input variables of USLE for soils of northern part of Somali region of Ethiopia.

Study sites	SL Basic 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
Amadle	30.80	19.62	10.81	17.62	20	17.62	20	19.70	10.56	16.04	27.14
Aw-bare	42.60	51.04	10.13	44.30	20	44.30	20	49.53	10.56	39.15	29.30
Babile	76.82	51.22	11.08	43.45	20	43.45	20	48.58	10.56	39.21	27.81
Beyo	111.37	74.66	10.61	66.42	20	66.42	20	74.27	10.56	59.94	27.81
Chinasan	4.78	14.37	9.749	12.41	20	12.41	20	13.87	10.56	10.63	31.48
Elbehe	65.36	41.61	10.86	37.40	20	37.40	20	41.82	10.56	34.06	27.14
Gabigabo	122.07	72.89	10.42	64.07	20	64.07	20	71.63	10.56	56.96	28.87
Hadaw	42.40	27.27	9.95	23.47	20	23.47	20	26.24	10.56	21.60	26.36
Harshin	12.04	21.47	10.81	19.28	20	19.28	20	21.56	10.56	15.84	34.30
Kabribyah	2.38	2.55	10.81	2.29	20	2.29	20	2.67	6.48	2.43	15.11
Shinile	11.31	20.38	9.89	18.12	20	18.12	20	20.71	8.54	14.53	35.85
Tulu	36.38	32.20	11.48	29.21	20	29.21	20	33.39	8.54	28.83	21.04

SL=soil loss

Table 4 Estimated input variables of SLEMSA model and calculated soil loss in t $ha^{-1}yr^{-1}$ for some selected sites in northern part of Somali region of Ethiopia.

Research Site	F	a	b	E	K	X	C	Z($tha^{-1}yr^{-1}$)
Amadle	4.0	29.956	3.53330	12200	38.317	4.0750	0.0636223	9.93
Aw-bare	4.5	34.061	3.91645	12200	24.302	10.7195	0.0639617	16.66
Babile	3.5	25.851	3.15015	14000	93.199	5.8338	0.0649713	35.32
Beyo	3.5	25.851	3.15015	14000	93.199	7.5314	0.0637647	44.75
Chinasan	6.0	46.376	5.06590	14000	12.451	2.0161	0.0643087	1.61
Elbehe	3.5	25.851	3.15015	14000	93.199	5.5799	0.0633837	32.96
Gabegabo	3.5	25.851	3.15015	14000	93.199	6.6811	0.0639223	39.80
Hadaw	2.5	17.641	2.38385	14000	208.496	3.5455	0.0640293	47.33
Harshin	4.5	34.061	3.91645	12200	24.302	2.1712	0.0636223	3.35
Kabribyah	4.0	29.956	3.53330	12200	38.317	0.9441	0.0636223	2.38
Shinile	4.5	34.061	3.91645	14000	41.661	1.8325	0.0642767	4.90
Tulu	4.0	29.956	3.53330	14000	62.312	2.7659	0.0638233	10.99

and Shinile. These sites have similar valves for the crop cover factor with other sites where relatively high soil losses were estimated. However, their valves of the K and X factors are very low resulting in low soil loss valves. At Elbehe, the estimated value of X factor is less by half than that of Aw-bare. Higher soil loss estimated for the former site was due to the higher K factor value. In general, although one or two factors may be responsible for the higher or lower soil loss in a given area, the combined effect of the valves of all the three factors of SLEMA is most important.

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

The estimated soil loss due to changes in one of its input variables while keeping the other constant and the percentage change as compared to the original estimated soil loss is presented in Table 5. Soil loss responded highly to change in soil erodibility factor F for all study sites. A 20% increase in the value of soil erodibility factor F almost halved the estimated soil loss at Amadle, kabribyah Tulu, Harshin, Shinile and Aw-bare, and the minimum response to change in soil erodibility factor was 33.14% which was recorded at Hadaw.

The change in soil loss due to 20% decrease in rainfall kinetic energy index (E) is directly proportional to the valves of the soil erodibility factors (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 Chinasan soil that has the highest estimated F values, the estimated soil loss decreased by 67.71% with 20% decrease in the E valve. Further more, the estimated soil losses at 11 of the 12 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 41.25% decrease in soil loss at Hadaw. This can be associated with the smaller F values for Hadaw soils.

A 20% decrease in slope gradient also reduced estimated soil loss by 15.13 - 29.28%. 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 gradient than those with lower slope gradients. Accordingly, for Aw-bare that has slope gradient of 13% and Kabribyahа with slope gradient of 2% the estimated soil loss was reduced by 29.28% and 15.13 % respectively for a 20% reduction in their slope gradients.

Table 5 Response of soil loss estimated by SLEMSA to changes in some input variable.

Study sites	SL Basic value	SL due to 20% increase in F		SL due to 20% decrease in E		SL due to 20% % decrease in S		SL due to 20% decrease in slope length		SL due to 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
Amadle	9.93	4.79	51.73	4.5156	54.54	7.23	27.12	8.88	10.56	9.53	4.10
Aw-bre	16.66	7.34	55.93	6.9535	58.26	11.78	29.28	14.90	10.56	16.00	3.97
Babile	35.32	20.10	43.08	17.4907	50.48	25.50	27.78	31.59	10.56	34.05	3.60
Beyo	44.75	25.47	43.08	22.1611	50.48	32.32	27.78	40.03	10.56	42.95	4.05
Chinasan	1.61	0.61	61.94	0.5212	67.71	1.22	24.28	1.44	10.56	1.55	3.84
Elbehe	32.96	18.76	43.08	16.3205	50.48	24.02	27.12	29.48	10.56	31.58	4.19
Gabegabo	39.80	22.65	43.08	19.7076	50.48	28.31	28.85	35.60	10.56	38.21	3.98
Hadaw	47.33	31.64	33.14	27.8056	41.25	34.86	26.34	42.33	10.56	45.46	3.95
Harsin	3.35	1.48	55.93	1.4009	58.26	2.58	22.86	3.00	10.56	3.22	4.10
Kabribyah	2.38	1.11	51.73	1.0462	54.54	1.95	15.13	2.05	10.56	2.20	4.10
Shinile	4.90	2.38	51.55	2.0477	58.26	3.99	18.59	4.38	10.56	4.72	3.85
Tulu	10.99	5.77	47.48	5.0000	54.54	8.68	21.03	9.83	10.56	10.56	4.02

SL=soil loss

The percent decrease in soil loss for 20% decrease in slope length was constantly 10.56 for all sites. For all the study sites, a 20% increase in percent cover (rainfall interception) reduced estimated soil loss by less than 4.2%. It seems that SLEMSA is the least sensitive to increase in percent cover as compared to that for the other input variables.

In general, though the response of soil loss to change in any one factor varied among the sites the changes was most sensitive to decrease in E as compared to the other factors. For most of the study sites, the effect of the five factors can be rated as E>F>S>L>i in accordance with their relative importance towards affecting the magnitude of the estimated soil loss with equal change in these factors. Bobe (2004) also reported similar results for selected sites in the eastern Ethiopia. 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 estimated in this study should be taken in to consideration during interpretation and comparison of soil loss values at various sites.

Comparison of soil loss estimated by SLEMSA and USLE

Figure 3 presents the soil loss values estimated by USLE and SLEMSA. For all the study sites, except for Hadaw and Kabribyaha, the soil loss estimated by USLE is by two to three and half times greater than that estimated by SLEMSA. The difference between the values of soil loss estimated by the two models can be attributed to the difference in the sensitivity of the two models to their input factors. Altshul (1993)

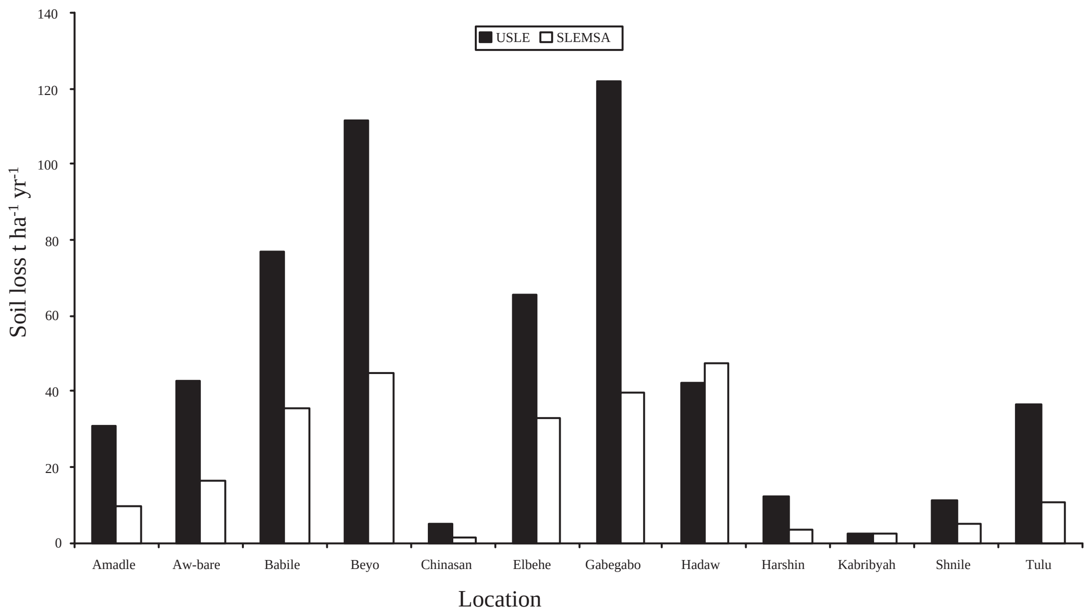

Figure 3 Soil loss (t ha^{-1} yr^{-1}) estimated by SLEMSA and USLE at selected sites in northern part of Somali region, Ethiopia.

applying the two models in the Middle Veld of Swaziland also found the soil loss estimations made by the USLE were four to five times greater than those of SLEMSA. Significant correlation (r=0.84) was obtained between the soil loss values estimated by USLE and SLEMSA. However, SLEMSA under estimated the amount of soil loss from a given site. It is, therefore, recommended to use USLE to estimate soil loss in the northern part of the Somali region of Ethiopia. Sultan *et al*. (2006) also validated the applicability of USLE for Jijiga by comparing predicted with measured annual soil loss values from standard runoff plots and by applying measure of goodness-of-fit.

CONCLUSIONS

The amount of estimated soil loss for 10 out of 12 sites by using the USLE is by two to three and half times greater than that estimated by SLEMSA. The difference between the values of soil loss estimated by the two models can be attributed to the difference in the sensitivity of the models to their input factors. In general, since SLEMSA underestimates the amount of soil loss from a given site, it is recommended to use USLE to estimate soil loss in the northern part of the Somali region of Ethiopia.

Sensitivity analysis of both models to their input variables indicated that USLE was highly sensitive to slope gradient factor (S), soil conservation practice factor (P) and rainfall erosivity factor(R) but less sensitive to slope length factor (L) and vegetal cover factor (C). Whereas, SLEMSA was highly sensitive to change in rainfall kinetic energy (E) and soil erodibility (F) and was less sensitive to slope gradient (S), slope length (L) and vegetal cover factor (C).

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