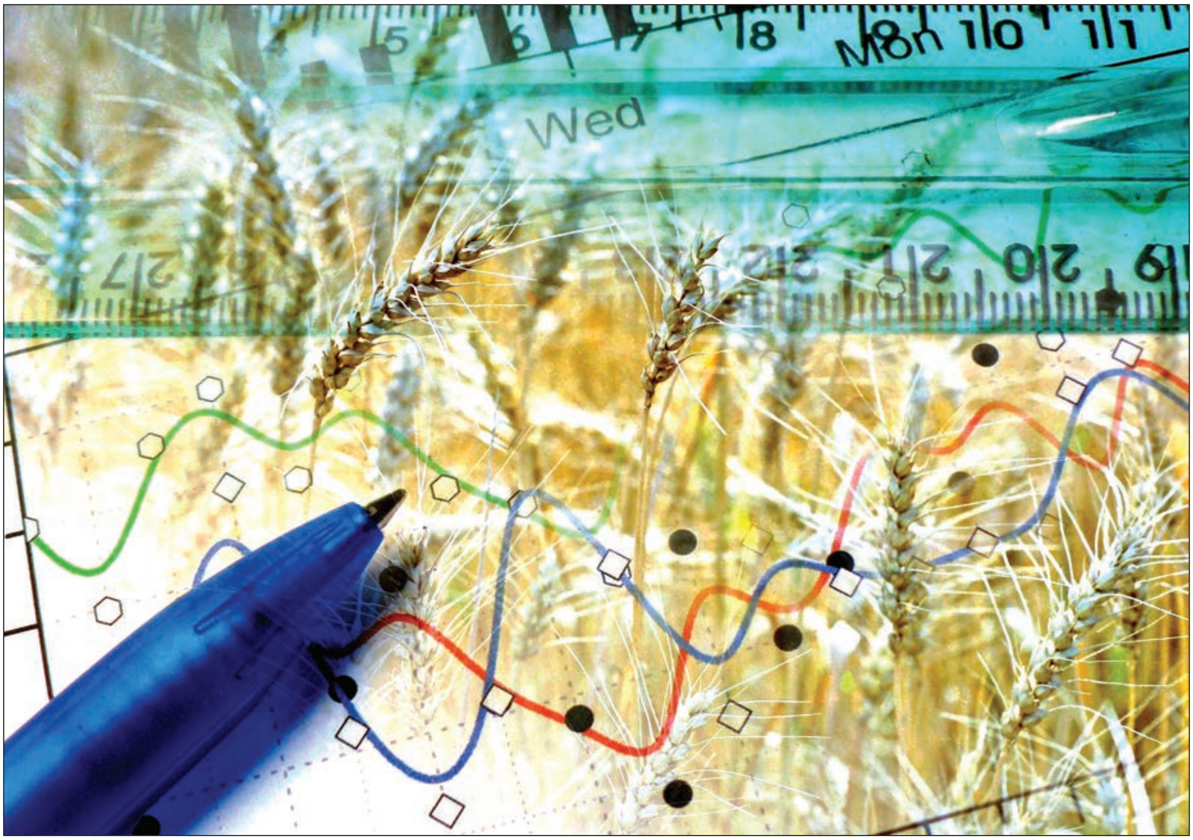

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Research Article
Estimation of Soil Loss Using Revised Universal Soil Loss Equation and Determinants of Soil Loss in Tiro Afeta and Dedo Districts of Jimma Zone, Oromiya National Regional State, Ethiopia

Adeba Gemechu

College of Agriculture and Veterinary Medicine, Jimma University, Ethiopia

Abstract
Soil erosion is the principal cause of land degradation and a major constraint to agricultural development in developing countries like Ethiopia. Tackling the problem of soil erosion requires understanding of the rates of soil loss. In this study, an attempt is made to quantify soil loss due to water erosion at plot level in Dedo and Tiro Afeta district areas. The amount of soil loss was predicted using RUSLE model and adapted to Ethiopian conditions. Primary data were collected from 150 randomly selected farm households, managing about 750 plots through individual interviews using semi-structured questionnaires. The result of the study revealed that, the lowest soil loss is estimated on flat plains (<2% slope) to be about 1.59 t ha^{-1} year^{-1}, which is less than the minimum tolerable soil loss (2 t ha^{-1} year^{-1}) for the country. However, the highest soil loss is from steep slopes (up to 35%) at about 31.7 t ha^{-1} year^{-1}, about twice the maximum tolerable soil loss (18 t ha^{-1} year^{-1}). The average soil loss rates at cut-off point ranges on average from 1.59-31.7 t ha^{-1} year^{-1}. In order to reverse the soil loss into fertile soil, the farm households need to have a minimum of formal education for using soil and water conservation technologies and guaranteeing the sustainability of soil loss for enhancement of productivity of each plot. The study results suggest that selecting priority intervention areas and rehabilitating soil loss management strategies should consider the socio-economic characteristics and plot specific characteristics of the farm households.

Key words: Soil loss, plot specific characteristics, RUSLE factors, tolerable soil loss

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Corresponding Author: Adeba Gemechu, College of Agriculture and Veterinary Medicine, Jimma University, Ethiopia

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Growing degradation and loss of soil means that the expanding population in many parts of the world is pushing this resource to its frontier. Thus soil degradation by accelerated water-induced erosion is a serious problem and will remain so especially in developing countries. Agriculture is the largest single source of livelihood and income (Ohlsson, 2000) for human beings and it requires natural resources, land and water and other inputs (Pagiola and Holden, 2001). Land degradation has been a problem ever since humans settled on the land and started to cultivate the soil and grazed domesticated animals. Periodically, land degradation has become so severe that it has contributed to the decline of civilizations. Land degradation interms of soil erosion and nutrient depletion contributed significantly to low agricultural productivity and thus food insecurity and poverty in many areas of the developing world (Pagiola, 1999; Shiferaw *et al*., 2009). The integrated process of land degradation and increased poverty has been referred to as the "Downward spiral of unsustainability" leading to the "Poverty trap" of developing countries (Greenland *et al*., 1994). Empirical studies by Novotny and Olem (1994) confirmed that the adverse effects of land degradation like loss of soil productivity, water quality degradation and less capacity to prevent natural disasters such as floods extremely affects production of food security. The rate of soil nutrient depletion in Sub-Saharan African countries is among the highest (Stoorvogel and Smaling, 1990) and soil erosion is a serious problem, especially in highland areas (Bagoora, 1988).

Soil erosion and its associated effects are recognized to be severe threats to the national economy of Ethiopia (Hurni, 1993; Tamene, 2005). Since more than 85% of the country's population depends on agriculture for living, physical loss of the soil and nutrient depletion lead to food insecurity. Hurni (1990, 1993) estimated that soil loss due to erosion in Ethiopia amounts to 1493 million tons per year out of which about 42 t ha^{-1} $year^{-1}$ have come from cultivated fields. This is far greater than the tolerable soil loss as well as the annual rate of soil formation in the country. According to Greenland and Nabhan (2001), 50% of the highlands of Ethiopia are already significantly eroded and erosion causes a decline in land productivity at the rate of 2.2% per year.

Most studies indicated that sheet and rill-erosion by water and burning of dung and crop residue are the major components of land degradation that affects on-site land productivity (Hurni, 1993). Land degradation in the form of soil water erosion and declining soil quality is a serious challenge to agricultural productivity and economic growth (Mulugeta, 2002). In addition to this problem, tillage in Ethiopia is carried out with a breaking arid plough, the structure of which has remained unchanged for several thousands of years (Nyssen *et al*., 2000). Soil erosion due to high tillage frequency and other soil management problems has seriously affected over 25% of the Ethiopian highlands (Kruger *et al*., 1996). Soil erosion is a phenomenon, which mainly occurs in the highlands of Ethiopia, a part that constitute about 45% of the total area of the country. The high lands of Ethiopia support more than 80% of the population and account for over 95% of the regularly cultivated land and about 75% of the livestock population (Shiferaw and Holden, 1998; Tadesse and Belay, 2004).

For this reason, accurate assessment of soil loss is essential for sustainable agricultural production, management and conservation planning, especially in productive rain-fed agro-ecosystems and protected areas. Soil erosion by water is the wearing away of the earth's surface by the force of water and gravity and consists of soil particle dislodgement, entrainment, transport and deposition (Altieri, 2002). Erosion and deposition are recognized to have occurred throughout the history of agriculture and notwithstanding a half-century of research into its causes and effects, considerable uncertainty persists about extent, magnitude and actual rates as well as on its economic and environmental consequences. When economic costs of soil loss and degradation and off-site effects are conservatively estimated into cost/benefit analyses of agriculture, it makes sound economic sense to invest in programs that are effective in the control of soil erosion (Merritt *et al*., 2003). Farmer's responses to land degradation in the form of soil loss are influenced by different socioeconomic, biophysical, demographic and institutional factors.

Water erosion is a major part of land degradation that affects the physical and chemical properties of soils and resulting in on-site nutrient loss and off-site sedimentation of water resources (Boardman, 1998; Lal, 1999; Bartsch *et al*., 2002; Erdogan *et al*., 2007). Soil erosion by water and its associated effects are recognized to be severe threats to the national economy of Ethiopia (Hurni, 1993; Sutcliffe, 1995; Tamene, 2005). Therefore, the purpose of this study was to estimate the amount of soil loss in the study areas using RUSLE model which is modified and adapted to Ethiopian conditions.

MATERIALS AND METHODS

Study area: The study was based on a survey conducted during May and October, 2015 in Dedo and Tiro Afeta districts of Jimma Administrative Zone in Oromiya National Regional

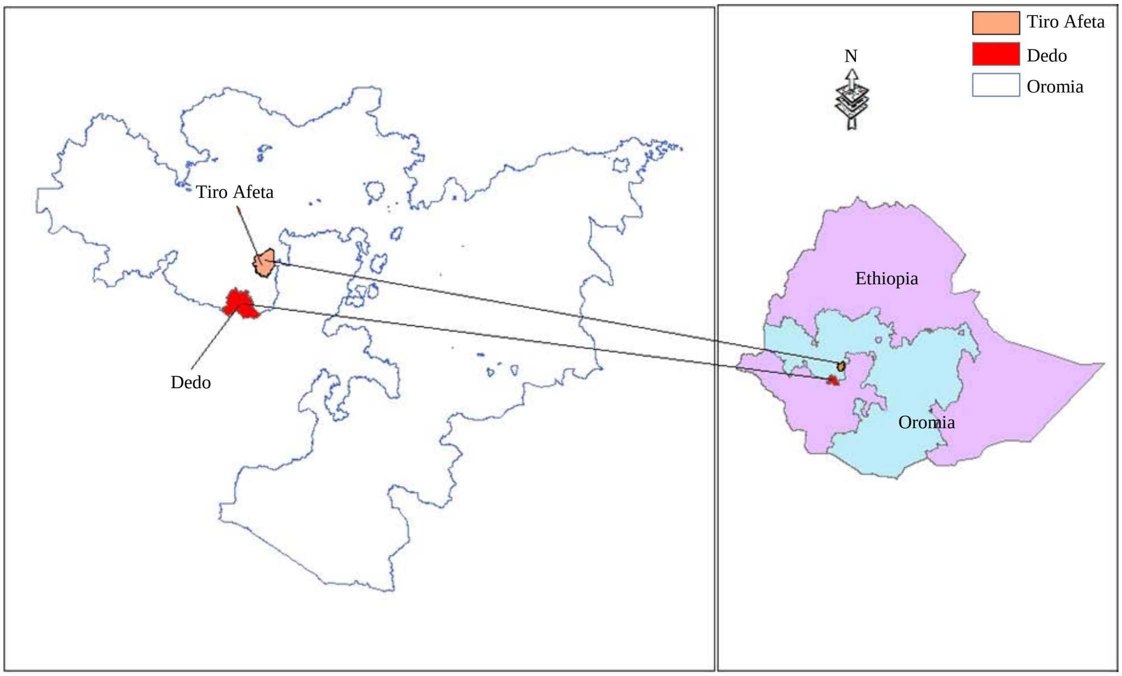

Fig. 1: Locational map of Tiro Afeta and Dedo

State, Southwestern part of Ethiopia. Dedo and Tiro Afeta districts are located about 360 and 320 km, respectively, to the Southeast of the capital city Addis Ababa (Finfinne). The districts were purposely selected because of the observed levels of land degradation and household food insecurity and of farmer's exposures to soil and water conservation measures that are likely to raise their awareness of the problems. The altitude of Tiro Afeta district in the range of 1340 and 2800 m a.s.l and Dedo district lies between 880 and 2400 m a.s.l. The mean annual rainfall ranges between 1200 and 2800 mm with a mean temperature of 20-25°C. In both districts, the most widely cultivated subsistence crops are maize, sorghum, teff, barley, horse bean, field pea and wheat. Some production of vegetable crops is observed in these areas. Hillside farming in these districts is intensive. Both districts suffer severe soil erosion problems due to the agro-climatic conditions on one hand and the lack of soil protection measures on the other. Coupled with a short fallow period of one to two years, the degradation of the soil causes the decline of the fertility level and consequently reduction of crop yields.

Data collection: The study of this objective involves estimating the rate of soil loss in the study area. Both Primary and secondary data were collected at Dedo and Tiro Afeta farm household and plot level related to the assessment of Soil and Water Conservation (SWC) measures (Fig. 1). Primary data were also gathered by informal discussion and observation. The secondary data such as climatic, demographic and others related information was collected from Bureau of Agriculture and Rural Development (BoARD) at Zonal and wereda administrative units. There are many models for estimating soil erosion.

Estimation of soil loss: The RUSLE has the advantage of being less data demanding than other models. A wide range of models that differ in their data requirement for model calibration, application, complexity and processes considered are available for use in predicting soil loss (Merritt *et al*., 2003). Physically based spatially distributed soil erosion models can be used to quantitatively determine the amount of soil loss from watersheds and also to identify critical soil loss source areas (De Roo *et al*., 1996; Erdogan *et al*., 2007).

Although, precise quantification of soil loss erosion is still challenging, the basic equation is:

$$A = R \times K \times L \times S \times C \times P$$

where, A is the direct estimated average predicted soil loss in tonnes per hectare per year due to water erosion, R is rainfall erosivity factor, K is soil erodibility factor, L is slope length factor, S is slope steepness factor, C is crop cover and management factor and P is conservation practice factor.

Rainfall erosivity factor (R): The climate factor (R) is the rainfall erosivity and is the product of rainfall energy and maximum 30 min intensity (EI30). It is often called erosion index which shows the erosivity of rainfall events (Wischmeier and Smith, 1978). Rainfall-runoff erosivity was determined by calculating the erosivity value for each storm using the method described by Wischmeier and Smith (1978). The storm erosivity of each storm was then accumulated to produce a yearly erosivity value (R factor). The greater the intensity and duration of the rain storm, the higher the erosion potential.

In this study, to determine the value of the R-factor, the average of annual historic rainfall event for twenty years was collected from meteorological stations located at a distance of 10 and 15 km from both study sites. Then, the R-value corresponding to the mean annual rainfall was found using the R-correlation established in Hurni (1985) with some modification in its parameter estimation to suit Ethiopian conditions (Appendix 1).

Soil erodibility factor (K): The soil erosivity factor, relates to the rate at which different soils erode. The soil erosivity factor is defined as the rate of soil loss per unit of R-factor on a unit plot (Renard *et al*., 1997). However, it is different than the actual soil loss because it depends upon other factors, such as rainfall, slope, crop cover, etc. Soil erosivity index factors (K) were evaluated by the soil erosivity (Wischmeier and Smith, 1978) using soil properties. The soil factor (K) represents soil erodibility or the soil loss rate per EI unit on a 22.13 m length and 9% standard fallow plot. To determine the value of the K-factor, a systematic observation on soil color of study sites was carried out, based on the approach described in Hurni (1985). For soils having different color in the same land use and landform, the K-factor was taken as their mean value as it is described in Hurni (1985). The soil erosivity factor (K), values for each type of soil was calculated as shown in Appendix 2 and 3.

Slope length and slope gradient factors (SL): The slope length factor (L) is a dimensionless ratio of soil loss from the field slope length to that from a 22.13 m plot under identical conditions and where the slope steepness factor (S) is a dimensionless ratio of soil loss from the field slope to that from a 9% plot under identical conditions. Often L and S are multiplied and considered as one overall terrain factor. The slope length-gradient factor SL factor represents a ratio of soil loss under given conditions to that of a site with the "Standard" slope steepness of 9% and slope length of 72.6 feet. The steeper and longer the slope, the higher is the risk for erosion. The SL is the topographic factor expressed as the expected ratio of soil loss per unit area from a field slope to that from a unit plot under otherwise identical conditions. Slope length and slope gradient factors were recorded using meter tape and clinometers, respectively, in the study areas watershed on different landform and land uses. It took the weighted value of the slope gradient and slope length range measured at the field for each landform and land use and so extrapolated, based on Hurni (1985) to Ethiopian condition (Appendix 4).

Crop cover and management factor (C): The C-factor is defined as the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous flow (Wischmeier and Smith, 1978). It is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The cropping management factor C depends upon several factors including crown coverage, ground cover, crop sequence, length of the growing season and tillage practice (furrow cropping). Hence, it was the most complicated of the USLE parameters as there were many ways of managing the growing crops in the entire study areas. There were also different types of forests according to their density fairly dense mixed forest, fairly open mixed forest, open scrub (small/dwarf plants) and shaded forest (a mix of dense and thin forest, i.e., medium density forest). For this study, crop cover and management factor (C) (Appendix 5) were considered by referring to the studies of Wischmeier and Smith (1978). Assessment of the type of land-use cover was made separately for each land unit and the corresponding land cover was obtained from Hurni (1985) which was developed to the Ethiopia condition. For variations in land cover with specific land unit or landform, the C-factor was obtained using weighted value of the different land cover. This generalized C factor, however, provides relative numbers for the different cropping and tillage systems, thereby helping you weigh the merits of each system (Appendix 6 and 7).

Supporting conservation practice factor (P): The management factor (P) represents supporting practices or the ratio of soil loss with a conservation practice to that with straight row farming up and down slope. Among the varying factors cover management is the most variable in that the type and amount of surface residues and crop cover change during the year and between years. Specific cultivation practices affect erosion by modifying the flow pattern and direction of runoff and by reducing the amount of runoff (Renard and Foster, 1983). In areas where there is terracing, runoff speed could be reduced with increased infiltration, ultimately resulting in lower soil loss and sediment delivery. Values for this factor were assigned considering local management practices and based on values suggested in Hurni (1985). Management factors were obtained by assessing the different supporting practices in the study areas and it had taken the weighted value for similar landforms and land use types. The data related to management practices were collected during the field data collection survey. The presence and status of conservation activities were assessed with emphasis on the existing conditions of terraces and protected areas. Most of the study areas are well-terraced, mainly the upslope parts. However, most of the terraces are broken due to high runoff and/or livestock trampling in many parts of the study areas. The Revised universal soil loss equation revised RUSLE was adopted for the assessment of soil water erosion as in Hurni (1985) to Ethiopia's condition (Appendix 8 and 9).

Determinants of soil loss: Following Greene (2000), the model is built around a latent variable given by:

$$Y_i = \beta'\chi_i + \varepsilon_i$$

where, Y_i is unobserved latent variable for level of land degradation, which is ordered, β' is a vector of coefficient of χ_i that will be estimated. The parameter estimates β' represent the effect of explanatory variables on the underlying order of status/severity, χ_i is explanatory variables, in this case it represents 17 independent variable, ε_i is disturbance term. What we do observe is:

$$Y = 0 \text{ if } Y^* \leq \mu_0$$

$$Y = 1 \text{ if } \mu_0 \leq Y^* \leq \mu_1$$

$$Y = 2 \text{ if } \mu_1 \leq Y^* \leq \mu_2$$

$$Y = 3 \text{ if } \mu_2 \leq Y^* \leq \mu_3$$

$$Y = 4 \text{ if } \mu_3 \leq Y^* \leq \mu_4$$

$$\ldots$$

$$Y = j \text{ if } \mu_{j-1} \leq Y^* \ (j = 1, 2, 3, \ldots, m)$$

where, μ_s is unknown threshold parameters separating the adjacent categories to be estimated with β_s. The thresholds μ is range of the normal distribution associated with the specific values of the response variable, Y is observed in j number of categories, in this case Y takes the level of land degradation. The Y = 1, undegraded; Y = 2, slightly degraded; Y = 3, moderately degraded and Y = 4, severely degraded plot, ε_i is assumed to be normally distributed across observation ($\varepsilon_i \approx$ IN (0,1)). With the normal distribution, we have the following probabilities:

$$\text{Pro}(Y = 0) = \Phi(-\beta' X_i)$$

$$\text{Pro}(Y = 1) = \Phi(\mu_1 - \beta' X_i) - \Phi(-\beta' X_i)$$

$$\text{Pro}(Y = 2) = \Phi(\mu_2 - \beta' X_i) - \Phi(\mu_1 - \beta' X_i)$$

$$\text{Pro}(Y = j) = 1 - \Phi(M_{j-1} - \beta' X_i)$$

where, ε has a cumulative distribution denoted by Φ_0 and a density function denoted by ϕ_0.

The level of land degradation data, Y are related to the underlying latent variable, Y*, through thresholds μ_j. Ordered probit estimation will give the threshold value μ_s and the parameter β'.

The remaining parameters, β', represent the effect of change in the explanatory variables on the underlying order. For all probabilities to be positive, we must have:

$$0 < \mu_1 < \mu_2 < \ldots\ldots\ldots < \mu_{j-1}$$

$\mu_1, \mu_2 \ldots \mu_{j-1} > \mu_{j-1}$ the maximum likelihood estimates usually will yield positive estimates for the parameters. Because Y_i is observed only ordinally, normalization rule var (u) = 1 was used. Thus, N (0, 1) a set of ordinal variables was defined:

$$Y^*_{ij} = 1, \text{ if } Y^* \text{ falls in the Jth category}$$

$$Y^*_{ij} = 0, \text{ otherwise}$$

The likelihood function for the model is Y^*_{ij}:

$$L = \prod_{i=1}^{n}\prod_{j=1}^{m}\left[\Phi(-\beta'\chi_i) - \Phi(M_{j-1} - \beta'\chi_i)\right]y^*_{ij}$$

And the log-likelihood function is:

$$L^* = \text{Log}\,L\sum_{i=1}^{n}\sum_{j=1}^{m} y^*_{ij}\log\left[\Phi(-\beta'\chi_i) - \Phi(M_{j-1} - \beta'\chi_i)\right]$$

A likelihood-ratio test is a statistical test relying on a test statistic computed by taking the ratio of the maximum value of the likelihood function under the constraint of the null hypothesis to the maximum with the constraint relaxed. Theoretically the likelihood ratio test rejects the hypothesis if the value of this statistic is too small. In reality, the significant explanatory variables do not all have the same level of impact on the determinants of land degradation. The relative importance of qualitative explanatory variables in determining land degradation can be measured by examining variables elasticity that would result from a given percentage change in values of these variables. Computation of the marginal effects (elasticity) is meaningful for the ordered probit model because the estimated parameter coefficients don't represent the magnitudes of the effect of variable X on the intermediate categories of the dependent variable. So the marginal effects of changes in the regressors are:

$$\frac{\partial \text{Pro b}(Y=0)}{\partial \chi_i} = \phi\,(\beta'\chi_i)\beta$$

$$\frac{\partial \text{Pro b}(Y=0)}{\partial \chi_i} = \phi\,(-\beta'\chi_i - \Phi\,(M_i - \beta\chi_i)\beta$$

$$\frac{\partial \text{Pro b}(Y=0)}{\partial \chi_i} = \phi\,(-\beta'\chi_i) - \Phi\,(M_2 - \beta\chi_i)\beta$$

$$\frac{\partial \text{Pro b}(Y=j)}{\partial \chi_i} = \phi\,(M_j - M_j - 1)$$

where, ϕ is the density function, $\partial\chi_i$ and ∂Prob (Y = j) stand for percentage change in the explanatory variable (χ_i). The impact of each explanatory variable on the probability of land degradation is calculated by keeping the continuous variables at their mean values and the dummy or discrete variables at their most frequent value (zero or one or two or three). The partial effect of Xi is invariant to the choice of response category J. The likelihood function implies that the estimated β should be the same regardless of which j is of concern. The effect of X_i would induce a change in the even responding category 0 instead of 1, 2 and 3 or 0 or 1 instead of 2 and 3 or 0 or 1 or 2 instead of 3 for the level of land degradation. The contrast is always between the probability of belonging to the first up to the Jth category and the probability of belonging to the remaining categories.

RESULTS AND DISCUSSION

Estimatation of soil loss using RUSLE: Six major factors are used to calculate the soil loss. The erosion values reflected by these factors can vary considerably due to varying weather conditions. Therefore, the values obtained from the USLE more accurately represent long-term averages (Table 1).

Table 1: Basic statistics for the RUSLE factors and soil loss in study areas

Soil loss of factors	Min.	Max.	Mean
Rainfall erosivity factor (R)	325.57	588.98	457.275
Soil erodibility factor (K)	0.15	0.30	0.22
Slope steepness factor (L)	1.40	4.11	2.755
Slope steepness factor (S)	0.05	1.495	0.359
Cover management factor (C)	0.02	1.00	0.51
Support practice factor (P)	0.25	1.00	0.625
Soil loss (A)	0.02	72.647	31.715

Spatial (reliable) average value is 31.7 t ha^{-1} $year^{-1}$, Min: Minimum, Max: Maximum

The average annual soil loss estimated by RUSLE from the study areas is 31.7 t ha^{-1} $year^{-1}$, which is generally higher than the tolerable soil loss of 2-18 t ha^{-1} $year^{-1}$ estimated for Ethiopia by Hurni (1985). In general, the average soil loss in the study area is about half of the maximum tolerable soil loss and five times the minimum soil loss tolerance value given by Hurni (1985). The implication is that there is a need to integrate sound management practices to decrease the amount of soil loss in the study areas below the maximum as well as the minimum tolerable value of soil loss for the country. As compared to the soil loss estimated for Ethiopia as 42 t ha^{-1} $year^{-1}$ from cultivated fields by Hurni (1990, 1993) and from 30-80 t ha^{-1} $year^{-1}$ (Tekeste and Paul, 1989) in Oromiya, South Western Ethiopia, the soil loss estimated on this study in 2007/08 is by far the smallest.

The results of the present study compared to past findings indicate that the amount of soil loss from a given unit of land is high. This could be due to high population and livestock growth leading to shortages of farm land for the sustenance of household livelihood, continuous plow of the same land without fallow, complete ruining of soil conservation structures and lack of perception to participate in soil conservation interventions for at least the last decades in the study areas in particular. Therefore, as noted in the above, the soil loss estimated by different scholars has showed discrepancy for the same environment. Soil erosion is one of the most serious causes of land degradation and it has exerted tremendous pressure on productivity and environmental stability of the study areas. Serious impacts led to the demand for conservation and management measures to reduce the magnitude of soil loss and the extent of its associated impact in many parts of the arid and semi-arid areas. It is a fact that environmental degradation has been a problem in Ethiopia. The land surfaces in the country is mainly a reflection of the past erosion processes. This is evident by the huge amount of soil loss, by water erosion and very low productivity of the farm lands. The SWC activities includes watershed treatment as area enclosure, aforestation, trench reclamation of big gullies using check dams, moisture harvesting techniques on farms, degraded grazing lands like soil, stone and trench bunds and soil faced stone bund on hillsides.

Table 2: Estimated soil loss (t ha^{-1} $year^{-1}$) on different slopes of study areas

Flat plain	Gentle slope	Steep slopes
457×0.216×1.4×0.05×0.25	457×0.216×1.9×0.05×0.25	457×0.216×2.7×0.05×0.25
1.72	2.34	3.33

Table 3: An ordered logit analysis result of factors influencing plot-level soil loss in Dedo and Tiro Afeta

Independent variable	Estimate	Standard error	Wald	Significance
Agro ecology (1 = Dega, 2 = Woinadega, 3 = Kola)	-0.880	0.386	5.182	0.005**
Household age (years)	-0.433	0.455	0.907	0.341
Educational status (discrete)				
1 = Completed 1-4 (formal school)	1.239	0.644	3.704	0.054*
2 = Completed 5-8 (junior school)	1.684	0.658	6.553	0.010**
3 = Completed 9-10 (senior high school)	1.386	0.678	4.182	0.041*
Total family size (numbers)	-0.051	0.032	2.627	0.105
Farm size (hectare)	-0.564	0.087	42.060	1.00
Distance of the plot (walking minutes)	-0.086	0.016	27.075	0.000***
Plot ownership (1 = Own/state, 2 = Rent-in, 3 = Share crop-in) 4 = Inherited from parents/clans, 5 = Bought, 6 = Gift, 7 = Others)	0.080	0.074	1.166	0.280
Land use type (1 = Cultivable crop land, 2 = Land left fallow, 3 = Grazing land, 4 = Forest wood land, 5 = Garden land, 6 = Irrigable land, 7 = Non irrigable land, 8 = Degraded land)	0.032	0.045	0.526	0.468
Soil type of plot (1 = Sandy, 2 = Clay, 3 = Loam, 4 = Sandy clay, 5 = Other (specify))	-0.173	99.00	3.071	0.080*
Soil color of plot (1 = Red, 2 = Black, 3 = Brown, 4 = Grey, 5 = If others (specify))	0.551	0.211	6.810	0.009**
Plot fertility (1 = Very fertile, 2 = Fertile, 3 = Medium, 4 = Infertile/poor)	-0.391	0.118	11.081	0.001**
Major crops type (1 = Maize, 2 = Sorghum, 3 = Teff, 4 = Finger millet, 5 = Others)	-0.009	0.067	0.018	0.892
Tendency of yield (1 = Increasing, 2 = Decreasing, 3 = Remain constant, 4 = Not measured)	-0.482	0.173	7.798	0.005**
Slope of plot (1 = Very steep slope, 2 = Steep slope, 3 = Gentle slope, 4 = Flat, 5 = Others (specify) discrete)	-0.405	0.140	8.386	0.004**
Number oxen (numbers)	-0.239	0.054	19.425	0.000***
Total income (Br $year^{-1}$)	0.000	0.000	0.117	0.733
Total expenditure (Br $year^{-1}$)	0.000	0.000	10.564	0.001**

***, **, *Coefficient significance at 1, 5 and 10% levels, respectively

The landforms in the watershed have difference in texture, drainage condition, soil depth, soil color, land cover, erosion controlling management practices and slope factors (Appendix 2 and 3). Fine texture soils dominate on flat land areas where as coarser textural class increase with increasing steepness. The same trend was observed for the soil depth with deeper soil on flat areas and shallow soil on high slope gradient landforms. The drainage condition is extremely high on steeper landforms and poor on flat areas of the watershed. Transportation and deposition processes are almost balanced in such occasions. Drainage is affected by the slope factor. Sand dominant soil textures are common on higher slopes of the study area.

If the soil conservation-planning structure with better management practice will be taken, it could be reduced to the following situation (Table 2).

The general trends of the finding indicate that soil loss increases as the slope increases in the study sites. The crop coverage and management C factor represents resistance of the ground surface to the transport of water-soil mixture on the very steep slopes of the study districts including bushes and shrubs which dissipate the force of the raindrops. The P-factor stands for erosion inhibition effect and reflects partly awareness and control measures implemented to minimize soil erosion by farm households. It is also noted that the lower slope landforms are susceptible to daily human interferences, where as the steepest landforms are protected areas. This proves that the USLE is useful for assessing the adequacy of conservation measures and management practices.

Therefore, the overall implication of this study is that after the implementation of SWC measures the amount of soil loss in a given land unit is decreased in many parts of the landforms by more than 50% in the study area watershed as compared to the high values indicated in the past studies in northern Ethiopia (Hurni, 1985, 1990, 1993; Tekeste and Paul, 1989; Gebreselasie, 1996). However, the present soil loss amount has also a significant influence on the overall productivity of the study area watershed unless the correct measures on the targeted landforms are undertaken. This is because compared to the soil formation in the region which is not more than 2 t ha^{-1} $year^{-1}$ (Hurni, 1985) the present soil loss estimated in study areas is very big. Therefore, based on the landforms identified in this study, soil conservation planning should be undertaken to address the problem of erosion in areas having large soil loss as areas of prioritization in the future.

Determinants of soil loss: To identify determinants of soil loss an ordered probit model was employed (Greene, 2000). For the dependent variable soil loss (Y): Y_1 = Underrated, Y_2 = Slightly degraded, Y_3 = Moderately degraded and Y_4 = Severely degraded plot (Table 3).

Determinant variables are as follows:

- **Agro ecology:** The effects of agro ecology on land degradation variable support the proposed hypothesis and it is significant at 5% level (0.05). A variety of agro ecological and participatory approaches show conservation of the natural resource base including biodiversity (Altieri, 2002). Farm household land holdings designs and agro ecology should promote integration among sub systems so that outputs from one subsystem become inputs into the other, creating efficient bio-resource flows as well as synergisms that may aid in sponsoring the soil fertility, plant protection, forest, fallow, pasture and productivity of annual crops and all other crops on the farm
- **Education levels of the household:** All education levels have the expected positive signs, confirming that as the level of education of the head of the household increases, the awareness of the household about land degradation increases. As expected, the education level of the head of the household increases understanding of the households on the causes and impact of land degradation and the increase in the extent of soil loss. The result proved that all levels of education of the household encourage land conservation and the coefficients for the education imply that the probability of investing in land improvements will increase with the level of education
- **Distance of the plot (in walking minutes):** Plot distance by not proving our expectation, has been found to be negatively related with land degradation and the relationship is significant at 1% probability level. It is in-line with the hypothesis that farm plot near to the home has a better chance of getting organic fertilizer and soil conservation technology than those away from homestead. The ordinal probability estimate for this variable had a coefficient of -0.086. The result indicated that distance of plot from the residence demands much time and effort while plots near the residence of the household get frequent management and improved soil conservation due to proximity and plots far away from the residences are usually neglected. The finding is consistent with Bekele and Drake (2003)
- **Slope of the plot:** The coefficient of this variable supports the proposed hypothesis and it is significant at 5% level of significance. The ordered model coefficient estimate for this variable is about -0.405. The effect of the slope of the plot on land degradation illustrates that slope of the plot is an important determinant of farmers disincentive to invest in SWC technology, soil improvement or direct application become unfavorable. Increase in the slope of the plots increases land degradation by increasing the speed of soil erosion. As the slope of the plot increases, the distance between two consecutive terraces will decrease. This creates disincentive to invest in conserving soil loss. This is because the structures of SWC take more area of land and it will create inconvenience for farm operation like oxen plough. The result is in conformity with the findings of Hurni (1988) and Gebremedhin *et al*. (1999)

Therefore, as noted in the above, the soil loss estimated by different scholars has showed discrepancy for the same study area environment. This implies that there is a need to have site specific information on soil erosion in order to support timely information for decision makers so that to plan the correct soil conservation planning.

According to Singh and Phadke (2006) classes of soil loss range (very slight, slight, moderate, severe and very severe), the spatial (reliable) average value soil loss (31.715 t ha^{-1} $year^{-1}$) from study area is categorized under severe class of soil erosion as compared by slight soil loss (5-9.99 t ha^{-1} $year^{-1}$).

According to them, the only part of the watershed landforms having very slight class of soil loss (0-4.99 t ha^{-1} $year^{-1}$) are the flat plains, undulating plains and the flat-flood prone areas and followed by slight soil loss (5-9.99 t ha^{-1} $year^{-1}$) for the very steep escarpment of the watershed and moderate soil loss class (10-24.99 t ha^{-1} $year^{-1}$) on rolling to hill landforms of the watershed, where as severe class of soil loss (25-44.99 t ha^{-1} $year^{-1}$) was estimated using RUSLE on slopes 30-50%. Hence, this study suggests for effective control of soil erosion in order to minimize the costs related to fertilizer and environmental rehabilitation:

$$A = R\times K\times L\times S\times C\times P$$

where, R is rainfall runoff erosivity factor, which we cannot do much about the weather so plan accordingly, K is soil erodibility factor, which looks at it from a surface erosion perspective so we have to work with and that top layer of material that is generally no good for structural fills is great for broadcasting before final erosion control because of its organic matter content, soil micro organisms and seed bank for long term native revegetation that reduces the C factor, LS is slope length steepness factor, which is very important and applies everywhere, C is cover management factor, which very important and applies everywhere, P is support practice factor, which is good for agriculture and construction sites on mild terrain and does not consider the unpredic table human element so it does not work all that great for roads stick with compaction. Generally, soil erosion is the most serious causes of land degradation that created tremendous pressure on productivity in the study area. Serious impacts led the demand for conservation and management measures to reduce the magnitude of soil and the extent of its associated impacts.

Empirical models are frequently used in preference to complex physically based models as they can be implemented in situations with limited data and parameter inputs, particularly as a first step in identifying sources and rate of soil loss (Merritt *et al*., 2003). It is, therefore, necessary to identify models that are not very much simplified and under-represent the physical basis or not too complicated and very expensive to implement. The RUSLE is an empirically based model developed in the United States by using data on soil erosion rates. This study was attempted in indicating the high soil loss in study area. The main causes of soil erosion in the study area among others were outlined by different researchers (Hurni, 1985; Tamene, 2005) and even witnessed by farmers as over cultivation, deforestation, over grazing, steep topography, high rainfall intensity, unwise land use and management. Soil loss in the study area is influenced by erosion factors differently. For instance, the soil erodibility (K) factor of the landforms in the study area is a function of soil texture, drainage condition and soil depth. These sub-factors can influence the soil color, which determined the value of K-factor in RUSLE, adapted from Hurni (1985). The study areas have different in texture, drainage condition, soil depth, soil color, land cover, erosion controlling management practices and slope factors. Therefore, the principle of Hudson (1992) that describe as fine soil particles resist to detachment by raindrops but they are susceptible to transport easily is soil drainage dependent. This is because if the landform is poor in drainage, so the probability of transporting by waters the fine particles long distance leaving the original area is too low.

The soil loss estimated on flat landform is below the minimum tolerable soil loss (2 t ha^{-1} $year^{-1}$) determined by Hurni (1985) for Ethiopia condition. This is the lowest soil loss as compared to the other landforms in the study districts. The present soil loss amount has also a significant influence on the overall productivity of the study area unless the correct measures on the targeted topographic are undertaken. Therefore, soil conservation planning should be undertaken to address the problem of erosion in areas having large soil loss as areas of prioritization in the future.

The entire study area experienced severe rainfall, steep gradient slopes, highly erosive runoff and soil detachment that is responsible for the high rate of soil erosion that ranges from 1.59-31.7 t ha^{-1} $year^{-1}$. There is a need to regulate this soil loss by all possible means so as to decrease the existing amount of soil loss and enhancing land rehabilitation and increasing productivity in the study area.

For quantifying soil loss intensity level due to degradation, household level and plot level data were employed. The econometric model results showed that socio-economic variables such as agro ecology, education level, distance of the plot and soil type and soil color, fertility of the plot, yield tendency and slope of the plot factors significantly affected land degradation in the form of soil loss. From a total of seventeen explanatory variables included in the model twelve were found to be significant at less than 10% probability level.

The results of the study have shown that the socio-economic characteristics of the household and other institutional factors are responsible for the difference in the current status of soil loss and land degradation in the study areas. Therefore, policy and program intervention designed to address land degradation in the form of soil loss issues in the districts are needed to take into account these important characteristics and farmer's alternatives. Crop production is costly, especially in areas with steep slopes. These costs can be attributed to several aspects including, but not limited to, loss of soil, nutrients, land cover and biodiversity. It is possible to quantify the costs ascribed to each category. Doing so, however, is a very challenging task due to the limited data available in this area. Data such as biodiversity and evolution of vegetative species, as well as production costs, are very scarce for the study.

Consequently, other land use products, such as trees, fruits, bushes and grasses were left out of the analysis. Data for soil losses and selective crop yields can be acquired directly from the study simulation results. The entire study areas experienced intensive rainfall which, when coupled with steep gradient slopes, cause highly erosive runoff as in many other parts of Ethiopia. It is this high runoff and soil detachment that is responsible for the high rate of soil erosion at Dedo and Tiro Afeta in south western Ethiopia that ranges on average from 1.59-31.7 t ha^{-1} $year^{-1}$. There is a need to regulate this soil loss by all possible means so as to decrease the existing amount of soil loss and enhancing food grain productivity. Long-term measures re-vegetation of hill slopes with trees and perennial grasses such as vetiver strips and belts; introduction of an agro-forestry program that is compatible with crops and livestock and forestry development. Short-term measures include soil and water conservation measures like cut-off drains, constructing and maintenance of stone and soil bund and trenches on proper slopes and soils and integrating these with vegetation intensively. This has to include interventions such as inter-bund management, bund stabilization and buffer zone establishment and re-bank re-vegetation and gully control by both vegetative and structural measures. The methodology used in this study provided a promising framework for developing a sustainable and cost effective soil conservation planning program.

CONCLUSION

To develop an economical, quick and efficient soil conservation program in similar areas as well as in other parts of the country. It is clear from the results of this study that the south western part of Ethiopia has been suffering seriously from soil loss by water erosion resulting from climate variations and mainly from human activities.

The modified RUSLE is a powerful model for the qualitative as well as quantitative assessment of soil erosion intensity for the conservation management planning. Since the crop cover is a powerful tool to reduce the direct impact of rainfall on soil particles, it can be recommended that all abandoned lands in local area be converted to plantation cover through proper land management recovery measures with basic grass root participatory approach.

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APPENDICES

The determining of RUSLE's numerical values were chosen according to the following parameters (Appendix 1-9).

Appendix 1: Rainfall erosivity factor (R) data

Meteorology stations	Districts	R-factor
Assendabo	Tiro Afeta	325.57
Jimma	Dedo	588.98
Average	Average	457.275

Source: Study survey

Therefore, the annual R-factor for the average rainfall (850 mm) in the study area cut-off point as extrapolated from Hurni (1985) is on average 457.275.

Appendix 2: Calculated soil erodibility index textural class factor used in the study area

Textural classes	Average	Less than 2%	More than 2%
Clay	0.22	0.24	0.21
Clay loam	0.30	0.33	0.28
Coarse sandy loam	0.07	-	0.07
Fine sand	0.08	0.09	0.06
Fine sandy loam	0.18	0.22	0.17
Heavy clay	0.17	0.19	0.15
Loam	0.30	0.34	0.26
Loamy fine sand	0.11	0.15	0.09
Loamy sand	0.04	0.05	0.04
Loamy very fine sand	0.39	0.44	0.25
Sand	0.02	0.03	0.01
Sandy clay loam	0.20	-	0.20
Sandy loam	0.13	0.14	0.12
Silt loam	0.38	0.41	0.37
Silty clay	0.26	0.27	0.26
Silty clay loam	0.32	0.35	0.30
Very fine sand	0.43	0.46	0.37
Very fine sandy loam	0.35	0.41	0.33

Appendix 3: Calculated soil erodibility index soil color factor used in the study area

Soil colors	Soil erosivity factor (K)
Black	0.15
Brown	0.20
White	0.18
Yellow	0.30
Red	0.25
mean value	0.216

Source: Own survey data

Appendix 4: Average slope length and LS factor for different slope gradient ranges used in the study areas

Average slope length	LS factor for different slope gradient ranges (%)				
S (%)	1-5	6-15	16-30	31-45	>45
Value of LS	1.4	1.9	2.7	3.2	4.11

Source: Own survey data

Appendix 5: Crop cover and management factor (C)

Land use types	Crop cover and management factor (C)
Medium density forest	0.004
Fairly dense mixed forest	0.002
Fairly open mixed forest	0.006
Open scrub	0.014
Agricultural land	0.380
Hill top bare land	1.000

Source: Own survey data

Appendix 6: Crop type factor

Crop types	Factors
Grain maize	1.00
Grain finger millet	1.00
Cereals teffe	0.05
Cereals sorghum	0.15
Seasonal horticultural crops	0.50
Other cereals	0.50
Fruit trees	0.10
Hay and pasture	0.02

Source: Own survey data

Appendix 7: Tillage method factor

Tillage methods	Factors
Fall plow for all cereals	1.00
Spring plow for maize	0.90
Mulch tillage	0.60
Ridge tillage	0.35
No-till	0.25

Source: Own survey data

Appendix 8: Supporting conservation practice factor (P)

Land use type (support practice)	Supporting conservation practice factor (P)
Agricultural land	0.39
All other land use except agricultural land	1.00
Traditional SWC (ditches, cuts of drains)	1.00
Biological soil conservation method	0.50
Improved soil conservation	0.80
Up and down slope	1.00
Cross slope	0.75
Contour farming	0.50
Strip cropping and cross slope	0.37
Strip cropping and contour	0.25

Source: Own survey data

Appendix 9: Soil loss tolerance rates

Soil erosion classes	Rates of soil loss tolerance (t ha^{-1} $year^{-1}$)	Top soil removed (mm)
Very low (tolerable)	0-3	0-0.25
Low	3-6	0.25-0.50
Moderate	6-12	0.50-1.0
High	12-25	1.0-2.0
severe	25-50	2.0-4.0
Extremely severe	>50.00	4.0-8.0 and >8.0

Technical steps for calculating predicted soil loss using the RUSLE by multiplying the six factors together to obtain the soil loss per acre:

- Determine the R factor (Appendix 1)
- Based on the soil texture determine the K-value (Appendix 2 and 3). If there is more than one soil type in a field and the soil textures are not very different, then use the soil type as their mean value of these colors. Repeat for other soil types as necessary
- Divide the field into sections of uniform slope gradient and length. Assign an LS value to each section (Appendix 4)
- Choose the crop type factor and tillage method factor for the crop to be grown. Multiply these two factors together to obtain the C factor for maize (1.00×0.9) = 0.9 (Appendix 5-7)
- Select the P factor based on the support practice used (Appendix 8 and 9)

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