Estimating the extent of soil degradation of Weito Watershed in lower Rift Valley Basin: Southern Ethiopia

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ABSTRACT

In this study, Revised Soil Loss Equation (RUSLE) was used to quantify the potential soil erosion in Weito Watershed. Rainfall data, soil data, DEM data and land use-land cover data were used as input data sets to generate RUSLE factor values. RUSLE factors such as R_ the erosivity factor, K_the soil erodibility factor, LS_ the topographic factor, C_ the crop management factor, and P_ the conservation support practice was analyzed and superimposed using raster calculator in ArcGIS10.1 to estimate and map the annual soil loss. The results showed annual soil loss ranging from 0 to 210 tons/ha and mean annual soil loss rate of 110ton/ha/yr. The annual soil loss rate in the western and south western part of the watershed was mainly identified as high and severe and hence, requires special attention with an immediate soil conservation practice.

Key words: conservation support practice; erodibility; erosivity; RUSLE; Soil erosion

1. INTRODUCTION

Soil erosion can be a natural and or man-made phenomenon resulting from removal of topsoil by natural agents like wind and water while human intervention could significantly affect soil erosion rate. It was one of the major agricultural problems and global environmental issues (Reshma Parven and Uday Kumar 2012). Soil erosion by water is a major problem in mountainous areas with steep slopes. Inappropriate land use and land mismanagement are likely to accelerate water erosion entailing soil loss and land fertility decline which in turn cause agricultural production decrease (Hussain et al., 2011).

According to Oldeman (1990), soil erosion was highly increased throughout the 20^{th} century. About 85% of land degradation in the world was associated with soil erosion, causing about 17% reduction of crop productivity (Angima, 2002). Therefore, investigating the highly affected and degraded area, identifying the type of soil vulnerable to soil erosion, and recommending an appropriate mitigation measures is very important.

The exponential increase of human and animal population on one hand and unwise utilization of natural resources for many years on the other, cause land degradation in Ethiopia. Increased demand for resources like arable land and fuel wood led to clearing of forests instead of increasing productivity per unit area. In such countries, the effects of soil erosion were felt most strongly as large proportions of the population based their livelihoods directly on the soil. The people were forced to clear forests for new fields because of having less productive agricultural lands.

Watershed management was found to be vital to reduce catchment soil erosion which can be caused by several anthropogenic and natural activities. Soil erosion is usually responsible for depleting soil productivity, destroying agricultural land and reducing canal capacity. Thus, estimations of soil loss and identifications of hotspot areas are important to preserve naturally balanced watershed. Over the past few decades, Weito Watershed has been under intensive commercial and public use, leading to rapid decline in the natural vegetation, water availability and productivity. To the right side, the Weito River was irrigated for more than three investors' commercial farm lands: Omo Sheleko, Sagla, and Nasa. Specifically, each of them covered more than 4000, 1500, and 1000ha irrigation farm lands, respectively. On top of that, local communities, farmers, and others diverted large amount of water to their farm lands; hence, the water flow to Airbore, the lowest most downstream part of the river, was significantly reduced. To the left side of the river, more than 60 local diversion structures known as Chefekas were used to irrigate unknown area of land. Konso, Bena and Tsemay community also diverted significant volume of water to their irrigation fields. This might have aggravated soil degradation and erosion which caused decrease in agricultural productivity. Therefore, identifying the adversely affected part of the watershed and proposing the necessary watershed management practice would be very important.

Consequently, the main objective of this study is to estimate the extent of soil degradation in Weito Watershed using the Revised Universal Soil Loss Equation (RUSLE) and recommend proper watershed management practices for the study area. The soil erosion rate from the catchment was quantified and hence soil degradation hotspot was also identified.

2. MATERIALS AND METHODS

2.1. Description of the Weito Watershed

Weito watershed is located at the lower part of Ethiopian Rift Valley Lakes Basin, between 36.6^{o}E–38.1^{o}E longitudes and 4.9^{o}N - 6.3^{o}N latitudes. The Weito River is one of the main rivers in Abaya-Chamo-Chew Bahir sub-basin system. It originates from the Guge Mountains, flowing south into Lake Chew Bahir. The Weito River Basin is classified under bimodal rainfall region with two main rainy seasons. The main rainy season (MAM) contributes more than 40% of the annual rainfall when compared to the short rainy season (SON). The annual rainfall ranges from 400mm in the dry lowlands to 2000mm in the mountain regions, with annual average of about 500mm. The mean annual temperature varies between 22^{0}C and 24^{0}C. The Weito Watershed falls under semi-arid tropical lowland climate. Figure 1 shows location map of the study area.

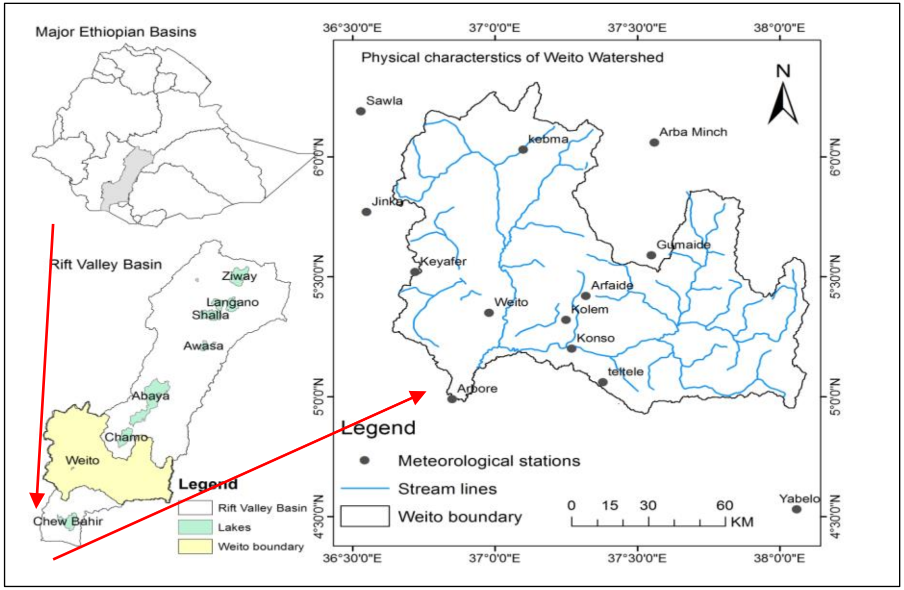

Figure 1 Location map of Weito watershed

2.2. Data Collection

In order to estimate the soil erosion from the Weito Watershed and determine the hotspot areas, daily rainfall and temperature data of 16 meteorological stations were collected from National Meteorological Agency (NMA). A 30mx30m resolution of land use/land cover map and Topographic map (DEM) were downloaded from http://www.earthexplorer.com/.The soil feature map of the study area was extracted from the soil map obtained from the GIS Department of Ministry of Water Irrigation and Electricity (MoWIE).

2.3. Watershed Soil Degradation Assessment Using Revised Universal Soil Loss Estimation (RUSLE)

The Revised Universal Soil Loss Equation was a regularly used approach for estimating soil loss of most undisturbed lands experiencing overland flow, lands undergoing disturbance, and newly established or reclaimed lands. RUSLE estimated soil loss from a hill slope caused by raindrop impact and overland flow, plus rill erosion. According to Jones et al. (1996), RUSLE had great acceptance and widely used. Besides, it is simple and easy model to parameterize, and requires less data and time to run in comparison to most other models dealing with rill and inter rill erosion. RUSLE retains the structure of its predecessor, the Universal Soil Loss Equation (Smith 1978). The average annual soil loss in tones/ha/year can be calculated using:

$$A = R\,K\,LS\,C\,P \tag{1}$$

Where, A = Average annual soil loss (tones/ha/year); R = Rainfall/runoff erosivity (MJ mm h-1 ha-1 yr-1); K = Soil erodibility; LS = Hill slope length and steepness; C = Cover-management and P = Support practice.

2.4. Input maps preparation

2.4.1. Rainfall and Runoff Erosivity: R-factor

The R-factor is an expression of the erosivity of rainfall and runoff at a particular location. The value of "R" increases as the amount and intensity of rainfall increases. The numerical value of R is the average annual sum of EI30 (rainfall energy over 30-min duration) for storm events during a rainfall record of at least 22 years. Because of the lack of half hourly rainfall data to compute EI30 values, an empirical equation developed by (Hurni, 1985) was used for Ethiopian highlands.. Accordingly, the Rainfall erosivity factor is given by:

$$R = -8.12 + 0.562P \quad (2)$$

where, R is the rainfall erosivity factor (MJ mm h^{-1} ha^{-1} yr^{-1}) and P is the mean annual rainfall (mm). Table 1 presents the computed rainfall runoff erosivity factors of Weito Watershed estimated from sum of the mean monthly rainfall in and around the watershed area.

Table 1 Mean annual rainfall-runoff erosivity(R-factor) calculated at each gauging station

S.No	Station	Longitude	Latitude	Mean Annual precipitation (mm)	Erosivity (R) factor (MJ mm h^{-1} ha^{-1} yr^{-1})
1	Jinka	36.55	5.77	1274	707.87
2	Murle	36.3	5.06	578	316.72
3	Arbore	36.85	4.99	407	220.61
4	Keyafer	36.72	5.52	1133	628.63
5	Arba Minch	37.56	6.06	818	451.6
6	Dimeka	36.28	4.58	719	395.96
7	Konso	37.27	5.2	854	471.83
8	Gumaide	37.55	5.59	1114	617.95
9	Weito	36.98	5.35	650	357.18

10	Teltele	37.38	5.06	787	434.17
11	Kemba	37.1	6.03	1393	774.75
12	Omo Ratte	36.07	5.02	305	163.29
13	Yabelo	38.06	4.53	605	331.89
14	Arfaide	37.32	5.42	940.83	520.63
15	Kolem	37.25	5.32	958.03	530.29
16	Sawula	36.53	6.19	1348.1	749.51

2.4.2. Soil Erodibility (K- factor)

The soil-erodibility factor (K-factor) represents susceptibility of soil or surface material to erosion, transportability of the sediment, and the amount and rate of runoff given a particular rainfall input as measured under a standard condition. The standard condition is that the unit plot, 72.6ft long with a 9% gradient, is maintained in continuous fallow, and tilled up and down the hill slope. The value of K is a function of the particle-size distribution, organic-matter content, structure, and permeability of the soil or surface material. RUSLE requires an initial K value based on soil properties. Therefore, the soil erodibility (K) factor for the study area was estimated from FAO (1984) and (Hurni, 1985) that was adapted to Ethiopia based on textural class, slope range, and organic matter content. In general, the Weito Watershed has four major soil classes which are chromic Cambisols, Dystric Nitosols, Eutric Cambisols, and Orthic Acrisols.

After obtaining the soil feature map of the study area from Ministry of Water Irrigation and Electricity, the soil map attribute table was edited for a new field of K-value before K-factor was produced for different soils. Finally, the resulting shape file was changed to grid file with a cell size of 30mx 30m. The raster map was then classified into four distinct classes based on their erodibility value (Table 2).

Table 2 Weito Watershed soil erodibility factor estimated by using FAO (1984) soil classification

S.No	FAO Soil Classification	Textural Class	Slope Ranges (%)	Organic Material Content (%)	Erodibility Factor (K)
1	Chromic Cambisols	Loam to sandy loam	2.0-8.0	3.0-6.0	0.11-0.3
2	Dystric Nitosols	Clay to Clay loam	0.2-8.0	3.0-10.0	0.05-0.055
3	Eutric Cambisols	Clay loam to silty loam	8.0-16.0	3.0-10.0	0.15-0.525
4	Orthic Acrisols	Clay to sandy clay loam	16.0-30	3.0-10.0	0.1-0.35

2.4.3. Hill slope Length and Gradient (LS factor)

The LS factor is an expression of the effect of topography, specifically hill slope length and steepness, on rates of soil loss at a particular site. In RUSLE, the LS factor represented a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 22 m plot. The value of "LS" increased as hill slope length and steepness increased, under the assumption that runoff accumulated and accelerated in the downslope direction. This assumption was usually valid for lands experiencing overland flow but might not be valid for forest and other densely-vegetated areas. The L factor has a value of 1 for a unit plot 72.6 feet in length with a gradient of 9%. However, the L value was less than 1 for hill slope lengths less than 72.6 feet and greater than 1 for lengths greater than 72.6 feet. Similarly, the S factor value was equal to 1 for a unit plot with a 9 percent gradient. Soil loss increased with gradient increase rather than length increase.

DEM of the study area was analyzed to generate the slope length and steepness (LS) factor. The elevation value from DEM was modified by filling the sinks in the grid to avoid the problem of discontinuous flow. Therefore, 30mx30m resolution DEM of the study area was pre-processed to drive the LS factor after appropriate size of the study area was clipped. Finally, Raster calculator function was used to compute LS factor and then the LS factor grid was estimated with the following equation (Foster 2003; Lim 2005; Shifarew 2011).

$$\text{LS} = \text{power}\left(\frac{[\text{Flow Acc}]\text{resolution}}{22.13{,}0.4}\right) * \text{power}(\sin\frac{[\text{local Slope gradient (deg)}]}{0.0896{,}1.3} \quad (3)$$

Where LS is slope steepness- length factor and resolution is 30m*30 m unit contributing area.

2.4.4. Cropping Management factor (C-factor)

The C-factor is an expression of the effects of surface covers and roughness, soil biomass, and soil-disturbing activities on rates of soil loss at a particular site. The value of "C" decreased as surface cover and soil biomass increased, thus protecting the soil from rain splash and runoff. In this study, land use and land cover map of the study area was prepared from Landsat imagery acquired over selected periods. Major portion of the watershed land use/land cover was changing from time to time because of difference in irrigation schemes. For example, Omo Sheleko irrigation farm had shown an increase by 1145ha (43.13%) from its initial irrigation farm 2650ha in 2006 (1998E.C) whereas, Nasa irrigation farm had increased its irrigation land by 700ha (133%) from its initial irrigation farm land by 300ha in 2008(2000EC) and hence this made it highly susceptible to soil erosion. The major portion of the lower and partly the upper parts of the watershed were primarily used for grazing and browsing with some fuel wood production and scattered cultivation. On the upper parts of the watershed, there was a moderate annual crop production mixed with informal and mixed timber production. Generally, the major vegetation cover in the sub-basin included broad leaved forest, coniferous forest, and extending bounds which covered about 59%, 26% and 15 % of the vegetation cover, respectively. Finally, supervised digital image classification technique and processing was employed in order to build C-map.

Table 3. Land use/ land cover type of the watershed and its corresponding C-factor

S. No	Land use	Area (Ha)	Area (%)	C-values
1	Moderately Cultivated	251797.11	18.2	0.230
2	Grassland	45109.38	3.26	0.020
3	Shrub land	892270.79	64.5	0.230
4	Intensively Cultivated	15332.14	1.11	0.267
5	Forest	42879	3.1	0.090
6	Riparian Vegetation	30402.09	2.2	0.078
7	Woodland	90752.56	6.56	0.123
8	Marshland	417.36	0.03	0.080
9	Wetland	14371.67	1.04	0.000

2.4.5. Support Conservation Practice Factor (P-factor)

The P-factor is an expression of the effects of supporting conservation practices, such as contouring, buffer strips of close-growing vegetation, and terracing on soil loss at a particular site. The value of "P" decreased with the installation of these practices because they reduced runoff volume and velocity and encouraged the deposition of sediment on the hill slope surface. The P-value in RUSLE was the ratio of soil loss with a specific support practice to the corresponding soil loss with straight-row upslope and downslope tillage. The P-value ranged from 0 to 1 depending on the soil management activities employed in the specific plot of land. In this study, P values were assigned based on the availability of data on permanent management factors and absence/presence of management practices. The support practice values (P-factor) for different slopes in the study area were adopted from Mekonnen (2014).

3. RESULTS AND DISCUSSION

3.1. Rainfall and Runoff Erosivity Factor: R-factor

The rainfall distribution map of Weito Watershed was developed from the surrounding twenty meteorological stations using the average annual rainfall data of each gauging stations. The mean annual rainfall in the study area varied between 305mm (at Omo Rate) to 1943mm (at Geresse). The rainfall & runoff erosivity factor map was developed in Arc-GIS 10.2 using the average annual rainfall data collected from each station. In general, the erosivity factor estimated showed a range of 220.74-774.47 MJ ha/mm/hr/yr. Figure 2 presented erosivity distribution map for Weito Watershed.

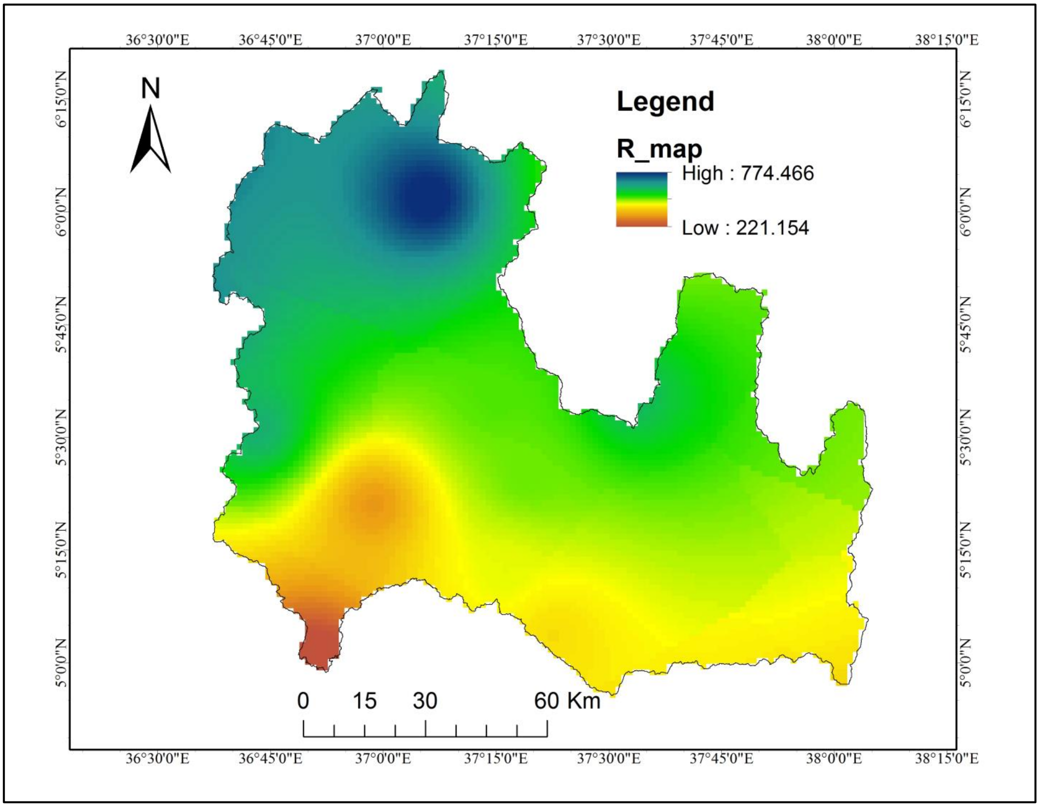

Figure 2 Runoff Erosivity map of Weito Watershed

3.2. Soil Erodibility (K-factor)

Quantitative estimation of erodibility of particular soil is dependent on the K-factor. The soil texture is the major factor affecting the capability of the soil to be eroded is essential. In addition, other factors such as soil structure, permeability, and organic matter content also influenced soil erodibility. It determined the susceptibility of soil or surface material to erosion or/and transportability of the sediment. The higher the K-value, the more susceptible the soil would be to erosion. For this particular study, the soil erodibility map of the watershed was prepared from soil map of the study area based on different soil textures. In general, K-value for Weito Watershed varied between 0.05- 0.34. Figure 3 showed Soil erodibility (K) map of study area.

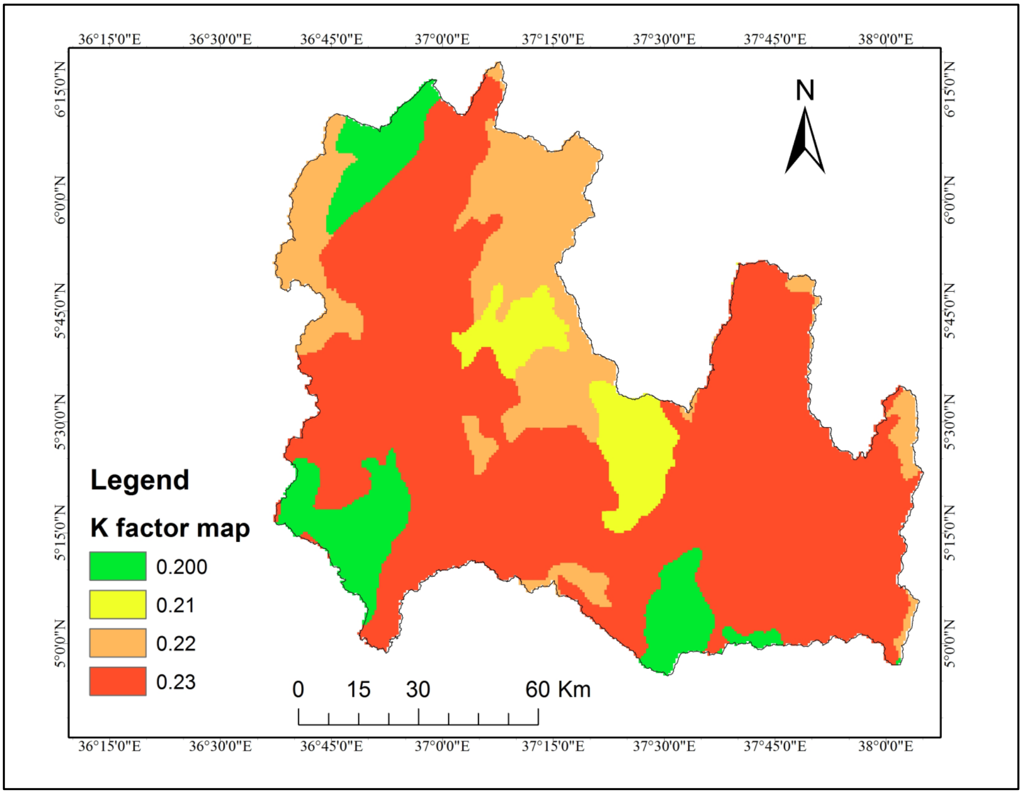

Figure 3 Soil erodibility (K) map of study area

3.3. Topographic factor (LS-factor)

The topographic factors (slope gradient and slope length) significantly influenced soil erosion. Slope and flow accumulation grid were prepared from DEM of the watershed. RUSLE was only applicable to rill and inter-rill erosion, and hence, there should be upper bound to slope length. Since DEM with 30mx30m resolution was used, the flow accumulation could not exceed 6 grid cells. Flow accumulation greater than and equal to 6 were assigned the value 6 for all cells in raster calculator. Slope was calculated using the available slope function in ArcGIS. Using DEM derived flow accumulation and slope grid, a LS-factor map was created, as shown in Figure 4.

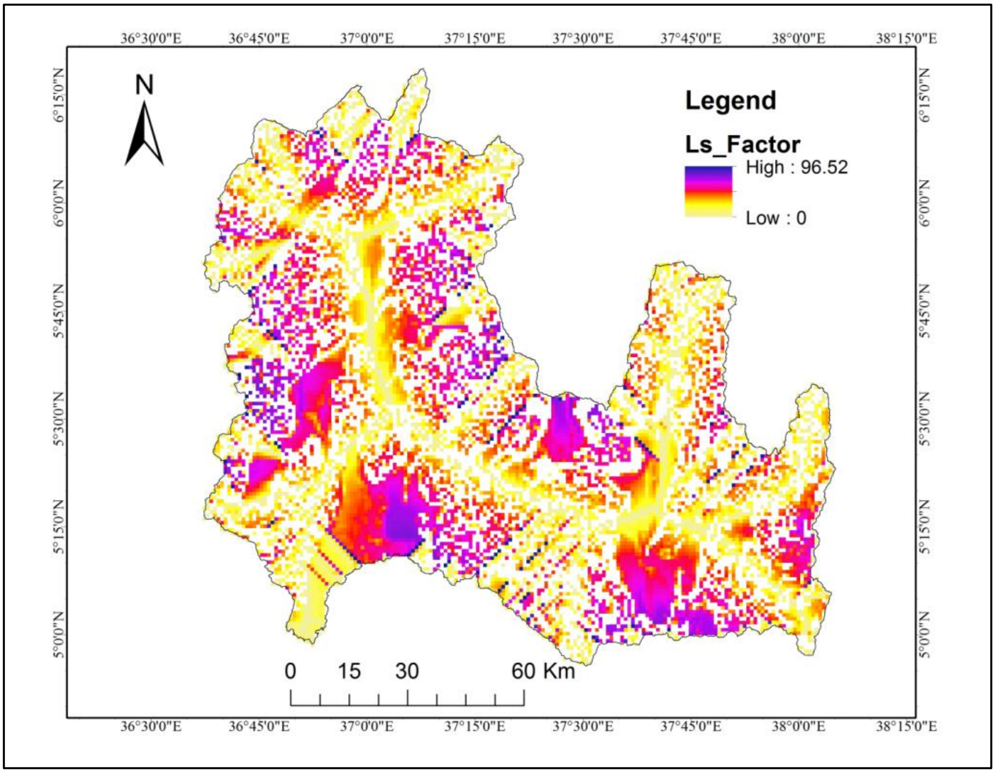

Figure 4 Slope length and Steepness factors (LS) map of study area

3.4. Cropping Management factor (C-factor)

Crop management factor (C) represented the ratio of soil loss under given crop to that of bare soil. The C-factor (Figure 5) in the present study area varied between 0 and 0.27. In order to determine C-factor, the Weito Watershed was classified into nine land use classes. This was generated from Landsat 8 OLI/TIRS data used for land cover classification. Then C-value for each land cover was assigned based on the available type of land use/land cover. Finally, the corresponding C-value was determined based on the suggestions of Hurni (1985) and thus the C-factor map was produced.

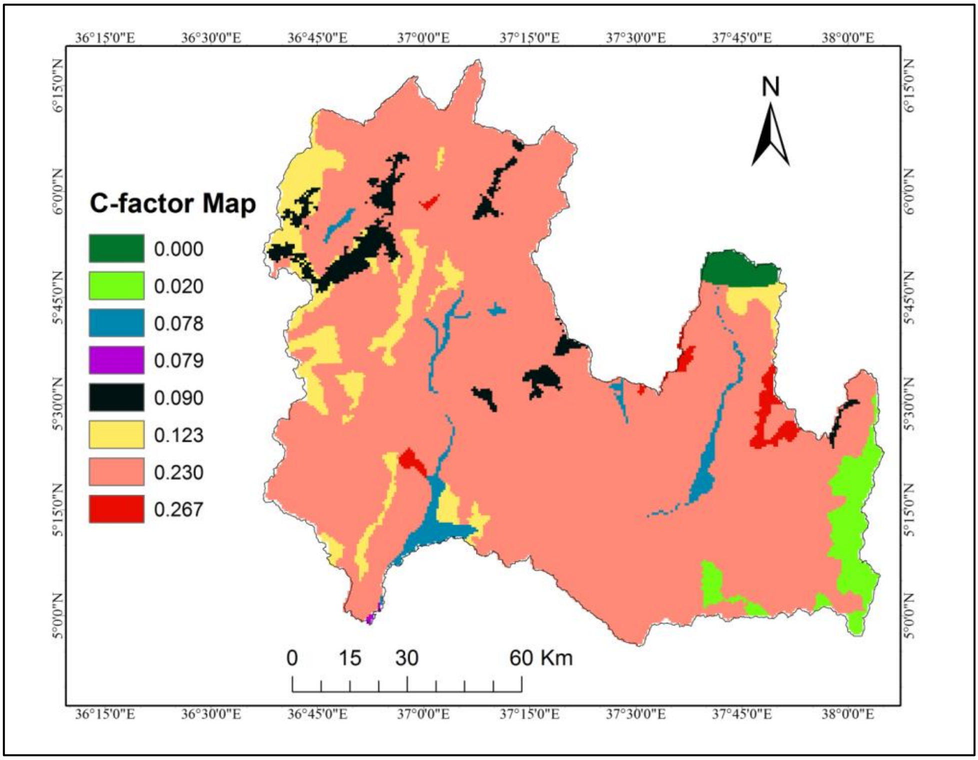

Figure 5 Cropping Management map of the study area

3.5. Supporting Conservation Practice (P-factor)

The support practice factor-P represents the effects of those practices such as contouring, strip cropping, terracing that help prevent soil from eroding by reducing the rate of water runoff. In the P value, 0 represents very good man-made erosion resistance facility whereas 1 represents no man-made erosion resistance facility. As the upper part of the watershed was well-known for its terracing practice, this study considered it as a man-made management practice throughout the entire basin and hence this assumption was used as an input in the model. The observed result revealed 0.11-0.31 P-value which indicated the availability of very good man-made erosion resistance facilities.

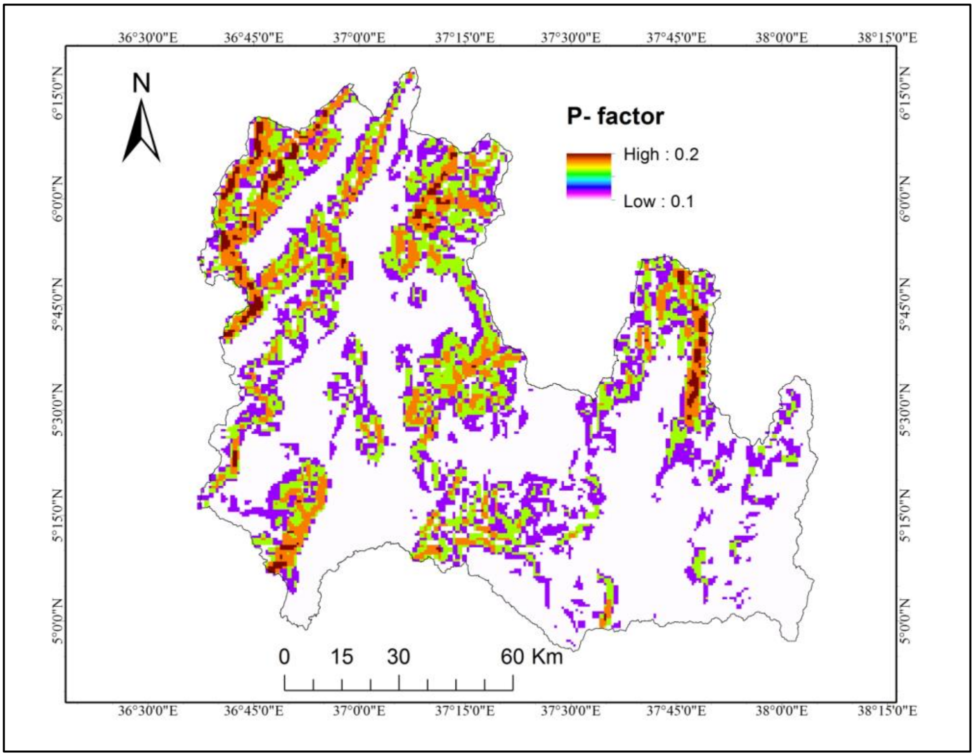

Figure 6 Supporting Conservation Practice (P-factor)

3.6. Estimated soil loss from the watershed

The combination of R, K, LS, C and P-map showed that the potential annual soil erosion from the Weito Watershed ranged from 0.0 to 210 ton/ha/year. The mean annual soil loss rate was 110 ton/ha/year, which was much greater than the tolerable level of 10 ton/ha/yr (Hurni,1984) for Ethiopian basins. The potential soil erosion risk map of the watershed was divided into five classes of severity. These classes are soil loss less than 25 ton/ha/yr which was described as minimal soil erosion risk class; between 25 and 85 ton/ha/yr described as low soil erosion risk class; between 85 and 130 ton/ha/year described as intermediate soil erosion risk class; between 130 and 210 ton/ha/year described as high soil erosion risk class; and above 210 ton/ha/year was described as very high soil erosion risk class (Hurni 1984; FAO (1984).

Table 4: Soil erosion rate, soil erosion risk classes and percent of soil loss from the study area

No	Soil erosion risk class	Coverage		Soil loss range (ton/ha/yr)	Erosion rate	
		Hectare	Percent		(x10^4/year)	in (percent)
1	Minimal	444835.9	31.8	0-25	451.13	3.96
2	Low	334326.4	23.9	25-85	1838.79	16.15
3	Moderate	283967.6	20.3	85-130	3052.65	26.81
4	High	251793.9	18	130-210	4280.5	37.6
5	Very high	83931.29	6	>210	1762.56	15.48
Total		1,398,855	100		11385.63	100

The areal coverage and relative percent of each class was derived from the soil erosion map of the study watershed. The map presented the five severity classes in a color scheme of grey (low risk) to red (very high risk). From the total area of the watershed 419656.5Ha (30%) was within the range of high to very high soil erosion risk class whereas the remaining 979198.5Ha (70%) area had moderate to minimal soil erosion risk.

In general, overlaying the land use land cover map, topography map on the erosion hazard created some relationships. The degree of erosion on moderate annual cultivated (MAC) land use type areas was very high which had steeper slopes. The existing cultivation practices without proper conservation measures on these slopes accelerated the extent of erosion in addition to the grazing and clearance of vegetation for fuel wood. In the lower slope, classes with grazing and browsing land use type occurred to be affected by moderate and slight erosion. On flat slopes, deposition of sediments was the major constraint which could be improved by applying integrated watershed management in the upland.

At woreda level, Bako Gazer, Bena and part of Teltele were classified as very high-risk soil erosion regions whereas the major portion of Konso, Burji and Teltele were considered safe. This might be due to the existing watershed management interventions that they had practiced for a long period of time. The spatial overview of the soil erosion risk map showed that some of the woredas of the study watershed were potentially prone to soil erosion risk (Figure 7).

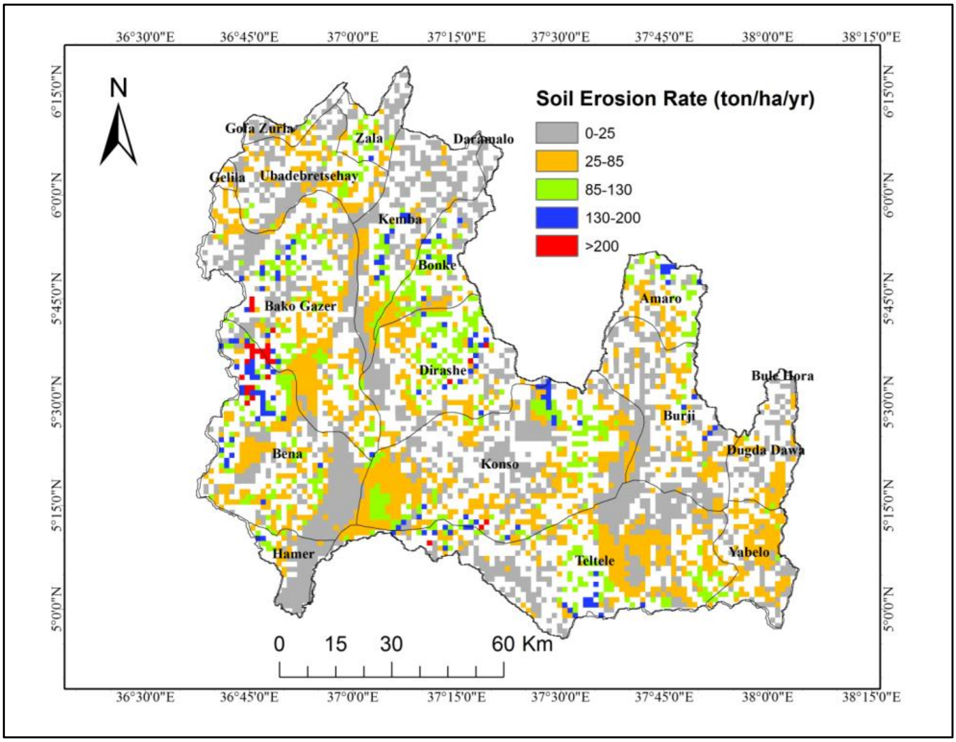

Figure 7 Soil erosion rate of Weito Watershed

4. CONCLUSIONS AND RECOMMENDATIONS

Soil erosion is a serious problem in many parts of Ethiopia. Hence, proposing different methods to evaluate soil loss at the woreda level is necessary for planning of soil erosion protection and conservation measures. For this study, RUSLE model in GIS interface was used to estimate average annual soil loss from the watershed. The average annual soil loss in the Weito Watershed was computed by overlaying the five factor maps using RUSLE with Spatial Analyst extension. A quantitative assessment of average annual soil loss was done for the study area. The average annual soil loss ranged from 0.0-210 tons/ha/year and the mean value was 110.15tons/ha/year. Thus, the study revealed that the area was covered by minimal, low, moderate, high, and very high soil loss potential zones and the coverage was 31.8% 23.9%, 20.3%, 18%, and 6.0% respectively. The average annual soil loss map will definitely be helpful in identifying the priority areas for implementation of soil conservation measures and effective checking of soil loss. Therefore, we recommend important mitigation measures and soil conservation practices to be implemented in the severely degraded sub-watersheds.

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