Spatial Erosion Hazard Assessment for Conservation Planning in the Gibe-III Dam Catchment, Southwest Ethiopia

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Abstract

Soil erosion is one of the biggest global environmental problems resulting in both on-site and off-site effects. Sedimentation as off-site effect is considered to be critical in reservoirs and water bodies, both in reducing capacity and loss of value. Soil erosion hazard was assessed using adapted USLE (Universal Soil Loss Equation) model to spatially identify and prioritize areas for conservation planning in Gibe –III dam catchment, southwest Ethiopia. Rainfall, soil map, a 30x30 m DEM, and satellite images were used to determine the USLE variables. Individual Geographic Information System (GIS) files (thematic layers) were built for each USLE factor and these layers were spatially overlaid and combined by a cell by cell-grid modeling procedure to predict the mean annual soil loss and develop erosion hazard intensity map of the study area. The mean annual soil loss rate ranges from 0 - 51.57 tons $ha^{-1}yr^{1}$ with an estimated average of 7.47 tons $ha^{-1}yr^{-1}$. Based on the level of soil erosion rates, the study area was classified into five priority categories for conservation interventions. The analysis showed that 53% of the study area suffers from a moderate to very high erosion risk (>6.25 tons $ha^{-1}yr^{-1}$). These areas are located around the steeper slope banks of Gojeb and Gibe Rivers. However, Woreda level prioritization indicate that Menjiwo, Merka Gena, Loma Bosa, Esara Tocha, Gimbo, and Kindo Koysha Woredas were the largest sediment producer Woredas; together they cover 43% of the study area but they produce 53% of the total annual soil loss. Moreover, the total potential soil movement in the study area was estimated 9,700,823 tons yr^{-1} from 1,298,402 ha. Thus, any intervention designed to reduce the sediment load reaching to Gibe –III dam should start from these prioritized Woredas.

Key words: Soil erosion, USLE, GIS, Gibe –III dam catchment, Prioritization, Ethiopia.
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INTRODUCTION

Soil erosion is the process of detachment, transportation, and accumulation of surface soil by erosive agents. Various human activities disturb the land surface, and thereby induce significant alteration of natural erosion rates. Rapid population growth, cultivation on steep slopes, clearing of vegetation and overgrazing are the main anthropogenic factors that accelerate soil erosion in Ethiopia (Reusing *et al.,* 2000). In Ethiopia, accelerated soil erosion by water constitutes a severe treat to the national economy (Sutcliffe, 1993; Hurni, 1993). On the average, Ethiopia losses 12 tons of soil per hectare per year, or an estimate of 1493 million tons of soil per year due to water erosion. On the other hand, the soil formation rate for Ethiopia is in the range of 2-22 tons per hectare per year (Mahmud *et al.*, 2005; Hurni, 1988).

The effects of erosion are both on-site and off-site. Sedimentation as off-site effect is considered to be critical in reservoirs and water bodies, both in reducing capacity as well as loss of value. According to World Commission on Dams (2000) about 25% of the world's existing fresh water storage capacity may be lost in the absence of measures to control sedimentation. The study also indicated that the problem is more severe in developing countries. Soil erosion reported to be a serious problem in Ethiopia through increasing sedimentation of reservoirs and lakes (Bezuayehu, 2006). Specific studies indicated that sediment concentration of 16.7 kg m^{-3} in Bilate river (Sileshi, 2001); accumulation about 3.5 million m^3 of silt in just 23 years for Koka dam (Gizaw *et al.*, 2004) and 50% of the studied reservoirs in Tigray have lost their economic life before half of the design period because of siltation (Haregeweyn *et al.*, 2005).

Soil erosion risk assessment and mapping of erosion prone areas under various land use/land cover helps to prioritize where in the watershed action to be taken and for overall soil conservation planning. This is important in order to encourage effective natural resource conservation and sustainable development. Therefore, the need for soil erosion assessment is not merely quantifying the erosion rate but spatial assessment of erosion can be core of any decision making and supportive in policy formulation for sustaining the environment as a whole (Kalpana and Bhaware, 2006)

Soil conservation activities do require planning and prioritizing locations for intervention. In reality due to various required resources (E.g. financial constraints), it is difficult to conserve all areas under the risk of erosion. Therefore, in practice, areas at high risk have to be prioritized first than other areas for management and conservation of soil and water resources. However, a critical element to the success and sustainability of any watershed management program is the ability to utilize limited time and funds most effectively to address priority areas, particularly in large watersheds. In fact, a range of sophisticated assessment tools currently exists to assist decision-makers and managers to identify key areas for the implementation and application of watershed management programs (Heidi *et al.*, 2011). For example, the hydrologic models that provide detailed assessments of hydrologic processes and calculate sediment loads, as well as providing information on the efficiency of alternative control practices and land-use changes applied at the field, farm, and sub-watershed scale. Recently, application of erosion models tend to favour the process based types in many parts of the world; like WEPP (Water Prediction Program); CREAMS (chemical, runoff and erosion from agricultural management systems). Process-based models provide an ideal tool for facilitating water resources management at small scale level. However, the accuracy and reliability of process-based hydrologic models decreases with the increasing complexity and size of the system being modeled (Novotny and Olem, 1994). These models however, do require large datasets as well as more variables than the simple model like USLE. Given the high erosion rate in Ethiopia and scarcity of detailed input data the USLE is considered to be the best option. Moreover; very large watersheds, like Gibe – III dam catchment, exhibit a high landscape variability that cannot be easily or accurately characterized at a minimal expense with process-based hydrologic models. This is also an added reason for using USLE utilizing remotely sensed data and Geographic Information Systems (GIS). Thus for large watershed areas; a coarser level of data can be used to provide an initial identification of areas exhibiting considerable soil loss.

The adapted USLE for Ethiopian condition has got great attention and application in many parts of Ethiopia; Bobe (2004) applied USLE in Harerghe; Gebreyesus and Kirubel (2009) estimated the amount of soil loss in different landforms and land uses using USLE in Medego watershed Tigray region. Habtamu et al. (2013) used it in Choko Mountain Northern Ethiopia. Using the adapted USLE Abate (2011) estimate the soil loss to establish priority categories for conservation interventions in south Wello. Most recently Beshir and Awdenegest (2015) applied USLE for predicting soil loss to identify hotspots in the Gibe catchment, Jimma zone western Ethiopia, while Meshesha et al., (2012) and Syed and Hamelmal (2016) applied adapted USLE for soil loss estimation in the Awassa catchment.

However the USLE model is not without limitations, it is developed to estimate long term average annual soil loss from sheet and rill erosion (Wischmeier and smith, 1978). Thus gully erosion rates, stream bank erosion and erosion in urban areas cannot be estimated. Moreover storm event soil loss rates could not be done unless modified as MUSLE (Modified Universal Soil Loss Equation) (Williams, 1975)

Determining the location of priority areas for Gibe III dam catchment is important and timely exercise to provide a management and decision tool for natural resource managers. This is critically important for the reduction of siltation in the reservoir (such like Gibe III dam) by developing and implementing successful and cost-effective erosion prevention programs. Thus the objective of this study was to assess spatial erosion hazard for Gibe III dam catchment using USLE model in a GIS environment and prioritizing erosion prone areas for soil conservation planning at woreda level.

MATERIALS AND METHODS

Description of the Study Area

The study area, Gibe-III dam catchment, is located at the central part of the Omo Gibe Basin, southwestern part of Ethiopia (Fig.1). Geographically the catchment area extends between 6.748^o – 7.815^{o}N latitude and 35.655^o – 37.919^o E longitude and has a total area of 12,984 km^2. Most parts of the study area lies in the Ethiopian highlands >1500masl (FAO, 1984). It lies in two regional states, namely: Southern Nations Nationalities and People Regional State in its southern part composed of twenty three Woredas covering about 71 % of the total area, and the Oromia Regional State in the north, crossing six Woredas which cover 29 % of the area. The average annual rainfall and air temperature of the study area is 1,499 mm and 20.4°C, respectively (EEPCo, 2009). According to FAO classification, soils of the study area are classified as Humic Nitosols (43%), Humic Alisols (24%), Lithic Leptosols (23%), Chromic Luvisols (7%) and Eutric Vertisols (3%).

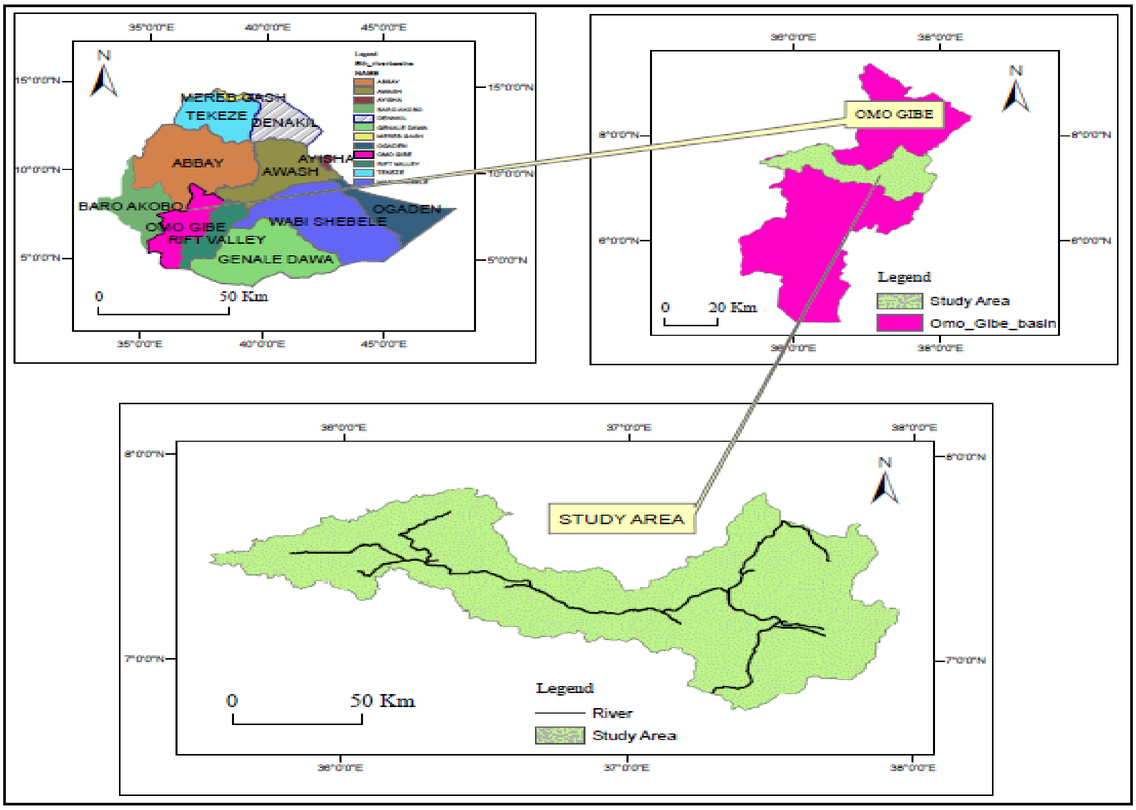

Figure 1. Location of the study area (Gibe-III Dam Catchment)

Data Generation and Data Analysis

The rainfall data was collected from Ethiopian Meteorological Agency and Omo – Gibe Basin master plan, Ethiopia. Monthly rainfall data for the period from 1980 to 2012 was used to compute rainfall erosivity (R) factor from 35 metrological stations that found within and around the study area. The soil data for this study were obtained from FAO soils and the soil map of Omo - Gibe basin master plan from Ministry of Water Resources, Ethiopia. ASTER; NASA source DEM with a spatial resolution of 30m was obtained from Ethiopian Geological Survey office and was used to prepare slope map, LS factor map and DEM based analysis. The LANDSAT 2013 ETM+ image for the study area was downloaded via FTP (http://glovis.usgs.gov). This image was used to prepare land use land cover map of the study area for C_factor and P_factor estimations.

ERDAS Imagine 10 was used for satellite image processing and land use land cover classification whereas Global Mapper 11 and Arc SWAT for delineation of the study area and ArcGIS9.3 was used for DEM processing and raster based overlay analysis.

The data analysis involved the use of adapted USLE model in a GIS environment. Individual GIS files were built for each factor in the USLE. Each factor is considered as a thematic layer. These layers were spatially overlaid and combined by a cell by cell-grid modeling procedure in ArcGIS 9.3 to predict the mean annual soil loss and develop erosion hazard intensity map of the study area. However, the various layers of data were brought to common coordinates before being processed together. The resulting mean annual soil loss map was then classified into different priority classes based on WBISPP (2001) classification of soil loss classes and simple algorithms were used to classify the area into different erosion hazard zones.

The Universal Soil Loss Equation (USLE) model could be written as:

$$A = R \times K \times (LS) \times C \times P \qquad (1)$$

where: A: soil loss in $t{\cdot}ha^{-1}$ $year^{-1}$; R: rainfall erosivity factor in $MJ{\cdot}mm{\cdot}ha^{-1}{\cdot}hr^{-1}$ $year^{-1}$; K: soil erodability factor in $t{\cdot}hr{\cdot}MJ^{-1}{\cdot}mm^{-1}$; LS: slope steepness-length factor; C: cover and management factor; and P: conservation practices factor. LS, C and P are dimensionless.

The USLE parameters are location specific and need to be calibrated to the specific area to enable reasonable prediction of the rate of soil loss. Hence, in this study the Universal Soil Loss Equation (USLE) model adapted for Ethiopian condition was considered (Hurni, 1985; Hellden, 1987; SCRP, 1996; Kaltenreider, 2007).

The parameters/factors that participate in the model were processed with 30m by 30m cell size and while the final model output was set to 100m by 100m to obtain the annual soil loss per hectare per year. All layers were projected with UTM Zone 37N using the WGS 1984 datum; these correspond to standards used by the Ethiopia Mapping Agency. The figure below show the steps followed in the analysis.

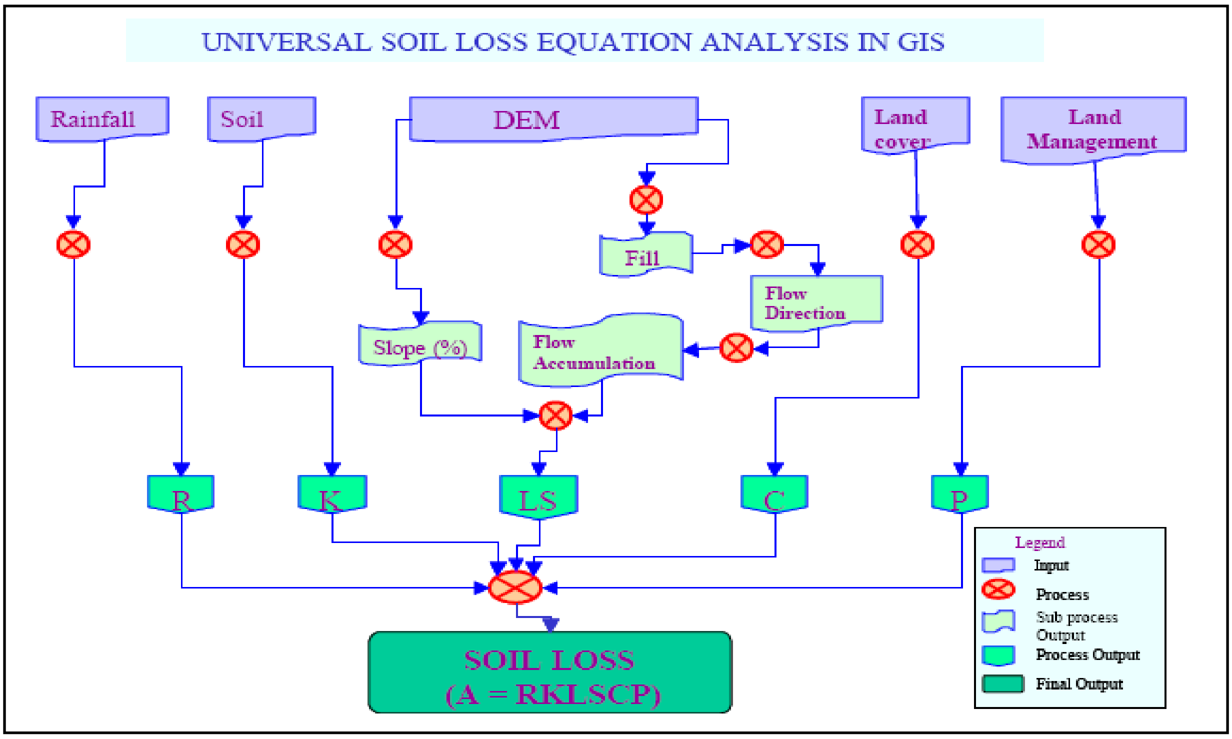

Figure 2. Flow Chart showing analysis of annual soil loss based on GIS application (adapted from Atesmachew et al., 2012)

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

Rainfall Erosivity /R_Factor/ Estimation:-The rainfall erosivity factor in USLE is estimated from the total storm energy and maximum 30min intensity (Renard et al., 1997). However, this relationship is limited in Ethiopia because of mainly the absence of rainfall kinetic energy and rainfall intensity data. The estimation of rainfall erosivity here used the modified method for Ethiopian condition by Kaltenrieder (2007) (Eq. 2).

$$R = 0.729*P - 376.2 \quad (2)$$

Where; R is the rainfall erosivity factor ($J \cdot m^{-1} \cdot hr^{-1}$ $year^{-1}$) and P is the mean annual rainfall (mm).

Monthly precipitation data of over 30 years (1980 - 2012) from 35 meteorological stations were used and the calculated R_factor values for each station are given in Table 1 and this was then transferred to ArcGIS9.3 and an attribute table was created.

The R factor value map (using the point theme) was produced using the nearest neighbor Kriging interpolation technique, with 12 neighborhoods in spatial analyst tool (Figure 3).

Soil Erodibility /K_Factor/ Estimation:-The soil data for this study were obtained from the soil map of Omo - Gibe river basin master plan and FAO soils and used for analyzing the soil erodibility factor (K_factor). The basic soil data set was found in vector format which changed to raster grid and re-classified in ArcGIS 9.3 Spatial Analyst Tool. The K_factor estimations for different soil types of Gibe-III dam catchment are shown in Table 2. Figure 4 shows the resulting K_factor value map.

Table 1: Mean Annual Rainfall (32-year average) and Calculated R_factor Value for 35 Stations

No	Station Name	Mean Annual RF (mm)	Calculated R_factor	No	Station Name	Mean Annual RF (mm)	Calculated R_factor
1	Agaro	1527	737.0	19	Gojeb	1523	734.1
2	Ambay School	1720	877.7	20	Hosaina	1194	494.2
3	Areka	1333	595.6	21	Jima	1495	713.7
4	Asendabo	1254	538.0	22	Metseso	2106	1159.1
5	Bele	1273	551.8	23	Morka	1128	446.1
6	Bilate	1101	426.4	24	Omonada	1205	502.2
7	Bonga	1784	924.3	25	Saja	1506	721.7
8	Chekorsa	1614	800.4	26	Sekoru	1430	666.3
9	Chena	1877	992.1	27	Serbo	1318	584.6
10	Chida	1690	855.8	28	Shebe	1622	806.2
11	Chira	2092	1148.9	29	Sodo	1199	497.9
12	Dedo Sheki	1898	1007.4	30	Wishwish	1768	912.7
13	Deneba	1031	375.4	31	Worancho	1074	406.7
14	Dimbira	1287	562.0	32	Woshi	1463	690.3
15	Dimtu	1425	662.6	33	Yebu	1963	1054.8
16	Durame	1083	413.3	34	Mizan Teferi	2071	1133.6
17	Gera	1789	928.0	35	Tepi	1561	761.8
18	Gesuba	1086	415.5				

Source: Ethiopian Meteorological Agency (1980 – 2012) (Computed)

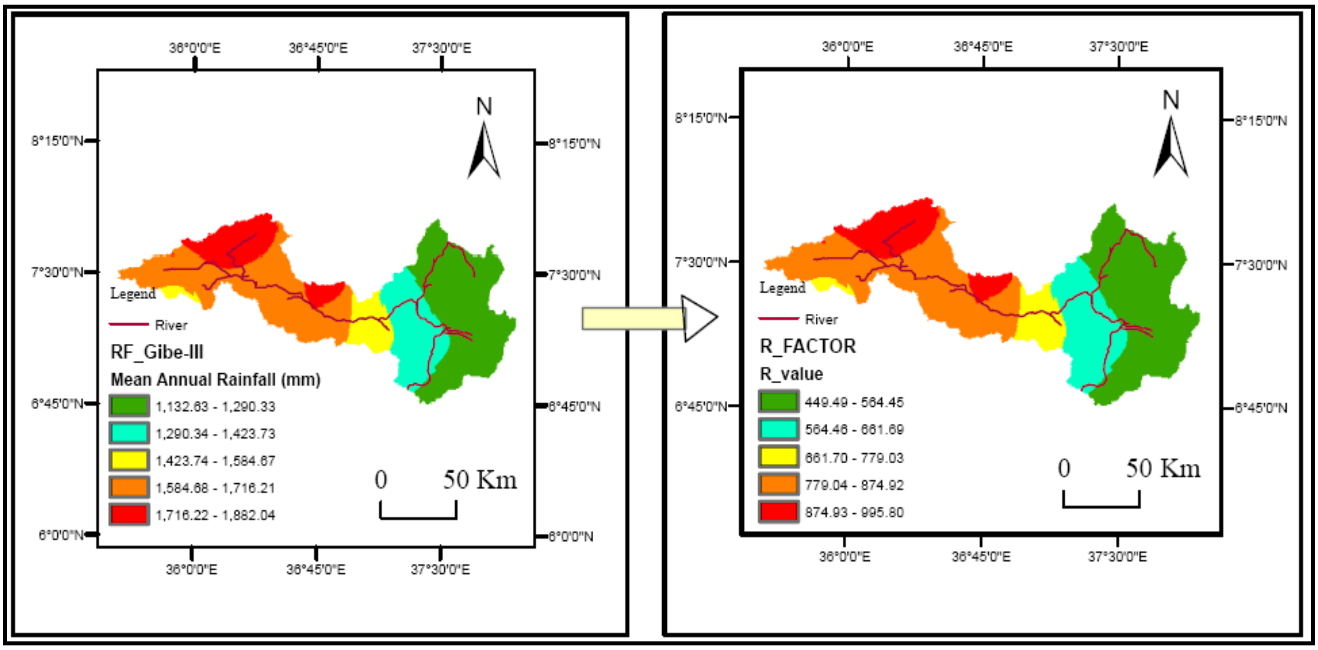

Figure 3. Rainfall erosivity /R_Factor/ map of the study area

Table 2. Soil Erodibility /K_Factor/ Value Estimated

No	Soil type	K_Factor value	No	Soil type	K_Factor value
1	Chromic Luvisols	0.14	4	Eutric Vertisols	0.19
2	Humic Nitosols	0.32	5	Humic Alisols	0.22
3	Lithic Leptosols	0.24			

Source: Adapted from Kaltenrieder (2007) and Ali and Hagos (2016)

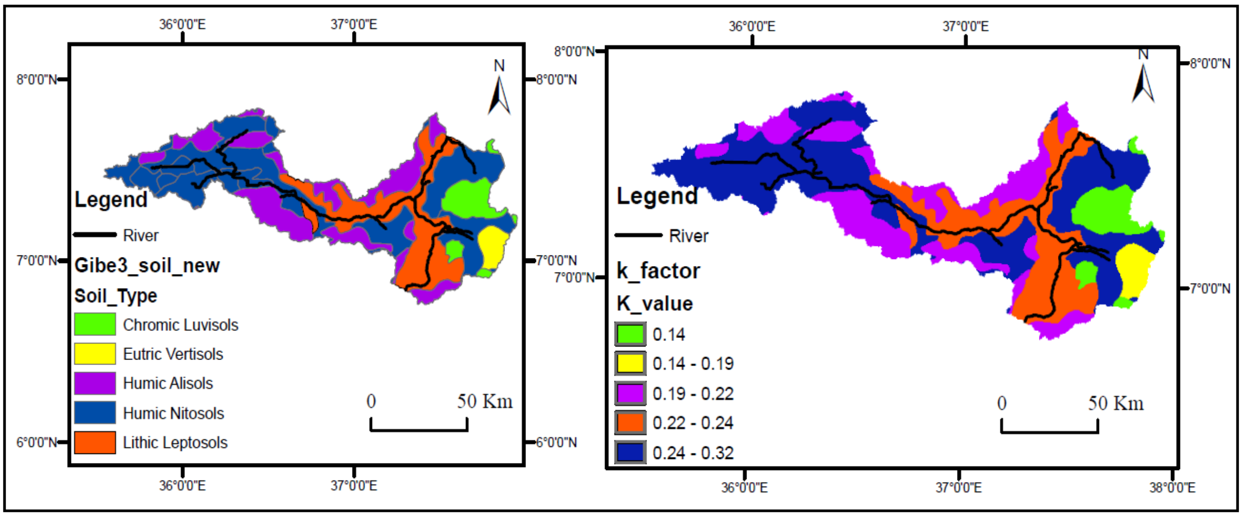

Figure 4. Soil erodibility /K_Factor/ map of the study area

Topographic (L and S) Factors Estimation:-The LS factor grid was estimated with the following equation (Eq. 3) proposed by Wischmeier and Smith (1978); Moore and Burch (1986a and 1986b); and Abate (2011).

$$LS = (\text{Flow Accumulation} * \text{Cell value} /22.13)^{m} *(0.065 + 0.045\, S + 0.0065\, S^2) \qquad (3)$$

where: LS is slope length- steepness factor, S is slope gradient (%), cell value is 30m contributing area and m is as in Table 3 (Wischmeier and Smith, 1978). The values of flow accumulation and slope gradient were derived from DEM after conducting FILL and Flow Direction processes in ArcGIS 9.3. Figure 5 shows the derivation process and the resulting topographic factor (LS) map of the study area.

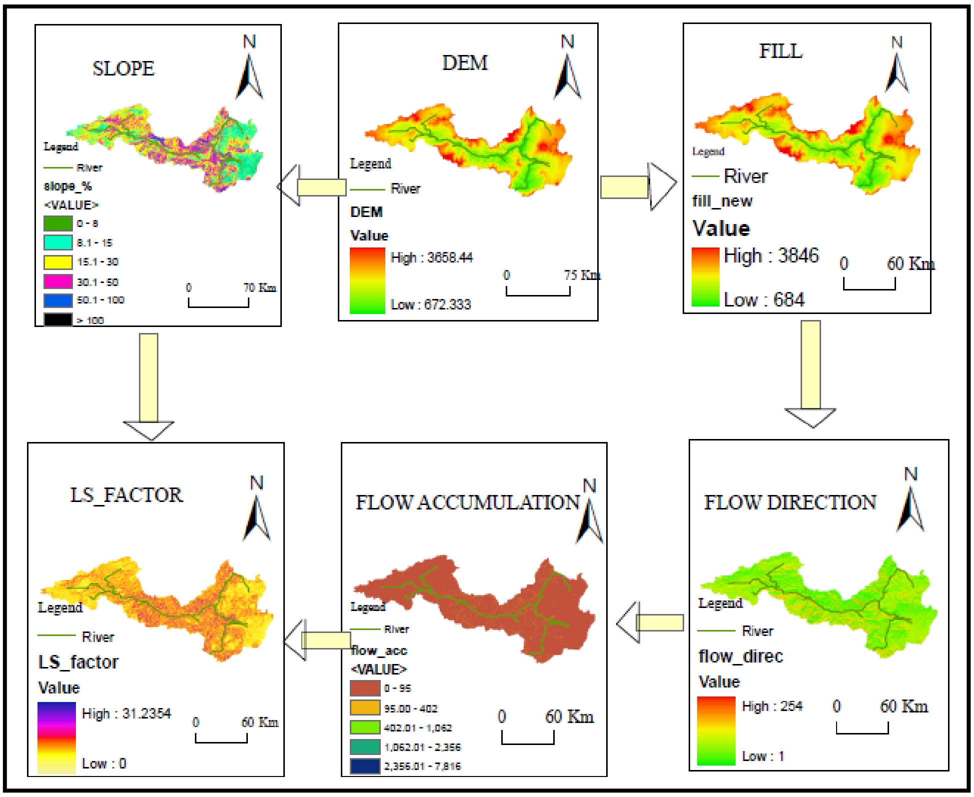

Figure 5. Topographic (LS_Factor) map of the study area

Table 3: **m**-value

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

Source: Adapted from Wischmeier and Smith (1978)

Cover and Management /C_Factor/ Estimation:- Seven major land use land cover (LULC) maps were produced from Landsat7 ETM+ (Dec.3, 2013), by a hybrid classification procedure (figure 6). *C*_factor values corresponding to each crop/vegetation condition were identified. In cultivated lands C_factor value were estimated based on the weighted average of the dominant crop types. Table 4 lists the average *C*_factor values for the different land use categories identified and these values were used to re-classify and obtain the *C*_factor map of the study area (Figure 6).

Table 4 Estimated C_factor values for the derived land use land cover classes

Land use Land cover type	Average C_Factor value	% Land Area
Cultivated Land; Rainfed; Cereal Land Cover System; lightly stocked	0.30	24.36
Cultivated Land; Rainfed; Cereal Land Cover System; moderately stocked	0.30	30.93
Forest; Open (20-50% crown cover)	0.05	17.57
Grassland; moderately stocked	0.05	14.57
Grassland; unstocked (woody plant)	0.01	1.58
Shrub land; Open (20-50% woody cover)	0.001	0.32
Woodland; Open (20-50% tree cover)	0.001	10.66

Source: Adapted from Kaltenrieder (2007)

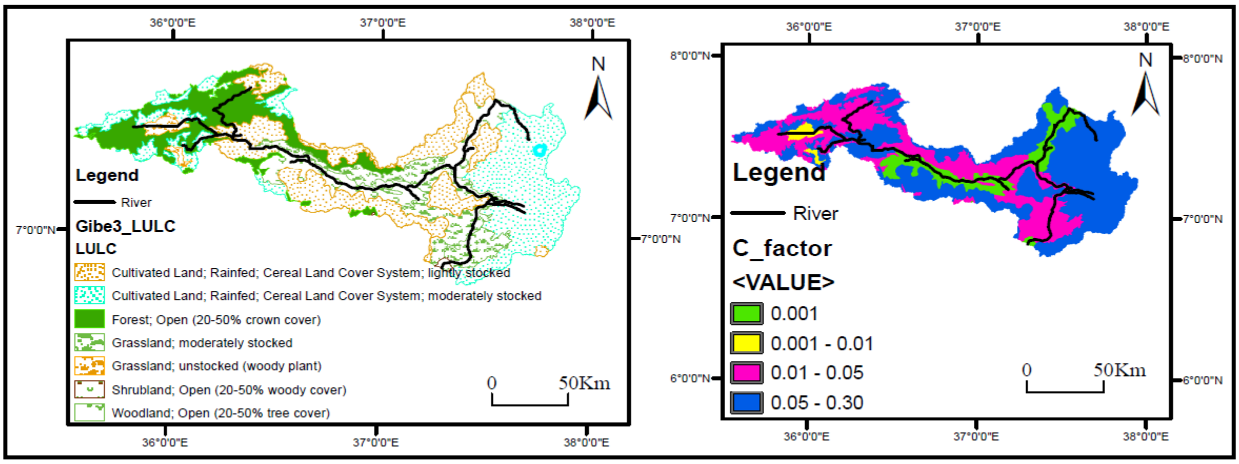

Figure 6. LULC and C factor map of the study area

Supporting Practice /P_Factor/ Estimation: - It depends on the type of conservation measures implemented in the area, with value ranges from 0 to 1. However, in the study area, as data were lacking the P-values suggested by Shi *et al*. (2002) and Abate (2011) was used (Table 5). The assumption here is the grass or forest lands are not treated with any conservation practice while the agricultural lands are treated and the effect of which is high in gentle slopes. Thus, the agricultural lands are classified into six slope categories and their respective P-values were assigned (Table 5).

In ArcGIS9.3, the original land use land cover map in a vector format was first re-classified in to two categories (i.e. Agricultural land and other land) then it was converted in to raster format. In Spatial Analyst Tool extension Local the new raster land use was combined with slope map (%) derived from DEM to get a combined land use - slope map of the study area and the P_factor values listed under Table 5 were assigned to each land use - slope combination grid. Finally the assigned P_factor values were looked up in Spatial

Analyst Tool extension Re-class to produce the resulting P_factor map (Figure 7).

Table 5 Conservation practices factor (P-Value)

Land use type	Slope (%)	P_factor value
Agricultural Land	0 – 5	0.11
	5 – 10	0.12
	10 – 20	0.14
	20 – 30	0.22
	30 – 50	0.31
	50 – 100	0.43
Other Land	All	1.00

Source: Adapted from Shi *et al.* (2002) and Abate (2011)

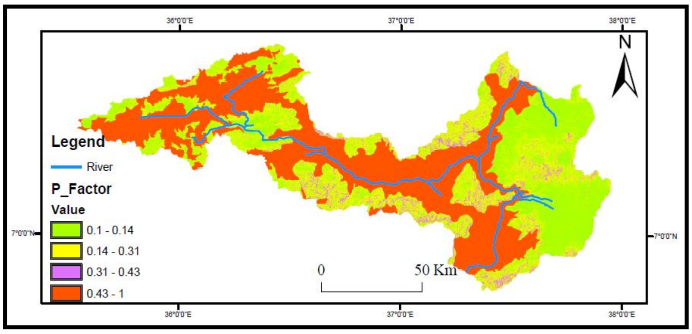

Figure 7. Supporting practice /P_Factor/ map of the study area

Analysis Based on Woreda and Kebele

In Ethiopia, resources, for conservation activities, are allocated by the government through political administrative boundaries (Region, Zone, Woreda, and Kebele) not through watershed or sub-watershed boundaries. Therefore, in order to effectively and efficiently utilize these limited resources and extracting meaningful priority locations, the catchment wise annual soil loss estimation has been considered as a better option. These estimations were further classified and prioritized, for conservation planning purpose, based on political administrative boundaries viz; Woreda and Kebele.

Hence, the catchment wise soil loss map of the study area was overlaid on the administrative Woreda and Kebele shape file map to extract Woreda and Kebele level average annual soil loss. This was done in ArcGIS9.3 using the command Spatial Analyst extension Extract by Mask. The average annual soil loss rate (t/ha/yr) of each Woreda and Kebele was then estimated as total soil loss (t/yr) of i^{th} Woreda and Kebele per total geographical area (ha) of i^{th} Woreda and Kebele.

RESULTS AND DISCUSSION

Erosion Hazard Assessment

The annual soil loss rate was determined in cell-by-cell analysis by multiplying the respective USLE factor values interactively in ArcGIS 9.3 Spatial Analyst extension Raster Calculator. Figure 8 shows the resulting soil loss rate map of the study area. The estimated annual soil loss rate ranged from 0 tons $ha^{-1}yr^{-1}$ (in the plain areas) to over 12 tons $ha^{-1}yr^{-1}$ (in much of the steeper slope banks of the main Rivers-*Gibe* and *Gojeb* and their tributaries). In few areas extreme values reaching to over 50 tons $ha^{-1}yr^{-1}$ was also estimated.

Acceptable soil loss rate of < 6.25 tons $ha^{-1}yr^{-1}$ was considered as a boundary (WBISPP, 2001) for evaluation of our estimate the study area. Accordingly, the soil loss rates (>6.25 tons $ha^{-1}yr^{-1}$) are particularly associated with high erosivity (R_value), large values of LS (especially of high slope, S), and lack of permanent supporting practice (P) (Fig. 3, 5, and 7). These areas are dominantly found at the steeper slope banks of *Gojeb* and *Gibe* Rivers at the western and northern parts of the study area respectively and at their tributaries. High soil loss rate was also found in randomly distributed cultivated lands having rugged topography (high LS_factor value) and high erodibility.

On the other hand, relatively the lower soil erosion rates (i.e. below 6.25 tons $ha^{-1}yr^{-1}$) were registered in forest cover areas (~17%; < 3.125 tons $ha^{-1}yr^{-1}$) and where most agricultural practices are carried out (~30%; <6.25 tons $ha^{-1}yr^{-1}$). With respect to areas of natural shrubs (11%), and grass lands (16%) had most of the highest soil losses (>12.5 tons $ha^{-1}yr^{-1}$); it appeared that the areas have a serious problem that should be dealt with conservation measures. This is attributed to the fact that the type of cover occurred on the steep slope area with high value of LS_factor and a higher K value ranges between 0.22 - 0.24. In the agricultural land, soil erosion was not as critical as in these areas, due to the fact that, although they had relatively higher C values (0.3 *vs* 0.001 and 0.05, respectively), mostly the land used for agricultural crops was located in areas where the least LS value was observed.

The total annual soil loss or movement in the study area was estimated 9,700,823 tons from 1,298,402 ha (Table 7). The largest size among soil loss categories was that of 6.25 -12.5 tons $ha^{-1}yr^{-1}$ which accounts for 40.28% of the study area (Figure 8 and Table 6). The average annual soil loss for the entire catchment was estimated at 7.47 tons $ha^{-1}yr^{-1}$.

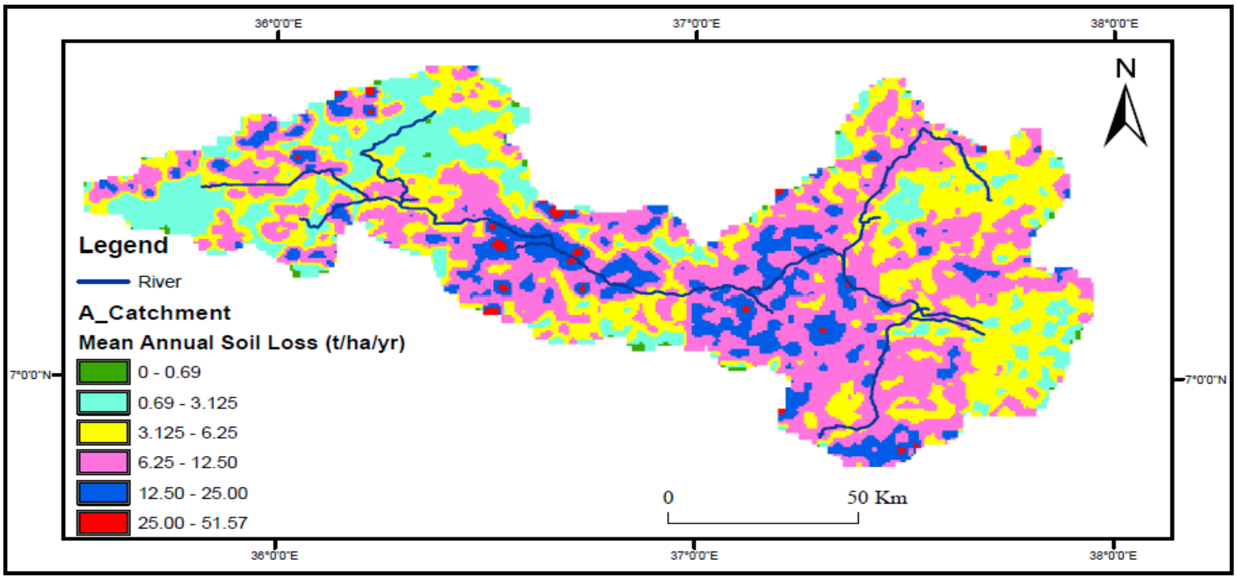

Figure 8. Spatial distribution of mean annual soil loss in the study area

The estimated soil loss rate and the spatial patterns are generally realistic compared to what can be observed in the field as well as results from previous studies. For instance, the results of this study falls within the ranges of the estimated soil loss for Ethiopia, which was ranging from 0 to 300 tons $ha^{-1}yr^{-1}$ with an estimated national average of 12 tons $ha^{-1}yr^{-1}$ Hurni (1985). Similarly the average annual soil loss for the entire Lake Hawassa catchment in the Rift Valley Basin, Ethiopia was estimated at about 5 tons $ha^{-1}yr^{-1}$ (Ali and Hagos, 2016 and Tigneh, 2009).

Prioritization for Soil Conservation Planning

The USLE model result was re-classified or prioritized in to different erosion hazard classes for conservation planning purpose. Prioritization of these areas means ranking in terms of conservation urgency. Studies have shown that the USLE model is more appropriate to show areas with differing degree of erosion hazard rather than their qualitative soil loss (Van Remortel, 2001). Soil loss tolerance (SLT) denotes the maximum allowable soil loss that will sustain an economic and a high level of productivity (Gebreyesus and Kirubel, 2009; FAO and UNEP., 1984). According to Renard *et al.* (1996), the common SLT values range from 5 to 11 tons $ha^{-1}yr^{-1}$. Morgan (1995) also argues that 10 ton $ha^{-1}yr^{-1}$is an appropriate boundary measure of soil loss over which agriculturists should be concerned. The assignment of a range depended on the judgment of how much erosion would be harmful to the soil. Accordingly, for this study WBISPP (2001) classification of soil loss classes were used and the extent of soil erosion was classified into five erosion hazard classes (Table 6). The least soil loss rate (less than 0.69 tons $ha^{-1}yr^{-1}$) category is considered as negligible and a severity class of no erosion is given. Area coverage in (ha) and percent proportion were also tabulated for each of the soil erosion potential categories.

Table 6. Erosion hazard classes and area coverage in Gibe-III catchment

Soil loss (t ha^{-1} y^{-1})	Equivalent top soil removal (mm)	Severity Classes	Conservation Priority classes	Area (ha)	Per cent of total area
<0.69	-	No erosion	-	5,231	0.40
0.69 - 3.125	< 0.25	Very Less	V	214,412	16.51
3.125 - 6.25	0.25 – 0.5	Less	IV	391,583	30.16
6.25 - 12.50	0.50 – 1.0	Moderate	III	523,018	40.28
12.50 - 25.00	1.00 – 2.0	High	II	156,584	12.06
>25.00	>2.0	Very High	I	7,574	0.58

Source: Adapted from WBISPP (2001) classification of soil loss classes

The total area with a soil loss potential higher than the SLT, i.e. > 6.25 tons $ha^{-1}yr^{-1}$, was 687,176 ha which comprises 53% of the total study area. Around 40% of the study area fall under the moderate erosion category while high severity class account for 12% of the area. The spatial locations of the areas highly affected by soil erosion, with a soil loss potential higher than the SLT, i.e. > 6.25 tons $ha^{-1}yr^{-1}$, are dispersed throughout the catchment mostly on the steeper slope banks of the *Gojeb* and *Gibe* rivers and their tributaries (Figure 8). These areas are under erosion severity classes of very high, high and moderate, where accordingly conservation priorities of the first, second and third level respectively. A closer look on the individual USLE factors output (Figure 3, 4, 5, and 7) revealed these areas are characterized by high rainfall erosivity, high soil erodibility, topographic ruggedness, and inadequate / poor vegetation cover during critical periods of the year.

The plane or relatively flat parts of the study area, which account for 47 percent of the total area fail in the least vulnerable to soil erosion category compared to other areas, as they are in the very less and less soil erosion severity classes. As can be seen from Figure 8, most of the least vulnerable areas to soil erosion (at the eastern part) are mainly found in gentle to flat topography but cultivated lands. This implies that topography seems dominant than cover. The other section of this category are under the natural forest and shrub lands at the upper western part in which good ground cover have multiple benefits in protecting the land from erosion (Morgan, 1995). In general, presumably rainfall, topography and cover were the dominant variables which determined the spatial distribution of erosion in the study area.

The soil loss rate map (Figure 8) and erosion hazard class (Table 6) clearly shows that nearly 53% of the total study area requires implementation of different types of soil and water conservation measures for a sustainable land use and reduction of both on site and off site effects of erosion. Where resources are limited, implementing conservation measures in only selected areas that are highly affected by erosion can significantly reduce great soil loss in the study area. Thus, it is necessary to identify and prioritize highly affected areas (i.e. administrative Woreda and Kebele) for treatment with appropriate soil and water conservation measures.

Annual Soil Loss Assessment by Woreda

The average annual soil loss rate of the study area Woredas ranges from 3.37 – 11.91 tons/ha/yr (Figure 9 and Table 7). Table 7 clearly shows that out of the total 29 Woredas, 18 Woredas fall under moderate to high soil loss rate category (>6.25 tons/ha/yr) and the rest 11 Woredas below the maximum soil loss tolerable limit (<6.25 tons/ha/yr). However prioritization was done considering the potential sediment generation capacity of Woredas. This is because the main intension of this research was to reduce the total sediment load reaching to Gibe –III dam through spatially identifying and prioritizing areas producing large sediment load for conservation planning. Here the sediment yield is considered as an index to judge the relative erosion rate across the study area, assuming sediment delivery ration of the whole catchment the same. This approach enabled us to make comparison and prioritize spatially for conservation intervention.

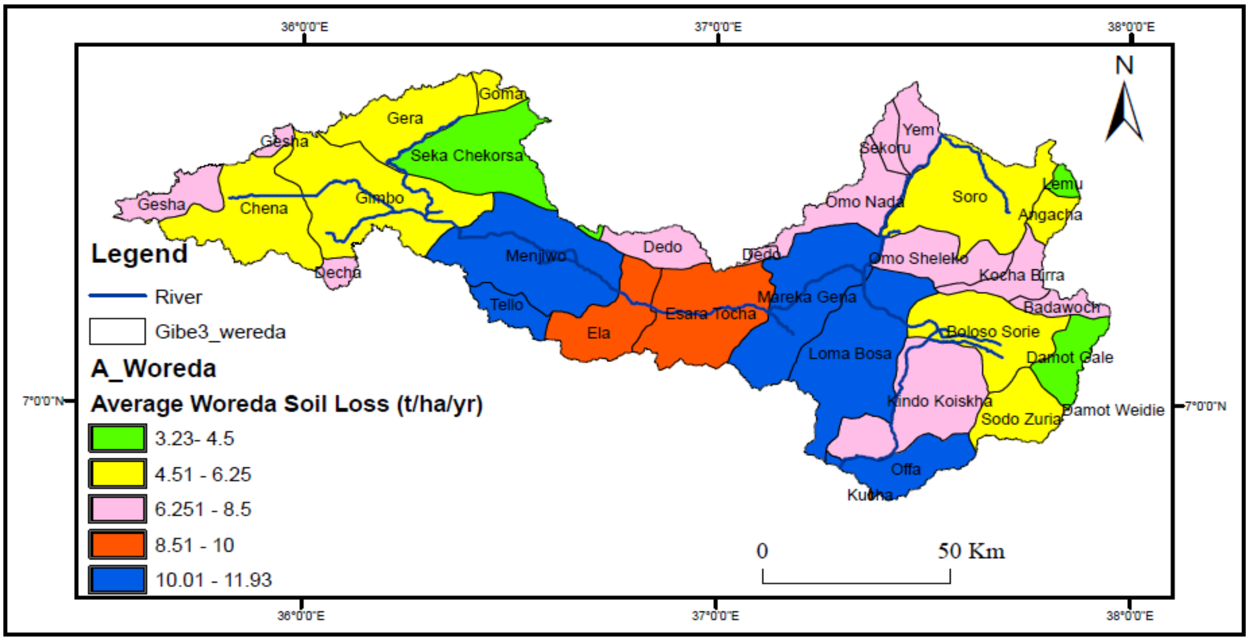

Figure 9. Average annual soil loss analysis based on Woreda

Table 7. Annual soil loss result of Gibe –III Dam catchment Woredas

Woreda	Average Annual erosion loss (ton/ha/yr)	Area (ha)	Total Annual soil loss (ton/yr)	Percent of soil loss
Menjiwo	10.61	105334	1117470	11.52
Merka Gena	11.91	88302	1051820	10.84
Loma Bosa	10.28	100614	1033790	10.66
Esara Tocha	8.48	78167	662933	6.83
Gimbo	6.07	107202	650534	6.71
Kindo Koysha	7.49	79428	594552	6.13
Soro	5.42	90049	488063	5.03
Ela	8.66	46169	399700	4.12
Chena	5.02	75307	377919	3.90
Boloso Sorie	5.87	64349	377909	3.90
Offa	10.38	35414	367719	3.79
Omo Nada	7.49	38450	287820	2.97
Omo Sheleko	7.03	38485	270662	2.79
Gera	4.93	51519	254012	2.62
Seka Chekorsa	3.37	71012	239003	2.46
Dedo	8.07	25624	206688	2.13
Gesha	6.84	28551	195136	2.01
Tello	11.02	16205	178506	1.84
Kacha Bira	8.03	21362	171431	1.77
Sodo Zuria	4.96	33315	165079	1.70
Yem	7.18	20632	148051	1.53
Badawoch	7.45	12420	92575.3	0.95
Damot Gale	3.52	25550	89878.1	0.93
Sekoru	7.98	10088	80536.5	0.83
Angecha	4.85	12207	59202.3	0.61
Goma	5.67	10355	58755.9	0.61
Decha	8.23	6950	57206.1	0.59
Lemu	4.32	5126	22153.8	0.23
Kucha	7.98	215	1714.87	0.02
TOTAL		**1,298,402**	**9,700,823.45**	**100.00**

Based on the analysis Menjiwo, Merka Gena, Loma Bosa, Esara Tocha, Gimbo, and Kindo Koysha Woredas are the first largest sediment producer groups and soil erosion sensitive Woredas in the study area (Table 7). In terms of the total annual soil loss Menjiwo Woreda generates the highest sediment load 1,117,470 t/yr which comprises 11.52% of the total annual soil loss of the entire study area followed by Merka Gena Woreda 1,051,820 t/yr (10.84%) and the remaining Loma Bosa, Esara Tocha, Gimbo, and Kindo Koysha Woredas produce the annual soil loss of 1,033,790 t/yr (10.66%), 662,933 t/yr (6.83%), 650,534 t/yr (6.71%), and 594,552 t/yr (6.13%) respectively. These six Woredas only covers 43% of the total catchment area but they contribute 53% of the annual soil loss of the entire catchment. Besides their area coverage the topographic ruggedness, insufficient permanent supporting practice, and poor vegetation cover during critical periods of the year coupled with erosive rainfall contributes to the high rate of soil erosion in the above prioritized Woredas.

Generally, as shown in Figure 9 and Table 7, the least annual soil loss rate was exhibited in Seka Chekorsa Woreda (3.37 ton/ha/yr) followed by Lemu Woreda (4.32 ton/ha/yr) whereas the maximum were estimated for Merka Gena Woreda (11.91 ton/ha/yr) and Menjiwo Woreda (10.61 ton/ha/yr). The main reason for higher soil loss rate in the study area was due to rugged topography, lack of permanent conservation practices, and high rainfall erosivity. While the probable reason for the least soil loss rate was observed as due to relatively a good forest cover with a lower C_factor value and plane topography with little LS_value.

Woreda level soil loss result was further analyzed by Kebele level to identify and prioritize the highest sediment producer Kebeles for intervention purpose.

Annual Soil Loss Assessment by Kebele

The study area consists of 29 political administrative Woredas and around 710 Kebeles. Kebele is the smallest political administrative boundary in Ethiopia, where a single Woreda consists of a number of Kebeles. Kebele level prioritization was done to identify the highest sediment generating Kebeles in the study area for conservation planning. Hence, Kebele level annual soil loss was extracted from the catchment wise soil loss map using Kebele shape file. Figure 10 shows the resulting Kebele level average annual soil loss map.

The average annual soil loss rate at Kebele level for the entire catchment ranges from 1.05 t/ha/yr to 30.97 t/ha/yr (Fig. 10). However, here prioritizing Kebeles for intervention was done based on previous determination of highest sediment producing six Woredas (Fig. 11). Table 8 shows the prioritized Woredas with their total number of Kebeles and the highest sediment producing Kebeles. The analysis result reveals that, for the prioritized six Woredas, the majority of the sediment was generated by less than half of their total Kebeles.

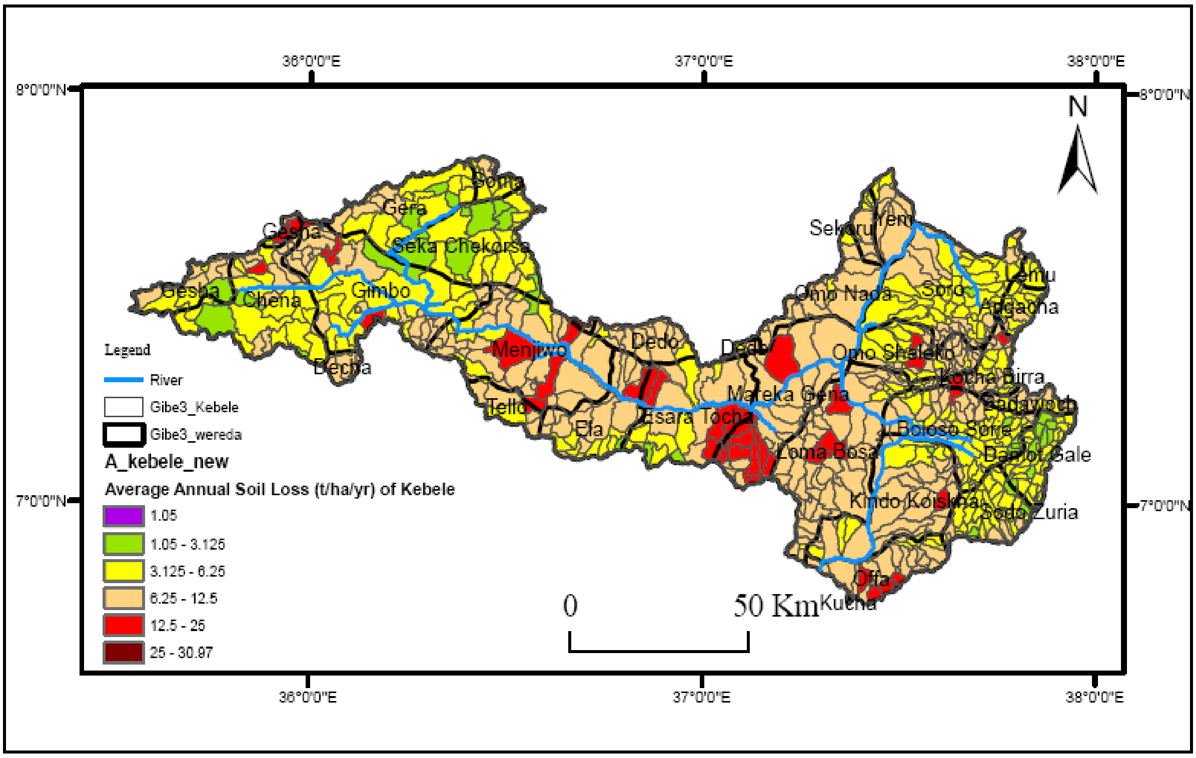

Figure 10. Average annual soil loss analysis based on Kebele

Table 8. Summary of kebele level soil loss analysis result for the prioritized six Woreda

Woreda Name	Woreda total sediment (ton/yr)	Total Kebele	Prioritized Kebele (total sediment in [ton/yr])	Percent proportion of sediment produced
Menjiwo	1,117,470	46	20 (943,630)	85
Merka Gena	1,051,820	47	20 (922,991)	88
Loma Bosa	1,033,790	71	25 (805,824)	78
Esara Tocha	662,933	26	13 (564,669)	85
Gimbo	650,534	56	19 (454,704)	70
Kindo Koyisha	594,552	54	18 (457,789)	77

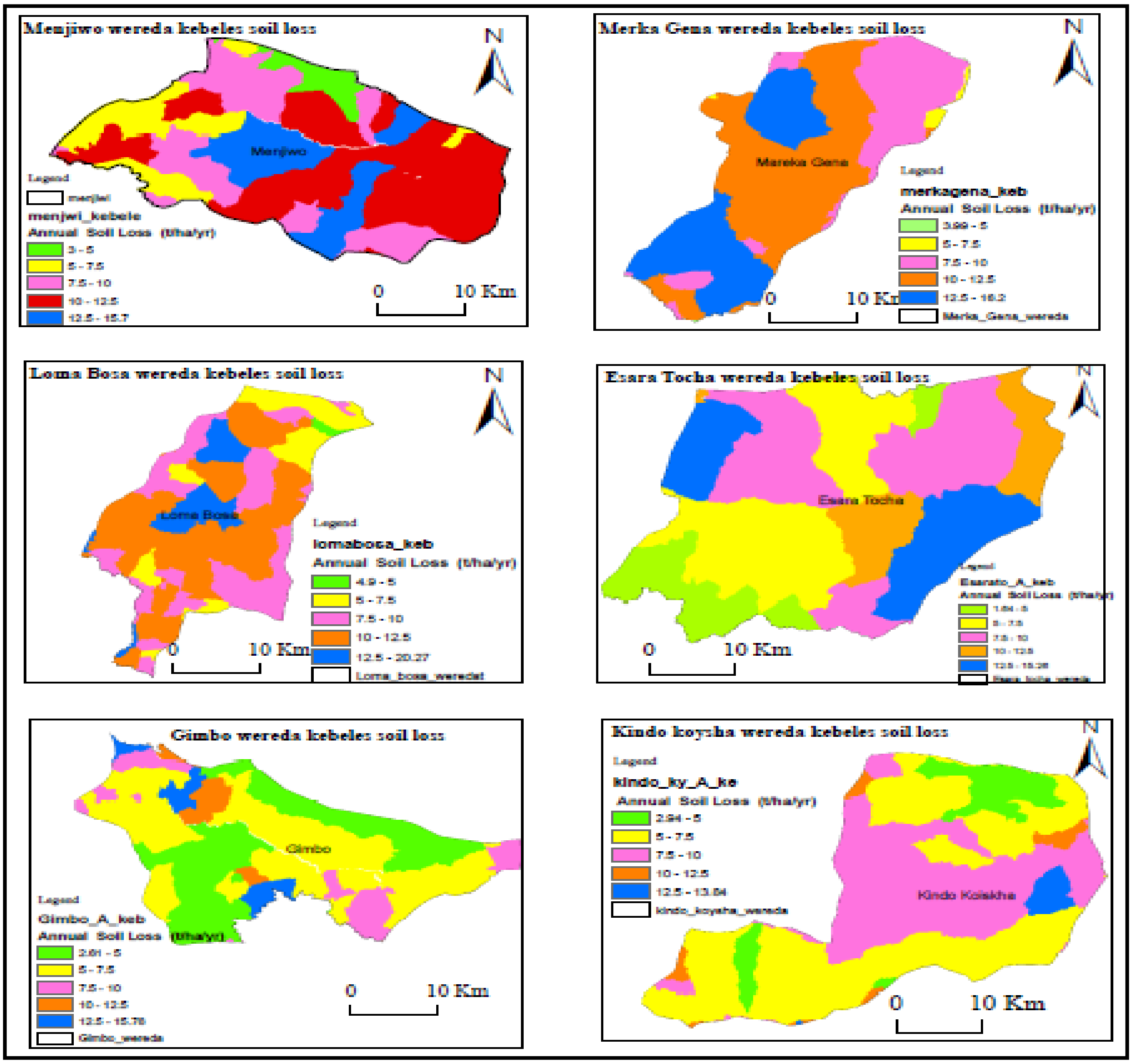

Figure 11. Total annual soil loss of the prioritized six woreda Kebeles

The largest sediment producer Woreda in the study area (i.e. Menjiwo) comprised of 46 Kebeles but 85% of its sediment was produced only by its 20 Kebeles (<50%). Similarly 88% of the total annual sediment of Merka Gena Woreda was generated only by 20 Kebeles (<50%) out of 47. Only one third of the kebeles (33%) produces 78% of the total annual sediment in Loma Bosa Woreda. A similar trend was observed in all of the six analyzed Woredas. Therefore, in terms of mobilizing the limited resources (i.e. material, human, and financial) and implementing appropriate soil and water conservation measures, authorities should focus on these prioritized Kebeles producing the large sediment load reaching to Gibe-III Dam.

CONCLUSIONS

A quantitative assessment annual soil loss was conducted to identify erosion hazard levels and prioritizing erosion prone areas for conservation planning purpose in Gibe – III dam catchment. The general approach involves estimation of individual USLE factors in ArcGIS9.3, preparation of erosion intensity map, and finally identifying and prioritizing erosion prone administrative Woredas and finally Kebeles for conservation planning. The estimated annual soil loss of the study area ranged from 0 – 51.57 tons $ha^{-1}yr^{-1}$ with an annual average of 7.47 tons $ha^{-1}yr^{-1}$. USLE is applied to estimate annual erosion rate integrating the spatially varying erosion rates. Given the study site covers vast area (over $1200km^2$) it is impractical to quantitatively validate it based on field measured data. Previous results of soil loss measured in the study area are not available. However, to avoid applying the model without evaluation, we evaluated the model's performance by comparing its output with results from other research of similar nature and the national average. The national average soil loss is 12 tons $ha^{-1}yr^{-1}$ (Hurni, 1985), estimates in the rift valley (ranging from 5 -50 tons $ha^{-1}yr^{-1}$) (Ali and Hagos, 2016; Meshesha et al., 2012) which all justify our estimated soil erosion rate is acceptable. This approach is reasonable and valid under the circumstances prevailing in our study area.

The potential total annual soil loss of the study area was 9,700,823 tons from 1,298,402 ha. Administrative Woreda level soil loss analysis indicated that out of the total 29 Woredas, 18 Woredas fall under moderate to high priority class. However, Menjiwo, Merka Gena, Loma Bosa, Esara Tocha, Gimbo, and Kindo Koysha were identified as the first largest sediment producers and soil erosion sensitive Woredas which requires immediate attention for soil conservation intervention. The highest sediment producing Kebeles of these Woredas were also identified. Thus, to utilize the limited resources in effective and efficient manner, any soil and water conservation intervention designed should focus these prioritized Kebeles which are at high risk of soil erosion and producing high sediment. Hence, the study demonstrates that the adapted USLE model useful tool to estimate mean annual soil loss over large areas with coarser data. Its use to facilitate sustainable land management through conservation planning is paramount importance.

The sustainability of Gibe - III dam may be depends on the management of its catchment area which provides both water and sediment. Hence, to alleviate the problem of siltation and increase the life span of the dam, proper design and urgent implementation of best management practices in the prioritized Woredas and their Kebeles are proposed. The proposed best management practice includes: in steep slope areas of cultivated lands: introduction of agro-forestry practices, properly designed cutoff drains, waterways, soil bunds, *fanya juu* bunds, and stone bunds; in gentle slope cultivated lands contour farming, grass strips, and multiple cropping systems; and at communal lands and or degraded remote areas: tree planting and area closure in conjunction with moisture improving structures like water collection trenches and micro-basins.

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