

Spatial soil loss risk assessment for priority intervention using GIS and remote sensing techniques: A case of Neri Watershed Southwestern Ethiopia

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Abstract: Soil loss by runoff is a severe and continuous ecological problem in Neri watershed. It affects agricultural production, drinking water quality, ecosystem health, and landscape aesthetics. This study was conducted to assess spatial risk of soil by estimating the average annual soil loss, and creating a soil erosion hazard map for this watershed. Revised Universal Soil Loss Equation (RUSLE) model supported by a GIS framework was used. To this end, data for the model parameters were derived from, a digital elevation model (DEM) of (30*30 m), thirty years (1988-2017) rainfall data at rain gauge stations, soil erodibility data from field soil samples, Landsat-8 satellite image for cover management and conservation support practices. Once raster layer of the input parameters created, overlay analysis was carried to assess the spatial distribution of soil loss. The estimated annual soil loss varies from 0 to 465.16 t ha⁻¹ yr⁻¹ with a mean annual soil loss of 9.95 t ha⁻¹ yr⁻¹. The empirical analysis also confirmed that the watershed losses a total of about 463365.46 t of soil annually. Out of the total area; 54.9% of the watershed was categorized below moderate classes and the remaining 45.1% of land area was classified under high to very high classes, which is about several times the maximum tolerable soil loss rate. Based on the classification of soil loss hazard map, six out of eleven Neri sub-watersheds need prior intervention in terms of integrated cover-management and mechanical conservation measures. Furthermore, model results can be refined by analyzing along with sub-watersheds level real time monitoring for conservation practices.

Keywords: Neri watershed, RUSLE model, soil loss, Tolerable soil loss.

Abbreviations: **DEM:** Digital elevation model; **GIS:** Geographic information system; **IDW:** Inverse distance weighted; **LULC:** Land use land cover; **RUSLE:** Revised universal soil loss equation; **TSL:** Tolerable soil loss; **NDVI:** Normalized Difference Vegetation Index.

INTRODUCTION

Soil erosion is the one among major threats to the sustainability of environment and productive capacity of agriculture (Yang et al., 2003; Feng et al., 2010), which makes plant shallow root depth, removes plant nutrients and results in moisture loss (Mahmud et al., 2005). It results in serious food insecurity in many developing countries as it depletes productive soils (Blanco and Lal, 2008). This can possibly be attributed to the fact that the impact of soil erosion is more damaging on bare land and

cultivated land than any other types of land use/land cover. A global scale productivity reduction due to soil erosion is 17% (Angima et al., 2003). The severe situation in Ethiopia is quantified by loss of 1 billion USD per year (Sonneveld, 2002) and is still affecting 50% of the agricultural area. In Ethiopia, the crop productivity of cultivated land is very low; which is because of soil fertility reduction by soil erosion. It affected the national economy of Ethiopia (Tamene, 2005).

Soil loss by surface runoff is a severe ecological problem occupying 56% (1,100 million hectares) of the world-wide area as accelerated by human-induced soil degradation (Bai et al., 2008). The extent and distribution is widespread in Africa and Asia, due to high population pressure, land shortage and lack of resources for conservation by subsistence small holder farmers (Blanco and Lal, 2008). About 43% (537,000 km²) of the total highland areas of Ethiopia are highly affected by soil erosion (Hurni, 1990).

The government of Ethiopia reaffirms its commitment to address the problem of land degradation in its official policies, stated in the Growth and Transformation Plan (GTP) yet the undertaking and investments to curb the problem are far lower than the scope and the complexity of the problem. Natural resource management and conservation has been taken up as an important intervention in all parts of Ethiopia. The overwhelming proportion of these activities is accomplished through mass mobilization. But it is not clear to what extent these initiatives are based on quantified evidence on the ground.

Quantitative understanding of the removal of valuable soil resource has got attention of scientific community in different parts of Ethiopia. For instance, in the Ethiopian highlands only, an annual soil loss reaches 200 to 300 tons ha⁻¹yr⁻¹ (FAO and UNEP, 1984; Hurni, 1993) and soil loss due to erosion in Ethiopia amounts to 1493 million tons per year, of which about 42 t ha⁻¹yr⁻¹ was estimated from cultivated fields of Ethiopia (Hurni et al., 2008). Specific studies in this basin, Omo-Gibe indicate that, average annual soil loss of Gibe-III Dam Catchment is 7.47 t ha⁻¹ yr⁻¹ (Gerawork and Awdenegest, 2014) and the mean annual soil loss rate reported by Bekele et al. (2019) which is 4.27 t ha⁻¹ yr⁻¹ in Karesa Watershed, Dawuro Zone.

The study area, Neri watershed, part of Omo Gibe basin, is acknowledged as one of the main agricultural production areas in South Ari district of South Omo zone, having conducive agro-ecology for high cereal crop yield to fulfil the food security demand of the dwellers. Moreover, enormous mega development projects like construction activities such as, airport, road and university expansions have been implemented in this watershed. However, all these considerable pressures of human economic activities, there is no strong conservation support practice based on quantified information for the risks of soil loss in general and its spatial distribution for prioritized intervention. Because, there was no previous research investigation to this particular watershed. Consequently, information on soil loss and its spatial distribution within this watershed is needed for decision makers in policy and strategy formulation and, for natural resource managers by providing a necessary tool to design the right intervention strategy for the specific climate, soil type, and topography and land use situation.

This study employed Revised Universal Soil Loss Equation (RUSLE) model (Renard et al., 1997). RUSLE is an erosion model predicting longtime average annual soil loss resulting from raindrop splash and runoff from

specified slopes in specified cropping and management system and from rangeland. However, RUSLE has limitations that it ignores the effects of gully erosion and dispersive soils, it is applicable to nonagricultural conditions such as construction sites and also it takes into account average soil loss over field slopes different greatly from one another.

Therefore, this study assesses spatial distribution of soil loss and identify areas that require prior soil conservation measures using RUSLE integrated with GIS at Neri watershed Southwestern Ethiopia.

MATERIALS AND METHODS

Description of the study area

The study area, Neri watershed (Figure 1) is situated in the lower part of the Omo Gibe basin southwestern Ethiopia with the drainage area of 465.46 km². Neri watershed has the highest and lowest altitudes of 3001 meter and 389 meters above sea level respectively. This watershed is generally characterized by rugged topography and degraded ecosystems. The degradation is due to poor land management practices, shifting cultivation, urban expansion and over-grazing. The land use of the study watershed is characterized by 48.4% agricultural land under intensive cultivation, 13.1% grazing land, 4% forest, 24.8% shrubs and bushes, 9% built up areas and 0.5% degraded barren lands.

Climate of the watershed is affected by the position of the north-south oscillation of the inter-tropical convergence zone (ITCZ), characterized by the annual rainfall variability. The mean annual rainfall of Neri watershed is 1342.033 mm, and characterized by bimodal type. The temperature increases throughout the watershed with a decrease in elevation. The maximum and minimum monthly average temperatures of the study area are 27.61 and 16.3°C, respectively (Figure 2).

The watershed is characterized by nine soil types (Figure 3), dominantly Orthic Solanchaks (28%) followed by Calcic Xerosols (17% ha) and Haplic xerosols (15%).

RUSLE model description

This study was designed to model soil erosion using Revised Universal Soil Loss Equation (RUSLE) model (Renard et al., 1997), which is comprehensive and detailed version of universal soil loss equation (USLE), and is based on empirical and process-based approaches to quantify the annual rate of soil loss from the watershed based on the established data base. The Revised Universal Soil Loss Equation (RUSLE) using GIS and remote sensing technique was used to estimate the mean annual soil loss occurred in Neri Watershed. The RUSLE (Renard et al., 1997) model can be expressed as Equation (1);

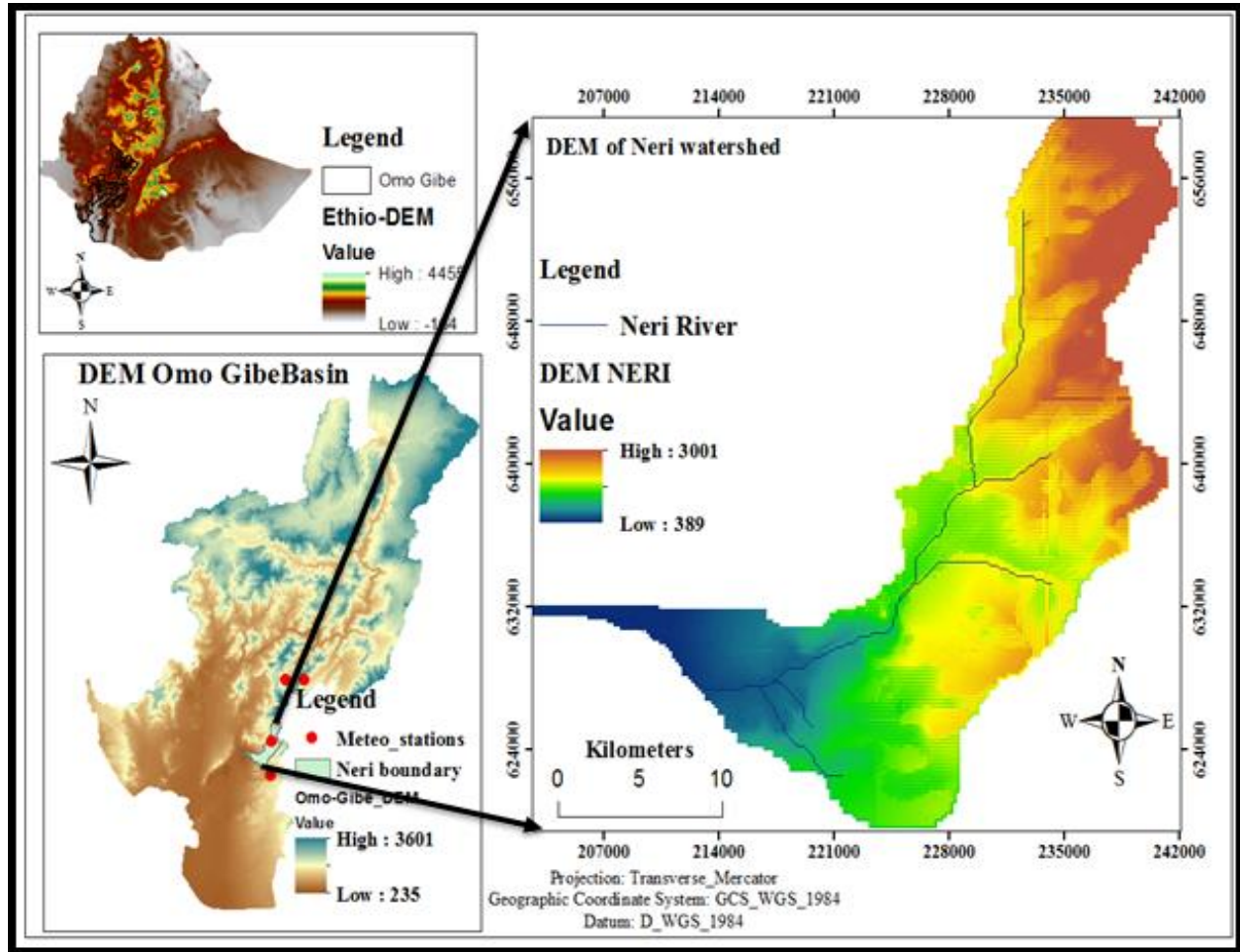


Figure 1. Location map of the Neri watershed.

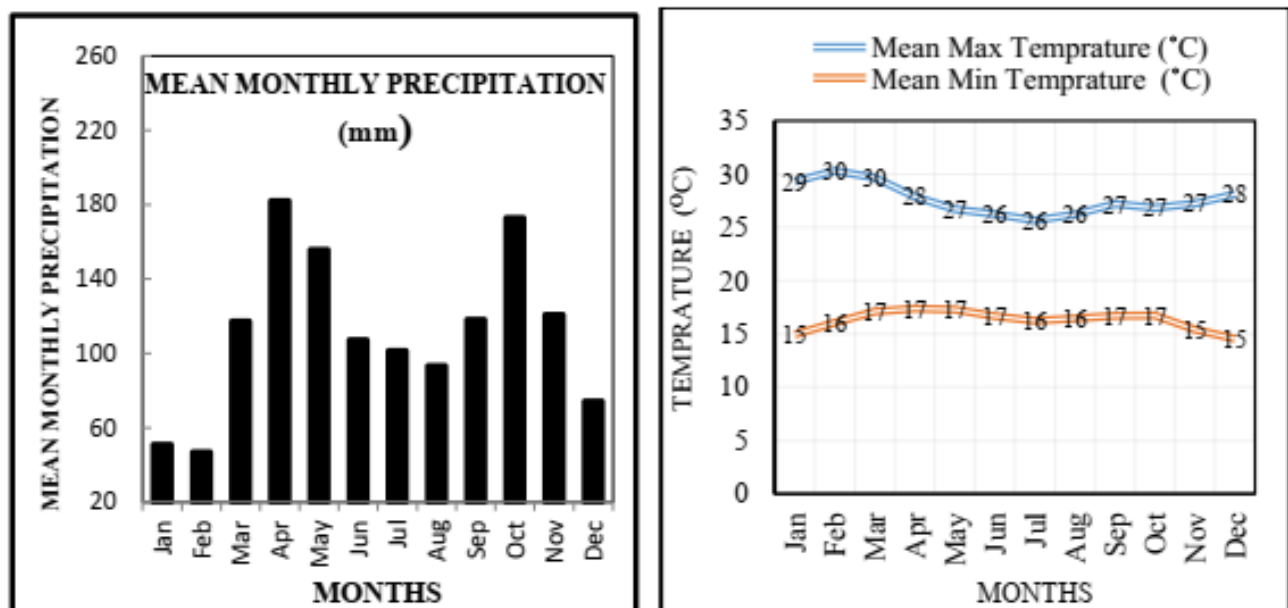


Figure 2. Climate elements (from year 1988-2017).

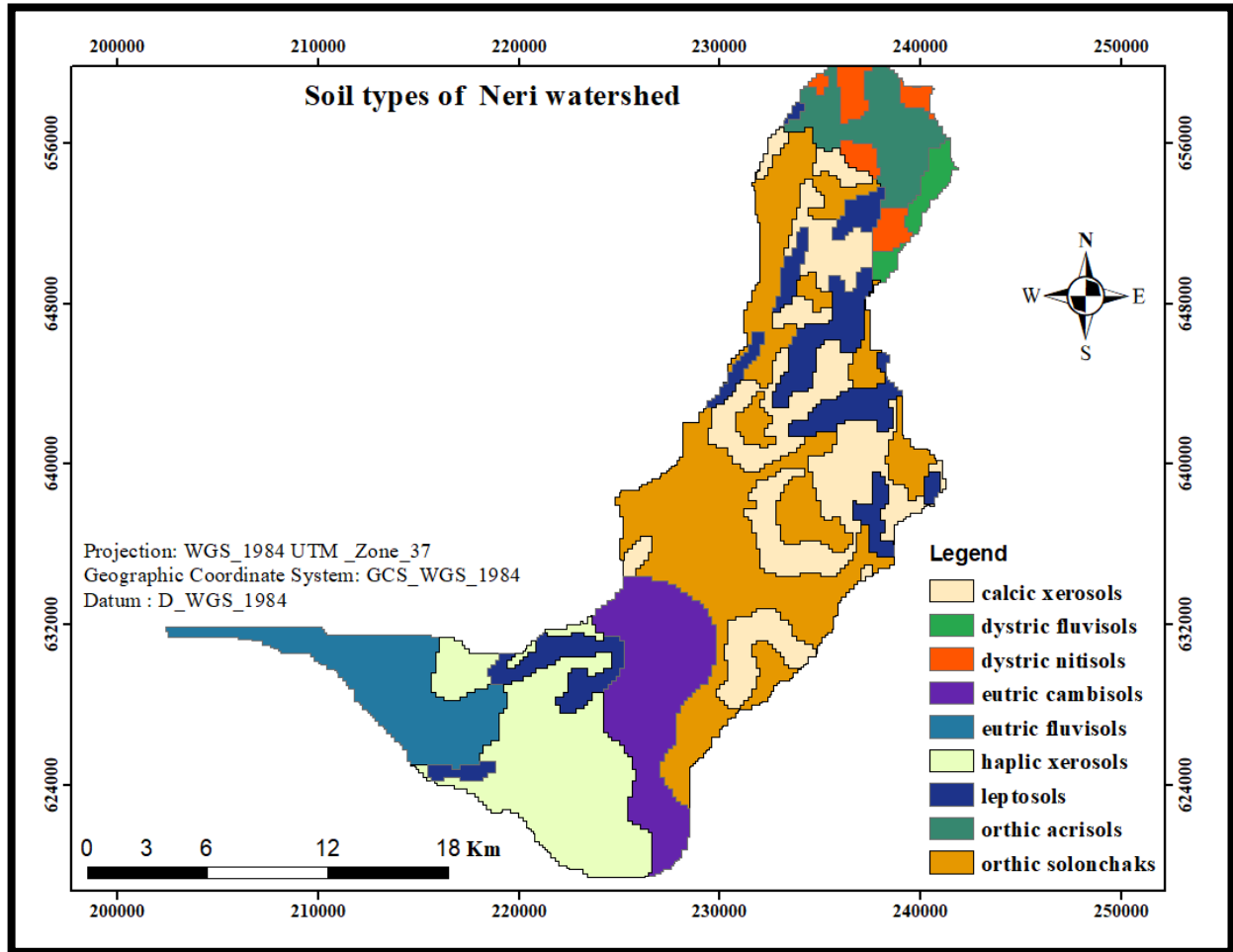


Figure 3. Soil types map of Neri watershed.

$A=R*K*LS*C*P$ Equation 1

Where: A = Computed soil loss per unit area per year ($t\ ha^{-1}\ yr^{-1}$), R = the rainfall erosivity factor ($MJ\ mm\ ha^{-1}\ h^{-1}\ yr^{-1}$), K =The soil erodibility factor ($t\ ha\ MJ^{-1}\ mm^{-1}$), LS = The slope length and steepness factor (dimensionless), C = The cover and management factor (dimensionless) and P = The support practice factor (dimensionless)

Rainfall erosivity (R factor)

The rainfall acts as the force for sheet and rill erosion without protection. The high rate of rainfall with large drop size can erode the soil particles faster than normal rainfall. Precipitation data sets were collected from the National Meteorological Agency (NMA) from 1988 to 2017 for four meteorological stations namely; Jinka, Bulk-mender, Sawla and Keyafer, which are within and nearby to Neri watershed. Prior to application in to erosion modelling, missing data was filled by IDW method, checked for outliers. The data homogeneity was tested by means of a frequency analysis using Rainbow software version 2.2

(Raes et al., 2006).

Erosivity can be predicted by a suitable regression equation in a case of insufficient rainfall intensity records (FES, 2009). Even though different regression equations have been developed in Ethiopia that estimate rainfall erosivity (R-value), R factor in this study was determined using regression equation (2) calibrated by Kaltenrieder (2007).

$R=(0.55*P)-4.7$ Eqn. 2

Where, R is rainfall erosivity factor, P is mean annual rainfall in (mm)

Then, the mean annual rainfall for four gauge stations, and geographical coordinates were used to create a point shape file using Arc Catalog 10.3.1. The created shape file was displayed on Arc Map 10.3.1 and the attribute fields for mean annual rainfall data was added to point shape file. Then the average rainfall data for each gauge stations was added to the attribute column. Finally, the point data shape file was displayed in Arc Map and interpolated using IDW

method and raster rainfall data for study area was obtained. The raster rainfall data of the study area was converted to erosivity map of the study area by using raster calculator (Equation 2).

Soil erodibility factor (K)

The soil erodibility factor (K) values reflect the rate of soil loss per rainfall-runoff erosivity (R) index. There are properties of soil that control erosion as stated by Fangmeier et al. (2006): the structure, texture, organic matter, clay mineralogy, density, and water content of the soil. Hence, in this study soil texture (particle size distribution) analysis was applied. In the context of soil texture analysis, soil erodibility is indicated by the relative proportion of different grain sizes of particles (Brady and Weil, 2002).

Once the soil types map of the study area is clipped in the GIS environment, field soil samples with depth of 0 to 20 cm were collected from all the nine soil type in the watershed and taking land use types into account. For estimation of soil erodibility factor values, these soil samples were made composites based on soil types. A total of 35 samples were brought to particle size distribution analysis by soil sieve method in laboratory. Particle size distribution was done by soil sieve based on United States Department of Agriculture (USDA) soils taxonomy (which is most commonly used systems among numerous systems of classifying) separates soil into different size classes. Based on the particle size distribution, primary soil separates having diameter size limits less than 2.00 mm are usually divided into three classes, sand, silt, and clay. Diameter limits of soil separates as sand (2.00 -0.05 mm), silt (0.05 - 0.002 mm) and clay (<0.002mm). Prior to mechanical sieving, soil samples were dispersed to remove binding agents. During sieving, the dispersed soil suspension pass through a nest of sieves of different sizes. The amount retained on a particular sieve represents the fraction that is larger than the sieve size on which it is retained but smaller than that of the preceding sieve in diameter size and weighted to represent the percentage of respective soil separates (Lal and Elliot, 1994). Afterwards, soil erodibility (K-factor) has been calculated by means of the following formulae which were developed from global data of measured K values, obtained from 225 soil classes (Renard et al. 1997).

$$K = \left\{ 0.0034 + 0.0405 \exp \left[\frac{-1}{2} \left[\frac{\log(Dg) + 1.659}{0.7101} \right]^2 \right] \right\} \dots \text{Eqn. 3}$$

$$Dg = \exp \left(\sum f_i \ln \frac{(d_1 + d_{i-1})}{2} \right) \quad \text{With } R^2 = 0.983$$

Where, Dg = Geometric mean particle size, for each particle size class (clay, silt, sand), d_i = Maximum diameter (mm), d_{i-1} = Minimum diameter and f_i is the corresponding mass fraction.

This relation is very useful with soils for which data are limited and/or the textural composition is given in a particular classification system.

Using Equations (3), soil erodibility factor (K) was calculated for each soil samples. Finally using kriging interpolation method in ArcGIS (version 10.3.1) software which is widely used in several researches (Smith et al., 1993; Vaezi et al., 2010 Bonilla et al., 2012) in this field, soil erodibility factor map was constructed for inter study area. Thus, to obtain soil erodibility raster map of the study area, spatial point K-factor values were interpolated to the watershed area extent by kriging method using spatial analyst tool.

Slope length and steepness factor (LS)

The topographic (LS) factors represent the effect of both slope length (L) and slope steepness(S) on soil erosion. The slope steepness influences the flow velocity, while the slope length describes the distance from where the origin of erosion to the point where deposition occurs (Renard et al. 1997). LS were calculated by unit stream power Erosion and Deposition methods which use both flow accumulation and watershed slope (Pelton et al., 2012).

For this study, LS factor was derived from DEM of ASTER 2014 with a spatial resolution of 30 m which was collected from Ethiopian Geological Survey office. DEM preprocessing was done to remove the depression. Both flow accumulation and slope in raster formats were prepared by using hydrology extensions in spatial analyst tools in ArcGIS 10.3.1 software. Final LS factor output raster was obtained by raster calculator using the map algebra expression in Equation 4 as suggested by Mitasova and Mitas (1999).

$$LS = \text{pow}([flowaccumulation] * cellsize / 22.13, 0.6) * \text{pow}(\sin([slope] * 0.01745) / 0.0896, 1.3) \dots \text{Eqn. 4}$$

Cover-management factor (C-factor)

The C- factor represents the relation between the soil loss in certain agricultural or cover conditions and the erosion that would be obtained from a standard fallow parcel (bare soil). Strict application of this factor as RUSLE guidelines is difficult on data shortage and large scale condition. To estimate C factor by traditional method, simply assigning values to land cover classes has also its own limitations since all pixels in a particular land use land cover class have the same C factor value, those pixels cannot represent spatial variation of this class over the study area (Wang et al., 2001). So that, for C-factor estimation two maps (LULC and NDVI) are generated. NDVI is a simple graphical indicator that can be used to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or non-vegetation area. Its value ranges from -1 for bare soil to 1

for forest.

To obtain land use types map of the study area, satellite image from Landsat 8 Operational Land Imager (OLI) TIRS (Thermal Infrared Sensor) with acquisition date of January 17th 2017, accessed online from the web site <https://glovis.usgs.gov>.

Prior to LULC classification, image preprocessing was implemented and classification was processed using supervised image classification technique according to the desired decision rule of maximum likelihood algorithm (Suji et al., 2015) using ERDAS IMAGINE 2010. Classification accuracy was assessed by using overall accuracy (OA) and Kappa coefficient (K) based on error matrix. The error or confusion matrix was calculated by comparing the classification results and ground truth data (Hassan et al., 2016). The accuracy was assessed by using 147 reference points. The OA is the total percentage of pixels correctly classified.

Based on the land use land cover classification map, a corresponding C factor values from land cover classes according to literature values of Hurni (1985) and Kaltenreider (2007) were assigned in ArcGIS 10.3.1 with the help of join and relate tool. These values were preferred since they are suitable and suggested for Ethiopian Highland conditions that is dominated by cultivated land and represents a good estimation of cover factor values. Then the C value was converted to raster by analyst conversion tool method from polygon to raster.

NDVI map generation in bands correspond to the red band (Red) and the near-infrared (NIR) for Landsat 8 Operational Land Imager (OLI) are band 4 and band 5 respectively. By means of Map algebra, raster calculator on Arc GIS 10.3.1 software, NDVI was calculated by applying the equation (5) by Rouse et al. (1974) and Jensen (2000).

$$\text{NDVI} = (\text{NIR} - \text{Red}) / (\text{NIR} + \text{Red}) \dots\dots\dots \text{Eqn. 5}$$

Therefore, regression model was employed to make correlation analysis between C factor values of land cover classes and NDVI values. This was done by assuming that in soil erosion modelling, NDVI and C-factor are inversely correlated each other. Then, regression equation for this study watershed in Figure 9 was obtained. Hence, this equation was applied for generation of final C factor map with the help of spatial analyst tool of ArcGIS 10.3.1.

Support practice factor (P)

Support practice (P-factor) reflects the impact of specific erosion management practices on the corresponding erosion rate with values between 0 and 1. No soil or water conservation measures are applied to the study area, except the start of mass mobilization works through agricultural extension program of the government for terracing though there is no maintenance. Considering the

nonexistence of conservation practices in the watershed, P values were analyzed based on the land-use map for different slope gradient classes (Wischmeier and Smith, 1978).

Slope gradient class map (%) derived from ASTER DEM by ArcGIS 10.3.1 spatial analyst hydrology and surface tools. Slope map of the study area was then reclassified and the P-factor values listed under Table 1 were assigned to each land use – slope class combination grid cells. Finally, the assigned P-factor values were lookup in spatial analyst tool extension, first reclassified into six classes. Then land use land cover map was combined with slope.

In Arc GIS10.3.1, the original land use land cover map obtained by supervised classification of LULC in a vector format was first reclassified into two categories (i.e. Agricultural land and other land) then it was converted into raster format. In spatial analyst tool extension local, the new raster land use was combined with slope class map (%) derived from DEM to get a combined land use – slope map of the study area and the P-factor values listed under Table 1 were assigned to each land use-slope class combination grids. Finally with the help of conversion tool, P-factor raster map was obtained by choosing assigned P-value for value field.

Soil loss estimation and erosion risk mapping

Revised Universal Soil Loss Equation (Renard et al. 1997), an empirically based model was applied for this research work. Its applicability has been confirmed including Ethiopian condition (Kaltenrieder, 2007; Bewket and Teferi, 2009) because of its simplicity and limited data requirement. The advent of geographical information system (GIS) technology has allowed the equation to be used in a spatially distributed manner because each cell in a raster image comes to represent a field-level unit.

Individual GIS files were built for each RUSLE factor and they were projected with UTM Zone 37N using the WGS 1984 datum; these correspond to standards used by the Ethiopian Mapping Agency (EMA). These factors raster maps with 30 m by 30 m cell size were combined on a cell by cell-grid modeling procedure in ArcGIS 10.3.1, spatial analyst, raster calculator based on Equation 5 to predict soil loss in a spatial domain. The final model output was set to 100 m by 100 m to obtain the annual soil loss yield per hectare per year. The average annual soil erosion rates were classified into the five severity classes.

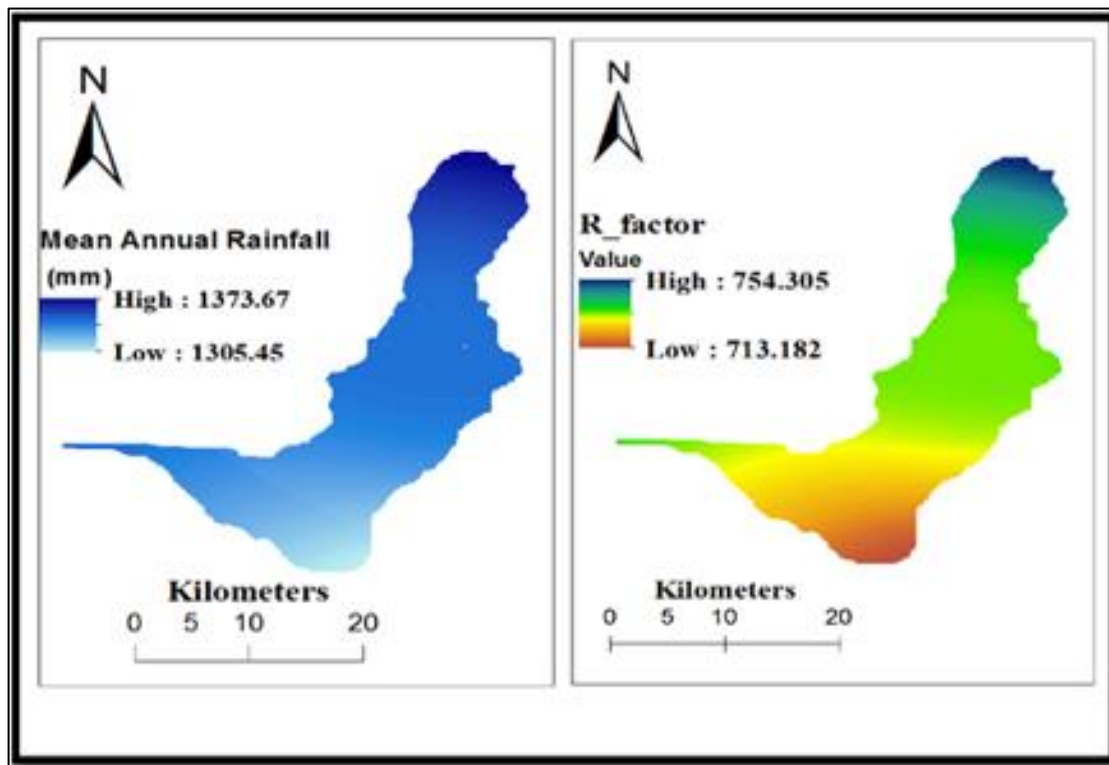
RESULTS AND DISCUSSION

Rainfall runoff erosivity factor (R) output

The erosivity factor estimated for the study area as result of Inverse Distance Weighted (IDW) interpolation method ranges from 713.1 to 754.43 MJ mm h⁻¹ ha⁻¹ yr⁻¹ with mean

Table 1. Conservation support practice (P- Factor Value) (Wischmeier and Smith, 1978).

| Land use type | Slope (%) | P-factor value |
|--|-----------|----------------|
| Agricultural land (Cultivated land) | 0-5 | 0.1 |
| | 5-10 | 0.12 |
| | 10-20 | 0.14 |
| | 20-30 | 0.19 |
| | 30-50 | 0.31 |
| | 50-62.199 | 0.43 |
| Other land | All | 1 |

**Figure 4.** Mean annual Rainfall (left) and erosivity map (right).

of 731.87 MJ mm ha⁻¹ h⁻¹ yr⁻¹. As shown in Figure 4, the R-value of Jinka station which is within the study watershed is 733.42MJ mm ha⁻¹ h⁻¹ yr⁻¹. Thus, this value has great weight to the R-value of the watershed.

Soil erodibility factor (K-factor) output

Based on soil particle size distribution analysis, primary particles (sand, silt and clay) distribution was defined. In the Figure 5, soil erodibility factor (K) as the function of geometric mean diameter size (D_g (mm)) was stated. Solid line shows the soil erodibility factor value calculated for 35 field samples whereas, vertical lines represent K-values in each D_g class plus or minus one stand deviation. The

weight based percentage of sand, silt and clay respectively are 21.6 to 43%, 21.25 to 33.3% and 21 to 62%. The spatial distribution of these textural classes as shown in map reveals that the middle catchment is characterized by lesser sand coverage but upper and lower catchments are having higher sand content.

Soil erodibility is low for extremely lowest and highest values of mean soil particles diameter size. Soils with high sand and high-clay content are having the lower K-values and high-silt content soils having the higher K-values. This reflects that, soil samples that are bearing higher percentage of medium sized soil separate (textural classes) are susceptible for detachment and transport by water. This is due to the weaker strength of bonds between soil particles (aggregate stability) ease to transport

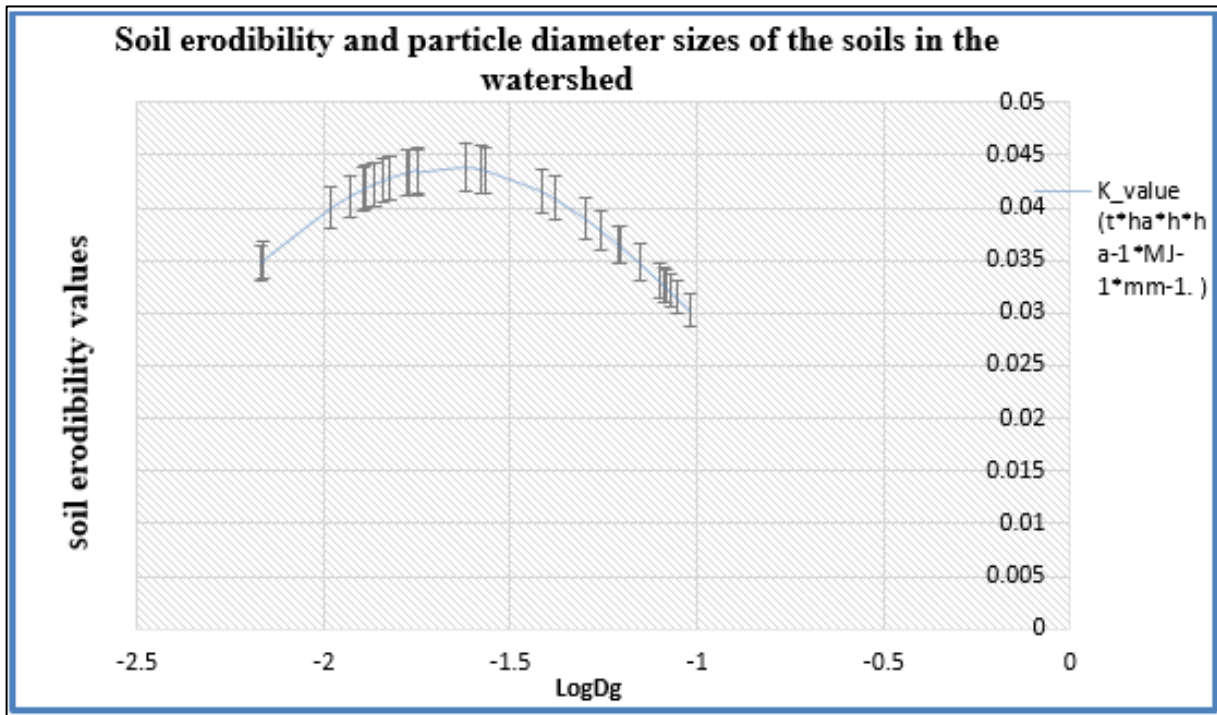


Figure 5. Relationship between soil erodibility values and their geometric mean diameter size.

(Murphy and Flewin, 1993). Whereas, clay is more cohesive and sand require high transportation energy. It indicated that silt spatial coverage shows smooth incremental from upper to lower parts of this watershed. Unlike sand, clay content in north and south of study area is more than central parts.

Soil erodibility factor map in Figure 6 is the result of kriging interpolation of calculated spatial K-values based on equation 3. K-factor values in the study watershed ranged between 0.0306 to 0.044 $\text{Mg h MJ}^{-1} \text{mm}^{-1}$. Annual average soil erodibility factor was estimated to be 0.0385 $\text{Mg h MJ}^{-1} \text{mm}^{-1}$, with standard deviation of interpolated K factor map of 0.002 $\text{Mg h MJ}^{-1} \text{mm}^{-1}$. According to Rosewell and Loch (2002), soil erodibility values of this study area are categorized under moderate to high ranges. Based on this, about 72% (33513.1ha) of the study area is categorized under moderate erodibility class ($<0.04 \text{ Mg h MJ}^{-1} \text{mm}^{-1}$) whereas, 28% (13032.9 ha) area is high range ($>0.04 \text{ Mg h MJ}^{-1} \text{mm}^{-1}$).

The higher the K values, the greater susceptibility of the soil to rill and sheet erosion by rainfall. High soil erodibility factor values greater than 0.04 $\text{Mg h MJ}^{-1} \text{mm}^{-1}$ from the background soil types of Orthic solonchaks, Calcic Xerosols and highland Dystric Nitisols was obtained. These areas are the middle catchments of the watershed where lower clay content area with moderate silt content of textural classes as shown in soil erodibility map (Figure 6). This result could be due to soil containing large amounts of coarse silt and fine sand which are the most erodible (Manrique, 1988). Soils with high-sand and high-clay

content are soils having the lower erodibility values, whereas high-silt content are soils having the higher values (Foster et al., 1981). Soils with high silt fraction have poor structure and are more erodible (Stern et al., 1991). The nature of the clay in the Cambisols of the watershed are known to be smectic, and smectic soils are generally known to be more erodible than soils which contain less smectite and high sesquioxide (Piccolo et al., 1996).

Slope length and steepness factor (LS- factor) output

The combined LS factor indicates the effect of slope length and slope steepness on soil loss. This indicates that the higher the value, greater its potentiality to erode. The values of the LS factor for Neri watershed ranges from 0 in some flat area to 37.3972 in steeper and longer slope areas of the study area and the mean value of 1.523 was obtained as shown in Figure 7. It is perceptible that drainage area may favor erosion highly. With respect to the slope gradient (degree), study area ranges from 0 to 32 degree. This indicates that, the area feature description ranges from straight to moderately convex slope.

Cover-management factor (C- factor) output

The spatial distribution of cover management factor in the study area is shown in Figure 9. As result of linear

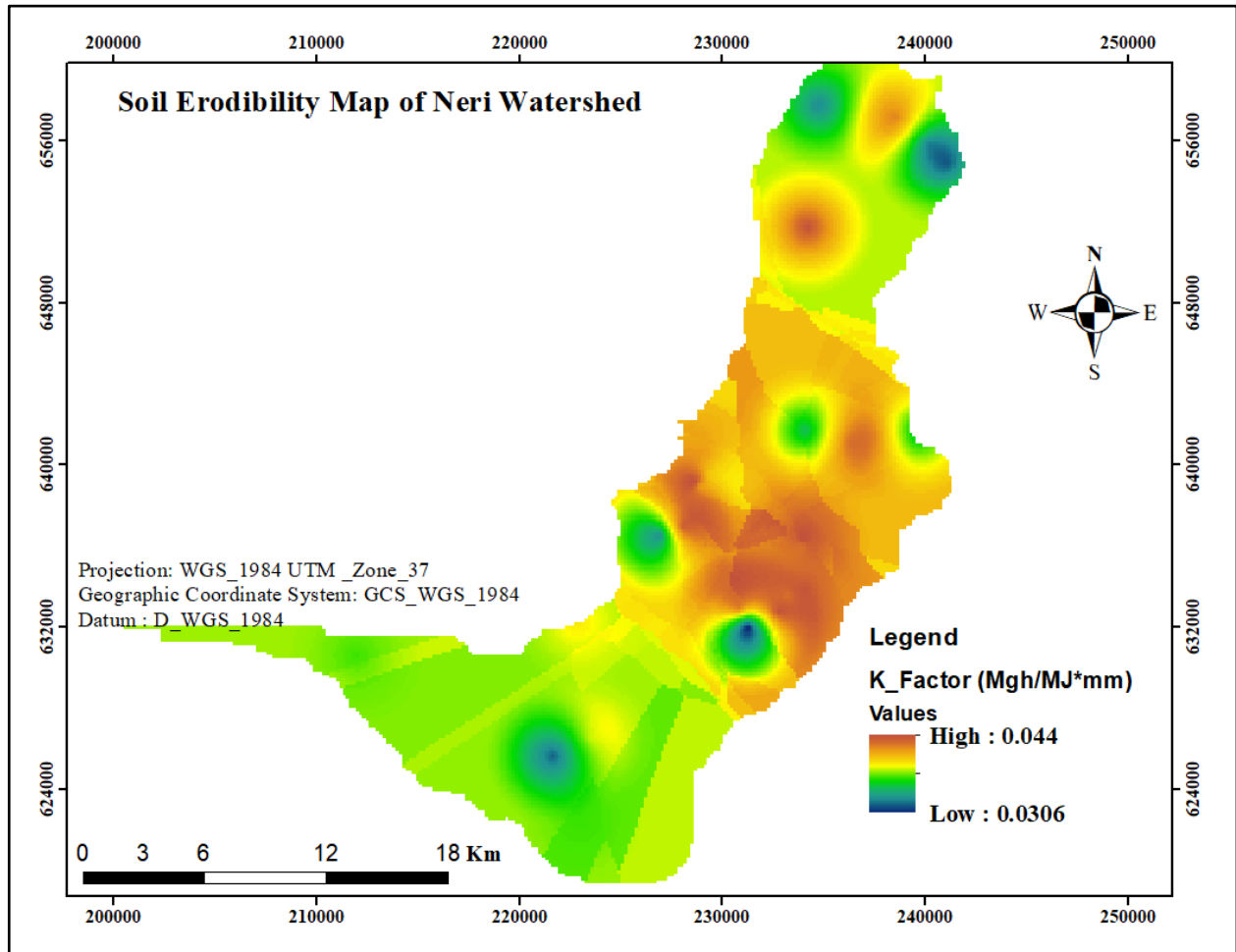


Figure 6. Soil Erodibility Map of the study area.

regression equation in Figure 8, C-factor output was found to its maximum value of 0.6141, minimum 0.01056 and average 0.385. (std. (± 0.072)). The vegetative cover condition to reduce erosion in this watershed is less except in the upper and some areas sparsely distributed areas of the watershed (totally 4% of total area). On this map, lower value of C factor indicates the area possesses good land cover and higher value indicates barren/open land and built up areas.

Support and conservation practices factor (P- factor) output

The P factor values of study area ranges between 0.11 and 1 with mean of 0.591 (Figure 10). No soil or water conservation measures were applied in the study area. So, P values were assigned by the land into grid codes of crop cultivated, open forests, grazing lands, bare lands, built ups and shrub land-use classes with intersection to their slope gradient. The management activities vary on the slopes of the cultivated lands. Therefore, the crop

cultivated land is also sub-divided in to six classes based on the slope percentage, to assign different P value for each slope classes (0–5, 5–10, 10–20, 20–30, 30–50 and > 50)%. With respect to the P factor, land cover types other than agricultural lands about (51.6%) of the area has a value of 1.

Soil loss estimation results

The RUSLE model output pixel level analysis result (in mean) of Neri watershed ranges from 0 ton $\text{ha}^{-1}\text{yr}^{-1}$ in some plain parts of the studied area (where the LS- factor value of zero) to the maximum amount of 465.16 tons $\text{ha}^{-1}\text{yr}^{-1}$ at the mid-eastern parts of the watershed. This particular spot is situated at Selmamer administrative kebele, South Ari woreda under Sub Watershed 6. The very high pixel values (more than 25 tons $\text{ha}^{-1}\text{yr}^{-1}$) are detected in a distributed manner throughout the watershed. However, the particular maximum pixel value found at much of the steeper slope banks with high LS factor value under city expansion built up areas with poor surface cover condition.

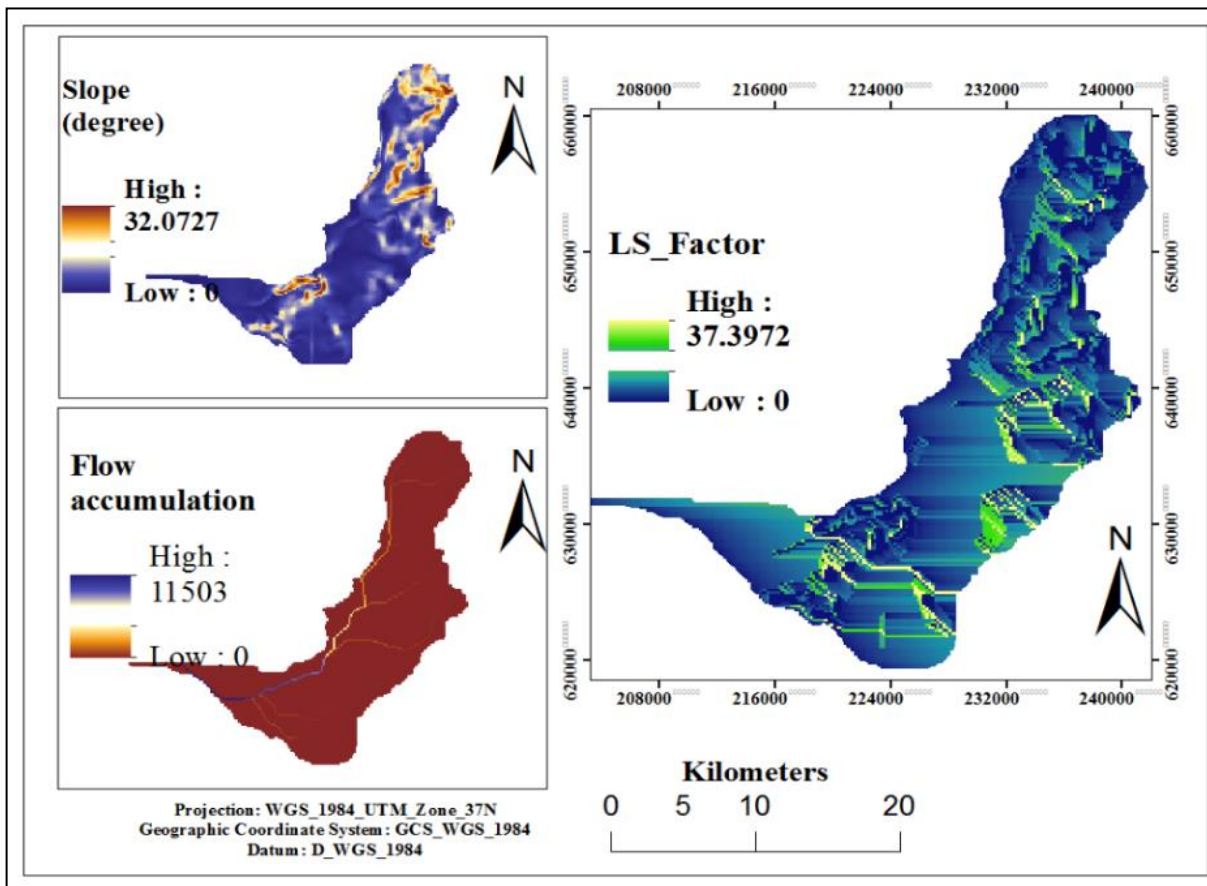


Figure 7. Derivation of LS factor from Digital Elevation Model.

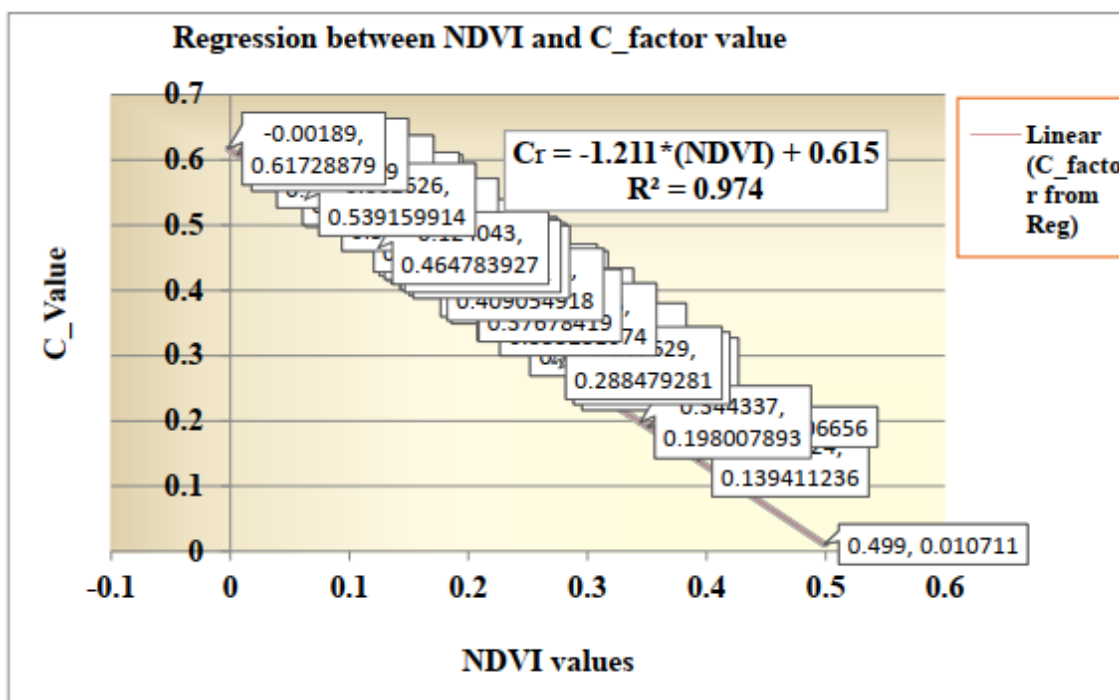


Figure 8. Derivation of Regression Equation for C-management factor.

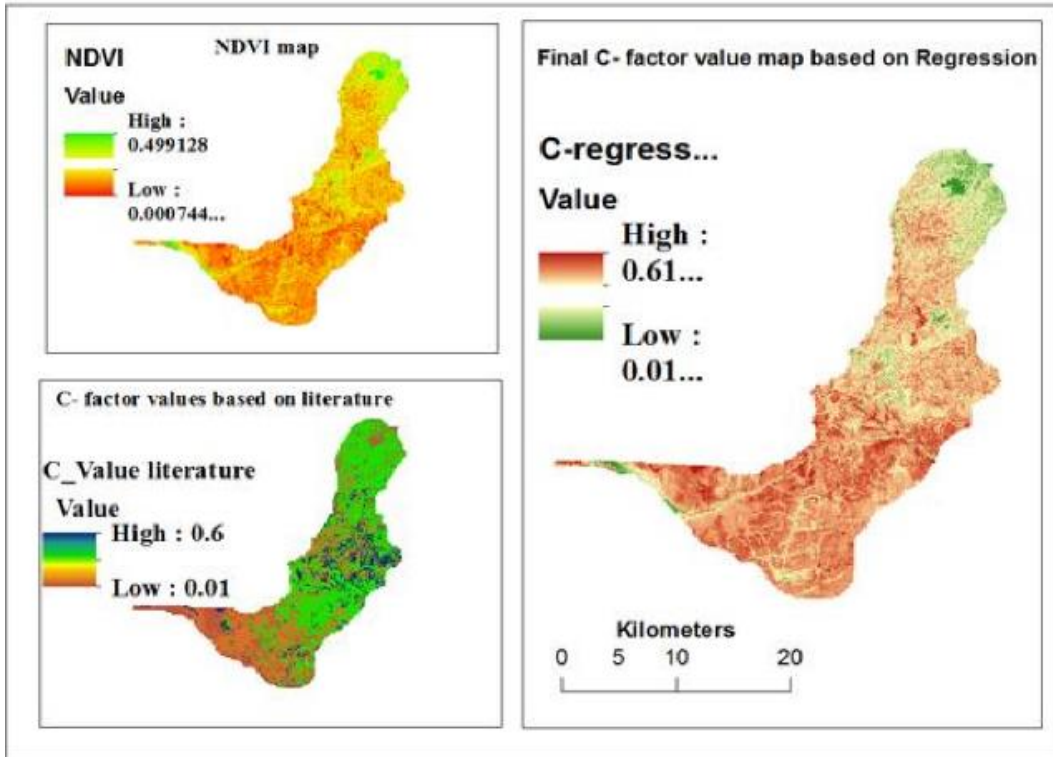


Figure 9. RUSLE-C factor map.

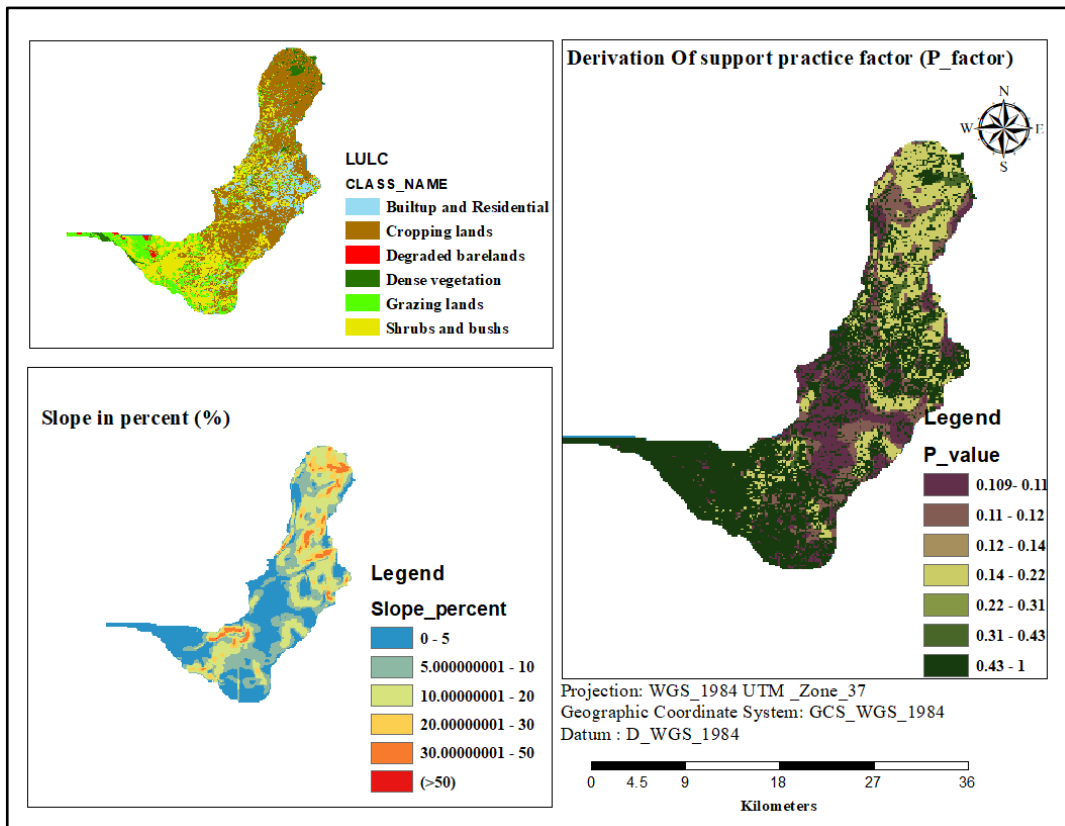


Figure 10. Derivation and spatial distribution of calculated P values.

The average annual soil loss rate is $9.95 \text{ t ha}^{-1}\text{yr}^{-1}$ from the entire watershed area (46546 hectare). The total amount of soil loss is $463365.46 \text{ t ha}^{-1}\text{yr}^{-1}$. Different reports suggested different soil loss tolerance (SLT) and use various soil loss severity classifications. According to FAO (1986) and Brhane and Mekonen (2009), there are six categories of soil loss risk in the study area, ranging from low (0 to $5 \text{ t ha}^{-1}\text{yr}^{-1}$) to extreme (100 to $465.16 \text{ t ha}^{-1}\text{yr}^{-1}$). Based on the analysis, about 54.88% (25536.8 ha) of the watershed was categorized under low to moderate classes. The remaining 45.12% (21009.2 ha) of land area was classified under high to extreme class about several times the maximum tolerable soil loss. However, this study used soil loss severity classification based on (WBISPP, 2001), the one more suitable for this study. Based on this severity classification, 32.67% of the total study area is beyond tolerable soil loss rate or ($>6.125 \text{ t ha}^{-1} \text{ yr}^{-1}$) and the remaining 67.33% is recognized as area not zone of a great danger of soil erosion.

Higher soil losses rates were detected as the effect of combination in areas where the convex topography having high LS-factor value, poor vegetation cover, heavy rains, susceptible soils and in a condition without conservation practices. The combined values of these factors are directly related to soil losses; the larger the values, the greater the losses (Renard et al., 1997). Soil loss in the study watershed is influenced by erosion factors differently. Ordinary least-square regression analysis on 147 locations of the entire watershed indicated that soil loss has high correlation with primarily soil erodibility, followed by cover-management, topographic factors, support practice and lastly rainfall erosivity, the overall coefficient of determination (R^2) respectively are (0.7674), (0.6801), (0.651), (0.598) and (0.5448). Single parameter dominancy in contribution was not significantly explained, however, the leading effect of soil inherent erodibility was cover management followed by slope length and gradient (LS) factor.

Rainfall erosivity is the powerful driver in overall erosion mechanism having a strong influence on detachment of soil particles as well as bearing on transport through runoff. It has not only a strong influence on detachment of soil particles, but also have bearing on transport through runoff (Lal and Elliot, 1994). Therefore, the high erosivity values in the upper catchment area are of major importance on any poorly vegetated steep slopes. Despite this truth, the variation in spatial distribution of soil loss in this study is not primarily influenced by rainfall erosivity. This is due to the resultant R factor map of the watershed by interpolation received the greater weight from Jinka meteorological station, the one with in the watershed. Fortunately, the upper catchment does not necessarily experience high erosion rates. It is apparent that the reason is a vegetation cover at upper catchment to the other parts of the watershed combined with lower erodible soil property at steeply slope spots. The actual erosive power of the rain depends highly on plant cover or

vegetation on soils that reduce the energy of raindrops (Bochet et al., 1998; Durán et al., 2007) and the inherent nature of soil having lower percentage silt content as well as they are not easily crumbled. For this reason, it is apparent that the surface cover upper catchment area does not necessarily experience high erosion rates.

The estimated mean annual soil loss results in the study area compared with the other previous reports in Ethiopian and particularly in Omo-Gibe basin condition. The mean annual soil loss results in the study area is lower than the annual average soil loss under Ethiopian condition which is $12 \text{ t ha}^{-1} \text{ yr}^{-1}$ and about $42 \text{ t ha}^{-1} \text{ yr}^{-1}$ from cultivated highland (Hurni, 1993). Similarly, $42 \text{ t ha}^{-1} \text{ yr}^{-1}$ reported by Molla and Sisheber (2017) at Koga watershed in the highlands of Ethiopia. The relatively low estimated average annual soil loss in the current study watershed could be due to mostly the land used for agricultural crops in this study area was located in areas where the least LS value was observed. In the watershed, out of the entire cultivated field shown in Table 1, 19587.29 hectare is area below 20% slope. Conversely, the mean annual soil loss rate from this watershed is slightly higher than the previous research report in the case of Gibe-III Dam Catchment which is $7.47 \text{ t ha}^{-1} \text{ yr}^{-1}$ by Gerawork and Awdenegest (2014) and twice higher than the mean annual soil loss rate reported by Bekele et al. (2019) which is $4.27 \text{ t ha}^{-1} \text{ yr}^{-1}$ in Karesa Watershed, Dawuro Zone, Omo- Gibe basin. In this case, the probable reason could be this study watershed made up of low proportion of forest cover than the watersheds in comparison. The soil loss rate is higher with respect to the soil formation rate for Ethiopia $2 \text{ t ha}^{-1} \text{ yr}^{-1}$, which is very low compared to soil erosion rates (Mahmud et al., 2005).

Soil erosion severity classes and prioritization for interventions

The average annual soil erosion rates were classified into the five priority classes (Table 2). To prioritize conservation planning, judgment of mean annual and total annual soil loss for sub watershed based identification was applied. To do this, geographical information system (GIS) technology has allowed the equation to be used in a spatially distributed manner because each cell in a raster image comes to represent a field-level unit. Even though the equation was originally meant for predicting soil erosion at the field scale, its use for large areas in a GIS platform has produced satisfactory results (Mellerowicz et al., 1994).

By delineating sub-watersheds as erosion prone areas according to the severity level of soil loss, priority was given for a targeted and cost-effective conservation planning (Kaltenrieder, 2007). Accordingly, Neri watershed was sub divided in to eleven (11) sub watersheds as shown in Figure 11.

The output under Table 3 and Figure 11 clearly shows that the mean annual soil loss rates from sub watersheds

Table 2. Soil loss severity classes.

| Soil loss (t ha ⁻¹ year ⁻¹) | Equivalent top removal (mm) | Soil loss risk class | Area (ha) | Area (%) |
|--|-----------------------------|----------------------|-----------|----------|
| (0 - 3.125) | (<0.2.5) | Very Less | 25023.13 | 53.76% |
| (3.125 - 6.25) | 0.2.5 – 0.5 | Less | 6316.29 | 13.57% |
| (6.25 - 12.5) | 0.5 - 1 | Moderate | 10896.42 | 23.41% |
| (12.5 - 25) | 1 - 2 | High | 3025.49 | 6.5% |
| (> 25) | >2 | Very High | 1284.67 | 2.76% |
| | | | 46546 | 100% |

Table 3. Soil loss rates by Sub watersheds.

| Sub Watershed | Local names (tributaries) | Mean annual soil loss | Area (hectare) | Weight of Area (%) | Total annual soil loss (t/yr.) | Weighted average | Rank weighted average |
|---------------|---------------------------|-----------------------|----------------|--------------------|--------------------------------|------------------|-----------------------|
| SW_1 | Neriwaset | 1.923 | 3024.025 | 6.50% | 5815.02 | 12.5% | 10 th |
| SW_2 | Zomba | 3.358 | 2395.130 | 5.15% | 8042.82 | 17.3% | 9 th |
| SW_3 | Uti | 5.620 | 7686.820 | 16.51% | 43197.91 | 92.9% | 7 th |
| SW_4 | Afia | 12.845 | 4788.774 | 10.29% | 61512.94 | 131.8% | 3 rd |
| SW_5 | Shaleka | 7.316 | 3180.054 | 6.83% | 23263.92 | 50.0% | 8 th |
| SW_6 | Gamayso | 10.015 | 7799.139 | 16.76% | 78104.71 | 167.7% | 1 st |
| SW_7 | Hacheker | 11.305 | 5436.154 | 11.68% | 61454.59 | 132.2% | 2 nd |
| SW_8 | Argon | 20.080 | 184.749 | 0.40% | 3709.73 | 8.0% | 11 th |
| SW_9 | Kibsh | 14.045 | 4047.001 | 8.69% | 56840.78 | 121.8% | 6 th |
| SW_10 | Beso | 16.867 | 3475.749 | 7.47% | 58623.93 | 126.2% | 5 th |
| SW_11 | Ufiker | 13.432 | 4528.407 | 9.73% | 60826.72 | 130.6% | 4 th |
| Total | | | 46546 | 100% | 463,365.46 | | |

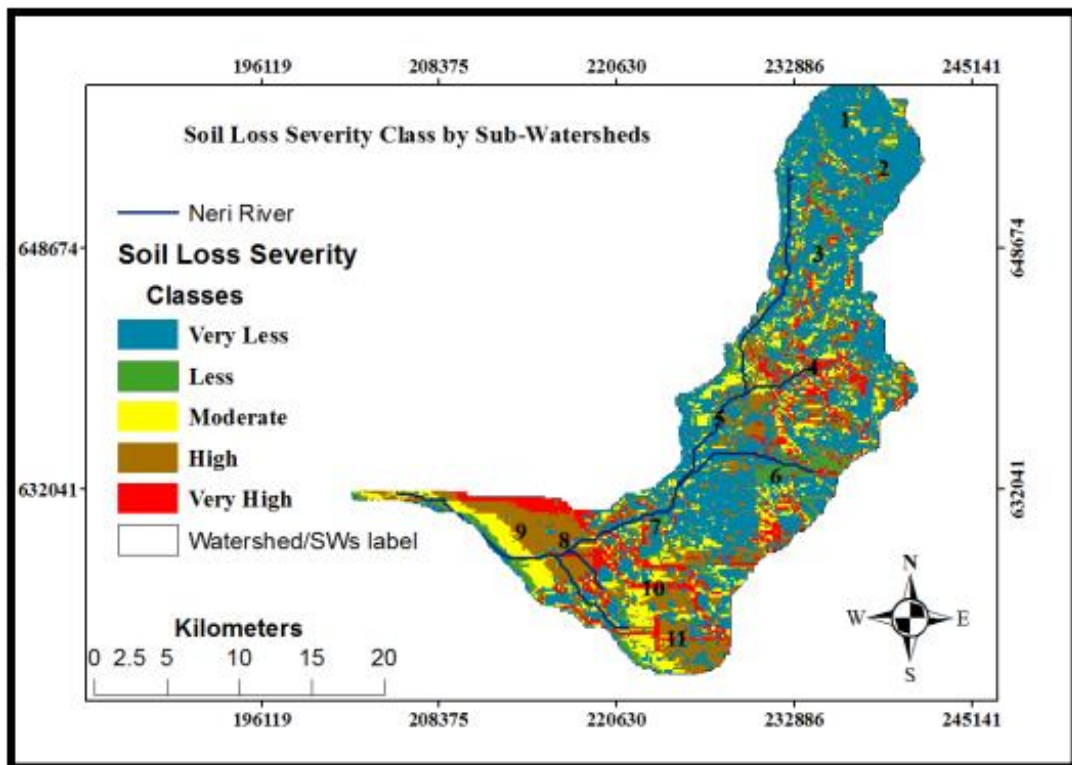


Figure 11. Soil erosion severity classes map by sub-watersheds.

Table 4. Soil loss rates by small administrative units.

| No. | Name of administrative Kebeles | Average annual soil loss (ton/ha/yr) | Area (hectare) | Area (%) | Total annual soil loss (ton/yr) | Percentage of soil loss/total |
|-----|--------------------------------|--------------------------------------|----------------|----------|---------------------------------|-------------------------------|
| 1 | Alga | 7.96 | 5113.3263 | 11.0% | 40712.77 | 8.8% |
| 2 | Arkisha | 9.70 | 7000.0579 | 15.0% | 67871.00 | 14.6% |
| 3 | Aydo | 1.54 | 222.2191 | 0.5% | 341.91 | 0.1% |
| 4 | Bako | 6.46 | 1813.4222 | 3.9% | 11708.58 | 2.5% |
| 5 | Dell | 2.86 | 954.8981 | 2.1% | 2733.08 | 0.6% |
| 6 | Dordora | 1.89 | 1580.2734 | 3.4% | 2987.49 | 0.6% |
| 7 | Gazer | 2.10 | 147.0273 | 0.3% | 308.82 | 0.1% |
| 8 | Gedir | 2.10 | 1898.7752 | 4.1% | 3987.44 | 0.9% |
| 9 | Goldia | 14.09 | 12256.688 | 26.3% | 172647.43 | 37.3% |
| 10 | Goyd | 6.41 | 2177.9349 | 4.7% | 13956.32 | 3.0% |
| 11 | Jinka | 16.37 | 889.4369 | 1.9% | 14557.01 | 3.1% |
| 12 | Kaysa | 13.33 | 1072.8883 | 2.3% | 14297.31 | 3.1% |
| 13 | MNP | 15.09 | 4041.7772 | 8.7% | 60996.13 | 13.2% |
| 14 | Pola | 3.08 | 323.8607 | 0.7% | 996.24 | 0.2% |
| 15 | Senegal | 19.02 | 285.3593 | 0.6% | 5428.41 | 1.2% |
| 16 | Selmamer | 14.35 | 2690.1142 | 5.8% | 38615.50 | 8.3% |
| 17 | Sh/weset | 1.70 | 1083.0168 | 2.3% | 1842.49 | 0.4% |
| 18 | Shepi | 4.47 | 520.2985 | 1.1% | 2325.74 | 0.5% |
| 19 | Zomba | 2.85 | 2474.6289 | 5.3% | 7055.69 | 1.5% |
| | Total | | 46546.002 | | 463369.34 | 100% |

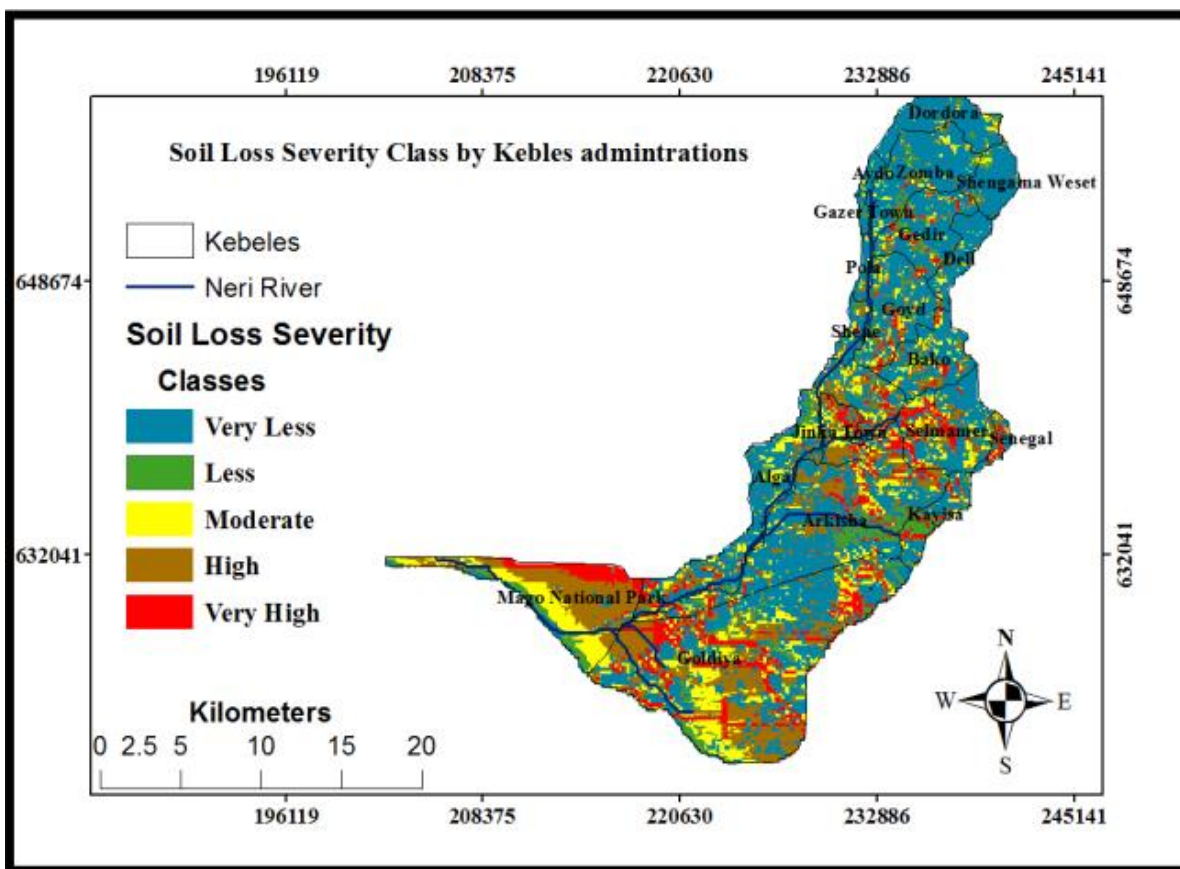


Figure 12. Soil erosion severity classes map by administrative kebeles.

range from 1.923 to 20.08 t ha⁻¹ yr⁻¹. The situation for sub watersheds numbered (SW₄, SW₅, SW₆, SW₇, SW₈, SW₉, SW₁₀ and SW₁₁) is beyond the soil loss tolerance (>6.125 t ha⁻¹ yr⁻¹) according to WBISPP (2001) and the remaining are not. Hence, for prioritization of conservation planning, their area weighted average was applied for ranking to take area coverage of these sub watershed into account.

Neri watershed consists of about 19 Kebeles administrations of 2 Woredas, i.e. South Ari and Bena Tsemay, an attempt was made to see which of these 19 kebeles highly affected by soil erosion in order to prioritize them for conservation planning (Figure 12). The average annual soil loss rate of the study area Kebeles ranges from 1.54 to 19.02 t ha⁻¹ yr⁻¹ (Table 4). Out of the total 19 Kebeles, 10 (Alga, Arkisha, Aydfo, Bako, Dell, Dordora, Gazer, Gedir, Goldia, Goyd, Jinka town, Kaysa, MNP, Pola, Senegal and Selmamer) produce a mean annual soil loss more than tolerable loss rate category (>6.125 t ha⁻¹ yr⁻¹) and the rest 9 kebeles are below the maximum mean annual soil loss tolerable limit. As shown in Figure 12, the average annual soil loss rate of these ten Kebeles are 7.96, 9.70, 6.46, 14.09, 6.41, 16.37, 13.33, 15.09, 19.02 and 14.35 tons per hectare per year respectively.

Conclusions

The RUSLE model with the aid of GIS and remote sensing applications was applied over the Neri watershed to generate soil loss estimation maps. The resulting soil loss map produced by overlaying of grid maps of the six factors showed that the soil loss rate of the watershed ranged from 0 to 465.16 t ha⁻¹ yr⁻¹ with a mean annual soil loss rate of 9.95 t ha⁻¹yr⁻¹ and overall total annual amount of 463,365.46 t/yr. So, it is perceptible that this watershed is under risk of soil erosion.

Soil loss severity classification result revealed that, 32.67% of the total study area is beyond tolerable soil loss rate and the remaining 67.33% is recognized as area not zone of a great danger of soil erosion. The highest soil loss recorded spots are areas of long steep slope areas at middle-eastern parts of the watershed where no or low existence of surface cover, without support practice and highly erodible soil and erosive rain combined.

Furthermore, for the prioritization of intervention, the soil loss map of baseline period was used to extract the soil loss per nineteen (19) kebele administrative units and eleven (11) sub-watersheds (SWs). But sub-watersheds having greater than SLT were chosen. Based on the analysis, sub-watersheds (SW₄, SW₆, SW₇, SW₉, SW₁₀ and SW₁₁), greater than SLT in their order of area weighted average soil loss were identified for priority intervention.

Based on the findings of this study, to ensure sustainable resource use, management practice like contour cropping with selected high biomass bearing ones complimented with soil and conservation practices in agricultural fields and with giving special attention to climate change through

strong policy measures, erosion minimization in non-agricultural land use classes are of paramount importance.

COMPETING INTERESTS

The authors declare that they have no competing interests.

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REFERENCES

- Angima, S. D., Stott, D. E., O'Neill, M. K., Ong C. K., & Weesies, G. A. (2003) Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agriculture, Ecosystems and Environment*, 97(1-3), 295-308.
- Bekele, B., Muluneh, A., & Wondrade, N. (2019). Geographic Information System (GIS) based soil loss estimation using Universal Soil Loss Equation Model (USLE) for soil conservation planning in Karesa Watershed, Dawuro Zone, South-west Ethiopia. *International Journal of Water Resources and Environmental Engineering*, 11(8), 143-158.
- Bai, Z., Dent, D. L., Olson, L., & Shaepman M. E. (2008) Proxy global assessment of land degradation. *Soil use and Management*, 24(3), 223-234.
- Bewket, W., & Teferi, E. (2009) Assessment of soil erosion hazard and prioritization for treatment at the watershed level: Case study in the Chemoga watershed, Blue Nile Basin, Ethiopia. *Land Degradation & Development*, 20(6), 609-622.
- Blanco, C. H., & Lal, R. (2008). Principles of soil conservation and management. Springer Science and Business Media B.V, Berlin, p. 240.
- Bochet, E., Rubio J. L., & Poesen, J. (1998) Relative efficiency of three representative matorral species in reducing water erosion at the micro scale in a semi-arid climate, *Geomorphology*, 23(2-4), 139-150.
- Bonilla, C. A., & Johnson, O. I. (2012). Soil erodibility mapping and its correlation with soil properties in Central Chile. *Geoderma*, 189-190, 116-123.
- Brady, N. C., & Weil, R. C. (2012). The nature and properties of soils. Pearson education, New Delhi.
- Durán, Z. V. H., Rodríguez, P. C. R., Francia, M. J. R., Cárceles R. B., Martínez R. A., & Pérez G. P. (2007). Harvest intensity of aromatic shrubs vs. soil-erosion: An equilibrium for sustainable agriculture (SE Spain), *Catena*, 73(1), 107-116.
- Fangmeier, D. D., Elliot, W. J., Workman, S. R., Huffman, R. L.,

- & Schwab, G. O. (2006). *Soil and Water Conservation Engineering*. 5th ed. Thomson Delmar Learning, New York. p.35.
- Feng, X., Wang, Y., Chen, L., Fu, B., & Bai, G. (2010). Modelling soil erosion and its response to land-use change in hilly catchments of the Chinese Loess Plateau. *Geomorphology*, 118(3-4), 239-248.
- Food and Agricultural Organization (FAO) and UNEP (1984). Provisional methodology for assessment and mapping of desertification. FAO, Rome, p.85.
- Food and Agricultural Organization (FAO).1986. Highland reclamation study: Ethiopia. Final Report. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Foster, G. R. (1981). Conservation practices in erosion models. In: Morgan, R. P. C. (ed.). *Soil Conservation: Problems and Prospects* (pp. 273-278). New York: John Wiley and Sons.
- Foster, G. R., McCool, D. K., Renard, K. G., & Moldenhauer, W. C. (1981). Conversion of the universal soil loss equation to SI metric units. *Journal of Soil and Water Conservation*, 36(6), 355-359.
- Brhane, G., & Mekonen, K. (2009). Estimating soil loss using Universal Soil Loss Equation (USLE) for soil conservation planning at Medego watershed, Northern Ethiopia. *Journal of American Science*, 5(1), 58-69.
- Gerawork, B., & Awdenegest, M. (2014). Spatial erosion hazard assessment for proper intervention in the case of Gibe-III Dam Catchment, Southwest Ethiopia. MSc Thesis, Haramaya University.
- Hassan, Z., Shabbir, R., Ahmad, S. S., Malik, A. H., Aziz, N., Butt, A., & Erum, S. (2016). Dynamics of land use and land cover change (LULCC) using geospatial techniques: a case study of Islamabad Pakistan. *SpringerPlus*, 5(1), 1-11.
- Hurni, H. (1985). Erosion - productivity - conservation systems in Ethiopia. *Proceedings of 4th International Conference on Soil Conservation, Maracay, Venezuela*. Pp. 654-674.
- Hurni, H., Herweg, K., Portner, B., & Liniger, H. (2008). Soil erosion and conservation in global agriculture. In *Land use and soil resources* (pp. 41-71). Springer, Dordrecht.
- Hurni, H. (1990). Degradation and conservation of the resources in the Ethiopian highlands. *Mountain Research and Development*, 8, 123-130.
- Hurni, H. (1993). Land degradation, famine, and land resource scenarios in Ethiopia. *World soil erosion and conservation*. Pp. 27-61.
- Jensen, J. R. (2000). *Remote sensing of the environment: An earth resource perspective* prentice hall, New Jersey. Joshi VU, Nagare Land use change detection along the Pravara River Basin in Maharashtra, using Remote Sensing and GIS Techniques. *AGD Landscape Environ*, 3,71-86.
- Kaltenrieder, J. (2007). Adaptation and validation of the Universal Soil Loss Equation (USLE) for the Ethiopian Eritrean Highlands. MSc Thesis, University of Berne, Centre for Development and Environment Geographisches Institute.
- Lal, R., & Elliot, W. (1994) Erodibility and erosivity. In: Lal, R. (ed.). *Soil Erosion research Methods*, St. Lucie Press, Delray Beach, Florida, pp. 181-207.
- Mahmud, Y., Alemu, M., Menale, K., & Pender, J. (2005). Cost of land degradation in Ethiopia: A Critical Review of Past Studies. *Environmental Economics Policy Forum in Ethiopia, and International Food Policy Research Institute*, Addis Ababa, Ethiopia.
- Manrique, L. A. (1988). Land erodibility assessment methodology. Manrique International Agro technology, Honolulu.
- Mellerowicz, K. T., Rees, H. W., Chow, T. L., & Ghanem, I. (1994). Soil conservation planning at the watershed level using the Universal Soil Loss Equation with GIS and microcomputer technologies: A case study. *Journal of Soil and Water Conservation*, 49(2), 194-200.
- Mitasova, H., & Mitas, Z. (1999). Modeling soil detachment with RUSLE 3D using GIS. IL, USA: University of Illinois at Urbana –Champaign.
- Murphy, B. W., & Flewin, T. C. (1993). Rill erosion on a structurally degraded sandy loam surface soil. *Australian Journal of Soil Research*, 31(4), 419-436.
- Pelton, J., Frazier, E., & Pickilings, E. (2012) Calculating slope length factor (LS) in the (revised) universal soil loss equation (RUSLE) to the Ethiopian highlands.
- Piccolo, A., Pietramellara, G., & Mbagwu, J. S. C. (1997). Use of humic substances as soil conditioners to increase aggregate stability. *Geoderma*, 75(3-4), 267-277.
- Raes, D., Willems, P., & Baguidi, F. (2006). RAINBOW – a software package for analyzing data and testing the homogeneity of historical data sets. *Proceedings of the 4th International Workshop on 'Sustainable management of marginal dry lands'*. Islamabad, Pakistan, 27-31 January 2006.
- Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., & Yoder, D. C. (1997). Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook, Vol. 703. US Department of Agriculture, US Government Printing Office, Washington DC, USA.
- Rosewell, C. J., Crouch, R. J, Morse, R. J., Leys, J. F., Hicks, R. W., & Stanley, R. J. (2007) Forms of Erosion. In 'Soils- their properties and management'. 3rd edition. Charman, P. E. V., & Murphy, B. W. (eds.). pp. 14–40. Oxford University Press: Melbourne.
- Rouse, J. W., Haas, R. H., Schell, J. A., & Deering, D. W. (1974). Monitoring vegetation systems in the Great Plains with ERTS. *NASA special publication*, 351(1974), 309-317.
- Smith, J. L., Halvorson, J. J., & Papendick, R. I. (1993). Using multiple-variable indicator kriging for evaluating soil quality. *Soil Science Society of America Journal*, 57(3), 743-749.
- Sonneveld, B. G. J. S. (2002). Land under pressure: The impact of water erosion on food production in Ethiopia. Shaker Publishing, Maastricht, the Netherlands.
- Stern, R., Ben-Hur, M., & Shainberg, I. (1991). Clay mineralogy effect on rain infiltration, seal formation and soil losses. *Soil Science*, 152(6), 455-462.
- Suji, V. R., Karuppasamy, S., & Sheeja, R. V. (2015). Prioritization using morphometric analysis and land use/land cover parameters for Vazhichal watershed using remote sensing and GIS techniques. *International Journal for Innovative Research in Science & Technology*, 2(1), 61-68.
- Tamene, L. (2005) Reservoir siltation in the drylands of Northern Ethiopia, Causes, Source Areas and Management Options. PhD Thesis, *Center for Development Research*, University Bonn, Bonn.
- Molla, T., & Sisheber, B. (2017). Estimating soil erosion risk and evaluating erosion control measures for soil conservation planning at Koga watershed in the highlands of Ethiopia. *Solid Earth*, 8(1), 13-25.
- Vaezi, A. R., Bahrami, H. A., Sadeghi, S. H. R., & Mahdian, M. H. (2010). Spatial variability of soil erodibility factor (K) of the USLE in North West of Iran. *Journal of Agricultural Science and Technology*, 12(2), 241-252.
- Wang, G., Gertner, G., Liu, X., & Anderson, A. (2001). Uncertainty

- assessment of soil erodibility factor for revised universal soil loss equation. *Catena*, 46(1), 1-14.
- Wischmeier, W. H., & Smith D. D. (1978). Predicting rainfall erosion losses: A guide for conservation planning. USDA Agricultural Hand book No 537, Washington, DC.
- Woody Biomass Inventory and Strategic Planning Project (WBISPP) (2001). Southern Nations Nationalities and People's Regional State: A strategic plan for the sustainable development, conservation, and management of the woody biomass resources. Addis Ababa, Ethiopia.
- Yang, D., Kanae, S., Oki, T., Koike, T., & Musiake, K. (2003). Global potential soil erosion with reference to land use and climate changes. *Hydrological processes*, 17(14), 2913-2928.