PREDICTING SOIL EROSION BY WATER: RUSLE APPLICATION FOR SOIL CONSERVATION PLANNING IN CENTRAL RIFT VALLEY OF ETHIOPIA.

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1 | INTRODUCTION[2],[3]

Soil erosion lowers the quality of Ethiopia's agricultural land resources (Haycho et al., 2015). It reduces agricultural and pasture production and exposed people to food insecurity and shortage of livestock feed. Soil erosion by water is a common environmental problem in developing countries including Ethiopia. Water erosion is the leading soil degradation problem in the mountainous regions such as Ethiopia (Hurni, 1988; Mengistu et al., 2015), Vietnam (Pham et al., 2018 citing Trinh, 2015) and Jordan (Farhan et al., 2013). On the top of lowering agricultural production, soil erosion leads to severe siltation of lakes, dams and irrigation canals, and drying both natural and artificially developed water sources (Assen, 2011; Farhan et al., 2013).

Soil erosion is caused and intensified by overexploitation of soil, indiscriminate deforestation, expansion of agricultural land onto ecologically fragile land and poor practice of land management strategies and technologies (Hurni, 1988; Asmamaw and Mohammed, 2019). As a result, soil erosion by water shows a spatiotemporal variability. In Brazil studies confirmed a presence of high (57 t ha^{-1} yr^{-1}) soil loss by water on cultivated and urban land use/land cover areas (Duque and Melese, 2016). In the highlands of Ethiopia, water erosion ranges from 16 to over 300 t ha^{-1} yr^{-1} (Hurni, 1988; Mengistu et al., 2015). The local and regional disparity of soil loss rate depends on variations of environmental

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and socioeconomic factors (Hurni, 1988). Water induced soil erosion is the result of the combined interaction of rainfall erosivity, soil erodibility, slope length and steepness, land use/land cover and land management practices (Renard et al., 1997; Vrieling, 2006). In Ethiopia, soil erosion adversely affecting agricultural and pastoral and/or agro-pastoral economic activities of high and lowland areas.

Several soil erosion models have been developed by scientists (e.g. Nearing et al., 2005) and applied in different parts of the world. However, the applications of these process-based erosion models are difficult to employ in developing countries where there is little and poorly measured data, due to their large and expensive data requirements (Sonneveld et al., 2001). Therefore, it would be useful to apply models which depend on available and cheap data such as RUSLE (Renard et al., 1997). Furthermore, knowledge of soil erosion is useful in identifying erosion sensitive hotspot corners and design appropriate soil and water management plans, strategies and technologies depending on the degree of the problem and available local resources.

In Ethiopia, most of the model and experimental based soil erosion studies have been concentrated in the highlands of the country (Abate, 2011; Belay & Bewket, 2012; Gebreyesus & Kirubel, 2009; Hurni, 1983; Mengistu et al., 2015; Moges & Holden 2008). As a consequence, the arid and semiarid lowlands of the country have been given little attention from the focus of scientific research (Woldemariam et al., 2018). However, the research carried by Schewel (2019) in Adami Tulu Jido Kombelcha, East Shewa zone of Oromia region, outside the present study areas in Ethiopia confirmed the transformation of the pastoral economy to agro-pastoral and finally to permanent agriculture over time. Some soil erosion assessments made in the lowlands of Ethiopia are too general and would not be useful for local specific applications (Bhan, 1988). On the other hand, mainly with the application of available irrigation technologies, present-day agriculture is expanding towards the arid and semiarid lowlands of Ethiopia (Mekonnen et al., 2019). Therefore, the present research is profoundly important and unique to fill the existing research gap on soil erosion studies lacking in the semi-arid and arid lowlands of Ethiopia at large and the Middle Awash Valley of Afar region in particular.

The present study aims to investigate the magnitude of soil loss and main drivers of soil erosion with the application of RUSLE in the Middle Awash Valley (MAV), Central Rift Valley of Ethiopia. The results of this research have relevance to (1) understand the degree of soil erosion in the arid and semi-arid lowlands of Ethiopia, (2) identify the major human and environmental factors accelerating soil erosion occurrence in semi-arid and arid agro-ecologies, and (3) produce potential soil erosion risk map and recommend appropriate land management strategies to be undertaken in preventing water-driven soil erosion challenges.

2 | MATERIALS AND METHODS

2.1 | Description of the study area

The study is made in the Middle Awash Valley (MAV) of the Awash Fentale and Amibara districts (locally called *woreda)* of the Afar region, Central Rift Valley of Ethiopia. It lies between $8^0$30’ 12” - $9^0$50’ 03” N latitude and $39^0$50’ 20” - $40^0$32’0” E longitude (Figure 1). The study area covers 2,148.72km^2 (214, 872ha and elevation ranges from 688m to 1852m asl (meters above mean sea level). The slope gradient is monotonously flat in large parts of the study area and ranges from almost zero on flat grounds to 30% to 45% in hilly landforms (FAO, 2006).

Insert FIGURE 1

Considering available meteorological data from Melka Worer station (730masl, 09^o 19’ 15.5” N latitude and 40^o 11’ 56.3’’E longitude (located in the centre of the study site), the MAV has a semi-arid climate with 550.95mm mean annual rainfall and 26.75^{0C} mean annual temperature. Temperature is high throughout the year, which is beyond the optimal requirements of most cultivated plants and animals. The mean monthly temperature varies from 24^oC in December to 32^oC in June (Figure 2). The mean annual rainfall ranges from 238.8mm in 2004 to 818.1mm in 1982, giving a high inter-annual variability. The low rainfall amount causes shortages of animal feed and water commonly leading to the toll death of livestock and human food insecurity. The trend of rainfall is irregular and difficult to predict. As Westphal (1975) discussed, the Middle Awash Valley experiences arid climate, low and uncertain rainfall and high evaporation rate. The available climatic data for Melka Worer station as well disclosed the occurrence of rainfall above the average (550mm) within in thirty-five years period was only in 1982, 1988, 1989, 1996, 2004, 2005 and 2012 (Figure 2).

Insert FIGURES 2a & 2b

The major soils of the study area include Leptosols, Luvisols, Cambisols, Fluvisols and Andosols (MoA, 2013; FAO, 1984; Figure 3). As the area is poorly vegetated mainly associated with scanty rainfall, the soils have low organic matter contents. The Leptosols occupy the steeper and higher grounds of the study area. Fluvisols are commonly found along the Awash River course. Luvisols are major soils of the flat slopes, whereas Andosols are common where volcanic ashes are locally found. The foot of local hills and intermediate sloppy lands are occupied by Cambisols (Figure 3).

Insert FIGURE **3**

Analysis of the 2016 satellite imageries of 30 X 30 m cell size resolution reveals that the study area has six land use/land cover (LU/LC) types (Figure 4). The shrub and cultivated lands, respectively, accounting 46.6% and 30.3% of the total area were the predominant LU/LC patterns.. The shrubland includes mixes of natural shrub and invasive *Prosopis juliflora* species. The remaining parts of the study area are covered with grassland (14.4%), urban settlement (4.9%), forestland (3.3%), and water body (0.5%).

Insert FIGURE 4

Most local communities of the study area are mainly traditional pastoralists. Crop cultivation in the MAV depends on irrigation water of the Awash River and its tributaries. Cotton, sugarcane and sorghum were the main crops. Most tributaries of the Awash River usually dry up in the lowlands as soon as rainfall ceases in their surrounding highlands (Kloos, 1982). Recently, mainly due to the villagization and expansion of irrigation, some pastoralist have started small-scale irrigation agriculture as additional source of livelihoods (Mekonnen et al., 2019). As a result, some pastoralists in fourteen *kebeles* (lower administrative units of Ethiopia) of Amibara and Awash Fentale *woreda* were becoming agro-pastoralists. However, the pastoral communities predominantly depend on livestock production, which includes large herds of camels, cattle, and ruminants such as sheep and goats. The agro-pastoralists practice both livestock rearing and crop production which mainly includes sugarcane, maize, onion, tomato, cabbage, and cotton. Shortages of grazing and irrigation land, and water, lack of access to the market for agricultural products, soil erosion in the form of gullies, flooding and wide invasion of land by *Prosopis juliflora* were challenges experienced by local communities (Mekonnen et al., 2019).

The Afar region with about 1,060,573 people in 1994 was one of the lowest sparely populated regions of Ethiopia (CSA, 1998). However, the population of the Afar region has increased to 1,390,217 in 2007, and possibly resulting in more demand for basic resources such as forest, water, and land for agriculture and settlement (CSA, 2010).

2.2 | Research Methodology[4]

Various spatial datasets were obtained from different organizations and processed using the RUSLE model with the applications of GIS tools and RS techniques. Thus, the RUSLE model is applied to

[4] Data Availability:the authors are in agreement if the results of this reserch have been shared for open accessibility

estimate soil loss rates, map the six RUSLE factors and spatial variability and mean annual of soil loss of the study area (sections 2.4.1-2.4.5). Besides, key informant interviews (KII) and focus group discussions FGD) were conducted with development agents and purposely selected local community members. The KII and FGD members were recruited based on experience and knowledge merit to understand the severity and spatial variation of soil erosion rates.

2.3 │The Revised Universal Soil Loss Equation (RUSLE) Model

The RUSLE is a widely used and validated erosion model in predicting the long term average annual soil loss rate. Soil loss results from the combined interaction of six RUSLE factors: rainfall erosivity, soil erodibility, slope length and steepness, land use/land cover and land management practices (Millward & Mersey, 1999).

The modified (RUSLE) model has several merits:1) it employs cheap and non-complicated data input generated from easily accessible sources 2) can be easily connected to GIS and RS technologies which makes the model variables and mean soil loss rate computation to be efficient, manageable and easy to handle (Pham et al., 2018), and 3) is executed in conjunction with a raster-based GIS to predict cell by cell potential erosion to identify spatial soil loss variation within the research area (Millward and Mersey, 1999). The spatial variation of soil loss in the MAV is the result of the spatial heterogeneity of the RUSLE factors (Farhan et al., 2013). For this research, the MAV has been divided into a small homogenous unit of 30m by 30m grid cell size before running the computation of the soil loss (Farhan et al., 2013). This RUSLE model computes the mean annual soil loss rate using equation 1:

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

Where, A = the average annual soil loss per unit area (tons ha^{-1} $year^{-1}$); R = rainfall erosivity (MJ mm ha^{-1} hr^{-1} yr^{-1}); K = soil erodibility (t ha hr ha^{-1} MJ^{-1} mm^{-1}); LS = slope length-steepness (dimensionless); C = land use/land cover (dimensionless); and P = conservation/management factors (dimensionless).

2.4│ Determining the six RUSLE Factors

The processes used to generate each of the six RUSLE model parameter values are explained as hereunder.

2.4.1 │Rainfall erosivity (R) factor

The R factor is the product of the total kinetic energy multiplied by the maximum 30 minutes rainfall intensity (Wischmeier & Smith, 1978).This factor measures the erosivity of average annual rainfall and runoff to cause soil erosion (Farhan et al., 2013). The spatial rainfall distribution of the study area was computed from gridded meteorological data (CHRIPS,ftp://ftp.chg.ucsb.edu/pub/org/chg/products/CHIRPS-2.0/). Kriging interpolation method has been used to generate the raster R factor. Kriging is a multistep process including exploratory statistical analysis of the data, variogram modeling, creating the surface, and exploring a variance surface (Burrough & McDonnell, 1998). The annual rainfall erosivity factor can be computed by different methods (Gitas et al., 2009; Parveen & Kumar, 2012) However, the spatial distribution of R factor value (Figure 5) was computed with the ArcGIS raster calculator tool using Hurni (1985) formula expressed in Equation 2:

$$R = -8.12 + 0.562P \quad \textit{(Hurni 1985)} \qquad (2)$$

Where R is the calculated rainfall-runoff erosivity factor and P is the mean annual rainfall (mm).

The Hurni's (1985) R factor formula shows the relationship between mean annual total rainfall and R factor. The variation of R factor depicts the difference in the amount and distribution of rainfall across spaces (Farhan et al., 2013).

2.4.2 | Soil erodibility (K) factor

The K factor refers to the susceptibility of the soil to erosion agents. It is mainly associated with some physical soil characteristics (Shabanin et al., 2014) which specifically depends on soil texture, soil structure, soil organic matter content, soil moisture and surface roughness (Lal, 2001; Millward and Mersey, 1999; Renard et al., 1997). The K factor indicates the degree of resistance of soil particles to raindrop detachment and transport capacity of runoff. Soil erodibility (K) value ranges from 0 to 1, where values closer to 0 show the least soil susceptibility to erosion and values closer or equal to 1 are the most erodible soils and highly prone to soil erosion (Farhan et al., 2013; Ganasri and Ramesh, 2016; Mhangara et al., 2012; Zerihun et al., 2018). Soils having better infiltration rates such as sandy textured one becomes less susceptible to water erosion and less surface water accumulation to initiate runoff (Wischmeier & Smith, 1978). As obtaining soil erodibility (K) data is one of the most challenging tasks (Bahrami et al., 2005), the K factor value of the soil types of MAV (Figure 3) estimated by FAO (1984) has been used in this study (Table 1).

Insert Table 1

In this study, the vector soil data were converted to raster format to produce a continuous spatial variability map of soil erodibility (Figure 6). Using the geoprocessing reclassification tool, the soil grid data/map had been recategorized based on the K value of each soil type (Table 1; Figure 6).

2.4.3 | Topographic (LS) factor

The LS factor is comprised of the effects of slope length (L) and slope steepness (S) on soil erosion rate (Farhan et al., 2013; Panagos et al., 2015). The LS factor influences the sediment transport capacity of the flow (Moore & Wilson, 1992).

Slope length is "the distance from the point of origin of overland flow to the point where either the slope decreases to the extent that deposition begins or runoff water enters to well-defined channel" (Ganasri & Ramesh, 2016). As slope length increases, soil loss per unit area rises as the gradual accumulation of runoff down slope increases (Farhan et al., 2013). Slope steepness refers to "the gradient of the land immediately surrounding the site" (FAO, 2006). The steeper slope is, the higher soil loss would be due to the impact of velocity and erosivity of runoff. However, slope steepness that indicates the effects of slope gradient on soil erosion has a greater impact than slope length (Farhan et al., 2013; Ganasri and Ramesh, 2016).

The topographic (LS) factors do not consider the three-dimensional distribution of the terrain in estimating soil loss (Mitasova, Hofierka, Zlocha, & Iverson, 1996). These LS factors assume soil loss increases with slope length and/or upslope contributing area (Desmet and Govers, 1996; Moore and Burch, 1986). However, slope length and/or upslope contributing factor does not necessarily lead to higher soil loss unless the three-dimensional terrain complexity is considered (Mitasova, et al., 1996). Therefore, this fact has to be taken as one limitation of the RUSLE model. As suggested by Mitasova and Mitas (1996), the LS factor is computed with equation 3 (using ASTER 2016 global raster satellite image with 30 x 30m resolution as a basic data source):

$$LS = \left(\frac{FA * \text{cell size}}{22.13}\right)^m * \left(\frac{\sin(\text{slope angle})/0.01745}{0.09}\right)^n \quad (3)$$

Where, FA = flow accumulation derived from Digital Elevation Model (DEM) after processing fill and flow direction in ArcGIS; cell size is the grid cell size derived from DEM 30 m by 30 m resolution, slope angle is in degrees (°), and 0.01745 is the parameter to convert degrees to radians, m and n are slope length and slope steepness exponents.

The exponent values are ranging from 0.2 to 0.6 for m and from 1 to 1.3 for n (Pham *et al*., 2018). The lower exponent values are used for prevailing sheet flow and higher values for prevailing rill flow. The 22.13m (72.6ft.) values and 0.09 radian (5.14°) are the length and slope angle of the standard USLE plot, respectively (Pham *et al*., 2018).

In the advanced LS equation 3, the slope length was substituted by the upslope contributing area to consider the impact of flow convergence and diversion on soil erosion in the three-dimensional complex terrain configurations. Thus, equation 3 has considered the contribution of upstream contributing area and slope gradient in estimating soil loss by LS factor.

2.4.4 | Land use/land cover (C) factor

The C factor reflects the influence of land use/cover types on soil erosion rate (Patil & Sharma, 2014). The C factor ranges from nearly 0 to 1, where values closer or equal to 1 indicate the absence of land use/land cover in the area and the surface is considered as barren land. However, the C factor value closer to zero (0) indicates the existence of a well-protected soil by forest or good plant cover (Ganasri & Ramesh, 2016). An increase in the C factor, therefore, portrays the higher exposure of soils to erosion and thus, the rise in potential soil loss (Farhan et al., 2013; Table 2).

Insert Table 2

The Normalized Difference Vegetation Index (NDVI) derived by RS technology (Equation 4) is the most commonly used indicator of vegetation growth (the C factor value). The 2016 Operational Landsat TM raster image of 30 x 30 m resolution was used to compute NDVI using equation 4 (Parveenu & Kumar, 2012).

NDVI is positively correlated with the amount of green biomass and indicates differences in green vegetation coverage (Knijff et al., 2000). Thus, NDVI value can be an input to calculate the C factor. The NDVI value has an inverse relationship with the land use/land cover (C) factor value. Therefore, the rise in the NDVI value shows the decline of C factor which ultimately indicates the decrease of soil loss with the improvement in vegetation cover (Farhan et al., 2013). Many researchers calculated the C-factor with different equations (Durigon, et al., 2014; Knijff et al., 2000). However, the formula suggested by Durigon et al. (2014) as indicated in equation 5 has been used to compute the C factor values of the study area. A reconnaissance survey was conducted to validate the computed LULC (C) factor value with the existing reality on the ground.

$$NDVI = \frac{(NIR - RED)}{(RED + NIR)} \quad (4)$$

$$C = \frac{(-NDVI + 1)}{2} \quad (5)$$

Where, C= the land use/land cover (C) factor; NDVI= Normalized Difference Vegetation Index; NIR= the surface spectral reflectance in the near-infrared band; and RED = surface spectral reflectance in the red band was extracted from Landsat images.

2.4.5 | Support practices (P) factor

The P factor is regarded as the impact of farming systems on soil erosion. It measures the effect of conservation practices in influencing the outbreak and prevalence of water-induced soil erosion. P factor adjusts the potential erosion by runoff through the implementation of contouring, strip cropping, and terraced farming (Kuok et al., 2013; Wischmeier & Smith, 1978).Some researchers suggested as the P-value is dependent on the slope inclination (Lufafa et al., 2003; Wenner, 1980; Wischmeier & Smith, 1978), whereas others use farming practices to calculate P value (Stone et al., 2000). If there would not be any erosion control practice, the P-value should be 1 (Table 3). The support practices (P) factor of MAV have been calculated using the combination of the 2016 land use/land cover and slope degrees suggested by Shin (1999) cited in El Jazouli et al., (2019) (Table 3).

Insert Table 3

3 | RESULTS AND DISCUSSIONS

The RUSLE model has been employed in estimating the magnitude of mean annual soil loss (metric ton ha^{-1} $year^{-1}$), map spatial soil loss variation and identify erosion hotspot areas by the combined interplay of the six RUSLE model factors. The impact of each of the main erosion factors on the rate of soil loss has been analyzed hereunder.

3.1 | Contribution of RUSLE factors on the soil loss rate

3.1.1 | Rainfall erosivity (R) factor

The intensity, amount and distribution of rainfall are some of the most important physical factors affecting the rate of soil erosion. As computed using equation 2, the R-factor of the MAV ranges from 471.39 to 817.34mm (Figure 5).

Insert Figure 5

The spatial distribution of R factor value varies across the study area. The northeastern corridor has experienced the lowest rainfall erosivity whereas the northwestern part has relatively encountered higher rainfall erosivity. In large parts of the Middle Awash Valley, rainfall erosivity ranges from 540.58 to 609.77 and gradually increases towards the east and west directions (Figure 5). As Batjes (1996) stated, the rainfall eorsivity factor value of 800 or below, as seen in most parts of the present study area, indicates the occurrence of low rainfall erosivity to erode soil resources. Therefore, the rainfall erosivity (R) factor is not the main driving agent of soil loss in the Middle Awash Valley of Ethiopia. (Figure 5).

3.1.2 | Soil erodibility (K) factor

The study area has seven different soil types (Table 1). However, depending on their water erosion vulnerability, these soil types of the Middle Awash Valley have been reclassified into four soil erodibility (K) factor classes (Table 1; Figure 6). The relatively low erodible Eutric Cambisols with soil erodibility factor of 0.15 covers 13.71% of the study area. Eutric Cambisols have a high infiltration rate because of their relatively high sand contents and low content of clay (Belay, 1998). Eutric Cambisols have, therefore, better resistant and less susceptibility to the eroding power of rainfall than other soil types of the study area (Table 1). Chromic Luvisols and Vertic Cambisols have relatively high and dominant clay content (Muller-Samann & Kotschi, 1994) and would have less infiltration rate, and will have high K values. The relatively most erodible Chromic Luvisols and Vertic Cambisols (K = 0.6) cover 2.36% and 50.55% of the total study area. The other relatively less erodible soils of Chromic Cambisols and Leptosols (K = 0.2) together covered 3.16% of the total study area. Chromic Cambisols (Asmamaw and Mohammed, 2012; Engdawork, 2002; Mohammed et al., 2005) are clayey with intermediate infiltration rates. Leptosols have shallow depths which would cause low moisture holding capacity that will generate more surface runoff (Asmamaw and Mohammed, 2012; Mohammed et al., 2005). Eutric Fluvisols and Vertic Andosols with soil erodibility factors of 0.3 covered 30.21% of the total study area (Figure 6). These soil types have an intermediate level of soil erodibility, as they contain relatively high silt content (Table 1), which is less cohesive and susceptible to detachment than other soils of the study area.

Insert FIGURE 6

3.1.3 | Topographic (LS) factor

The slope length-steepness (LS) of the study area factor ranges from 0 to 20.71 (Figure 7). Most of the study area, therefore, has a low topographical factor of soil loss owing to the prevalence of low slope length-steepness in the largest part of the study area. As a result, the LS factor has a low contribution to soil erosion occurrence in many parts of the Middle Awash Valley of Afar region, Ethiopia (Fig. 7).

Insert FIGURE 7

3.1.4 │The land use/land cover (C) factor

The C factor of the study area (Farhan et al., 2013) which has been computed from NDVI of the Landsat satellite image (Figure 8), ranges from 0.3 in relatively forested areas to 0.6 in low vegetation cover area.The presence of low land cover which is directly understood from the lowest NDVI value would negatively affect the occurrence and spread of rainfall-induced soil erosion (Figure 8). As a result, the trend of soil erosion is increasing with the decline of vegetation cover. The shrub, grassland and cultivated areas covering 30.3%, 46.6% and 14.4% of the Middle Awash Valley, respectively, are moderately vulnerable to water erosion. The study carried out by Pamo and Pieper (2000) confirmed that heavy grazing over the grassland removes the vegetation cover, thereby exposing soil surfaces to erosion. Similarly, shrublands of semiarid areas have sparse vegetation cover whereas cultivated areas of annual crops are with no plant cover during their early stage of crop growth and none cropping periods contribute to the rise of water-induced soil loss. Therefore, it is relevant to create a suitable balance between resource use and their capacity while implement sustainable use of soil resources management (Pamo and Pieper, 2000).

Insert FIGURE 8

Low soil erosion is experienced in 3.3 % of the study area covered by forest. Therefore, the impact of the C factor is moderately significant in triggering water-induced soil loss. The land use/land cover patterns of the area have to be properly utilized and managed to curb the contribution of the C factor in halting soil loss and sustainably use the soil resources.

3.1.5 │Support practices (P) factor

The P factor values ranges from 0 to 1 (Ganasri & Ramesh, 2016). The P factor value closer to 0 indicates the existence of good conservation practice. However, the P-value of 1 or closer indicates poor/slight conservation practices (Ganasri & Ramesh, 2016; Hurni, 1988).The support (P) practices factor of Middle Awash Valley ranged from 0.003 to 1 (Table 2; Figure 9). As portrayed in Figure 9, areas with the P value of 0.003 have very limited areal coverage with better conservation practices.

However, the P-value of 1 portrays the poor/slight land management practice in most of the Middle Awash Valley areas of Afar region, Ethiopia (Figure 9). As a result, poor land management practices significantly contribute to the high occurrence of soil erosion by water in the northeastern parts of the study area.

Insert FIGURE 9

3.2 │ Magnitude and Spatial Pattern of Soil Loss

The six RUSLE model (RKLSCP) factors are overlaid and multiplied pixel by pixel using the raster geoprocessing calculator tool in the ArcGIS 10.5 environment to estimate the soil loss rate (Metric tons ha^{-1} year^{-1}) and map the spatial soil loss variation of the study area (Figure 10).

Insert FIGURE 10

The mean annual soil loss ranges from close to 0 to over slightly 20 tons ha^{-1} year^{-1} (Figure 10). Depending on soil loss magnitude, the soil erosion of the study area has been classified into five soil erosion severity classes (Table 4). The classification of the soil loss risk was carried out to map the spatial distribution of soil loss and identify soil erosion hotspot areas for land management prioritization.

Insert Table 4

As confirmed by the RUSLE model result, water-induced soil loss is very low and would not be considered as the major constraint in about 60% (1271.03km^2) of the study area. In the very low erosion rate corners, the magnitude of soil erosion accounts for up to 0.5 ton soil loss ha^{-1} year^{-1} (Table 4). This is mainly attributed to the lower effect of rainfall erosivity and local LS topographical factors. Such areas have the fifth (V) priority of land management which could be implemented after all the other soil erosion-prone areas have been conserved.

In some of the study areas, sugarcane plantation forms the major cultivated crop. As sugarcane plantation cover protect soil from raindrop detachment and runoff, the sugarcane cultivated area has a low rate of soil loss, below 1 ton ha^{-1} year^{-1} (Figure 10). Similarly, low soil erosion rate has been experienced in sugarcane farms of semi-arid areas of Morocco (North Africa) (Lahlaoi, Rhinane, Hilali, Lahssini, & Khalile, 2015). This contradicts contradictory to results obtained from highland cereal cultivated areas of Ethiopia as proved by many research findings (Asmamaw & Mohammed, 2019; Bewket & Teferi, 2009; Gelagay & Minale, 2016). Similarly, low soil erosion rate has been experienced in sugarcane farms of semi-arid areas of Morocco (North Africa) (Lahlaoi, Rhinane, Hilali, Lahssini, & Khalile, 2015). About 75% of the total area in many semi-arid lowlands of the world experience slight (0-2) tons of soil loss ha^{-1} $year^{-1}$ (Mohammed et al., 2017). On the contrary, the wetter intensively cultivated and rugged highlands of Ethiopia are highly vulnerable to the risk of severe and very severe soil erosion than the drier flat lowland areas of the country (Mohammed et al., 2017; Esa et al., 2018). Thus, over many highland areas, the magnitude of soil loss exceeds both the tolerable soil loss rate of 18 tons ha^{-1} $year^{-1}$ and estimated soil formation rate of 2 to 22 tons ha^{-1} $year^{-1}$ (Hurni, 1983).

The low to medium soil loss areas with the soil loss rate of 0.5-1 and 1-10 tons ha^{-1} $year^{-1}$, accounted for only 10.72% (230.24km^2) and 8.07% (173.47km^2) of the Middle Awash of Afar region, Central Rift Valley of Ethiopia. Generally, a very low to medium rate of soil loss areas covered over three-quarters (77.94%) of the research area. The high (10-20) and very high (over 20) tons of soil loss ha^{-1} $year^{-1}$ together covered 22.06% (473.98km^2). The existence of relatively high and very high erosion rate in some corners of the study area was attributed to the presence of intrinsically less resistant soils to water erosion, the sparse nature of shrub and vegetation cover, poor support practices experienced across these parts of the study area (Figures 4, 5, 7 and 8). Therefore, the first and second priority of soil management has to be given in 4.96% (106.48km^2) and 17.10% (367.50km^2) of the study area which have very high and high hotspot soil loss rates (Table 4). The rotational use of grazing lands and enhancement of support and soil water conservation practices would contribute in curbing the high to very high soil loss rate in 22.06% (473.98km^2) of the study area.

The customary dependence only on the present poor land management practices would drastically lead to the decline in the productivity of grass and cultivated lands. Hence, sustainable livestock breeding and irrigation agriculture would be challenged in the face of the current adverse impact of climate change and variability. The productivity of the grasslands can be efficiently enhanced with effective dryland water conservation strategies, rotation of grazing lands and minimizing the density of livestock per unit area that focuses on the quality of animal husbandry. Besides, the support practices and availability of required resources have to be improved along the various land use/land cover categories to enhance the productivity of cultivated and grasslands. In the Northern highlands of Ethiopia, the scarcity of loans to farmers by Rural Saving and Credit Cooperative Institutions limits the access of lighting solar panel and force them to deforest the nearby shrubs (Hishe et al., 2018). Thus, provision of alternative source of light and biomass energy in a long run can minimize the shrub and forest resources degradation of pastoral, agro-pastoral and farming communities.

4. Conclusions

The arid and semi-arid climate of the present research area commonly has mean annual rainfall below 700mm with dominantly low slope length and steepness. The present study indicates that rainfall erosivity (R) and slope length and steepness (LS) factors were not the main drivers of water-induced soil loss. However, the nature of the soils, land use/land covers and lack of required soil management practices were found to be the main accelerators of moderate to very high soil loss by water. To minimize water induced soil loss, the modest erodibility of the soils has to be managed through locally acceptable land management practices. To control the overgrazing of the grasslands, it is important providing public awareness to the community to transform their economies from owning too many into few livestock with a focus on quality animal breeding systems. Besides, the rangeland of the semi-arid areas of the study sites has to be used through rotation. Therefore, applications of locally fitting land management practices with the consideration of diverse strategies and other measures would minimize soil loss, enhance land quality, maximize agricultural productivity and promote the livelihood status of the local community in the study area.

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