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

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Abstract

In Ethiopia, research on soil erosion hazard assessment has largely focused in its cereal crop dominated subtropical and temperate highlands. This study has been carried out in the semiarid and arid lowland areas of pastoral and agro-pastoral economic belts of Ethiopia where little research attention has been given. The RUSLE model is employed to estimate soil loss erosion rates in this present study area, Ethiopia. The RUSLE parameters were acquired from meteorological, available soil and satellite image data, key informant interviews, focus group discussions and field observations. The result showed that mean annual soil loss rates varied from 0.5 t on flatter slopes to slightly over 20 t ha^{-1} yr^{-1} on poorly vegetated areas. The study area was classified into very high (>20 t ha^{-1} yr^{-1}), high (10-20 t ha^{-1} yr^{-1}), medium (1-10 t ha^{-1} yr^{-1}), low (0.5-1 t ha^{-1} yr^{-1}) and very low (0-0.5) erosion risk categories. Areas with high (10 to 20 t ha^{-1} yr^{-1}) and very high (>20 t ha^{-1} yr^{-1}) erosion risk parts of the study site need to be prioritized for land management interventions. Areas which require immediate land management account about 22.06% (473.9km^2) of the study area. The severity of soil erosion was largely linked to high soil erodibility, poor vegetation cover and lack of conservation practices. Therefore, improving soil erodibility, vegetation cover and implementing locally suitable soil and water conservation technologies are commendable.

Key words: agro-pastoral economies, erosion risk, hotspots, pastoral area, RUSLE, semiarid land

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1. Introduction

Soil erosion by water is a serious environmental challenge of development endeavor all over the world (Angima et al., 2003). To cite examples, it is the leading soil degradation problem in the mountainous regions of different countries such as Ethiopia (Hurni, 1988; Kebede, 2014; Mengistu et al., 2015), Vietnam (Pham et al., 2018 citing Trinh, 2015), Jordan (Farhan et al., 2013) and loess plateau of China (Zhang, 2005). Soil erosion lowers the quality of agricultural land resources (Haycho et al., 2015). In Ethiopia, soil erosion adversely affects agricultural, pastoral and agro-pastoral economic activities of high and lowland areas. As a result, it reduces agricultural and pasture production and exposed people to food insecurity and shortage of livestock feed. On the top of this, soil erosion leads to severe siltation of lakes, dams and irrigation canals, and dry up of both natural and artificially developed water sources (Assen, 2011; Farhan et al., 2013; Kebede, 2014).

Soil erosion is triggered by various natural and socioeconomic forces. As a result, water erosion is the serious, constant and main cause of soil degradation in many parts of the world (Recep et al., 2008). It 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 (Asmamaw and Mohammed, 2019; Hurni, 1988). According to RUSLE model, water induced soil erosion is the result of the combined interaction of

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rainfall erosivity, soil erodibility, slope length and steepness, land use/land cover and land management practices (Vrieling, 2006). Instigated by different drivers, soil erosion by water shows a spatiotemporal variability in various countries of the world. For example, in Brazil, studies confirmed a presence of high (57 t ha^{-1} yr^{-1}) soil loss rate by water on cultivated and urban land use/land cover areas (Duque and Melese, 2016). In the different parts of highland 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 and socioeconomic factors (Hurni, 1988). Several researchers have confirmed the effectiveness of different soil and water conservation (SWC) strategies in controlling soil loss, and conserving soil moisture (Taye et al., 2013). Some SWC practices are relevant to reduce slope length and slope gradient between structures which in turn reduces the volume and velocity of runoff and soil loss rate (Kebede, 2014). A study made in semiarid northern highlands of Ethiopia (Taye et al., 2013) confirmed the reduction of soil loss rate both in the range and crop lands with the application of stone bund and stone bund with trenches. The same research in the study area disclosed the reduction of soil loss rate on an average by 63% on the rangeland and by 47% on the cultivated land with the implementation of stone bund compared to the control land (Taye et al., 2013). Other similar studies (Kebede, 2014), conducted in the humid southern Ethiopia reported the contribution of the channel and embankment of soil bunds to accumulate excess water, enhance water infiltration, reduce surface runoff and improve soil moisture for cropping in low and medium rainfall areas.

In Ethiopia, most of the model and experimental based soil erosion studies have been concentrated in its humid highland areas (Abate, 2011; Belay and Bewket, 2012; Gebreyesus and Kirubel, 2009; Hurni, 1983; Mengistu et al., 2015; Moges and Holden, 2008). However, the arid and semiarid lowlands of the country have been given little attention from the focus of scientific research (Woldemariam et al., 2018). The research carried out by Schewel (2019) in Adami Tulu Jido Kombolcha site, (central Ethiopia) confirmed the transformation of the pastoral economy to agro-pastoral and then to sedentary agriculture over time, requiring availing of reliable information on natural resource management and related problems. Furthermore, some soil erosion hazard assessment studies made in the lowlands of Ethiopia are too general and would not be useful source of data for local and specific application of soil management (Bhan, 1988). On the other hand, mainly with the application of available irrigation technologies, present-day agriculture is rapidly expanding towards the arid and semiarid lowlands of Ethiopia (Mekonnen et al., 2019). Therefore, the present research is profoundly important and will fill the existing research gap lacking on soil erosion studies in the semiarid and arid lowlands of Ethiopia at large and the Middle Awash Valley (MAV) of the Afar region in particular.

Therfore, knowledge of soil erosion is useful in identifying erosion sensitive hotspot areas and design appropriate soil and water management plans, strategies and technologies mainly depending on the magnitude of the problem and available local resources. As data is a scarce resource in Ethiopia, the present research has employed RUSLE model which relatively has simple computational processes and easily obtainable and accessible data requirement (Renard et al., 1997).

The present study aims to investigate the magnitude and drivers of soil loss with the application of RUSLE model 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 semiarid lowlands of Ethiopia, (2) identify the major human and environmental factors accelerating soil erosion occurrence in semiarid 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.

2. Material 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 Central Rift Valley of Afar region, 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 (Fig. 1). The study area covers 2,148.72km^2 (214, 872ha), where elevation ranges from 688m to 1852masl. In large parts of the study area, the slope gradient is monotonously flat and ranges from almost zero on flat grounds to 30% and 45% in hilly landforms (FAO, 2006).

Considering available meteorological data from Melka Worer station (730masl, 09^o 19’ 15.5” N latitude and 40^o 11’ 56.3’’E longitude (which is positioned in the heart of the study site), the MAV has arid and semiarid climate type (Fig. 1) with 550.95mm mean annual rainfall and 26.75^{0}C mean annual temperature. Temperature is high throughout the year, which is beyond the optimal requirement of most cultivated crops and animals. The mean monthly temperature varies from 24^{o}C in December to 32^{o}C in June (Fig. 2). The mean annual rainfall ranges from 238mm in 2004 to 818mm in 1982, giving a high inter-annual variability. The low and high variability of rainfall cause shortage of animal feed and water supply that commonly leads to the toll death of livestock and human food insecurity. In fact, the pastoral and agro-pastoral communities primarily depend on their livestock for income and livelihoods, which is sensitive to adverse impacts of shortages of rainfall and variation (Bruce et al., 2015). The occurrence of rainfall trend is irregular and difficult to predict. As Westphal (1975) discussed, the MAV experiences arid climate, low and uncertain rainfall and high evaporation rate. Total rainfall amount of above the mean annul (550mm) had been experienced only in seven years in 1982, 1988, 1989, 1996, 2004, 2005 and 2012 within thirty-five years period (Fig. 2).

The major types of soils of MAV include Leptosols, Luvisols, Cambisols, Fluvisols and Andosols (FAO, 1984; MoA, 2013; Fig. 3). 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 flatter slopes, whereas volcanic ashes are commonly covered by Andosols. The local hill foots and intermediate sloppy lands are occupied by Cambisols (Fig. 3). Mainly due to the scarce vegetation cover partly associated with low amount of rainfall, the soils of the study area have low organic matter content.

Analysis of the 2016 satellite imageries of 30 X 30m cell size resolution revealed the presence of six land use/land cover (LU/LC) types (Fig. 4). The shrub and cultivated lands accounting for about 47% and 30% of the total area were the predominant LU/LC patterns respectively. The shrubland includes mixes of natural shrub and invasive *Prosopis juliflora* species. The remaining parts of the study area are covered with grassland (14%), urban settlement (5%), forestland (3%), and water body (1%). Most local communities of the study area are mainly traditional pastoralists. Crop cultivation in the MAV depends on available irrigation water of the Awash River and its tributaries. Cotton, sugarcane and sorghum were the main cultivated crops. Most tributaries of the Awash River usually dry up in the lowlands as soon as the summer rainfall ceases in their surrounding highlands (Kloos, 1982). Mainly due to the recent villagisation and expansion of irrigation agriculture, some pastoralists have started small-scale irrigation agriculture as additional source of livelihoods (Mekonnen et al., 2019). Thus, some pastoralists in fourteen *kebeles* (lower administrative units of Ethiopia) of Amibara and Awash Fentale *woredas* have become agro-pastoralists. However, the pastoral communities predominantly depend on livestock production, which includes large herds of camels, cattle, and sheep and goats ruminants. 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 market for agricultural products, soil erosion in the form of gullies, flooding and wide invasion of land by *Prosopis juliflora* were the common 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 region has increased to 1,390,217 in 2007, and possibly resulting in more demand for forest, water, agricultural and settlement land (CSA, 2010).

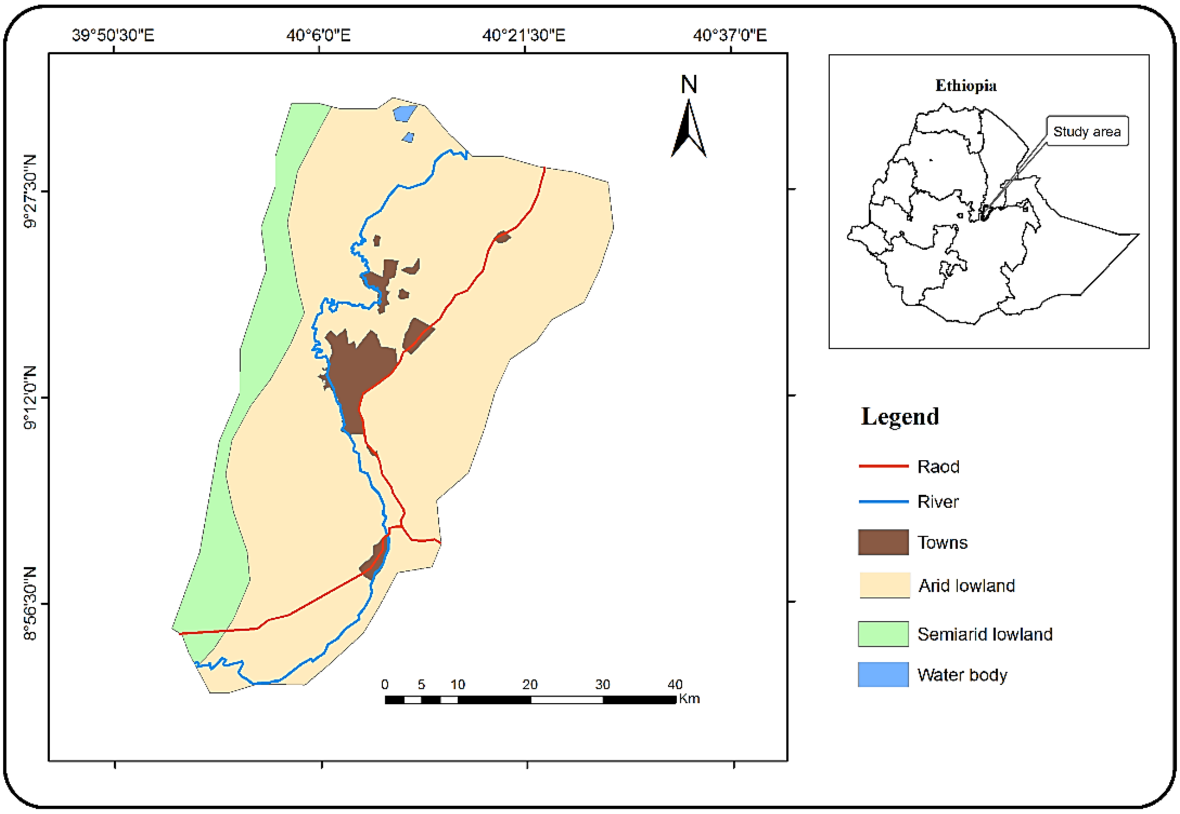
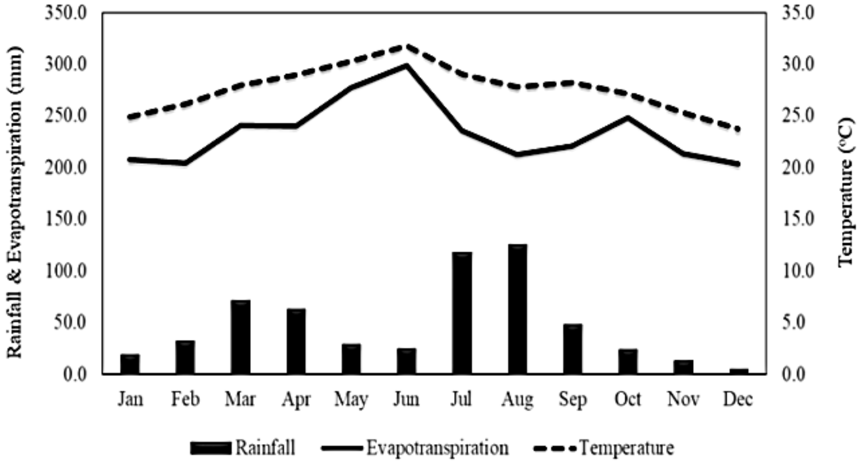
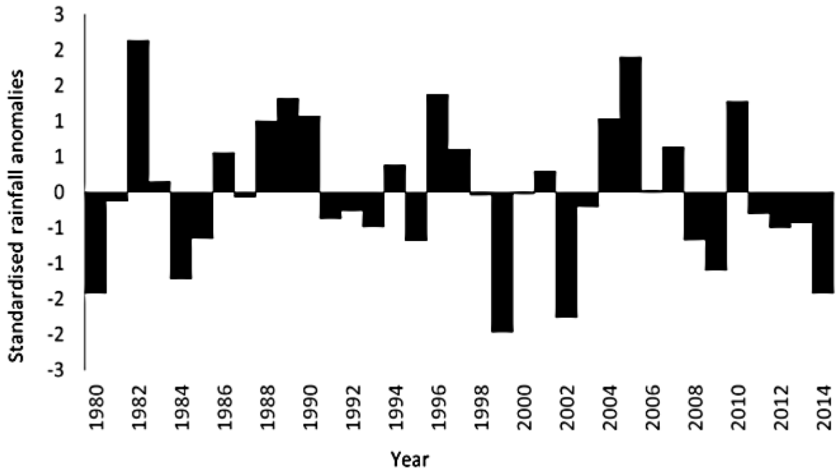


Fig. 1. Location Map of MAV of Afar region, Ethiopia



(a)



(b)

Fig. 2. Climate characteristics of MAV of Afar region, Ethiopia from 1980-2014: (a) mean monthly rainfall, temperature, and potential evapotranspiration and (b) inter-annual rainfall variability (Source: Melka Worer Agricultural Research Center, Unpublished data)

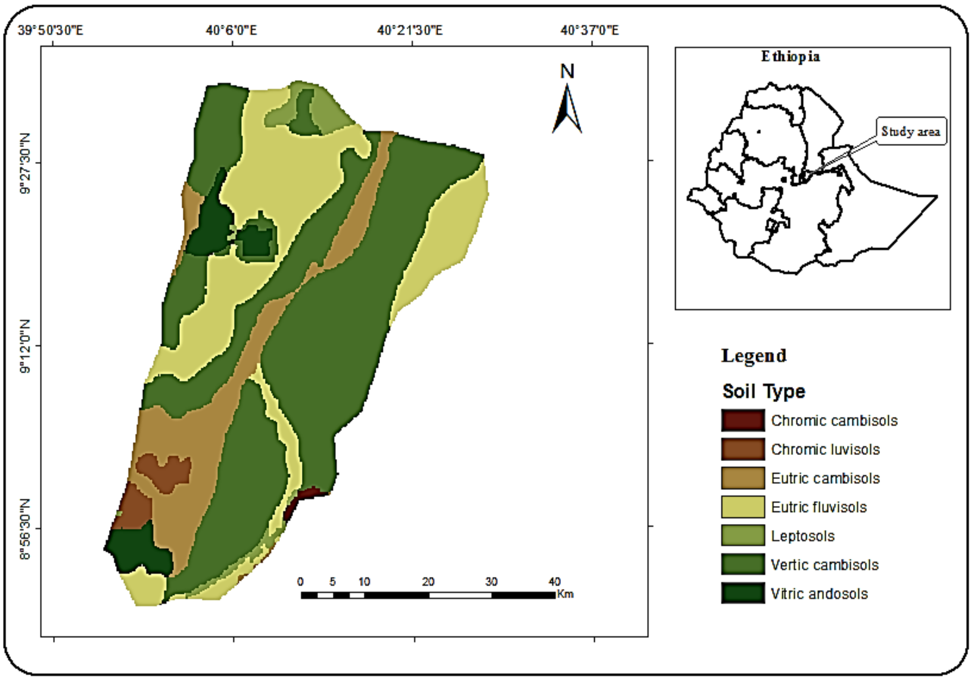


Fig. 3. Soils Map of the MAV of Afar region, Ethiopia (MoA, 2013)

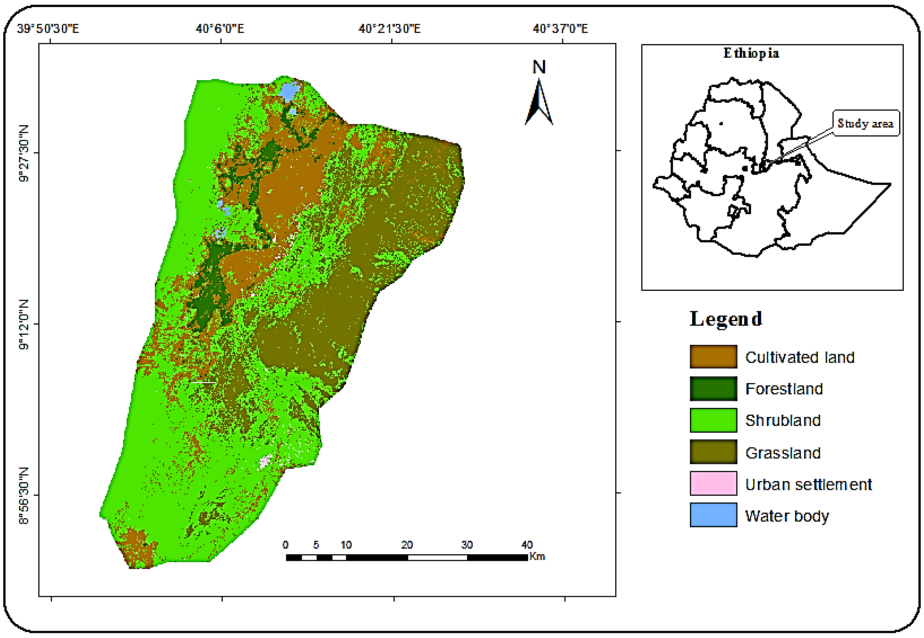


Fig. 4. The 2016 land use/land cover Map of MAV of Afar region, Ethiopia (Source: OLI/TIS 2016 Satellite Image analysis)

2.2. The Revised Universal Soil Loss Equation (RUSLE) model

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

The RUSLE model has several merits: 1) it employs easily obtainable data input that can be 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 and easily manageable (Pham et al., 2018), 3) is executed in conjunction with a raster-based data to predict cell by cell potential erosion and identify/predict the spatial variation of soil loss hazard within the research area which is not possible using USLE (Dutta, 2016; Millward and Mersey, 1999). Furthermore, USLE requires large amount of asset and time to prepare input data and to run the model in a new environment (Dutta, 2016), and 4), thus RUSLE overcomes the limitation of USLE. Hence, 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 rate (Farhan et al., 2013). The RUSLE model has computed the mean annual soil loss rate using (Eq.1):

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

where: A = the mean annual soil loss per unit area in unit time (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).

2.3. Determining the five RUSLE factors

Various spatial datasets were obtained from different organizations and processed using the RUSLE model, GIS tools and RS techniques to map the spatial variability of the five RUSLE factors (Figs. 5-9) and estimate the magnitude of mean annual soil loss rate (Fig. 10). Besides, key informant interviews (KIIs) and focus group discussions (FGDs) were conducted with development agents and purposely selected local community members. The KIIs and FGDs members were recruited based on their experience and knowledge merit to understand the severity and spatial variation of soil erosion rates. The processes used to generate each of the five RUSLE model parameter values are explained as hereunder.

2.3.1. Rainfall erosivity (R) factor

The R factor is the product of the total kinetic energy multiplied by the maximum 30 minutes rainfall intensity (Wischmeier and Smith, 1978).This factor measures the erosivity of mean 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, 2018). Kriging interpolation method has been used to generate the raster R factor. Kriging is a multistep process including exploratory statistical analysis of data, variogram modeling, creating the surface, and exploring a variance surface (Burrough and McDonnell, 1998). The annual rainfall erosivity factor can be computed by different methods (Gitas et al., 2009; Parveen and Kumar, 2012). However, in this study the spatial distribution of R factor value (Fig. 5) was computed with the ArcGIS raster calculator tool using Hurni (1985) formula expressed in Eq. (2) (Hurni, 1985):

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

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 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).

2.3.2. Soil erodibility (K) factor

The K factor refers to the inherent susceptibility of the soil to water erosion. It is mainly associated and determined with intrinsic physicochemical soil characteristics (Mhangara et al., 2012), specifically related to soil texture, structure, 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 processes of 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 texture becomes less susceptible to water erosion, as there will be less surface water accumulation to initiate runoff (Wischmeier and Smith, 1978). Obtaining soil erodibility data in particular in data scarce country such as Ethiopia is one of the most challenging task (Bahrami et al., 2005). For this reason, the K factor values of MAV soil types (Fig. 3) estimated by FAO (1984) has been used for this study (Table 1).

In this study, the vector soil data were converted to raster format to produce a continuous spatial variability of soil erodibility map (Fig. 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, Fig. 6).

2.3.3. Topographic (LS) factor

The LS factor is comprised of the effects of slope length (L)-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 and Wilson, 1992).

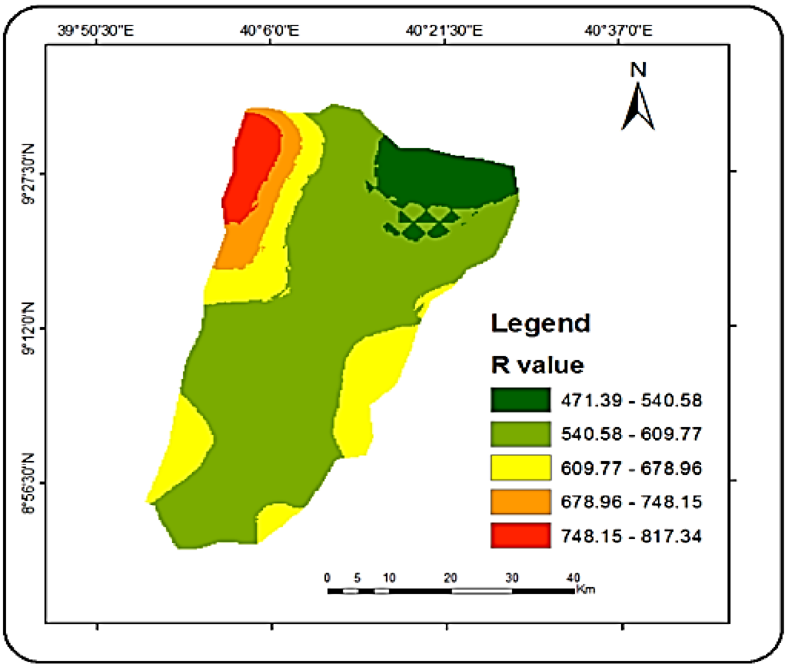


Fig. 5. The Rainfall erosivity Map of (R) factor values of the MAV in Afar region, Ethiopia

Table 1. The soil erodibility (K) factor values of the soil types of MAV in the Afar region of Ethiopia (Source: FAO, 1984)

Soil types	***Texture****	***OM (%)***	***K-value***
Eutric Cambisols	CL-SCL	1-3	0.15
Chromic Cambisols & Leptosols	-	-	0.20
Vertic Andosols & Eutric Fluvisols	SiL- SL	3-10	0.30
Chromic Luvisols &Vertic Cambisols	CL-SCL	1-3	0.60

** Soil texture class: SL-Sandy loam; SiL-Silt loam; SCL-Sandy clay loam; CL-Clay loam.*

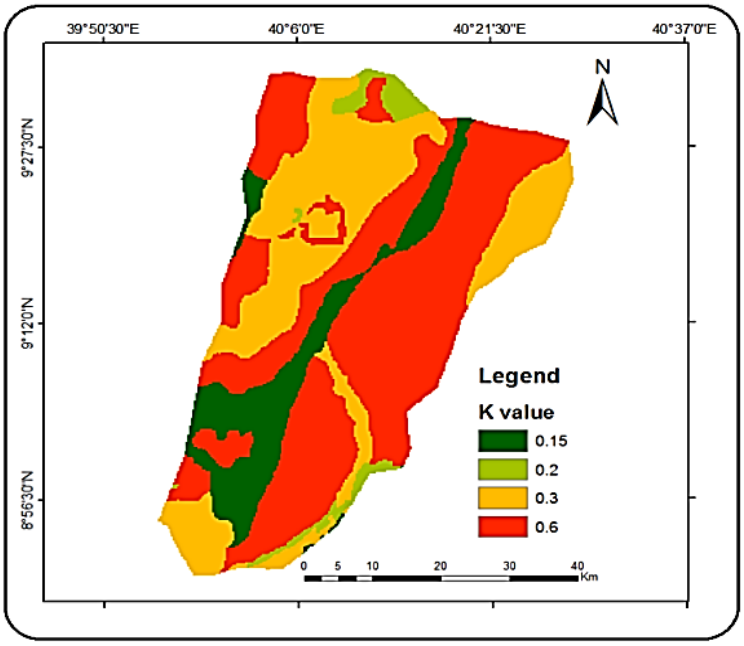


Fig. 6. Soil erodibility Map of (K) factor values of the MAV in Afar region, Ethiopia

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 and Ramesh, 2016). As slope length increases, soil loss per unit area rises as the gradual runoff accumulation increases down slope (Farhan et al., 2013). Slope steepness refers to "the gradient of the land immediately surrounding the site" (FAO, 2006). The steeper the slope is, the higher soil loss would be due to the impact of velocity and runoff erosivity. 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 LS factors do not consider the three-dimensional distribution of the terrain in estimating soil loss (Mitasova et al., 1996). The LS factors assume soil loss increases with slope length (Desmet and Govers, 1996; Moore and Burch, 1986). However, slope length 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 RUSLE model limitation. As Mitasova et al. (1996) suggested, the 2016 Advanced Space born Thermal Emission and Reflection Radiometer (ASTER) global raster satellite image of 30 x 30m resolution has been employed as a source of data to calculate the LS factor indicated in Eq. (3):

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

where: *FA* = flow accumulation derived from Digital Elevation Model (DEM) after processing fill and flow direction using 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 LS (Eq. 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, Eq. (3) has considered the impact of upstream contributing area and slope gradient in estimating soil loss by LS factor.

2.3.4. Land use/land cover (C) factor

The C factor reflects the influence of land use/land cover types on soil erosion rate (Patil and 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 0 indicates the existence of well-protected soil by forest or good plant cover (Ganasri and Ramesh, 2016). An increase in the value of C factor, therefore, portrays the higher exposure of soils to erosion and the rise in potential soil loss (Farhan et al., 2013) (Table 2). The Normalized Difference Vegetation Index (NDVI) derived by RS technology (Eq. 4) is the most commonly used indicator of vegetation growth (i.e. the C factor value). The 2016 Operational Landsat TM raster image of 30 x 30m resolution was, therefore, used to compute NDVI using Eq. (4) (Parveen and Kumar, 2012).

Table 2. The LULC types, NDVI & C values of MAV in the Afar region of Ethiopia

LULC	*NDVI*	*C-value*
Cultivated land	0.01	0.50
Forestland	0.24	0.38
Shrubland	0.20	0.40
Grassland	0.15	0.43
Urban Settlement	-0.15	0.58

Source: NDVI values are computed from 2016 Landsat TM satellite image using Eq. (4) & again the NDVI values are used as an input to compute the C-factor values using Eq. (5).

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 decline 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 Eq. (5) has been used to compute the C factor values of the present study area. A reconnaissance survey was conducted to validate the computed LULC (C) factor values with the existing reality on the ground.

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

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

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 as extracted from Landsat images.

2.3.5. Support practices (P) factor

The P factor is regarded as the impact of farming systems on rates of soil erosion. It measures the effect of conservation practices in influencing the outbreak and prevalence of water-induced soil erosion. The P factor adjusts the potential erosion by runoff through the implementation of contouring, strip cropping, and terracing (Kuok et al., 2013; Wischmeier and Smith, 1978).

Some researchers suggested as the *P value* is dependent on the slope inclination (Lufafa et al., 2003; Wenner, 1980; Wischmeier and Smith, 1978), whereas others use farming practices to calculate *P value* (Stone, 2012). If there would not be any erosion control practice, the P value would be 1 (Table 3). The support practice (P) factors of *MAV* have been calculated using the combination of the 2016 land use/land cover types and slope degrees modified from suggestion given by Shin (1999) (Table 3)

3. Results and discussion

The RUSLE model has been employed in estimating the magnitude of mean annual soil loss (metric ton ha^{-1} year^{-1}), map spatial variation of soil loss rate and identify erosion hotspot areas by the combined interplay of the five erosion factors. The impact of each of the main erosion factors on the rate of soil loss has been analyzed as 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 in Eq. (2), the R-factor of the MAV ranges from 471.39 to 817.34mm (Fig. 5). The spatial distribution of rainfall erosivity (R) factor varies across the study area. The northeastern corridor has experienced the lowest rainfall erosivity whereas the northwestern part has encountered relatively higher rainfall erosivity. In large parts of the Middle Awash Valley (MAV), rainfall erosivity ranges from 540.58 to 609.77 and gradually increases towards the east and west directions (Fig. 5).

As Batjes (1996) stated, the rainfall eorsivity factor of 800 or below, as experienced in most parts of the present study area, indicates the occurrence of low rainfall erosivity. Therefore, the rainfall erosivity (R) factor may not be the main deriving agent of soil loss in the MAV (Fig. 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 MAV have been reclassified into four soil erodibility classes (K) factor (Table 1 and Fig. 6).

Table 3. The support practice (P) factors of MAV in the Afar region of Ethiopia (Source: modified from Shin, 1999)

LULC types	*Slope (º)*					
	0-5	*5-10*	*10-20*	*20-30*	*>30*	*P-value*
Forestland	1	1	1	1	1	1
Grassland	1	1	1	1	1	1
Shrubland	0.55	0.60	0.80	0.90	1.00	0.55
Cultivated land	0.27	0.30	0.40	0.45	0.50	0.27
Settlement area	0.003	0.003	0.003	0.003	0.003	0.003
Water body	-	-	-	-	-	0

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 and low clay content (Belay, 1998). Eutric Cambisols of the study area have, therefore, better resistant and less susceptibility to rainfall erosivity than the other soil types (Table 1). Chromic Luvisols and Vertic Cambisols have relatively high clay content (Muller-Samann and Kotschi, 1994) and would have less infiltration rate, and 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 (Fig. 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.

3.1.3. Topographic (LS) factor

The LS factor of the study area ranges from 0 to 20.71 (Fig. 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 low contribution to soil erosion occurrence in many parts of the MAV of Afar region, Ethiopia (Fig. 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 (Fig. 8), ranges from 0.3 in relatively forested areas to 0.6 in low vegetation cover area. The plant species of forest cover of the study area include indigenous* *Acacia nilotica, Acacia asak, Acacia seyal, Salvadora persica, Grewia ferrugina, Grewia bicolor, Sporobulus iocladus and* invasive *Lantana camara*. (*The Vernacular Afar name of the plant species have been indicated infront of the scientific name in` the parenthesis: *Acacia nilotica* (Keseltot), *Acacia asak* (Eibeto), Acacia seyal (Adiquento), *Salvadora persica* (Adayito), *Grewia ferrugina* (Hedayito), *Grewia bicolor* (Adepto), *Sporobolus iocldaos* (Hamilto) and *Lantana camara* (Dathara).

The relatively low rate of soil erosion is experienced in 3.3 % of the study area covered by forest. Similarly, the water erosion research conducted in the north western Syria confirmed the relevance of citrus and forest cover to provide good protection to the soil from intensive raindrops and runoff (Safwan et al., 2020).

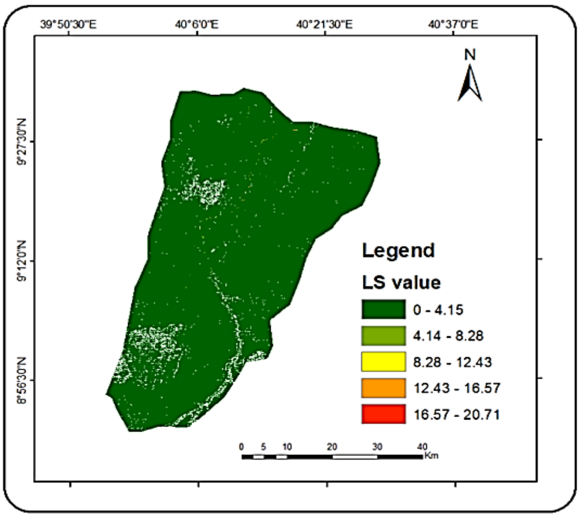


Fig. 7. The slope length-steepness Map of (LS) factor values of the MAV in Afar region, Ethiopia

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 (Fig. 8).The trend of soil erosion is increasing with a decline of vegetation cover. The shrub, grassland and cultivated areas covering 30%, 7% and 14% of the MAV, respectively, are moderately vulnerable to water erosion. Therefore, the impact of the C factor is moderately significant in triggering water-induced soil loss.

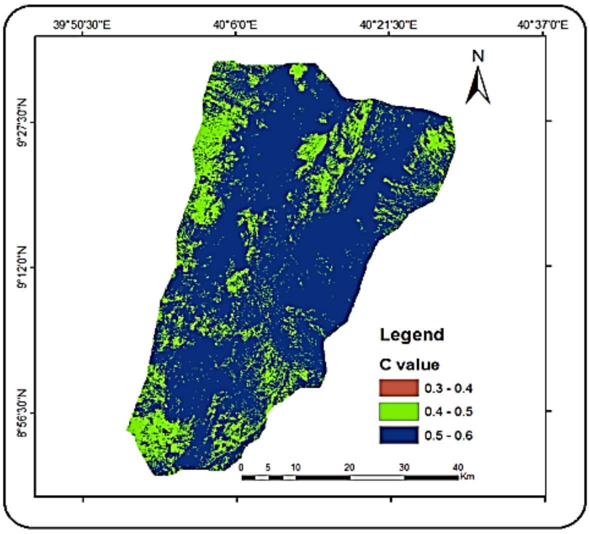


Fig. 8. The Land use/land cover Map of (C) factor values of the MAV in Afar region, Ethiopia

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 soil erosion. Similarly, shrublands of semiarid areas with low sparse vegetation cover, cultivated lands of annual crops with no plant cover during their early stage of crop growth and non 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 in implementing sustainable use of soil resources (Pamo and Pieper, 2000). The land use/land cover patterns of the area have to be properly used 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 value ranges from 0 to 1 (Ganasri and Ramesh, 2016). The P 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 and Ramesh, 2016; Hurni, 1988). The support (P) practices factor of MAV ranged from 0.003 to 1 (Table 2; Fig. 9).As portrayed in Fig. 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 MAV areas of Afar region, Ethiopia (Fig. 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.

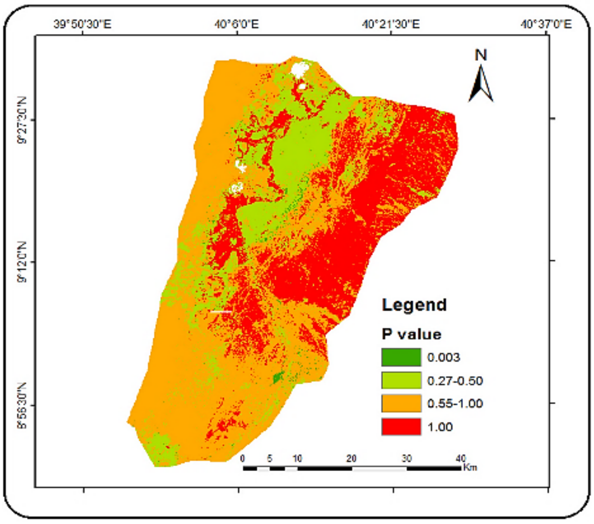


Fig. 9. The Support practices Map of (P) factor values of the MAV of Afar region, Ethiopia

3.2. Magnitude and spatial pattern of soil loss

The five RUSLE model (RKLSCP) factors (Eq. 1) are overlaid and multiplied pixel by pixel using the ArcGIS 10.5 geoprocessing calculator tool to estimate the soil loss rate (Metric tons ha^{-1} year^{-1}) and map the spatial soil loss variation of the study area (Fig. 10). In the present research, the mean annual soil loss ranges from close to 0 to slightly over 20 tons ha^{-1} year^{-1} (Fig. 10). Depending on soil loss magnitude, the rate of soil erosion of the study area has been classified into five soil erosion severity classes (Table 4). This classification of soil loss rates is relevant to prioritize conservation practices according to soil loss risk level of areas (Zerihun et al., 2018). The soil erosion risk classification was carried out to map the spatial distribution and variation of soil loss and identify soil erosion hotspot areas for land management prioritization.

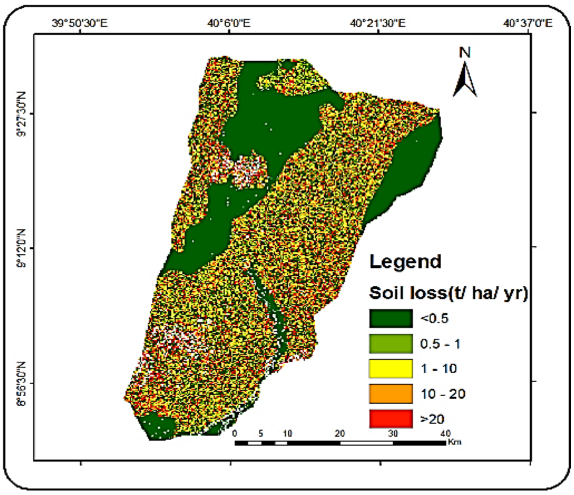


Fig. 10. Potential mean annual soil loss rate and distribution of hotspot erosion hazard areas Map of the MAV of Afar region, Ethiopia

As confirmed by the RUSLE model result, water-induced soil loss is very low and would not be considered as the major constraint of soil resource in about 60% (1271km^2) of the study area (Table 4). In the very low erosion rate corners of the study area, the magnitude of soil loss is up to 0.5 ton ha^{-1} year^{-1} (Table 4). This is mainly attributed to the lower effect of rainfall erosivity and local topographical (LS) 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. The LS factor triggers low degree of soil erosion and soil loss over a plain land surface.

In study area, sugarcane plantation covers the major parts of the cultivated land. Thus, dense sugarcane plantation cover can protect the soil from raindrop detachment and runoff. Hence, the cultivated land covered by sugarcane plantation has low rate of soil loss below 1 ton ha^{-1} year^{-1} (Table 4; Fig. 10). Similarly, a low soil erosion rate has been experienced in sugarcane plantation farms of semiarid areas of Morocco, North Africa (Lahlaoi et al., 2015). However, this contradicts to results obtained from highland cereal cultivated areas of Ethiopia as proved by many research findings (Asmamaw and Mohammed, 2019; Bewket and Teferi, 2009; Gelagay and Minale, 2016) since cereal cultivation exposes the cultivated land to the rain drop detachment impact mainly before the seedling and vegetative period. About 75% of the total area in many semiarid 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 more vulnerable to the risk of severe and very severe soil erosion than the drier flat lowland areas of the country (Esa et al., 2018; Mohammed et al., 2017).

Table 4. Soil erosion risk, soil loss rate and their areal coverage ofMAVin the Afar region of Ethiopia

Soil erosion risk class	*Soil loss (tons ha^{-1} year^{-})^{1}*	*Management Priority Classes**	*Total Area (Sq.km)*	*Total Area (%)*
Very low	0-0.5	V	1271	59
Low	0.5-1	IV	230	11
Medium	1-10	III	174	8
High	10-20	II	368	17
Very high	>20	I	107	5

Management Priority Classes I - V= Roman No. I to V*

Thus, over many humid 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 11% (230 km^2) and 8% (174 km^2) of the MAV, Afar region (Ethiopia). Generally, a very low to medium rate of soil loss areas covered over three-quarters (78%) of the research area. The high (10-20) and very high (over 20) tons of soil loss ha^{-1} year^{-1} together covered 22% (474 km^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 (Figs. 4, 5, 7 and 8). Therefore, the first and second priority areas of soil management have to be given in about 5 % (107km^2) and 17% (368km^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 practices would contribute in curbing the high to very high soil loss rate in 22% (474km^2) of the study area. The customary dependence on 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 grasslands can be efficiently enhanced with effective dryland water conservation strategies, rotation of grazing lands and minimizing the density of livestock per unit area with a focus on the quality of animal husbandry. Besides, the support practices and availability of required resources have to be improved along the various LU/LC categories to enhance the productivity of cultivated and grasslands.

For instance, 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 present research work revealed that most parts (70%) of the study area experienced very low to low soil loss risk. However, significant portion (17%) and very small parts (5%) encountered high to very high soil loss rates, whereas small parts (8%) of the study area had medium soil loss rate.

The arid and semiarid climate of the present research area commonly has mean annual rainfall below 700mm with dominantly low slope length and steepness. As a result, the present study indicates that rainfall erosivity (R) and slope length and steepness (LS) erosion factors were not the main derivers of water-induced soil loss. However, the nature of the soils, LU/LCs patterns and lack of required soil management practices were found to be the main accelerators of moderate to very high soil loss rate by water. This study verifies that rates of soil erosion in the arid and semiarid ecologies largely depend on density and types of vegetation cover.

Thus, to minimize water induced soil loss, the modest erodibility of the soils has to be managed through increasing vegetation cover and selecting locally acceptable land management practices e.g. cropping type. In arid and semiarid areas, where irrigation farming could be an activity, crop production systems such as sugarcane farming have been found to reduce soil erosion rate. Thus, choosing appropriate cropping systems in farming semiarid ecologies would reduce rates of water erosion. As the soils of dryland are suitable for sugarcane farming, cultivation of sugarcane is a good land management approach in enhancing agricultural production in the study area and elsewhere in similar environments.

To control the overgrazing of the grasslands, it is important to provide public awareness to the community to transform their economies from owning too many into few but quality livestock raising systems. Besides, the rangeland of the semiarid areas of the study site has to be used through rotation.

Therefore, applications of locally fitting land management practices with the consideration of diverse strategies and 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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