American Journal of Geographic Information System 2019, 8(4): 141-157
DOI: 10.5923/j.ajgis.20190804.01

Integrated Remote sensing and GIS-based Universal Soil Loss Equation for Soil Erosion Estimation in the Megech River Catchment, Tana Lake Sub-basin, Northwestern Ethiopia

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Abstract Severe land degradation occurred in northern highlands of Ethiopia due to its complex topography, rainfall, and various anthropogenic activities. Soil erosion in the Megech river catchment, one of the major catchments of Lake Tana sub-basin of the Abbay River basin using Remote sensing, and GIS based Universal Soil Loss Equation (USLE) was quantified. The study was conducted by estimating the important factors that affect soil erosion namely, rainfall erosivity (R), topography (LS), soil erodibility (K), cropping management practice (C), and support practice (P). The results showed that the annual soil loss in the total catchment is 8,43,736 tons with an average soil erosion rate of 41.54±75.92 tons $ha^{-1}yr^{-1}$ of which the soil loss from the upper catchment is 6,86,705 tons (36.63±64.2 tons $ha^{-1}yr^{-1}$) while from the lower catchment 1,57,031 tons (32.68±57.41 tons $ha^{-1}yr^{-1}$). In 3.1% of the total catchment area the soil erosion is extreme with the rate greater than 50 tons $ha^{-1}yr^{-1}$; in 20.5% of the area it is greater than 10 tons ha^{-1} yr^{-1}; and in 50.5% of the area it is very low, less than 1 ton $ha^{-1}yr^{-1}$. Soil erosion rates varied from various land uses in a given topographic condition, and from a particular land use type in different topographic conditions. Soil conservation- neglected post-harvested land is eroded by small rainfall intensities. Substantial soil erosion occurs from degraded lands and decreased vegetative covers. Implementation of scientific measures of land use management, agriculture, and restoration of degraded lands would control soil erosion.

Keywords Soil erosion, Megech river catchment, Ethiopia, Universal Soil Loss Equation, Remote sensing, Geographical Information System

1. Introduction

Soil erosion and degradation of land resources are very significant problems in many countries. Land degradation is the most serious growing threat to food production, food security, and natural resource conservation, particularly for the poor and vulnerable population in the dry lands of developing countries in Africa and Asia and consequently to global security since it has been seriously threatening people's livelihoods, soils and landscapes [1,2]. Land degradation is defined as the loss of production capacity of land in terms of loss of soil fertility, soil biodiversity, and degradation of natural resources [3] that have put the world's ecosystems under intense pressure [4]. Globally, about 2 billion hectares were already degraded, and the average rates of soil erosion were estimated between 12 and 15 tons $ha^{-1}yr^{-1}$ [5]. Land degradation is caused by soil water erosion (46%), wind erosion (36%), loss of nutrients (9%), physical deterioration (4%), salinization (3%) [6], and in rural areas by overgrazing (49%), agricultural activities (24%), deforestation (14%), and overexploitation of vegetative cover (13%) [7].

Ethiopia experienced moderate to severe land degradation problems. Very severe degradation occurred in northern Ethiopia [8]. Soil erosion is one of the most dangerous hazards in high land regions. In the highland areas of north Gondar district in Amhara region, soil erosion rates mainly depend on the intense rainfalls, erodible soils, topography, slope gradient, land use types etc. Excessive soil erosion with a resultant high rate of sedimentation in the reservoirs and decreased soil fertility has become solemn

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environmental problem for the country with disastrous economic consequences. The estimated total mean annual sediment load in the Megech reservoir in north Gondar was 496,066 tons that corresponds to 1,170 tons km^{-2} yr^{-1} [9].

A quantitative assessment is needed to infer on the extent and magnitude of soil erosion problems so that sound management strategies can be developed on a regional basis with the help of field measurements [10]. Researchers have developed many tools for estimating soil loss, such as the Soil and Water Assessment Tool (SWAT), the Water Erosion Prediction Project (WEPP), the Universal Soil Loss Equation (USLE), the Revised Universal Soil Loss Equation (RUSLE), etc. [11]. Among them, USLE is widely used for the study of soil erosion by water because of its simplicity, despite some inconveniences due to its extensive requirement for input data [12,13]. The USLE method predicts the long term average annual rate of erosion on a field-based rainfall pattern, soil type, topography, crop system and management practices. The major purpose of the soil loss equation is to guide methodical decision making in conservation planning on a site basis. Using conventional methods to assess soil erosion risk is expensive and time consuming. Hunri (1985) [14] conducted conventional study on soil erosion for the highest areas in Ethiopia focusing on various soil erosion factors.

The integration of existing soil erosion models, field data and data provided by remote sensing (RS) technologies through the use of geographic information systems (GIS) appears to be an asset for further studies [15-17]. Recently developed RUSLE that has a similar structure as that of the USLE contains several improvements in identifying input factors based on the updated database in the United States. We chose the USLE model due to its wider use, relative simplicity to assess soil loss, and most importantly its easiness to compare with other studies on soil erosion in various river catchment areas. RS and GIS are capable of handling easily and efficiently large amount of spatial data. For this reason, many researchers use GIS as main approach to estimate soil erosion at all scales. Therefore, this study, conducted in the Megech river catchment area, aims to utilize the USLE model with RS and Arc GIS to determine the soil erosion rates.

2. The Study Area

The Megech River is one of the major river catchments of Lake Tana sub-basin of the Abbay River, a major river basin in Ethiopia. The Megech river and its tributaries namely Angereb, Shinta, Keha, Dimaza, Gilgel Megech, and Wizaba that rise on the Ethiopian highlands in North Gondar in Amhara region are concentrated at elevations of 3000 meters mean above sea level (m.a.s.l.) having a high and perennial, but highly seasonal in their runoff (Figure 1). The upper and lower catchment areas of Megech River encompass about 80757 ha with an annual runoff of 350×10^6 m^3 which is half of the total northern river catchments of Lake Tana including Garno, Arno, Dirma, and Gabi Kura rivers. [18]. A well developed dendritic drainage pattern is observed at the area with a chain of ridges bordering the catchment area (Figure 2). The elevation of the total catchment area fluctuates from 1755 m to 2974 m m.a.s.l. and decreases from north to south. The upper river catchment area is not flat like the lower one but very broken and hilly ragged terrain containing grassy uplands, swamp valleys, scattered vegetation, and occasional rocky peaks which are of volcanic origin consisting of varied range of altitudes (Figure 3). The upper catchment area fluctuates from 1900 m to 2974 m m.a.s.l., whereas it decreases from the north to south to 1755 m m.a.s.l. Slope of the terrain is complex and varies from nearly level to very steep slope with a range of 0.3° to 63°. The northern part of the catchment area has a characteristic of gentle to very steep slope, while the southern part has gentle slopes and plain surfaces that are mostly near the outlet of the Megech River to Lake Tana.

The climate in the catchment area shows tropical monsoon characteristics with an annual rainy season from June to September. The altitudinal variations within a short distance that allow the research site into different climates are classified into: Humid subtropical climate (Cwa), Subtropical highland oceanic climate, (Cwb) and Tropical savanna climate (Aw) respectively [19,20]. The two main seasons are mostly wet (monthly precipitations above 150mm) during May to October, while mostly dry during November to April (below 30mm). It has a varied landscape, dominantly covered with ragged hills and plateau basalts which impart variations in temperatures largely favoring a wide range of rainfall. According to statistics of a decade of 2009−2018, the average annual precipitation fluctuated from 1038 to 2187 mm due to highly varied and complex terrain, while an exceptional rain fall about 3259 mm was recorded at the Binchen area (Figure 4). The average minimum and maximum daily temperatures ranged between 12-18℃ and 19-28℃ respectively. The highest temperatures reach in April (>30℃), while the lowest temperatures in August (about 15℃). The annual mean maximum, mean, and mean minimum temperatures were 25, 19, and 13℃ respectively.

Rock units existing in this study area are Cenozoic grouped into four major categories: (i) Alluvial and lacustrine deposits (quaternary), (ii) Tarmaber Gussa formation (oligocene–miocene): alkaline to transitional basalts often forming shield volcanoes with minor trachyte and phonolite flows, (iii) Aiba basalts (middle–late oligocene): flood basalts with rare basic tuff, and (iv) Ashangi formation (eocene): deeply weathered alkaline and transitional basalt flows with rare intercalations of tuff often tilted. The great variability of Ethiopian highlands gives rise to the formation of different physical landscapes which in turn cause the variations in soil parent materials. Similarly, the physiographic position, parent materials, drainage characteristics and soil depth are the key factors to classify the soils in the study area. Surface soil depths are between 25 cm to 200 cm (average 70 cm) covered by black, red, brown and grey colored soils. Lithic leptosols are the dominant soil types in the upper catchment area followed by Eutric

Fluvisols, Humic Nitisols, Eutric leptosols, and Chromic Luvisols, whereas Haplic Luvisols and Eutric Vertisols are dominant in the lower catchment that also is associated with Eutric cambisols [21]. The dominant textures identified in this area are silt clay loam and silt clay. The Lithic leptosols soils are shallow underlined by unconsolidated medium sized gravels with loose joints which in turn underlined by watertight rocky layers [22]. There are various land use types in the catchment area with plantation, dense forest, barren land, cropland, grassland, built-up land and impervious rock as the chief categories (Figure 7).

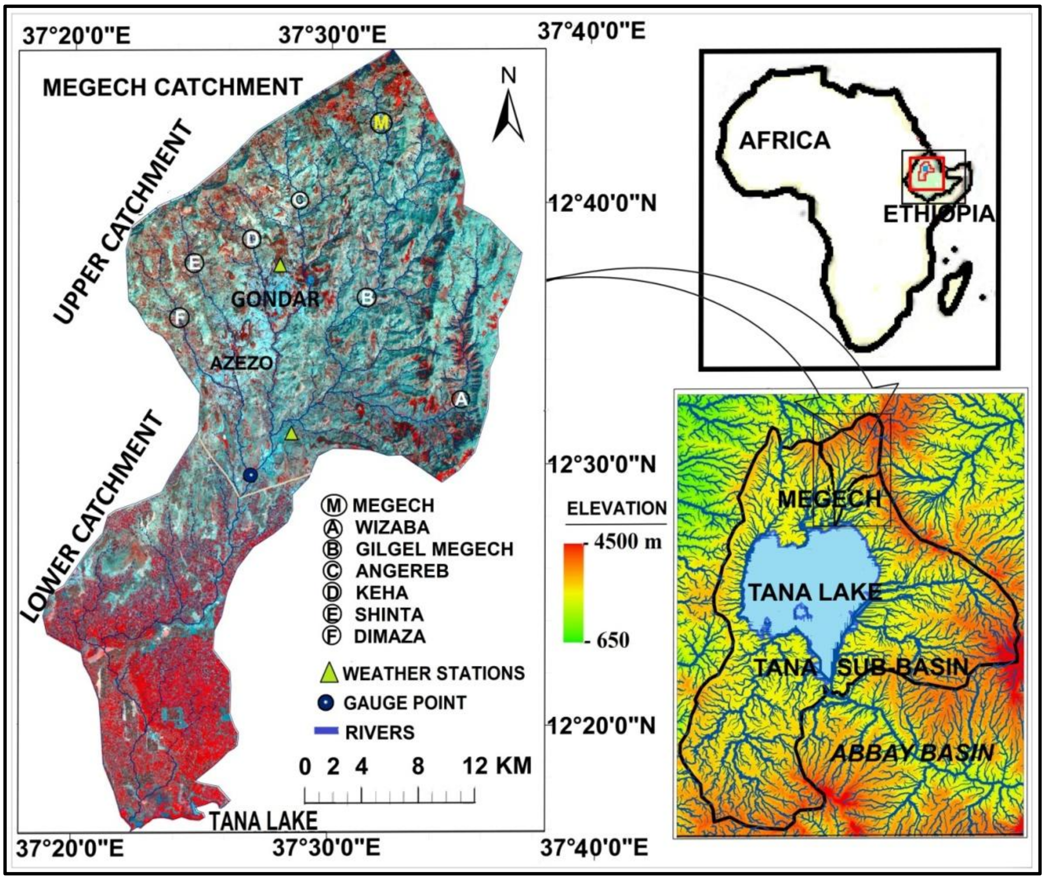

Figure 1. Location of the study area

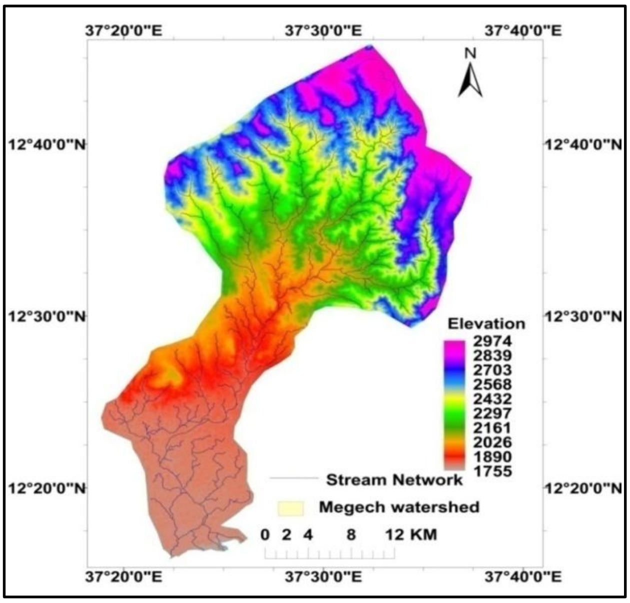

Figure 2. Stream network of the River Megech catchment

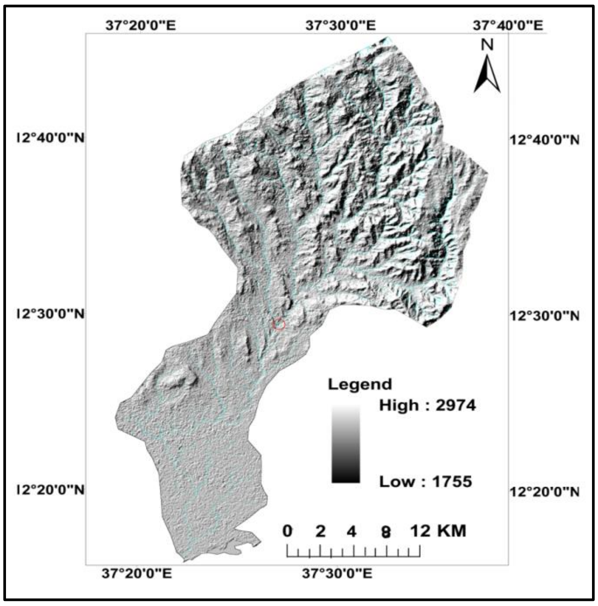

Figure 3. Terrain and flow direction of the Megech catchment

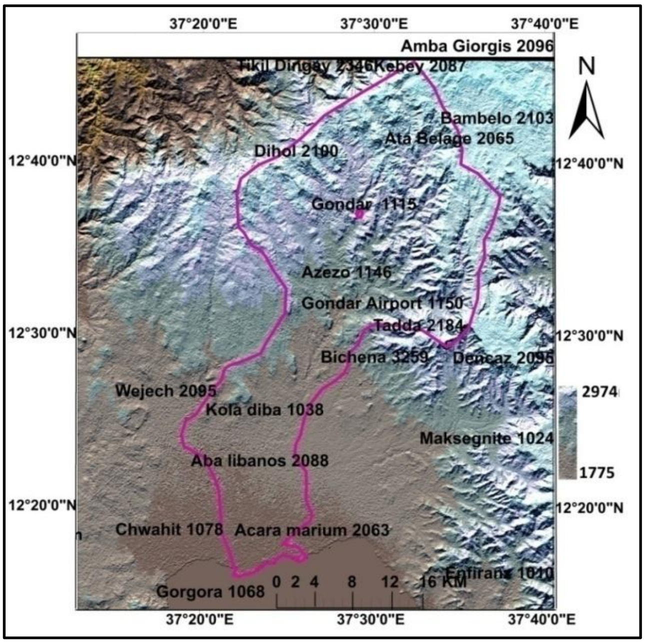

Figure 4. Rainfall Stations and Annual Average Rainfall (mm)

3. Methods

3.1. Universal Soil Loss Equation (USEL)

The USLE is an erosion model designed to compute longtime average soil losses in runoff from sheet and rill erosion under specified conditions [23]. It was applied in many areas worldwide. It calculates erosion as a product of five factors: rainfall erosivity, soil erodibility, slope length and steepness, land cover and management, and support practice, and the resources for identifying their values are rainfall, soil properties, terrain data and, land use. The soil loss equation is:

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

where,

A is the average annual soil loss (tons $ha^{-1}yr^{-1}$),

R is the rainfall erosivity (MJ mm $ha^{-1}h^{-1}yr^{-1}$),

K is the soil erodibility factor (tons ha h $ha^{-1}MJ^{-1}mm^{-1}$),

LS is the topographic factor (dimensionless),

C is the cropping management factors (dimensionless), and

P is the practice support factor (dimensionless).

The USLE was applied to the Megech River catchment by representing the basin as a grid of square cells and by calculating soil erosion for each cell which a five levels namely, very low, low, moderate, high and extreme erosion levels.

3.1.1. Rainfall Erosivity Factor (R)

R-factor is an index of rainfall erosivity that estimates the erosive forces of the rainfall and its directly associated runoff. Rainfall erosivity (R) is defined as the product of total storm kinetic energy (E) times the maximum 30-minute rainfall intensity (I_{30}) for a given rain storm, (EI_{30}) (Wischmeier & Smith 1978) [23]. According to the definition, the detailed continuous precipitation data with 30-minute time resolution and the rainfall kinetic energy measurement that derived from drop-size, drop-velocity, and drop-volume measurements as well as drop-size distribution are required to calculate the R-factor. Moreover, the calculation of R-factor is a complex process and, data on the nature of the distribution of those sizes and intensities of the individual rainstorms are rarely available. However, there are other methods suggested by various researchers to calculate the annual R-factor. Hurni (1985) developed a method of USLE adapted for Ethiopian conditions to measure R-factor based on mean annual precipitation by analyzing the rainfall data as given in the following equation:

$$R = 0.55 * P - 4.7 \quad (2)$$

where, P is the mean annual precipitation (mm).

The annual precipitation values from minimum 10 years (2009-2018) to maximum 40 years (after 1978) of rainfall that 28 meteorological stations recorded were used to estimate the R-factor in the present study. The R-factor values were also predicted by using the other mostly accepted methods of erosivity indexes to evaluate the effect of rainfall on soil erosion. Six methods of rainfall erosivity were selected in the present study: Modified Fournier Index (MFI) [24], Precipitation Concentration Index (PCI) [25], Fournier Index (FI) [26], Total annual rainfall (P) and a regression equation provided by the Derege et al. (2016) [27] in the Ethiopian region.

$$\text{Total annual rainfall (P)} = \sum_{i-1}^{12} p_i \quad (3)$$

$$\text{Modified Fournier Index (MFI)} = \frac{\sum_{i=1}^{12} p_i^2}{p} \quad (4)$$

where, p_i = the monthly rainfall depth (mm) in *i* month, and p = the annual rainfall (mm).

$$\text{Fournier Index (F)} = \frac{p^2}{p} \quad (5)$$

where, *p* is the precipitation in the wettest month and P is the total annual rainfall.

$$\text{Precipitation Concentration Index (PCI)} = 100\frac{\sum_{i=1}^{12} p_i^2}{p^2} \quad (6)$$

where, *pi* is the monthly rainfall and P is the total annual rainfall.

Derege et al. (2016) proposed the following power-law equation to estimate the rainfall erosivity factor in the Ethiopian Region:

$$R = 0.366 * D^{2.064} (R^2 = 0.99) \quad (7)$$

where rainfall R is the erosivity and D is the rainfall depth (max. I_{30}).

The annual values for the period covered by each rainfall station were calculated using the monthly rainfall data for the six methods using Eqs. 2, 3, 4, 5, 6 & 7 and then averaged. Figure 5a shows the values of erosivity indexes of each method and average monthly rainfall at 28 stations. The effect of rainfall length on each method was studied with these values. R-factor values obtained from these methods were compared and found that their correlation was not satisfactory because as per the USLE the two most relevant parameters, rainfall's kinetic energy and intensity were not involved in these methods except the power-law equation which was provided by Derege et al. R-values were estimated from the Derege et al., method with a few available rainfall intensity data for two stations namely, Azezo and Gondar, by using the Eq.7. These R-values were correlated with the R-values of other methods. The results showed a better correlation (R^2=0.95, p=0.014) with the R-values from the Hunri's model (Figure 5b). Therefore, we used Hunri's model in our study to determine the R-values for estimation of the soil erosion.

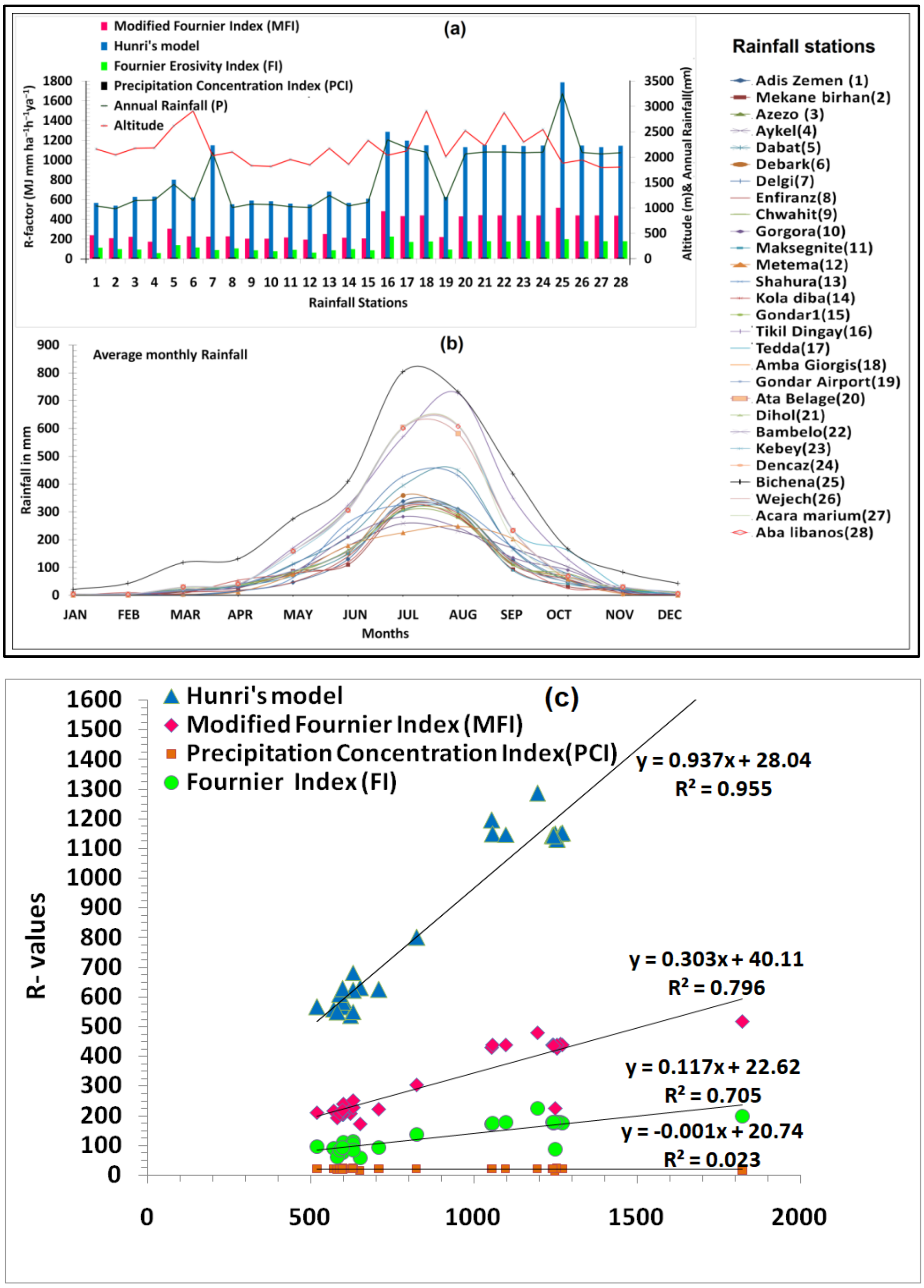

Figure 5. a. Rainfall erosivity (R); and b. monthly average rainfall at 28 stations in and around Megech River catchment; c. Correlation of R-values between Derge's power-law and other methods

3.1.2. Soil Erodibility Factor (K)

The soil erodibility factor, K, is the rate of soil loss per rainfall erosivity for a specified soil, which reflects the combined effect of all the soil properties and soil profile characteristics. K-factor in the soil loss equation is experimentally determined quantitative value. Measurement of the K-factor requires several physical parameters for each soil type such as soil texture, soil organic matter, percent of sand, silt, and clay in the soil, soil structure code, and profile permeability. Therefore, K is one of the most challenging factors, requiring substantial time, cost, resources, field surveys, and analyses [28]. Hurni, (1985) used methods of Bono & Sheiler (1984) and Weigel (1985) [29,30] to estimate K-factor values based on the color for soils in Ethiopia. However, in the current study, the K is estimated based on soil texture and organic material content. This relationship was used by many researchers to estimate K values for their soil samples [31]. The soil information for our study was obtained from the Harmonized World Soil Database (HWSD) v.1.21. (2013) [32], jointly developed by Food and Agriculture Organization of the United Nations (FAO), International Institute for Applied Systems Analysis (IIASA), ISRIC-World Soil Information, the European Soil Bureau Network, and the Institute of Soil Science, China. The percentage of organic material was estimated by multiplication of organic carbon with a factor value 1.72. The mean K-values were obtained based on percentage organic material in association with the sand, silt and clay percentage of soil composition by using the United States Department of Agriculture (USDA) [33] soil textural class fields at <2 and ≥2 organic matter values. The K values, soil type and soil classes were derived for the present study site by following the above procedure.

3.1.3. Topographic Factor (LS)

Topographic factor *(*LS) is the slope length gradient that reflects the effect of the topography on erosion rates. Both the length and the steepness of the land slope substantially affect the rate of soil erosion by overland flow particularly in complex terrain areas. Many researchers agree that the amount of land lost depends on the three-dimensional distribution of the terrain [34,35]. Various methods have been devised to calculate the LS for topographically complex terrain that requires high resolution Digital Elevation Model (DEM) data. In the present study, we calculated the combined LS factor using the DEM data extracted from Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model Version 2 (GDEM V2), 2011 with a spatial resolution of 30 m following an approach developed by Mitasova et al. (1996) [34]:

$$LS = (m+1)\left(\frac{As}{22.13}\right)^{m}\left(\frac{\sin(\theta)}{0.0896}\right)^{n} \tag{6}$$

where,

A_s is normalized upslope area that is the contributing area per contour width (m),

θ is the slope angle in radians, and

m (0.4–0.7) and n (1.0–1.4) are calibrating parameters.

The terrain of the catchment is very complicated with dense stream systems (Figure 2) resulting in dominating rill, gully erosion. Therefore, the calibrating parameters 'm' and 'n' were respectively assigned 0.5 and 1.3 as recommended by Mitasova and Mitas (1999) and Liu, Nearing, Shi, and Jia (2000) [36,37].

LS can be calculated by the use of the raster calculator tool in Arc GIS as follows:

$$LS = \left(Flow\ accumulation \times \frac{Cell\ size}{22.13}\right)^{0.5} \times \left(\frac{Sin\ (Slope\ (\theta) \times 0.01745)}{0.0896}\right)^{1.3} \times (1.5)/100 \tag{7}$$

3.1.4. Cropping Management Factor (C)

Cropping management factor (C) reflects the effect of cropping and management practices on the soil erosion rate. The vegetation cover and management factor is the ratio of soil loss from an area with specified vegetation cover and its management to the soil loss from an identical area in tilled continuous fallow. Remote sensing technology provides a lot of information about the land surface through the Normalized Difference Vegetation Index (NDVI) which is positively correlated with the amount of green biomass and gives an indication of differences in green vegetation coverage [38]. Time series Landsat-8 imageries data in January, April, June, September and December of year 2018 with a spatial resolution of 30 m (path 170; row 51) as given in Table were used for our study to calculate NDVI, an index of vegetation abundance. These months were chosen to maximize the ability to distinguish agricultural land from natural vegetative covers. A significant proportion of noises were normalized by converting the digital number (DN) to at-satellite reflectance value. The DNs of NIR and RED bands for Landsat-8 were converted into reflectance by the following equation:

$$\rho\lambda = \frac{\rho\lambda'}{\sin(\theta)} \tag{8}$$

where,

$\rho\lambda$ is true top of atmosphere (TOA) planetary reflectance,

$\rho\lambda'$ is TOA planetary spectral reflectance, and

θ is solar elevation angle (in Radians).

$\rho\lambda'$ is obtained by the following formula:

$\rho\lambda' = Mp * Qcal + Ap$

where,

Mp is reflectance multiplicative scaling factor for the band,

Qcal is level one pixel value in DN, and

Ap is reflectance additive scaling factor for the band.

The spectral reflectance of NIR and RED bands were used to calculate NDVI for each image with the following equation:

$$NDVI = \frac{NIR - RED}{RED + NIR} \tag{9}$$

NDVI values were used to calculate C factor that is the average value of the time series of NDVIs of 5 times in January, April, June, September and December of year 2018 (Figure 6) following the equation suggested by Durigon *et al* (2014) [39]:

$$C = \frac{(-NDVI+1)}{2} \quad (10)$$

Table 1. Landsat imageries data

Landsat-8 Imageries	*Data acquired*	*Resolution (in m)*
LC08_L1TP_170051_20180111	11 January 2018	30 x 30, Panchromatic 15x15
LC08_L1TP_170051_20180417	17 April 2018	
LC08_L1TP_170051_20180620	20 June 2018	
LC08_L1TP_170051_20180924	24 Sept. 2018	
LC08_L1TP_170051_20181213	13 Dec. 2018	
Landsat-7 ETM+ Imagery		
EPP170R051_7F20000127	27 January 2000	

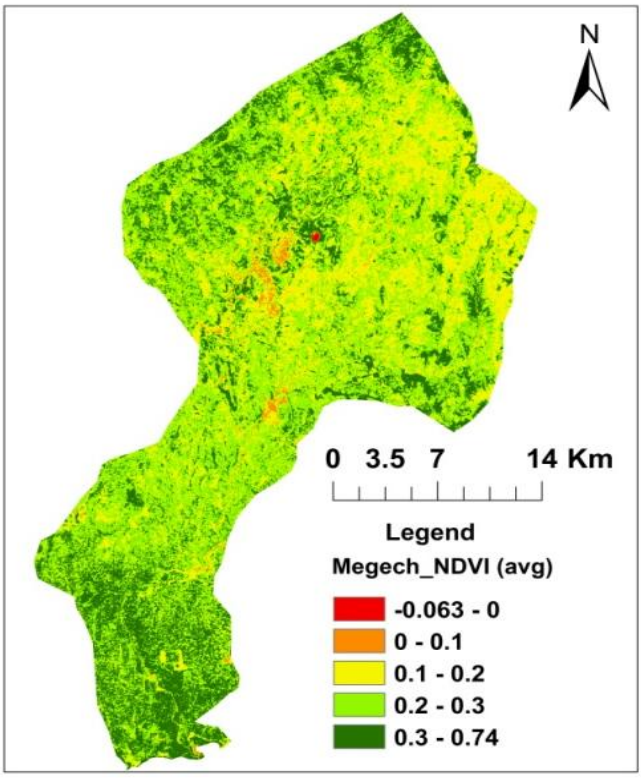

Figure 6. Average Normalized Difference Vegetation Index (NDVI) for Megech River catchment

3.1.5 Support Practice Factor (P)

The support practice factor (P) represents erosion prevention practices to reduce the amount of soil erosion. P is defined as the ratio of soil loss with support practices like contouring, strip cropping, or terracing to the soil loss with the practice of straight-row farming up and down the slope. If there are no conservation practices, then the P-value should be 1.0. Determining the P-value is difficult as it requires direct and long-term field observations of specific land use types and farming practices at several places in the catchment area that are time-consuming and involve high finances. However, in order to overcome the constraints of more time and money, the P-values can be derived from either image classifications using remote sensing data, previous studies, or even expert knowledge [40]. Many researchers use the information of slope inclination or farming practices to calculate P-values. In the present study, the P-value is determined by the slope based on land use map. The land use map of year 2018 was generated from the pan sharpened Landsat-8 image with a resolution of 15 m (Figure 7). The areas of various land use types were given in Table 2. Inseparability of contiguous land features result in poor accuracy in unsupervised and supervised classifications due to spectral and spatial resemblances in VIS and NIR bands. Thus, spectral response of different surface features from all bands of Landsat image was analyzed. In addition, the Google earth data were used to confirm the type of land feature in generation of land use map. The researchers focused on identifying the land cover types in areas that presented problematic spectral signatures in the unsupervised classes (e.g., sparsely vegetated, lava flows, and emerging row crops). Table 3 shows the result of the accuracy and error matrix estimations for such land use classification. Figure 8 and Table 4 show various degrees of slope categories in the Megech catchment.

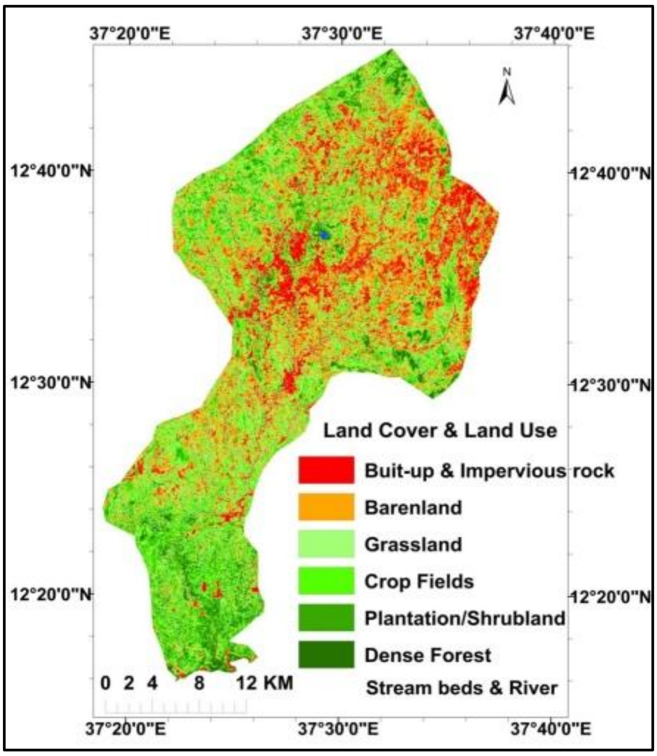

Figure 7. Land Cover and Land Use

Table 2. Area of land use type

Land use Type	Area (ha)	Area (%)
Built-up, Impervious rock	10867	13.4
Barren land	22662	28.0
Grass land	20471	25.3
Crop fields, Perennial cash crops	15085	18.6
Plantation, Shrub	8096	10.0
Dense forest	2480	3.1
Water	1270	1.6

Table 3. Accuracy and error matrix estimations

Class Name	*Barren land*	*Built-up & Impervious*	*Cropland*	*Dense Forest*	*Grassland*	*Plantation/ Shrub*	*Water*	*Grand Total*	*Classified Totals (%)*	*Number Correct (%)*	*Users Accuracy (%)*
Barren land	10				1	1		12	83	100	83.33
Built-up & Impervious		26						26	100	81.5	100
Cropland			1					1	100	100	100
Dense Forest		1		1				2	84	89	50
Grassland				1	2			3	86.5	79.5	67
Plantation/Shrub		2				1		3	78	69.5	83
Water		2					1	3	100	85.5	89
Grand Total	10	31	1	2	3	2	1	50			
Producers Accuracy %	100	83.87	100	50	66.67	50	100				
Total reference	42										
Overall Classification Accuracy (%)	85										
Overall Kappa Statistics	0.81										

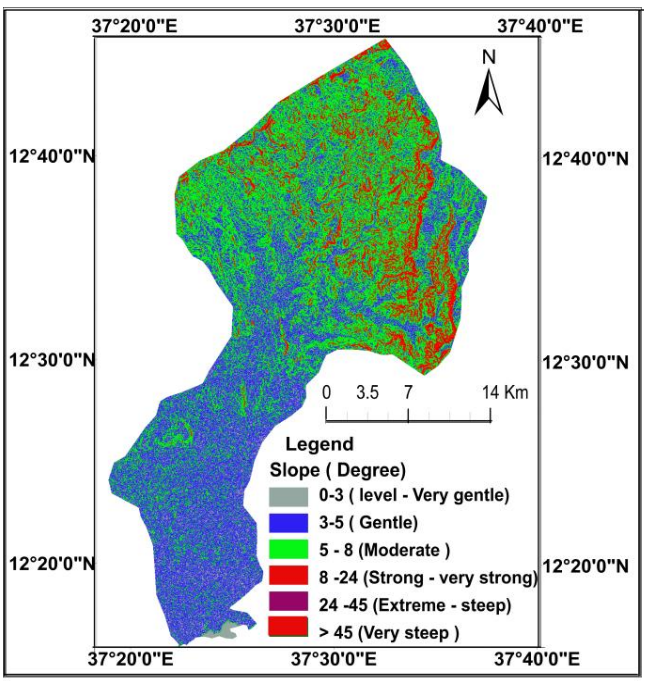

Figure 8. Slope in the Megech River Catchment

Table 4. Area of various degree of slope categories in the catchment area

Slope (degree)	*Terminology*	*Area (%)*
0 −3	Near level – Very gentle slope	9.7
3 −5	Gentle slope	34.5
5−8.5	Moderate slope	43.0
8.5 −24	Strong – Very strong slope	11.1
24 – 45	Extreme – Steep slope	2.1
> 45	Very steep slope	0.1

3.1.6. Stream Power Index (SPI)

SPI is a measure of the erosive power of flowing water. SPI is calculated based upon slope gradient and contributing area [41]. As catchment area and slope gradient increase, the amount of water contributed by upslope areas and the velocity of water flow increase, and hence the SPI and the erosion risk increase. SPI can be used to describe the potential flow erosion at the given point of the topographic surface and approximate the locations where gullies are most likely to form, and to identify suitable locations for soil conservation measures to reduce the effect of concentrated surface runoff. High SPI values represent locations vulnerability to gully erosion on the landscape where very steep slopes and flow accumulations exist. For this reason, SPI is very useful for determining potential critical source area locations. SPI is calculated using the following equation:

$$SPI = \ln(Contributing\ Area\ \star \tan(slope\ in\ radians)) \quad (11)$$

3.1.7. Descriptive Statistics

In this study, we focused on determining the effect of each input factor on soil loss rate for which the pixels have been chosen randomly where soil erosion occurred. The soil loss equation (Eq.1),

A = R * K * LS * C * P, was transformed as follows:

$$\ln(A) = \ln(R * K * LS * C * P)$$
$$= \ln(R) + \ln(K) + \ln(LS) + \ln(C) + \ln(P) \quad (12)$$

A multiple linear regression was applied to investigate and describe the relationship between dependent variable i.e., soil loss (A) and five independent variables i.e., input factors. The Standardized (regression) coefficients or β weights were estimated from a regression analysis using the SPSS 20 software. The conditions for linear regression equation are, the significance level (Sig) value must be <0.05 (with 95% confidence) and the Variance Inflation Factor (VIF) must be <10 as the coefficients β that have been standardized.

$$\ln(A) = \beta_0 + \beta_1 \ln(X_{i1}) + \beta_2 \ln(X_{i2}) + \ldots\ldots$$
$$i = 1, 2, \ldots, n \quad (13)$$

where, β value in Eq. (8) is a standardized coefficient due to the dissimilar units of the input factors,

$\ln(X_{i1})$ is the natural logarithm of value of 1st input factor, and

β_1 and β_2 are the estimated regression coefficients that quantify the association between the factors X_{i1}, X_{i2} and A.

4. Results

4.1. Rainfall Erosivity Factor (R)

The average annual rainfall data was used to calculate the R-factor for the entire catchment using Eq. (2). The average annual rainfall (ranged from 986 to 3259 mm) and consequently the estimated rainfall erosivity (ranged from 515 to 1850 MJ mm $ha^{-1} h^{-1} yr^{-1}$) are increasing from the West to the East and South to North on the Megech River catchment area (Figure 9a). Seventy percent of the catchment area showed erosivity factor ranging from 900 to 1300 MJ mm $ha^{-1}h^{-1}yr^{-1}$ (Table 5). The MFI values in this study ranged from 172.8 to 516.7 (avg. 317.5). The MFI value of greater than 160 is an indicator of very high erosivity according to the classes of MFI (CEC, 1992) [42]. The higher MFI values indicate higher rainfall erosivity in the catchment area. The PCI% values in this study ranged from 15.1 to 23 % (avg.20.1%), which is between moderate and high seasonality according to the Oliver's (1980) [25] conceptual scale to evaluate the PCI index. The average PCI% indicated that the rainfall follows a seasonal pattern without changes during the study period. The FI values ranged from 60 to 225 (avg. 131), which is between severe to extremely severe according to the Oduro-Afriyie's (1996) [43] conceptual scale for assessing the Fournier index. The annual rainfall (P) was correlated with MFI and PCI% (Figure 5c). P had a significant +ve correlation with the MFI (r=0.915, p =0.01) and significant negative correlation with the PCI% (r= -0.158, p=0.68), and the MFI was +ve'ly correlated with the PCI% (r= 0.232, p=0.698). The impact of altitude on P, MFI, FI and PCI% was found not significant.

Table 5. R-value ranges in the Megech catchment area

R-factor (MJ mm $ha^{-1} h^{-1} yr^{-1}$)	*Area (ha)*	*Area(%)*
500-700	13282	16.4
700-900	7273	9.0
900-1100	29080	36.0
1100-1300	27762	34.3
1300-1600	2404	3.0
1600- 1850	1069	1.3

4.2. Soil Erodibility Factor (K)

There are six soil types within the Megech River catchment, with K-factors ranging from 0.20 to 0.34 tons ha h $ha^{-1}MJ^{-1}mm^{-1}$ (Table 6). Soil types were extracted from the HWSD. The Lithic Leptosols, (LPq, 40.8%) and Eutric Vertisols (VRe, 33.5%) occupy the largest area, about 75%, of the total area of the catchment with the highest K-factor of 3.3 and 2.4. In the river catchment, the lowest K-values are concentrated in the low lands, whereas the highest K-values are concentrated in the high elevation areas (Figure 9b).

Table 6. Soil types and the K-factors

Soil Type	*USDA soil textural classification*	*K-factor (tons ha h $ha^{-1}MJ^{-1}mm^{-1}$)*	*Area (ha)*	*Area (%)*
Eutric Leptosols, (Lpe)	Loam	0.34	1803	2.23
Lithic Leptosols, (LPq)	Clay loam	0.33	32896	40.62
Chromic Luvisols (LVx)	Clay/clay loam	0.27	3722	4.60
Haplic Luvisols (LVh)	Sandy clay loam	0.20	7276	8.98
Humic Nitisols, (Ntu)	Clay	0.21	8184	10.11
Eutric Vertisols (VRe)	Clay (light)	0.24	19054	23.53
Eutric Fluvisols (FLe)	Clay (light)	0.22	8046	9.94

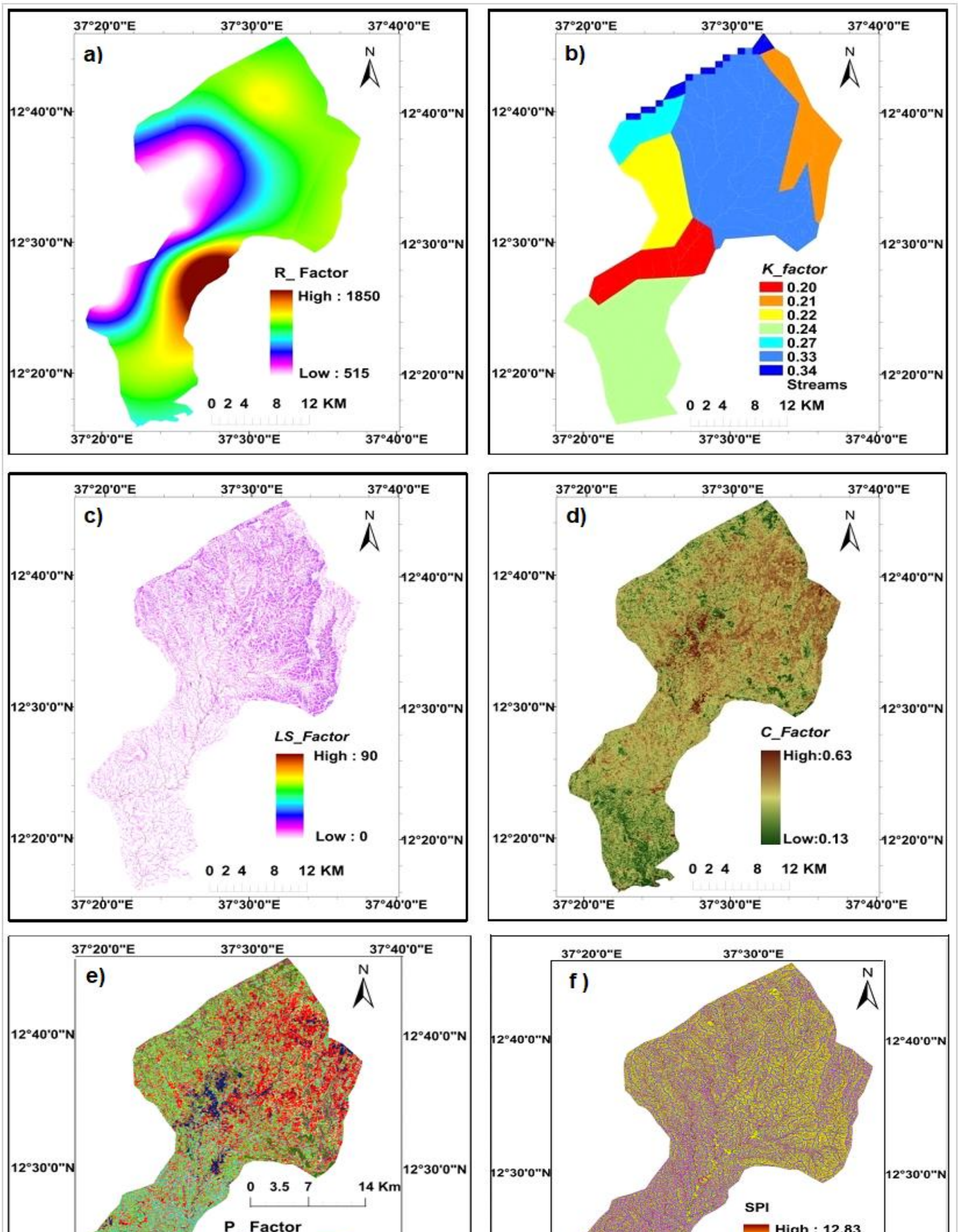

Figure 9. a. Rain fall erosivity factor (R), b. Soil erodibility factor (K), c. Topographic factor (LS), d. Cropping management factor (C), e. Support practices factor(P), and f. Stream power index

4.3. Topographic Factor (LS)

It accounts for the effect of topography on erosion. The DEM data show that terrain is very complex, particularly in upper catchment area with 13% of the natural area having a strong slope steeper than 9°. The result of Eq. (7) shows that the LS factor in the catchment ranges from 0 to 90 (Table 7; Figure 9c) with almost all of them being below 1.0, meaning that the slope is very steep and slope lengths are short. This factor leads to a very powerful rain flow rate and makes the soil erosion more serious.

Table 7. LS factor in the Megech catchment area

LS Factor	*Area (ha)*	*Area (%)*
0 ≤ LS ≤ 1	79730	98.59
1 < LS < 2	574	0.71
2 < LS ≤ 10	444	0.55
10 < LS ≤ 20	81	0.10
LS > 20	42	0.05

4.4. Cropping Management Factor (C)

The catchment area shows NDVI values ranging from −0.063 to 0.74 (Figure 6) that are the average values of time series NDVIs of satellite images, and are applied in Eq.(10) to calculate the cropping management factor (C). The results showed that the C-factor in the research area ranged from 0.13 to 0.63 with the highest coefficient of C concentrated in high altitude regions (Table 8; Figure 9d).

Table 8. C-factor in the Megech catchment area

C-Factor	*Area (ha)*	*Area (%)*
0 < C ≤ 0.2	22	0.03
0.2 < C ≤ 0.3	2698	3.34
0.3 < C ≤ 0.4	57063	70.57
0.4 < C ≤ 0.5	3951	4.89
0.5 < C ≤ 0.63	17126	21.18

4.5. Support Practices Factor (P)

As the erosion prevention practices depend on land use type, six different land use types are identified in the catchment. The support practices factor (P) for the catchment was calculated by the land use type and the slope degrees as suggested by Shin (1999) [44], resulting in values ranging from 0.003 to 1.00 (Table 9; Figure 9e). The dense forest and grass land accounted for 25.5% of the total area, and P-value is 1.0 as there are no conservation practices. The land use map of 2018 was generated with the accuracy of 84% and was estimated in the table of error matrix (Table 3).

Table 9. Support Practices Factors in the Megech catchment area

Land use type	*Slope*					
	$0\text{-}5^0$	*$5\text{-}8^0$*	*$8\text{-}10^0$*	*$10\text{-}15^0$*	*$>15^0$*	*Area (ha)*
Dense forest, Grass land	1.0	1.0	1.0	1.0	1.0	22951
Plantation forest, Shrub, Perennial & Cash crops	0.55	0.6	0.8	0.9	1.0	10100
Crop fields	0.27	0.3	0.4	0.45	0.5	13045
Built-up, Impervious rock, Barren land	0.003	0.003	0.003	0.003	0.003	33529
Water	-	-	-	-	-	1270

4.6. Stream Power Index (SPI)

SPI values ranged from −13.82 to 12.83 and suggest that the stream flow accumulates at one point. (Figure 9f). A strong correlation was found between the rill cross sections and a power function of slope gradients and contributing area reference. The negative values appeared by otherwise high positive main convergent flows and were symbolized in white color whereas the other colored ones were of positive values. Stream power index (SPI) is very indicative about soil erosion potential, and it represents the upstream watershed area multiplied with slope. This index is related to erosion processes, constituting an indicator of the capabilities of a flow to generate net erosion [45]. SPI of the upper Megech watershed is obtained from Arc hydrology module, like derivative of slope and watershed area. The SPI values have large range and their mean value is 217.7 ± 35. SPI values in the range of 2−12.83 cover 74.8% of the entire area, whereas nearly 25% area has below 2. Hypsometrically, highest SPI values have altitude zones of 2200−2950 m which indicate high erosion and transport capabilities of streams in that area.

4.7. Soil Erosion Risk Mapping

The raster values of all five factors (i.e., R, K, LS, C, and P) are used as input data for USLE model, and are applied in Eq. (1) to compute the average annual soil loss per hectare (A). The potential soil loss predictions in the study area have been categorized into five levels based on rate of erosion: very low, low, moderate, high and extreme erosion levels (Table 10; Figure 10).

The results given in the table 10 showed that the soil erosion rate was greater than 10 tons ha^{-1} yr^{-1} in 20.5% of the total Megech River catchment area, mostly at high elevations. The extreme erosion area with the erosion rate greater than 50 tons ha^{-1} yr^{-1} accounted for 3.1% of the catchment area, particularly in mountains and hilly region of upper catchment along the sides of the main streams. The downstream area of the basin had an erosion rate which was less than the other regions. Nearly 50.5% of the catchment area produced very low erosion of less than 1 ton ha^{-1} yr^{-1} (3315 tons annually), whereas extreme erosion area, 3.1 % of the basin area, produced soil erosion of 446138 tons annually.

Table 10. Soil Erosion Levels and corresponding areas and rate of soil loss

Erosion Level	*Soil loss (tons / ha / yr)*	*Area (ha)*	*Percentage of area*	*Total annual Soil loss (tons/yr)*	*Total annual Soil loss (%)*
Very low	0 −1	40867	50.5	3315.13	0.4
Low	1−5	13928	17.2	38018.53	4.5
Moderate	5−10	8207	10.1	60895.85	7.2
High	10−50	14068	17.4	293193.42	34.8
Extreme	≥50	2526	3.1	446138.34	53.0
Water		1270	1.6		

Table 11. Estimated soil erosion rates in the upper and lower catchments of the Megech river [a]

Megech Catchment Area	*Very Low erosion ha(%) & Soil loss t/yr (%)*	*Low erosion ha (%) & Soil loss t/yr (%)*	*Moderate erosion ha (%) & Soil loss t/yr (%)*	*High erosion ha (%) & Soil loss t/yr (%)*	*Extreme erosion ha (%) & Soil loss t/yr (%)*
Upper catchment	25370 (46.60) & 1173 (0.17)	7494 (13.56) & 22516(3.28)	7050 (12.54) & 49769 (7.25)	12579 (23.11) & 267217 (38.9)	2381 (4.19)& 346032 (50.4)
Lower catchment	15097 (58.24) & 2152 (1.37)	6559 (25.3) & 15176 (9.66)	1996 (7.7)& 9828 (6.98)	1483 (5.72)& 23024 (14.66)	786 (3.03)& 105717 (67.32)

[a] Area with estimated erosion rates of 50 t ha^{-1} yr^{-1} or more comprised 4.19% of the upper catchment area and 50.4% of the total estimated soil loss with the mean erosion rate was 151.7 tha^{-1} yr^{-1}, whereas the area with extreme erosion comprised 3.03% of the lower catchment area and 67.32% of the total estimated soil loss with the mean erosion rate was 134.5 tha^{-1} yr^{-1}.

Table 12. Soil losses from various land use types and slopes

Land use Type	*Total annual Soil loss (t/yr)*	*Total annual soil loss (%)*	*Area (ha)*	*Area (%)*	*Soil loss rate (t/ha/yr)*
Built-up, Impervious rock	103420.6	12.3	10864.0	13.4	9.52
Barren land	272052	32.3	22666.0	28.0	12.00
Grass land	227160.1	27.0	20469.0	25.3	11.10
Crop fields, Perennial & Cash crops	138414.6	16.5	14984.0	18.5	9.24
Plantation forest, Shrub	72415.36	8.6	8125.0	10.0	8.92
Dense forest	27928.36	3.3	2479.0	3.1	11.26
Water	0		1270.0	1.6	
Slope					
0- 3^o	39937.41	4.7	7614	9.4	5.25
3- 5^o	201810.8	24.0	28214	34.9	7.15
5- 8.5^o	426980.4	50.7	34991	43.3	12.21
8.5- 24^o	169142.8	20.1	8587	10.6	19.70
24- 45^o	3502.052	0.4	138	0.2	25.37
> 45^o	15.6156	0.0	40	0.1	0.39

The total annual soil loss from the entire catchment area of the River Megech was 8,43,736 tons with an average rate of 41.54±75.92 tons ha^{-1} yr^{-1}. From the upper catchment area (54,874 ha) the annual soil loss was 6,86,705 tons with an average rate of 36.63±64.2 tons ha^{-1} yr^{-1}, while from the lower catchment area (25,938 ha) the loss was 157031 tons per annum with an average rate of 32.68±57.41 tons ha-^{1} yr^{-1}. The soil loss from 28 percent of the total upper catchment area was negligible, but it was not so in the case of lower catchment area. The areas with various estimated soil erosion rates and total estimated annual soil loss of the upper and lower catchments of the Megech river is shown in Table 11.

The soil losses from various land use types and at various topography conditions and their percentages are shown in Tables 12 and 13. Among the land use types, the barren land accounted for the highest soil erosion rate at 12 tons ha^{-1} yr^{-1} followed by dense forest at 11.26 tons ha^{-1} yr^{-1}, grassland at 11.10 tons ha^{-1} yr^{-1}, built-up and exposure rock at 9.52 tons ha^{-1} yr^{-1}, crop field areas at 9.24 tons ha^{-1} yr^{-1} and, plantation and shrub grown land at 8.92 tons ha^{-1} yr^{-1}. Extreme to steep slope topography (24−45^o) accounted for the highest erosion rate at 25.37 tons ha^{-1} yr^{-1} followed by strong to very strong slope (8.5−24^o) at 19.7 tons ha^{-1} yr^{-1}, moderate slope (5−8.5^o) at 12.21 tons ha^{-1} yr^{-1}, gentle slope (3−5^o) at 7.51 tons ha^{-1} yr^{-1} and nearly level (0-3^o) at 5.25 tons ha^{-1} yr^{-1}.

Table 13. Percentage and rate of soil loss from land use type at various topographic conditions

Land use Type	*Slope*					
Built-up, Impervious rock	**0- 3 °**	**3- 5 °**	**5- 8.5 °**	**8.5- 24 °**	**24- 45 °**	**> 45 °**
Area %	7.8	33.2	49.2	9.6	0.2	0.0
Annual Soil loss (%Tons)	4.1	24.8	54.6	16.0	0.4	0.0
Mean Soil loss (t/ha/yr)	54.0	77.0	115.0	171.0	238.0	
Barren land						
Area %	7.4	31.9	48.6	11.9	0.2	0.0
Annual Soil loss (%Tons)	4.3	22.5	53.9	18.9	0.4	0.0
Mean Soil loss (t/ha/yr)	75.0	92.0	144.0	207.0	260.0	
Grass land						
Area %	9.4	35.7	43.9	10.8	0.2	0.0
Annual Soil loss (%Tons)	4.2	23.1	49.5	19.4	0.4	0.0
Mean Soil loss (t/ha/yr)	55.0	80.0	141.0	223.0	279.0	
Crop fields, Perennial & Cash crops						
Area %	11.5	38.8	39.6	10.0	0.2	0.0
Annual Soil loss (%Tons)	5.6	25.9	46.6	21.6	0.4	0.0
Mean Soil loss (t/ha/yr)	49.0	67.0	117.0	216.0	262.0	
Plantation forest, Shrub						
Area %	12.9	40.0	36.1	10.5	0.2	0.5
Annual Soil loss (%Tons)	6.2	25.7	43.4	24.2	0.5	0.0
Mean Soil loss (t/ha/yr)	46.0	62.0	116.0	222.0	287.0	59.0
Dense forest						
Area %	16.4	39.9	32.0	11.6	0.1	0.0
Annual Soil loss (%Tons)	7.1	21.9	41.7	29.2	0.1	0.0
Mean Soil loss (t/ha/yr)	53.0	67.0	159.0	307.0	182.0	

The regression analysis results showed that the annual soil loss rate (A) had a significant correlation and no multicollinearity with the each input factor of USLE ($p < .002$, VIF < 10) (Table 14). This indicates the impact of each input factor of USLE on annual soil erosion rate was significant. The estimated standardized coefficient values (β) (ranged from 0.158 to 0.571) were used for multiple linear regression. The multiple linear regressions of soil loss rate and each input factor in the Megech catchment follow Eq. (14):

$$\ln (A) = 0.162 * \ln (R) + 0.229 * \ln (K) + 0.571 * \ln (LS) + 0.158 * \ln (C) + 0.473 * \ln (P) \quad (14)$$

Table 14. Standardized coefficients (β) for USLE factors at 0.05 significant level

Coefficients[a]

Independent factors of USLE model	Standardized Coefficients	Sig. [b]	Collinearity Statistics	
	β (Beta)		Tolerance	VIF [c]
Ln (R)	0.162	.001	.813	1.219
Ln (K)	0.229	.002	.801	1.227
Ln (LS)	0.571	.000	.873	1.132
Ln (C)	0.158	.001	.608	1.329
Ln (P)	0.473	.000	.613	1.315

a. Dependent Variable: A; b. Level of significance @ .05 ; VIF @ <10

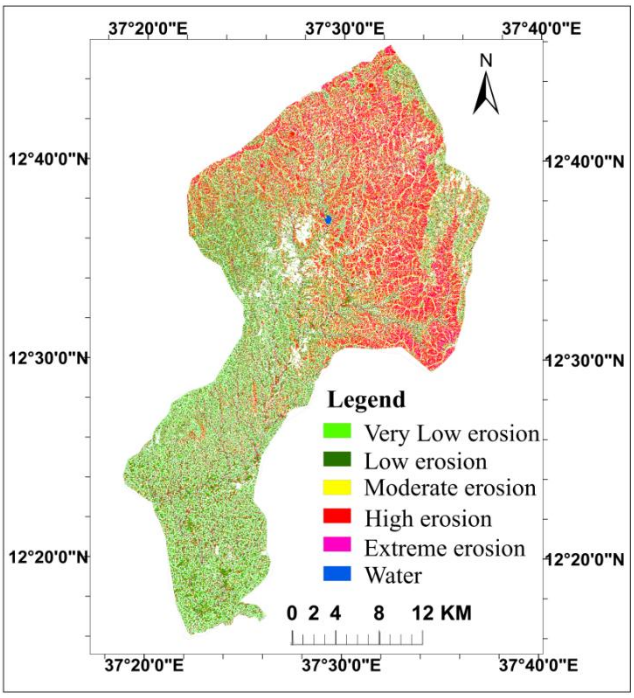

Figure 10. Soil erosion risk levels in the Megech River catchment

The values of standardized coefficients, β, for Eq. (14) indicate that the relative strength of influence of each input factor on annual soil erosion rate. The factor LS had the strongest influence on soil erosion rate (β= 0.571), which is followed by factors P (β = 0.473), K (β =0.229), R (β = 0.162) and C (β = 0.158).

The five levels of soil erosion rate in the Megech River catchment are demarcated in the generated soil erosion risk map (Fig. 10).

5. Discussion

The soil erosion and land degradation problems in Ethiopia are due to increased human population pressures, deforestation, poor soil management and farming practices, insecurity in land tenure, variation of climatic conditions, marginal lands development, escarpment areas and steep slopes for cultivation, free grazing and intrinsic characteristics of fragile soils. The substantial soil erosion from the Megech River drains off most of the nutrients into the Lake Tana polluting it and decreasing the soil fertility in and around the catchment area. The erosion also carries and dumps large quantity of sediment into the lake.

5.1. Rate of Soil Erosion in the Catchment Area

The gross amount of soil loss accounts for 8,43,736 tons per year in the catchment of Megech River with an average soil erosion rate of 41.54 tons $ha^{-1}yr^{-1}$. Estifanos (2014) [46] estimated the average rate of soil loss as 39.8 tons ha^{-1} yr^{-1} in the Ribb watershed that is adjacent to the present research site. Gelagay and Menale (2016) [47] estimated the average soil loss rate as 47.4 tons $ha^{-1}yr^{-1}$ in the Koga watershed that is situated in the south of the current research site. The Ribb and the Koga are the catchments of Lake Tana sub basin of the Abbay River basin. Our results show that the soil erosion is higher in the Megech River catchment than that in the catchments of the Ribb and Koga rivers. We suppose that the differences between the R, K, and LS factors of the Megech catchment and the other catchments could be the main reason for higher soil loss rate in the Megech river catchment. The extreme erosion of soil in the mountainous and hilly regions of upper catchment of the Megech river, particularly along the sides of the main streams and down slopes, as we found, may be due to rill and sheet erosion.

5.2. Soil Erosion and Land Use

Most studies conclude that the land use influences both soil erosion results and characteristics [48-50]. Our research indicates that different land uses impact the degree of soil erosion differently. The barren land experiences the most severe erosion followed by dense forest and grassland. The main causes of the high soil erosion in these land uses are geographical factors. The soil erosion rate is more in very strong and steep slopes. In the same topographic condition, the soil erosion rate between these land uses varies. Similarly, the soil loss rate varies from particular land use in different topographic conditions. The agricultural fields and plantation are in very strong and steep slopes and they show high rate of soil erosion. The plantation shows more soil erosion rate in steep slopes, while dense forest shows in strong slopes, and in the same topography condition, from steep slopes, the eroded soil rate between dense forest and plantation forest is 1.5 times greater. The volcanic surface rock shows more soil erosion in very strong and steep slopes. These rocks are basic and rich in magnesium causing high weathering.

5.3. Impact of Cultivation Practices on Soil Erosion

The soil erosion rate and the seasonal calendar have a close relationship with C factor. In the Megech catchment, mainly there are three types of agricultural land use: forest plantation (mostly wood plants), cultivation of annual crops including *teff* (a staple food millet), and growing of seasonal crops. The growth cycle for each of these vegetations is different. They are usually planted in September when the flood-borne wet sediment comes from the up-lands and settles, and harvested in the following February in low-catchment areas. Usually there is no growth during the initial period, September to November. However, there is rainfall during that time causing severe soil erosion rate.

In the up-land areas, sowing is done during May and harvesting is done during October – November. After harvesting, the agricultural land is left as it is without any soil conservation measures. Consequently, soil from such lands is being eroded considerably even by small rainfall intensities. Similarly, there is erosion from the forest plantations where the woods were harvested and the land is prepared for new plantations during the early rainfall season, i.e., May–June. In addition, the agricultural practices in the areas at the foot of steep slopes have been causing more soil loss.

5.4. Impact of Increase in Agricultural Area on Soil Erosion Rate

We attempted to analyze the impact of land use and land cover changes on soil erosion rate by comparing the current Landsat-8 data of the year 2018 with the Landsat-7 data of 2000. Such a comparison of historical data revealed that the agricultural land increased substantially with the decrease of forest and grasslands. The crop management factors, C, for the increased agricultural area were derived from NDVI. The gross amount of erosion has been increased to 15% when compared with the actual soil loss in 2018 that is due to increase in agricultural area and decrease in forest and grassland area. The increase in soil loss was found mainly due to the unscientific agricultural practices like primitive ploughing, tillage, land preparation, etc. In addition, conversion of scrublands, grazing fields, and uncultivated barren lands to agricultural fields has been leading to more soil loss. The original forest cover was reduced from 90% to a mere 5.6% of the total Ethiopian highlands area coverage [51].

5.5. Impact of Land Use and Land Cover Changes for Developmental Programs on Soil Erosion Rate

Urban Planning and Implementation are the major focused areas of Ethiopia. The developmental corridor in the North Gondar area, particularly transportation corridors in the highlands, is now undergoing rapid urbanization causing land degradation and soil erosion. For example, cutting of hillocks and stone crushing for development of road corridors for connecting various villages for transport purposes, but leaving the cut portions of hillocks without any landslide control measures, have been causing the land erosion.

6. Conclusions

Prevention and control of substantially high annual soil erosion from the Megech River catchment needs an attention for sustainable conservation of the soil fertility in and around the catchment as well as to prevent nutrient and sediment pollution loads into the Lake Tana. Appropriate strategies and action plans must be drawn and implemented for protection and conservation of the catchment and its soil and land resources. Scientific land use allocation and management, agricultural and forest cultivation practices must be propagated among the farmers and their implementation shall be regularly monitored. Soil conservation in the agricultural lands in the catchment area, and the restoration of the lands degraded due to various infrastructural developmental activities also would prevent and control soil erosion and land degradation.

ACKNOWLEDGEMENTS

We would like to express our sincere appreciation to the Mrs. Ertiban Wondifraw, Co-ordinator, Soil and Water management, Agricultural Research Centre, Gondar, for providing the meteorological data. We are also grateful to the National Meteorological Service Agency (NMSA), Addis Ababa, and Landsat/EO/NASA/USGS for their unconditional support.

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