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Research article

The impact of land use and land cover (LULC) dynamics on soil erosion and sediment yield in Ethiopia

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ABSTRACT

The central highlands of Ethiopia are characterized as a region of high rates of land degradation and soil erosion. This study aimed to estimate total amount of soil loss and sediment yield using RUSLE model within GIS environment. LULC maps of 1973–2015 were used to evaluate the impact of land use change on soil loss and sediment yield. Each model parameter and sediment deliver ration was computed by using Williams and Berndt empirical equation. The net soil erosion and sediment yield at the Guder river mouth and soil risk map was estimated for the watershed. LULC dynamic for the study period and watershed have shown that there existed a rapid conversion of vegetated land uses to human modified land uses. The study revealed that the mean soil loss from the watershed ranges between 25 and 30 t/ha−1 yr−1 which accounted 25.8, 28.7 and 30.3 t/ha/yr for 1973, 1995 and 2015 periods respectively. The estimated total soil loss in 1973, 1995 and 2015 periods were 198Mt yr-1, 221Mt yr-1 and 239Mt yr-1 respectively. The mean sediment yield estimated was 6.79, 8.65 and 9.44t ha-1 yr-1 for 1973, 1995 and 2015 periods respectively. The sediment deliver ratio (SDR) of the watershed ranged between 0 and 0.26. The spatial distribution of SDR showed that the highest value was recorded on central and eastern part of the watershed. Prioritizing erosion host spot areas is recommended to rehabilitate degraded lands using suitable soil and water conservation structures.

1. Introduction

Land use and land cover change (LULC) implies anthropogenic and natural modification of the land surface (Van Remortel et al., 2001; Lambin and Geist, 2008; Brhane and Mekonen, 2009; Jacob et al., 2015; Tolessa et al., 2019). The expansion of cultivated land at the expense of natural vegetation is significantly affecting the natural environment (Tolessa et al., 2019). This continuous expansion of cultivated land is a major cause of land degradation which imposes a greater threat to fertility of soils. Different studies have quantified the impact of LULC on soil resources of the world at large and Ethiopia in particular (Cerdan et al., 2010; Jones et al., 2011; Borrelli et al., 2013; Haregeweyn et al., 2017; Zerihun et al., 2018; Ebabu et al., 2019).

Recent studies in the Blue Nile basin and central highlands of Ethiopia have reported the expansion of agricultural land in to forested area and it is the major cause of degradation and environmental change which will likely to have an effect in the future (Lambin et al., 2003; Bewket and Sterk, 2005; Hurni et al., 2005; Bewket and Teferi, 2009; Fisseha et al., 2011; Gebrehiwot et al., 2014; Tolessa et al., 2017, 2019; Gashaw et al., 2018; Hassen and Assen, 2018). Studies in different part of the Blue Nile basin revealed that, there are many factors which caused LULC changes among which population density is one of the major factors which further has caused increasing erosion risks (Haregeweyn et al., 2017). There are numerous prevailing and complex factors involved in changing the natural environment which are driven by socio-economic, regime and policy changes (Lambin et al., 2003; Teferi et al., 2010; Haregeweyn et al., 2017; Tolessa et al., 2019). The impact of climate change and variability are felt after a long period of time on land uses but the impacts of human modification of the land is felt within a short period of time in relation to soil loss (Taye et al., 2015; Tolessa et al., 2019).

An increasing population growth aggravates land degradation because a very high pressure on land resources. Ethiopia has a population of more than 100 million with a growth rate of 2.7%. Of this about 80% of the population solely depends on agricultural practices as a source of employment and income (CSA, 2015). According to Hurni (1988), nearly 27 million hectares of the Ethiopian highland was significantly eroded and over 2 million hectare of the land was beyond reclamation. These problems are aggravated due to unsustainable land resource

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management strategies coupled with population pressure (Rientjes et al., 2011; Jacob et al., 2015; Haregeweyn et al., 2017).

The central highlands of Ethiopia are highly degraded and characterized as a region of high rate of land degradation and soil erosion (Zeleke and Hurni, 2001). Soil erosion affects the soil physical and chemical properties and reduces soil fertility. This in turn resulted in decline agricultural productivity, which force farmers to look new fertile land leading to the expansion of cultivated land at the expense of forest ecosystems (Zeleke and Hurni, 2001; Bewket and Sterk, 2005). The Ethiopian highlands are heavily degraded, and frequently affected by drought and famine (Meshesha et al., 2014). As a result of population growth in the highland areas, more and more marginal lands are being used for agriculture.

Loss of top soil as a result of soil erosion is a challenge for most of the watershed community in Guder sub watershed. Thus, there is a need for appropriate assessment of soil loss and sediment yield to determine the severity and yield of the prevailing soil erosion using suitable soil loss model (Prasannakumar et al., 2012; Gebrehiwot et al., 2014; Asres et al., 2016; Benavidez et al., 2018; Alewell et al., 2019).

Several studies estimated the net and mean soil erosion and sediment yield at the river mouth for different basins using RUSLE model due to its applicability under various ecosystem types and management scenarios (Jain and Kothyari, 2000; Ganasri and Ramesh, 2016; Kayet et al., 2018; Zerihun et al., 2018; Alewell et al., 2019). In this study the impact of LULC dynamics (1973–2015) on soil erosion and sediment yield (SY) were evaluated. Moreover, the study assessed trends of soil loss and sediment yield at sub watershed. The study used RUSLE soil erosion models to estimate the mean and total soil loss and sediment yield in different period of time (1973, 1995 and 2015). Furthermore, the study also assessed trends of soil erosion and SY together with the spatial distribution of erosion severity map.

2. Materials and methods

2.1. Description of the study area

This study was carried out at Guder sub watershed located in West Shewa Zone of Oromia Regional State, Ethiopia (Figure 1). The watershed is within three Woredas of the Zone and at about 125km from Addis Ababa in the West. The watershed is characterized by different topographic conditions which ranges from flat plains to steep areas. After classifying DEM into five FAO slope classes, 5.01% of the total area has gentle slope (0-2^{o}), whereas 20.32% and 20.03% of the total areas are characterized as slightly undulating (2.1-5^{o}) and moderate steep (>5.1-8^{o}) slopes respectively. The rest land slope is labeled as steep and very steeper which range 8.1–15^{o} (33.06%) and >15^{o} (21.57%) respectively (Table 1).

Table 1. Watershed slope classes.

No	Slope Class	Area	
		ha	%
1	0–2	2337.32	5.01
2	2.1–5	9481.27	20.32
3	5.1–8	9346.14	20.03
4	8.1–15	15421.30	33.06
5	>15	10064.14	21.57

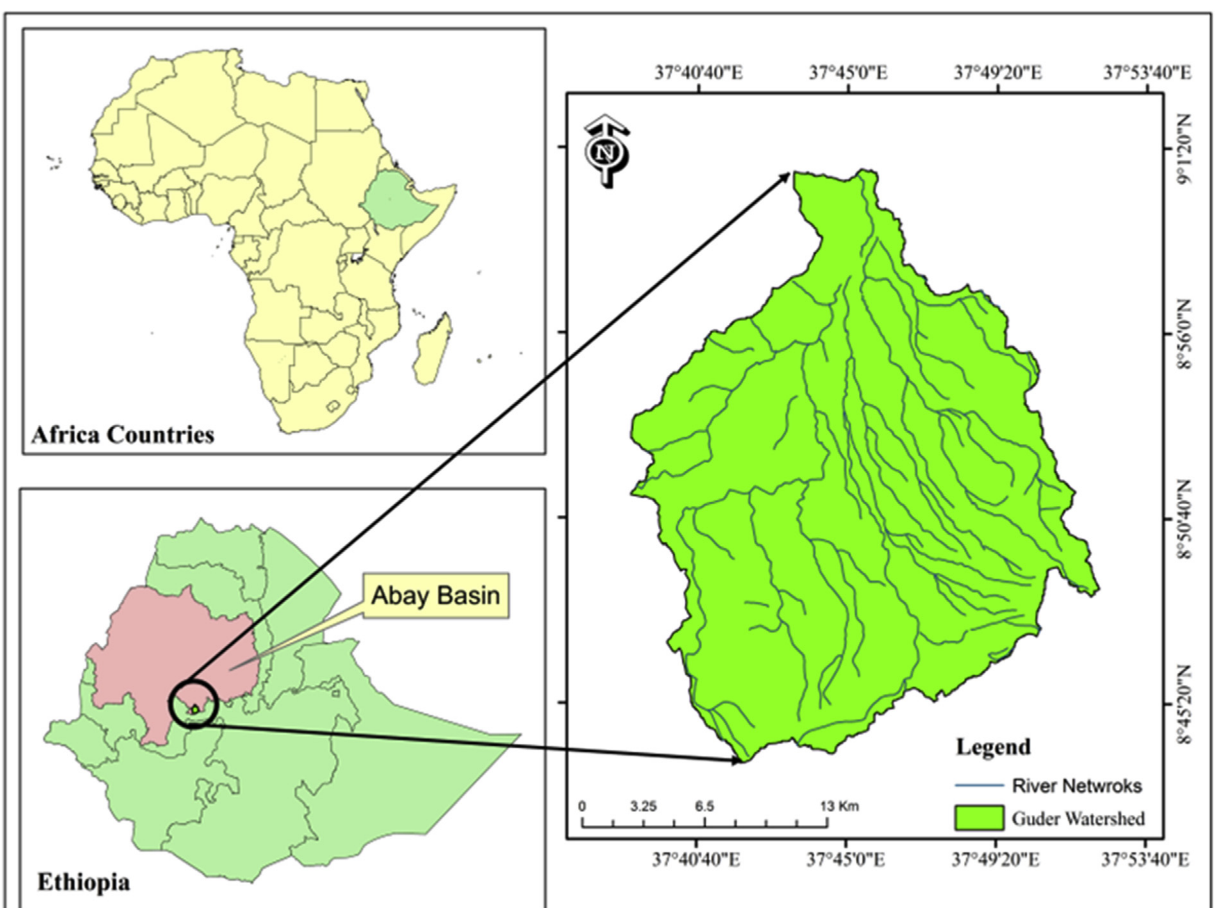


Figure 1. Map of the study area.

The average annual rainfall of the watershed is 1445 mm with two rainy seasons (low rain occur from March to May and much rain from June to September, with the highest occurrence of rainfall in July and August). The mean minimum and maximum temperatures of the watershed are 9.3 °C and 23 °C respectively (Kidane et al., 2019). The lowest temperature is recorded during October and highest temperature is within the month of May. The study sub watershed is found within the highland, where the area is generally exposed to soil erosion. Hence, the area belongs to the moist *Dega* agro-climatic zone. It has bi-modal rainy season: the main "*kiremt*" rain that extends from June to September and the short "*Arfassa*" or "*Belg*" rainy that stretch from February to April. The "*kiremt*" rainy season cover over 80–90% of the total precipitation whereas the rest 10–20% is received during the "*Arfassa*" or "*Belg*" and "*Birra*" or "*Tsedey*" seasons. The "*Bona*" or "*Bega*" is the driest season with no precipitation received. The predominant source of the communities' livelihood is subsistence agriculture (Kidane et al., 2019). A large number of populations within the watershed have a profound influence on the natural resources and the environment.

2.2. Land use and land cover

Cultivated land constitutes the major areas of the watershed with dominant crops being cultivated that includes teff *(Eragrostic tef),* wheat *(Triticum vulgare)* and barley *(Hordeum vulgare)* constituting 80.2% of area covered by crops. *Beans (Vicia faba)* and maize *(Zea mays)* are the second major crops grown in the area. Five LULC classes such as forest, shrub, grass, cultivated land and settlement were identified for three periods (1973, 1995 and 2015). Cultivated land accounted for more than 62% of the total watershed area. This value shows clearly that agriculture plays an important role in the socioeconomic development of the watershed (Kidane et al., 2019). Table 2 and Figure 2 illustrate the LULC classification and distribution in the watershed over forty years in three times series.

2.3. Data collection

The methodological framework of the study integrates revised universal soil loss equation (RUSLE) model and GIS spatial analysis environment. The model combines various parameters which were acquired from different sources. RUSLE model is one of the empirical erosion model widely used to calculate sheet and rill erosion based on a large dataset (Renard et al., 1991; Prasannakumar et al., 2012). Information on soil loss and sediment yield is limited for Guder Sub watershed for this particular study. As described earlier the sub watershed is experiencing a rapid LULC changes for the last forty years. Therefore GIS and Remote Sensing integrated with RUSLE soil loss model is applied to evaluate impact of LULC change on soil loss and sediment yield.

2.4. Estimation of soil loss

The procedures adopted for the watershed to compute soil loss was based on the empirical concepts of revised USLE (Andersson, 2010; Alewell et al., 2019). This involves implementation of the empirical formula in raster based spatial analysis. To calculate each parameters grid-based approach were used and after each values of the model parameters were determined and raster calculator was used to compute the total soil loss for each grid cell (Renard et al., 1991). Various scholars applied the model and try to confirm its applicability and effectiveness to determine soil loss in Ethiopian highlands (Galagay and Minale, 2016; Zerihun et al., 2018). The model is widely applicable in different parts of the world and found to be effective in estimating soil loss and sediment yield (Galagay and Minale, 2016; Zerihun et al., 2018; Yesuph and Dagnaw, 2019). Furthermore, the RUSLE model is simple, compatible, and applicable in limited data conditions and its adoption in Ethiopian highland conditions. In data scarce areas for validation of models, it is suggested to be cost effective soil erosion estimation method for effective conservation planning (Hurni, 1985; Belayneh et al., 2019).

Table 2. Land Use Land Cover change from 1973 – 2015 (Kidane et al., 2019).

Class Name	1973		1995		2015	
	ha	%	ha	%	ha	%
Shrub land	7730.44	16.57	5736.24	12.30	3983.76	8.54
Settlement	1017.07	2.18	3064.95	6.57	6836.31	14.65
Grass land	1920.38	4.12	1114.47	2.39	317.25	0.68
Forest land	6749.64	14.47	5722.47	12.27	4216.5	9.04
Cultivated Land	29236.3	62.67	31015.70	66.48	31300	67.09
Total	46654.00	100	46654.00	100	46654.00	100.00

The total annual soil loss was estimated by raster grid spatial analysis of the six parameters (Wischmeier and Smith, 1978; Renard et al., 1991, 1997; Renard and Freimund, 1994).

$$\text{Total Soil Loss(SL)} = R \times K \times L \times S \times C \times P \tag{1}$$

where; SL is the soil loss in t/ha/yr, *R* is the rainfall-runoff erosivity factor in MJ (mm/ha/year); *K* is the soil erodibility factor (t h/(MJ mm)); *L* is the slope length factor; *S* is the slope steepness factor; *C* is the cover and management factor; and *P* is the soil and water conservation practices factor.

2.4.1. Estimation of RUSLE parameters

Studies confirmed that there are drawbacks within the RUSLE model in determining the mean soil loss at regional scale but it has been extensively used to estimate soil losses at watershed and sub watershed scales since it incorporates LS factor computation approach (Borrelli et al., 2013; Galagay and Minale, 2016; Alewell et al., 2019). Thus, this study employed the model to be used at sub watershed level to asses the model effectiveness in determining mean soil loss. After the six GIS layers were computed; these layers were resampled and multiplied to estimate the mean and total soil loss. Hurni (1985) adopted the RUSLE model to the Ethiopian conditions by modifying some of the factors to the real situation. For this study each of the RUSLE factors were calculated systematically following the standard procedures (Hurni, 1985).

2.4.2. Rainfall erosivity (R) factor estimation

R factor represents the aggressiveness of the rainfall and it is associated with the amount and rate of runoff, which have a potential to cause erosion. For this study the value of rainfall erosivity factor was calculated using the regression equation developed by Hurni (1985) for different climatic zones. The spatial regression equation was developed with 1973–2015 mean annual rainfall (P) from four stations. Geo-statistical interpolation techniques were applied to create continuous raster grids of the long term mean annual rainfall. After the raster grid was developed, the following equation (Eq. 2) was used to compute R factor in ArcGIS raster calculator.

$$R = (0.562 * P) - 8.12 \tag{2}$$

where, P is annual rainfall (mm).

2.4.3. Soil erodibility (K) factor estimation

K factor is the physical and chemical characteristics of the soil which determines the susceptibility of the soil to erosion (Yue-Qing et al., 2008; Cerdan et al., 2010; Sharma et al., 2011). K factor can be calculated using the regression equation developed by Wischmeier and Smith (1978). The equation yields K values as a total role of the soil texture, permeability, OM content and structure of the soil. However such monograph equation is difficult to determine K value in areas where change in land use is indispensible (Zhang et al., 2013). So, in

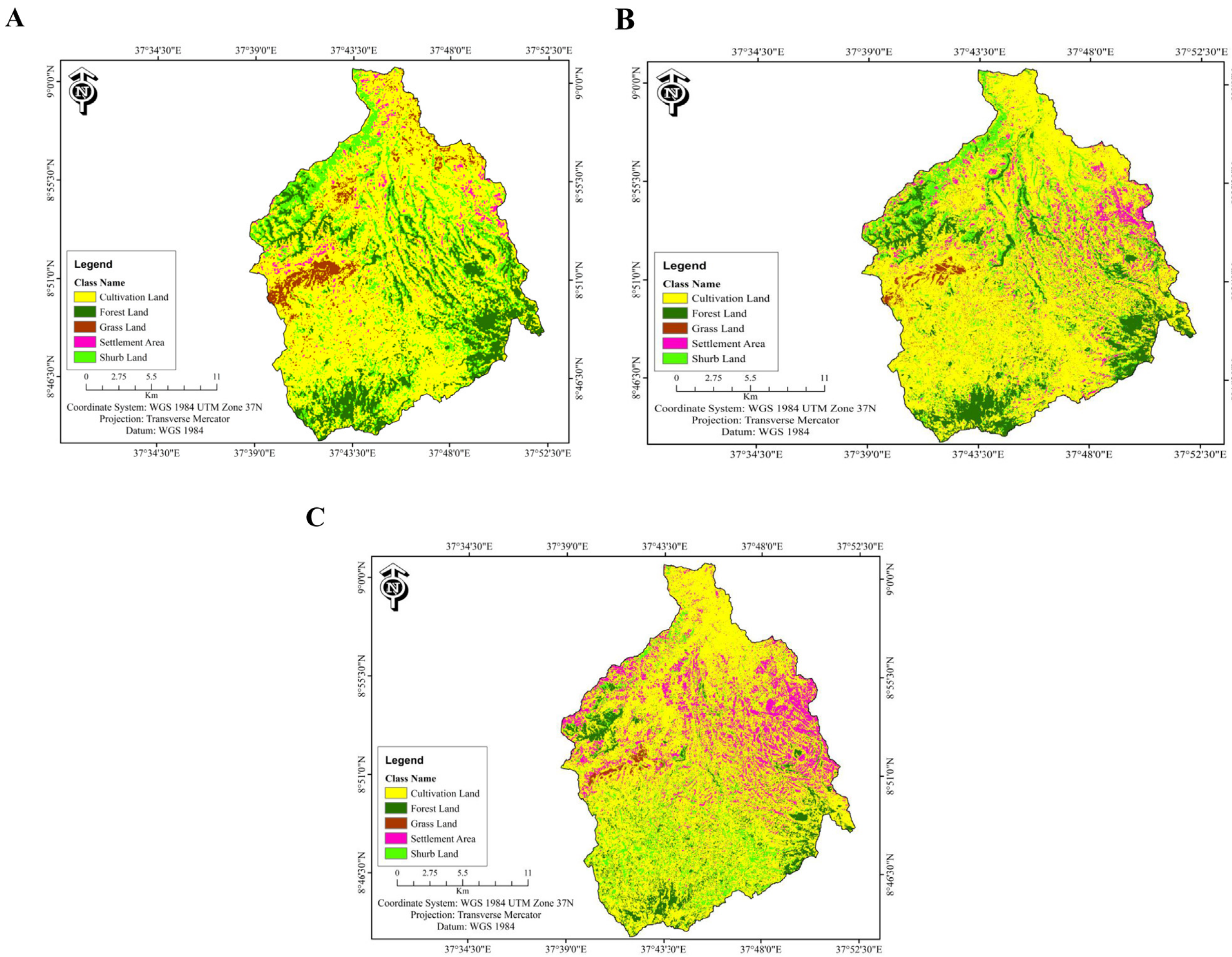


Figure 2. LULC map for the year 1973–2015 (A, B & C). A. LULC map for the year 1973; B. LULC map for the year 1995; C. LULC map for the year 2015.

this study we obtained the value of K factor based on the soil type and their associated properties, which are indicators for soil vulnerability to erosion for the highlands of Ethiopia (Hurni, 1985). Soil types for the study sub watershed were extracted from master plan of Abay basin for the year 2011 to develop associated soil property and color. For each soil type K value were assigned and these values were converted to raster grid in ArcGIS environment following the standard procedure (Table 3). A 1:250,000 scale map of the soil was used within the ArcGIS environment to determine K values for each soil type.

2.4.4. Topographic parameters (LS) factor estimation

Topographic factor is one of the important RUSLE model parameter in determining soil erosion, since the gravity force is playing a pivotal role in surface runoff (Moore and Wilson, 1992; Zhang et al., 2013). This factor incorporates both slope length (L) which measure the distance between the source and culmination of inter rill process; and steepness (S). Measuring slope length is inadequate, where the watershed is characterized as heterogeneous and considering the scale of topography and LULC related aspects (Moore and Wilson, 1992; Van Remortel et al., 2001; Brhane and Mekonen, 2009). To calculate spatially distributed LS value for three dimensional complex terrain geometry, we used the upslope contributing area approach. These effectively comprehend the spatial distribution of soil erosion and deposition process (Zhang et al., 2013). Upslope contributing area approach includes computing flow accumulation which is calculated by summing the areas of all upslope cells draining into it for each raster grid.

Table 3. RUSLE K Value using soil color and type recommendations.

Soil Type	Textural Properties	Soil Color	K factor	Area
Calcic Vertisols	Clay	Vary Black	0.15	1520.36
Chromic Luvisols	Sandy clay	Brown	0.20	8799.14
Eutric Fluvisols	coarse sand to clay	Yellow	0.30	7864.28
Eutric Leptosols	silty clay, loam to silty clay	Darker	0.22	361.80
Eutric Vertisols	Clay	Vary Black	0.15	4827.49
Haplic Alisols	loam to clay	Red	0.25	20544.00
Haplic Luvisols	Clay	Brown	0.20	2736.93

Flow accumulation and slope were derived from DEM in ArcHydro extension of ArcGIS environment. Finally LS were computed using DEM and slope, by using the following equation (Mitasova and Mitas, 1999; Simms et al., 2003):

$$LS = \left(\text{Flow Accumulation} \times \frac{\text{Cell Size}}{22.31}\right)^{0.4} \times \left(\frac{\text{Sin (slope)}}{0.0896}\right)^{1.3} \quad (3)$$

where, LS is Slope length-steepness value. Slope is slope length in meters and varies with slope steepness (s). Cell Size is the length and width of the raster grid side.

2.4.5. Land cover and management (C) factor estimation

Cover management factor accounts for the protection of the soil from the impact of rain drops and subsequent loss of soil particles. The value of C ranges between 0 (represent ideal case) where there is no soil erosion and 1corresponds to the greater amount of soil erosion (Foster et al., 2002; Tamene et al., 2006). The value is dimensionless that determine the ratio of soil loss between specific area with different land cover management conditions (Zeleke, 2000). The watershed land use and land cover showed rapid change overtime (Kidane et al., 2019; Muleta and Biru, 2019) and the values were assigned for each cover based on intensive review of similar studies (Galagay and Minale, 2016; Molla and Sisheber, 2017). To evaluate the impact of LULC change on soil erosion and sediment yield three C factor raster grid were derived for 1973, 1995 and 2015 (Table 4).

2.4.6. Management practices (P) factor estimation

P factor includes the support practice and measure the impact of soil and water conservation (SWC) practices on annual soil loss (Wischmeier and Smith, 1978; Betrie et al., 2011; Galagay and Minale, 2016; Molla and Sisheber, 2017). It is the ratio of soil loss with different SWC strategies on agricultural land. Mishra et al. (2007) stated that P factor correspond to a treatment that retain eroded soil loss particles and control them from further soil loss transport. Hurni et al. (2015) proposed two considerations to calculate P value. The first method considers the conservation practice and second corresponding to P factor with the combination of watershed topography and land use and land cover. In this study we adopted the second method, by categorizing LULC into two, which are cultivated and other land use types. Cultivated land was subdivided into six slope classes and for each slope class a value between 0 and 1 was assigned (Table 5). It was assumed that in all cultivated land soil and water conservation practices were applied. According to Wischmeier and Smith (1978), P factor effectiveness may vary according to slope and soil and water conservation practices, thus the values indicated on Table 5 was assumed due to the existing policy for soil and water conservation in Ethiopia (Hurni et al. 2016).

2.5. Estimation of sediment delivery ratio

Sediment delivery ratio (SDR) is the fraction of gross erosion delivered to the outlet of the watershed area in a given period of time (Renard and Freimund, 1994; Anderson, 2006; Andersson, 2010). The SDR value shows the topographic ability of the drainage area for transporting and sedimentation of eroded soil. The amount of sediment stored within the drainage basin is affected by slope length, sediment particle size, runoff-rainfall and land use and land cover management (Tamene et al., 2006). A number of methods were developed to determine a watershed SDR by considering the above biological, topographic, climatic and hydrological factors. Studies in northern Ethiopia used various approach to determine SDR (Zerihun et al., 2018). According to Nyssen et al. (2009), SDR values were determined as a function of land use type with or without soil and water conservation practices. Such kind of estimation generalizes the main factor such as stream slope and hydrology. For this study Williams and Berndt (1972) equation was used to calculate SDR (eq4).

$$SDR = 0.627 \times (SCS)^{0.403} \quad (4)$$

where, SCS is main stream channel slope measured in percent.

Main stream cannel slope were computed using ArcGIS HEc GeoHMS extension. Flow direction, accumulation and stream network were mapped after preprocessing DEM for any cell depression and sink. Furthermore HEc GeoHMS extension used DEM and flow path to calculate average main stream cannel slope for each raster grid. SCS raster grid includes average upstream cell slope that affect the stream channel sediment deliver capacity.

Table 4. Adopted values of C factor for the watershed land use and land cover classes (LULC).

LU/LC	Definition	C factor	Source
Cultivated land	Areas used for crop cultivation, both annuals and perennials. This category includes areas currently under crop, fallow, and land under preparation.	0.20	http://www.sciencedirect.com/science/article/pii/S2095633915301076 Hurni, 1985
Forest land	Area covered by Trees where the trees cover density is greater than 10%. It includes plantation and natural forest	0.02	Hurni, 1985 and http://www.sciencedirect.com/science/article/pii/S2095633915301076
Shrub land	Areas covered with small trees, bushes, and shrubs, usually not exceeding 3 m in height	0.10	http://www.sciencedirect.com/science/article/pii/S2095633915301076 Wischmeier and Smith (1978)
Grass land	Areas are covered by both long, short grasses, annual wet lands which are used for private and communal grazing purpose with the mix up scattered trees, shrub/bushes and also cover, mainly with classic gullies and exposed rocks, Includes rock outcrops, denuded land, and badlands.	0.11	http://www.sciencedirect.com/science/article/pii/S2095633915301076 Hurni, 1985 and http://www.sciencedirect.com/science/article/pii/S2095633915301076
Settlement	Land dominated with houses and huts	0.01	http://www.sciencedirect.com/science/article/pii/S2095633915301076 Hurni, 1985 and http://www.sciencedirect.com/science/article/pii/S2095633915301076

2.6. Estimation of sediment yield (SY) and soil erosion risk map

Sediment yield is the amount of sedimentation at the river mouth which leaves the watershed (Tamene et al., 2006). Most parts of Ethiopian highlands are characterized by dynamic variation in land use and land cover and sediment yield. Ministry of Water, Irrigation and Electricity (MWIE) continuously assess total sediment yield for the major river basins using rating curves, including Abay basin (BCOM, 2006). However, these rating curves require periodic measurements of sediment concentration and stream discharge. Since there is no detailed periodic measurement in our study sub watershed, sediment yield was determined using SDR and total soil loss. After computing total soil loss and SDR of the drainage area, sediment yield was calculated using ArcGIS spatial analysis tool.

The net result of soil erosion and stream sediment delivery potential within the basin manifested using sediment yield at the river mouth. The total amount of sediment yield and soil erosion from the catchment changed because of the variation in LULC. To evaluate the impact of LULC change on soil erosion and sediment yield, three (1973, 1995 and 2015) separate LULC maps were used (Kidane et al., 2019; Muleta and Biru, 2019). Comparisons were made between LULC and the final net soil erosion and sediment yield at three periods. Raster pixel based quantifiable erosion maps were converted to soil risk map by classifying the map to different severity classes.

3. Results and discussions

3.1. Overview of watershed LULC change

The sub watershed is found at the headwaters of the Blue Nile Basin towards south and is characterized by a potentially irrigable land. Its suitable agro climatic condition to agricultural activity and irrigation

Table 5. Adopted RUSLE P values watershed conservation practices.

Land use type	Slope (%)	P factor
Cultivated land	0–5	0.10
	5–10	0.12
	10–20	0.14
	20–30	0.19
	30–50	0.25
	50–100	0.33
Other land	All	1

potential put the watershed to a dynamic land use system. This rapid LULC change can potentially influence soil physical and chemical properties, rainfall-runoff relationship, land degradation in terms of soil erosion and sedimentation. The rapid dynamics of LULC observed in Guder sub watershed has a negative impact on both the environment and socio economic conditions. For instance, the expansion of cultivated land in the study area is at the expense of forest and shrub land. The satellite images analysis showed that the sub watershed has been recording a significant spatial and temporal LULC change over the last 40 years. A significant change was recorded between cultivated land, settlement and forest land. During the classification year of 1973 and 2015 cultivated, settlement and forest land converted from 62.67%, 2.18% and 14.47%–67%, 14.65% and 9.04% respectively (Kidane et al., 2019; Muleta and Biru, 2019).

Deforested lands are exposed to the potential impacts of rain drops, which accelerate the detachment, removal and transportation of soil particles. Furthermore, due to the expansion of intensive and extensive agricultural systems on the steep slopes, land has been greatly deteriorated and degraded. The intensification of agriculture and the expansion of croplands into marginal lands which is dominated by the traditional system/practices have led to severe land degradation (Borrelli et al., 2013; Hurni, 1988). The other most serious problems in the area are exploitation of forest resources for construction purposes, charcoal and timber production, fuel wood for income and domestic consumption (Kidane et al., 2019).

3.2. Evaluating soil erosion using RUSLE

The effect of LULC change on the amount of soil erosion was evaluated using RUSLE model. The model includes determining values for each factor and superimposing each raster layer to compute the final mean annual soil loss. The estimated values for each factor were computed following the above methodology and the results are presented.

3.2.1. Rainfall erosivity (R) and soil erodibility (K)

To compute the Erosivity value for the study area and period (1973–2015), we used the mean annual precipitation of the respective years. The long term erosivity value for the watershed varies between 500 and 1179.4 MJmmh^{-1} ha^{-1} yr^{-1}. The highest erosivity value was recorded in the highland part of the sub watershed. This indicates that the particular topography can be characterized as the area of high rainfall compared with downstream site. Subsequently the value of R factor for the study showed significant variation within the watershed. Effect of such variation in the results determines estimated soil erosion. Thus, rate of soil erosion on the highland part of the region contribute the highest amount of sediment yield. In addition, Erosivity gradually increases from west central to the river mouth (Figure 2a). Although erosivity values of the study sub watershed is less than the global average, that is, 2000 MJ mmh^{-1} ha^{-1} yr^{-1} (Borrelli et al., 2013), the amount of soil loss contributed by this factor (R) is significant. Studies such as Ganasri and Ramesh (2016) and Meusburger et al. (2012) found that soil erosion rate is more sensitive to rainfall. R factor for our study area is much higher than the one found by Thomas et al. (2018) for the south Western Ghats.

Erodibility (K) value was computed based on recommendation provided by Hurni (1985) for Ethiopian highlands. Physical and chemical properties including soil color was used to determine K value for each class of the soil. In general the watershed contains seven classes of soil and their recommended erodibility values were determined with respect to the recommend soil color (Table 3). Haplic Alisols were the dominant type of soil which covers 44% of the study area and the soil is characterized as poor to moderate drainage capacity. The spatial distribution of the soil type also shows that Haplic Alisols were located in highland of

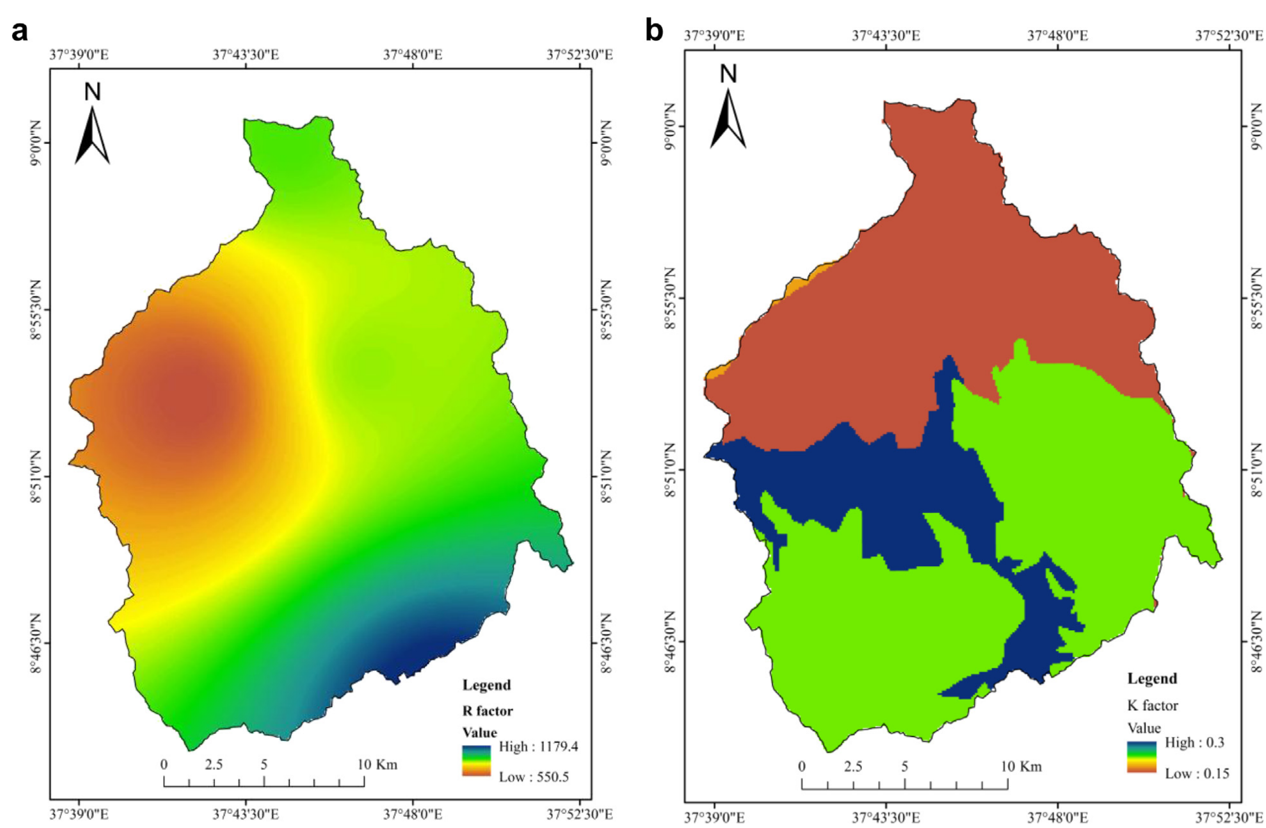
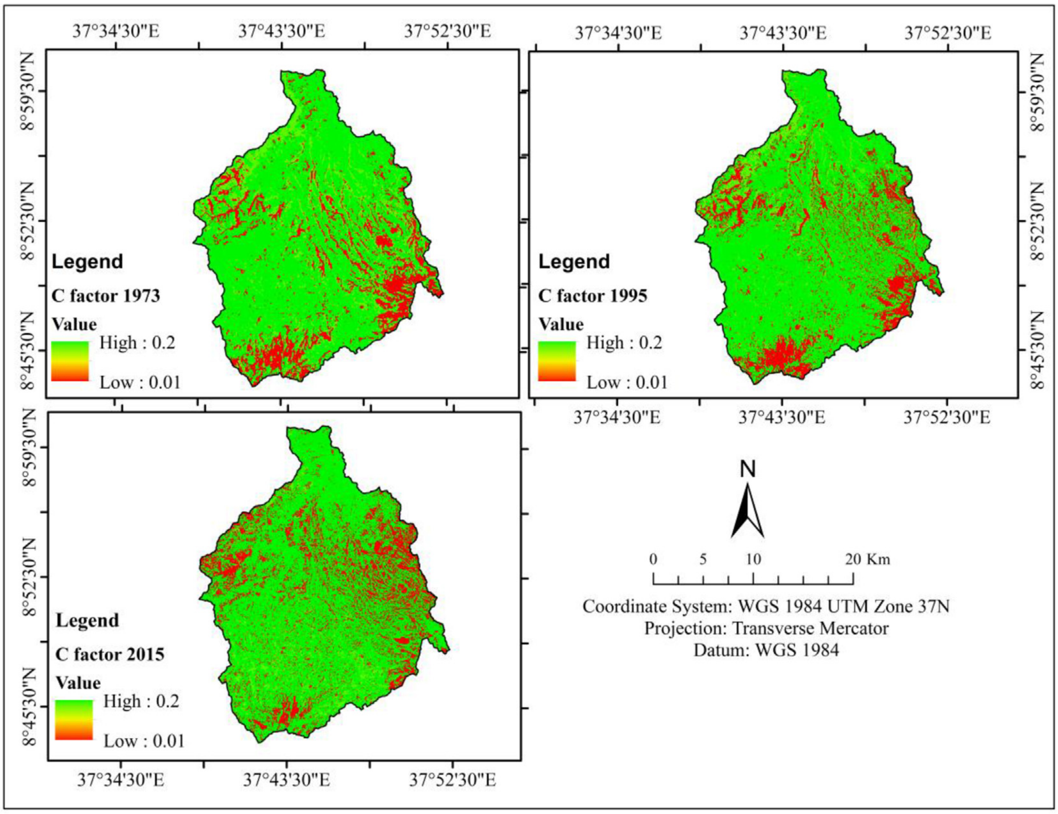
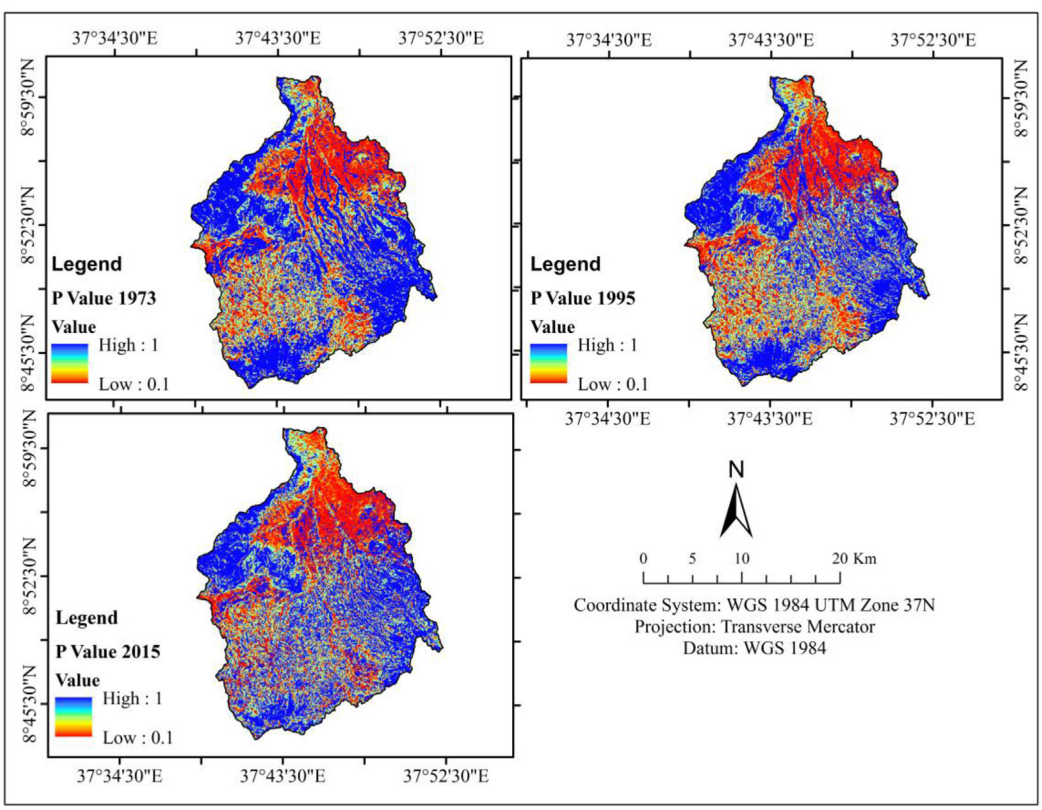


Figure 3. (a) Rainfall (R)-erosivity, (b) Soil type Erodibility (K) factor map.



A



B

Figure 4. (Top) Crop management (C-factor) for 1973, 1995 and 2015 map from left to right; (Bottom) Conservation practices (P-factor) for 1973, 1995 and 2015 map from left to right.

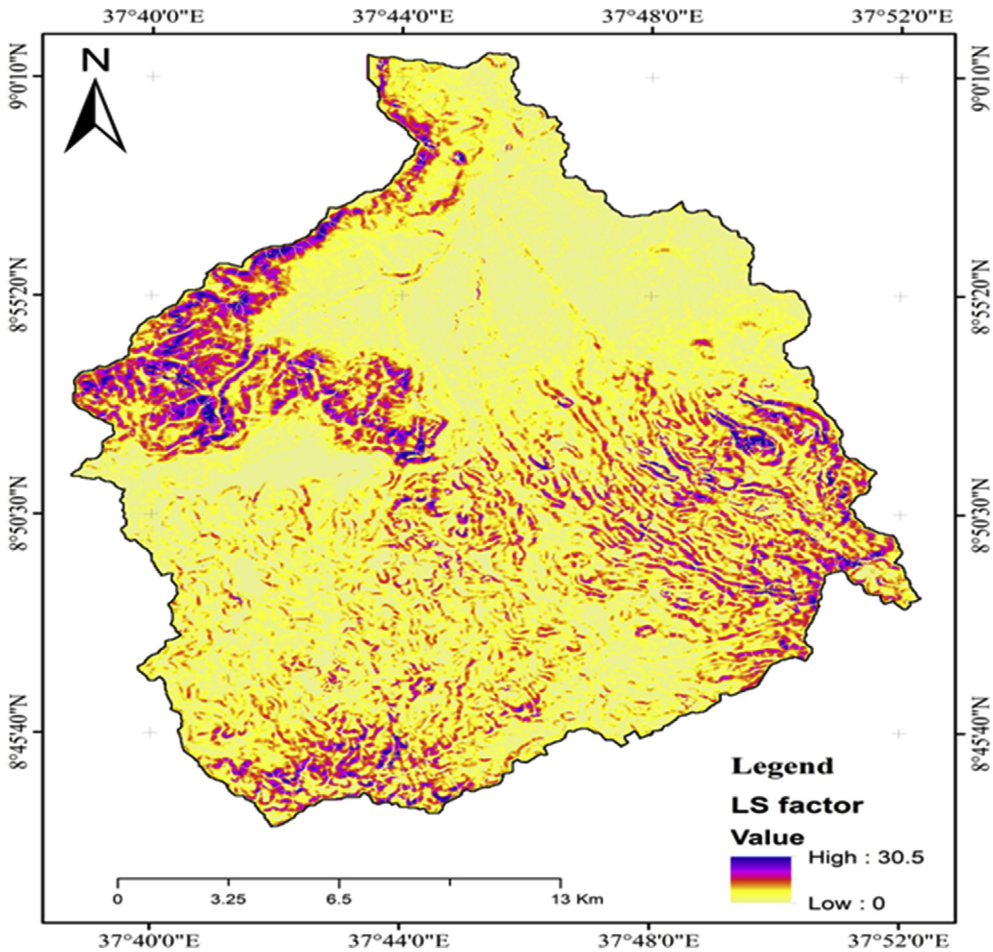


Figure 5. Slope length and steepness (LS-factor) map.

the watershed which resulted in high erodibility. The erodibility map was computed based on the value specified for each class which ranged from 0.15 to 0.30. The map revealed that Eutric Fluvisols and Haplic Alisols were considered highly susceptible to erosion, with Erodibility values of 0.3 and 0.25 respectively. The lowest value were assigned to Eutric Vertisols and Calcic Vertisols which are characterized as cracking heavy clay; both with a value of 0.15 located at the river mouth (Figure 2b). These values were found to be with the range reported by Ganasri and Ramesh (2016).

3.2.2. Slope length and steepness (LS)

By using 30*30m resolution DEM, the slope of the study area range from 0 to 54.1° (137.9%). The steepest slopes located in the western and eastern highland parts and are highly susceptible to soil erosion than the flat slope. The LS value was estimated using up slope contributing area approaches and it ranged from 0 to 30.5 which correspond to the topography factor of the region (Table 1 and Figure 3). The higher values of LS factor characterize steep slopes which were found on the highland areas of the sub watershed with severe erosion problems. This result is in line with other studies elsewhere in tropical countries which calls for more attention with regard to the various land management practices such as the need for soil and water conservation practices (Moore and Wilson, 1992; Prasannakumar et al., 2012; Kayet et al., 2018).

Table 6. Soil loss (t ha^{-1} yr^{-1}) result for 1973, 1995 and 2015 LULC.

Year	Minimum	Maximum	Mean	Total
1973	0	126	25.80	198618.3
1995	0	150	28.74	221221.3
2015	0	157	30.25	239171.0

3.2.3. Support practices and cover management factor (C)

The Wischmeier and Smith 1978 method was applied to compute support practice value. Soil and water conservation practices that were constructed along the side of steep slope area have poor design. Even though the values for P were estimated by considering the type of LULC and based on the suggested values for each LULC, similar studies showed non-significant difference between the values obtained for field measurement of SWC. Hence the method includes assigning different value for each LULC depending on the slope class. Based on the LULC change trend three P factor maps were created and used to determine the total soil loss using Eq. (1). Higher p values were recorded for the higher slope areas (Table 5 and Figure 4).

LULC change is considered as one of the most influencing factor for soil erosion. LULC of the study area used to compute C factor map and values were assigned for each cover management. The values of C factor for the watershed range from 0.02 to 0.36 for the three LULC for 1973, 1995 and 2015 years. The LULC change trend analysis result showed that the watershed was subjected to sizable changes. This in turn affects the value of C factor. The study assigned lowest value for forest and highest value for cultivated land which pointed out that the highest value of C factor accelerate soil erosion (Figure 5). This result agrees with other results which indicated that the presence of vegetation greatly reduced soil loss and sediment yield in yellow river basin in China and other

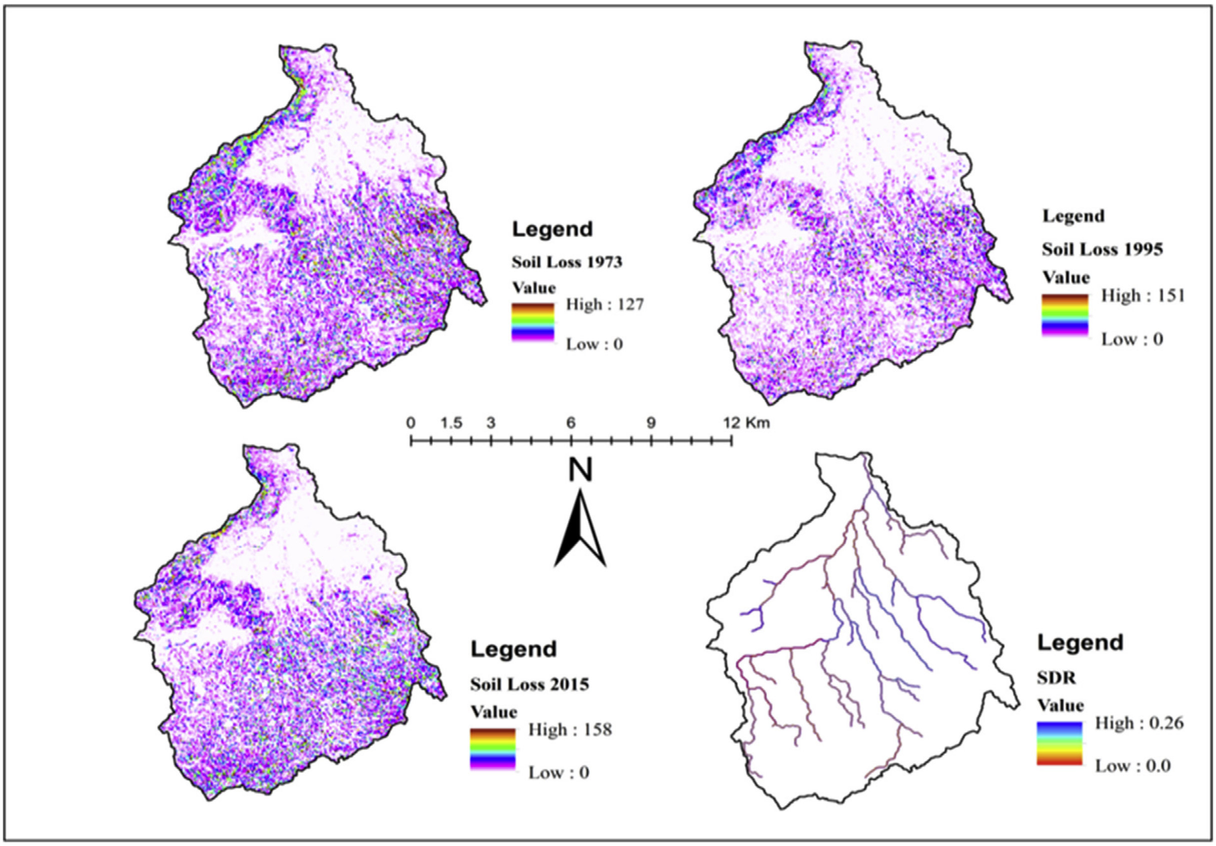


Figure 6. (a) Spatial distribution of soil loss during 1973, 1995 and 2015; (b) Map that show the watershed sediment deliver ration (SDR).

countries elsewhere (Maeda et al., 2008; Ouyang et al., 2010; Thomas et al., 2018; Ebabu et al., 2019; Sahle et al., 2019).

3.3. RUSLE analysis of soil erosion

The LULC change study of the watershed showed expansion of cultivated land. This change consequently affected the amount and rate of both soil erosion and sediment yield at the river mouth. In this study we evaluated impact of LULC change maps using 1973, 1995 and 2015. The resultant soil erosion map of each LULC for the three periods was presented (Tables 4, 5, and 6 and Figures 6, 7, and 8). The study revealed that the mean soil loss in the watershed ranged between 25-30 t ha^{-1} yr^{-1} accounting for 25.8, 28.7 and 30.3t $ha^{-1}yr^{-1}$ in 1973, 1995 and 2015 respectively. The estimated total soil losses for the 1973, 1995 and 2015 periods were 198 Mt yr^{-1}, 221 Mt yr^{-1} and 239 Mt yr^{-1} respectively (Table 6 and Figure 6).

The mean annual soil losses of the sub watershed were generally higher than the tolerable soil loss of 5–11 $t^{-1}ha^{-1}$ yr^{-1} as estimated by Hurni (1985) for Ethiopian highlands but it is lower than the value reported by Yesuph and Dagnaw (2019) for Bishillo catchment of the Blue Nile Basin in Ethiopia which is 37 t ha^{-1} yr^{-1}. Recent report on observed soil loss due to sheet and rill erosion at national level show an annual soil loss of 29.9 $tha^{-1}yr^{-1}$ from 25 observation sites in different parts of the country (Haregeweyn et al., 2015, 2017; Molla and Sisheber, 2017). Study by Hurni et al. (2015) estimated the total soil loss at the Ethiopian Grand Renaissance Dam river mouth was 320 Mt yr^{-1} using a modified USLE (MUSLE) model. This result has a reasonable agreement with others and can be used to evaluate the impact of LULC change on the watershed soil erosion and sediment yield.

Our estimated gross soil erosion showed significant change on mean soil erosion due to LULC change. The dominant change was observed between 1973 and 1995 LULC. During these two periods cultivated land showed a significant increase whereas forest and shrub land decreased considerably. Soil erosion was significantly higher on crop land and low in forested areas (FAO, 1986; Hurni, 1985; Reusing et al., 2000; Maeda et al., 2008; Ouyang et al., 2010; Prasannakumar et al., 2012; Ganasri and Ramesh, 2016; Haregeweyn et al., 2017; Kayet et al., 2018). Therefore soil erosion is an urgent agricultural problem, which presents a major threat to soil fertility and land productivity in the watershed. This problem coupled with lack of and inappropriate soil and water conservation structures intensify the magnitude of the problem.

Although soil loss during 1995 and 2015 showed increment, the change compared to 1973 to 1995 were found to be the lowest. During 1995–2015 change in cultivated land was comparatively lowest as compared to the previous period (Figure 6a). The soil erosion assessment in the northwestern highland, Chemoga watershed reported average soil loss of 93 t ha^{-1} $year^{-1}$ (Bewket and Teferi, 2009). Similarly a study conducted in Koga watershed reported an average soil erosion rate of 47.4 t ha^{-1} $year^{-1}$ (Gelagay, 2016). This variation on the reported soil loss record was because of LULC and topography difference considered for each study (Ouyang et al., 2010; Sahle et al., 2019).

3.4. Soil sediment analysis

Sediment yield of the river network is determined by SDR of the watershed. For this particular study the sediment deliver ratio were computed using empirical equation considering average slope channel and the result ranged from 0 to 0.26. The spatial distribution of SDR shows that the highest value was recorded on central and eastern part of the watershed. The result indicated that the eroded soil material which passes to the river channel system was converted to sediment yield up to the maximum of 26% (which is SDR of 0.26). On the other hand, out of the gross soil loss materials 74% were re-deposited in the sub watershed. Although the gross soil loss on the watershed was higher, the amounts of

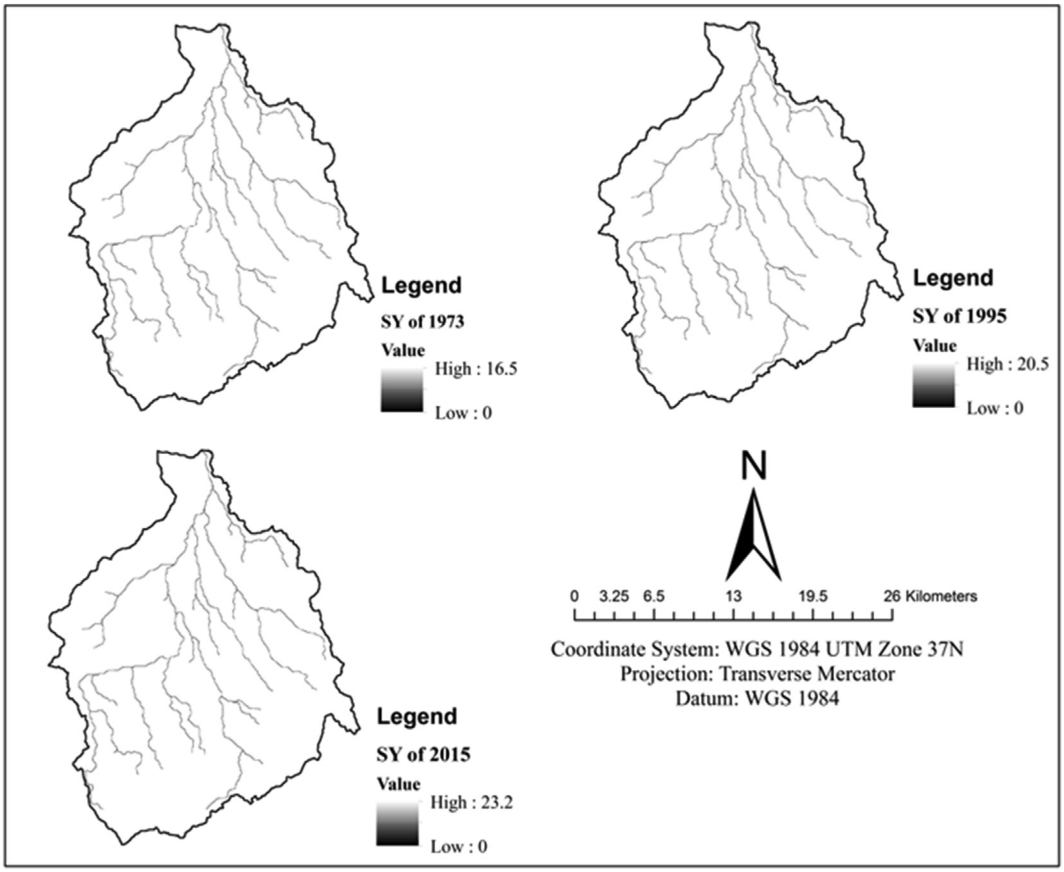


Figure 7. Sediment Yield at the river mouth in 1973, 1995 and 2015.

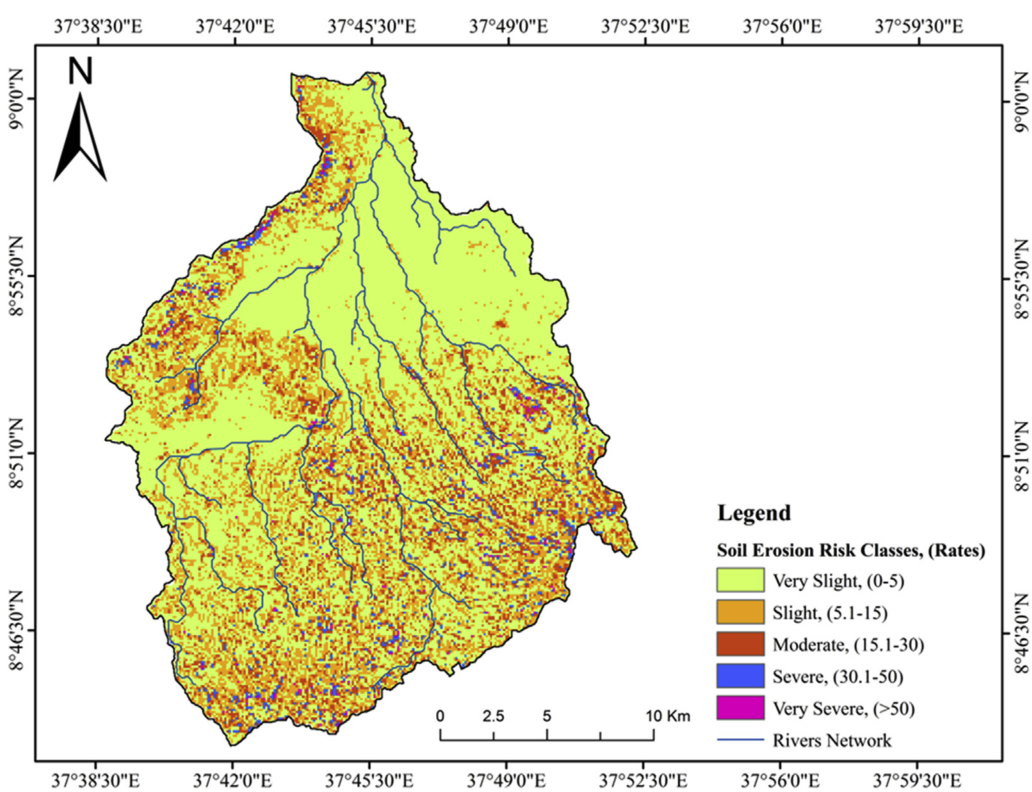


Figure 8. Soil erosion severity levels for Guder sub watershed.

Table 7. Soil sediment (t ha^{-1} yr^{-1}) result during 1973, 1995 and 2015 LULC periods.

	1973	1995	2015
Mean	6.79	8.65	9.44
Max	16	20	25
Total	46476.69	59287.32	74860.52

converted to very sever soil erosion classes. This increasing soil loss observed between 1973 and 2015 periods can be associated with higher rate of forest land conversion as well as practicing cultivation on steeply slope areas. A study report by Gashaw et al. (2017) found similar results in Geleda watershed of the Blue Nile Ethiopia.

Although soil loss rate in the study area showed increment during the two periods (1973–1995 & 1995–2015) with a slight increasing rate on the second period (i.e. less change observed in the second period (1973–1995) than the first, that is, for 1973–1995). During field observation there have been various activities undertaken in the watershed at different scale which are conducted by local agricultural office with financial support of Sustainable Land Management (SLM) program. The activities include different type of biological and physical soil and water conservation structures, such as *Fayna juu* and terracing on steep cultivated land and several tree planting campaigns. With this positive intervention to reduce the gross soil erosion still there is a continued problem of natural forest clearance, cultivation of steep slope and over grazing to support the rapid population growth in the watershed.

Table 8. Soil erosion severity classes, recorded gross soil loss and area coverage.

Severity Classes	Soil Loss (t ha^{-1} year^{-1})	Area (A)			Total Annual soil Loss (t ha^{-1} year^{-1})		
		1973	1995	2015	1973	1995	2015
Very Slight	0–5	28681.3	25593.4	21661.7	91227.0	83309.0	73562.0
Slight	5.1–15	11292.9	7682.0	7003.4	68963.3	78538.7	72804.0
Moderate	15.1–30	4407.8	9697.4	13267.2	25975.0	41082.0	59413.0
Severe	30.1–50	1787.9	2967.5	3802.9	9488.0	14333.3	19338.7
Very Severe	>50	484.1	713.8	918.9	2965.0	3958.3	14053.3
Total Area		46654	46654	46654	198618	221221	239171

soil material that pass the river mouth depend on SDR (Figure 6b). Our finding on the amount of sediment deposition within the sub watershed is in agreement with other studies in Ethiopia (Galagay and Minale, 2016).

The mean sediment yields for the three periods (1973, 1995 and 2015) were 6.79, 8.65 and 9.44 t ha^{-1} yr^{-1} respectively (Tables & Figure 7). Furthermore, the model witnessed change in LULC affected sediment yield during these periods. Estimated sediment yield in different part of the region and Blue Nile basin at different periods showed a close range with our model output. Even if the model is different, similar studies in Blue Nile basin estimated a total annual sediment yield of 118 Mt at the river mouth (Betrie et al., 2011).

Comparative study between the above years in terms of sediment yield also showed higher value for 2015. This implies that the sediment at the river mouth increased due to the direct and indirect consequence of LULC dynamics.

In contrast to the Hurni et al. (2015) tolerance limit, the result of this study for the three periods considered falls within the range of the other findings (FAO, 1986). According to the estimate of FAO (1986) the annual soil loss for the highlands of Ethiopia ranged from 1248-23,400 million ton per year from 78 million hectare of pasture, range lands and cultivated fields. The Ethiopian Highlands Reclamation Study also suggested the average annual soil loss of 100 t/ha/yr for the Ethiopian highlands (FAO, 1986).

3.5. Spatial distribution of soil erosion and severity analysis

The severity of soil erosion was significantly higher on areas where forest cover was converted to less vegetated area due to deforestation and coupled with steep slopes topography. Figure 8 show the spatial distribution of soil erosion severity classes. Over the three study periods, the severity has been observed and all classified land units have different magnitude of soil loss and categorized under different severity levels. High and severe soil loss is an indication of the causes of land degradation.

For the entire sub watershed the recorded gross soil loss was 198618.3 t/yr, 221221.3 t/yr and 239171 t/yr in 1973, 1995 and 2015 respectively (Table 6). Knowing the spatial distribution is imperative to tackle soil loss and sediment yield problem by applying appropriate soil and water conservation strategies based on severity level. Accordingly, the moderate to very severe soil erosion severity class which ranges from 30.1-50 t ha^{-1} yr^{-1} and >50 t ha^{-1} yr^{-1} concentrated on cultivated land and sloppy areas within the watershed. This indicates that the above two locations have high susceptibility to soil erosion (Figure 8). In 1973 only 9.45% of the total area was under moderate soil severity class, but these changed to 28.4% during 2015. Additionally 434ha of land was

The main reasons for increasing soil erosion prone areas in the watershed within study period were due to the reduction of forest coverage. Local communities continue to expand their cultivated land to more erosion prone areas and practicing non sustainable farming and grazing system. The result also showed that the transition of other LULC categories to cultivated land was most detrimental, while forest was the most effective barrier to soil loss. Since cultivated and grass lands are the two dominant LULC categories, implementation of best agricultural practices, tillage operation, and avoidance of overgrazing would be suggested for reducing soil erosion potential within the Watershed. Similar results have been reported in India (Ganasri and Ramesh, 2016; Ebabu et al., 2019), Brazil (Maeda et al., 2008) and Ethiopia (Sahle et al., 2019).

4. Conclusions

Land use and land cover change is a major cause of soil loss at watershed, regional and global scales. The mean annual soil loss in the study area was estimated using RUSLE model. The result showed that the mean annual soil loss for 1973, 1995 and 2015 were 25.8, 28.7 and 30.3 tone ha^{-1} yr^{-1} respectively. The result also revealed that sediment yield at the river mouth of the watershed follows the LULC change. The total sediment loss during the above three periods ranged from 23.4% to 31.3% and the lowest value was recorded in 1973. The spatial distribution of soil severity classes showed an increasing trend, that is, it increased from moderate to severe and very severe classes while areas under very slight and slight soil severity class decreased sharply. In the study period (1973–2015) 62.7–67.1% of the watershed area was categorized under cultivated land and considered as highly erosion susceptible area coupled by the nature of the topography.

Conversion of natural forest area from steep slope of the watershed to extensive farm land caused high rate of soil loss. Due to this change in land use, high amount of sediment yield can be easily transported to the downstream regions. In general, the model revealed that, erosion prone areas were increasing during the past four decades (1973–2015). Therefore, it is important to prioritize erosion prone areas and reclaim using physically and biological SWC structures to alleviate land degradation. This includes institutionalizing sustainable biological and physical soil conservation measures to mitigate land degradation and improve the livelihood of the local community in the watershed.

Our results indicated the continuous loss of soil from cultivated land due to improper land management practices and an increasing level of soil loss over the study period which calls for concerted efforts to be taken to reduce soil erosion and its associated problems.

Declarations

Author contribution statement

Moges Kidane, Alemu Bezie, Nega Kesete, Terefe Tolessa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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