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ARTICLE

Impact of deforestation on soil erosion in the highland areas of western Ethiopia using geospatial techniques: a case study of the Upper Anger watershed

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Abstract

Soil erosion is a major environmental problem in developing countries mainly due to forest cover loss driven by agricultural expansion. The current study aimed to analyze the impact of vegetation cover loss from elevated areas on soil erosion in the Upper Anger watershed using geospatial techniques and the revised universal soil loss equation (RUSLE) model. The mean annual soil loss in the study area was calculated using five factors: rainfall, soil type, slope length and steepness, cover management, and conservation practices. Furthermore, the normalized difference vegetation index and slope were used to calculate the relationship as well as the cause and effect of soil loss in the study area. The results revealed that the mean annual soil loss in the Upper Anger watershed was 44 ton/ha/year in 1989, 66.4 ton/ha/year in 2002, and 87.9 ton/ha/year in 2020. The annual soil loss in agricultural land increased from 75.9 ton/ha/year in 1989 to 98.5 ton/ha/year in 2002 and 103.8 ton/ha/year in 2020. The annual soil loss of the Upper Anger watershed increased by 99.8% due to a decline in vegetation cover from elevated areas for agricultural expansion based on adjusted R^2, with the remaining percentage possibly increasing due to other factors. Due to deforestation, the area of soil erosion increased from 551.8 km^2 (29.5%) in 1989 to 821.6 km^2 (44%) and 1043.8 km^2 (55.8%) in 2002 and 2020, respectively. This study identifies severe erosion loss areas for mitigation measures. To minimize the severity of soil loss in the study area conservation measures, such as re-afforestation, area closure, agroforestry practices, and participatory watershed management, should be promoted by governmental and nongovernmental organizations.

Keywords RUSLE · Soil loss · Vegetation covers loss · Elevated land · Soil loss

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1 Introduction

Soil erosion caused by a loss of vegetation cover in highland areas is the most serious environmental problem worldwide (Gobin et al. 2004; Pimentel 2006; Borrelli et al. 2017). Rainfall intensity, soil erodibility, poor soil conservation practices, and land use land cover (LULC) change is a challenge in Ethiopia, particularly in the highlands where highly rugged topography, and cultivating on steep slope lands, which accelerate soil erosion (Shiferaw 2011; Belayneh et al. 2019; Olika and Iticha 2019; Tsegaye 2019; Aneseyee et al. 2020; Nut et al. 2021). The removal of fertile soil is aggravated by an increase in surface runoff and a decrease in vegetation cover from steep slopes (WoldeYohannes et al. 2018; Kidane et al. 2019). The LULC change and ridged topography are the most important key parameters influencing soil erosion, particularly in Ethiopian highlands (Bewket and Abebe 2013; Gessesse et al. 2015; Moisa et al. 2021; Negash et al. 2021). According to Li et al. (2020), the rate of soil erosion increases as the catchment slope length and gradient increase. In areas where soil erosion is a risk, immediate action is required to implement soil and water conservation strategies (Haile et al. 2006; Molla and Sisheber 2017; Girmay et al. 2020; Moisa et al. 2021). The expansion of agricultural land to the highlands is a major cause of soil erosion in Ethiopia (Sisay et al. 2014; Kidane and Alemu 2015). Earlier studies (Gashaw et al. 2017, 2018, 2019) have reported that the expansion of cultivated land around steep slopes is the major driving force for soil erosion in the Ethiopian highlands. Every year, approximately 3.5 billion tons of top soil is removed due to soil erosion in the Ethiopian highlands, and soil erosion rates in Ethiopia are extreme (Kidane and Alemu 2015).

There are three soil erosion models, which include conceptual-, physical-, and empirical-based model (Santos et al. 1998). The conceptual models emphasized on the process governing system behaviors that makes unique from physical and empirical models (Beck 1987). The conceptual models focused on catchment processes, without considering various interactions (Renschler 1996). The physical-based models focused on the understanding of the physics of erosion process and the parameters used are measurable and known. In physical-based model, the parameters should be calibrated against observed data (Beck 1987). The empirical models are based on simulation of natural processes (Adongo et al. 2019) and mathematically simple to use but they are limited to the area where they have been developed (Santos et al. 1998). The revised universal soil loss equation (RUSLE) model, developed by Renard et al. (1997) was widely used due to relatively easy to use. The compatibility with geographic Information System (GIS) and remote sensing techniques is another advantage of using RUSLE model in soil erosion loss assessment and prioritization of hotspot areas for conservation action (Moisa et al. 2021).

Ethiopia has 60 million hectares of agricultural land (Douglass 1984; Sisay et al. 2014). Approximately 27 million and 14 million hectares of agricultural land have been highly and extremely eroded (Lema et al. 2016; Tilahun et al. 2018). In Ethiopia's highlands, agricultural land has a high risk for soil fertility decline (Habtamu et al. 2014; Balabathina et al. 2020). In Ethiopia, soil loss from cultivated fields is estimated to be approximately 42 ton/ha/year (Hurni et al. 2008; Bekele and Gemi 2021). According to Hurni et al. (2015) and Atoma et al. (2020), western Ethiopia has the highest rate of soil erosion. The Upper Anger watershed is located in western Ethiopia and is known for its undulating terrain with rolling plains and valleys, agricultural expansion, deforestation, overgrazing, land fragmentation, and poor land management practices, all of which have exacerbated the situation.

Although the consequences of soil erosion as a result of declining vegetation cover in elevated areas were severe, it received little research attention. Several studies have been conducted on the impact of LULC change on soil erosion in Ethiopia (Kidane et al. 2019; Gashaw et al. 2019; Aneseyee et al. 2020; Moisa et al. 2021, 2022c; Negash et al. 2021; Negese 2021), but these studies did not address the impacts of vegetation cover losses from elevated areas on soil erosion. The southwestern parts of the country do not get the attention of scholars because of its relatively good in vegetation cover as compared to other parts of Ethiopia. Even though, some areas are covered by vegetation, substantial areas are highly exposed to deforestation driven by agricultural land expansion. The loss of vegetation cover aggravates the problem of soil erosion in southwestern parts of Ethiopia which in turn leads to decline in agricultural productivity and increased the problem of food insecurity. This problem needs research attention to sustain communities' wellbeing on one hand, and on the other hand, providing robust evidence on the linkage between deforestation and soil loss can alert local administration and decision-makers to actively engaged in natural resources conservation in general and soil erosion protection in particular, which may increase agricultural productivity. Furthermore, this study analyzes the correlation between normalized difference vegetation index (NDVI) and slope with mean soil loss in the study area. Finally, this study indicates the effectiveness of RUSLE model and geospatial technologies to estimate the impact of vegetation cover loss on soil erosion in the highland areas of Ethiopia.

2 Materials and methods

2.1 Descriptions of the study area

This research was conducted in the Upper Anger watershed which is situated in the Abay River basin. The study area was located between the East Wollega Zone and the Horo Guduru Wollega Zone of Oromia National Regional State, Western Ethiopia (Fig. 1). Geographically, the Upper Anger watershed lies between 9°27′30″ and 10°23′00″ N and 36°39′00″ and 37°73′00″ E and the elevation of the study area lies between 1330 and 3171 m above sea level. It covers an area of 1869.1 km^2.

2.2 Data sources and data types

In the present study, the required data were obtained from Landsat TM, Landsat ETM+and Landsat OLI/TIRS for the years of 1989, 2002 and 2020, respectively from

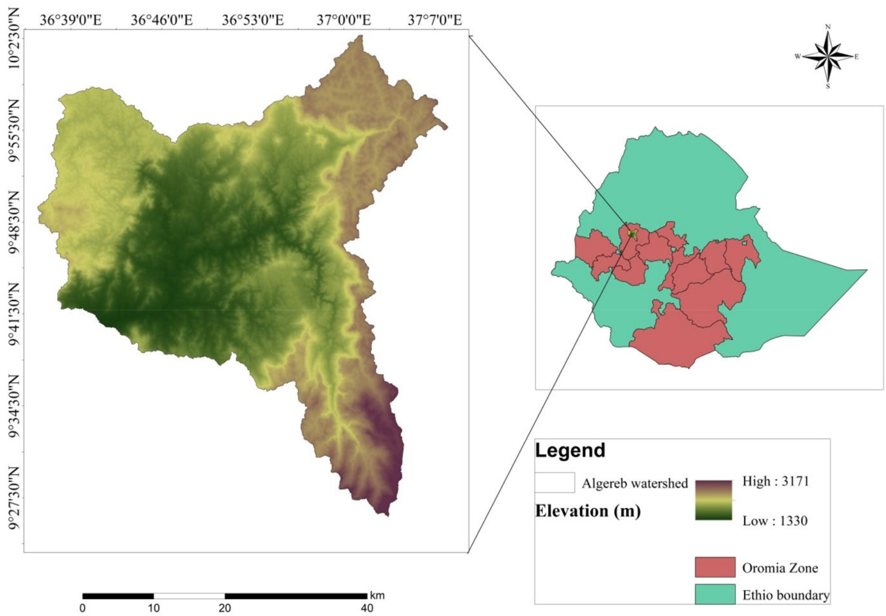

Fig. 1 Map of the study area

the U.S. Geological Survey (USGS) website (https://earthexplorer.usgs.gov/). Rainfall data from the National Meteorological Agency of Ethiopia, and soil types from digital soil map of Ethiopia developed by Food and Agriculture Organization (FAO), 30 m resolution of digital elevation model (DEM) from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) website https://asterweb.jpl.nasa.gov/gdem.asp of USGS were used for this study (Fig. 2). Materials used for the study included: Handled GPS and Digital Camera as well as software, such as ArcGIS 10.3, ERDAS 2015, Arc SWAT and Google Earth pro, were used for the analysis.

2.3 Data analysis

2.3.1 Land use land cover change analysis

In classifying the images, supervised image classification with the maximum likelihood algorithm was used to categorize different LULC types (Khatami et al. 2016). Images were classified into agricultural land, forest land, grassland, bare land and settlement using the ERDAS Imagine 2015 software.

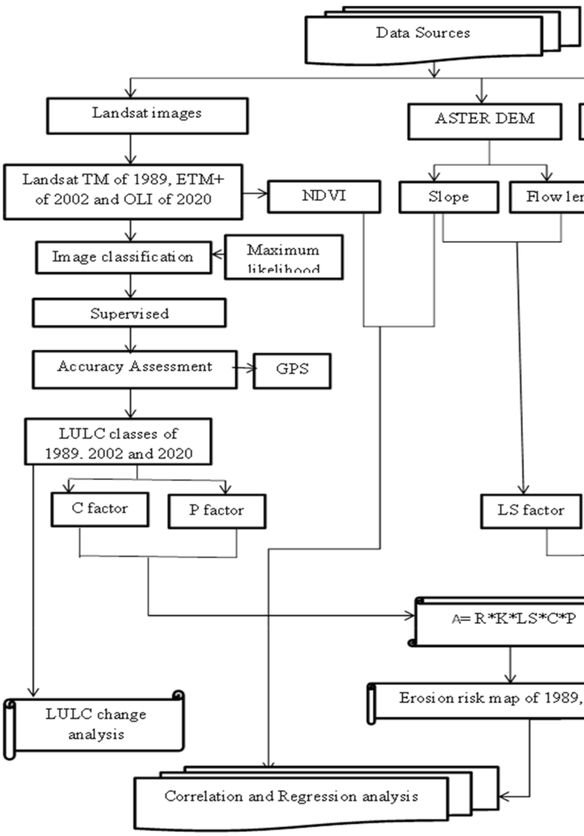

Fig. 2 Methodological flowchart of the study

2.4 Estimation of soil loss

To estimate the amount of soil loss in the Upper Anger watershed, the RUSLE model with integration of the Geographic Information System (Wischmeier and Smith 1978) was adopted to estimate the annual soil loss (Eq. 1).

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

where A = average soil loss per unit area in ton/ha/year, R = rainfall–runoff erosivity factor in MJ mm ha^{-1} h^{-1} year^{-1}, K = soil erodibility factor in ton ha/MJ/mm, LS = slope length and steepness, C = cropping and management systems, P = conservation practices

2.4.1 Rainfall erosivity (R) factor

The erosivity factor reflects the effects of raindrops on soil erosion (Ganasri and Ramesh 2016; Napoli et al. 2016; Lal and Elliot 2017; Ouyang et al. 2018; Koirala et al. 2019). Therefore, the erosivity factor R was calculated according to the equation given by Hurni (1985), derived from a spatial regression analysis for Ethiopian conditions based on the available mean annual rainfall data (Eq. 2).

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

where P is mean annual rainfall in (mm).

Seven metrological stations (Shambu, Anger Gute, Sibu Sire, Nekemte, Haro, Chagni and Debremarkos) with mean annual rainfall of 31 years were used to calculate the R factor. The annual rainfall was interpolated from each station using Inverse Distance Weighting (IDW) interpolation techniques (Fig. 3).

2.4.2 Soil Erodibility (K) factor

The K factor is used to estimate the vulnerability of soil to erosion (Prasannakumar et al. 2012; Atoma et al. 2020; Nasidi et al. 2020). The susceptibility of soil to erosion varies based on the soil types (Gayen et al. 2020). The value of K was estimated using soil color which adopted by Hurni (1985) for Ethiopian condition (Table 1). The FAO digital soil map of Ethiopia were used for this study, which was obtained

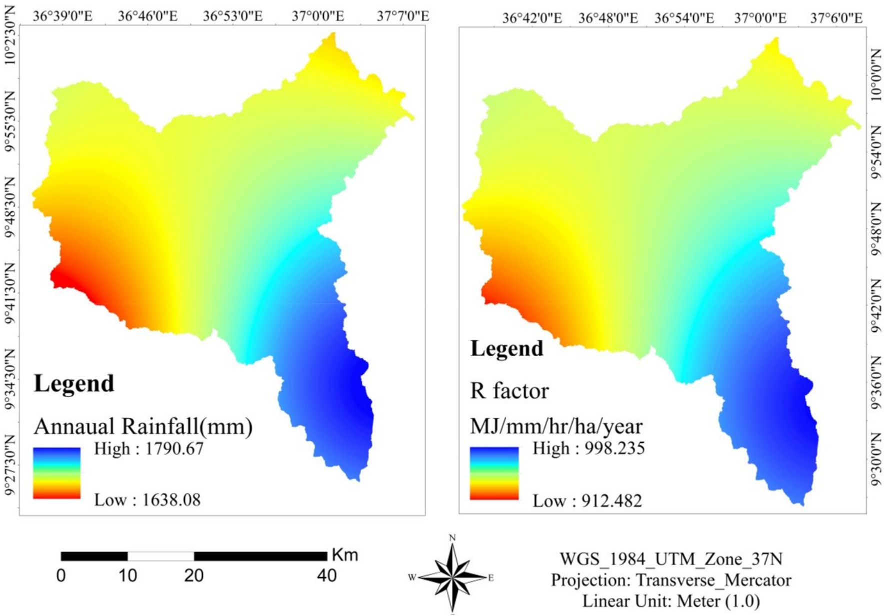

Fig. 3 Annual rainfall and R factor map

Table 1 Soil types and K factor

Soil types	Area (km^2)	K factor
Calcic cambisols	50.1	0.05
Chromic cambisols	254.5	0.28
Dystric gleysols	71.5	0.35
Dystric nitisols	522.2	0.25
Eutric cambisols	3.0	0.34
Eutric nitisols	305.0	0.25
Haplic xerosols	117.3	0.2
Leptosols	155.3	0.3
Orthic acrisols	17.5	0.22
Orthic luvisols	93.3	0.2
Orthic solonchaks	232.9	0.15
Phaeozems	2.4	0.2
Vertic cambisols	44.0	0.24

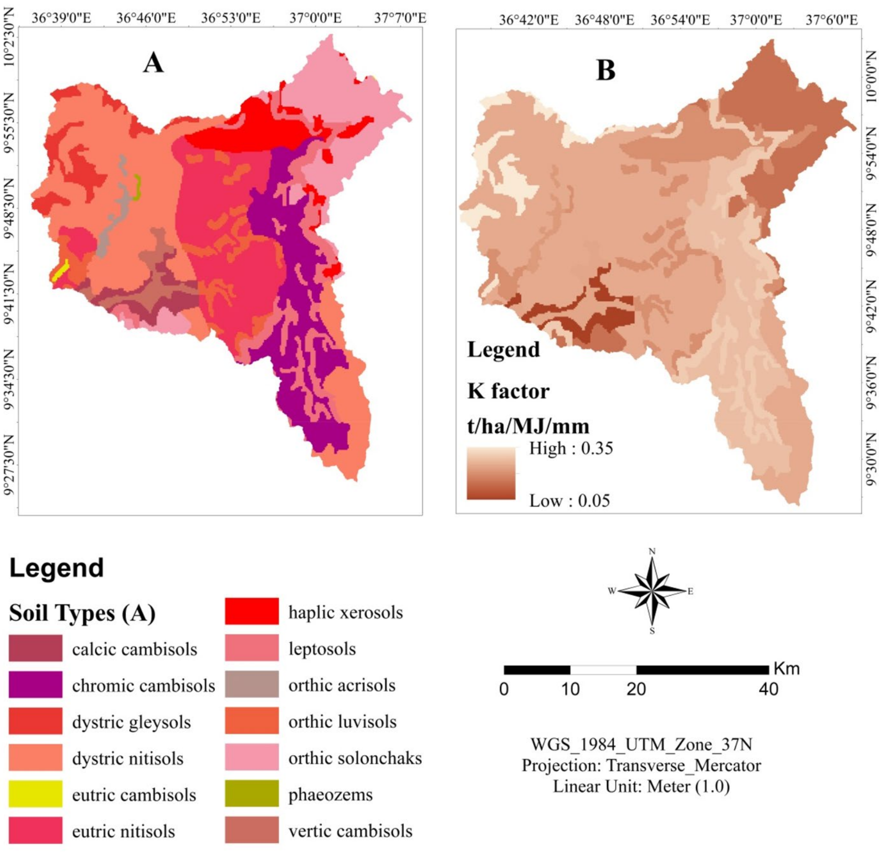

Fig. 4 Soil types and K factor map

from Oromia Water Works Design and Supervision Enterprise (OWWDSE) and used to develop the soil map for soil erosion risk analysis (Fig. 4). Then, erodibility value (K factor) is assigned for each of the soil types based on their colors according to (Hurni 1985; Gelagay and Minale 2016; Gashaw et al. 2017; Esa et al. 2018; Desalegn et al. 2018).

2.4.3 Slope length and steepness (LS) factor

In this study, the slope length and steepness factor were determined using digital elevation model (DEM) with 30 m resolution (Fig. 5). Based on FOA (2006) slope gradient classes (Table 2), we re-classified slope class of the Upper Anger watershed by considering great topographic variation (1330–3171), and LULC dynamics. Accordingly, the slope of the study area was classified as: flat to almost flat terrain (0–2%); gently flat to undulating terrain (2–10%); rolling terrain (10–15%); hilly terrain (15–30%), and steep dissected to mountain terrain (> 30%).

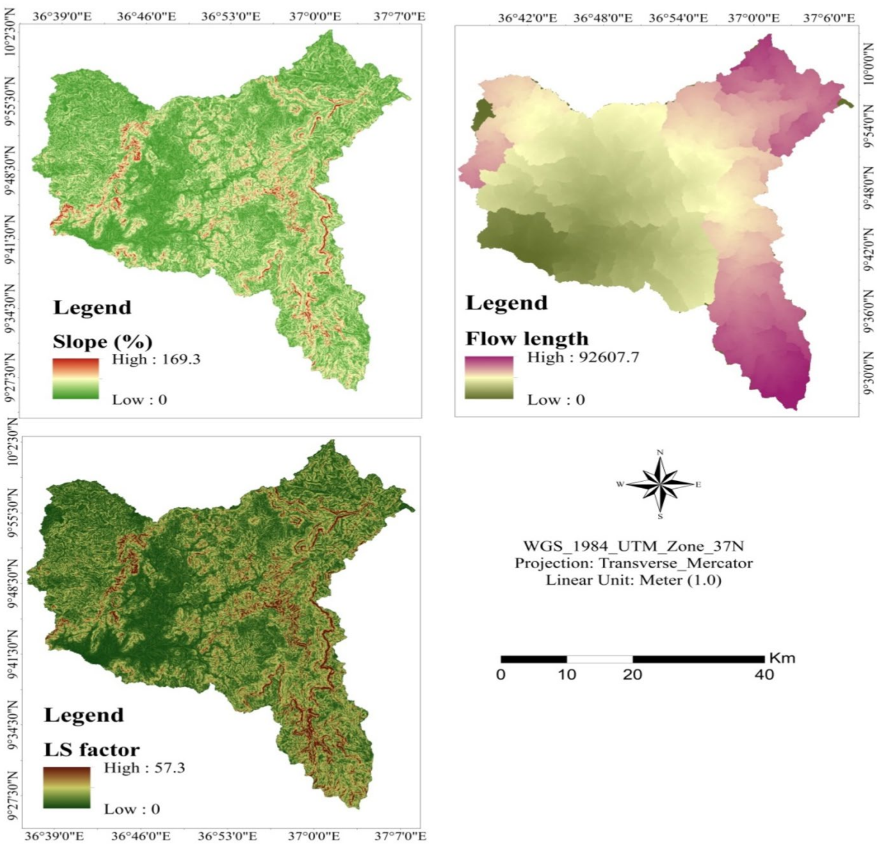

Fig. 5 LS factor map of the study area

Table 2 Slope gradient classes (FOA 2006)

Description	Slope range in %
Flat	0–0.2
Level	0.2–0.5
Nearly level	0.5–1.0
Very gently sloping	1–2
Gently sloping	2–5
Sloping	5–10
Strongly sloping	10–15
Moderately sloping	15–30
Steep	30–60
Very steep	> 60

The LS is calculated using (Eq. 3). LS is the ratio of observed soil loss related to the soil loss of standardized plot (22.13) as developed by Moore and Burch (1986), and used by (Ostovari et al. 2017).

$$\mathrm{LS} = \text{Flow accumulation}\, X\left(\frac{\text{Cell size}}{22.13}\right)^{0.4} X\left(\frac{\text{sin Slop}}{0.0896}\right)^{1.3} \tag{3}$$

where Flow accumulation represents the contribution of an area accumulated upslope for a given cell, LS is the combination of the slope length and slope steepness factor, cell size refers to the size of the grid cell (for this study, the specific DEM is 30 m pixel size) and the sin slope is the slope degree value in sin.

2.4.4 Cover management (C) factor

Cover management (C factor) is used to estimate the relative influence of the management approach on the conservation plan (Fayas et al. 2019; Almagro et al. 2019) which was calculated from LULC types in the study area. The Upper Anger watershed was classified into five LULC types and the C factor value was assigned (Table 3; Fig. 6) based on the existing literature (Moisa et al. 2021; Negash et al. 2021).

Table 3 C factor and P factor of the study area

LULC types	C factor	P factor
Agricultural land	0.18	0.9
Bare land	0.05	0.73
Forest	0.001	0.53
Grassland	0.05	0.63
Settlement	0.05	0.63

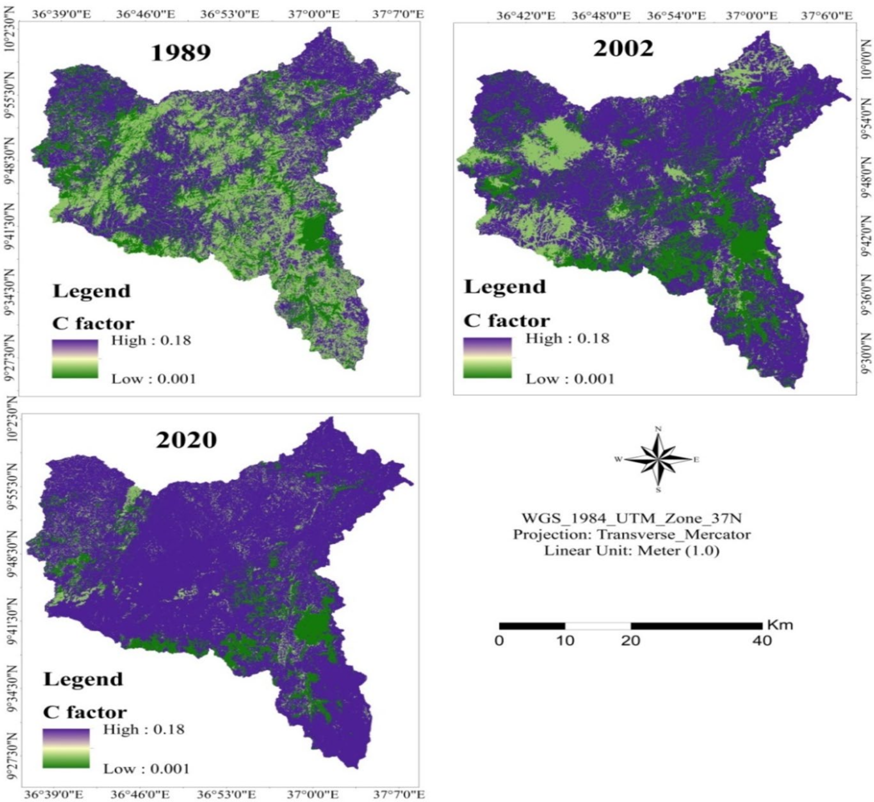

Fig. 6 C factor map of the study area

2.4.5 Erosion control practice factor

The P factor signifies the ratio of soil erosion from a land treated with a specific conservation measure to its equivalent soil loss from up and down slope tillage (Esa et al. 2018; Belayneh et al. 2019). The P factor for different land use categories was assigned based on the existing literature (Fig. 7) as previously used by (Fayas et al. 2019; Olika and Iticha 2019; Prasannakumar et al. 2012).

2.5 Normalized difference vegetation index (NDVI)

The NDVI was calculated from Landsat images of multi-spectral bands and used to calculate the extent to which vegetation covers the earth's surface (Tran et al. 2017). Band 4 was used to measure near-infrared bands on Landsat 5 and 7, and band 5 was used on Landsat 8. The red bands of the Landsat data were measured using band 4 for Landsat 8 and band 3 for Landsat 5 and 7 (Asare et al. 2020). In this study, NDVI was calculated using red bands and near-infrared images from Landsat 5 in 1990, Landsat

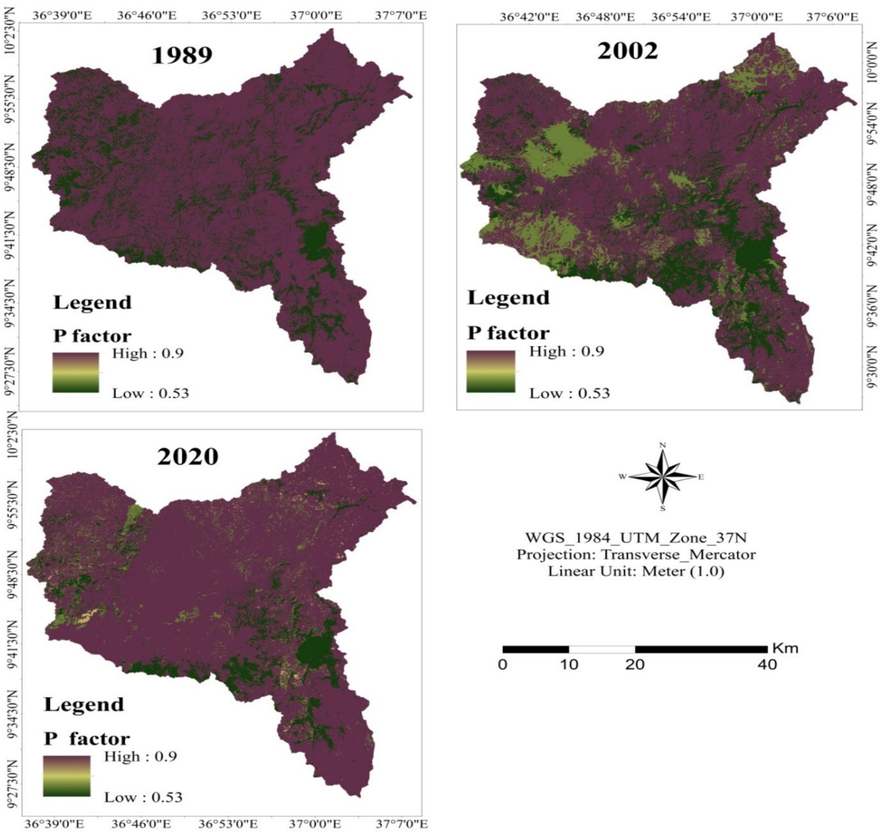

Fig. 7 P factor map of the study area

7 in 2000, and Landsat 8 in 2020. High reflectivity in the near-infrared (NIR) region indicates healthy vegetation, while low reflectance in the red band indicates stressed vegetation (Mahajan and Bundel 2016). This index's formula is presented in (Eq. 4)

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{4}$$

The NDVI scale spans from − 1.0 to 1.0 (Mahajan and Bundel 2016). For health and dense vegetation, the NDVI values are always between 0.2 and 0.9 (Ahmed and Akter 2017). Land cover such as rock, water, and barren plains, on the other hand, are represented by values less than 0.1 (Ju and Masek 2016).

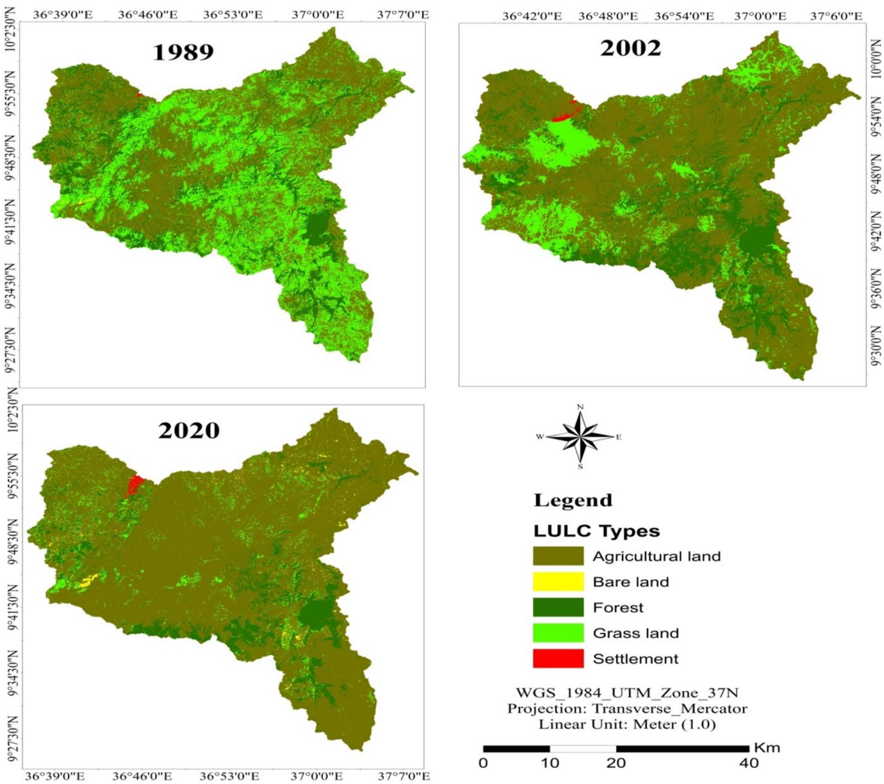

Fig. 8 LULC types of the study area between 1989 and 2020

3 Results and discussion

3.1 Land use land cover of the study area

Land use land cover classes in the study area were classified into agricultural, forest, grassland, bare land and settlement during the study period (1989, 2002 and 2020) (Fig. 8). The results show that, agricultural land was the most dominant LULC types with an area of 846.9 km^2 (45.3%), 1245.8 km^2 (66.7%) and 1554.3 km^2 (83.2%) during 1989, 2002 and 2020, respectively. This clearly revealed that agricultural lands were growing significantly over the study period. A recent study by Moisa et al. (2022a) in the Anger River Sub-basin reported the increasing trends of agricultural land between the year 1990 and 2020. The results revealed that forest land shows a decreasing trend from 1989 to 2020 due to the encroachment of agricultural land and other underlying factors. Results show that forest cover in 1989 was about 380.2 km^2 (20.3%) and declined to 342.0 km^2 (18.3%) in 2002 and then rapidly reduced to 200.3 km^2 (10.7%) in 2020 (Table 4). Bare land and settlement cover classes showed an increasing trend. For instance, the bare land has been increased

Table 4 LULC change of the study area

Area of LULC	1989		2002		2020	
	(km^2)	%	(km^2)	%	(km^2)	%
Agricultural land	846.9	45.3	1245.8	66.7	1554.3	83.2
Bare land	3.9	0.2	12.0	0.6	18.4	1.0
Forest	380.2	20.3	342.0	18.3	200.3	10.7
Grassland	636.8	34.1	265.7	14.2	90.4	4.8
Settlement	1.3	0.1	3.6	0.2	5.6	0.3
Total	1869.1	100.0	1869.1	100.0	1869.1	100.0

from 3.9 km^2 in 1989 to 18.4 km^2 by the year 2020. Similarly, the settlement increased from 1.3 km^2 in 1989 to 3.6 km^2 and 5.6 km^2 in the year 2002 and 2020, respectively.

3.2 Land use land cover conversion between 1989 and 2020

The land use transfer matrix (LUTM) method was used to analyze the LULC change over the study period (1989 to 2020) as recently used by Moisa et al. (2021). The results show that about 530 km^2 of grassland land cover was converted to agricultural land, while about 241.5 km^2 of forest cover was converted to agricultural land between 1989 and 2020 (Table 5). The high conversion of forest cover to agricultural land has been reported by Negassa et al. (2020) in Komto protected forest priority area from the years 1991 to 2019. Other study by Moisa et al. (2022b) found that vegetation covers substantially declined due to agricultural expansions. The spatial distribution of the major LULC conversion is presented in (Fig. 9).

3.3 Topography of the study area

Similar to other highland areas in southwestern parts of Ethiopia, the study area was dominated by hilly terrain with an area of 718.3 km^2. Next to hilly terrain, study area

Table 5 LULC change matrix of the study area (km^2)

LULC class		2020					
		Agricultural land	Bare land	Forest	Grassland	Settlement	Total
1989	Agricultural land	781.6	11.7	24.9	25.8	2.7	846.7
	Bare land	0.8	0.4	0.0	0.7	1.0	2.9
	Forest	241.5	0.6	116.9	22.1	1.2	382.2
	Grassland	530.0	5.8	58.5	41.9	0.5	636.7
	Settlement	0.0	0.0	0.0	0.0	0.7	0.7
	Total	1553.8	18.4	200.3	90.4	6.1	1869.1

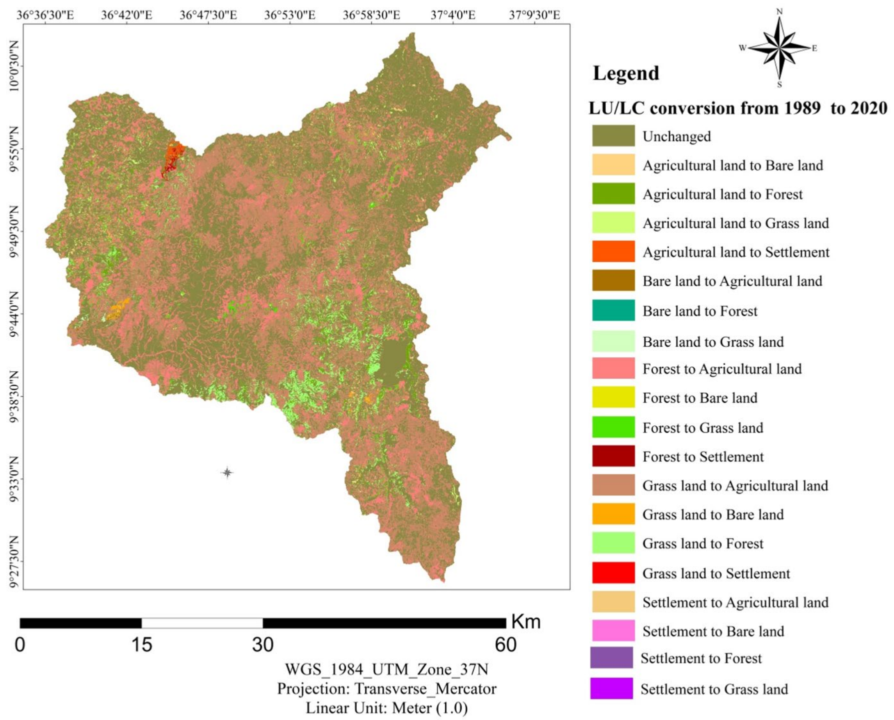

Fig. 9 Spatial distribution of LULC conversion map between 1989 and 2020

Table 6 Slope classes name and their corresponding area coverage

Slope range (%)	Classes name	Area (km^2)
0–2	Flat to almost flat terrain	21.6
2–10	Gently flat to undulating terrain	477.5
10–15	Rolling terrain	383.5
15–30	Hilly terrain	718.3
> 30	Steep dissected to mountainous terrain	267.9

situated in gently flat to undulating terrain and rolling terrain by area of 477.5 km^2 and 383.5 km^2 respectively (Table 6; Fig. 10).

3.4 Land use land cover change over slope range in 1989

From the result of LULC change, agricultural land was increased on highland (> 30%) slope than gentle slope or low land (0–2%) in 1989 by an area of 50.3 km^2 and 13.8 km^2, respectively. This is the main reason for the decline in vegetation cover and increase of soil erosion rate (Table 7).

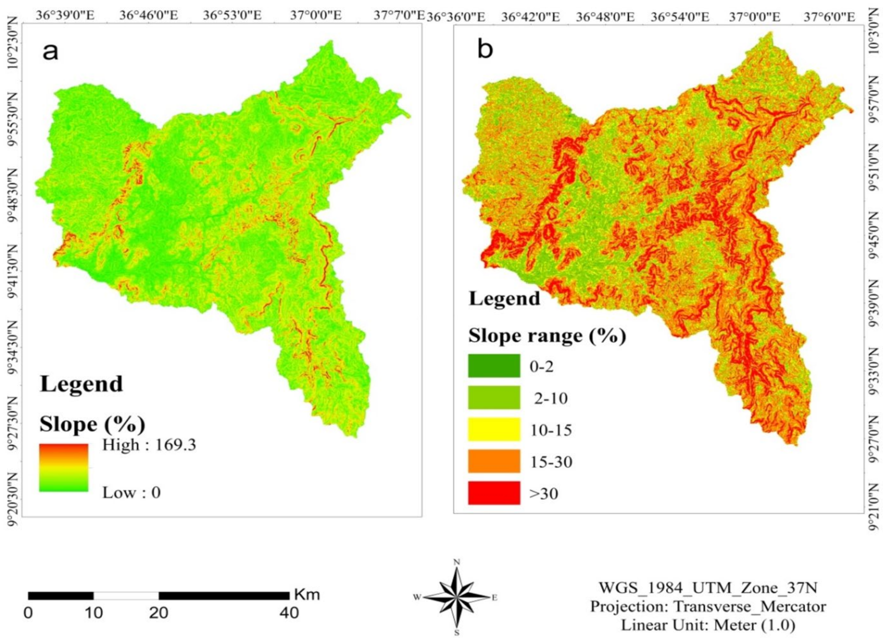

Fig. 10 Slope and slope range of the study area

Table 7 LULC types with slope range in 1989

LULC types	Slope (%)				
	0–2	2–10	10–15	15–30	> 30
Agricultural land	13.8	290.5	205.4	286.1	50.3
Bare land	0.003	0.05	0.07	0.5	1.2
Forest	3.1	75	64.5	148.6	90.7
Grassland	4.3	110.3	113.2	282.8	125.6
Settlement	0.09	0.4	0.08	0.1	0.01

Table 8 LULC types with slope range in 2002

LULC types	Slope in (%)				
	0–2	2–10	10–15	15–30	> 30
Agricultural land	14.3	334.4	270.8	458.3	116.5
Bare land	0.02	0.35	0.17	0.23	0.17
Forest	3.1	71.4	64.6	161.7	101.6
Grassland	3.6	68.4	47	96.7	49.5
Settlement	0.2	1.6	0.6	1	0.07

3.5 Land use land cover change over slope range in 2002

From the result of LULC change, agricultural land was increased on high land (> 30%) slope than gentle slope or low land (0–2%) in 2002 by an area of 116.5 km^2 and 14.3 km^2 respectively. This is the main reason for decline of vegetation cover and increment of soil erosion rate (Table 8).

3.6 Land use land cover change over slope range in 2020

From the result of LULC change, agricultural land was increased on highland (> 30%) slope than gentle slope or lowland (0–2%) in 2020 by an area of 187.2 km^2 and 18.9 km^2 respectively. This is the main reason for decline of vegetation cover and increment of soil erosion rate (Table 9).

3.7 Estimation of annual soil loss of Upper Anger watershed

The results revealed that the mean annual soil loss in the Upper Anger watershed increased from 44.8 ton/ha/year in 1989 to 66.4 and 87.9 ton/ha/year in 2002 and 2020, respectively (Fig. 11). The annual soil loss of the Upper Anger watershed is greater than the indicated tolerable range by Hurni (1985) for different agro-ecological zones of Ethiopia, i.e., 2 ton/ha/year to 16 ton/ha/year. The rate of soil erosion increases as the slope length and gradient of the catchment increase. The highest key parameters that affect soil erosion are LULC change and ridged topography. It is necessary to implement soil and water conservation strategies in areas where soil erosion is a risk. As the result, decline of vegetation cover for agricultural expansion to steep slope was the main causes for substantial increasing of soil loss rate from time to time in the study area. Moisa et al. (2021) confirmed that, LULC change has an impact on soil erosion.

Results revealed that about 68% of the study area were classified under sever and very sever soil loss severity range in 2020 while it was about 44% in the year 1989 (Table 10). This clearly indicates that there is high LULC change in the study area which was driven by agricultural expansions. Moisa et al. (2021) confirmed that changes in LULC have an effect on soil erosion. Other study by Gemeda et al. (2021) reported that LULC change is one of the major driving forces for the increasing trends of temperature in southwestern parts of Ethiopia. The LULC

Table 9 LULC types with slope range in 2020

LULC types	Slope (%)				
	0–2	2–10	10–15	15–30	> 30
Agricultural land	18.9	420.6	331.6	594.6	187.2
Bare land	0.2	4.4	4.1	7.2	2.3
Forest	1	29.9	31.8	81.3	56.1
Grassland	0.9	18.4	14.7	34.1	22.2
Settlement	0.28	2.7	0.9	0.6	0.1

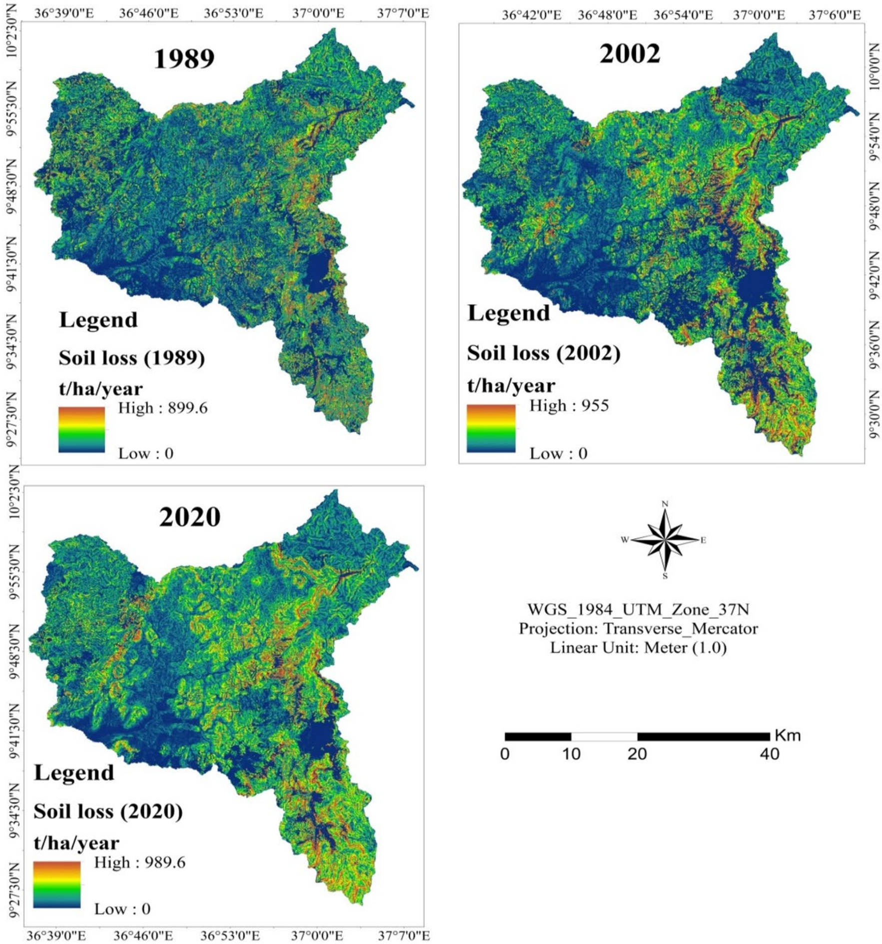

Fig. 11 Annual soil loss map of the study area

Table 10 Severity classes and area of soil loss in the study area

Severity range (ton/ha/year)	Severity classes	1989		2002		2020	
		Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
0–5	Very slight	477.5	25.5	474.2	25.4	256.5	13.7
5–15	Slight	242.6	13.0	158.5	8.5	136.2	7.3
15–30	Moderate	324.7	17.4	203.8	10.9	202.0	10.8
30–50	Severe	272.6	14.6	211.0	11.3	230.6	12.3
> 50	Very severe	551.8	29.5	821.6	44.0	1043.8	55.8
Total		1869.1	100.0	1869.1	100.0	1869.1	100.0

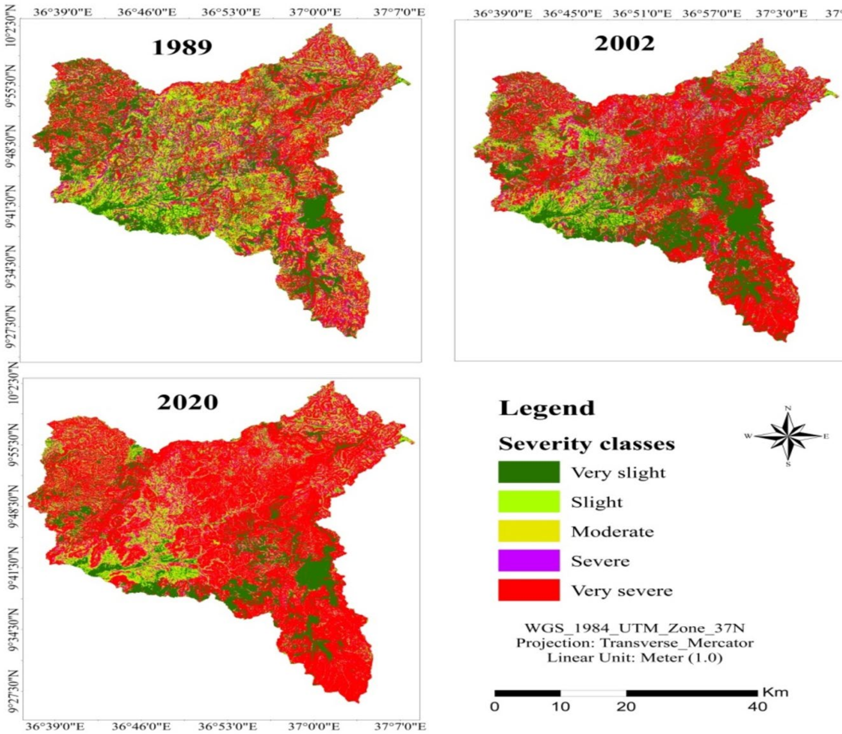

Fig. 12 Soil loss severity map of the study area

change highly contributes to annual soil loss. The spatial distribution of soil loss severity varies across the study area and very severe soil loss was observed in the southeastern parts of the watershed (Fig. 12). The annual rainfall and R factor map showed that the southeastern parts of the watershed receive high amount of annual rainfall, while the northwestern receive low amount of annual rainfall.

3.8 Soil loss rate per slope from 1989 to 2020

The mean of soil loss in the study area increased from low land (0–2%) slope to high land (> 30%) slope from 1989 to 2020 by 2.25 ton/ha/year to 207.6 ton/ha/year,

Table 11 Mean soil loss and slope range

Slope range (%)	Mean soil loss (t/ha/year)		
	1989	2002	2020
0–2	2.25	3	3.3
2–10	16.2	19.3	22.9
10–15	34.7	45.2	53.3
15–30	57.9	85.4	107.4
> 30	78.5	134.2	207.6

Table 12 LULC types with mean soil loss from 1989 to 2020

LULC types	Mean soil loss (t/ha/year)		
	1989	2002	2020
Agricultural land	75.9	98.5	103.8
Bare land	19.7	21.7	35.7
Forest	0.5	0.6	3.1
Grassland	21.1	28.2	28.8
Settlement	12.2	12.4	23.3

Table 13 Correlation of soil loss with NDVI and slope

Correlation	Soil loss	NDVI	Slope
Soil loss	1		
NDVI	− 0.8633	1	
Slope	0.99766	− 0.893	1

respectively (Table 11). Expansion of agricultural to high land area by decreasing vegetation cover is the main factor for increasing soil erosion over the study period. Beyene (2019) confirmed that soil erosion increased with slope.

3.9 Land use land cover change and soil erosion rate

The relationship between LULC types and mean soil loss was calculated in ArcGIS using zonal statistics. As a result, soil erosion in agricultural land increased in the study area from 1989 to 2020. By reducing vegetation cover, agricultural land was expanded to elevated land. Soil loss was increased from 75.9 ton/ha/year in 1989 to 98.5 ton/ha/year in 1990, and 103.8 ton/ha/year in 2020 (Table 12). The findings of this study are consistent with Moisa et al (2021) and Negash et al. (2021) in the case study areas of Temeji and Chogo watersheds, respectively.

3.10 Correlation analysis of mean soil loss with NDVI and slope

Soil erosion in the study area has a negative relationship with the NDVI with $R^2 = -0.89$ and a positive relationship with slope with $R^2 = 0.99$ (Table 13). The results show that a significant decrease in vegetation cover for agricultural expansion to large land areas was the primary reason for an increase in mean annual soil loss from time to time in the study area.

3.11 Correlation analysis of annual soil loss with rainfall erosivity

In the study area, soil loss showed a positive correlation (Fig. 13) with the rainfall erosivity factor ($R^2 = 0.93$). This indicates that as the amount of rainfall increases

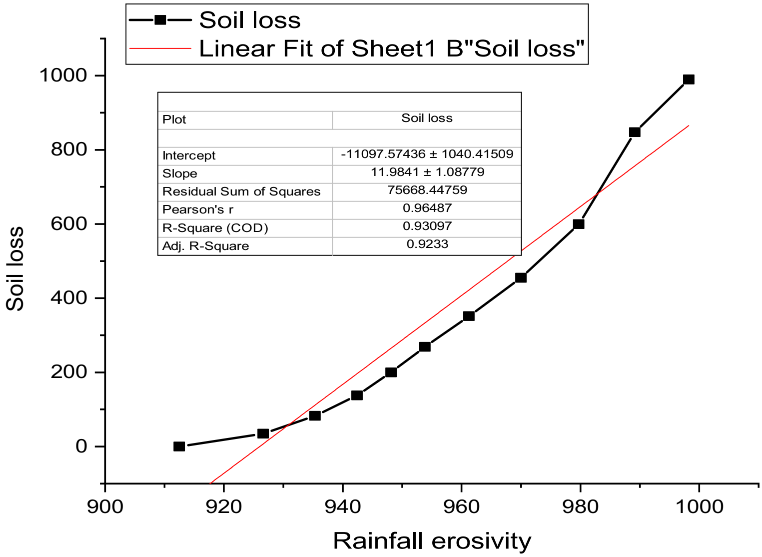

Fig. 13 Correlation between soil erosion and rainfall erosivity

there is an increment in annual soil loss that significantly affects the environment in general and agricultural production in particular in Ethiopian highlands particularly during the crop growing season (June to September).

3.12 Regression analysis of soil loss rate with NDVI and slope

Descriptive statistics were used to summarize the data, primarily mean annual soil loss, while inferential statistics in the form of a one-way analysis of variance (ANOVA) were used to investigate the effect of vegetation cover and slope. The independent variables in the ANOVA were NDVI and slope, while the dependent variable was annual soil loss (Fig. 14). According to the R^2 values for each year, NDVI and slope as a predictor of annual soil loss. The primary causes for the rising of annual soil loss were the declining of NDVI and an increasing of slope. Other investigations have yielded similar results (Zhou et al. 2014; Akinyemi et al. 2019). The coefficient of determination (R^2) between annual soil loss, NDVI, and slope was determined for the years 1989 to 2020 ($R^2 = 0.99$). In general, the p values in (Table 14) show that an increase in agricultural output. The annual soil loss of the Upper Anger watershed increased by 99.8% due to a decline in vegetation cover from elevated areas for agricultural expansion based on adjusted R^2, with the remaining percent possibly increasing due to other factors.

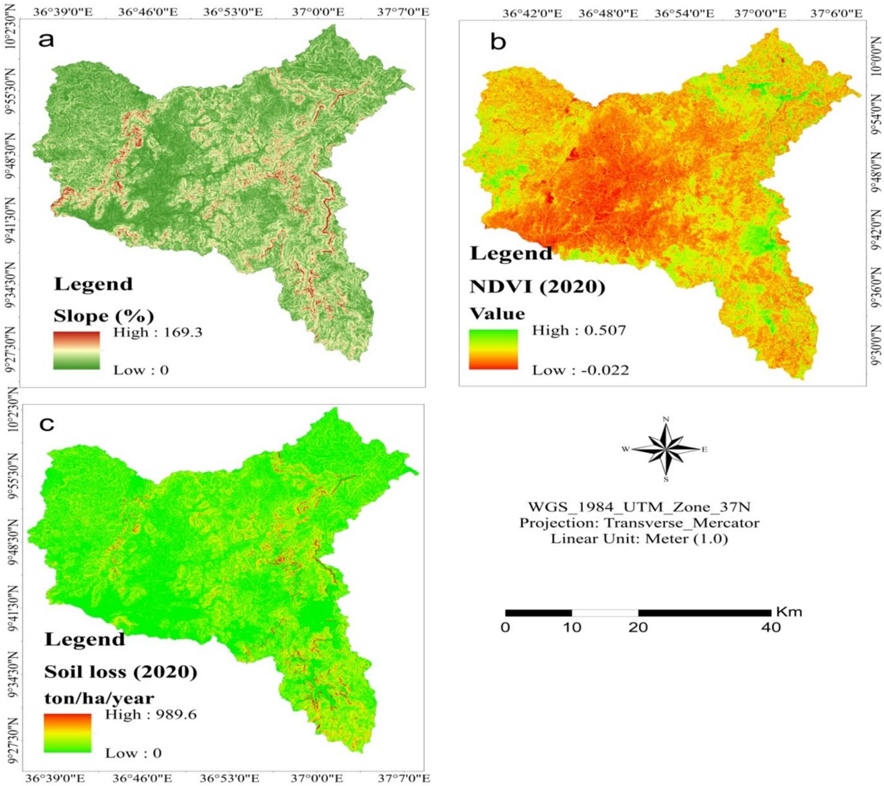

Fig. 14 Slope, NDVI and soil loss regression analysis of the study area

Table 14 Regression analysis of the study: soil loss, NDVI and slope

Variables	Coefficients	Standard error	*t* Stat	*p* value	Lower 95%	Upper 95%
*Soil loss	– 257.48491	32.770649	– 7.85718	$4.97E^{-05}$*	– 333.0542	– 181.91565
NDVI	520.465344	90.982379	5.720507	0.000444*	310.6596	730.27109
Slope	12.0100062	0.2551894	47.0631	$4.59E^{-11}$*	11.421538	12.598474

*Dependent variable: Soil loss; Coefficient is statistically significant at $p < 0.01$

4 Conclusion

Water erosion is the most common and serious problem in Ethiopian highland particularly in western parts of the country due to decline in vegetation cover from steep slope. In the present study, the causes and effects of slope and decline of vegetation cover on soil loss are calculated using multiple regression analysis.

The loss of vegetation cover from elevated areas has a significant impact on soil erosion. Soil erosion has a significant impact on food security by reducing agricultural yields due to the loss of fertile soil. In this study, an integration of RUSLE model and a geospatial technique are used to estimate the impact of deforestation on soil erosion in highland areas of Ethiopia. In this study, different parameters, such as rainfall, soil types, slope length and steepness, cover management, and conservation practices, are considered. In the study area, the NDVI and slope are computed to determine the cause-and-effect relationships with soil loss. Our results conclude that a decline in vegetation cover is a key factor on soil erosion in the study area. Due to the declining trend of vegetation cover and continuous LULC change, the mean annual soil loss in the study area is substantially increased from 44.8 ton/ha/year in the year 1989 to 87.9 ton/ha/year in the year 2020. Our study concludes that the increasing trend of annual soil loss was associated with the declining of vegetation cover over the study period. Moreover, the amount of annual soil loss is influenced by slope steepness and LULC conversion. Our findings clearly identify erosion hotspot areas that require further research and policy intervention. Hence, conservation measures, such as re-afforestation, area closure, agroforestry practices, and community mobilization, to strengthen the ongoing participatory watershed management should be encouraged by all concerned stakeholders.

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References

Adongo TA, Agyare WA, Abagale FK, Kyei-Baffour N (2019) Soil loss estimation using the spatial integrated revised universal soil loss equation (RUSLE) in reservoir catchments in the northern Ghana. Int J Eng Sci Technol 11(4):58–74

Ahmed KR, Akter S (2017) Analysis of landcover change in southwest Bengal delta due to floods by NDVI, NDWI and K-means cluster with Landsat multi-spectral surface reflectance satellite data. Remote Sens Appl Soc Environ 8:168–181

Akinyemi FO, Ikanyeng M, Muro J (2019) Land cover change effects on land surface temperature trends in an African urbanizing dryland region. City Environ Interact 4:100029. https://doi.org/10.1016/j.cacint.2020.100029

Almagro A, Thomé TC, Colman CB, Pereira RB, Junior JM, Rodrigues DBB, Oliveira PTS (2019) Improving cover and management factor (C-factor) estimation using remote sensing approaches for tropical regions. Int Soil Water Conserv Res 7(4):325–334

Aneseyee AB, Elias E, Soromessa T, Feyisa GL (2020) Land use/land cover change effect on soil erosion and sediment delivery in the Winike watershed, Omo Gibe Basin, Ethiopia. Sci Total Environ 728:138776

Asare YM, Forkuo EK, Forkuor G, Thiel M (2020) Evaluation of gap-filling methods for Landsat 7 ETM+ SLC-off image for LULC classification in a heterogeneous landscape of West Africa. Int J Remote Sens 41(7):2544–2564

Atoma H, Suryabhagavan KV, Balakrishnan M (2020) Soil erosion assessment using RUSLE model and GIS in Huluka watershed, Central Ethiopia. Sustain Water Resour Manag 6(1):1–17

Balabathina VN, Raju RP, Mulualem W, Tadele G (2020) Estimation of soil loss using remote sensing and GIS-based universal soil loss equation in northern catchment of Lake Tana Sub-basin, Upper Blue Nile Basin, Northwest Ethiopia. Environ Syst Res 9(1):1–32

Beck MB (1987) Water quality modeling: a review of the analysis of uncertainty. Water Resour Res 23(8):1393–1442

Bekele B, Gemi Y (2021) Soil erosion risk and sediment yield assessment with universal soil loss equation and GIS: in Dijo watershed, Rift valley Basin of Ethiopia. Model Earth Syst Environ 7(1):273–291

Belayneh M, Yirgu T, Tsegaye D (2019) Potential soil erosion estimation and area prioritization for better conservation planning in Gumara watershed using RUSLE and GIS techniques. Environ Syst Res 8(1):1–17

Bewket W, Abebe S (2013) Land-use and land-cover change and its environmental implications in a tropical highland watershed, Ethiopia. Int J Environ Stud 70(1):126–139

Beyene AA (2019) Soil erosion risk assessment in nashe dam reservoir using remote sensing, GIS and RUSLE model techniques in Horro Guduru Wollega Zone, Oromia Region, Ethiopia. J Civil Const Environ Eng. https://doi.org/10.11648/j.jccee.20190401.11

Borrelli P, Robinson DA, Fleischer LR, Lugato E, Ballabio C, Alewell C, Panagos P (2017) An assessment of the global impact of 21st century land use change on soil erosion. Nat Commun 8(1):1–13

Desalegn A, Gessesse AT, Tesfay F (2018) Developing GIS-based soil erosion map using RUSLE of Andit Tid Watershed, central highlands of Ethiopia. J Sci Res Rep. https://doi.org/10.9734/JSRR/2018/40841

Douglass GK (1984) Agricultural sustainability in a changing world order. Boulder

Esa E, Assen M, Legass A (2018) Implications of land use/cover dynamics on soil erosion potential of agricultural watershed, northwestern highlands of Ethiopia. Environ Syst Res 7(1):1–14

Fayas CM, Abeysingha NS, Nirmanee KGS, Samaratunga D, Mallawatantri A (2019) Soil loss estimation using rusle model to prioritize erosion control in KELANI river basin in Sri Lanka. Int Soil Water Conserv Res 7(2):130–137

FOA (2006) Guidelines for soil descriptions, 4th edn. Food ana Agriculture Organization of the United Nations, Rome

Ganasri BP, Ramesh H (2016) Assessment of soil erosion by RUSLE model using remote sensing and GIS-A case study of Nethravathi Basin. Geosci Front 7(6):953–961

Gashaw T, Tulu T, Argaw M, Worqlul AW (2017) Evaluation and prediction of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia. Environ Syst Res 6(1):1–15

Gashaw T, Tulu T, Argaw M (2018) Erosion risk assessment for prioritization of conservation measures in Geleda watershed, Blue Nile basin, Ethiopia. Environ Syst Res 6(1):1–14

Gashaw T, Tulu T, Argaw M, Worqlul AW (2019) Modeling the impacts of land use–land cover changes on soil erosion and sediment yield in the Andassa watershed, upper Blue Nile basin, Ethiopia. Environ Earth Sci 78(24):1–22

Gayen A, Saha S, Pourghasemi HR (2020) Soil erosion assessment using RUSLE model and its validation by FR probability model. Geocarto Int 35(15):1750–1768

Gelagay HS, Minale AS (2016) Soil loss estimation using GIS and Remote sensing techniques: a case of Koga watershed, Northwestern Ethiopia. Int Soil Water Conserv Res 4(2):126–136

Gemeda DO, Korecha D, Garedew W (2021) Evidences of climate change presences in the wettest parts of southwest Ethiopia. Heliyon 7:e08009. https://doi.org/10.1016/j.heliyon.2021.e08009

Gessesse B, Bewket W, Bräuning A (2015) Model-based characterization and monitoring of runoff and soil erosion in response to land use/land cover changes in the Modjo watershed, Ethiopia. Land Degrad Develop 26(7):711–724

Girmay G, Moges A, Muluneh A (2020) Estimation of soil loss rate using the USLE model for Agew-mariayam Watershed, northern Ethiopia. Agric Food Secur 9(1):1–12

Gobin A, Jones R, Kirkby M, Campling P, Govers G, Kosmas C, Gentile AR (2004) Indicators for pan-European assessment and monitoring of soil erosion by water. Environ Sci Policy 7(1):25–38

Habtamu A, Heluf G, Bobe B, Enyew A (2014) Fertility status of soils under different land uses at Wujiraba Watershed, North-Western Highlands of Ethiopia. Agric for Fish 3(5):410–419

Haile M, Herweg K, Stillhardt B (2006) Sustainable land management: a new approach to soil and water conservation in Ethiopia. https://boris.unibe.ch/19217/1/e308_slm_teachingbook_complete.pdf. (Accessed on 5 Feb 2022)

Hurni H (1985) Erosion-productivity-conservation systems in Ethiopia. In: Proceeding's 4th international conferences on soil conservation, Maracay, Venezuela, pp. 654–674

Hurni H, Herweg K, Portner B, Liniger H (2008) Soil erosion and conservation in global agriculture. Land use and soil resources. Springer, Dordrecht, pp 41–71

Hurni K, Zeleke G, Kassie M, Tegegne B, Kassawmar T, Teferi E, Hurni H (2015) Economics of land degradation (ELD) Ethiopia case study: soil degradation and sustainable land management in the rainfed agricultural areas of Ethiopia: an assessment of the economic implications. Water and Land Resource Centre

Ju J, Masek JG (2016) The vegetation greenness trend in Canada and US Alaska from 1984–2012 Landsat data. Remote Sens Environ 176:1–16

Khatami R, Mountrakis G, Stehman SV (2016) A meta-analysis of remote sensing research on supervised pixel-based land-cover image classification processes: general guidelines for practitioners and future research. Remote Sens Environ 177:89–100

Kidane D, Alemu B (2015) The effect of upstream land use practices on soil erosion and sedimentation in the Upper Blue Nile Basin, Ethiopia. Res J Agric Environ Manag 4(2):55–68

Kidane M, Bezie A, Kesete N, Tolessa T (2019) The impact of land use and land cover (LULC) dynamics on soil erosion and sediment yield in Ethiopia. Heliyon 5(12):e02981

Koirala P, Thakuri S, Joshi S, Chauhan R (2019) Estimation of soil erosion in Nepal using a RUSLE modeling and geospatial tool. Geosciences 9(4):147

Lal R, Elliot W (2017) Erodibility and erosivity. Soil erosion research methods. Routledge, London, pp 181–210

Lema B, Kebede F, Mesfin S, Fitiwy I, Abraha Z (2016) Use of the revised universal soil loss equation (RUSLE) for soil and nutrient loss estimation in long-used rainfed agricultural lands, North Ethiopia. Phys Geogr 37(3–4):276–290

Li P, Zang Y, Ma D, Yao W, Holden J, Irvine B, Zhao G (2020) Soil erosion rates assessed by RUSLE and PESERA for a Chinese Loess Plateau catchment under land-cover changes. Earth Surf Proc Land 45(3):707–722

Mahajan U, Bundel BR (2016) Drones for normalized difference vegetation index (NDVI), to estimate crop health for precision agriculture: a cheaper alternative for spatial satellite sensors. In Proceedings of the International Conference on Innovative Research in Agriculture, Food Science, Forestry, Horticulture, Aquaculture, Animal Sciences, Biodiversity, Ecological Sciences and Climate Change (AFHABEC-2016), Delhi, India (Vol. 22)

Moisa MB, Negash DA, Merga BB, Gemeda DO (2021) Impact of land-use and land-cover change on soil erosion using the RUSLE model and the geographic information system: a case of Temeji watershed, Western Ethiopia. J Water Climate Chang 12(7):3404–3420

Moisa MB, Dejene IN, Merga BB, Gemeda DO (2022a) Impacts of land use/land cover dynamics on land surface temperature using geospatial techniques in Anger River Sub-basin, Western Ethiopia. Environ Earth Sci 81:99. https://doi.org/10.1007/s12665-022-10221-2

Moisa MB, Merga BB, Gemeda DO (2022b) Multiple indices-based assessment of agricultural drought: a case study in Gilgel Gibe Sub-basin Southern Ethiopia. Theor Appl Climatol. https://doi.org/10.1007/s00704-022-03962-4

Moisa MB, Dejene IN, Merga BB, Gemeda DO (2022c) Soil loss estimation and prioritization using geographic information systems and the RUSLE model: a case study of the Anger River sub-basin, western Ethiopia. J Water Climate Chang 13(3):1170–1184

Molla T, Sisheber B (2017) Estimating soil erosion risk and evaluating erosion control measures for soil conservation planning at Koga watershed in the highlands of Ethiopia. Solid Earth 8(1):13–25
Moore ID, Burch GJ (1986) Physical basis of the length slope factor in the universal soil loss equation. Soil Sci Soc AM 50(5):1294–1298
Negassa MD, Mallie DT, Gemeda DO (2020) Forest cover change detection using Geographic Information Systems and remote sensing techniques: a spatio-temporal study on Komto protected forest priority area, East Wollega Zone, Ethiopia. Environ Syst Res 9:1. https://doi.org/10.1186/s40068-020-0163-z
Napoli M, Cecchi S, Orlandini S, Mugnai G, Zanchi CA (2016) Simulation of field-measured soil loss in Mediterranean hilly areas (Chianti, Italy) with RUSLE. CATENA 145:246–256
Nasidi NM, Wayayok A, Abdullah AF, Kassim MSM (2020) Vulnerability of potential soil erosion and risk assessment at hilly farms using InSAR technology. Alger J Eng Technol 3:001–008
Negash DA, Moisa MB, Merga BB, Sedeta F, Gemeda DO (2021) Soil erosion risk assessment for prioritization of sub-watershed: the case of Chogo Watershed, Horo Guduru Wollega, Ethiopia. Environ Earth Sci 80(17):1–11
Negese A (2021) Impacts of land use and land cover change on soil erosion and hydrological responses in Ethiopia. Appl Environ Soil Sci. https://doi.org/10.1155/2021/6669438
Nut N, Mihara M, Jeong J, Ngo B, Sigua G, Prasad PV, Reyes MR (2021) Land use and land cover changes and its impact on soil erosion in Stung Sangkae catchment of Cambodia. Sustainability 13(16):9276
Olika G, Iticha B (2019) Assessment of soil erosion using RUSLE and GIS techniques: a case of Fincha'a Watershed, Western Ethiopia. Am Euras J Agric Environ Sci 19:31–36
Ostovari Y, Ghorbani-Dashtaki S, Bahrami HA, Naderi M, Dematte JAM (2017) Soil loss estimation using RUSLE model, GIS and remote sensing techniques: a case study from the Dembecha Watershed, Northwestern Ethiopia. Geoderma Reg 11:28–36
Ouyang W, Wu Y, Hao Z, Zhang Q, Bu Q, Gao X (2018) Combined impacts of land use and soil property changes on soil erosion in a mollisol area under long-term agricultural development. Sci Total Environ 613:798–809
Pimentel D (2006) Soil erosion: a food and environmental threat. Environ Dev Sustain 8(1):119–137
Prasannakumar V, Vijith H, Abinod S, Geetha NJGF (2012) Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using revised universal soil loss equation (RUSLE) and geo-information technology. Geosci Front 3(2):209–215
Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC (1997) Predicting soil erosion by water: a guide to conservation planning with the revised universal loss equation. Agriculture Handbook No. 703, U.S. Department of Agriculture, Washington, DC, USA
Renschler C (1996) Soil erosion risk mapping by means of Geographic Information Systems (GIS) and Hydrological modeling. MSc, Technical University of Braunschweig, Braunschweig
Santos CAG, Watanabe M, Suzuki K (1998) A conceptual soil erosion model. Ann J Hydraulic Eng JSCE 42:1033–1038
Shiferaw A (2011) Estimating soil loss rates for soil conservation planning in the Borena Woreda of South Wollo Highlands, Ethiopia. J Sustain Dev Afr 13(3):87–106
Sisay A, Chalie N, Girmay Z, Takele G, Tolera A (2014) Landscape-scale soil erosion modeling and risk mapping of mountainous areas in eastern escarpment of Wondo Genet Watershed, Ethiopia. Int Res J Agric Sci Soil Sci 4(6):107–116
Tilahun H, Taddesse G, Melese A, Mebrate T (2018) Assessment of spatial soil erosion hazard in Ajema Watershed, North Shewa Zone, Ethiopia. Adv Plants Agricul Res 8:552–558
Tran HT, Campbell JB, Tran TD, Tran HT (2017) Monitoring drought vulnerability using multispectral indices observed from sequential remote sensing (Case Study: Tuy Phong, Binh Thuan, Vietnam). Gisci Remote Sens 54(2):67–184
Tsegaye B (2019) Effect of land use and land cover changes on soil erosion in Ethiopia. Int J Agric Sci Food Technol 5(1):026–034
Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses: a guide to conservation planning (No. 537). United States Department of Agriculture, Beltsville, Maryland
WoldeYohannes A, Cotter M, Kelboro G, Dessalegn W (2018) Land use and land cover changes and their effects on the landscape of Abaya-Chamo Basin, Southern Ethiopia. Land 7(1):2
Zhou Y, Yang G, Wang S, Wang L, Wang F, Liu X (2014) A new index for mapping built up and bare land areas from Landsat8 OLI data. Remote Sens Lett 5(10):862–871

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