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Soil erosion modeling and sediment transport index analysis using USLE and GIS techniques in Ada'a watershed, Awash River Basin, Ethiopia

Abayneh Tilahun[1*] and Hayal Desta[2]

Abstract

Ethiopia faces a significant challenge in combating soil erosion. This study addresses the concern within Ada'a watershed of the Awash River basin. GIS and the Universal Soil Loss Equation (USLE) Model were used to predict soil loss and the sediment transport index (STI) in the Ada'a watershed of the Awash River basin. RUSLE model required intensive rainfall data registered continuously for 30 min, due to unavailability of this Rainfall data USLE model were preferred. Moreover, USLE model was chosen because of its straightforward methodology and accessibility to data. The study's objectives were to determine the mean annual soil loss rate, STI, and to identify and rank the most important erosion-prone spots for soil conservation planning. Using the interactive Spatial Analyst Tool Map Algebra Raster Calculator in the ArcGIS environment, the mean annual soil loss was estimated based on grid cells by multiplying the corresponding USLE factor values (R, K, LS, C, and P). The STI was also calculated on the Raster Calculator in ArcGIS using flow accumulation and slope gradients. The result shows that R, K, LS, C, and P factor values were estimated in the watershed as 344.9 to 879.65 MJ mm h^{-1} $year^{-1}$, 0.11 to 0.38, 0% to 22.23%, 0 to 1, and 0.55 to 1, respectively. The overall annual soil loss in the watershed ranged from 0 to 457.4 tons ha^{-1} $year^{-1}$. The Sediment Transport Index ranges from 0 to 856.193. The result implies there is increasing rate of soil losses and sediments observed at alarming rate. The highest rate of soil loss was found in the watershed's lowest parts. Accordingly, sustainable erosion control mechanisms based on topography and land use types are highly recommended, especially in the upper part of the watershed.

Keywords USLE, Sediment transport index, Land degradation, Soil erosion, Soil losses, GIS

Introduction

Globally, soil erosion accounts for 85% of land quality deterioration (Singh 2017). This in turn causes a 17% decline in agricultural output and a permanent degradation of the land (Gessesse 2014). Life on earth is either directly or indirectly reliant on soil, and land degradation caused by soil erosion has advanced impacts of human activities and the environment (Bishop, 2014; Dotterweich Markus 2013; Hansen 2001), primarily on crop productivity (Pimentel 1995; Tully et al. 2015). According to Kassie (2007), soil erosion in sub-Saharan Africa results in nutrient loss, land

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degradation, and unsustainable agricultural productivity. Land degradation is mainly instigated by poor soil conservation planning, extensive farming, and plowing in hilly areas. Moreover, declining vegetation cover due to overgrazing, deforestation, rapid population growth, and urbanization has significant potential for severe land degradation consequences (Bahrami 2005; Bekele 2019; Nikonya 2016; Pimentel and Burgess 2013; Reusing et al. 2000; Schiettecatte et al. 2008). Furthermore, high rainfall intensity and soil erosivity due to light soil depth and poor soil foundation structure eventually lead to severe land degradation (Girmay et al. 2020).

Soil erosion is a prevalent and significant problem in East Africa's highlands, resulting in severe soil degradation throughout the region (Gachene 1995; Tiffen et al. 1994). In Ethiopia, the highest erosion rate is recorded (Gessesse 2014; lanckriet 2015). According to Tesfaye et al. (2014) and Tesfaye (2018), high runoff-triggered annual soil loss in Ethiopia ranges from 16 to 300 t $Ha^{-}1$ $year^{-}1$ due to steep slope gradients, minimal vegetation cover, and severe precipitation.

According to Birhanu (2014) and Tiruneh (2015), 100 to 300 t $ha^{-}1$ $year^{-}1$ of soil are lost annually in farms in the highlands of Ethiopia. In addition, 27 million hectares of the 60 million hectares of agriculturally viable land are seriously eroding, and around 2 million hectares have permanently lost their ability to produce food. Additionally, cropland soil is disappearing at a rate of 42 tons per hectare per year, totaling up to 2 billion tons per hectare every year, or $1 billion USD (Ma 2014; Sonneveld 2001). According to Tiruneh (2015), severe soil erosion affects about 45% of the agriculturally productive land in the country's highlands. Consequently, Ethiopia turns out to be the lowest crop producer per plot of land compared with international standards. Due to top soil removed by erosion, which results in nutrient depletion of the soil, this eventually leads to poor crop yield (Bekele 2019; Haileslassie 2005; Sertsu 2000). Desta et al. (2000) revealed that rapid population growth, tilling in hilly areas, deforestation, and overgrazing are the core factors that worsen soil erosion in Ethiopia.

Furthermore, sediment yields are transported downstream by surface runoff following upstream soil erosion caused by high rainfall (Freebairn et al. 1996). Moreover, sediment transportation and soil erosion are increasing due to intensified complex rainfall and increased annual precipitation triggered by climate change (Mullan 2018). Obviously, soil erosion could be aggravated by many agent factors like wind, heavy rainfall, and water flow, but significantly, sediments can be transported at higher levels due to intense water flow or runoff (Alhamid, 2002; Horton 1945; Vanoni 2006). Consequently, it's critical to calculate the annual soil loss and sediment transport by water-induced erosion.

According to Wischmeyer (1978), there are many different types of advanced erosion models being developed and used around the world. The USLE model is a highly employed erosion prediction model that predicts soil losses due to sheet and rill erosion under specific cropping and management system conditions. Due to its simplicity, the USLE model is employed all over the world (Smith 1999). Because the improved RUSLE model requires detailed and continuous rainfall data as well as maximum 30-min rainfall intensity and rainfall kinetic energy data, it is challenging to apply it to newly created research locations. This crucial and in-depth information is consequently unavailable on several research websites due to a number of technical challenges (Kim 2005; Renard 1997).

Sediment Transport Index (STI) can also be calculated, as suggested by Moore and Burch (1986), using the Raster Calculator environment on ArcGIS. Hence, due to the many factors mentioned above, soil losses and sedimentation due to severe erosion have become a threat in the Ada'a watershed. Even though rapid urbanization and climate change impacts have been significantly observed in the area, various studies could not include this specific watershed area. Obviously, this would create a heavy research gap and hinder scholars from exercising different modeling methodologies due to a lack of references. As a result, the primary goals of this study were to estimate the average yearly soil loss rate, identify and prioritize significant erosion-prone regions for conservation planning purposes using the Universal Soil Loss Equation Model (USLE), and compute the Sediment Transport Index of the study watershed by integrating GIS and remote sensing technology.

Methodology

Description of the study area

This study was conducted in the Ada'a watershed, which is found in the east shoa zone of Oromia regional state, 47 km away from the capital, Addis Ababa.

A study watershed is located within latitude of $6^{0}30'00''$N and a longitude of $38^{0}59'9''$E (Fig. 1). The Elevation of Ada'a watershed ranges from 1748 to 2193 m above sea level, and the mean annual temperature varies between 15 and 20 ℃.

Rainfall

The rainfall pattern in Ada'a watershed is mono-modal with a single peak. The Wadecha-Belbela River system catchments, however, have an even longer wet season (March–September, with mean monthly rainfall varying from 50 to 223 mm). June to September rainfall contributes 74%

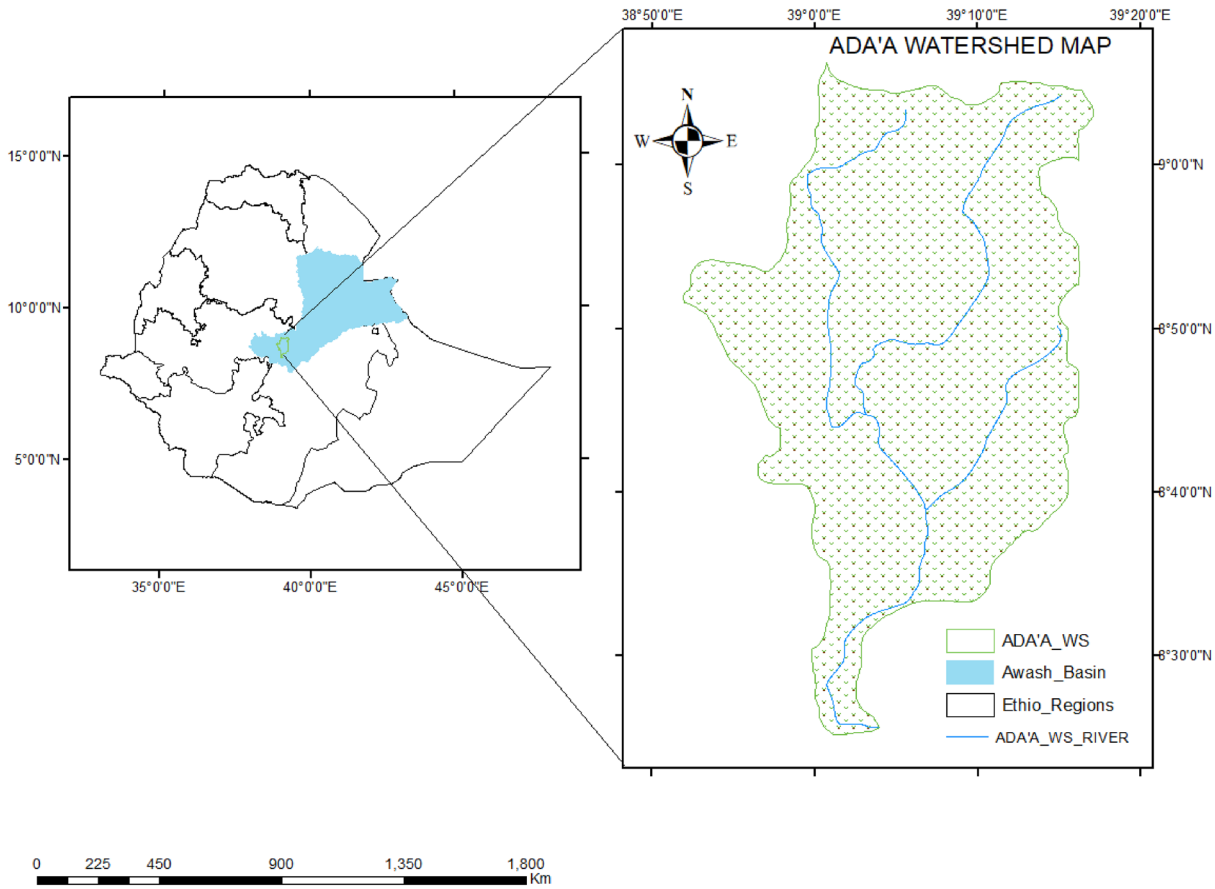

Fig. 1 Ada'a watershed map

to the mean annual precipitation in the catchment. The mean annual rainfall obtained from the monthly rainfall on the basis of 53 years of records at the Bishoftu Research Center meteorological station gauge is about 866.6 mm. The highest amount of rainfall was registered between June and September, and the lowest between February and May. The effective rainfall is 662.5 mm (Oromia Agricultural Research center, 2017).

Data sources

Over time, the methods for predicting soil loss have changed. The Universal Soil Loss Equation (USLE), which includes five factors whose values were calculated using their formulas, is the most commonly used equation for predicting soil loss over the whole watershed. Using the USLE model, the following empirical equation—a sum of five significant erosion-governing parameters—was utilized to quantify soil erosion in the study catchment (Wischmeyer 1978):

$$A = R \times K \times LS \times C \times P$$

The USLE model variables are acquired from innumerable sources. The rainfall erosivity factor (*R*-value) was derived from annual rainfall data on the tropical rainfall measurement mission (TRMM) websites. The soil erodibility factor (*K* value), which consists of organic matter, texture, and structure of the soil of the study area, is also determined from the FAO soil portal database. Slope length and slope gradient factor (LS value) were obtained from the analysis of DEMs with 30 m resolution. The crop factor (C) and conservation practice factor (P) values are estimated by analyzing the Landsat 7 image and DEM of the study area (Table 1).

Rainfall erosivity factor (R)

Rainfall erosivity, or R factor, is an index of rainfall erosion that is the average annual total of the storm El values in a particular locality. The R factor for Ethiopia can be calculated based on the equation that applies IDW (inverse distance weighted) techniques (Hurni 1988; Kaltenrieder et al. 2007).

$$R = 0.55 * MAP - 24.7$$

Table 1 *P* value for respective slope (%) derived by (Shin 1999)

Slope (%)	Terracing	Contouring	Strip cropping
0–7	0.1	0.55	0.27
7–11.3	0.12	0.3	0.3
11.3–17.6	0.16	0.4	0.4
17.6–26.8	0.18	0.45	0.45
> 26.8	0.2	0.5	0.5

where: R is the rainfall erosivity factor in MJ mm ha-1 yr-1 and MAP is the mean annual precipitation (mm).

Soil erodibility factor (K)

One of the major elements in soil erosion, the soil erodibility factor (K), is commonly viewed as the rate of soil loss per unit of erosion index (Wischmeyer, 1978). According to Bahrami (2005), the soil texture (composition of sand, silt, and clay), organic matter content, soil structure index, and soil permeability index are the main soil parameters that have an impact on the K-factor. Hence, the soil erodibility (K) factor for the watershed was estimated based on soil texture percentage depending on FAO–UNDP (1984) soil database adapted to Ethiopia by Hurni (1988) and Helldén (1987), as shown in Table 2. Based on the percent composition of sand, silt, and clay (soil texture) in relation to the percent organic matter equation, the *K* values for the various soil types in the research region were computed, as formulated by Moore and Burch (1986).

$$K_{USLE} = f_{csand} * f_{cl-si} * f_{orgc} * f_{hisand}$$

where:

F_{csand} is a coarse-sand content, $f_{cl\text{-}si}$ representing clay-to-silt ratios, f_{orgc} indicating organic carbon content, Whereas f_{hisand} signifying high sand content.

$$f_{csand} = \left\{0.2 + 0.3 \times \text{Exp}\left[-0.256 \times m_s \times \left(1^{-m}\text{silt}\right)\right]100\right\}$$

$$f_{cl-si} = \left(\frac{m_{silt}}{mc + m\text{silt}}\right)^{0.3}$$

Table 3 Land use and land cover of the Ada'a Watershed with area coverage and *C* value

Land use type	Area coverage in Ha	*C* Value
Agricultural land	385,302.33	**0.15**
Barren land	253.44	**1**
Forest cover	11,604.24	**0.01**
Grass land	3,400.02	**0.015**
Shrub land	2,487.15	**0.014**
Urban area	5,552.01	**0.5**
Water bodies	1,937.07	**0**
Grand Total	410,536.26	

$$f_{orgc} = \left(\frac{1 - 0.25 * \text{orgC}}{\text{orgC} + \text{Exp}\left(3.72 - 2.95 \times \text{orgC}\right)}\right)$$

$$f_{hisand} = \frac{1 - 0.7 * (1 - ms/100)}{(1 - m_s/100) + \exp\left[-5.51 + 22.9 * (1 - m_s/100)\right]}$$

where: m_s—The sand fraction content (0.05–2.00 mm diameter) [%]; m_{silt}—the silt fraction content (0.002–0.05 mm diameter) [%]; m_c—the clay fraction content (< 0.002 mm diameter) [%]; orgC—the organic carbon content [%].

Topographic factor (LS)

The product of the slope factor's length (L) and gradient (S) yields the topographic factor (Schiettecatte et al. 2008). The slope length factor (L) is the ratio of soil loss from the slope of the given length to that from the slope of the land with a length of 22.13 m, provided all other factors remain constant. Additionally the slope gradient factor (S) measures the ratios of soil loss from a specific slope gradient to that from land with a 9% slope under the same conditions (Wischmeyer. 1978). Moore and Wilson (1992) introduced a simplified equation to determine the LS for three-dimensional terrain using a unit contributing area, as follows:

Table 2 FAO soil database information with *f* value and K factor

Soil unit symbol	sand % topsoil	silt % topsoil	clay % topsoil	OC % topsoil	f csand	f cl-si	f orgc	f hisand	K_Factor
BE	36.4	37.2	26.4	1.07	0.5	0.851385	0.90537	0.999948	**0.385389**
NE	68.4	10.5	21.2	0.6	0.2	0.717859	0.980337	0.962738	**0.135504**
VP	25.1	12.2	62.7	0.68	0.20043	0.580181	0.972718	0.999995	**0.113113**
WD	19.8	55.2	24.8	4.27	0.230968	0.894653	0.750008	0.999999	**0.154979**
XH	54.8	20.6	24.9	0.53	0.200004	0.788418	0.985552	0.997509	**0.155022**

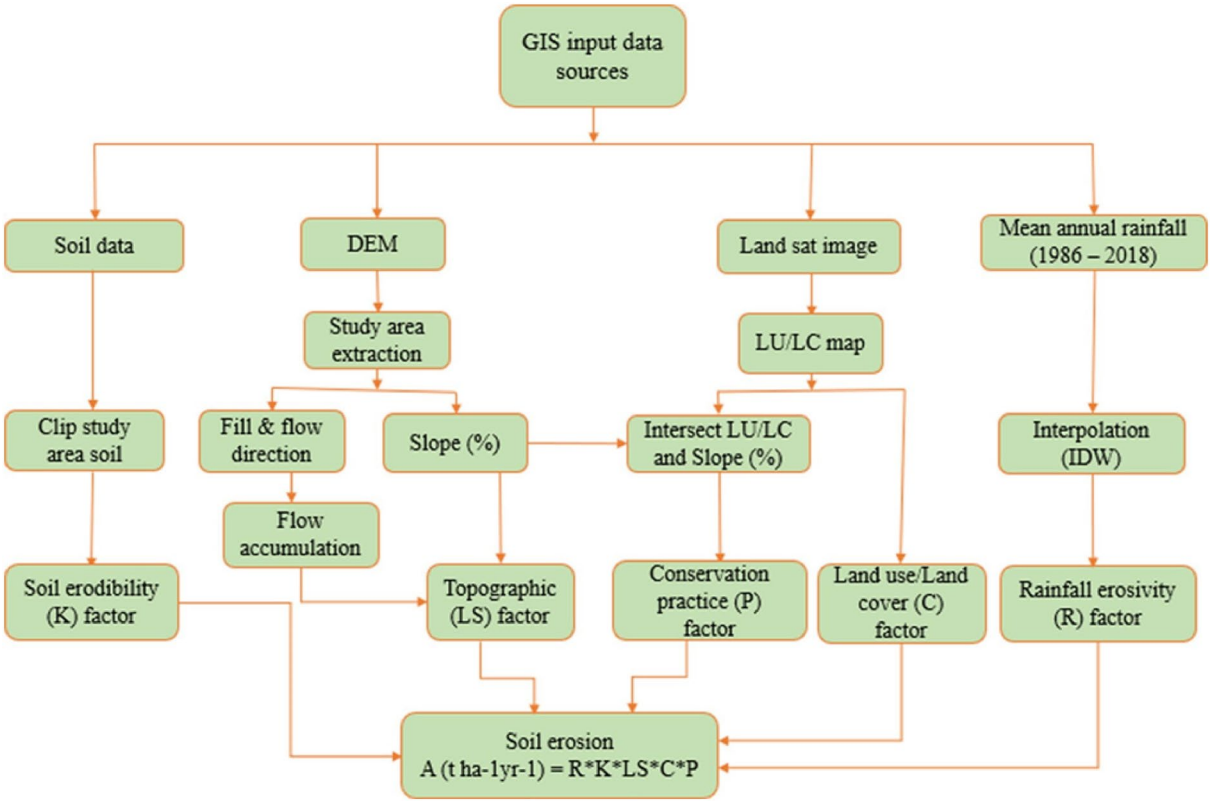

Fig. 2 Depict overall methodological workflow for estimating soil loss using USLE: excerpted from (Mengie et al. 2022)

$$LS = (As/22.13)^{m} * (\sin B/0.0896)^{n}$$

Slope length and gradient factors were estimated by ArcGIS 10.8. In this study, the DEM with a resolution (grid cell) of 30 m by 30 m, which is available from USGS Earth explorer, was used. The flow accumulation, slope steepness, and slope gradient were generated from DEM in the ArcGIS 10.8 environment. The following scholars, such as Freeman (1991), Griffin et al. (1988), and Pham, (2018) suggested LS factor analysis: But, for this study, the LS factor was computed using the equation that was proposed and simplified by Mitasova et al. (1999):

$$LS = (m+1) * (\text{Flow accumulation} * \text{cell size}/22.13)^{m} \times \left(\sin\left(\text{slope angle} * 0.01745\right)/0.0896\right]^{n}$$

where: cell size represents the resolution of the grid (30 m), 22.13 is the length of the research field plot, and flow accumulation is the number of cells contributing flow to a given cell.

Where FA is the flow accumulation, cell size is the size of DEM data (30 × 30 m), slope angle is in radians, and $m = 0.5$ (0.4–0.7) and $n = 1.3$ (1.0–1.4) are the exponent values proposed by (Liu 2000; Mitasova 1996).

Estimation of crop/cover management factor (C)

If all other factors stay constant, the crop management factor (C) is the ratio of soil loss from a specific agricultural management to that from land kept permanently fallow (Girmay et al. 2020). The cumulative impact of all the interconnected cover, crop, and crop management variables on the rate of soil erosion is represented by the C-factor. A Landsat 7 ETM+image with a spatial resolution of 30 m × 30 m resolution acquired on March 5, 2016 from sentinel was used to derive the Land use and land cover map of the study watershed.

Supervised digital image classification techniques were employed using ArcGIS 10.8 software. Land use classification was conducted by the maximum likelihood classification method. Fifty reference points were generated from Google Earth for validation and finally authenticated on the ground. A systematic sampling technique was used to evaluate the accuracy of the LULC classification of the study area. To measure agreement between image classification results and ground truth, overall accuracy, user accuracy, producer accuracy, and the Kappa coefficient were used. Finally, as shown in Table 3, seven land use land covers were identified from the study watershed: forest cover, Water body, Agricultural land,

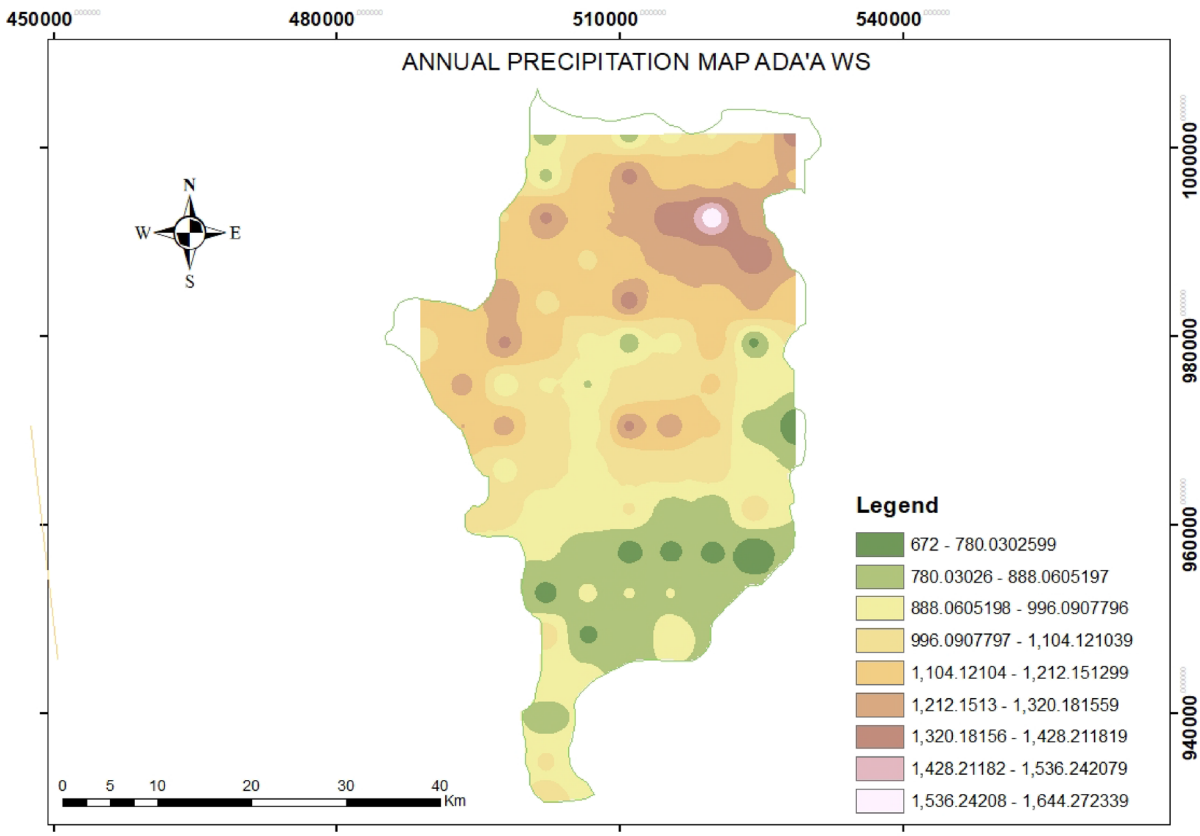

Fig. 3 Annual precipitation map of Ada'a Watershed

grass land, Barren land, Built area, urban area, and shrub land.

The corresponding (C) values were assigned to each land use and land cover classes using reclassify tools in the ArcGIS 10.8 environment. Finally, the study area's (C) factor raster layer was constructed by assigning an adapted (C) value to each land use and land cover class.

Estimation of conservation/support practice factor (P)

According to Pham (2018), the support practice factor (P) is the effect of a farming system or land usage on soil erosion. It represents techniques for preventing soil erosion from runoff, such as contouring, strip-cropping, and terracing. The range of *P* values is 0 to 1, with 0 denoting a top-notch man-made facility for preventing erosion and 1 denoting a lack of such a structure (Pham 2018).

Using the spatial analyst capabilities in ArcGIS, slope range maps were utilized to determine the P-factor value. Each slope range was given a P value by selecting representative values suggested by Shin (1999).

Soil loss analysis

The average annual soil loss was calculated on a grid cell basis by multiplying the respective USLE factor values (R, K, LS, C, and P) interactively using the Spatial Analyst Tool Map Algebra Raster Calculator in the ArcGIS environment (Fig. 2).

Where A is the annual soil loss (t ha − 1 year − 1); R is the rainfall erosivity factor (MJ mm h − 1 ha − 1 year − 1); K is the soil erodibility factor (Mg ha − 1 MJ − 1 mm − 1); LS is the slope length factor (dimensionless); C is the management factor (dimensionless); and P is the dimensionless conservation practice factor.

Sediment transport index (STI)

Sediment Transport Index (STI) can be calculated as suggested by Moore and Burch (1986) using the Raster Calculator environment on ArcGIS; the equation is stated below.

$$\mathrm{STI} = (m+1) * (\mathrm{As}/22.13)^{\mathrm{m}} * \sin(\mathrm{B}/0.0896)^{\mathrm{n}}$$

where: As is the specific catchment area (the region contributing to the upslope per unit contour length)

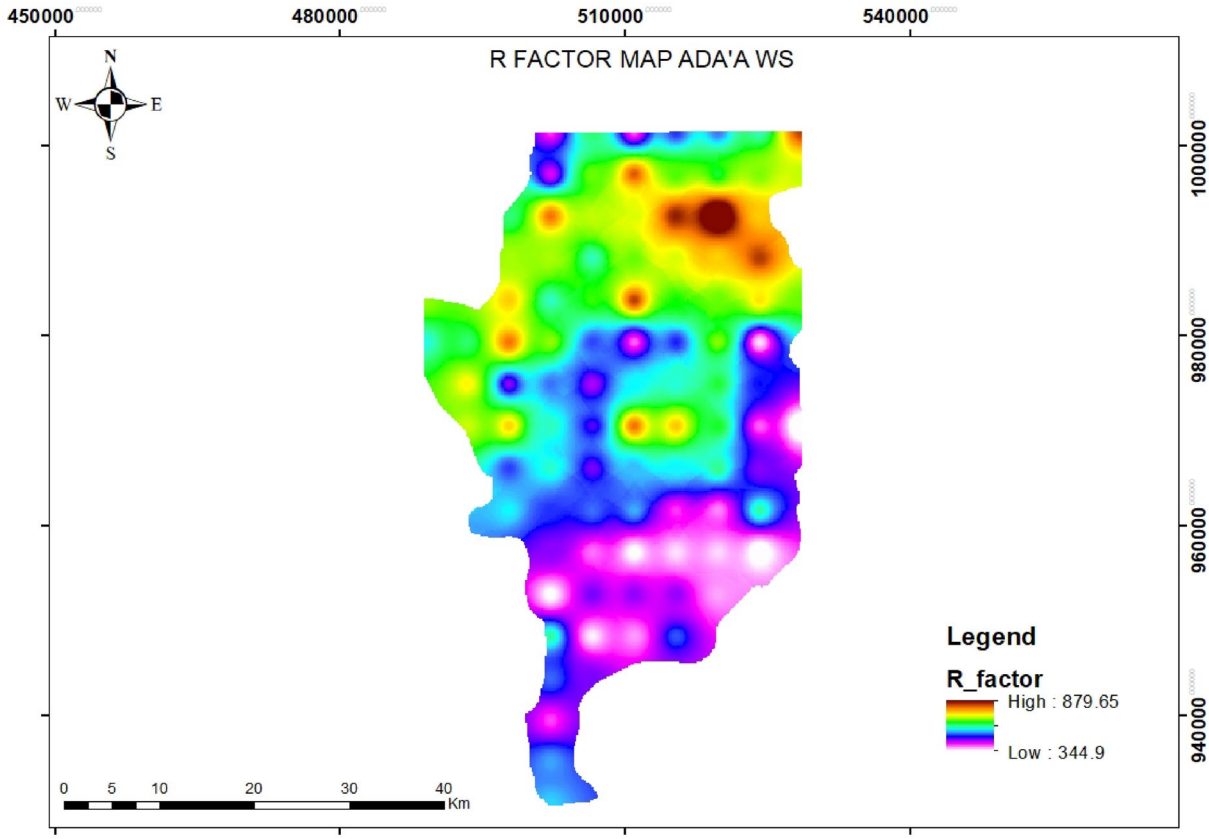

Fig. 4 Rainfall erosivity (R) factor map of the Ada'a Watershed

estimated using one of the available flow accumulation algorithms in hydrology toolboxes; B is the local slope gradient in degrees; contributing area exponent, m, regularly ranges from 0.4 to 0.6; and slope exponent, n, usually ranges from 1.3 to 1.6. As per Wischmeyer. (1978), STI is a basic element of USLE because it can estimate spatial sediment transport volume and analyze soil erosion features. In Raster Calculator, STI can be calculated based on the following formula:

$$= \text{Power (flow\_accumulation\_Raster/22.13, 0.6)} * \text{Power (sin(Slope\_Raster/0.0896), 1.3)}$$

Result and discussion

Rainfall erosivity (R) factor

The annual average precipitation of the study area is about 1158 mm per year and ranges from 672 mm to a high of 1644 mm (Fig. 3). The value of the rainfall erosivity factor (R) in Adda watershed area, which was estimated to be from 344.9 to 879.65 MJ mm ha-1 $h^{-}1$ $year^{-}1$ (Fig. 4), is higher than many other findings due to higher rainfall intensity in the Adda watershed, especially in the upper catchment and winter season. When the R-value is lower, it means that the research area experiences less intense rainfall and rainfall that are less likely to erode the soil (Asmamaw 2019).

Soil erodibility (K) factor

The K-value of the study area ranged from 0.113 to 0.385 (Fig. 5), which shows similarity with findings of the *K* value in tropical soils, which range from 0.06 to 0.48 EI-Swaify. (1982), and According to FAO–UNDP (1984), the majority of Ethiopian soils have *K* values between 0.05 and 0.6. In the study area, the mean organic matter content was 2.4% in a range of 0.53 to 4.27%. The low clay and organic matter levels in the designated watershed region are amplified by the high *K* value, which implies high soil erodibility and exposure to severe soil erosion (Bartoli et al. 1992).

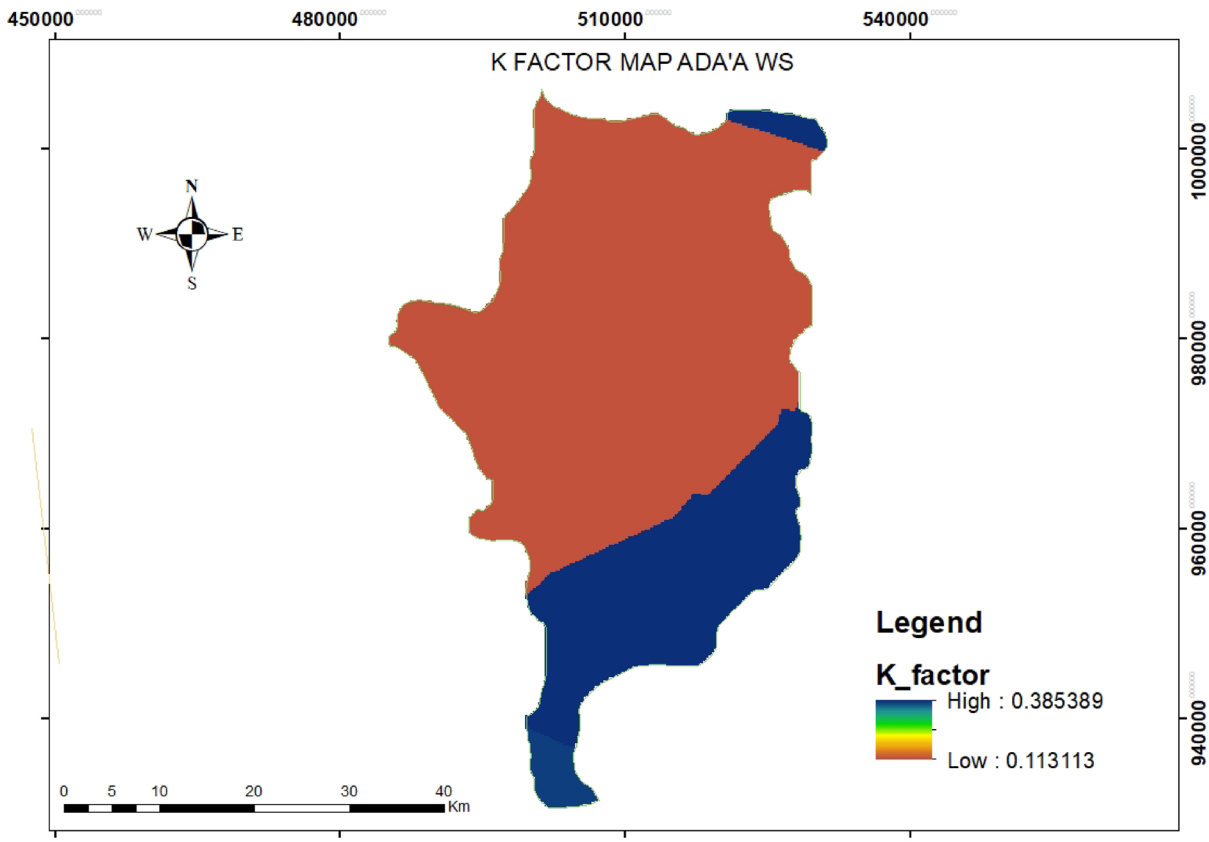

Fig. 5 K Factor map of Ada'a Watershed

Topography factor (LS factor)

The LS factors of the study area range from 0% to 22.23% (Fig. 6), and the majority of the watershed is covered with flat areas or gentle slopes, and slope lengths are shorter. Many scholars depict that Higher LS values indicate greater erosion vulnerability due to high velocity and runoff accumulation. Moreover, the quantity of erosion is determined by the interaction of the slope's angle (Fig. 7) and length. As a result of this interaction, the effects of slope length and degree of slope should always be considered together (Mitasova et al. 1999).

Cover and management (C _Factor)

Based on satellite image classification, the study watershed LULC was classified into seven classes: Agricultural land, forest, Barren land, urban area, shrubs, grass land, and water bodies (Fig. 8). Agricultural land is the dominant land use type in the study area, which covers more than 90% of the total study area, while other land uses cover less than 10% of the area. The C-factor result of Ada'a watershed ranges from 0 to 1 (Fig. 9); the higher the C value indicates that the higher exposure for soil loss. The area coverage of each land use class is clearly identified (Table 3). Water bodies cover 1937 ha of land; the highest area is covered by agricultural land, which accounts for 385,302 ha of land; shrubs, forest, urban areas, Grass, and Barren land also cover 2,487, 11,604, 431, 5, 552, 3,400 and 253 ha of land, respectively. The overall accuracy of image classification and kappa coefficient value is 90 and 0.85, respectively, which indicates that it's an acceptable result as per many scholars and scientific standards.

Conservation practice factor (P)

The conservation practice (P) factor, often referred to as the erosion control practice factor, is a measure of how much soil is lost when a particular conservation practice, such as contouring, strip cropping, or terracing measures, is used in comparison to the loss experienced when up- and downslope cultivation is used

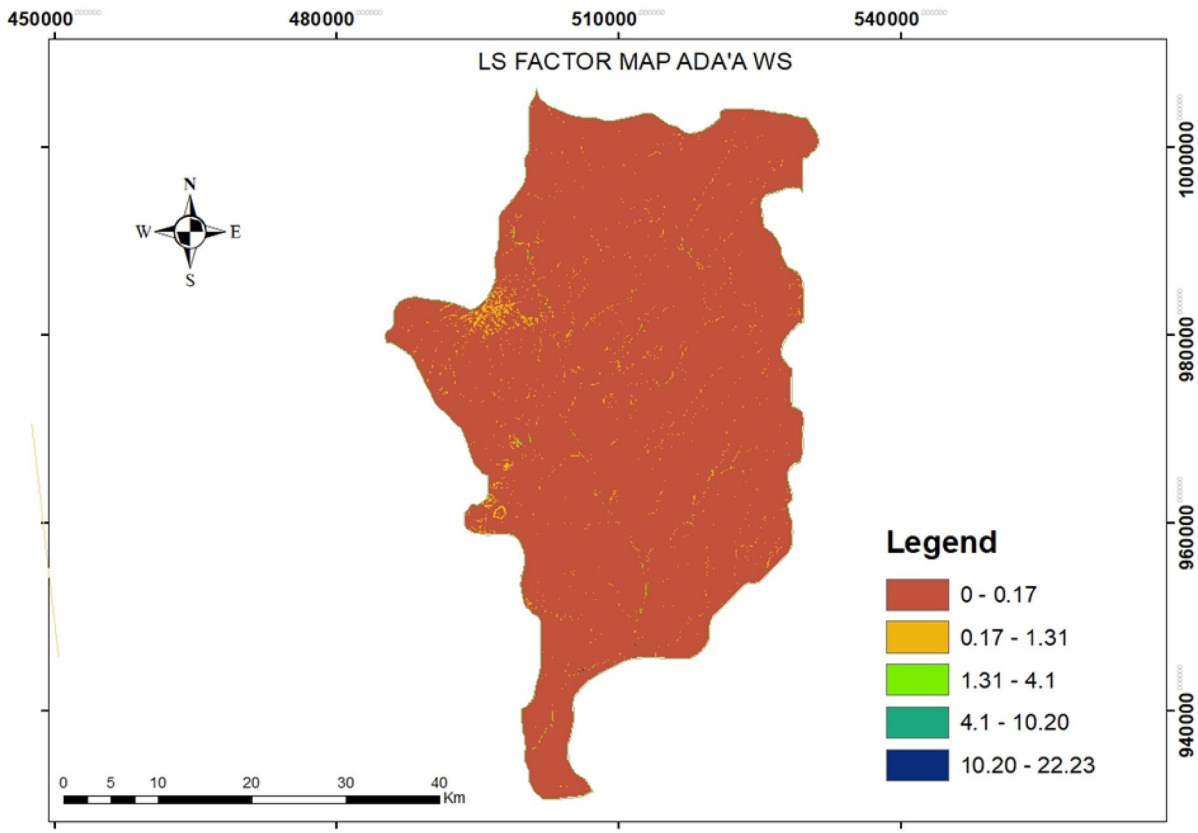

Fig. 6 Topography length and slope (LS) factor map of Ada'a Watershed

(Wischmeyer 1978). The p factor for study area ranges from 0.55 to 1 (Fig. 10). The higher *P* value indicates higher erosion vulnerability in the specified watershed.

Soil loss potential

The average annual soil loss was estimated based on the analysis of rainfall Erosivity factor (R), Soil erodibility factor (K), slope degree factor (LS), cover management (C), and supporting factor (P) using the ArcGIS 10.8 application. The USLE map shows that the annual average soil loss potential (A) in Adda watershed area is displayed in (Fig. 11). The result illustrates that the annual average soil loss in Adda watershed area is ranges from 0 to 457.37 ton ha^{-1} $year^{-1}$ (Fig. 11). The highest coverage region of the research area has the lowest result, which is 0% soil loss, indicating that soil erosion in this area is minimal. The second-highest area coverage is between 0 and 10.76 ton ha^{-1} $year^{-1}$losses, which indicate that soil erosion is largely present and is thought to be of moderate severity. The rest are displayed as ranging from 10.76 to 39.45 ton ha^{-1} $year^{-1}$, which is considered a high-severity area for soil erosion; the rest are displayed as ranging from 39.45 to 114.79 ton ha^{-1} $year^{-1}$, which is considered very high severe; and the remaining 114.79 to 457.37 ton ha^{-1} $year^{-1}$, which is insignificant portion of the study area, is considered an extremely severe potential area for erosion. The large share (63%) of the Ada'a watershed falls under the slope percentage of 0 to 7%, hence the erosion witnessed in the area is significantly low; moreover, the presence of forest and grass, which play a vital role in protecting soil from eroding, is also important. Recurrent changes on vegetation covers results erosion rates, particularly in semi-arid regions. Hence, vegetation consists major roles in keeping soil from severe erosion.

Agriculture is predominantly supported by contouring and terracing in the study area, which improves the soil's protection against losses. The remaining research area, which has slope percentage coverage of 4% and 2%, however, is seriously affected and shows a considerable rate of soil loss. Due to heavy rainfall and runoff in the higher catchments, the lowest areas of the watershed have the highest rate of soil loss. Wolka et al. (2015) depict that acceptable soil loss limit in the central rift valley is less than 10 t ha^{-1} $year^{-1}$ averagely, likewise Hurni (1993) stated for Ethiopian highlands that range from 6 t ha^{-1} $year^{-1}$ to 10 t ha^{-1} $year^{-1}$ and estimated soil loss also ranges from 1248 to 23,400 t ha^{-1} $year^{-1}$. Moreover, the maximum tolerable erosion limit is about 11 t

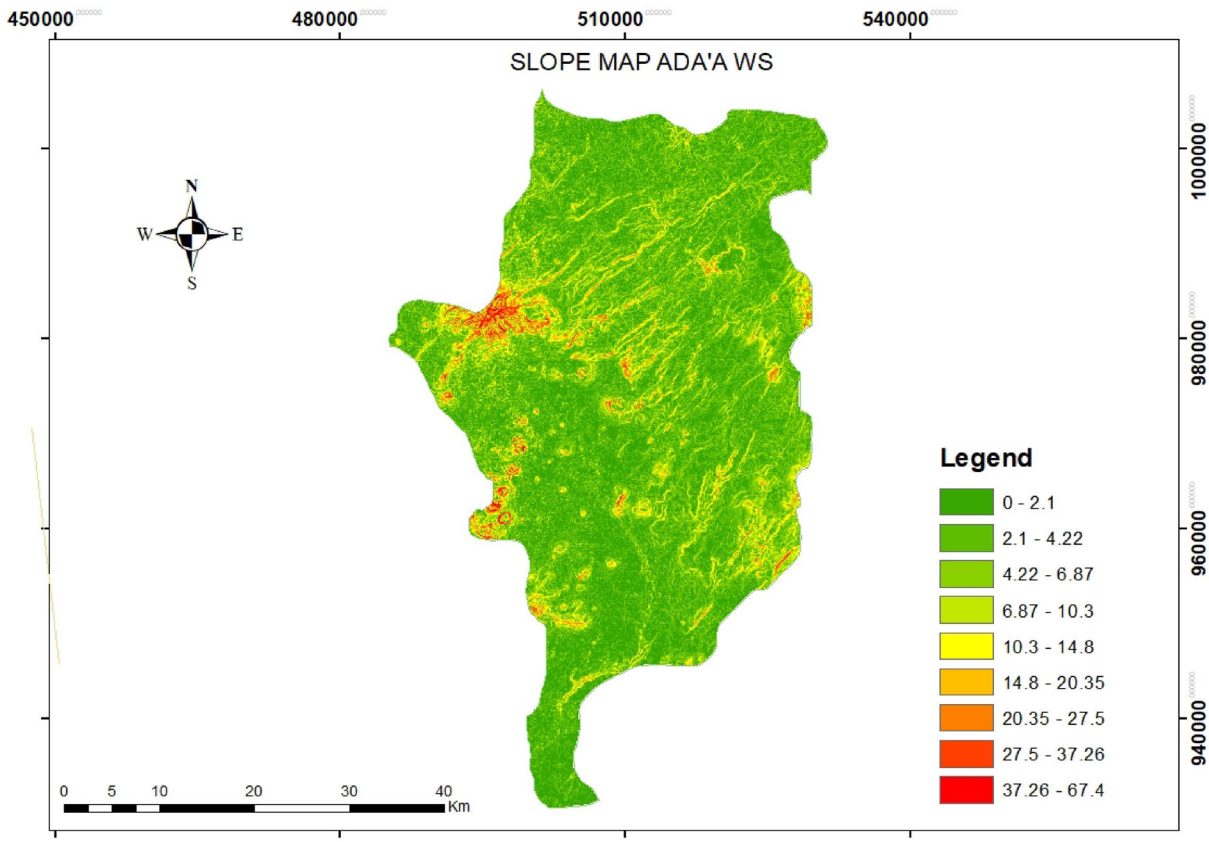

Fig. 7 Slope map of Ada'a watershed in Degree

ha⁻1 year⁻1 (Renard et al. 1996). Total annual estimated soil losses of Ada'a watershed are 457 ton ha⁻1 year⁻1 and Mean annual soil loss is estimated about 5.24 ton ha⁻1 year⁻1. According to Wolka, Renard and Hurni analysis it lays under tolerable limit of soil losses, but, due to rapid urbanization and intensive scale of forest degradation this number will increase inevitably unless the necessary precautions and measurement take places.

Others study in different parts of Ethiopia reports that: Negese et al. (2021); for Chereti Watershed, Northeastern Ethiopia (38.7 t ha − 1 year − 1); Elnashar et al. (2021); for the Blue Nile Basin (39.7 t ha − 1 year − 1); Bekele (2021) for Anka-Shashara watershed (15.22 t ha − 1 year − 1); Tsegaye and Bharti (2021) for Anjeb watershed, Northwest Ethiopia (17.3 t ha − 1 year − 1); Hurni (1985a) for the highland of Ethiopia (20 t ha − 1 year − 1); M. Jothimani et al. (2022) for kulfo river catchment, rift valley (68.47 t ha − 1 year − 1) And Mequanent (2022) for Tashat watershed, north western Ethiopia reports 64.2 t ha − 1 year − 1.

Sediment transport index (STI)

The result is computed in the ArcGIS Raster Calculator environment using the formula given for STI. It is a measure of the capability of a stream's flow to transport sediments and dimensionless. In the Ada'a watershed, the STI ranges from 0 to 856.193 (Fig. 12), meaning the stream flow in the watershed has huge capability to transport the given size ranges, but with full consideration of other factors such as channel morphology, land use land cover of the area, and sediment supply of the watershed,

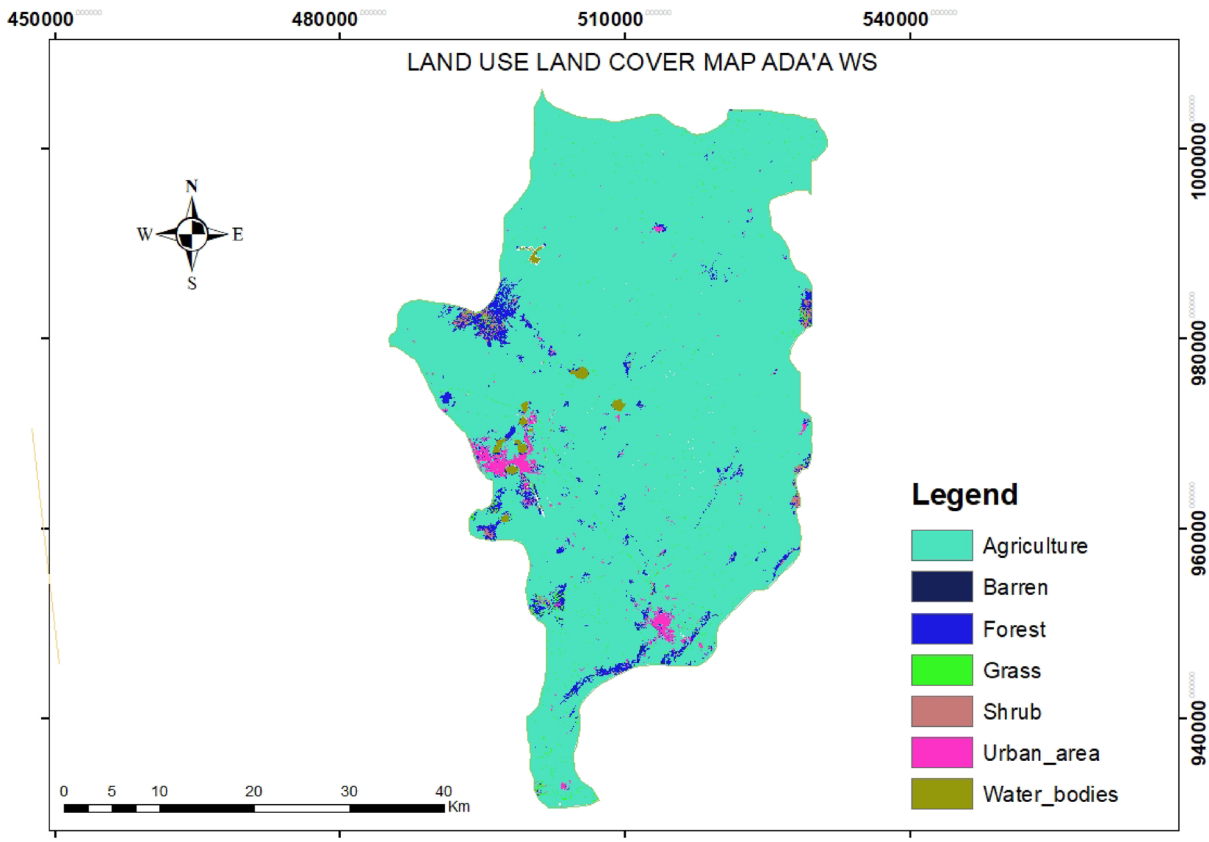

Fig. 8 land use and land cover map of the Ada'a watershed

the STI can be interpreted and analyzed for better conservation management.

Conclusion and recommendation

To calculate the annual soil losses in the research area, this study used USLE modeling. Most of the catchment region has low to moderate levels of erosion, and the remaining catchment coverage demonstrates extremely high to extremely severe erosion, according to the findings of the ArcGIS analysis. The highest percentage of the land is slightly prone to soil erosion since the majority of the watershed slope percentage is plain. Additionally, the catchment's soil erosion is significantly reduced by forest, grass, and well-managed agricultural activities. Because of heavy runoff and enhanced rainfall in the higher catchments, the downstream part of the catchment experiences the biggest soil losses. Soil loss in the area ranges from 0 to 457.37 tons per hectare per year, with STI ranging from 0 to 856.193. As a result, scholars and decision-makers have the opportunity to put the study into action based on the revealed outcomes. In portions of the Ada'a watershed that have been recognized as being prone to soil loss and sediment deposition, sustainable erosion management measures according to topography and current land use types are strongly recommended.

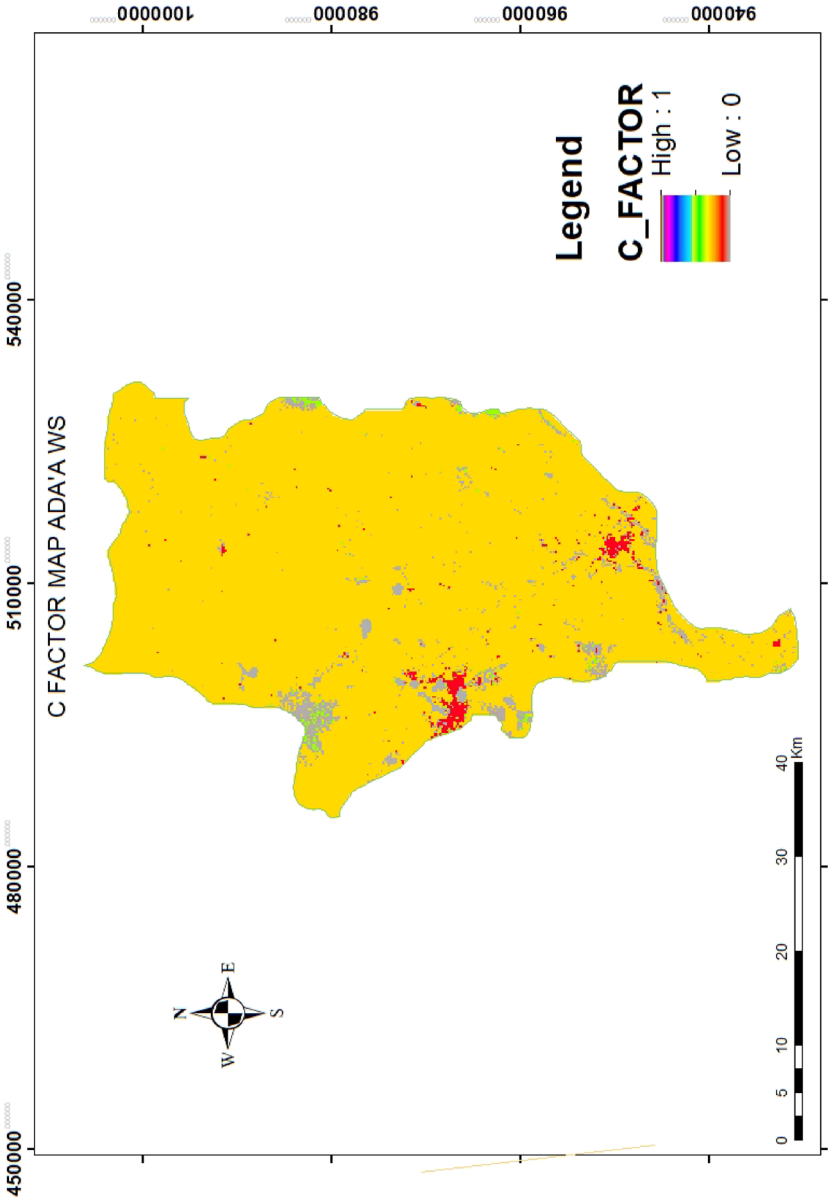

Fig. 9 C Factor map for Ada'a Watershed

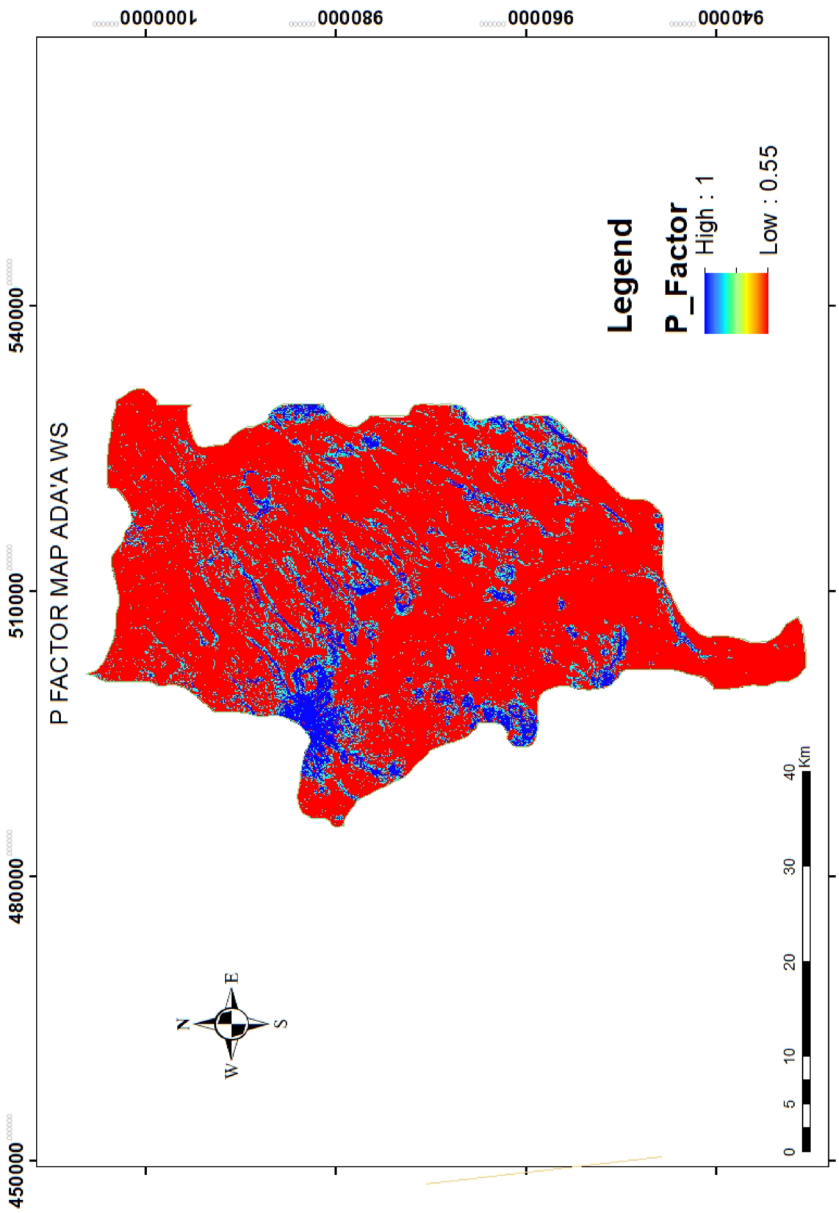

Fig. 10 P factor map of the Ada'a Watershed

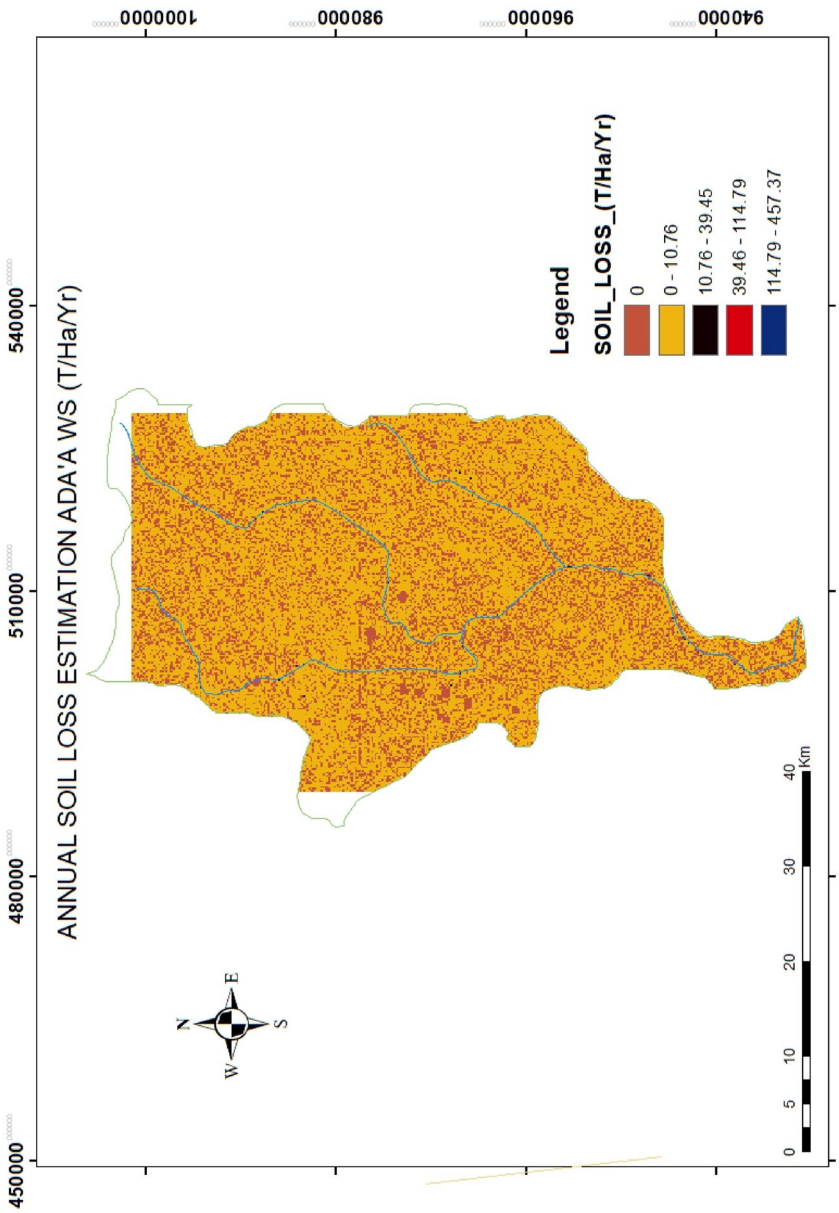

Fig. 11 Average soil loss estimation map of Ada'a Watershed

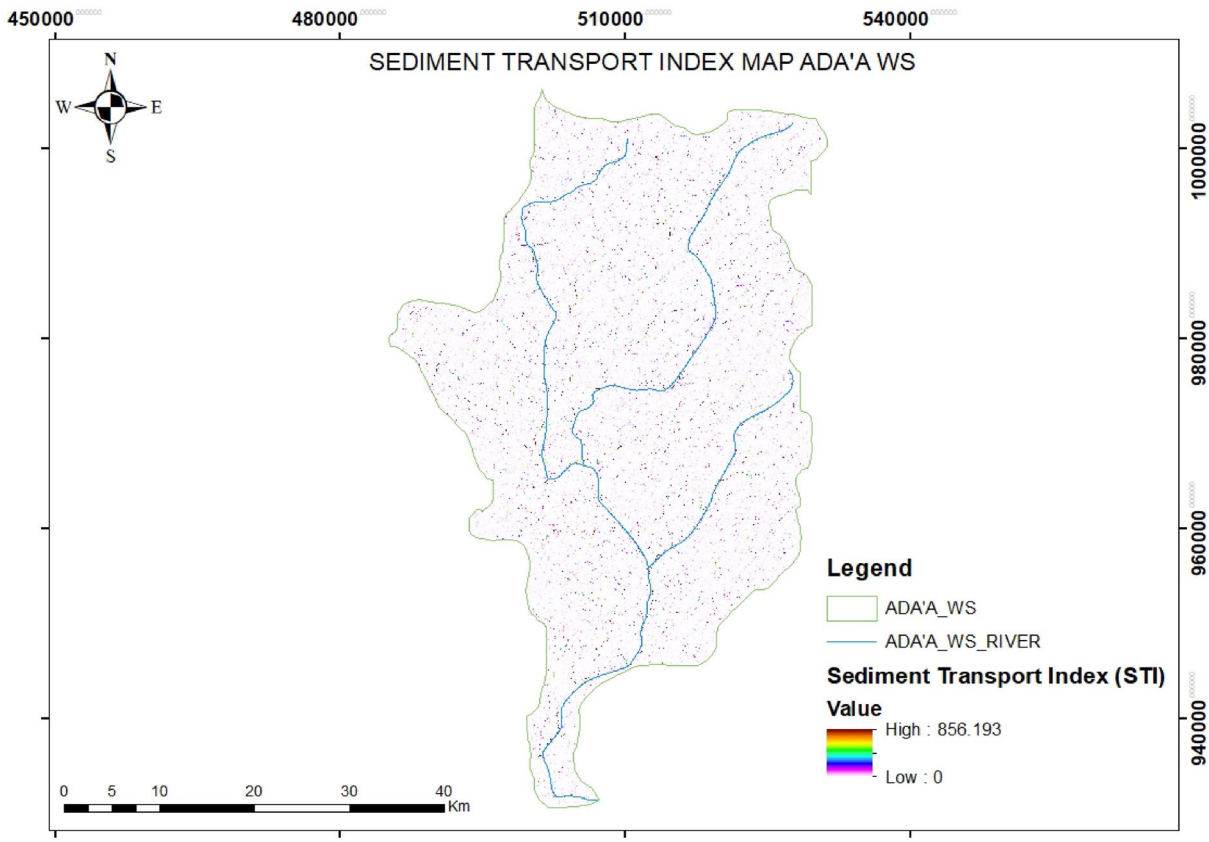

Fig. 12 Sediment Transport Index map of Ada'a watershed

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Availability of data and materials
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Declarations

Ethical approval and consent to participate
This article does not contain any study conducted by any of the authors that would require ethical approval. This article does not contain any studies involving human participants or animals performed by any of the authors.

Informed consent
Informed consent was obtained from both authors to submission and publication.

Competing interests
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