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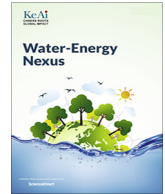
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Research paper

Spatial distribution mapping of erosion and sediment yield estimation using RUSLE and Arc GIS of Aygebiere watershed, North Shewa zone of Amhara region, Ethiopia

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ABSTRACT

Soil erosion and sedimentation are the major threats to Ethiopia's economy by impacting the productivity of agricultural land and shortening the life of dams. Aygebiere watershed was one of the most erosion-susceptible watersheds in Menz Gera district of Ethiopia. At the outlet, there was a soil dam (Godebe soil dam) which covered 12.7 ha. The dam was designed for irrigation purposes wishing to serve 378 households on 68 ha of land. However, the dam was facing a huge challenge of siltation due to the soil erosion brought from the upper reaches of the watershed. Therefore, the purpose of this study was to identify the erosion-affected area and to estimate the watershed's annual sediment yield delivered to the dam. The study used rainfall, DEM and satellite image data obtained from different sources. The result shows the annual soil loss of the watershed was 47 tons $\text{ha}^{-1} \text{yr}^{-1}$. The regions along the drainage lines were identified as erosion hotspot areas and they contribute 76.6% of soil loss. The estimated annual sediment washed from the watershed and reached the Godebe soil dam was found to be 8710 m^3 (60969 m^3) since the time the dam became operational). From the finding, it could be concluded that the watershed was highly vulnerable to soil loss above the tolerable soil loss limit of the country i.e., 10 tons $\text{ha}^{-1} \text{yr}^{-1}$. Therefore, it's recommended the high erosion and sediment-producing areas along the waterlines and side banks of the dam get priority for management.

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1. Introduction

Erosion is the removal of soil particles from their place of origin through the involvement of detachment, transport, and deposition process of soil particles and aggregate (Kumar et al., 2015). It is a universally recognized a universal threat to human well-being with its effect on the productivity of agricultural land by removing the uppermost fertile layer of the soil (Suresh, 2012). The Ethiopian highlands have been seriously affected by water erosion for a while (Fenta et al., 2020; Worku and Tripathi, 2015). Currently, its impact has reached a peak level along with a highly growing population (Hurni, 1985). Ethiopia loses 1.5 billion tons of fertile topsoil from its highland area which can add 1–1.5 million tons of grain to the country's product (TADDESE, 2001). Particularly, research by Desalegn et al., 2018, reported an average soil loss of 22.3 tons $\text{ha}^{-1} \text{yr}^{-1}$ in the watershed found in the highland of Ethiopia.

In the Ethiopian highlands, the sediment mobilization from cultivated land causes serious land degradation (Guzman et al., 2013). As it is difficult to quantify and mapping of soil loss in a traditional way most researchers commonly use the USLE (Wischmeier and Smith, 1978), and RUSLE (Renard and Freimund, 1994) models as predictive tools for hotspot area identification of the watershed.

Besides, sedimentation is also another threat to Ethiopia through its impact on reservoirs and dams constructed for different purposes throughout the country. The accumulation of sediment affects the reservoir's lifetime and water-holding capacity. Many dams are built in Ethiopia for household and irrigation needs. The issue of siltation has an impact on these Ethiopian irrigation and hydroelectric reservoirs, including Legedadi, Abasamuel, Angerib, Borkena, Tekeze, and Gilgel Gibie I (Tsegaye and Bharti, 2021). According to reports, these reservoirs' intended usage and lifespan are at risk due to their shrinking size and declining water quality (Wolancha, 2012). Sedimentation increases water conveyance maintenance costs and has a detrimental effect on downstream agricultural products by blocking irrigation channels. Siltation causes a long-term socioeconomic problem as

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sediments get into reservoirs and lower reservoir water storage capacity.

Estimation of sediment is important for planning, developing, operating, and maintaining water resource structures, however sediment monitoring and sampling techniques are time-consuming and expensive (Kumar et al., 2015). The scholars developed the sediment transport efficiency called the sediment delivery ratio (SDR) which has a direct relation with the watershed area and total soil loss of the watershed (Vanoni, 2006). In watersheds with insufficient sediment yield observations, the SDR allows for an estimation of sediment transport (Tsegaye and Bharti, 2021). The RUSLE and SDR are used in this study to determine the soil loss and sediment delivery, respectively. In Ethiopian ungagged watersheds, which are susceptible to high soil erosion and sediment yield, estimating sediment yield by combining soil loss with SDR is uncommon. Additionally, it is still unknown how much sediment from the watershed upstream is accumulating in the Godebe soil dam. Knowing this information is essential for managing the dam properly and choosing and putting into effect the best watershed management strategies. The approach we used in the study fills the knowledge and information gap for quantifying soil loss and sediment yield in data-scarce ungagged watersheds and enables those who are responsible for establishing appropriate watershed management strategies. It gives planners and decision-makers insight into how susceptible the watershed is to erosion and how to build strategies for soil and water conservation.

Aygebire watershed was one of the most erosion-susceptible watersheds in Menz Gera woreda. The major land use type of the watershed was cultivated land and the watershed did not have soil erosion conservation activities. As a result, different erosion indicators (sheet, rill, and gully erosion) were dominantly visible. At the outlet, there was a soil dam (Godebe soil dam) that covered 12.7 ha. The dam was constructed by the Amhara Water Works Construction Enterprise between 2010 and 2014. The dam was designed for irrigation purposes wishing to serve 378 households on 68 ha of land. However, the dam was facing huge challenges of siltation due to the soil erosion brought from the upper reaches of the watershed. The population that depends on irrigation is currently being impacted by the decreasing size of the dam and the irrigation region beneath it. Studying soil loss and sedimentation processes of the watershed was determined to be a crucial concern to plan and implement watershed-level management measures and to decrease the sediment load of the reservoir. Therefore, the objectives of this research were to spatially locate the regions of the watershed that produce higher amounts of soil erosion and to quantify the amount of sediment washed from the watershed and delivered to the Godebe soil dam.

2. Materials and methods

2.1. Description of the study area

The study was conducted at the Aygebire watershed which is located in the southern parts of the Amhara region of Ethiopia. The watershed is 152 km far away from Debre Birhan city which is the capital city of the north Shewa zone. The elevation of the study area varies from 3160 to 3437 meters above mean sea level and is located between 390 42'40"–390 45'32" longitudes and 100 20'18"–100 21'14"latitudes (Fig. 1). On the other hand, 30–50, 0–5 and >50% slop classes have 13.1, 6.9 and 4.9% of the area coverage of the watershed respectively.

The region receives 923.2 mm of rain on average yearly. According to the rainfall statistics, the watershed has a bimodal rainfall distribution between the two crop seasons in 2016 and 2019 (Belg

and main season). The watershed's minimum and maximum average annual temperatures are 7.5 °C and 18.9 °C, respectively. The watershed covers a 485 ha area. The dam (water body) covers 2.6% of the watershed with 79.8% cultivated land, 13.8% grassland, 2.1% bare land, 1.3% forest land and 0.23% bushland. The forest and bushlands are mainly covered with Eucalyptus globules and Asta (Erica arborea L. (Ericaceae) respectively. About 38.4% of the watershed area has a 10–20% slope class followed by 19.2% and 17.5% area coverage of the watershed exhibits 20–30 and 5–10% of slop class respectively. Barley, Fababean, lentil and potato are the main crops produced within the watershed. Cultivation activity is mainly held in the main season (summer) and sometimes in the Belg season within the wurchi agro-ecology zones of the watershed which are located in the northeast parts of the watershed. In Belg season barley is the only crop produced in the watershed. Plowing frequency in the watershed varies depending on crop type; usually, it is three times for barley and two times for Fababean and potato, but there is no plowing for lentil production before sowing. The main objective of plowing is to minimize weed population and improve soil aeration. About 55.5%, 26.7% and 17.8% portion of the watershed are dominated by Loamy, silt and Sandy soil textural class respectively.

2.2. Data collection and analysis

Rainfall data (1995–2021) was obtained from Ethiopia National Meteorological Agency ENMA) for the analysis of rainfall erosivity. A 20 m resolution was obtained from the website of the United States Geographical Survey (USGS) and Shuttle Radar Topographic Mission (SRTM). Satellite image to estimate cover factor was acquired from Google earth imagery. A soil sample was collected for soil erodibility analysis, and consecutive field observations were carried out to gather actual ground truth points for image classification and accuracy assessment. Data analysis and processing were done by digitizing, classifying, calculating, and overlaying the necessary information of each thematic layer using Arc GIS software. The conceptual framework followed during the life cycle of this study was illustrated in the chart (Fig. 2).

2.3. Generation of RUSLE factors

The mean yearly soil loss that happened in the study watershed was calculated using the Revised Universal Soil Loss Equation (RUSLE), which was built with GIS and remote sensing technology (Renard and Freimund, 1994). The annual soil loss was calculated by overlying all six RUSLE factors in a raster format using a raster calculator in GIS software (1).

$$A = R * K * LS * C * p \quad (1)$$

where A is mean annual soil loss (tons ha⁻¹ yr⁻¹), R is the rainfall erosivity factor, K is the soil erodibility factor, LS is the slope length and steepness factor, C is land use land cover factor and P is land management practices factor.

2.4. Rainfall erosivity (R) factor

The daily recorded rainfall data on the nearby station (7 km from the watershed) which is obtained from the east Amhara metrological information center was used to generate the rainfall erosivity factor (R-value). The daily rainfall data were summarized to get mean annual rainfall and then the rainfall erosivity factor was calculated using the formula adapted for Ethiopia (Hurni, 1985) (2).

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

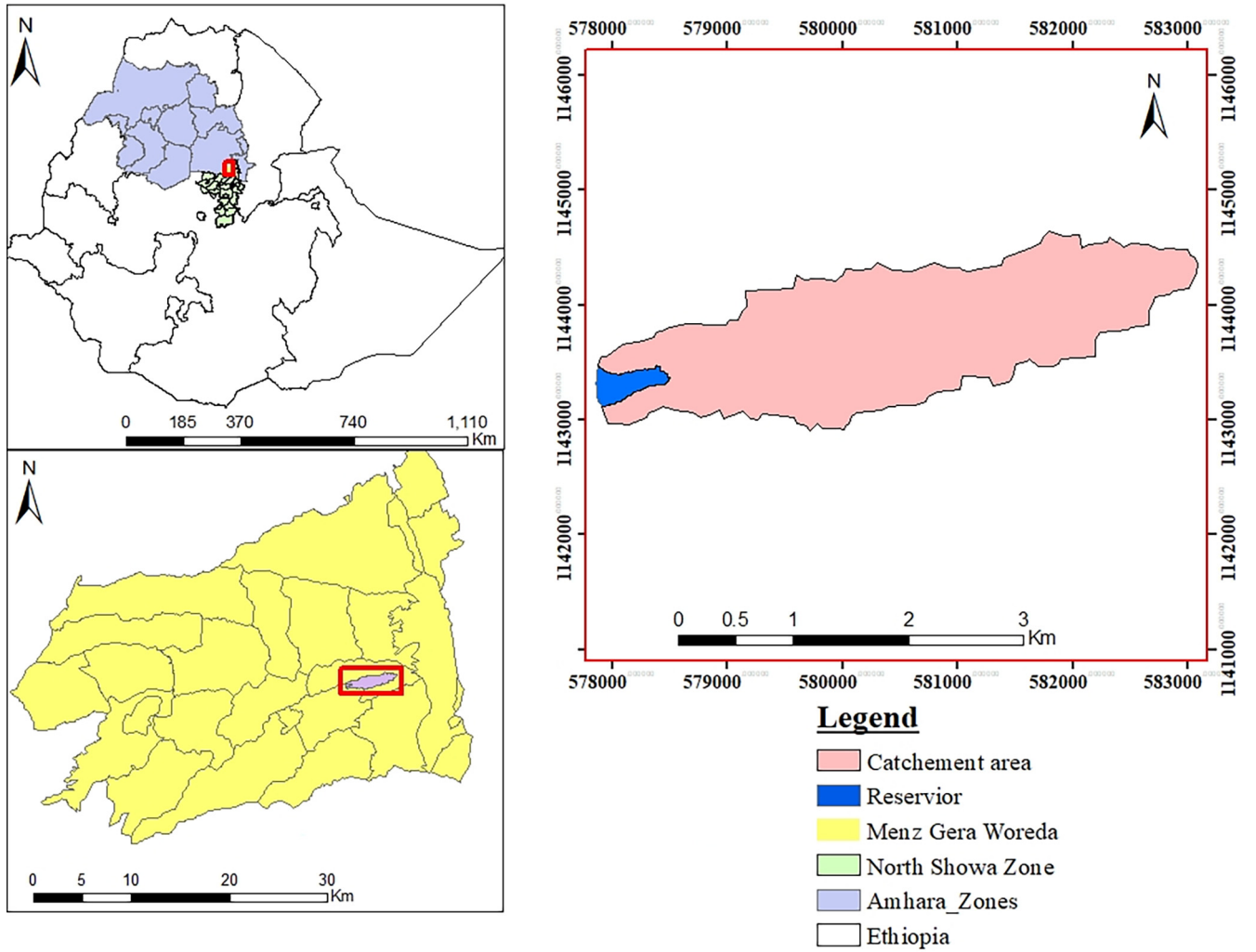


Fig. 1. The location map of the study area.

where R is the rainfall erosivity factor and P is the mean annual rainfall (mm) of the study watershed.

2.5. Soil erodibility (K) factor

Soil erodibility is more sensitive to soil texture and organic matter content because of its ability to govern the permeability, infiltration rate, and structural stability of the soil (Suresh, 2012). Based on land use and slope variability the watershed was divided into several strata. From all strata, 120 soil samples were collected. All sampling points were geo-referenced using handheld GPS. These representatives collected soil samples which were delivered to the soil laboratory for soil texture (sand, silt, and clay) and organic carbon (OC) analysis. Depending on the soil texture and OC content of the soil, the K factor was calculated using the (3) developed by (Williams, 1975)

$$K_{USLE} = K_W = f_{csand} * f_{cl-si} * f_{orgc} * f_{hisand} \quad (3)$$

where f_{csand} is a factor that lowers the K indicator in soils with high coarse sand content and higher for soils with little sand, f_{cl-si} gives low soil erodibility factors for soils with high clay-to-silt ratios, f_{orgc} reduces K values in soils with high organic carbon content, while f_{hisand} lowers K values for soils with extremely high sand content. Finally, the K -factor map of 20 m * 20 m resolution was developed using ordinary kriging interpolation

2.6. Slope length and steepness (LS) factor

The LS factor shows the effect of topography on erosion, which is proportional to the length and steepness of the slope. To get the LS factor ASTER DEM having a 20-meter resolution was processed in Arc Map to generate flow accumulation and slope gradient. Finally, the factor was computed using a raster calculator in Arc Map using (4) derived from (Griffin et al., 1988)

$$LS = POW \left[(Flow \ accumulation) * \frac{cellsize}{22.1}, 0.6 \right] * POW \left[\frac{\sin(slope) * 0.01745}{0.09}, 1.3 \right] \quad (4)$$

2.7. Land use land cover (C) factor

The C factor is directly related to the land use land cover class of the study area. The land use map has been generated manually from Google Earth. To avoid incorrect land use classification accuracy assessment was done by maximum likelihood algorithm using recorded GPS points as a reference on each land use class in addition to a detailed field survey and the researcher gained 91.6% of the land use was accurately classified. Finally, as proposed by Hurni (1985) the corresponding C -values were developed in a

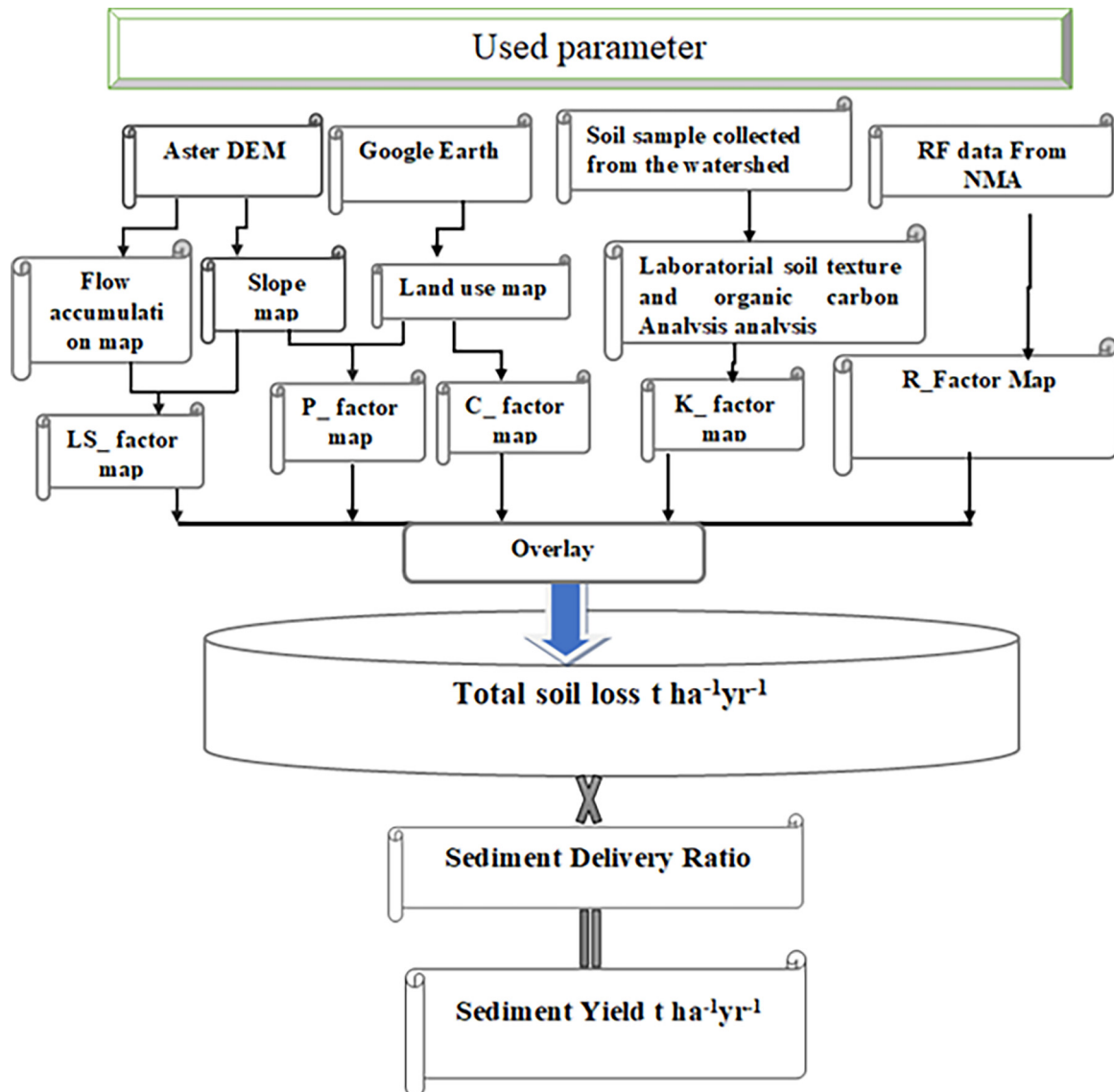


Fig. 2. Conceptual framework showing the whole process of analysis.

raster format having 20 m resolution after assigned cover factor values for each land use class.

2.8. Management practice (P) factor

The p-factor was assigned using major land use and slope interaction adopted by (Wischmeier and Smith, 1978).

2.9. Estimation of sediment delivery ratio

Sediment delivery ratio is defined as the amount of sediment detached and transported directly to the catchment outlet compared to the total amount of soil that is detached over the area of the catchment above the common outlet (Tsegaye and Bharti, 2021). It is the efficiency measurement of sediment transport of the watershed. All the detached soils are not transported to the outlet of the watershed; some of them are deposited near the eroding source. The sediment delivery ratio accounts for the amount of sediment delivered to the outlet compared to the total amount of soil that is detached throughout the watershed. In this research, the sediment delivery ratio and the total amount of sediment that

was transported and reached from eroding sources to the reservoir were estimated using the relationship developed by (Mockus, 1972) as described in (Eqs. (5) and (6)).

$$SDR = 0.5656 * AW^{-0.11} \quad (5)$$

$$SY = SDR * A \quad (6)$$

where SDR is sediment delivery ratio, AW is the Area of the watershed (km^2), SY is Sediment Yield ($\text{tons ha}^{-1}\text{yr}^{-1}$) and A is soil loss ($\text{tons ha}^{-1}\text{yr}^{-1}$) obtained by the RUSLE model.

2.10. Estimation of the total sediment in the dam

To estimate the volume of sediment stored in the dam converting the gained mass of the sediment into volume units by determining the bulk density of the sediment is the first step. But practically taking soil samples for bulk density analysis from the sediment stored within the dam is difficult. To overcome these challenges different scholars have developed different bulk density estimation methods of sediment stored within the dam based on the proportion of soil separates derived to the dam from their place

Table 1

The initial density of soil texture adopted from.

Reservoir type	Initial(t = 0)			Compacted after time t		
	ρ_{clay} (kg/m ³)	ρ_{silt} (kg/m ³)	ρ_{sand} (kg/m ³)	$\rho_{\text{clay,initial;K}}$ (kg/m ³)	$\rho_{\text{silt,initial;K}}$ (kg/m ³)	$\rho_{\text{sand,initial;K}}$ (kg/m ³)
Always submerged	415	1120	1550	480 K = 255	1040 K = 90	1550 K = 0

of origin and their duration within the dam. Scholars state that the bulk densities of the deposits vary with the proportion of soil separates and type of reservoir operation (exposed or submerged sediment deposits) and the consolidation period. Based on data from reservoirs they derive an expression for the initial (at t = 0) bulk density as (7):

$$\rho_{\text{bulk}} = p_{\text{clay}} \rho_{\text{clay}} + p_{\text{silt}} \rho_{\text{silt}} + p_{\text{sand}} \rho_{\text{sand}} \quad (7)$$

where p = percentages of clay, silt and sand in sediment deposits; but the values of ρ_{clay} , ρ_{silt} , and ρ_{sand} are given in (Table 1).

After generating the initial bulk density of the sediment its bulk density after T years of compaction due to later deposits was also estimated using the following formula (8).

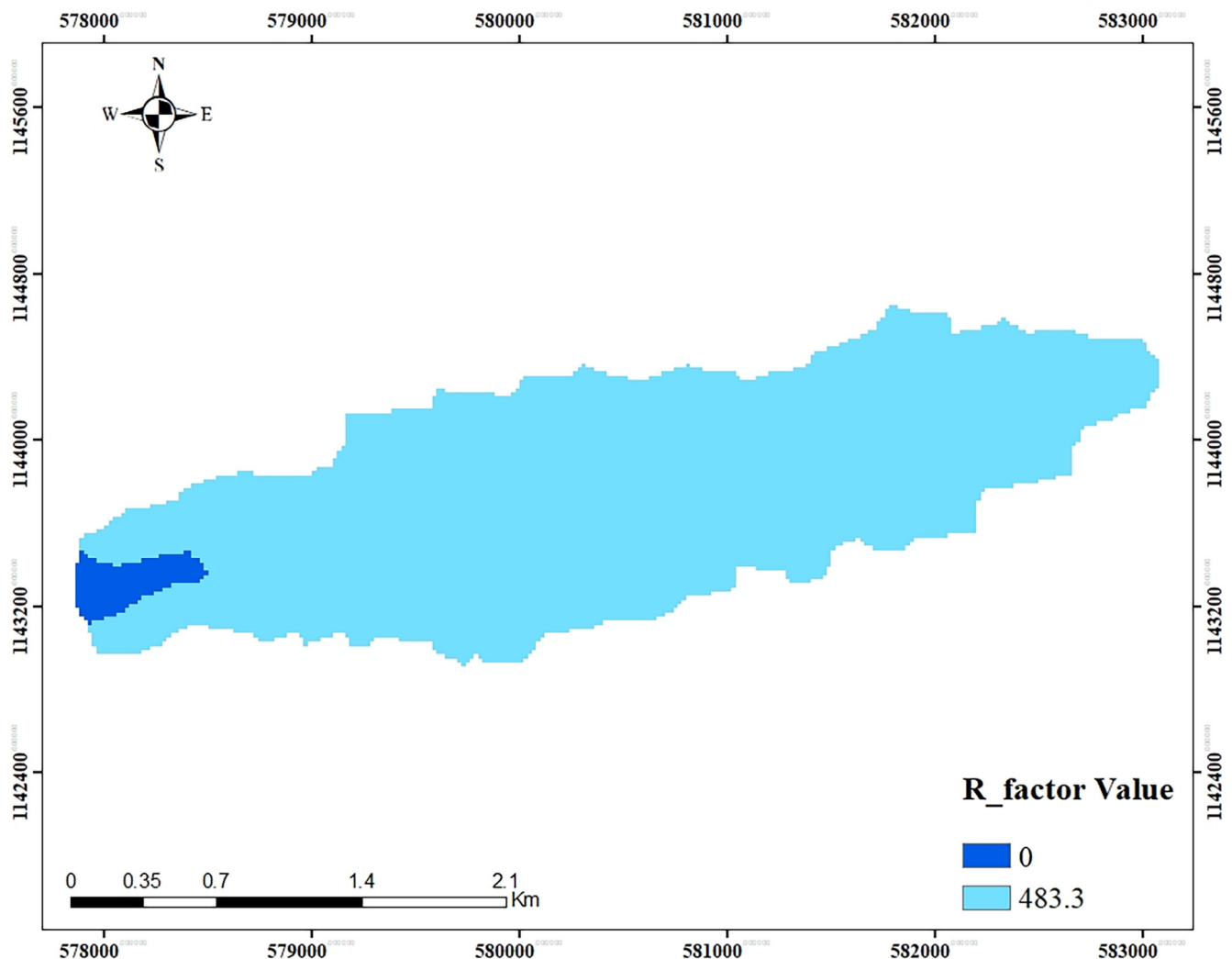
$$\rho_{\text{bulk}} = \rho_{\text{initial}} + K \log(T) \quad (8)$$

where ρ_{initial} = initial bulk density, K = coefficient, T = time (years).

Standing from a yearly and cumulated bulk density of the sediment stored in the dam total sediment yield in metric tons was converted to the volume of soil in m³ units. Finally, the volume of the dam occupied by sediment was evaluated.

2.11. Sensitivity analysis

The most sensitive characteristics that will guide targeted and selected treatments were chosen through the sensitivity analysis (Diwediga et al., 2018). Sensitivity analysis evaluates the relationship between changes in the values of the model's input parameters and changes in the model's output (Zelege and Hurni, 2001). The baseline for the sensitivity analysis was the average values of the five RUSLE parameters. A tornado chart is a particular sort of bar chart that is employed as a graphical method of portraying a result of a deterministic analysis in order to highlight the most

**Fig. 3.** Rainfall erosivity factor map of the study watershed.

sensitive variables (PRINSLOO, n.d.). It shows how much each variable contributes to the variation in a certain metric while all other variables are at their baseline values (Borgonovo and Rabitti, 2023; Eschenbach, 1992). Therefore, in this study we used tornado chart for ranking sensitivity of the RUSLE parameters.

3. Results and discussion

3.1. Rainfall erosivity (R) factor

The watershed's erosivity factor was found to be $483.3 \text{ MJ} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$. Due to the similarity in the watershed's rainfall pattern, the erosivity factor is the same for all grids. The erosivity map of the watershed is illustrated in Fig. 3.

3.2. Soil erodibility (K) factor

The soil of the study watershed has an organic carbon value between 0.6 and 3.1. The North-East side of the watershed produced the highest amount of soil organic carbon. The Guassa community protected area borders this side of the watershed, this might be the reason that this area of the watershed has soil with a loamy texture and high levels of organic carbon. The southwest side of the watershed, on the other hand, had a lower organic matter level. Compared to the northeast side of the watershed, this

side is primarily used for agriculture and has sand-textured soil as its predominant soil type. The soil erodibility factor values for the watershed were developed after the spatial overlaying of the texture and organic carbon map of the watershed, and they were found to range from 0.123 to 0.19 (3). Although it has a clay texture soil, the northwest and southwest regions of the watershed have the highest soil erodibility due to their low organic carbon contents. In contrast, the watershed's western and eastern edges, where a dominating loam soil texture and a loam textured soil with high organic carbon content, had the lowest soil erodibility values (Fig. 4).

3.3. Slope gradient and length (LS) factor

Based on (5) the LS factor of the watershed has a value ranging from 0–29.5 and was generated using watershed slope steepness and flow accumulation. The result shows that the maximum LS factor has been found in the western part of the watershed along the drainage line. This is so because the slope length and steepness (LS) factor value increases with slope steepness. By taking into account the length of a slope and the influence of surface runoff, which can be active on eroding soil material before it infiltrates or continuous as interflow, the LS factor reflects the contribution of the topography to the soil erosion risk (Schmidt et al., 2019) (Fig. 5).

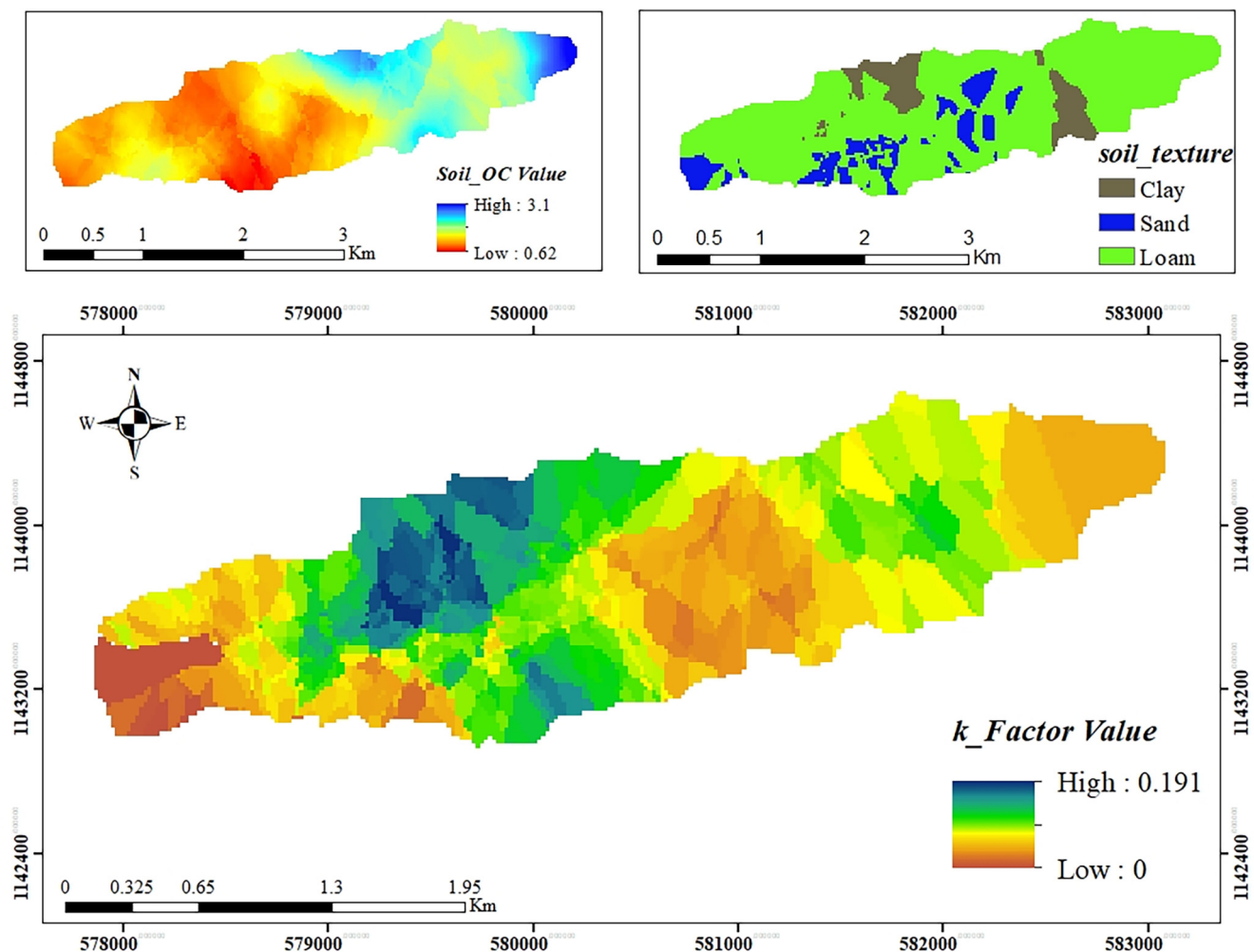


Fig. 4. Soil erodibility factor map.

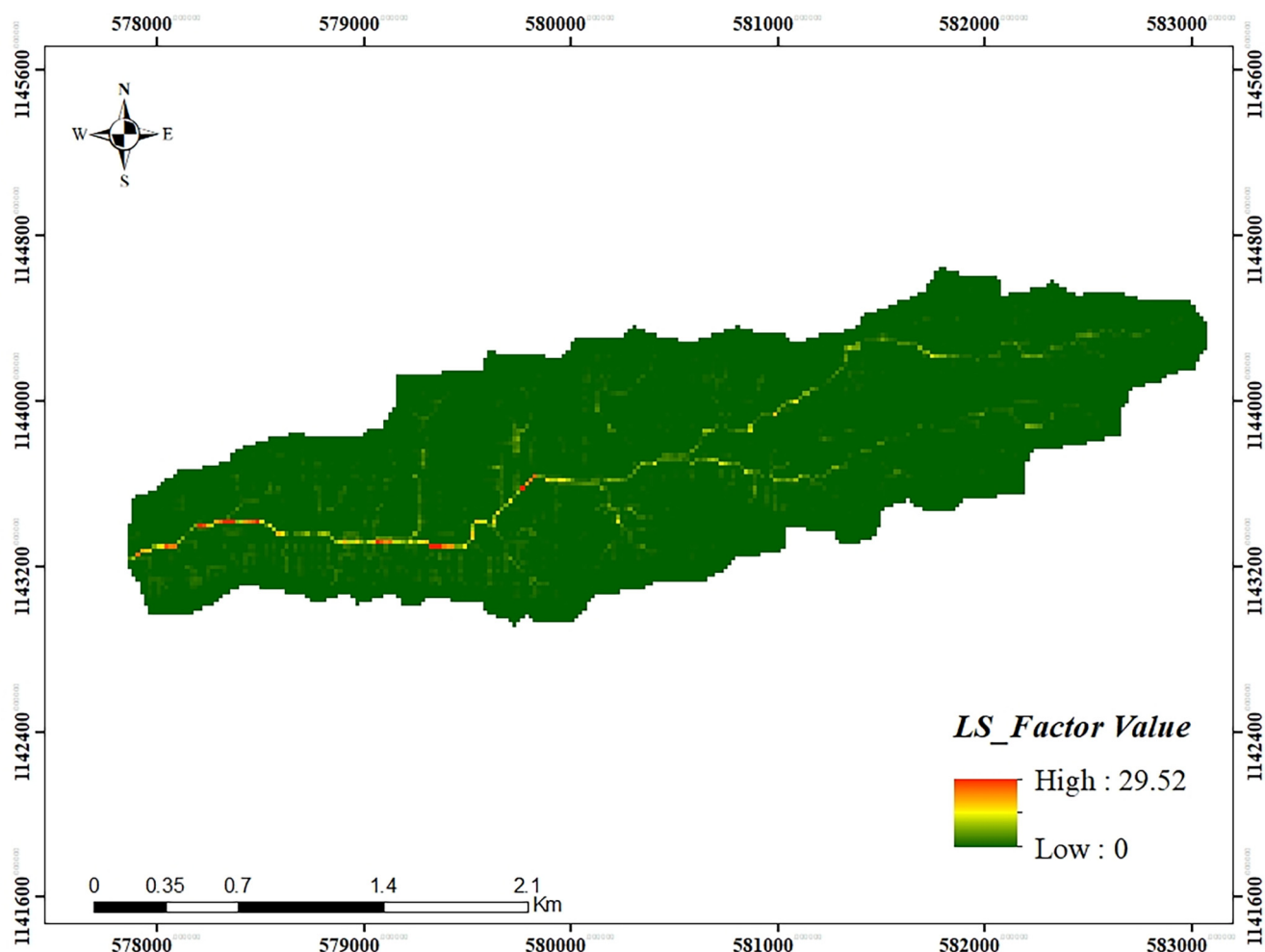


Fig. 5. Slope steepness and length (LS) factor map.

3.4. Land use land cover (C) factor

The watershed was classified into six land use types using Google Earth manually with the strong ground survey and the cover factor was assigned for each land type as presented in (Table 2). According to the land use classification, cultivated land was discovered to be the predominant (79.8%) land use type in the watershed, followed by grassland (Table 2).

Based on the assigned crop cover factor value the C-factor map was generated to make it suitable for the final overlay. The land use that was subject to erosion owing to frequent tillage and farming activities has the highest cover factor, followed by bare soil was soft for erosion, as shown in Fig. 6. The soil gets ease to erosion when it become loose and fine by repeated tillage operations. Moreover, plowing may aggravate soil erosion if it conducted following the slope or across the contour lines.

Table 2
C-factor value of the watershed adopted from Hurni (1985).

Land use type	Area-ha	Coverage (%)	Corresponding 'C' value
Cultivated land	387	79.8	0.15
Grassland	67	13.8	0.03
Reservoir	12.7	2.6	0
Bare land	10.4	2.1	0.05
Forest land	6.3	1.3	0.01
Bushland	1.6	0.3	0.01
Total area	485	100	

3.5. Management practice (P) factor

The soil-loss ratio of a particular support practice is linked by this factor to the comparable soil loss caused by upslope and downslope tillage (Renard et al., 1997). It demonstrates the results of methods that modify runoff's quantity and rate, leading to less erosion. The watershed was stratified into six land uses and slope classes. After slope and land use classification, the P-factor values of 0.1, 0.1, 0.14, 0.19, 0.25, and 0.33 were assigned for cultivated land use type with slope class of 0–5, 5–10, 10–20, 20–30, 30–50 and >50 respectively (Table 3) as recommended by (Wischmeier and Smith, 1978). Other land use types which include bushland, grassland, forest land, and bare land were grouped into other land uses and a P-value of 1 was assigned to all slope classes.

Following the intersection procedure between slope, land use, and slope in the Arc GIS environment, the following management practice (P) factor map (Fig. 7) was produced. The watershed's steep slope part (the red-shaded zone), which primarily follows the watershed's hillside and rivers, is where the highest P value was found, illustrated in Fig. 7.

3.6. Estimated soil loss from the watershed

The spatial distribution of annual soil loss of the study watershed was significantly varied and ranged from 0 to 288 tons $\text{ha}^{-1} \text{yr}^{-1}$. It was 0 on the water body (dam) and 288 tons $\text{ha}^{-1} \text{yr}^{-1}$ on

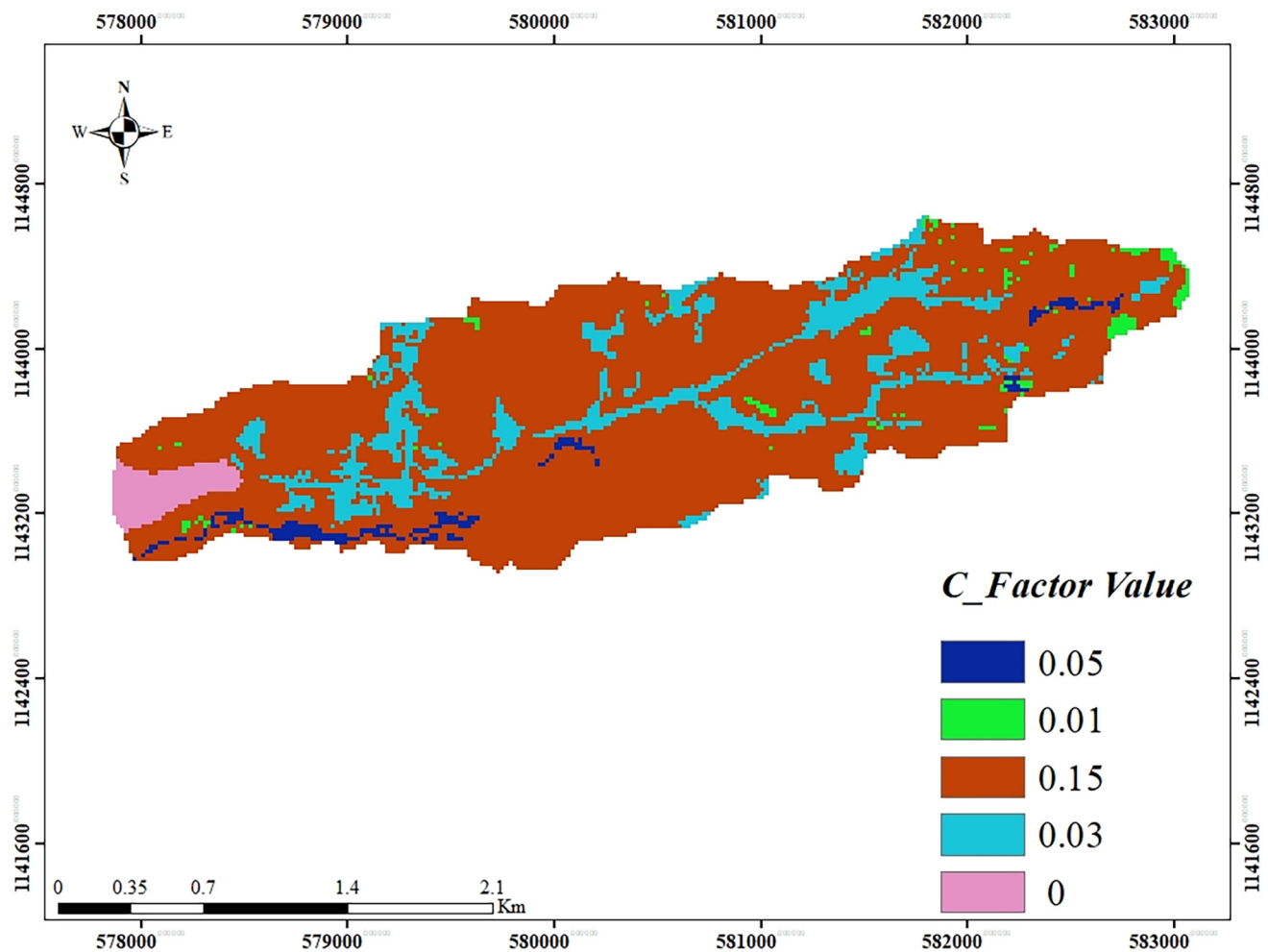


Fig. 6. Land use and land cover (C) factor map.

Table 3

P-factor value of the watershed adopted from [Wischmeier and Smith \(1978\)](#).

Land use type	Slope (%)	P-value
Reservoir	0	0
Cultivated land	0–5	0.1
Cultivated land	5–10	0.12
Cultivated land	10–20	0.14
Cultivated land	20–30	0.19
Cultivated land	30–50	0.25
Cultivated land	>50	0.33
Other land use	All	1

the regions along with the main river. With this range, the average annual soil loss of the watershed was found to be $47 \text{ tons ha}^{-1} \text{ yr}^{-1}$. The findings of this study indicated that the watershed is much more susceptible to soil loss than the country's tolerated soil loss limit, which is $10 \text{ tons ha}^{-1} \text{ yr}^{-1}$. This result is in line with the soil loss rate reported by other scholars ([Gelagay, 2016](#)) is $47.4 \text{ tons ha}^{-1} \text{ yr}^{-1}$ in the case of the Koga watershed in the upper Blue Nile of Ethiopia similar to the finding of ([Tesfaye, 2018](#)), i.e., about $63 \text{ tons ha}^{-1} \text{ yr}^{-1}$ at Gilgel Gibe-1 catchment, southwest Ethiopia but out of the range of the finding of ([Yesuph and Dagnew, 2019](#)) $37 \text{ tons ha}^{-1} \text{ yr}^{-1}$ at Bashillo catchment of Blue Nile basin in Ethiopia. On the other hand, the result of this research showed that the watershed is two times more vulnerable than the finding of [Desalegn et al., 2018](#) which is $22.3 \text{ tons ha}^{-1} \text{ yr}^{-1}$ at Andit Tid

watershed in the central highland of Ethiopia. In contrast to our findings, the research by [Tesfahunegn \(2009\)](#) and [Tiruneh and Ayalew \(2016\)](#) reported 9.6 and $4.8 \text{ tons ha}^{-1} \text{ yr}^{-1}$ soil loss at the Medego watershed in northern Ethiopia and Enfraz watershed in highland Ethiopia respectively. The annual soil loss of the watershed is $22194.8 \text{ tons yr}^{-1}$ ([Fig. 8](#)).

3.7. Spatial distribution of soil erosion

The land along the drainage line is identified as an erosion hot spot area of the watershed which contributes about 76.6% of soil loss from the total area, even though 58.8% of the soil loss arises from the lower parts of the watershed along the main drainage line which falls under a very severe soil erosion class as adopted from [Gelagay \(2016\)](#). This is due to the nature of the dominant sand texture class with a low organic carbon content that is responsible for making the soil well-structured and resistant to erosion.

3.8. Sensitivity of parameters

According to our findings, independent of the method used for parameter estimation or the range of estimates, cover management (C factor) was the main variable influencing estimated soil loss in RUSLE ([Table 4](#)). The level of heterogeneity in model predictions was also highest with the C factor. This aligns with early sensitivity analyses for the RUSLE when applied at the plot level

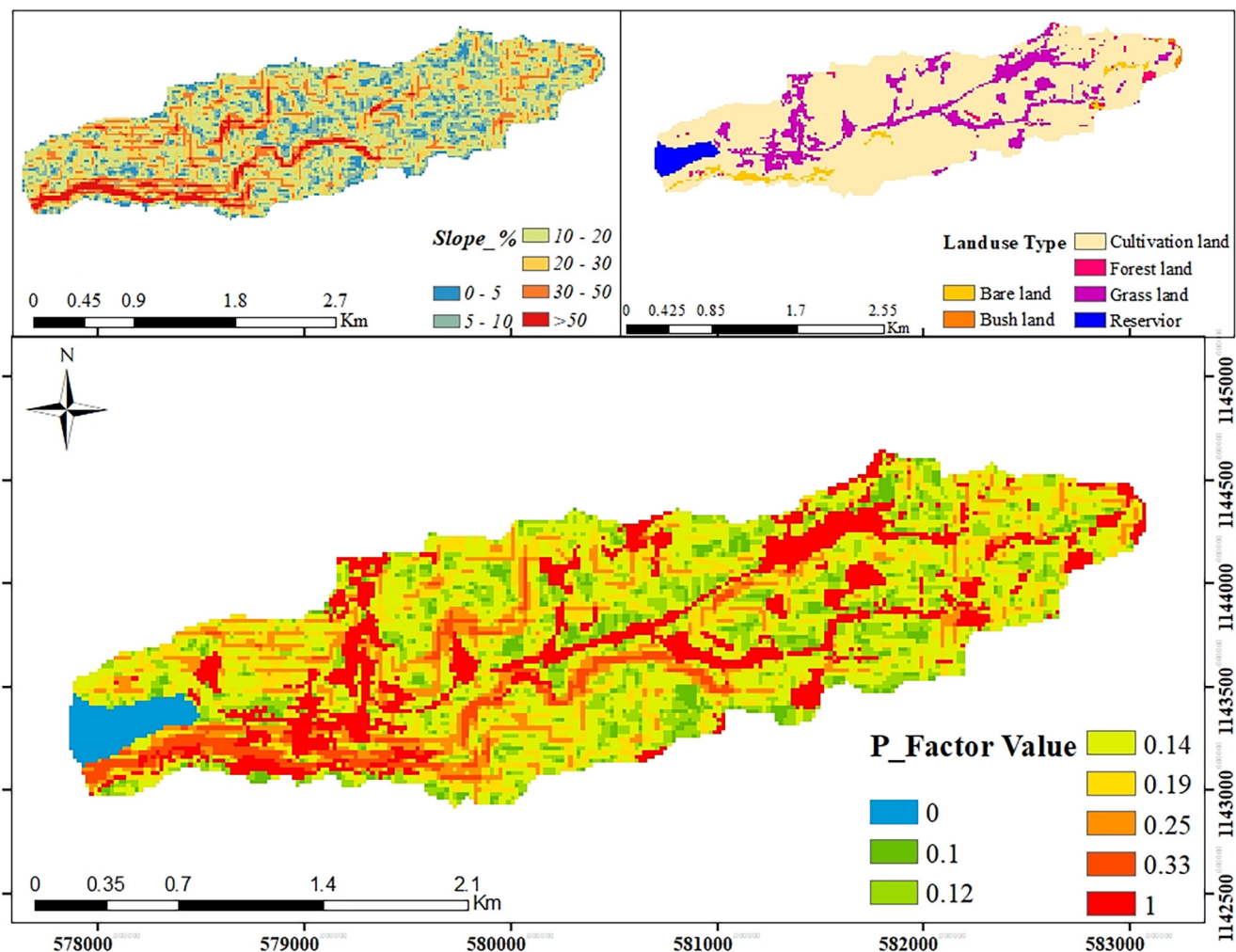


Fig. 7. Management practice (P) factor map.

(Estrada-Carmona et al., 2017; Kanito et al., 2023), but does not concur with another sensitivity study at the watershed level who reported rainfall erosivity as the most sensitive parameter (Sujatha and Sridhar, 2018). Due to significantly greater R values and prior sensitivity study in a subtropical zone (Zhang et al., 2013), we thought the R factor to be more significant, but this factor was not the case in our study watershed. The chart showing the level of sensitivity of RUSLE parameters is illustrated in Fig. 9.

3.9. Estimated sediment delivery ratio

The sediment delivery ratio of the Godebe watershed is 0.48. This shows that almost half (48%) of the eroded soil reaches the dam and 52% of the eroded materials are re-deposited within the watershed. This result is in reasonable agreement with the finding of Mengistu et al. (2015) and Kanito et al. (2023) who reported 0.5 and 0.529 mean SDR, respectively. The result strongly disagrees with the finding by Gelagay (2016) in the Koga watershed. This result may be due to the small drainage area (485 ha) of the watershed, and the homogeneity of the watershed to land use, topography, and soil (Vanoni, 2006). For example, 79% of the watershed is covered by cultivated land use, 89.8% of the watershed exhibits a 0–5% slope, and the watershed exhibits a short distance to the main drainage line having a slope of (4%). With this, the sediment delivery ratio which is the amount of sediment reached to the dam

was found to be 22.6 tons $\text{ha}^{-1} \text{yr}^{-1}$ (6). This result strongly agrees with the finding of Setegn et al. (2010) i.e., 24.6 tons $\text{ha}^{-1} \text{yr}^{-1}$ sediment yield in northern Ethiopia. In contrast, our finding strongly disagrees with the finding of Haregeweyn et al. (2008) which was 9.9 tons $\text{ha}^{-1} \text{yr}^{-1}$ and determined using 11 reservoirs in the northern part of Ethiopia. Moreover, the Godebe soil dam receives an average of 10653.5 tons (8710 m^3) of sediment each year. This means, approximately 74,575 tons (60969 m^3) of sediment have been supplied and stored during the past seven years, beginning on the day the dam became operational for water harvesting.

4. Conclusion and recommendation

The findings of this research confirmed that the watershed is highly vulnerable to erosion, which is beyond the tolerable soil loss limit of the country. Consequentially, the sediment delivery ratio and sediment yield delivered to the dam are also high. This process will shorten the life expectancy of the reservoir due to this high siltation. The main driving factor for the higher soil loss was determined to be the land use system in the watershed: cultivated land is the dominant land use (79.8% coverage) on which soil is easily disturbed, detached and transported by rainfall runoff, plowing and cultivation practices.

Therefore, to minimize the rate of soil erosion and the amount of sediment yield delivered to the dam it is advised that (1) soil

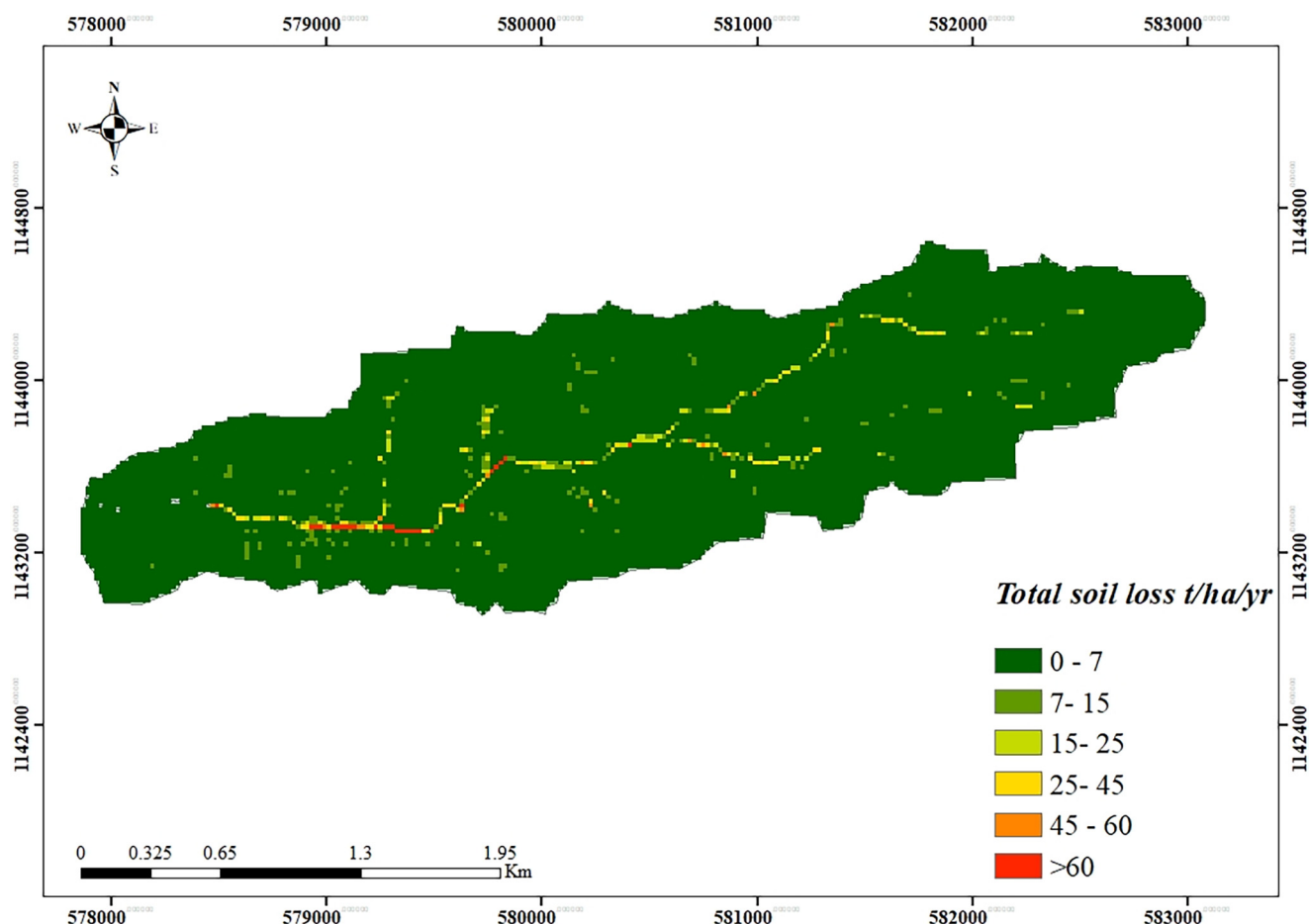


Fig. 8. Management Factor Map.

Table 4

Result of the sensitivity rank of the RUSLE parameters.

No	Baseline	Parameter adjustment	Minimum	Maximum	Decrease	Increase	Sensitivity rank
1	47	Removal of R-factor	0	0.10	47	−46.90	5
2	47	Removal of K-factor	0.123	260.23	46.88	213.23	2
3	47	Removal of LS-factor	0	1.68	47	−45.32	4
4	47	Removal of C-factor	0	828.40	47	781.40	1
5	47	Removal of P-factor	0	163.50	47	116.50	3

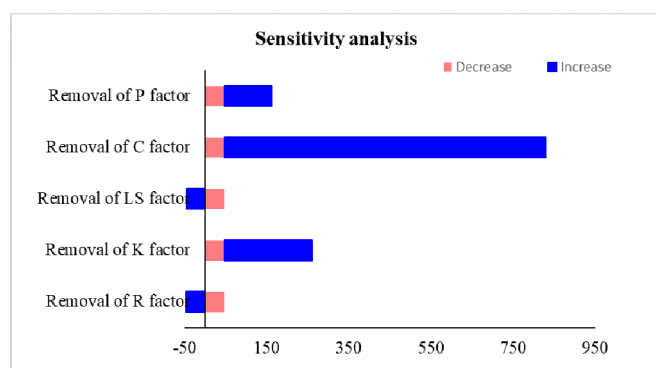


Fig. 9. The chart of sensitivity of parameters in varying the estimated soil loss.

erosion hotspot area along with the main drainage line should be given serious attention for the immediate and appropriate soil and water conservation and (2) priority should be given to land

management activities that help to reduce soil disturbance and transportation of sediment, particularly to improve the land use and land cover system and (3) awareness about proper land management for the farmers who are practicing cultivation and plowing activities very close to the dam should be risen.

CRediT authorship contribution statement

Tilahun Getachew : Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization. **Ayele Woldemariam**: Conceptualization, Data curation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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