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Research Article

Prioritization of Erosion Hotspot Microwatersheds for Conservation Planning Using GIS and Remote Sensing Techniques in Antsokia-Gemiza District of North Shewa Zone, Ethiopia

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Soil erosion is one of the most severe forms of land degradation, which has a wide range of adverse on-site and off-site impacts in the highlands of Ethiopia in general and in the study area in particular. The objective of this study was to estimate soil erosion, identify and prioritize erosion hotspot microwatersheds in Antsokia-Gemiza district. The Revised Universal Soil Loss Equation (RUSLE) was used to estimate the potential annual soil loss. Geographic Information System (GIS) and remote sensing techniques were used to delineate the microwatersheds, produce the spatial map of all parameters and outputs, and prioritize microwatersheds. Based on the analysis, the potential soil loss of the district ranges from 0 to 240 $t \cdot ha^{-1} year^{-1}$ with a mean annual soil loss of 43.21 $t \cdot ha^{-1} year^{-1}$. About 12442.86 ha (33.18%) of the district falls under low and moderate severity classes, and it has a total soil loss not exceeding 11 $t \cdot ha^{-1} year^{-1}$ (which is an acceptable or tolerable range of soil loss). The rest of the land, which covers 25046.32 ha (66.82%) of the area, falls under high to extremely severe classes (which need prime attention), with soil loss amounts ranging from 11.01 to 240 $t \cdot ha^{-1} year^{-1}$. For prioritization purposes, the estimated potential soil loss of the district was reclassified into 12 microwatersheds. Based on the amount of soil loss across each microwatershed, MW10, MW9, and MW11 ranked 1st, 2nd, and 3rd with a percentage of 96.3%, 94.36%, and 89.28%, respectively. On the other hand, the total area covered by the existing soil and water conservation practices in the district was 5606.10 ha, of which 3808.06 ha was covered by physical conservation measures, 1305.67 ha of the area was covered by biological conservation measures and 492.37 ha was covered by area closure. Most of the existing soil and water conservation measures were implemented under high to extremely severe erosion classes. The hotspot microwatersheds with higher severity percentages will get higher priority for soil and water conservation intervention. Hence, the integrated results will provide useful information for the decision-making process concerning the erosion susceptibility of microwatersheds. Besides, GIS and remote sensing approaches in the identification and prioritization of erosion hotspot microwatersheds using RUSLE parameters are found to be more appropriate.

1. Introduction

Land degradation, a decline in land quality, is a serious threat to the prosperity of the rural population in the world [1]. Globally land degradation is affecting 1.9 billion hectares of land and is increasing at a rate of 5 to 7 million hectares each year [2]. It has negative effects on the standard of living of the population, especially in developing countries like Ethiopia, where agriculture is considered the main source of people's income and food [3, 4]. Soil erosion is the most serious form of land degradation, in which its on-site and off-site effects threaten the food security and the national economy of the country [5–7]. It is a worldwide environmental problem that treats the lives of most smallholder farmers [2]. Lack of vegetation cover, along with high erosive rain and steep slopes, is exposing the area to high rates of soil erosion and loss of soil fertility [8–10]. According to sources cited in [11], diverse soil loss rates were observed across the

globe. For example, in Europe, it ranges between 10 to 20 $t \cdot ha^{-1} year^{-1}$, in Asia, Africa, and South America, it ranges between 20 to 40 $t \cdot ha^{-1} year^{-1}$, while in the US, the annual soil loss rate is 16 $t \cdot ha^{-1} year^{-1}$. However, the recorded annual soil erosion in Ethiopia ranges from 16 to 300 $t \cdot ha^{-1} year^{-1}$ depending mainly on the slope, land cover, and rainfall intensities, which is by far higher than the above-stated parts of the globe [12]. Besides, in the mid-1980s, 27 million ha (50%) of the Ethiopian highland area was extensively eroded, 14 million ha of it was seriously eroded, and over 2 million ha was eroded beyond reclamation [13]. Similarly, Antsokia-Gemiza (hereafter Antsokia) district is one of the most erosion-prone areas in the highland of Ethiopia, which received little attention.

Therefore, to solve the above-mentioned soil erosion problems in Ethiopia, particularly following the famines period of the 1970s and 1980s, many conservation programs were launched [7, 10, 14]. Thus, large areas have been covered with various soil and water conservation practices and millions of tree seedlings have been planted. However, the success rate has been very low and has not yielded any considerable effect in solving the problem of land degradation [10, 15]. If the soil erosion problem continues consistently, huge areas of land now being cultivated may be rendered economically unproductive. Thus, this problem is being tackled by developing ideal conservation plans which are supported by mathematical models that simulate soil erosion processes [16]. As stated by [10], many erosion models such as Universal Soil Loss Equation/Revised Universal Soil Loss Equation (USLE/RUSLE), Soil and Water Assessment Tool (SWAT), Limburg Soil Erosion Model (LISEM), Simulator for Water Resources in Rural Basins (WRRB), Morgan-Morgan-Finney model (MMF), Soil Erosion Model for Mediterranean Regions (SEMMED), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS), Water Erosion Prediction Project (WEPP), and European Soil Erosion Model (EUROSEM) were used to develop best soil erosion management plans and to assess soil erosion in regional scale [17, 18]. Each model has unique characteristics and application scopes [18, 19]. However, among the above-mentioned erosion models, the most widely used soil loss model is the Universal Soil Loss Equation (USLE) [20], which was modified and is now being called the Revised Universal Soil Loss Equation (RUSLE) [21]. RUSLE was to account for temporal changes in soil erodibility and plant factors that were not originally considered [21]. Therefore, due to its worldwide applicability to soil loss prediction, its convenience in application, and compatibility with GIS [18], RUSLE is applied in this study.

Furthermore, the recently available geospatial technologies such as geographic information systems (GIS), remote sensing, and global positioning system (GPS) play a vital role in collecting, analyzing, and mapping eroded or degraded lands [22]. Hence, GIS incorporation with the RUSLE model can be used to predict cell by cell basis soil erosion and to effectively identify the spatial distribution of soil loss available within the study area or watershed area [23]. Moreover, both the geospatial technologies and the RUSLE model have been used by different researchers in estimating the rate of soil erosion and in mapping erosion risk areas across the world and showed significant and feasible results [10, 17–19, 24–27]. Similarly, there are several soil erosion estimation studies conducted in the Ethiopian highlands [10, 17, 28–31]. However, due to the spatial variation of local climate, management practices, soil susceptibility, topography, population density, and watershed heterogeneity, the soil loss estimation is found to have large variability [10, 31]. This signifies that site-specific research is still needed to solve the problem of soil erosion. In addition, a satellite rainfall product was used for estimating erosivity, which is not used in previous related studies conducted in Ethiopia. Hence, it is crucial to assess soil erosion in the study area for optimal conservation planning.

Keeping in mind these facts, there is an urgent need for proper and effective conservation planning at the watershed level [32]. Watersheds have been identified as fundamental planning units for the management of land and water resources, mostly in fragile and erosion-susceptible hilly regions [4, 10, 11]. Due to the expensiveness and cumbersomeness of soil and water conservation programs, the application of soil and water conservation measures is implemented in steps from the most vulnerable watershed [33]. Moreover, as resources for conservation are often limited, there will be a need to define priorities so that conservation action can be targeted where it is needed most. Therefore, it is important to assign relative priorities for healthy and productive watershed management. Accordingly, the larger watershed could be divided into several microwatersheds or management units. The prioritization process identifies the highest priority watershed or erosion susceptibility zone to conduct soil and water conservation [7, 32]. As a result, the identification of priority areas is essential for effective and efficient planning and implementation of watershed management programs. Therefore, the present study focused on prioritizing erosion hotspot microwatersheds based on the amount of annual soil loss from the given watersheds. So that the "Green Legacy for Greener and Cleaner Ethiopia," a national go-green campaign, declared in the country to combat environmental degradation, could be implemented as per the priorities of erosion hotspot microwatersheds in the study area. Overall, this study attempted (1) to estimate the annual soil loss, (2) to compare the existing conserved area against the areas of high, very high, severe, and exteremly severe classes, and (3) to identify and prioritize erosion hotspot microwatersheds based on their erosion severity to apply proper intervention and conservation measures.

2. Data and Methods

2.1. Description of the Study Area. Antsokia district is one of the 24 districts of the North Shoa Zone of the Amhara region, located 350 km northeast of Addis Ababa, the capital city of Ethiopia. The geographic location of the Antsokia district extends from 10°44′0″ N to 10° 74′0″ N and 39°68′0″ E to 39°93′0″ E, covering a total area of about 374.98 km^2 (Figure 1). The district has 15 kebeles (smallest administrative unit) and two small towns. Mekoy is the center

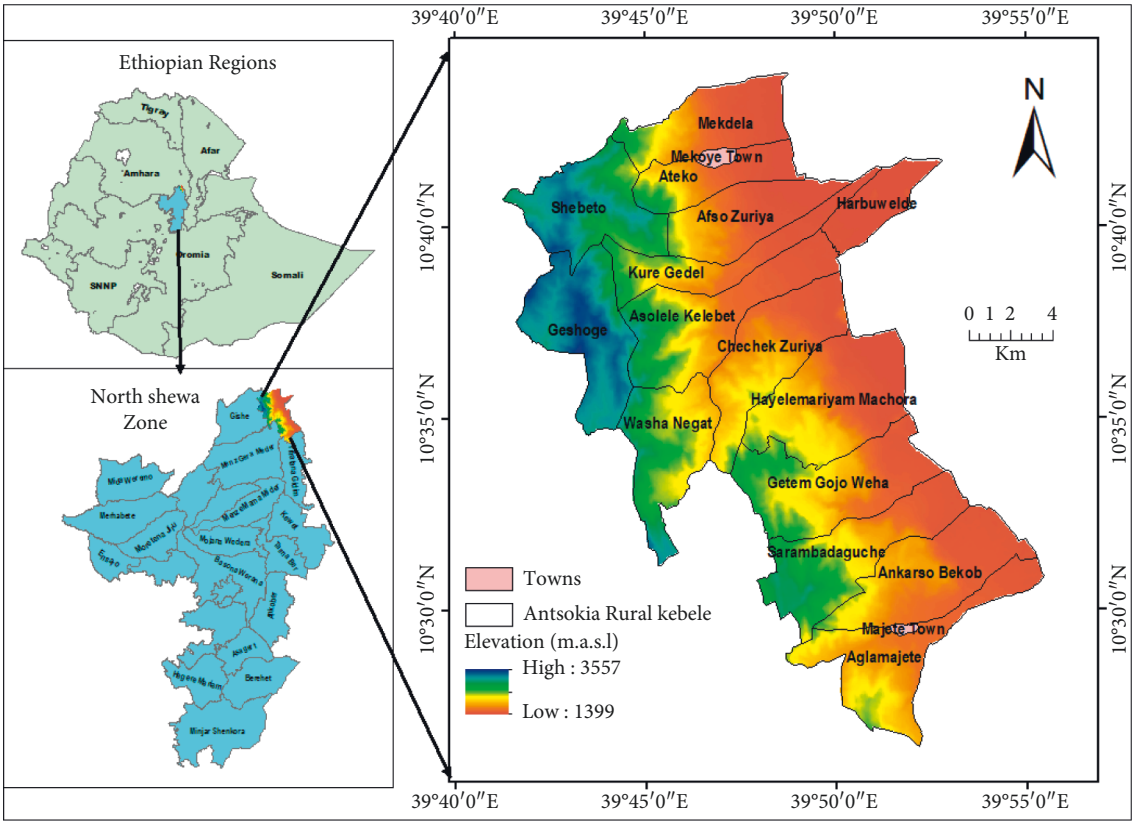

Figure 1: Location map of the study area.

(capital) of the district and is found 12 km away from Addis Ababa through Dessie's main road. The district lies on the west part of the Ethiopian rift valley within the watershed of the Borkenna river, one of the main tributaries of the Awash River. Its mean annual rainfall ranges between 800 and 1200 mm with a mean annual temperature between 19.10°C and 25.23°C and experiences bimodal rainfall [34]. The main rainfall months of the district are June, July, August, and September and whereas its smaller rainy season extends from February to May [35]. The topography of the area exhibits distinct variation and contains flat, low-lying plains surrounded by steep hills and rugged land features, and altitude ranges from 1399 to 3557 meters above sea level (m.a.s.l). The rugged and mountainous nature of the topographical features has made the area very liable to extensive soil erosion and heavy gully formation. The soil for the study area includes predominantly leptosols and vertisols, where the leptosols dominate the western elevated region and the vertisols occupy the Eastern low land and relatively plane areas of the district. Besides some of the Northeastern portion of the study area has exhibited marshland, even though the area coverage of the marshland is continuously reducing. Based on the information collected from the District Administration Office, the district has a total population of 86,825, of which 42,650 are men and 44,175 are women; more than 85% of the population are agrarian. According to the information obtained from the District Agriculture and Rural Development Office, agriculture is the predominant source of the community's livelihood. Major crops grown in the study area include Teff, Wheat, Barley, Maize, and Sorghum. Fruit and vegetable production is also a familiar farming activity that generates additional income for a considerable number of farmers. In this respect, animal rearing is an integral part and common practice of the community in the district. Hence, due to extensive farming practices of crops and livestock in the district, farmland of significant size has been marginalized year after year in the valley. In general, natural resource degradation, soil erosion, and soil fertility loss are the most alarming problems identified in the study area.

2.2. Data Types and Source. Both primary and secondary data were used to achieve the objectives of the present study. The following relevant data types were collected from various sources and used for the same.

2.2.1. Satellite Data. To quantify the magnitude of the major land use/land cover types in the study area, cloud-free Landsat 8 image of the year 2020 was obtained from the USGS website. The utility of Landsat imagery for studying soil erosion has been suggested as a time and cost-efficient method. The NASA Global DEM (Digital Elevation Model) products with 30-meter resolution were also collected from the USGS website to produce the slope length and steepness (LS) factor and to delineate microwatersheds.

Due to the scarcity of ground-based weather station rainfall data in Ethiopia in general and in the study area in

particular, recently available satellite rainfall estimate has been used for erosivity estimation. Among the recently available satellite rainfall estimates, Climate Hazards Group Infrared Precipitation with station data version 2 (hereafter CHIRPSv2) has been used for many applications such as hydrological modeling, drought, and soil erosion assessment [35]. The CHIRPSv2 product is available at a spatial resolution of $0.05^{\circ} \times 0.05^{\circ}$ for the quasiglobal coverage of 50 N to 50 S from 1981 onwards. For the current study, CHIRPS v2, the new version of daily rainfall data, has been used to estimate erosivity because this data is calibrated with more gauge data than the previous version (CHIRPS v1.8). The final CHIRPSv2 product is available with a latency period of three weeks [36]. CHIRPSv2 daily rainfall product was obtained from https://chg.geog.ucsb.edu/data/chirps/ for the period 1981 to 2020.

2.2.2. Field Data. Currently implemented soil and water conservation measures data (it means existing soil and water conservation practices implemented in the study area measured in ha) were collected from the study area using Garmin 72 H handheld GPS. These collected data were used for validation and comparison purposes. Ground Control Points (GCPs) or training samples from different land use land cover types were also collected to assess the accuracy of image processing and classification.

2.2.3. Soil Data. Soil erodibility is the manifestation of the inherent resistance of soil particles to the detaching and transporting power of rainfall [20]. The digital soil map of the African Soil Information Service (AFSIS) and Ethiopian Soil Information Service (Ethiosis) was also collected from the Debre Berhan Agricultural research center (DBARC) to develop the erodibility factor (soil factor). Overall the data types and sources used for this research have been summarized in Table 1.

2.3. Methods. In this research, the RUSLE soil erosion model was used to estimate the potential annual soil loss of the district. GIS and remote sensing technology were also applied to produce maps for each parameter and annual soil loss map and to delineate microwatersheds. Figure 2 shows the overall framework of soil loss estimation and prioritization of erosion hotspot microwatersheds.

2.3.1. Soil Loss Estimation. As mentioned above in the background section, RUSLE model was selected and applied in this study. RUSLE is one of the most tested empirical models used in both agricultural and forested watersheds to assess the average annual rate of soil loss [37]. It is developed by Renard [21] to estimate soil erosion from fields. RUSLE is a function of five input factors in raster data format: rainfall erosivity factor (R), soil erodibility factor (K), slope length factor (L), slope steepness factor (S), ground cover factor (C), and conservation support practice (P). Depending on the configuration of these factors implemented in the watershed, the potential for soil erosion varies from watershed to watershed [38, 39]. The RUSLE method is expressed as follows [21]:

$$A = R \times K \times LS \times C \times P, \tag{1}$$

where A is the computed spatial mean annual of soil loss over a period selected for R, usually on a yearly basis ($\mathrm{t{\cdot}ha^{-1}year^{-1}}$), R is the rainfall erosivity factor ($\mathrm{MJ\ mm{\cdot}ha^{-1}\ h^{-1}year^{-1}}$), K is the soil erodibility factor ($\mathrm{t{\cdot}h{\cdot}MJ^{-1}{\cdot}mm^{-1}}$), L is the slope length factor, S is the slope steepness factor, P represents the conservation support practice factor, and C represents the crop or plant cover and management factor. The values of C, P, L, and S are dimensionless.

The above-mentioned five parameters or factors were derived and generated from different data sources such as DEM, soil map, climate (rainfall data), and Landsat images. These data sources may have different data formats, projections, data quality, and spatial resolution. Hence, GIS provides the tools to manage, organize, and analyze the data in a grid format with a cell size of 30 meters × 30 meters. Since the spatial resolution of DEM and Landsat images is 30 meters, the spatial resolution of the other factors was also reclassified and set to 30 meters too. Based on the relationship defined by the RUSLE model, all the existing spatial information layers were combined by multiplying each cell of identical position. The spatial map of each factor and the final soil loss map were developed using ArcGIS 10.8.1 software. Finally, the annual soil loss was classified into five severity classes. Each severity class was again compared with the field-collected existing soil and water conservation measures.

2.3.2. Microwatershed Delineation and Prioritization. The watershed understudy was delineated from DEM by using Arc Hydro Extension in ArcGIS 10.8.1. In the process of watershed delineation from DEM, fill, flow accumulation, flow direction, and watersheds were generated. The microwatersheds were delineated by increasing the threshold value in the stream definition. One of the most important aspects of conservation planning is watershed prioritization. Prioritizing microwatersheds is the first step in planning and implementing strategies for watershed restoration strategies. Accordingly, it plays a vital role in the conservation of resources like soil, water, and forest in the watershed [40]. Hence, calculated soil loss across the entire study area was reclassified into microwatersheds to identify and prioritize severely affected microwatersheds. Prioritization was conducted based on a comparison of the sum of percentages of soil loss from high to extremely severe erosion classes across each microwatershed.

2.4. Data Analysis. To identify the spatial pattern of potential annual soil loss in the study area, all soil erosion factors (R, K, LS, C, and P) were surveyed and calculated as per the recommendation of Hurni [41] for Ethiopian conditions.

2.4.1. Rainfall Erosivity (R) Factor. The rainfall erosivity (R factor) is a property of rainfall that can quantitatively

Table 1: Types of data used and its source.

No	Data types	Data sources
1	Field data (existing soil and water conservation measures and GCP data)	Collected through direct field survey using GPS
2	Digital Elevation Model (DEM)	USGS earth explorer
3	LANDSAT 8 (OLI) image dated Jan 25/2020 with spatial resolution of 30 m × 30 m (Path:168 and Row:053)	USGS earth explorer
4	Topographic map	Ethiopian Geospatial Information Institute (EGII)
5	Soil data	Debre Brehan Agricultural Research Center, Ethiopia and African Soil Information System/service (AFSIS): https://africasoils.net/
6	Satellite rainfall product (CHIRPSv2) with a spatial resolution of 0.05 × 0.05°, from 1981 to present	https://chg.geog.ucsb.edu/data/chirps/.

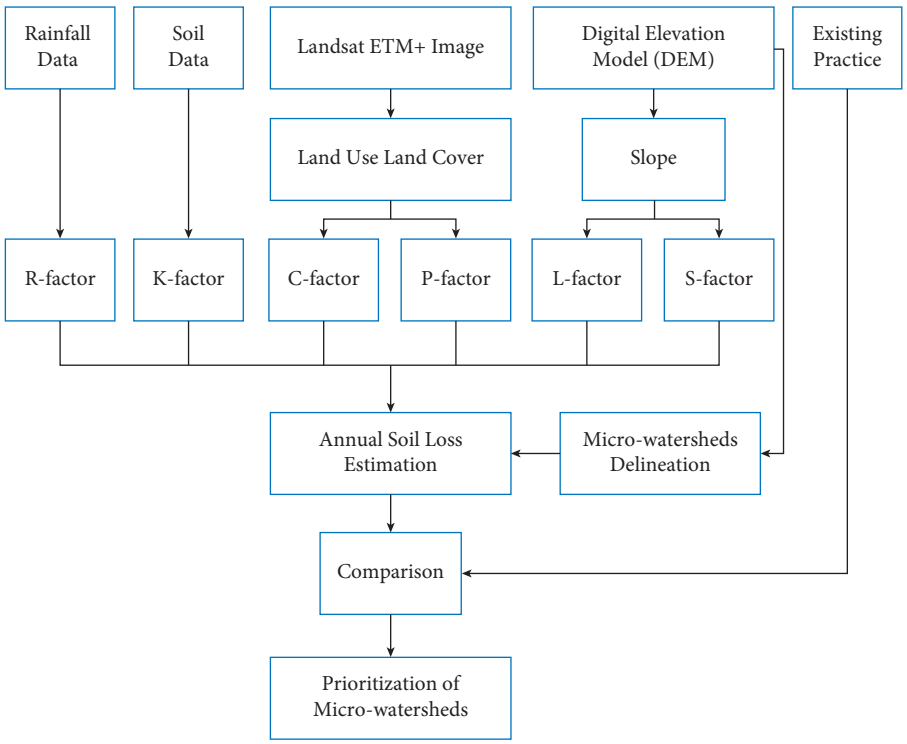

Figure 2: Overall framework of soil loss estimation and prioritization.

evaluate the potential capacity of rain to cause erosion in given circumstances. The combined effect of both rainfall and its associated runoff is considered by the erosivity factor. Therefore, the R factor was calculated based on the equation developed by Hurni [41], which is derived from spatial regression analysis for the Ethiopian condition. The model works based on the available mean annual rainfall data (P). The regression empirical equation is given as follows:

$$R = (PKR \times 0.562) - 8.12, \quad (2)$$

where P = mean annual precipitation in mm.

Some literature did not consider rainfall as a parameter in soil erosion risk mapping by assuming that the same climatic conditions existed over the area considered. However, it is misleading if we consider the Antsokia district, which shows diverse topography and altitude. The altitude of the district varies between 1399 and 3557 m.a.s.l. (Figure 1) which has made the distribution and amount of rainfall to be varied widely both in spatial and temporal terms across the area. Therefore, it is relevant to consider the distribution of rainfall when making a variety of decisions, including those related to soil erosion risk analysis. As a result, for this study, pixel-based satellite rainfall product (CHIRPSv2) has been used to calculate the erosivity factor (R). The satellite rainfall data were collected from 1990 to 2020 and mean annual rainfall was calculated across each gird/pixel. The erosivity value (R factor) was calculated from the mean annual rainfall data at each pixel using equation (2). The calculated raster erosivity values were reclassified into five classes. Particularly the northeastern part of the study area experiences higher rainfall. As a result, it showed high erosivity (R) values which range from 590.1 to 635 $MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} year^{-1}$ (Figure 3).

2.4.2. Soil Erodibility (K) Factor. Erodibility of soil indicates its resistance to both detachment and transport by erosion

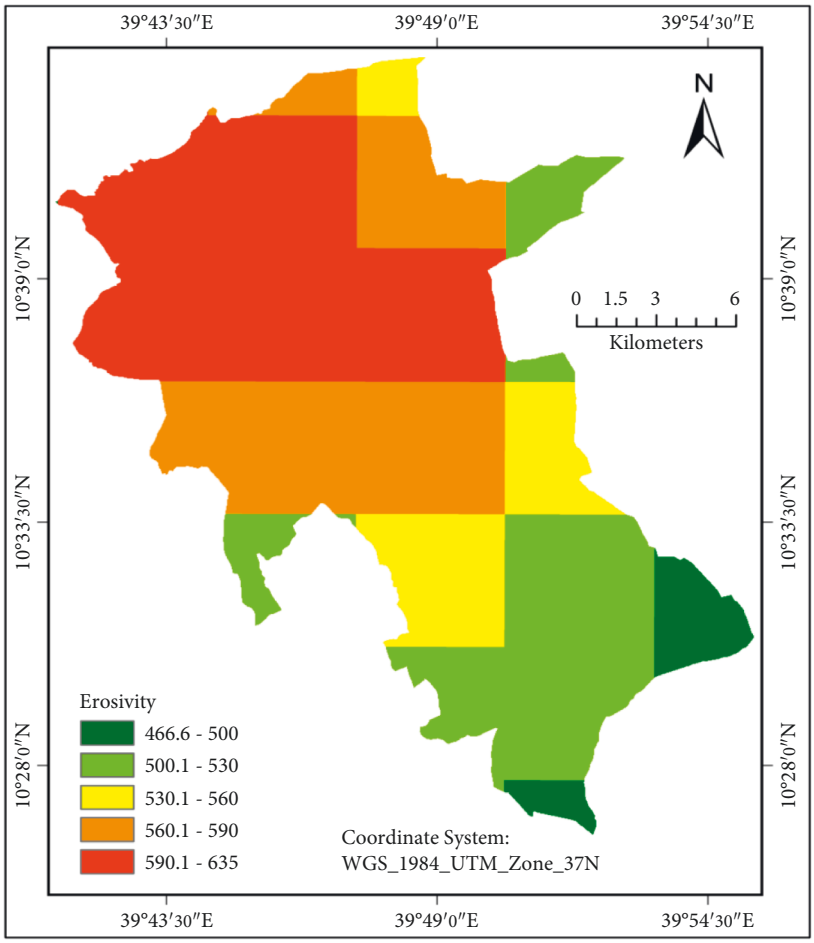

Figure 3: Erosivity map (R-factor map).

[21]. Different soil types are naturally resistant and susceptible to more erosion than other soils and are a function of grain size, drainage potential, structural integrity, organic content, and cohesiveness [42]. According to Renard [21], the K-factor is defined as the rate of soil loss per unit of erosivity factor on a unit plot. In the RUSLE model, the "K" factor is determined from the soil erodibility nomograph [20] by considering the particle size, organic matter content, and permeability class. The estimated "K" values for the textural groups vary from $0.13\,t{\cdot}ha^{-1}{\cdot}h^{-1}{\cdot}MJ^{-1}{\cdot}mm^{-1}$ to $0.30\,t{\cdot}ha^{-1}{\cdot}h^{-1}{\cdot}MJ^{-1}{\cdot}mm^{-1}$. According to soil data sources from AFSIS and Ethiosis, the study area has five major soil categories (Leptosols, Vertisols, Cambisols, Regosols, and Fluvisols) and three soil textural classes (clay, clay loam, and loam). However, for the current study, soil textural classes were used for assessing the "K" values. The "K" values for each soil texture of the district were mapped and reclassified into 30 meter by 30 meter grid sizes (Table 2, Figure 4). A higher value of K indicates that the soil is more erodible. Hence, the district has K-factor values of 0.15 and 0.2 with coverage of 11.86% and 88.14%, respectively.

2.4.3. Slope Length and Steepness (LS) Factor. Slope length and steepness affect the total sediment yield from the site and are accounted for by the LS factor in the RUSLE model. Erosion is influenced both by the slope steepness and length of the slope. The potential erosion on uniform slopes increases as these parameters increase. On steep and long slopes, the downslope splash by rainfall is higher, and water movement is faster, resulting in higher kinetic energy of water to erode the soils. In addition to steepness and length, other factors such as compaction, consolidation, and disturbance of the soil were also considered while generating the LS factor [21]. The combined LS factor was computed using ArcGIS spatial analyst extension from the DEM using equation (3), as proposed by Moore and Burch [43]. Factors derived from DEM, such as flow accumulation and slope steepness, are used for the computation of the LS factor.

Table 2: Soil textural class, area coverage, and their erodibility factor.

Soil textural class	Area in (ha)	Area in %	K-factor values
Clay soil	4448.19	11.86	0.15
Loam soil	176.17	0.47	0.20
Clay loam soil	32873.82	87.67	0.20
Total	37498.18	100.00	

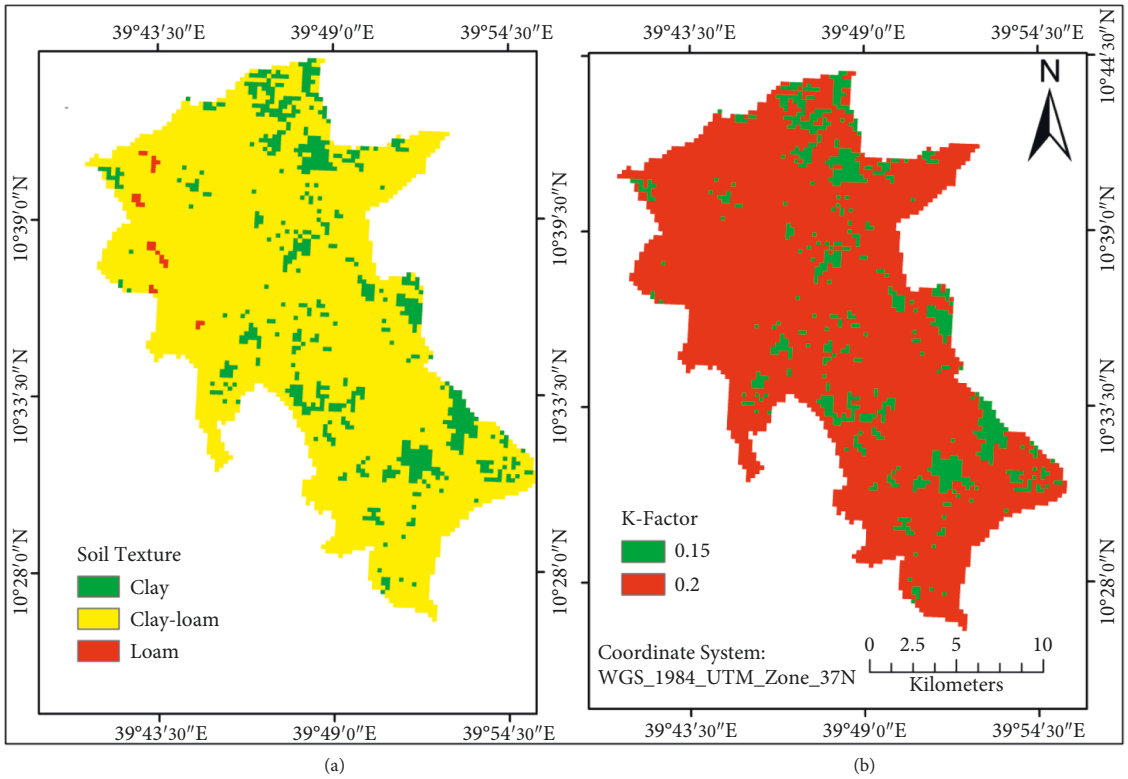

Figure 4: Map of (a) soil texture and (b) erodibility map (K-factor map) of the district.

$$LS = \left(\frac{\text{Flow accumulation} \times \text{cell size}}{22.13}\right)^{0.4} \times \left\{\frac{(\text{Sin}(\text{slope}) \times 0.01745)}{0.09}\right\}^{1.4}, \quad (3)$$

where flow accumulation denotes the accumulated upslope contributing area for a given cell, LS represents the combined slope length and slope steepness factor, cell size is the size of the grid (that is 30 meters by 30 meters for this study), and sin slope means slope degree value in sin. The LS-factor value in the study area varies from 0 to 22.36 (Figure 5). As a result, the LS factor of RUSLE extends from 0 in the lower part of the district to 22.36 on the steepest slope upper part of the district. This implies that the influence of the combined slope length-steepness (LS) factor for soil loss is significant in the upper part of the district. On the contrary, the topographic (slope length-steepness) factor contributes insignificantly to soil erosion in the lower and middle parts of the district.

2.4.4. Cover (C) Factor. The C-factor is defined as the ratio of soil loss from land with specific vegetation to the corresponding soil loss from continuous fallow with the same rainfall [20]. It represents the influence of soil disturbing activities such as crop sequence and productivity level, soil cover, and subsurface biomass on soil erosion. Moreover, variations of the land cover type (crop or plant type) and tillage make the greatest difference in the amount of erosion that occurs in a given area. Land use/land cover classes were used for analyzing the C-value. Different land cover types can be derived from the remotely sensed data, which in turn is used to estimate the C-factor [24]. Hence, for the present study, the 2020 land use land cover (LULC) of the study area was extracted from Landsat 8 image. Vegetation, settlement, grazing land, bare land, and agriculture were the major land use land covers of the district extracted from the selected Landsat image using ERDAS Imagine 2015 software of supervised classification method (Table 3). Agriculture land has the greatest coverage of the district (57.83%), followed by grazing land (20%), while settlement occupies the least (0.71%). The results from a classified image have been used to generate the cover (C) factor and supporting conservation practice (P) factor for the RUSLE model. The corresponding C-value was obtained from Gashaw et al. [44]. Then the C-factor map was produced and shown in Figure 6. The areas with the highest C-factor are seen in the western and central parts of the district, which is covered by agriculture with a C-factor of 0.15, followed by bare land and grazing land with a C-factor of 0.01 (Table 3, Figure 6(b)) (Gashaw et al. [44]).

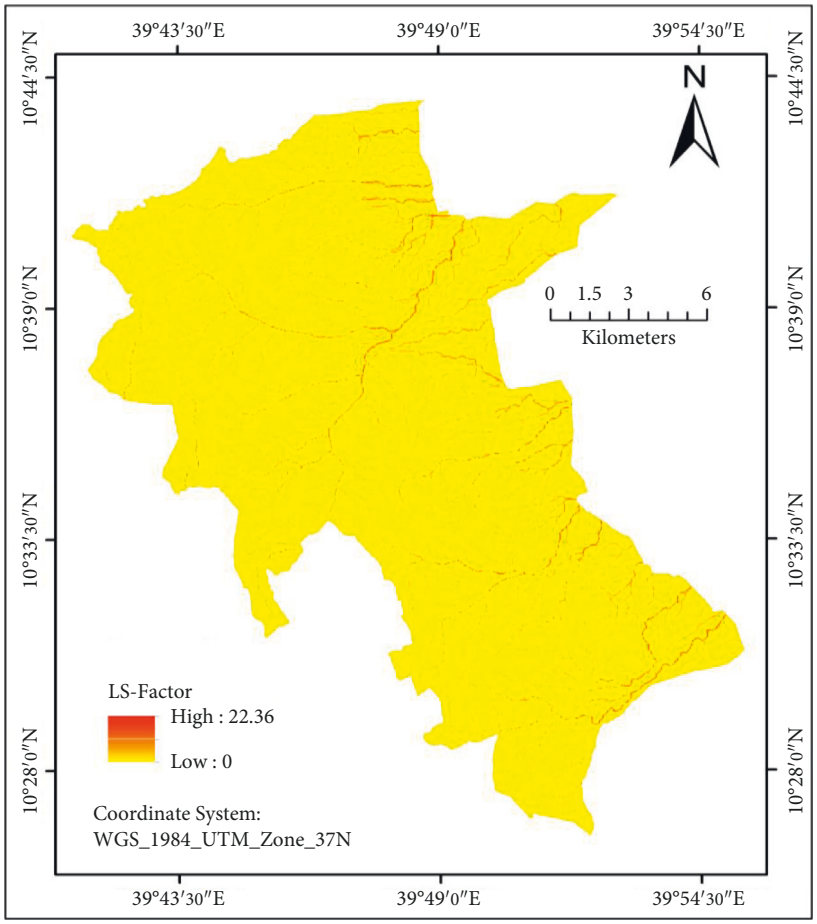

Figure 5: Slope length and steepness map (LS-factor map).

Table 3: Cover (C) factor of the district.

LULC types	Area in (ha)	Area in %	C-factor
Settlement	264.98	0.72	0.004
Bare land	3555.66	9.48	0.01
Agriculture	21686.62	57.83	0.15
Grazing land	7500.75	20.00	0.01
Vegetation	4490.17	11.97	0.001
Total	**37498.18**	**100**	—

2.4.5. Management Practice (P) Factor. The management practice factor (P) indicates the effect of conservation practices on soil erosion, where in the land which has adequate conservation interventions [21]. Different cultivation practices affect soil erosion by reducing runoff and by modifying the pattern of runoff and flow direction [21]. Hurni [41] gives parameters for different land management practices on cultivated land though these are more suited to small-scale mapping than regional or basin-wide erosion hazard assessment since areas with different land management practices such as contour plowing or strip cropping cannot be mapped out at this scale. A combination of LULC types and slope was used in computing P-factor and provided us with conservation factor maps for the district [20]. This study has therefore used these two parameters for land support or management practice mapping. Among the land use, land cover classes of the study area, agricultural land, bare lands, and settlements are the most soil erosion-susceptible parts of the study area, whereas grazing land and vegetation are less susceptible with p-values of 0.8 and 0.7, respectively (Table 4). As a result, the LULC map has been reclassified into three classes. The P-factor map was produced and shown in Figures 7(a) and 7(b) (Wischmeier and Smith [20] modified by Gashaw et al. [44]).

2.4.6. Quantification of Annual Soil Loss. The final annual soil loss estimation, as described above, was determined by multiplying the respective RUSLE factor, i.e, erosivity (R), erodibility (K), topographic parameters (LS), cover management (C), and conservation support practice (P) factor using raster calculator in ArcGIS spatial analyst environment. The annual soil loss of the area was then reclassified into six classes based on the FAO soil loss classification system or standards [13]. These categories are low (0–5 $t \cdot ha^{-1} year^{-1}$), moderate (5.1–11 $t \cdot ha^{-1} year^{-1}$), high (11.1–25 $t \cdot ha^{-1} year^{-1}$), very high (25.1–45 $t \cdot ha^{-1} year^{-1}$), severe (45.1–60 $t \cdot ha^{-1} year^{-1}$), and extremely severe (>60 $t \cdot ha^{-1} year^{-1}$) soil erosion classes (Table 5, Figure 8).

2.4.7. Assessing the Status of Existing Conservation Measures. The commonly implemented soil and water conservation practices in the study area are generally classified into three

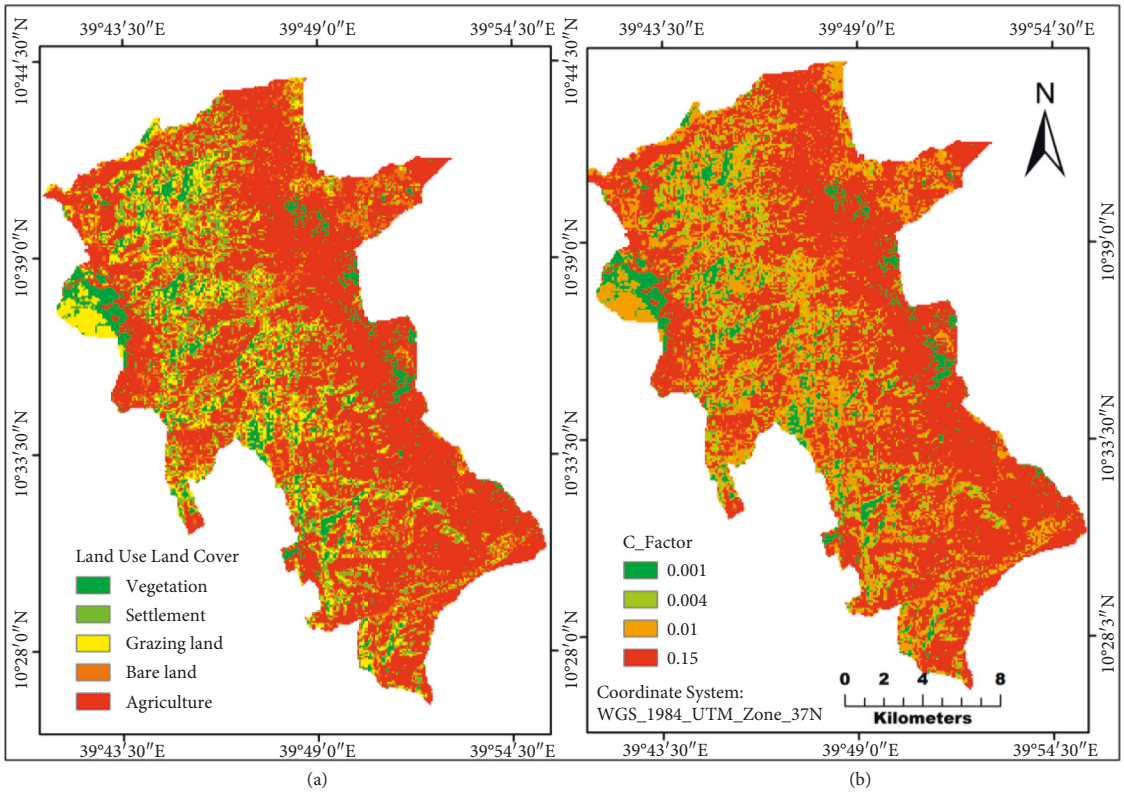

Figure 6: Map of (a) land use land cover types and (b) cover factor (C-factor).

Table 4: Management practice (P) factor values.

LULC types	Area in (ha)	Area in %	P-factor
Settlement	264.98	0.71	0.9
Bare land	3555.66	9.48	0.9
Agriculture	21686.62	57.83	0.9
Grazing land	7500.75	20.00	0.8
Vegetation	4490.17	11.97	0.7
Total	**37498.18**	**100**	

types, i.e., physical conservation practices, area closure, and biological conservation practices. Physical conservation practices are those structures constructed from locally available resources such as stone, soil, and wood. The physical conservation practice includes stone bund, soil bund, bench terrace, check dams, drainage ditch, cut off the drain, percolation pit, microbasin, etc. An area closure is a method of protecting or conserving the degraded or susceptible area (by using zero or free grazing systems like cut and carry, tattering, and tethering (tying)) from human and animal contact. Whereas biological measures are planting tree seedlings and protecting existing trees and other grasses to protect the area from soil erosion problems. The existing constructed or implemented conservation practices in the study area were collected using GPS and mapped using ArcGIS 10.8.1 software (Figure 9).

The related attribute and spatial data were also collected from each rural kebele and district agricultural offices and from direct field observation. Both spatial and attribute data of the study area were analyzed using ArcGIS10.8.1 software. Then, the status of existing constructed or implemented conservation practices was compared with the soil erosion severity classes (Table 6).

2.4.8. Microwatershed Delineation. Based on the aforementioned method microwatersheds of the study area were delineated from DEM data. In the study area, 12 microwatersheds were delineated (Figure 10). The area of the microwatersheds ranges from 975.90 ha at microwatershed 9 (MW 9) to 7530.38 ha at microwatershed 3 (MW3).

3. Result and Discussion

In this study, the RUSLE model was integrated with GIS and remote sensing techniques to conduct cell by cell calculation of annual soil loss in $t \cdot ha^{-1}$ $year^{-1}$ and to identify and map soil erosion hotspot microwatersheds. Raster maps of each factor derived from different data sources were produced and presented above under the data analysis section. In this section, the results of annual soil estimation and microwatershed prioritization are discussed hereunder.

3.1. Annual Soil Loss Estimation. The final soil erosion map that shows the potential annual soil loss of the district was produced by overlaying the above five parameters (R, K, LS, C, and P) using equation (1). As shown in Figure 8 and Table 5, the annual soil loss of the district extends from 0 to 240 $t \cdot ha^{-1} year^{-1}$. The estimated average annual soil loss in the district is 43.21 $t \cdot ha^{-1} year^{-1}$ (Table 5). The annual soil

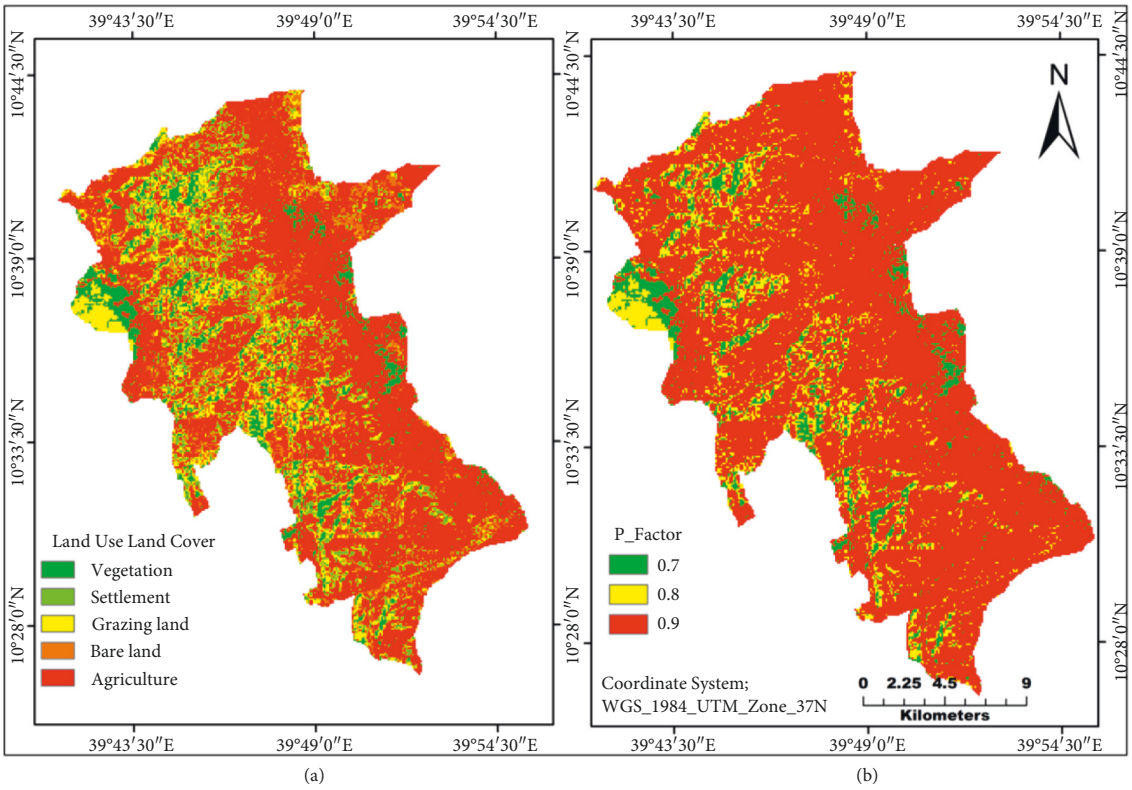

Figure 7: Map of (a) land use land cover types and (b) management factor (P-factor).

Table 5: Soil loss severity class and annual soil loss at Antsokia district.

Soil erosion severity class	Annual soil loss ($t \cdot ha^{-1} year^{-1}$)	Area in (ha)	Area in %
Low	0–5	7564.20	20.17
Moderate	5.01–11	4878.66	13.01
High	11.01–25	4899.29	13.07
Very high	25.01–45	3937.24	10.50
Severe	45.01–60	2602.18	6.94
Extremely severe	>60	13616.60	36.31
Total	—	**37,498.18**	**100**

loss in the study is divided into six different soil loss severity classes. These are low (0–5 $t \cdot ha^{-1} year^{-1}$), moderate (5.1–11 $t \cdot ha^{-1} year^{-1}$), high (11.1–25 $t \cdot ha^{-1} year^{-1}$), very high (25.1–45 $t \cdot ha^{-1} year^{-1}$), severe (45.1–60 $t \cdot ha^{-1} year^{-1}$), and extremely severe (>60 $t \cdot ha^{-1} year^{-1}$) soil erosion classes (Table 5 and Figure 8).

As estimated by Hawando [12], the annual soil loss rate in the Ethiopian highlands ranges from 16–300 $t \cdot ha^{-1} year^{-1}$ which is in agreement with the present annual soil loss rate ranging from 0 to 240 $t \cdot ha^{-1} year^{-1}$. The annual soil loss map (Figure 8) showed the spatial overview of the potential soil loss in the study area. It indicates that the district is potentially prone to soil erosion risk. The estimated average annual soil loss for the district, (43.21 $t \cdot ha^{-1} year^{-1}$), is in agreement with the globally estimated average annual soil loss with a range of 30 to 40 $t \cdot ha^{-1} year^{-1}$ [45]. However, the result of the present study is much higher than the most exposed to erosion in European countries such as Slovenia, Italy, and Austria [10, 46]. Besides, the observed average soil loss at the Antsokia microwatershed is much higher than the "permissible" soil loss in the country, which is less than 18 $t \cdot ha^{-1} year^{-1}$ [41], and the mean soil loss in the country (29.9 $t \cdot ha^{-1} year^{-1}$) [10, 47]. However, the soil profile in Ethiopia shows a strong spatial variation [7, 10]. For example, the highest and the lowest soil loss estimates in Ethiopia were observed at the Chemoga and Medego watersheds, with the soil loss estimates of 93 $t \cdot ha^{-1} year^{-1}$ and 9.63 $t \cdot ha^{-1} year^{-1,}$ respectively [15, 48].

Based on Table 5, about 12,442.86 ha (33.18%) of the district has a total soil loss not exceeding 11 $t \cdot ha^{-1} year^{-1}$ (which is an acceptable mean tolerable soil loss). The rest of the land, which covers 25,055.32 ha (66.82%), falls under high to very severe classes (which need prime attention), where soil loss ranges between 11.01 and 240 $t \cdot ha^{-1} year^{-1}$ (Table 5; Figure 8(a)). Nevertheless, the threshold level of acceptable soil loss is controversial; various studies suggest different tolerable values. However, Morgan [49] estimated its maximum to be 15–20 $t \cdot ha^{-1} year^{-1}$, overall the permissible mean soil loss is 11 $t \cdot ha^{-1} year^{-1}$, and the recommended value for sensitive areas to be below 2 $t \cdot ha^{-1} year^{-1}$. Therefore, 33.18% of the study falls under acceptable mean tolerable soil loss. Whereas, 66.82% of the district is highly vulnerable to soil erosion, particularly, in the western and the central-highland region of the area, where rainfall and the slope gradient are relatively high. Overall, the estimated average soil loss value of the district is comparable to other similar studies conducted in various parts of Ethiopia

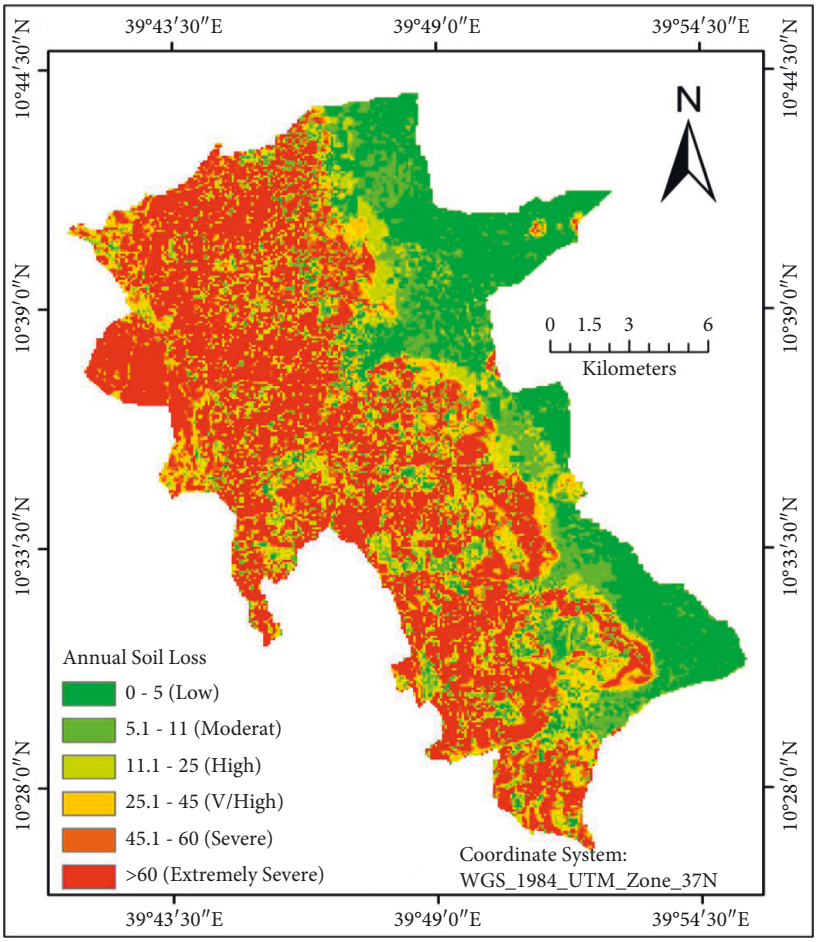

Figure 8: Map of (a) annual soil loss.

[10, 14, 17, 28–30, 48]. However, it should be noted that the amount of soil loss varies over time depending on land management type [50].

Since soil erosion is recognized as one of the threats to the territory of the Northern highlands of Ethiopia, where the study area is found, hindered the sustainability of livelihoods security. In Ethiopia, many research findings have shown that vast areas of the highlands are being affected by accelerated erosion [6, 9, 14, 17, 48]. It is initiated and aggravated specifically by overgrazing, deforestation, overpopulation, overgrazing, over-cultivation as well as rural development policies [51, 52]. Furthermore, Feoli et al. [53] pointed out that the past and present agricultural activities, mountainous and hilly topography, heavy rainfall, and low degree of vegetative cover have been the major causes and aggravating factors of the destructive soil erosion in the highland areas of Ethiopia. Similarly, the result of the current study has observed greater similarity between the soil loss map with the LS map and Erosivity (R) map. Therefore, the LS factor and R factor here, probably are critical factors that are responsible for high potential soil erosion.

3.2. Comparison of Existing Conservation Measures with the Soil Loss Severity. As indicated in Table 6, the total area covered by the existing conservation practices/measures is 5606.10 ha, of which 3808.06 ha is covered by physical conservation measures, and 1305.67 ha is covered by biological conservation measures and 492.37 ha is covered by area closure (Figure 9). Among these conservation measures, 45.58% of physical practices, 47.22% of biological conservation measures, and 55.57% of area closure were implemented at extremely severe erosion classes followed by high, very high, and severe classes, respectively. The smallest percentage of conservation measures were implemented under low and moderate severity classes (Table 6). The result shows that most of the existing conservation measures were implemented under high to very severe erosion classes; however, there is a problem with identifying and covering all the severely affected areas in the district. This indicates that the implementation of soil and water conservation measures has been done everywhere haphazardly without identifying and prioritizing the severely affected parts of the district. Therefore, it needs identification, prioritization, and development of conservation plans based on the erosion severity level of the district.

3.3. Prioritization of Microwatersheds. As can be seen in Section 2.4.8 (Figure 10), the study area was delineated into 12 microwatersheds. The area of each microwatershed varies from 1002.49 ha at MW9 to 7397.34 ha at MW3. To identify

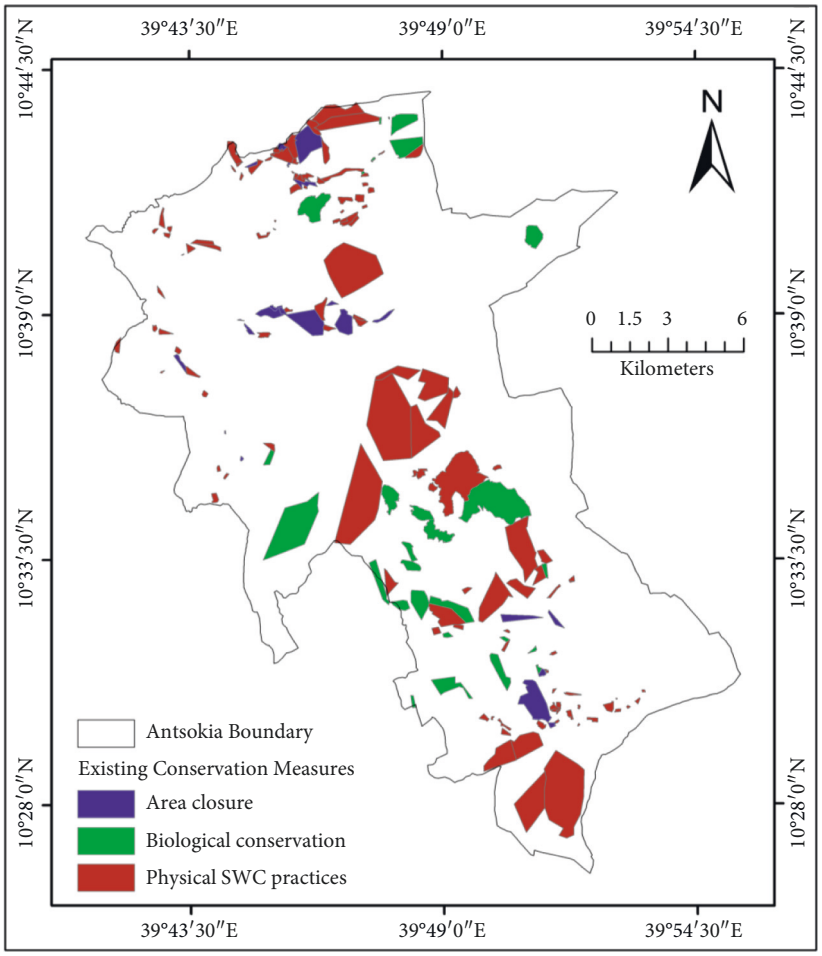

Figure 9: Map of existing soil and water conservation measures (Authors' own map from field-collected data).

Table 6: Area and percentage of existing conservation practices implemented at each soil erosion class (prepared from field data by the authors).

Conservation practice types	Total area in (ha)	Low		Moderate		High		Very high		Severe		Extremely severe	
		Area in		Area in		Area in		Area in		Area in		Area in	
		ha	%	ha	%	Ha	%	Ha	%	Ha	%	Ha	%
Physical SWC practices	3808.06	236.47	6.21	413.83	10.87	429.03	11.27	542.20	14.24	450.99	11.84	1735.54	45.58
Biological conservation	1305.67	153.71act	11.77	130.90	10.03	163.00	12.48	130.90	10.03	110.64	8.47	616.52	47.22
Area closure	492.37	7.60	1.54	53.21	10.81	59.12	12.01	45.61	9.26	53.21	10.81	273.63	55.57

and prioritize the most vulnerable microwatersheds in the study area, the estimated annual soil loss in the entire study area was reclassified into twelve microwatersheds (Table 7). The priority of microwatershed was carried out by comparing the percentage of the area covered with high to extremely severe erosion classes against the total area of their respective microwatershed. The microwatersheds with the highest percentage has given the top priority in developing soil and conservation plan to curb soil and nutrient losses. As indicated in Table 7, Figure 11, based on the soil loss severity percentage, the microwatersheds MW10, MW9, MW11, MW12, MW7, MW8, MW3, MW4, MW5, MW1, MW2, and MW6 were ranked from 1st to 12th respectively. Microwatersheds MW10, MW9, MW11, MW12, and MW7 were ranked as 1st, 2nd, 3rd, 4th, and 5th with high to extremely severe soil loss contribution with 96.37%, 94.36%, 89.28%, 88.46%, and 71.01% respectively. Hence, these microwatersheds were found to be critical and given higher priority. The severity of soil loss in these watersheds could be due to (1) the absence of any support practice (high P-factor value) and (2) the dominance of Lithic Leptosols with clay loam and loam textural classes is naturally less resistant to the eroding power of rainfall (erosivity), and the steepness of the slope (LS factor). Therefore, these parts are the main hotspot areas that need crucial conservation measures.

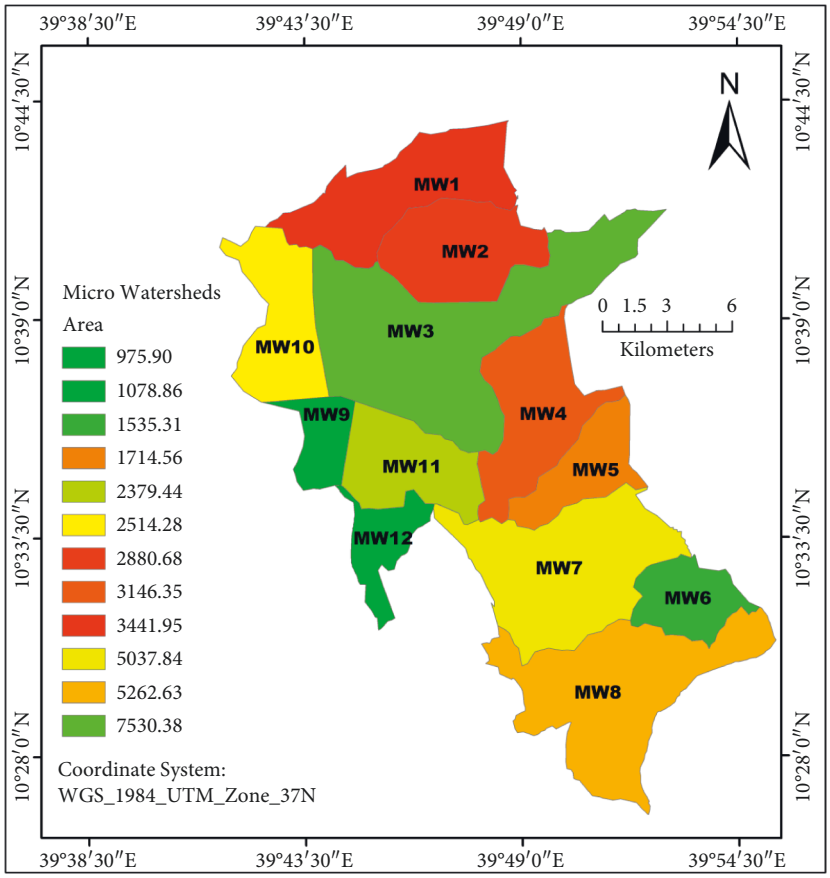

Figure 10: Map of microwatersheds.

Table 7: Priority rank of each microwatershed based on the erosion severity percentage.

Number of MW	Severity class coverage in (ha)						MW total area in ha	Area of H, V/H, S & E/S classes	Severity in %	Priority rank
	Low	Moderate	High (H)	Very high (V/H)	Severe(S)	Very severe (V/S)				
MW1	901.56	529.67	306.10	171.45	162.62	1370.55	3441.95	2010.71	58.42	10
MW2	867.18	510.53	465.37	273.76	199.70	564.15	2880.68	1502.97	52.17	11
MW3	2074.74	760.03	881.12	528.00	365.57	2920.92	7530.38	4695.60	62.36	7
MW4	715.06	573.16	396.05	435.26	284.63	742.19	3146.35	1858.13	59.06	8
MW5	359.25	344.85	363.43	198.21	84.84	363.99	1714.56	1010.47	58.93	9
MW6	916.33	223.21	151.28	71.37	32.25	140.87	1535.31	395.77	25.78	12
MW7	642.21	818.11	754.55	567.22	347.35	1908.40	5037.84	3577.53	71.01	5
MW8	967.72	713.48	742.29	710.41	434.98	1693.75	5262.63	3581.43	68.05	6
MW9	10.59	44.42	102.68	231.66	144.50	442.04	975.90	920.89	94.36	2
MW10	14.22	77.03	212.80	361.57	249.13	1599.52	2514.28	2423.02	96.37	1
MW11	76.38	178.60	344.66	277.47	195.70	1306.62	2379.44	2124.45	89.28	3
MW12	18.96	105.56	178.97	110.86	100.92	563.59	1078.86	954.34	88.46	4

Besides, the microwatersheds MW8, MW3, MW4, and MW5 were ranked 6th, 7th, 8th, and 9th with soil loss severity percentages of 68.05%, 62.36%, 59.06%, and 58.93%, respectively (Table 7). These microwatersheds are characterized by steep to very steep slopes, associated with very shallow to moderately shallow soils and well to excessive drainage conditions. Hence, they need immediate attention next to the first five microwatersheds to take up mechanical soil conservation measures, gully control structures, and biological soil and water control methods to protect the topsoil loss. At the same time, the remaining microwatersheds such as MW1, MW2, and MW6 were ranked 10th, 11th, and 12th with a percentage of 58.42%, 52.17%, and 25.78%, respectively. These microwatersheds consist of moderate to gentle slopes, moderate drainage density, and relatively, it can give some time for implementing conservation measures. Even though these groups of watersheds are said to be categorized under the low soil erosion class,

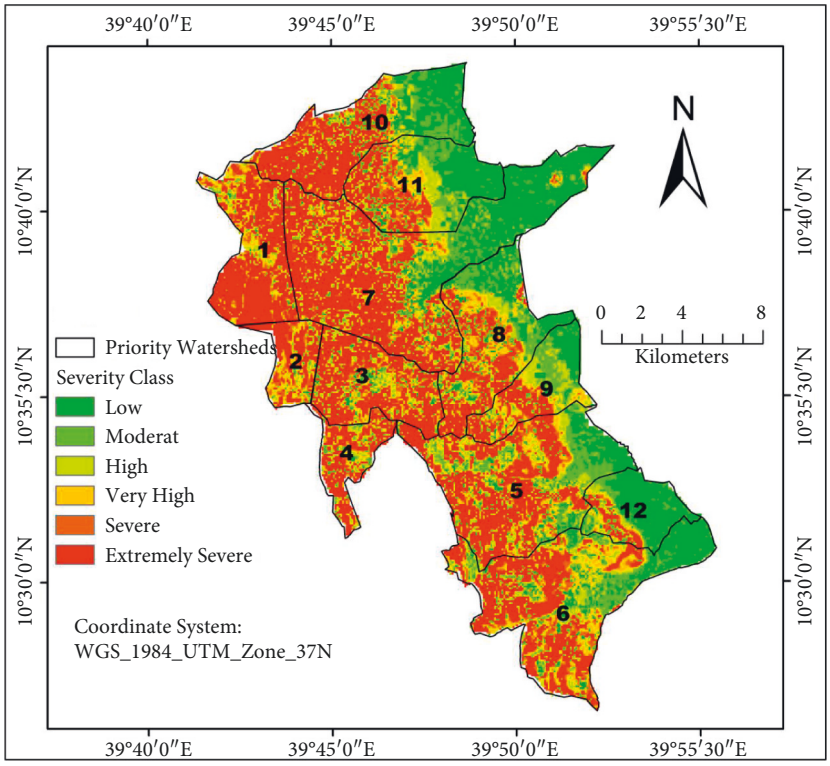

Figure 11: Map of microwatershed priority.

these portions of the study area also have a series of soil erosion problems as compared to other parts of the country.

Overall, extremely severe and severe priority microwatersheds indicate a greater degree of erosion, and these become potential candidates followed by very high priority for applying soil conservation measures. Soil and water conservation measures can also be applied to high priority microwatersheds after very high priority microwatersheds. The remaining microwatersheds are under low and moderate priority (tolerable range), but still, they need proper treatment next to a high level of severity. Therefore, based on the mentioned priority rank, it is recommended to adopt management measures to reduce the soil losses and conserve the resources within the microwatersheds.

4. Conclusion

The objective of this study was to estimate the annual soil loss rate and to identify erosion hotspot microwatersheds in the Antsokia district. The study proves that the RUSLE model, together with GIS and RS, provides a great advantage in analyzing multilayer spatial data and estimating soil loss rate over the study area. Thus, the integrated result has provided useful information for the assessment and decision-making process about the erosion susceptibility of microwatersheds. The findings obtained after applying RUSLE, GIS, and remote sensing include spatially distributed soil loss rate and priorities of microwatersheds over the study area. The annual soil loss of the district extends from 0 to 240 $t \cdot ha^{-1} year^{-1}$ with a mean annual soil loss of 43.21 $t \cdot ha^{-1} year^{-1}$. About 33.18% of the study falls under acceptable mean tolerable soil loss, whereas 66.82% of the district exceeds the tolerable soil loss limits. This could be due to the steepness of the slope and the dominance of intrinsically less resistant soil texture (Loam and clay loam) to the eroding power of rainfall coupled with the absence of supporting practice. The overall result is also well agreed with the estimates of [13, 54] annual soil loss of the highlands of Ethiopia (16–300 $t \cdot ha^{-1}$ $year^{-1}$) and which is large enough to degrade the area.

Based on the percentage of soil loss severity class coverage, prioritization of microwatersheds was conducted. Of all the 12 microwatersheds delineated in the study area, MW10, MW9, and MW11 fall under high to extremely severe classes and ranked 1st to 3rd with a percentage of 96.37%, 94.36%, and 89.28%, respectively. Therefore, microwatersheds with higher rank will get higher priority for soil and water conservation intervention. As a result, unless some conservation measures are not taken timely, it would seriously reduce the production of crops and animal feed which finally affects the food security of the farming community in the district. Though soil and water conservation practices were implemented for a longer period in the study area, due to inappropriate application of site-specific and demand-driven technology, the sustainability of soil and water conservation practices was demolished every year. Hence, GIS and remote sensing approaches in prioritizing and identifying erosion hotspot microwatersheds based on estimated soil loss obtained from RUSLE parameters are found to be more appropriate. The method can also be applied in other parts of the North Shoa Zone and the country depending on the topography, soil types, and other

factors of that specific site. To effectively curb soil erosion and nutrient depletions, further study is needed to identify effective human practices of soil and water conservation methods.

Data Availability

The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

EL has made considerable contributions in designing the study, data acquisition, data collection, analysis, interpretation, and manuscript writing; TG and YS have made a significant contribution in designing and analysis of data, in commenting, suggesting ideas, and editing the manuscript. All authors read and approved the final manuscript.

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