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Soil Erosion Mapping and Severity Analysis Based on RUSLE Model on Welmel Catchments of Ganale-Dewa River Basin Bale Lowland South Eastern Ethiopia

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A B S T R A C T

Soil erosion is a kind of environmental deterioration, decreased agricultural output, increased floods, and habitat loss, soil degradation has an impact on many people's livelihoods, either directly or indirectly. There isn't precise scientific research that gives information, identifying locations that are susceptible to soil erosion is also insufficient in welmel watershed. Through the use of a geographic information system (GIS), remote sensing (RS), and numerous characteristics such as land uses, and climate, this study has attempted to identify prospective places in need of SWC techniques by undertaking a spatial modeling of soil erosion within the Welmel watershed's Genale Dawa basin. It made use of data from a digital elevation model (DEM) on interpolated rainfall erosivity (R), soil erodibility (K), plant cover (C), topography (LS), and conservation practices (P) from satellite pictures. The study demonstrates that the RUSLE using GIS taking into account various climates and land management practices. An estimated 546,769.92 tons of top, productive soil are lost from the watershed each year at an average rate of 32 t ha $^{-1}$ year^{-1} of soil erosion. The percentage of the watershed from moderate to extremely high soil erosion rates was calculated to be 3.42%. The local people should quickly put into place soil conservation measures on their agricultural lands by employing a variety of soil preservation techniques, such as mulching, strip cropping, terracing, contour plowing, multiple cropping, and other conventional indigenous soil conservation practices.

Introduction

Natural resources like soil are vital, but they are being destroyed at a rate and magnitude that has never been seen before. Water-induced soil erosion is a significant environmental issue of the twenty-first century, particularly in developing countries (Bekele *et al.,* 2022; Kuo *et al.,* 2016; Lal, 2001). Soil erosion contributes to the deterioration of agricultural land in the world to a degree of around 80% (Rodrigo *et al.,* 2015), and it also results in the loss of 10 million hectares of crops per year (Tian *et al.,* 2021). Wider issues with land degradation present a serious challenge to Sub-Saharan African (SSA) nations, notably greater soil loss, and crop nutrient depletion issues that halt sustainable agricultural output and aggravate food insecurity (Menale *et al.,* 2007; FAO, 2015). One of the SSA countries Ethiopia, is struggling with serious soil degradation issues that are causing a decrease in various soil functions and are the ultimate cause of an irreversible impact on the hardly renewable soil resources.

Since the 1970s, water-induced soil erosion has been Ethiopia's most significant environmental problem (Hurni *et al.,* 2010). In comparison with today, when it is 940 million tons per year, (Hurni *et al.,* 2015) report that the average annual soil loss rate was 1500 million tons per year thirty years ago. A significant amount of nutrients (N and P) is also lost when these sediments are lost (Hurni *et al.,* 2015). Because of the uneven topography and inability to replace lost nutrients, the economic effects of soil erosion are more severe in Ethiopia's Northwestern highlands (Hurni, 1993; Tadesse and Abebe, 2014). This is likely a result of the region's high population pressure, which encourages the intensification of the use of already-stressed resources and the cultivation of marginal and arid land.

In Ethiopia's highlands, soil loss was studied by (Haregeweyn *et al.,* 2017) and (Zerihun *et al.,* 2018), who concluded that soil erosion brought on by water is the main issue preventing agricultural production and sustainability. This suggests that one of the issues affecting rural livelihoods is soil erosion, which also worsens poverty and food insecurity by reducing output and productivity. According to Ganasri and Ramesh (2016) and Arabameri *et al.,* (2020), geospatial techniques (remote sensing and GIS) and the RUSLE model are now more successful instruments for resolving the majority of issues with land and water resource planning and management than traditional data processing techniques.

Despite this, there is less information and documentation available on good watersheds that takes into account soil nutrient loss, identifies places that have been significantly impacted by soil erosion, and recommend appropriate SWC using GIS and the RUSLE model. Therefore, this study was initiated to identify soil erosion severity areas and develop prioritized areas, estimate rates of soil loss, and develop a soil loss intensity map developing a baseline for soil and water conservation measurement for the study area and recommending appropriate management options for specific soil conservation measurement for specific soil conservation plans using GIS and RUSLE model.

Significance of the Study

The goal of this study is to encourage the use of soil erosion vulnerability maps, soil erosion mapping, and severity analyses based on the RUSLE model, which assists in identifying regions that may be at risk of experiencing significant soil loss. The goal of this study was to provide policymakers, land use planners, and natural resources managers with baseline data so they could develop and put into practice successful soil conservation measures.

Materials and Methods

Description of the study area

HarennaBuluk District of the Bale Zone of Ethiopia's Oromia Regional State is. 570 kilometers from Addis Ababa, the capital of Ethiopia, and 132 kilometers from Robe, the capital city of the Bale Zone, lies Angetu, which serves as the district's administrative center.

Geographically speaking, this district is situated between latitudes 06°07′33′′−06°44′00′′Nand longitudes 39°16′41′′−39°46′10′′E. Goba District to the north, Meda Walabu District to the south, Delo-Mena District to the east, and Nansebo District to the west are the districts that border HarennaBuluk District. This district, which spans 1923 km^2 (Figure 1), is made up of highlands in the ranges 1108–3310 m, which include the upper catchments of several significant rivers, including Genele and Welmel. The National Metrological Agency (NMA) states that the study area experiences two distinct seasons: a dry season, which runs from November to February and is characterized by low temperatures, low humidity, and low rainfall; and a wet season, which runs from March to October and is characterized by high temperatures, high humidity, and low nighttime and daytime temperatures. The research region has a maximum temperature of 26.83 °C and a minimum temperature of 14.56 °C.

Methods of Data Collection

Both primary and secondary data were employed in the study. Different governmental and non-governmental groups provided secondary data, including satellite images, aerial photos, topographic maps, meteorological data, and others. Additionally, regular field observations utilizing the Global Positioning System (GPS) were made to gather first-hand data on the accuracy of the ground truth for image classification and soil loss vulnerability evaluation. Primary data were gathered Soil data collection for texture and carbon analysis, using key informant interviews and filed survey or ground truth observations and verification using GPS devices.

Data Processing and RUSLE factor generation

To predict soil erosion in the current study, the RUSLE input parameters were developed using remote sensing as well as information received from the field afterward integrated in a GIS context (Figure 2). Arc GIS 10.7.1, ERDAS Imagine 2015, and related GIS software were used to create the different RUSLE factor maps in a digital GIS environment. To calculate the yearly rates of soil erosion and their severity, these factor images were combined using the RUSLE model.

RUSLE model description

The Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) are two of the best-known and most often applied soil erosion models for agricultural watersheds worldwide (Udaya kumara *et al.,* 2010). According to Renard *et al.,* (1997); Wischmeier and Smith (1978), the RUSLE model has defects when compared to the USLE model, hence it was chosen as the fourth model in the research. The RUSLE model also allows for easy integration with a GIS for spatial analysis and is adaptable in how it models soil erosion in terms of its flexibility to adjust circumstances and parameters (Wischmeier and Smith, 1965). The RUSLE (Renard *et al.,* 1997) model is represented as

$A = R\,KLSCP$………………….. Eq. (1)

A =computed soil loss per unit area per year (t/ha per year)

LS = The slope length and steepness factor (dimensionless)

K = The soil erodibility factor (thaMJ^{-1} mm^{-1})

R= The rainfall erosivity factor (MJmmha_1 h_1 year_1)

C= The cover and management factor (dimensionless)

P =The support practice factor (dimensionless

Some of the factors that led to the model's acceptance were its minimal data needs, free and easy access to the required information sets, relative ease of use, and compatibility with remote sensing and GIS inputs in the computer interface (Farhan and Nawaiseh, 2015). The majority of the model's input parameters are also calibrated for the Ethiopian context (Hurni, 1985). RUSLE models have been used as well (Tamene *et al.,* 2017) to determine the rate and patterns of soil loss in different regions of the Ethiopian highlands.

Data Analysis and Derivation of RUSLE Parameters

Rainfall Erosivity Factor (R)

Rainfall erosivity is influenced by rainfall volume, intensity, and dispersion. The strength of a raindrop separating from the soil surface and the contribution of rain to runoff is two ways that rainfall is intimately connected to soil erosion (Morgan, 1994).

The values of the R factor for this study were computed using the equation that (Hurni,1985) applied for Ethiopian conditions, even if there were other techniques for assessing the rainfall erosivity based on the local characteristics of the study area (country).

$\mathbf{R = -8.12 + 0.562P}$**… (**Equation 2)

Where R is the rainfall erosivity factor (MJ mmha^{-1}h^{-1}) and P is the mean annual rainfall (mm).

To compute the R factor, mean annual rainfall.

Soil Erodibility Factor (K)

The soil erodibility factor (K factor) reflects the effect of soil properties and profile characteristics on soil loss (Molla and Sisheber, 2017; Pham *et al.,* 2018). It is defined as the mean annual rainfall soil loss per unit of R for a standard condition of bare soil. With the support of GPS locations, soil samples from the generated soil map of the watershed were collected at a depth of 20 cm while taking into account the representatives of the whole watershed Then soil samples were collected and air dried at room temperature, grind and sieved finally analysis using standard laboratory procedure; respectively at Sinana Agricultural Research Center, Soil Laboratory.

Byizigiro *et al.,* (2020) assert that because the topsoil layer is directly impacted by the raindrop energy, it should be taken into account when calculating the K Factor. The reference's supplied equation was a he soils loss (Kouli *et al.,* 2009).

$$\text{K ftor} = f\text{Sand} * f\text{Clay} * f\text{OrgC} * f\text{Silt} * 0.1317$$

… (Eqn 3)

$$f\text{Sand} = (0.2 + 0.3 * \exp\left[-0.256 * \text{mSasoilnd} * \left(1 - \frac{\text{mSilt}}{100}\right)\right]$$

…(Eqn 4)

$$f\text{Clay} = \left(\frac{\text{mSilt}}{\text{mClay} + \text{mSilt}}\right) 0.3$$

… (Eqn 5)

$$f\text{OrgC} = \left(\frac{1 - 0.0256 * \text{OrgC}}{\text{OrgC} + \exp[3.72 - 2.95 * \text{OrgC}]}\right)$$

… (Eqn 6)

$$f\text{Silt} = \left(\frac{1 - 0.7\left(1 - \frac{\text{mSand}}{100}\right)}{\left(1 - \frac{\text{mSand}}{100}\right) + \exp\left[-5.51 + 22.9\left(1 - \frac{\text{mSand}}{100}\right)\right]}\right)$$

… (Eqn 7)

Where: $mSand$ is the proportion (%) of sand content (0.05-2.0 mm diameter particles), $mSilt$ is the proportion (%) of silt content (0.002-0.05 mm diameter particles), $mClay$ is the proportion (%) of clay content (<0.002 mm diameter particles), and $orgc$ is the amount (%) of the organic carbon content of the layer (%).

Topographic factor

The slope length and steepness components are sometimes combined into one index, known as LS, and are known as the topographic factor. The distance from the site of origin of overland flow to the point at which either the slope gradient falls sufficiently for deposition to start or the runoff water enters a clearly defined channel that may be a component of a drainage network is referred to as the slope length. A field's slope determines how much of it is pushed downhill, how quickly water runs, and how much soil will be lost to erosion by water. For this reason, slope steepness has been regarded as one of the most important factors in RUSLE analysis. Due to the increased the accumulation of runoff as the slope length grows, soil erosion by water also increases. The formula suggested by Griffin *et al.,* (1988) utilizes the modified equation for determining the topographic factor (LS factor) in a GIS system. Where, using ArcGIS, the fill, flow direction, and flow accumulation processes, flow accumulation is the number of cells that contribute to flow into a particular cell. The size of the cells utilized in the grid-based model of the landscape is referred to as cell size. The formula mentioned earlier was then entered into the ArcGIS spatial analysis raster calculator tool to produce the LS factor map.

Cover Management Factor (C)

The cover management factor (Morgan, 1994; Kinnell, 2010) is the ratio of soil loss under a specific cover to that of the base soil. Erosion and deposition are significantly influenced by land cover. Surface cover, such as vegetation or plant debris, may stop and lessen the erosiveness of raindrops, enhance infiltration, decrease runoff, and lessen the flow of water it may convey.

A comparable C-value was assigned to each land use class based on cover values suggested by Hurni (1985) after the raster land use/land cover map was transformed to a vector format. (Table 1). Finally, using reclassification and vector to raster conversion the land use/ land cover map was converted to C factor map.

Conservation Practice Factor (P Factor)

The overall problem of soil erosion and the remedies on a farm are directly impacted by conservation practices and land management. The P factor in RUSLE is the ratio of soil loss with a certain conservation method to the comparable loss with up and down slope agriculture, which has a value of one. Depending on the soil management practices used in the particular plot of land, the P-value can vary from 0 to 1. The slope of the area has a significant impact on these management efforts. Due to the lack of any control practice measures, the P-factor is only computed for agricultural land and is assumed to be 1 for all other land uses (Wischaneier and Smith, 1978).

The local office of natural resource management (NRM) was contacted for interviews and regular field observations in order to calculate the P-factor. Only counter-plowing and terracing, which are particularly used in steep and mountainous sections of the study area, are conservation practices that are carried out in agricultural fields and to a smaller degree in bare lands

Results and Discussion

Determinates factors for Soil Loss

Rainfall Erosivity (R) Factor

Annual average precipitation of the study area amounted to 835.2 mm year^{-1}, varying between 690.0 mm year^{-1} and 939.7 mm year^{-1}. In particular, the northern part of the watershed experiences higher rainfall. The northern part of the watershed exhibited high values of Rainfall Erosivity factor (R) which was estimated to be from 441 to 518 MJ mm ha^{-1} h1 year^{-1}.

The amount of soil lost due to soil erosion is directly correlated with rainfall frequency, intensity, and the detachment of raindrops when they hit the soil surface. Erosivity factor (R) for rain fall runoff According to studies (Dabral *et al.,* 2008; Ganasri and Ramesh, 2016), rainfall is one of the most sensitive factors for soil erosion. The results of the R factor map for the welmel watershed ranged from 549 to 575 MJmm ha^{-1}year^{-1} in Figure (3).

A high R factor value indicates an area that is more vulnerable to erosion due to a steep slope, an area that received a lot of rainfall and a lack of or limited surface covers. Areas with low R factors indicate low slope or flat land, high infiltration, and less vulnerability to erosion. The R factor value therefore showed that surface management, covers, and appropriate soil and water conservation measures were needed for the watersheds.

Soil Erodibility Factor (K)

The Ministry of Agriculture and Rural Development provided the FAO standard soil type classification for use in the K factor analysis. In the study area, two major soil types Pellic Vertisols, and Lithosols, were found to correspond to FAO soil classification. Grid dataset was reclassified using K-values adopted by Hurni (1985) after changing the vector format to grid.

The current study's findings showed that the soil erodibility (K factor) values ranged from 0.15 to 2 MgMJ1 mm^{-1} watershed (Figure 4). As a result, the significant variation in soil erodibility K may be caused by variations in soil type, organic matter content, soil particle size distribution, and soil color in the area. The soil types that are more and less susceptible to erosion are indicated by the highest and lowest values of the k factor, respectively. According to Yongsik (2014) and Habtamu *et al.,* (2020), soils with a high percentage of clay, like vertisols, tend to have low K values in terms of texture because they are more susceptible to erosion. This leads to higher soil loss when conditions are given, whereas low K-factor values are generally preferred because they result in ideal low soil loss.

Slope Length and Slope Steepness (LS) Factor

Welmel Watershed's value ranged from 0.22 to 21.25, according to the result customized (LS) factor map. The steep slope changes and highly fractured terrain close to the drainage channels may be to blame for the high values. According to the studies of different researchers, hilly, gully, and mountainous areas with very steep topography tend to have higher LS factor values and are more likely to experience severe erosion as a result of topography (Ashiagbor *et al.,* 2013; Sun *et al.,* 2014 and Kalambukattu and Kumar, 2017).

Crop Management Factor (C)

The crop management factor (C factor) value for Welmel was calculated based on the analysis and ranged from 0.001 to 0.15 (Figure 6). According to Gizachew and Mersha (2015), the C factor assesses how cropping and management practices together have an impact on soil loss in non-agricultural conditions, as well as how ground cover, tree canopy, and grass cover has an impact. Higher C factors indicate no cover effect and soil loss similar to that from bare soil, while lower C factors indicate a very good vegetation cover effect and less soil loss similar to bare soil and consequently less or negligible erosion (Kalambukattu and Kumar, 2017).

Conservation Practice Factor (P)

The P factor ranged from 0.1 to 1 according to the results for the seven classes (seven slope classes) that were used to classify agricultural land (Figure 7). This factor indicates the relationship between soil loss with good support practice and soil loss with up and down slope tillage (Wischmeier and Smith, 1978; Renard *et al.,* 1996). Thus; it reflects the effect of various soil conservation practices to control soil erosion (Kidane *et al.,* 2019; Phinzi and Ngetar, 2019). Dimensionless P-factor usually ranges from 0 to 1 with higher values indicating the absence of soil erosion control, and lower values indicating the near absence of soil erosion depending on the support practices applied in the region. This result is based on the conservation practice available on the study area.

Estimated Annual Soil Loss

With an average soil erosion rate of 32 t ha^{-1} year^{-1}, an estimated 546,769.92 tone of top fertile soil have been lost from the watershed annually (Table 3). This finding is consistent with the 30–40 tons ha^{-1} year^{-1} average annual loss computed globally (Pimentel *et al.,* 1995). Certain rangeland areas were frequently found to have a higher rate of erosion than Welmel.

The model predicted a higher rate of soil loss in all instances than the country's estimated tolerable rate of 10tha-1 y-1 (Hurni, 1985). This finding in line with study conducted by Tamene (Tamene *et al.,* 2017) in Adikenafiz, Ger-ebmihiz and Laelaywukro catchments about 56,44 and 20tha^{-1}y^{-1}, respectively. Even though the estimated soil loss in the Welmel watershed is moderate in comparison to estimates elsewhere in Ethiopia, it exceeded the maximum tolerable soil loss, i.e., the Soil Loss Tolerance (SLT) (Hurni, 1985), denoting the presence of a soil erosion problem. SLT denotes the maximum allowable soil loss that will sustain optimum agricultural productivity.

Also, agreement with the Habtamu *et al.,* (2020) Yisir Watershed**,** soil loss rate map shows various soil erosion rates with an estimated soil loss ranging from 2.5 t/ha/yr. in the plain areas and those covered with plantation forests, such as the Eucalyptus plantations, to a little over 100.62 t/ha/yr. in the areas of agricultural lands, waterways and drainages.

An estimated of the average annual sediment load in Northern Iran, was 51 tons ha^{-1} year^{-1} (Jafarian *et al.,* 2017). In the heavily eroded northern regions of Morocco, an average annual soil loss of approximately 44 tons ha^{-1} year^{-1} has been reported (El Arousii *et al.,* 2014). In Spain's agricultural regions, where the presence of olive groves exacerbates erosion processes, high soil loss values (66–77 tons ha^{-1} year^{-1}) were also recorded (Barruiso *et al.,* 2017). In regions that are highly vulnerable to erosion, like the Chinese Loess Plateau, the average annual soil erosion of a watershed can approach 80 tons ha^{-1} (Pan and Wen, 2014). Furthermore, under severe circumstances, the average yearly soil loss in this area surpasses 130 tons ha^{-1} year^{-1} (Tang *et al.,* 2015). In the watershed, it was estimated that 0.09 % of the area had soil erosion rates that were severe or very severe. This is much more than the acceptable limit for soil erosion rate. Five different soil loss potential (SLT) severity classes were assigned to the study area (Table 3; Figure 8).

1. try to classify the watershed into sub-watershed and
2. Overlay the districts/PAs to the classified sub-watershed
3. Indicate and prioritize the sub watershed overlaid by PAs/ based on the severity estimated for easily intervention management recommendation

A total annual soil loss of less than 5 tons ha^{-1} year^{-1} occurs on approximately 16500.31ha (96.57%) of the Welmel watershed. In the remaining 586.25 ha (3.42%) was above 5 tons ha^{-1} year^{-1} in welmel watershed. Where soil loss ranges from 0 tons per year to 100 tons per year, it is deemed to have high to extremely high levels of soil loss. RUSLE model's outcome thus demonstrates that it is more trustworthy than earlier research. According to test plot measurements made in the Ethiopian highlands (Hurni, 1985; Hurni *et al.,* 2008), the annual rate of soil loss ranges from 130 to 170 t /ha. Based on the result of Hurni (1985) and Hurni (1983), under Ethiopian conditions, confirmed Welmel watersheds soil loss is greater than the maximum tolerable soil loss. This soil loss is comparable to the average annual losses calculated on a global scale, which are estimated to be in the range of 30 to 40 tons per hectare per year (Pimentel *et al.,* 1995). However, it is over three times greater than in the European nations that are most susceptible to erosion, such as Italy, Austria, or Slovenia (Fenta *et al.,* 2020), and it is comparable to that of erosion-prone hillslope farmlands in mountainous catchments in Poland (Strugaa *et al.,* 2018). Similar to our study area, a much moderate rate of erosion approximately 7 tons ha-1 year-1 was estimated in Soummam in Northeast Algeria.

Soil erosion and land use

Land use of the welmel watershed was dominated by natural forest, grassland, settlement, shrubs and agricultural land respectively. Those type of land uses are related with soil erosion severity and positive coloration with Rusel model input. According to studies of Fu *et al.,* (2009); Garcia-Ruiz (2010); Wang *et al.,* (2012), land use affects both soil erosion results and soil characteristics.

Table.1 The land use/land cover map was used for the estimation of C-value

LULC type	C-factor	Sources
Forest	0.001	Hurni, 1985, Reusing *et al.,* (2000); Morgan (2005)
Woodland	0.01	
Shrubs	0.014	Wischaneier and Smith, (1978), Asmamaw et al. (2012)
Grass land	0.05	Morgan (2005), Eweg and Lammeren (1996)
Agriculture	0.15	Morgan, (2005), Tiruneh and Ayalew, (2015), Gashaw et al., (2017)
Bare land	0.4	Amdihun *et al.,* (2014)
Settlement	0.09	Ganasri and Ramish, (2015), Ganasri and Ramesh, (2016)
Perennial crop	0.014	
Bush land	0.04	
Rocky surface	0.09	

$$LS = Pow\left(\text{“flowacc”} * \frac{[\text{cell resolution}]}{22.13*0.4}\right) * \frac{Power(Sin(\text{“sloperasterdeg”}*0.01745))}{(0.0896,1.4)*1.4} \text{......(Equation 8)}$$

Table.2 The land use/land cover map was used for the P-factor -value.

LULC type	Slope	P-factor
Cultivated land	0-5	0.1
	5 to 10	0.12
	10 to 20	0.14
	20 to 30	0.19
	30 to 50	0.25
	50 to 100	0.33
Other LULC	All	1

Source:(Wischaneier and Smith, 1978).

Table.3 Soil loss severity extent for Welmel watershed

Annual soil loss (t ha−1 year−1)	Severity classes	Area (ha)	Area (%)
0-5	Low	16500.31	96.57
5-15	Moderate	569.14	3.33
15-30	High	12.38	0.07
30-50	Very high	2.18	0.01
50-100	extremely high	2.55	0.01
		17086.56	100.00

Figure.1 The land use/land cover map was used for the P-factor -value.

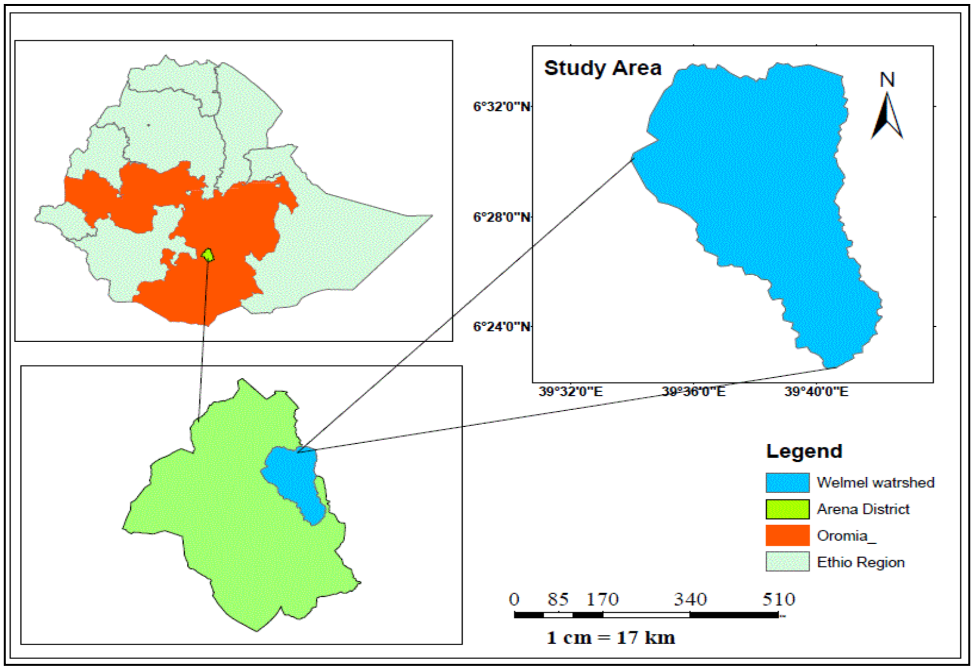


Figure.2 Procedures of RUSLE implementation in GIS

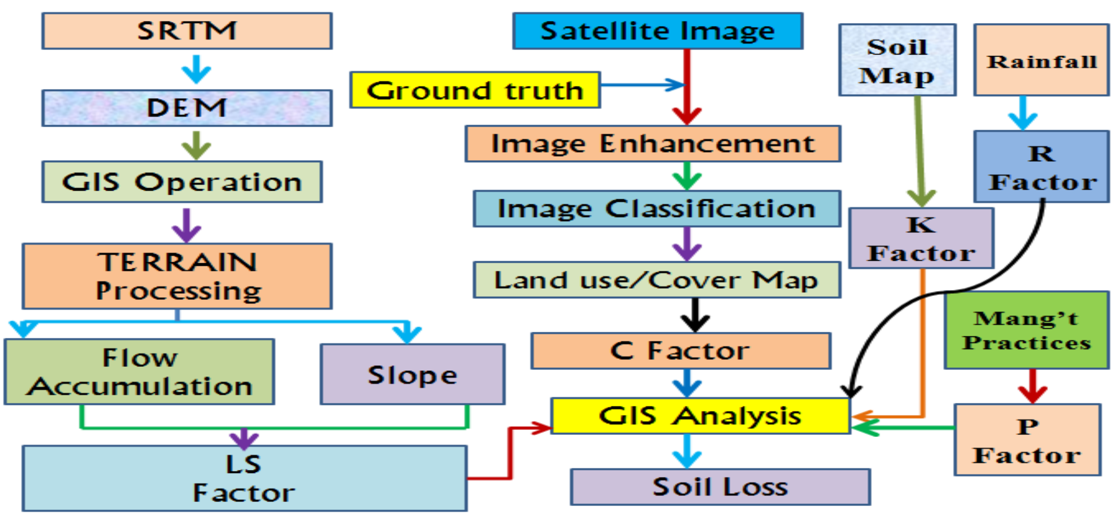


Figure.3 Rainfall Erosivity (R) Factor value of welmel watershed

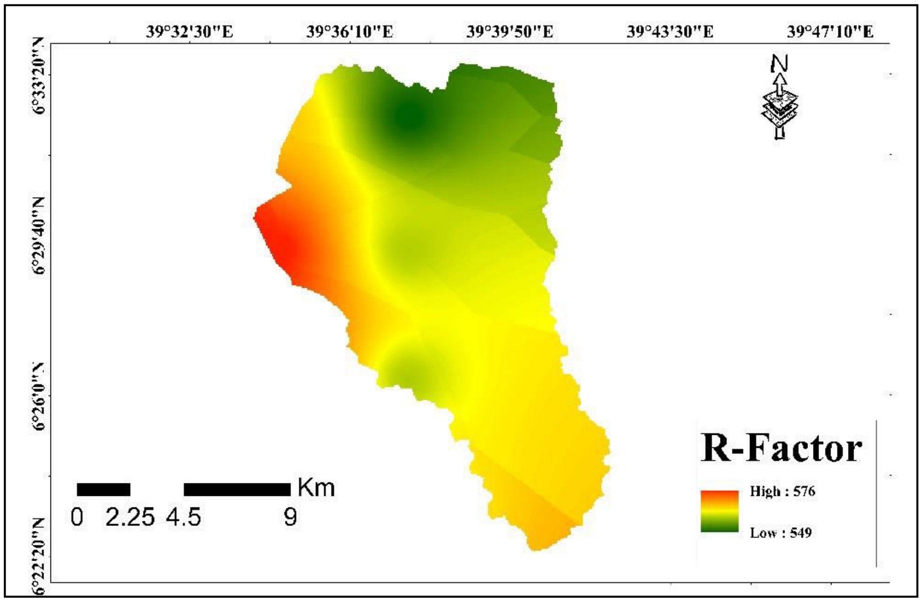


Figure.4 Soil Erodibility Factor (K) value of Welmel watershed

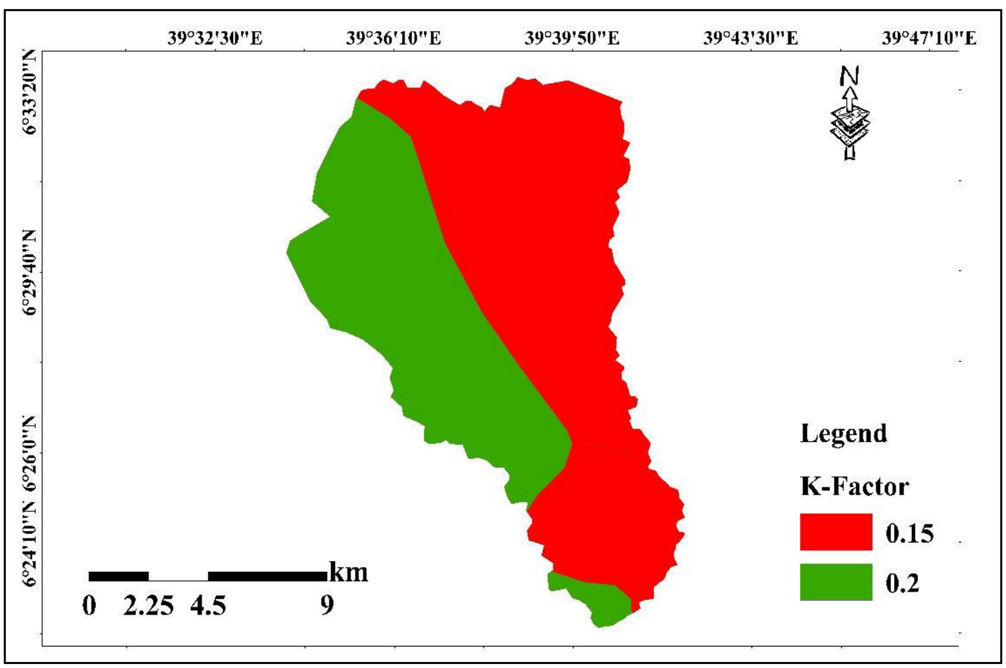


Figure.5 Slope Length and Slope Steepness (LS) Factor value

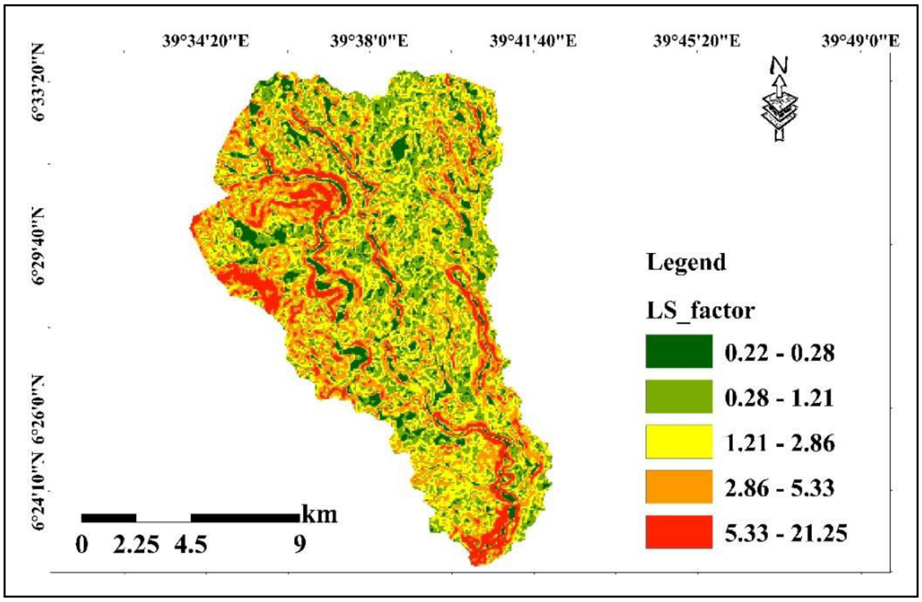


Figure.6 Crop Management Factor value

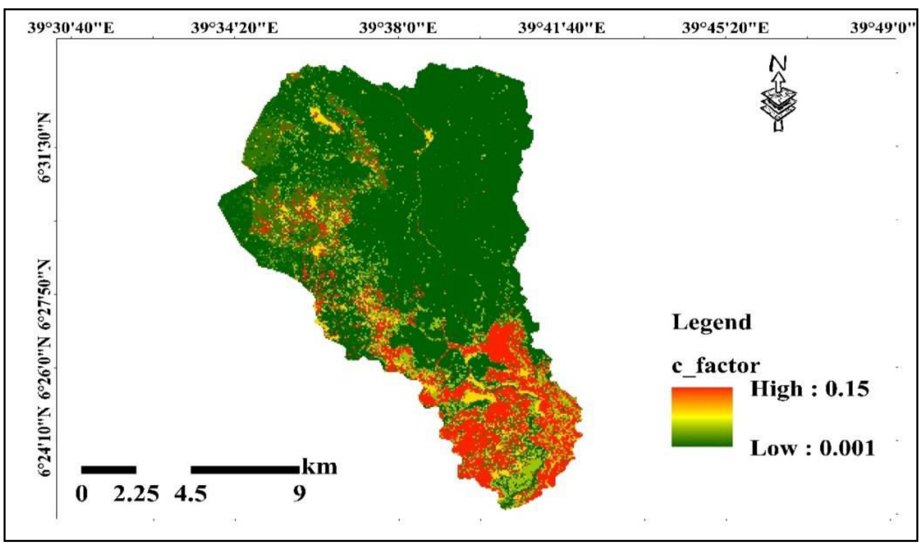


Figure.7 Conservation Practice Factor (P) value of welmel watershed

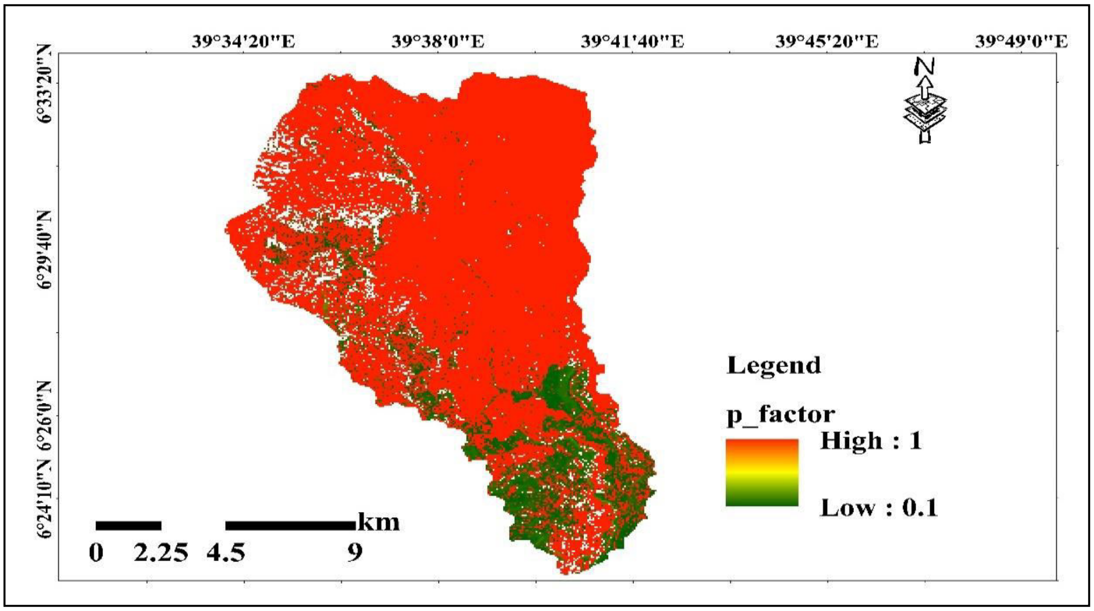


Figure.8 Annual soil loss classes of welmel watershed

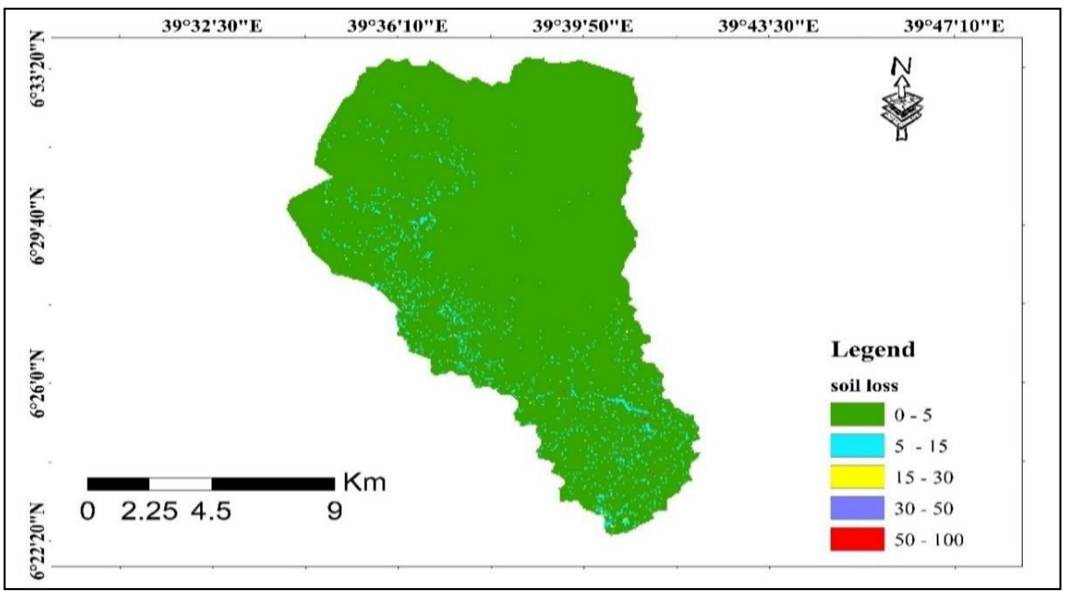
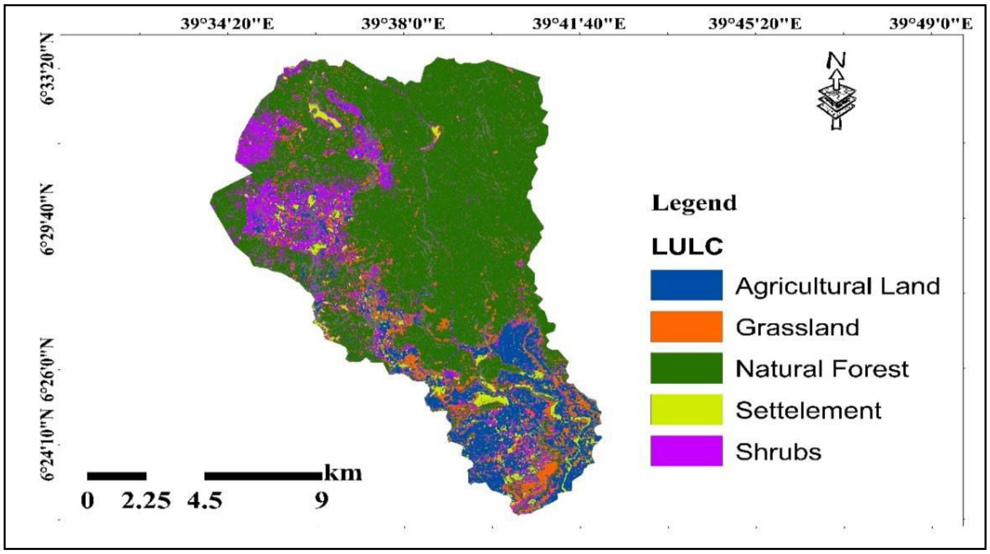


Figure.9 Land use type of welmel watershed



In contrast to Pham's (2008) statements that plantation forests are the most severely eroded, Erskine, Mahmoud Zadeh, and Myers' (2002); Gangcai's (2005) and (Tran *et al.,* 2014) argument that agriculture has the most severe erosion.

According to our study of the Welmel watershed, there are significant differences in the erosion risks for various types of land use, slopes, and rainfall. Where forest cover is currently being converted to cropland and settlement, there is a high risk of soil erosion at the border between agricultural and vegetated landscape. According to earlier research, human activity is the primary cause of Ethiopia's scale's erosion. Farmland soil erosion in flat areas is, however, only moderate. However, croplands near the boundary between the heavily farmed landscape and the vegetated landscape are severely impacted by sheet and rill erosion. With an average soil erosion rate of 32 t ha^{-1} $year^{-1}$, an estimated 546,769.92 tone of top fertile soil have been lost from the watershed annually.

In the watershed, it was estimated that 0.9 % of the area had soil erosion rates that were severe or very severe. This is much more than the acceptable limit for soil erosion rate.

Recommendations

The researchers provide the following crucial recommendations based on the findings of the study, even though the effectiveness of conservation and management practices rely on a combination of elements including resources, time, technical expertise, proper regulations, and cultural perspectives of the people.

The soil loss hazards map shows regions where considerable soil loss has occurred, and these locations should get serious consideration and top priority for undertaking soil conservation and management actions before the area experiences permanent soil degradations.

The local populations should immediately implement soil conservation measures on their agricultural lands by using various soil protection techniques as mulching, strip cropping, terracing, contour plowing, multiple cropping, and other traditional indigenous soil conservation techniques.

Long- and short-term timely updated natural resource management systems, including the appropriate forest regulations, should be put into place by local planners and decision-makers.

It is judged essential for the sustainability of soil and other natural resources in the study area to protect and preserve current vegetation cover and/or restore forests in farmed areas in order to minimize erosion over the long term, especially on steeper slopes.

Although GIS, RS, and the Multi-Criteria Evaluation model are useful for mapping and quantifying the estimated value of soil loss across multiple locations, it is advised to do further research at a smaller spatial scale using high resolution data in order to monitor and mitigate areas as appropriate.

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Conflicts of Interest

Authors declare no conflicts of interest.

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