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Soil Erosion Risk Assessment and Prioritization of Midhagdu Micro Watersheds for Conservation Measure Using RUSLE, GIS, RS and SPSS in Eastern, Ethiopia

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Abstract: Soil erosion is being detected as a risk to human survival by diminishing the food and water availability of the planet Earth in the 21st century. Assessment and management of this resource are becoming extremely important. This study aimed to investigate Soil Erosion Risk and Prioritize for soil and water conservation measures in the study area. Satellite data, SRTM DEM, Land sat 8 OLI with 30m resolution; rainfall and soil data were used to generate all soil erosion risk factor maps and integrated to generate a composite map of soil loss for the watershed. The RUSLE model in combination with remote sensing and GIS techniques was used to identify the five thematic maps as an input to estimate mean annual soil loss. The results of the spatial distribution of soil erosion risk factors indicated that rainfall erosivity, soil erodibility, slope length and steepness, cover management, and anthropogenic soil erosion control practices values ranged from 41.365 to 43.793MJ mm $ha^{-1}yr^{-1}$, 0.26 to 0.31t $ha^{-1}MJ^{-1}mm^{-1}$, 0 to 220.512, 0.21 to 0.87 and 0.11 to 1 respectively. And the most powerful factor that influences soil erosion risk is topography followed by anthropogenic soil erosion control practices. The results of the study showed that the annual soil loss rate in the watershed ranged from 0 in gentle slopes to 1504 t $ha^{-1}yr^{-1}$ at the steepest slope of the watershed with a mean annual soil loss of 48.5 t $ha^{-1}yr^{-1}$ at Midhagdu watershed level. The soil loss map was categorized into five soil loss numerical ranges and soil loss risk nominal scales: low, moderate, high, very high, and extremely high using Ethiopian highland maximum soil loss threshold level 18 t $ha^{-1}yr^{-1}$. The soil loss risk levels identified at 28 micro watersheds showed that twelve micro watersheds rated as first, eleven micro watersheds as second, and three micro watersheds as the third priority for soil and water conservation measures implementation. Out of 28 micro watersheds, 26 fell above Ethiopian highland maximum soil loss threshold levels. Therefore, the study result indicated that the Midhagdu watershed needs immediate intervention for better for soil and water conservation measures implementation planning by considering identified soil erosion risk areas and priority classes to control soil erosion risk below the national threshold level.

Keywords: Erosion Risk, Micro Watershed, Midhagdu, Prioritization, RUSLE Model, Soil and Water Conservation Measures

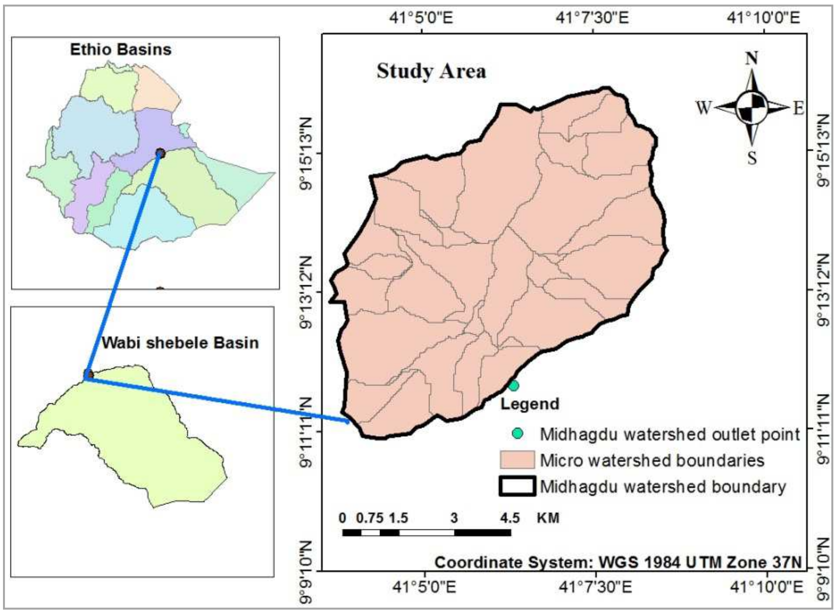
1. Introduction

Water-induced soil erosion is considered to be the riskiest form of soil degradation [1]. Depletion of soil, water, and forest resources continues to be a serious environmental risk worldwide and threatens poor nation's survival [2]. Though soil erosion is a natural phenomenon and has persisted on earth for a longer period, the problem has become very serious in recent decades due to increased man-environment interactions [3]. Globally, about 75 billion tons of soil is eroded from the land each year at a rate that is about 13-40 times as fast as the natural rate of erosion [4]. Soil erosion risk from agricultural land was 74% in Central America, 45% in South America, and 65% in Africa [5]. Soil erosion generally deteriorates soil quality, reduces the productive capacity of the land, and thereby increases the risk of food security at global and local scales [6]. Soil erosion is threatening Ethiopian ecosystems especially West Hararghe Highlands agriculture and ecosystems. In response to accelerated threats of water-induced soil erosion risks, the Ethiopian government has been designing the policy and programs on soil and water conservation and has adopted SWC measures as participatory watershed management programs [7].

More importantly, a watershed is the most acceptable unit to plan for soil and water conservation and rehabilitation measures and also for most hydrological studies [3]. However, prioritization of the micro-watersheds of a large watershed is an essential step in this direction and to achieve sustainable development of the Midhagdu watershedunder traditional and limited financial resource availability for soil erosion risk assessment and management following a priority area basis (ecosystems). The Revised Universal Soil Loss Equation (RUSLE) model is applied worldwide for soil erosion risk prediction. Although it is an empirical model, it not only predicts erosionrates of ungagged watersheds using knowledge of the watershed characteristicsand local hydro-climatic conditions but also presents the spatial heterogeneity ofsoil erosion that is too feasible with reasonable costs and better accuracy in largerareas [8]. It has been extensively used to estimate soil erosionloss to assess soil erosion risk, and guide development and conservation plansto control erosion under different land-cover conditions, such as croplands, rangelands, and disturbed forest lands [9]. Remote Sensing and GIS have become important tools to study andunderstand landscape changes and management of natural resources at watershedscales including prioritization of micro-watersheds for conservation planning anddevelopment [10]. Various studies havebeen conducted in the past on the prioritization of watersheds using the RUSLE model, to suggest best soil and water conservation measures [11]. Among those, onlya few studies were conducted in the Western Hararghe Highlands including the *Midhagdu* watershed (for example, [7]. Thus, Western Hararghe highlands including the *Midhagdu* watershed is one of the soil erosion rampant areas where the topography is very high and used for cultivation, long dry season followed by intense rainfall, flooding every year, high rate of soil erosion, poor biophysically integrated land management practices, high deforestation rate, bare land dominated area, and low land productivity are highly visible [12, 7].

In general, there is a gap of scientific investigationinline to RUSLE incombination with RS and GIS techniques that used for assessing soil erosion risk and prioritizing the microwatershedsbased on average annual soil loss and soil erosion risk to plan various soil and water conservation/ rehabilitation measures within Midhagduwatershed in Western Hararghe Highlands, Eastern Ethiopia.

Hence, this research bridged the existing gaps by providing geospatial information through identifying soil erosion risk factors and prioritizing management options at a micro watershed level for proactive decision making to control the menace of soil erosion risk in the area. Therefore, the study was undertaken with the objective: toassess soil erosion risk and prioritize management options in Midhagdu Watershed, Western Hararghe Highland, Eastern Ethiopia.



Source: Own output (2020)

Figure 1. *Location Map of the Study Area.*

2. Research Methodology

2.1. Description of the Study Area

Location and Size

This study was conducted in the *Midhagdu* watershed of*Tulo* district; West Hararghe Zone of Oromia Regional State, Eastern Ethiopia. Geographically, the watershed lies between 41°5'0"E to 41°10'0"E longitude and 09°9'10"N to 09°15'13"N latitude (Figure 1). It is situated at a distance of about 370 km from Addis Ababa, the capital city of Ethiopia, along with the main Addis – Harar asphalted highway and 150 km West ofHarar city on the Addis Ababa-Harar highway. The size of the *Midhagdu* watershed selected for this study has an area of 54.3 km^2.

The *Midhagdu* watershed is part of the *Fugug*mountains of Western Hararghe *Chercher*highlands which is part of Eastern Ethiopia highlands. The watershed is characterized by rugged terrains, undulating topography with hills, mountains, plains, and river valleys. The elevation of the study area ranges from 1760 to 2500m above mean sea level. The average elevation of the study area is 2130m above sea level. The *Midhagdu* watershed's main drainage line is called the *Hirna* river drains into Wabishebele Basin one of the 12 river basins of Ethiopia [13]. *Midhagdu* watershed is situated in the semiarid to sub-humid agro-ecological zones of the country [12]. According to Ethiopian Meteorological Agency 2019, reveals that an average annual rainfall of 1040 mm with mean minimum and maximum air temperatures of 12 and 26°C with an average temperature of 19°C, respectively. The study area is characterized by distinct dry and wet seasons. The precipitation of the area is characterized by bi-modal distribution. And the average rainy days are 150 days in the year and are characterized by highly erratic rainfall [14]. The dry seasons occur between November and April and the Wet season between May and October; small rains occur sporadically during April and May.

2.2. Materials and Methods

This present study has been used both primary and secondary data. Secondary data (satellite imagery (Landsat 8 OLI), digital elevation model (30m resolution DEM), rainfall data, soil data, and document reviews) were collected from different governmental and non-governmental organizations [15]. These data were obtained from https://glovis.usgs.gov, shuttle radar topographic mission (SRTM), https://power.larc.nasa.gov/data_access_viewer, and ministry of water irrigation and energy of Ethiopia (Table 2). Watershed and microwatershed shapes were delineated from DEM in Arc GIS software. In addition to this, frequent field observations using the Global Positioning System (GPS) and Google Earth Pro were carried out to generate primary information regarding the ground truth for image classification and soil loss vulnerability verification.

The average soil loss generatedfromMidhagduwatershed is estimated using the RUSLE model, outlined by [16] and improved and modified by [17]. The RUSLE is a combination of five factors which are represented as follows:

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

Where: A = the average annual soil loss (in ton $ha^{-1}yr^{-1}$); R the rainfall and runoff-Erosivity (in MJ.mm.$ha^{-1}h^{-1}yr^{-1}$); K = the soil erodibility factor (in ton.h.MJ^{-1}.mm^{-1}); LS = the topographic factor (dimensionless), with the slope length factor (L) and the slope gradient (S) factor; C = vegetation/land cover factor (dimensionless) and P = the specific erosion control practices factor (dimensionless).

2.2.1. Rainfall-Runoff Erosivity (R) Factor

The Erosivity factor R was calculated according to the equation given by Nysen*et al.,* 2007 which is derived from spatial regression analysis [18] for Ethiopian conditions. It is based on the available mean annual rainfall data.

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

Where R is the Rainfall-Runoff Erosivity factor, P is the mean annual rainfall in mm. In this study, historic rainfall data of 31 years (1988-2019) was collected from six sites of gridded rainfall stations near the study area namely *Chiro, Kuni, Shenen, Mulu, Afdem, Deder* (Table 1).

Table 1. *Gridded rainfall Stations and their mean annual rainfall and rainfall erosive factor.*

SN	Station name	X_Coordinate	Y_Coordinate	Mean annual rainfall (mm/yr) (1988-2019)	Station R_Factor	Elevation
1	Kuni	713058	983889	99	48	1863
2	Chiro	712886	1016157	91	43	1738
3	Shanan	744923	1020957	94	45	1849
4	Deder	745232	970240	75	34	1774
5	Mulu	721750	1066907	54	22	1225
6	Afdem	744719	1053219	61	26	1370

Source: Own Output (2021).

The mean annual rainfall was first interpolated to generate continuous rainfall data from each station by spatial Analyst Tools Raster Kriging Interpolation which gives the best linear unbiased prediction of the intermediate values [8] in ArcGIS 10.4 environment. The interpolated rainfall (P) map was changed to a raster of 30m resolution and used in the Raster Calculator in Arc GIS to obtain spatial continuous data of R-value [20].

2.2.2. Soil Erodibility (K) Factor

Vulnerability of the soils to get eroded is referred to as erodibility of soils. Soil Erodibility Factor (K) is defined as mean annual rainfall soil loss per unit of R for a standard condition of bare soil, recently tilled up-and-down on a slope with no conservation practices and a slope of 5 and 22m length [21]. And also, the K-factor is the rate of soil loss per unit of R-factor on a unit plot [17]. The value of K ranges from 0 to 1 where 0 refers to soils with the least susceptibility to erosion and 1 refers to soils that are highly susceptible to erosion by water [20]. Generally, soils become of low erodibility if the silt content is low, regardless of corresponding high content in the sand and clay fractions [22].

To obtain the K-factor for soil, the ERFAC (Proposed Alternative Soil Erodibility Factor) a nonlinear regression equation designed for data-scarce regions where organic matter data is not available in an area, was suggested by Geleta in his Ph.D. dissertation [23] and used also in [24] was used for each soil types in the study area as follows.

$$\mathrm{ERFAC(K)} = \mathrm{a}\left(\frac{\%\mathrm{silt}}{\%\mathrm{sand}+\%\mathrm{clay}}\right)^{\mathrm{b}}. \quad (3)$$

Where, ERFAC: Proposed Alternative Soil Erodibility Factor, % silt=silt content of the soil, % clay = % clay content of the soil, % sand = % sand content of the soil, a = 0.32, and b = 0.27 a and b are factors obtained from regression coefficient.

2.2.3. Cover Management (C) Factor

Cover-management factor calculated from the Landsat 8 satellite image of January 2019 through the Normalized Difference Vegetation Index (NDVI) was generated and used in this analysis. Since the C factor ranges from 0 (full cover) to 1 (bare land) and the NDVI values range from 1 (full cover) to 0 (bare land), the calculated NDVI values were inverted using the following equation [25], NDVI-values were scaled to approximate C values using the following provisional formula [26, 27]

$$C = exp\left[-\alpha.\frac{NDVI}{\beta - NDVI}\right] \quad (4)$$

Where: C is Cover management factor, exp is exponent, NDVI is Normalized Difference Vegetation Index α, β: Parameters that determine the shape of the NDVI-C curve, an α-value of 2 and a β-value of 1 seem to give reasonable results [25, 27].

2.2.4. Topographic (LS) Factor

The topographic (length and steepness) factor expresses the effect of local topography on soil erosion rate, combining the effects of slope length (L) and slope steepness (S). Thus, LS is the predicted ratio of soil loss per unit area from a field slope from a 22.1 m long, 9% (5.16°) slope under otherwise identical conditions [28]. L factor and S factor are usually considered together. Both GIS and remote sensing techniques were applied to access the *LS* factor in the RUSLE equation using the digital elevation model (DEM) [29]. The LS factor was calculated by multiplying L and S factor together [30] in a raster calculator in the ArcGIS platform with the help of the following equation:

$$LSPOW\ \left(FA * \frac{CS}{22.13}, 0.4\right) * Pow\ \left(\sin\left(SD * \frac{0.01745}{0.09}, 1.4\right)\right) 1.4 \quad (5)$$

Where, LS= Slope Length and steepness factor, CS = Cell Size, Pow is Power, SD= is a slope in degree. Whereas the *Midhagdu* watershed flows accumulation and slope (degrees) as shown below figure 8.

2.2.5. Anthropogenic Soil Erosion Control Practice (P) Factor

The anthropogenic soil erosion control practice (P) factor is the most important parameter in the RUSLE method and it is a dimensionless factor. Anthropogenic soil erosion control practice factor, as the ratio of soil loss in a particular support practice to the corresponding soil loss with up and downslope cultivation [31]. P-value ranges from 0 to 1, where the value 0 indicates a good erosion-resistant facility made by man and the value 1 indicates an absence of an erosion-resistant facility. The P values were assigned by delineating the land into agricultural, forest, grass, and shrub and built-up land-use classes using Landsat 8 satellite image classification.

After the processes of the study area, LULC map preparation, and accuracy assessment report generation, the LULC map of the watershed wasbroadly categorized into agricultural and Non-agricultural land uses, and a P-value of 1 was assigned for Non-agricultural land uses. As it was suggested by [9] the agricultural land use was reclassified into 6 classes based on the slope (%) of the land, and the respective P-value for each class was assigned in Figure 9.

Accordingly, the P-value of the agricultural lands with slope of 0-5% (0.11), 5-10% (0.12), 10-20% (0.14), 20-30% (0.22), 30-50% (0.31), 50-100%(0.43), 0-100%(1) was assigned [32, 9].

The classified agricultural land use map based on slope and Non-agricultural land use maps were overlaid after converting into vector format and assigning respective *P*-values. Finally, the overlaid map was converted into a raster format with a 30-m pixel size using its *P*-value to make it suitable for pixel-by-pixel overlay analysis to estimate soil erosion [9, 19] as stated in Table 2 below.

Table 2. *Anthropogenic soil erosion control practices factor values.*

Land use types	Slope (%)	P-value
Agricultural land use 1	0-5	0.11
Agricultural land use 2	5-10	0.12
Agricultural land use 3	10-20	0.14
Agricultural land use 4	20-30	0.22
Agricultural land use 5	30-50	0.31
Agricultural land use 6	50-100	0.43
Nonagricultural land uses	0-100	1.00

Adapted from [32, 9].

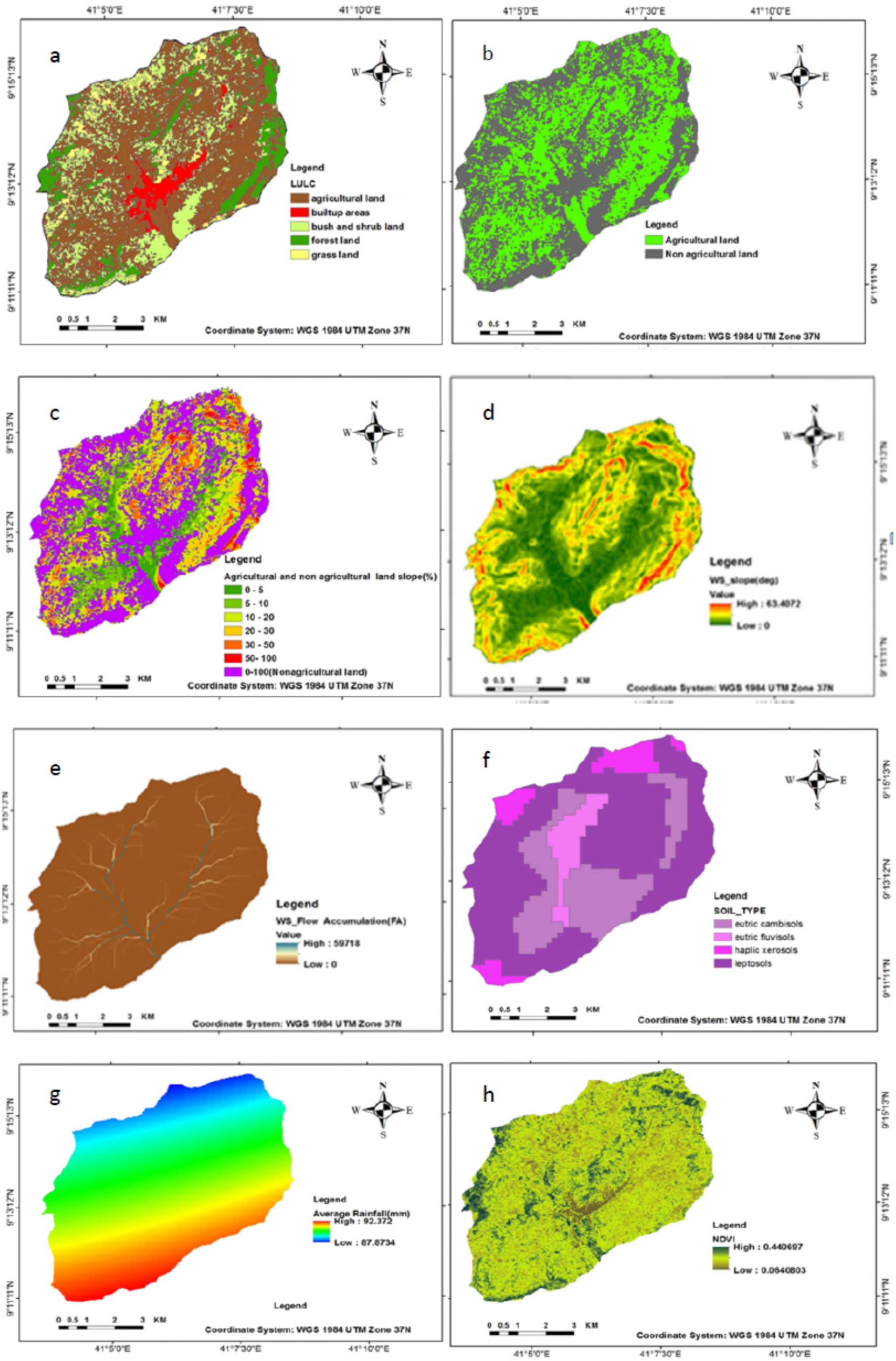


Figure 2. *Data preparations map for RUSLE model input factors: LULC map (a); agriculture and non agriculture LULC map (b); agricultural land slope map (c); slope degree map (d); flow accumulation map (e); soil map (f); mean rainfall map (g) and NDVI map (h).*

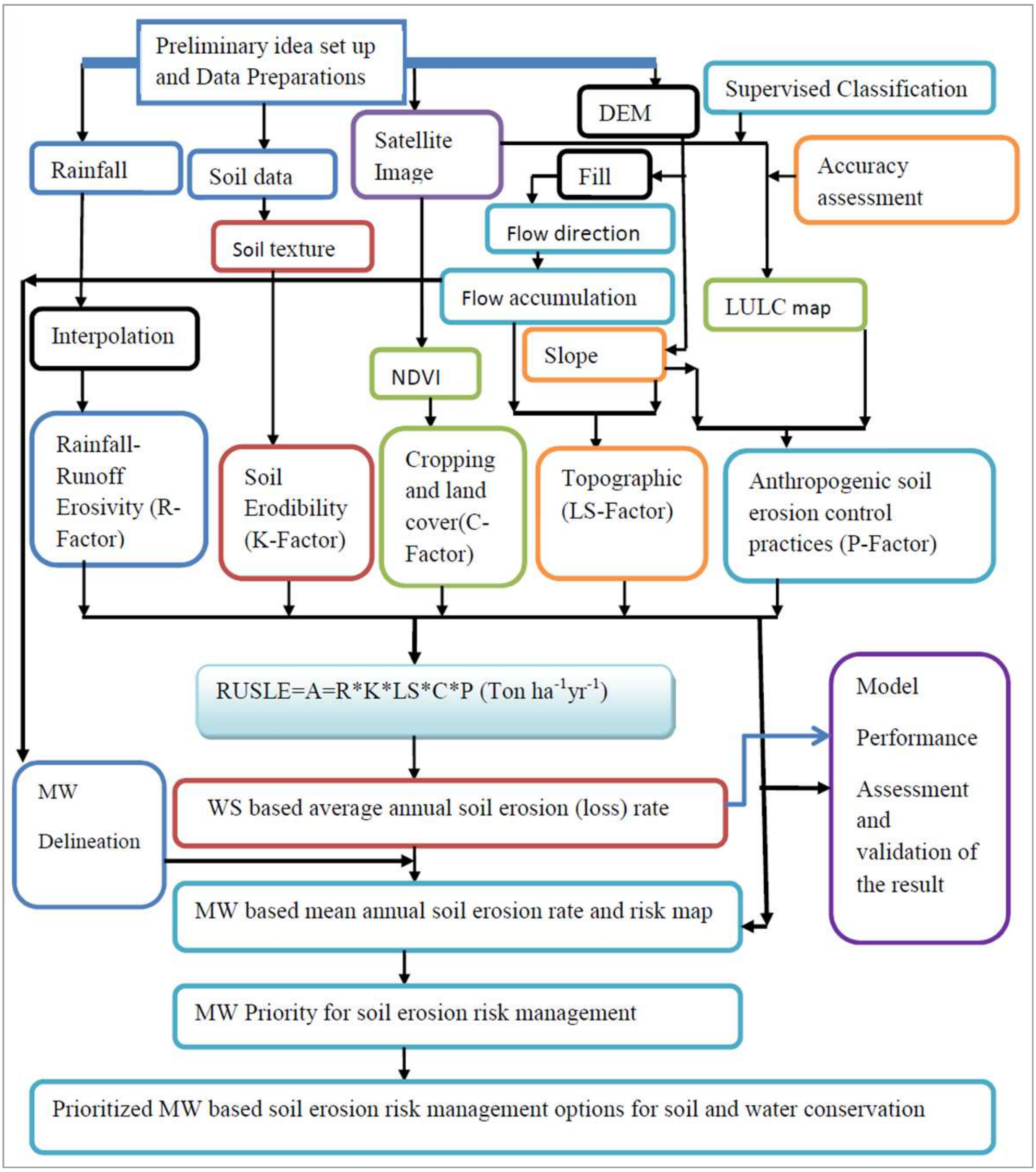
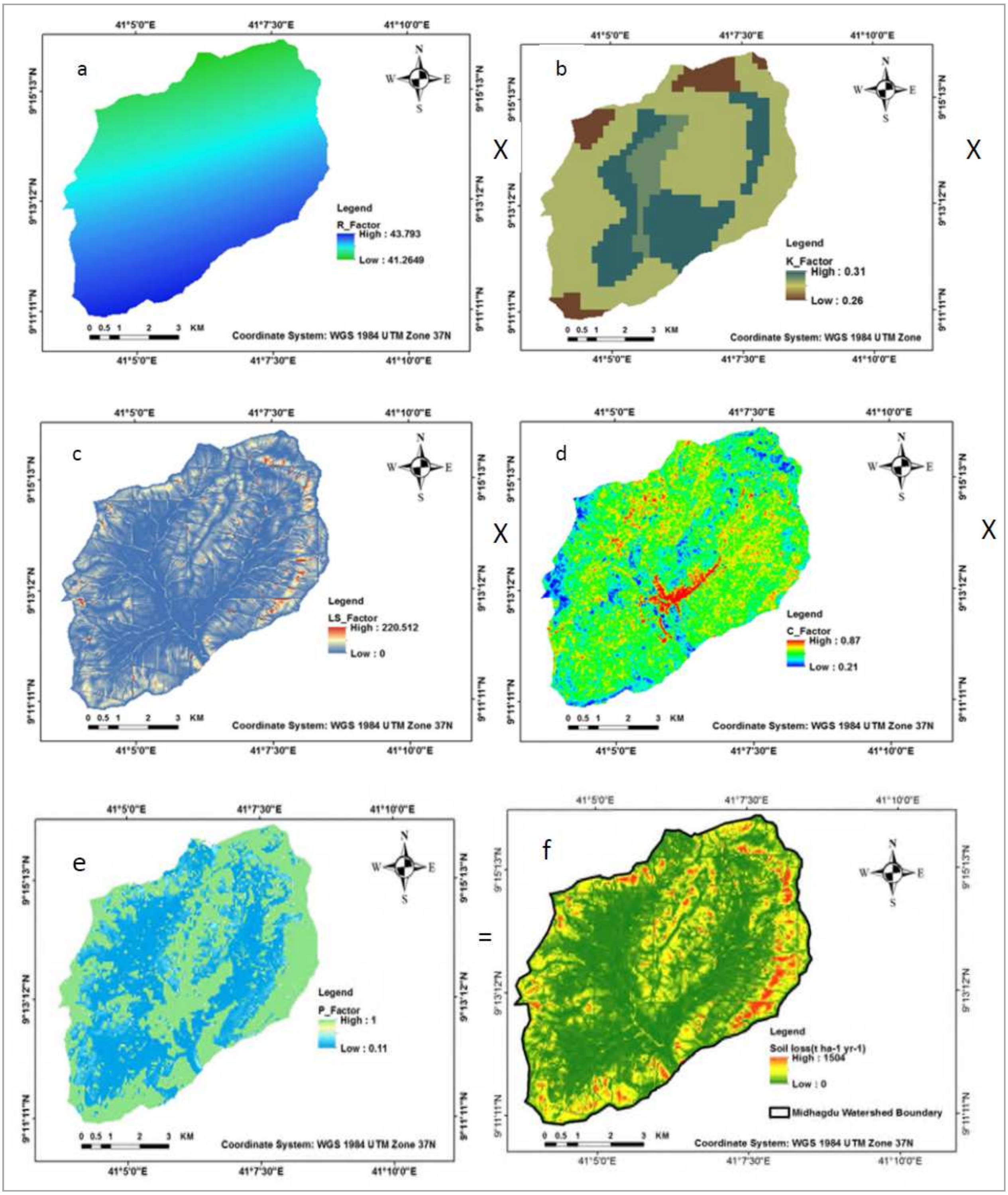


Figure 3. *Methodological flow chart followed to assess soil erosion risk and prioritizes management options in the Midhagdu watershed.*

3. Results and Discussions

3.1. RUSLE Model Input Factors Thematic Maps and Soil Loss Raster Map Generation

RUSLE model takes as an input five soil erosion risk factors of raster-based thematic maps. The results of the spatial distribution of soil erosion risk factors indicated that rainfall erosivity, soil erodibility, slope length and steepness, cover management, and anthropogenic soil erosion control practices values ranged from 41.365 to 43.793MJ mm $ha^{-1}yr^{-1}$, 0.26 to 0.31t $ha^{-1}MJ^{-1}mm^{-1}$, 0 to 220.512, 0.21 to 0.87 and 0.11 to 1 respectively (Figure 4). The map results of all five RUSLE factors were unevenly distributed in the Midhagdu watershed and the multiple regression analysis in SPSS showed the most powerful factor that influences soil erosion risk is topography followed by anthropogenic soil erosion control practices in the study area. And the combination of these five factors using Map algebra function in Arc GIS resulted in the soil erosion raster map with sediment yield of soil loss ranging from 0-1504 tonnes per ha^{-1} per yr^{-1} (Figure 4).



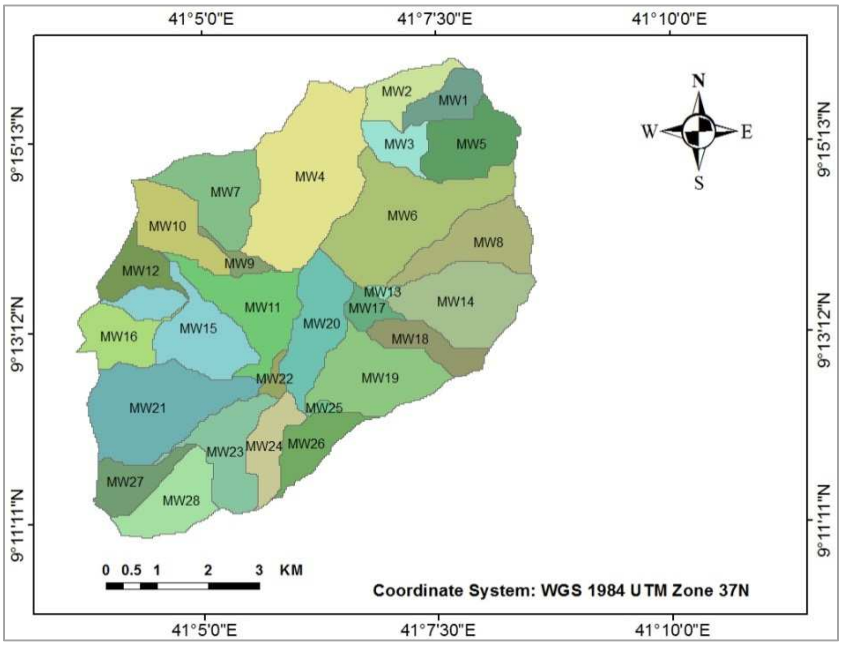
Source: Own survey (2021)

Figure 4. *Conbinations of RUSLE model input factors and the model output:- Rainfall-runoff erosivity (R) factor (a); Soil erodibility (K) factor (b); Slope Length-steepness (LS) factor (c); Cover management (C) factor (d); Support practice (P) factor (e); Soil loss map (f) of Midhagdu watershed.*

3.2. Prioritization of Soil Erosion Risk Management Options at Micro Watershed Level

The concept of prioritization plays a vital role in the identification of areas that require more attention in respect to soil erosion risk management [24]. It is very much effective for the application of proper planning and soil erosion risk management program in adverse erosion risk-prone areas [9]. Several studies successfully implemented this method for micro-watershed prioritization [33, 34].

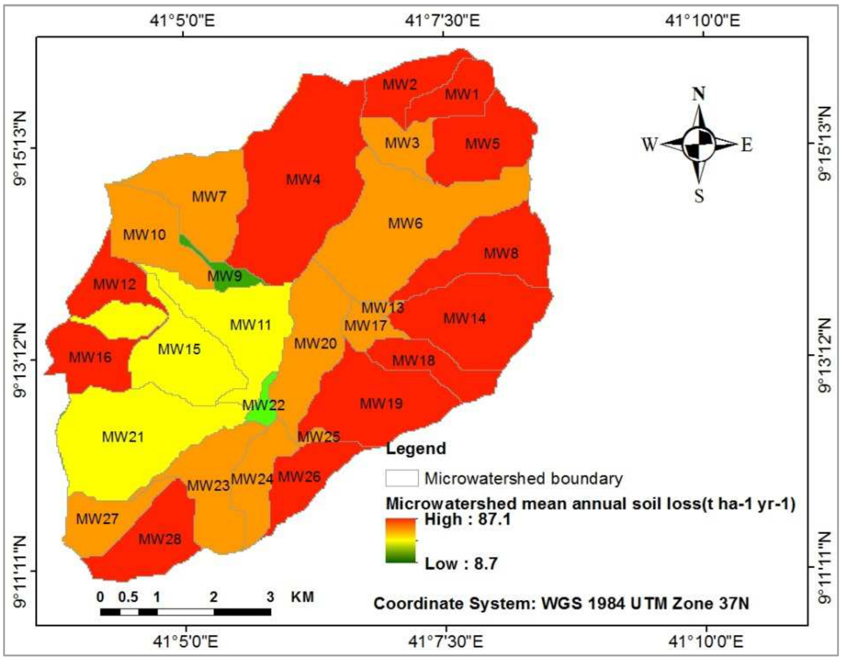
The soil erosion risk class map of micro-watersheds revealed nearly the entire watershed needs the implementation of different types of conservation measures. However, the implementation of conservation measures in all micro-watersheds may not be possible and effective [9]. Therefore prioritization of soil erosion risk management options at the micro-watershed level is quite important to manage resources, times, quality, and quantity of soil erosion risk abatement measures. To perform this objective, the *Midhagdu* watershed was classified into 28 micro-watersheds using an automatic watershed delineation algorithm of archydro tools in ArcGIS 10.4 and their soil erosion risk classes were identified as shown in (Figure 5).



Source: Own output (2020)

***Figure 5.** Micro-watershed map within Midhagdu watershed.*

For the present purpose, 28 micro-watersheds of the *midhagd*u watershed variation have been regionalized using zonal statistics as a table and produced area-weighted mean soil loss at each micro-watershed level as shown in (Figure 6).



Source: Own output (2021)

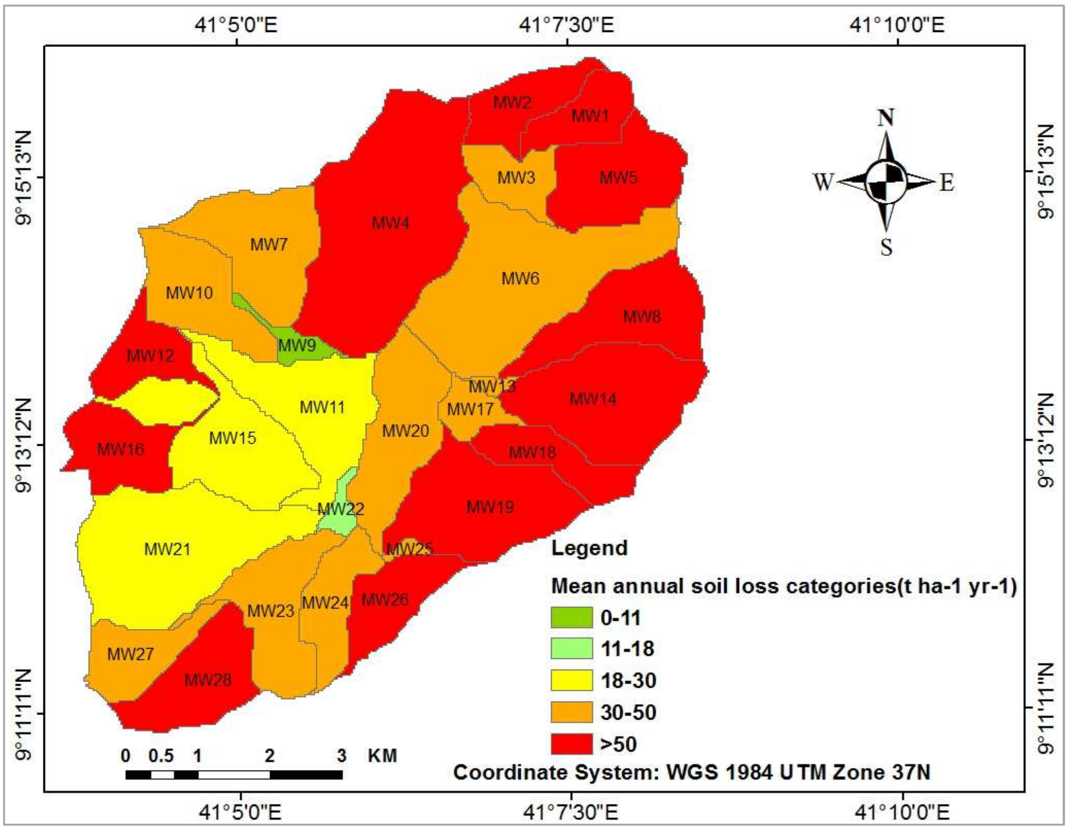
***Figure 6.** Micro watershed-based mean annual soil loss map.*

In this case, the variation among micro-watersheds was considered to be attributed to individual model parameter characteristics and their interaction. As per the model estimates, micro-watersheds experienced a potential mean annual soil erosion rate ranging from 8.7 to 87.1 t ha^{-1} yr^{-1} (Table 4; Figure 6). Proper identification of areas that are highly vulnerable to soil loss is a critical factor for designing and implementing appropriate SWC measures or soil erosion risk management options. Prioritization was done at micro-watershed scales considering areas with a higher soil loss and increases in erosion risk levels. Thus, a higher priority for soil erosion risk management options was set for micro-watersheds with increasing mean annual soil loss rate and its corresponding nominal soil loss risk levels.

Accordingly, the micro-watersheds are categorized under five soil erosion risk management options priority classes based on mean annual soil loss rate and increases in soil loss risk levels following [35, 36]. which were: (i) low priority (< 11 t ha^{-1} yr^{-1}, low risk level);, (ii) medium priority (11–18 t ha^{-1} yr^{-1}, medium risk level), (iii) high priority (18–30 t ha^{-1} yr^{-1}, high risk level) and (iv) very high priority (30 -50t ha^{-1} yr^{-1}, very high risk level) and extremely high priority (>50t ha^{-1} yr^{-1}, extremely high risk level) which can be seen (Tables 4 and 5; Figures 7 and 8). Based on the analysis, Micro Watershed 14 and Micro watershed 9 were recorded as the highest mean annual soil loss (87.1 t ha^{-1} yr^{-1}) and the lowest mean annual soil loss (8.7 t ha^{-1} yr^{-1}) respectively (Table 4).

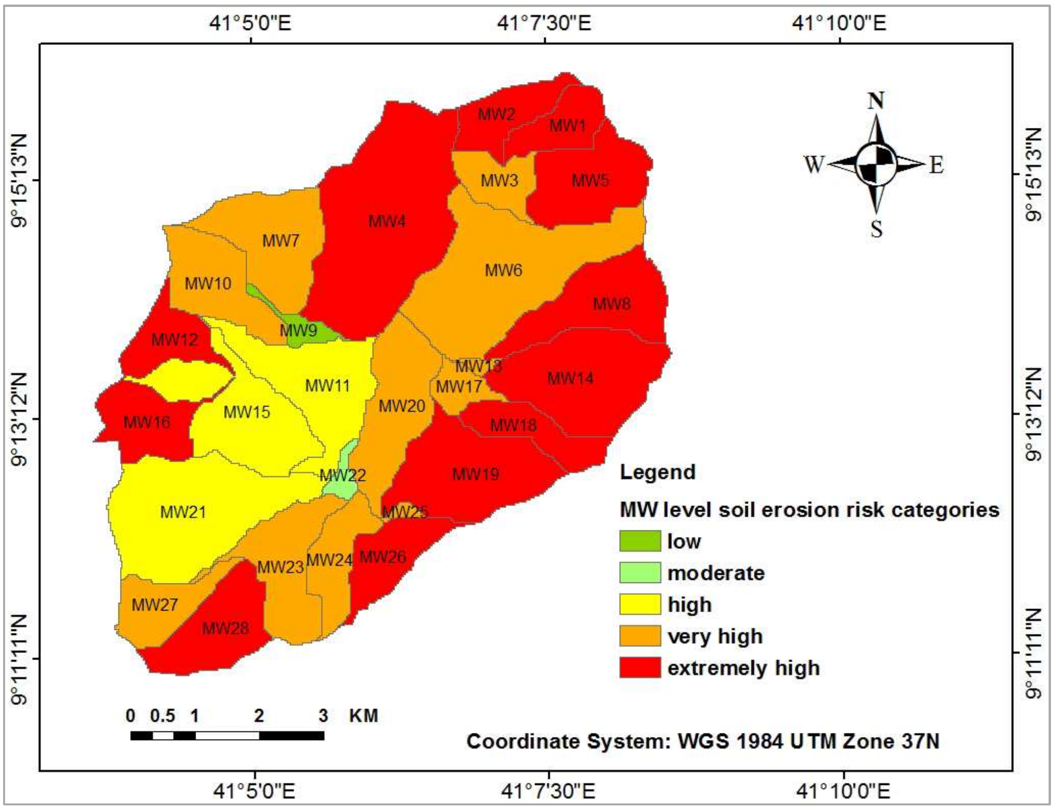
Micro watersheds (1, 2, 4, 5, 8, 12, 14, 16, 18, 19, 26, 28) that cover an area of 25.92 km^2 or 48% of the *Midhagdu* watershed; were found under extremely high soil erosion risk level (mean soil loss of >50 t ha^{-1} yr^{-1}) (Table 4) this is above *Midhagdu* watershed mean annual soil loss (48.5 t ha^{-1} yr^{-1}). This result shows all twelve micro watersheds were primarily prioritized for immediate actions of soil erosion risk management options implementations by all entities. Moreover, eleven micro-watersheds (3, 6, 7, 10, 13, 17, 20, 23, 24, 25, 27) that cover an area of 17.83km^2 or 33% of Midhagdu watershed, the study area, fell under very high soil erosion risk level (30-50 t ha^{-1} yr^{-1}), the level that assigned as a secondary priority for soil erosion risk management options implementation (Table 5).

Whereas three micro-watersheds (11, 15, 21) that cover an area of 9.91 km^2 or 18% of *Midhagdu* watershed, the study area, fell under high soil erosion risk level (18-30 t ha^{-1} yr^{-1}) which also categorized as high soil erosion risk management options third priority level. Micro watershed (22) fell under moderate soil erosion risk level (11-18 t ha^{-1} yr^{-1}) that cover an area of 0.25 km^2 or 0.5% of *Midhagdu* watershed; the study area and prioritized for the fourth priority of soil erosion risk management options implementation and micro watershed (9) fell under low soil erosion risk level (<11 t ha^{-1} yr^{-1}) that cover an area of 0.7 km^2 or 0.7% of *Midhagdu* watershed; the study area, which categorized as the fifth soil erosion risk management options priority area (Table 4; Figure 9).



Source: Own output (2021)

Figure 7. *Micro-watershed based mean annual soil loss category map.*



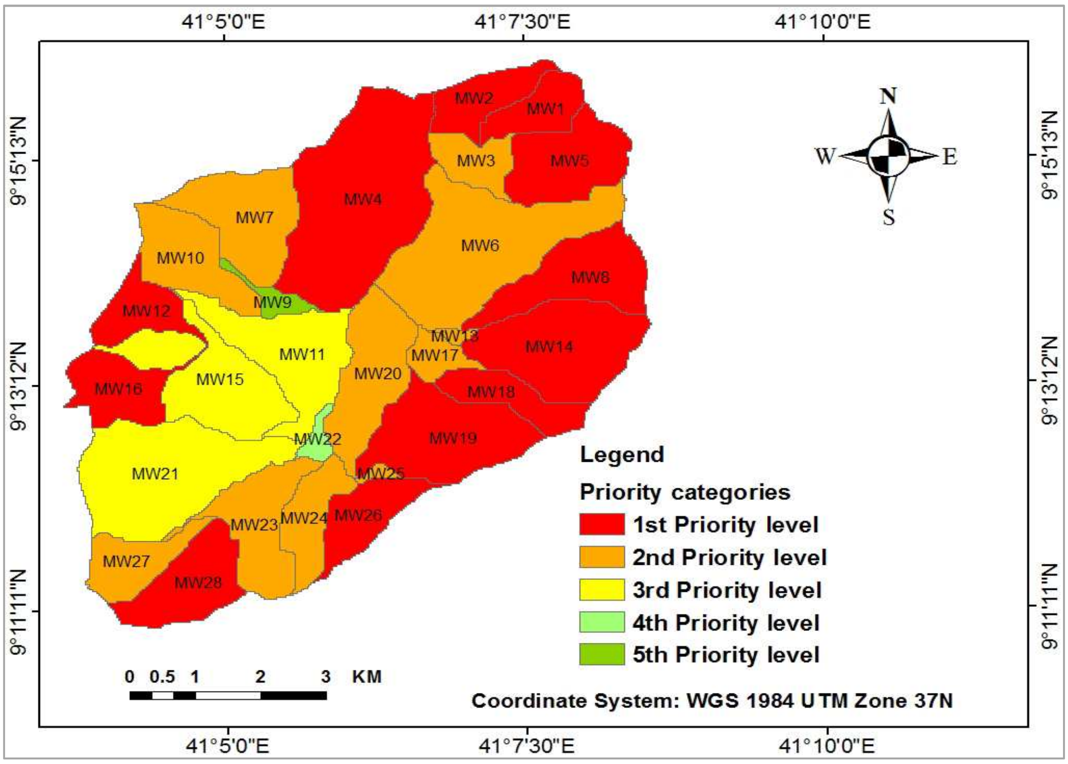
Source: Own output (2021)

Figure 8. *Micro-watershed based soil erosion risk category map.*

Table 3. *Priority rankings of micro-watersheds based on mean annual soil loss.*

Micro watershed Code	Mean annual soil loss (t ha^{-1} yr^{-1})	Soil erosion risk levels	Area (km^2)	Area (%)	Soil erosion risk management options priority level
WS1	61	Extremely high	1.05	1.94	1^{st} priority level
WS2	79.9	Extremely high	1.21	2.24	1^{st} priority level
WS3	41.4	very high	0.94	1.73	2^{nd} priority level
WS4	55.3	Extremely high	5.96	10.98	1^{st} priority level
WS5	65.1	Extremely high	2.12	3.91	1^{st} priority level
WS6	50	very high	4.88	8.99	2^{nd} priority level
WS7	38.2	very high	2.39	4.41	2^{nd} priority level
WS8	61.5	Extremely high	2.31	4.25	1^{st} priority level
WS9	8.7	Low	0.36	0.66	5^{th} priority level
WS10	50	very high	1.89	3.48	2^{nd} priority level
WS11	24.3	High	2.65	4.89	3^{rd} priority level
WS12	50.8	Extremely high	1.15	2.11	1^{st} priority level
WS13	49.7	very high	0.11	0.20	2^{nd} priority level
WS14	87.1	Extremely high	3.20	5.90	1^{st} priority level
WS15	25.3	High	3.01	5.54	3^{rd} priority level
WS16	70	Extremely high	1.50	2.75	1^{st} priority level
WS17	30.8	very high	0.56	1.04	2^{nd} priority level
WS18	82.5	Extremely high	1.19	2.19	1^{st} priority level
WS19	53.4	Extremely high	3.00	5.52	1^{st} priority level
WS20	47.9	very high	2.39	4.39	2^{nd} priority level
WS21	25.2	High	4.25	7.83	3^{rd} priority level
WS22	16.7	Moderate	0.25	0.46	4^{th} priority level
WS23	47.3	very high	2.07	3.81	2^{nd} priority level
WS24	30.4	very high	1.26	2.32	2^{nd} priority level
WS25	31.9	very high	0.10	0.19	2^{nd} priority level
WS26	62.8	Extremely high	1.34	2.46	1^{st} priority level
WS27	49.6	very high	1.25	2.30	2^{nd} priority level
WS28	77.7	Extremely high	1.90	3.50	1^{st} priority level
			54.3	100.00	

Source: Own output (2021).



Source: Own output (2021)

Figure 9. *Soil erosion risk management options priority categories at different micro-watersheds levels in Midhagdu watershed.*

Table 4. *Soil erosion risk management options priority categoriazation.*

MASLC (Ton ha^{-1} yr^{-1})	SERC	MWC	Area (km^2)	AC (%)	NMW	Soil erosion risk management options priority levels
<11	Low	MW1	0.36	0.7	1	5th priority level
11-18	Medium	MW22	0.25	0.5	1	4th priority level
18-30	High	MW11, MW15, MW21	9.91	18	3	3rd priority level
30-50	Very high	MW3, MW6, MW7, MW10, MW13, MW17, MW20, MW23, MW24, MW25, MW27	17.83	33	11	2nd priority level
>50	Extremely high	MW1, MW2, MW4, MW5, MW8, MW12, MW14, MW16, MW18, MW19, M26, MW28	25.92	48	12	1st priority level
		Total	54.3	100	28	

MASLC means Mean Annual Soil Loss categories, yr= Year; SERC means Soil erosion risk categories; MWC means Micro watershed code; AC means Area coverage, NMW stands for Number of the micro watershed, and MW stands for the micro watershed.
Source: Own output (2021).

Out of twenty-eight micro-watersheds identified through automatic watershed delineation using archydro tools; twenty-six micro watersheds were found above the national maximum soil loss tolerance level of 18 t $ha^{-1}yr^{-1}$ and 27 micro watersheds fell above the normal soil loss tolerance level of 11 t $ha^{-1}yr^{-1}$. The result showed that there was greater variability of the soil erosion not only on a pixel basis at the watershed level but also among micro-watersheds. All micro watersheds except micro watershed 9 need attention to plan and implement soil erosion risk management options to reduce soil erosion rate below national threshold levels; the maximum allowable soil-loss value that will sustain an economic and a high level of productivity (Tables 4 and 5 and Figures 7, 8 and 9).

In general, the micro-watershed risk class-map revealed that 53.69 km^2 (98.87%) of the micro-watershed areas was evaluated as high to the extremely high level of soil erosion risk classes (Table 4). In addition, the mean annual soil erosion rate for 98.87% (about 53.69 km^2 out of 54.3 km^2) of the micro-watershed areas was beyond the maximum tolerable soil erosion limit estimated for Ethiopian highlands (>18 t $ha^{-1}yr^{-1}$).

3.3. Consistency and Validation of the Model Estimate

Multiple Linear Regression Analysis

To check the model performance and the aggressiveness of each soil erosion risk factor on soil erosion risk distribution in the *Midhagdu* watershed, each soil erosion factor thematic map, and soil loss map was transformed into natural logarithms in the ArcGIS platform map algebra function Raster calculator. The mean values of the natural logarithm of each soil erosion factor and soil loss values of 28 observation sites (micro watersheds) were extracted using Zonal statistics as table in ArcGIS.

The natural logarithmic mean values of each soil erosion factor and resultant mean annual soil loss of 28 micro watersheds (28 numbers of observations sites) within *midhagdu* watersheds were used as an input for SPSS. The natural logarithmic (ln) RUSLE soil erosion risk influencing factors (independent variables) and the resultant soil loss (dependent variable) data transformation analysis results showed that the average annual estimated soil erosion rate (A) had a significant correlation and there was no multicollinearity with each input factor of the RUSLE model ($P < 0.05$, $VIF < 10$). This indicated that the impact of each input factor of the soil erosion on the annual soil erosion rate was significant. The results presented in (Table 4) show that the estimated standardized coefficients, (β) values ranging from 0.079 to 0.893 for multiple linear regressions of the average annual estimated soil erosion rate (A) and each input factor of soil erosion at 28 micro watersheds within the *Midhagdu* watershed as follows:

$$\ln(A) = 0.079 * \ln(R) + 0.120 * \ln(K) + 0.893 * \ln(LS) + 0.199 * \ln(C) + 0.539 * \ln(P)$$

The β values indicated that the relative influential strength of each input factor on the annual soil erosion rate. The LS-factor had the strongest influence on soil erosion rate (β = 0.893) followed by the other factors, P (β = 0.539), C (β = 0.199), K (β = 0.120), and R (β = 0.079) respectively (Table 5).

Table 5. *Standardized Coefficient (β) for RUSLE Model-independent factors.*

Independent Factors	Standardized Coefficients Beta, β	Sig	Collinearity Statistics	
			Tolerance	VIEW
lnR	0.079	0.036^{**}	0.918	1.089
lnK	0.120	0.004^{***}	0.826	1.210
lnLS	0.893	0.000^{***}	0.715	1.399
lnC	0.199	0.000^{***}	0.811	1.233
lnP	0.539	0.000^{***}	0.965	1.036

*Significance at $p< 0.05$; Source: Own output (2021).

The model performance assessment revealed that the correlation between the observed value of performance (soil loss) and the optimal linear combination of the independent variables (rainfall erosivity, soil erodibility, topographic, crop and cover management, anthropogenic soil erosion control) was 0.987 as indicated by multiple R; and the R-Square value of 0.974 and Adjusted-R square value of 0.969. Thus, it can be interpreted as 97.4% of the variation in performance (soil loss) can be explained by the combined effect of the independent variables in the study area (Table 5).

4. Summary and Conclusions

Summary

Soil erosion is being detected as a risk to human survival by diminishing the food and water availability of the planet Earth in the 21st century. Assessment and management of this resource are becoming extremely important. This study aimed to investigate Soil Erosion Risk and Prioritize soil and water conservation measures at microwatershed level. Satellite data, ASTER DEM, Land sat 8 OLI with 30m resolution; rainfall and soil data were used to generate the five soil erosion risk factor maps and integrated to generate a composite map of soil loss for the watershed. The RUSLE model in combination with remote sensing and GIS techniques was used to identify the five thematic maps as an input to estimate mean annual soil loss. The results of the spatial distribution of soil erosion risk factors indicated that rainfall erosivity, soil erodibility, slope length and steepness, cover management, and anthropogenic soil erosion control practices values ranged from 41.365 to 43.793MJ mm $ha^{-1}yr^{-1}$, 0.26 to 0.31t $ha^{-1}MJ^{-1}mm^{-1}$, 0 to 220.512, 0.21 to 0.87 and 0.11 to 1 respectively. 28 micro-watersheds was automatically delineated using arc hydro tools in Arc GIS environment and prioritized for soil erosion risk management options implementation based on computed mean annual soil erosion rate using zonal statistics as table and the mean annual soil loss obtained at micro-watershed level ranged from 8.7 to 87.1 t $ha^{-1}yr^{-1}$. The microwatershedlevel produced soil loss map was categorized into five soil loss numerical ranges and soil loss risk nominal scales: low, moderate, high, very high, and extremely high using Ethiopian highland maximum soil loss threshold level of 18 t $ha^{-1}yr^{-1}$. Whereas, the micro-watershed risk class map revealed that 53.69 km^2 (98.87%) of the micro-watershed area was evaluated as high to extremely high level of soil erosion risk classes. In addition the mean annual soil erosion rate for 98.87% (about 53.69 Km^2 out of 54.3 Km^2) of the micro -watershed area was beyond the maximum tolerable soil erosion limit estimated for Ethiopian highlands (>18t$ha^{-1}yr^{-1}$). Groups of micro watershed (MW1, MW2, MW4, MW5, MW8, MW12, MW14, MW16, MW18, MW19, M26, MW28) was rated as first priority for soil and water conservation measures implementation and microwatersheds (MW3, MW6, MW10 MW13, MW17, MW20, MW23, MW24, MW25, MW27) was categorized as second priority for soil and water conservation measures implementation. Whereas MW11, MW15 and MW21 was categorized under third priority level. Soil erosion in the watershed has been a threatening problem for agricultural production to day, its sustainability and to be worsening in the future unless abatement measures were taken, mainly due to high topography and anthropogenic factor. Therefore, Midhagdu watershed needs immediate intervention for better soil and water conservation measures by considering identified soil erosion risk areas and priority classes at micro-watershed level.

Conclusions

This study aimed to investigate Soil Erosion Risk and Prioritize soil and water conservation measures at microwatershed levelUsing RUSLE, GIS, RS and SPSS Techniques. Using RUSLE model integrated with GIS, RS and SPSS techniques can identify and generate biophysical factors of soil erosion, assess erosion risk area in timely, resource wise manner and aid decision makers in knowing and acting in implementation of soil and water conservation measures for soil and water erosion control.

Further, from the analysis it is concluded that the order of soil loss risk influencing factors in the watershed is LS>P>C>K>R which showed the stronger factor that initiated soil loss risk in the study area. RUSLE model performance in predicting soil loss was 97.4% in the *Midhagdu* watershed. Managing the underlying risk factors of soil erosion (topography, anthropogenic soil erosion risk management, cropping and land cover management, soil characteristics, rainfall-runoff) in the study area need to be given attention following the identified order through effective implementation of appropriate; integrated soil and water conservation measures for reducing the effect that each factor has on soil loss risk. The study watershed experienced a very high mean annual soil loss rate which is far beyond the Ethiopian highland maximum soil erosion rate tolerable limit (18 t ha^{-1} yr^{-1}).

From the total 28 MWs studied 98.8% or 26 MWs are fell in High to extremely high soil erosion risk class and beyond the National maximum soil erosion rate tolerable limit (18 t ha^{-1} yr^{-1}) and prioritized top for soil erosion risk management options for soil conservation measures. Specifically, based on the soil loss risk at micro watershed levelstwelve microwatersheds (MW1, MW2, MW4, MW5, MW8, MW12, MW14, MW16, MW18, MW19, M26, MW28) were rated as 1st priority for soil erosion risk management options for soil conservation measures; eleven microwatersheds (MW3, MW6, MW10, MW13, MW17, MW20, MW23, MW24, MW25, MW27) were rated as 2nd priority; three MW11, MW15 and MW21 were rated as 3rd priority. RUSLE model validation indicated soil erosion is a real threat and risk to the community in the *Midhagdu* watershed. This calls for design and implementation of watershed management programs and projects as well as appropriate, integrated watershed management and soil and water conservation measures following the soil erosion rate and risk levels identified in *Midhagdu* watershed and prioritizations set at micro watershed levels within *Midhagdu* watershed to control the threats posed by soil erosion risk in a sustainable manner. RUSLE model integrated with GIS and RS which can identify erosion rate, risk, and priority watersheds for decision making and management need to be applied in other studies.

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