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Erosion Sensitivity Mapping Using GIS and Multi-Criteria Decision Approach in Ribb Watershed Upper Blue Nile, Ethiopia

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Abstract: Soil erosion considered as one of the most important obstacles in the way of sustainable development of agriculture and natural resources. In Ethiopia, soil erosion is a serious problem. The studies on erosion risk in the watershed show a trend towards increasing land use, accelerating erosion in the study area. The influencing factor for the give watershed are the land use, the elevation, the slope, TWI, SPI, and soil. This study focus to determine and mapping the hotspot areas to erosion of rib watershed with an area of 1174.7 km^2. The sensitivity area for erosion was done by a multi-criteria decision evaluation method with parameters of influencing factors. The analysis of the maps using GIS analysis tools for different criteria which shows that the findings vary from one criterion to another. Considering all criteria, the finally obtained map shows that the areas with a high, moderate, low and very low vulnerability to erosion are 1.13%, 8.11%, 88.34% and 2.42% respectively in the given watershed. Overall, the soil erosion changes analysis and mapping as well as its distribution is effective and important for identifying natural resource prone areas. Therefore, the local experts and administrative bodies uses this information to prepare plan for those priority areas to conserve and monitor the degraded resources.

Keywords: Soil Erosion, Ribb Watershed, MCE, GIS, Raster Calculator, Pairwise Comparison

1. Introduction

Soil erosion is one of the most significant environmental degradation processes that affect all landforms. Soil erosion refers to soil detachment, movement, and deposition by water, wind or farming activities such as deforestation, intensive ploughing, etc. Soil erosion rate depends on factors such as intensify of rainfall, topography, vegetative cover, type of soil, and land-use practices. In Ethiopia today, soil erosion is the serious problem that arises because of land use changes. Overgrazing, improper management and expansion of settlements accelerate land loss, reduce agricultural production and increase sedimentation in the next catchment areas [1-5]. Since farmers are more dependent on rainfed farming practices, grazing and exercise in steep slopes, scarce of natural resources affect the population [6-11]. In the Ethiopian highlands, reduce the productivity of agricultural land through soil erosion. This problem occurs through both anthropogenic and natural activities, such as poor land-use practices, storm storms, particularly inadequate management systems, soil protection measures and steep slopes. As a result, the phenomenon causes land degradation problems in the highlands of Ethiopia [5]. About 1.3 billion tonnes of fertile soil are lost each year, and soil erosion and land degradation increase significantly due to the undulate and irregular topography of the area [12]. According to various specialists in the

Ethiopian highlands, much of the lost land and heavily eroded land will make it economically inefficient in the near future [13-14]. As a result, it would cost $ 1.9 billion in land erosion between 1985 and 2010 [15]. This requires immediate action to protect the country's water resources and physical quality. Spatial information exploration is a new approach that can identify, analyse and manage complex watersheds and catchment areas. Today, GIS is a good alternative tool for better decision support in the implementation, planning and management of land and water resources. GIS is important for viewing, processing, manipulating, and storing geodatabases. The Multi-Criteria Assessment (MCE), an instrument for improving GIS, could help users to improve their decision-making processes. To explore a range of alternatives in terms of goal conflicts and multiple criteria, the MCE technique is used [16].

In order to achieve this, a ranking of alternatives and compromise alternatives according to their attractiveness must be produced [17]. In the last decade, MCE has received renewed attention in the context of a GIS-based decision making [18-20]. Numerous researchers have been study using MCE techniques in particular areas to conserve natural resources management [21-27]. In this outcome, MCE seems to be applicable to GIS-based spatial delineation of erosion exposure areas, which helps to carry out the delineation of the most erosion prone area in study watershed.

In general, this discovery explains the decision support system with STMs in the categorization of areas at risk of erosion in the Ribb watershed. GIS combines land cover, TWI, SPI, slope, elevation, curvature and soil as impacts that contribute to the development of soil erosion. The main objective of this result was the delineation of vulnerable erosion areas by MCE in a Ribb GIS extension tool.

Multi-criteria assessment (MCE) often compares different alternatives based on specific criteria to identify sensitive areas of erosion. Various criteria were used to help identify the MCE hotspot area in the Ribb watershed. These are land use, TWI, SPI, slope, Elevation, curvature and soil. The geographic information system (GIS) uses a specific map for each criterion. An effluent rate depends on topography and slope, which is one of the criteria for calculating the erosive potential. Satellite images were used for GIS land use classification to classify areas with good and low area coverage. Soil erodibility is also a factor in MCE, which influences soil erosion. Maps of land use, soil, soil, elevation, TWI, SPI and slope were ranked with different researchers [28-30]. For each evaluation criteria, weight is assigned which indicates importance relative to the other criteria that were under consideration. The study were projected to identify the vulnerable area for soil erosion in a ribb watershed through using the GIS based-MCE model.

2. Methodology

2.1. Location of Study Area

Lake Tana Basin comprises a total area of 15,096 km^2. The mean annual rainfall of the catchment is a bout 1280mm [31]. Gilgel Abbay, Ribb, Gumara and Megech are the main source of water for the Lake which contributes more than 93% of the flow [31]. Ribb Watershed is situated mainly in FartaWereda of South Gonder Zone in Amhara Region (Figure 1). Geographical coordinate of the area is 12°35′ North and 41°25′ East and 13°54′N and 35°E. The main river Ribb drained the upper parts of the watershed to Tana Lake. The total area of the watershed is approximately 1174.7 km^2. The mean annual precipitation is about 1295mm and means annual temperature is about 20.4°C

2.2. Description of MCDA Model

GIS approach with the integration of MCE techniques used to identified erosion hotspot areas to advance decision-making in operation and planning of water and soil conservation measures. The technique is able to analyse complex problems in the allocation and assessment of natural resources in ordered to address erosion hotspot areas. Consequently, the model is a decision support method that combines a number of different criteria to complete one or more goals [16]. Therefore, an objective is standpoint that serves to guide the structuring of decision rules, which is the procedure whereby criteria are combined and selected to arrive at a particular evaluation, and evaluations are compared and acted upon. Many GIS software systems deliver the basic tools for estimating such a model. For this study, the GIS software MCE with IDRISI module was used. The major factors selected for this study based on its contribution for soil erosion were land use, soil, TWI, SPI elevation and slope. The model includes a set of evaluation criteria and a set of geographically defined alternatives represented as map layers. The problem, which is to combine the criteria maps according to the preferences of the decision maker using a decision rule (combination rule) and the criteria values (attribute values). The main problem in MCE technique is the question of how to combine information from multiple criteria into a single rating index. As shown in (Figure 2), the procedure for creating the final erosion hotspot map for the study area was presented.

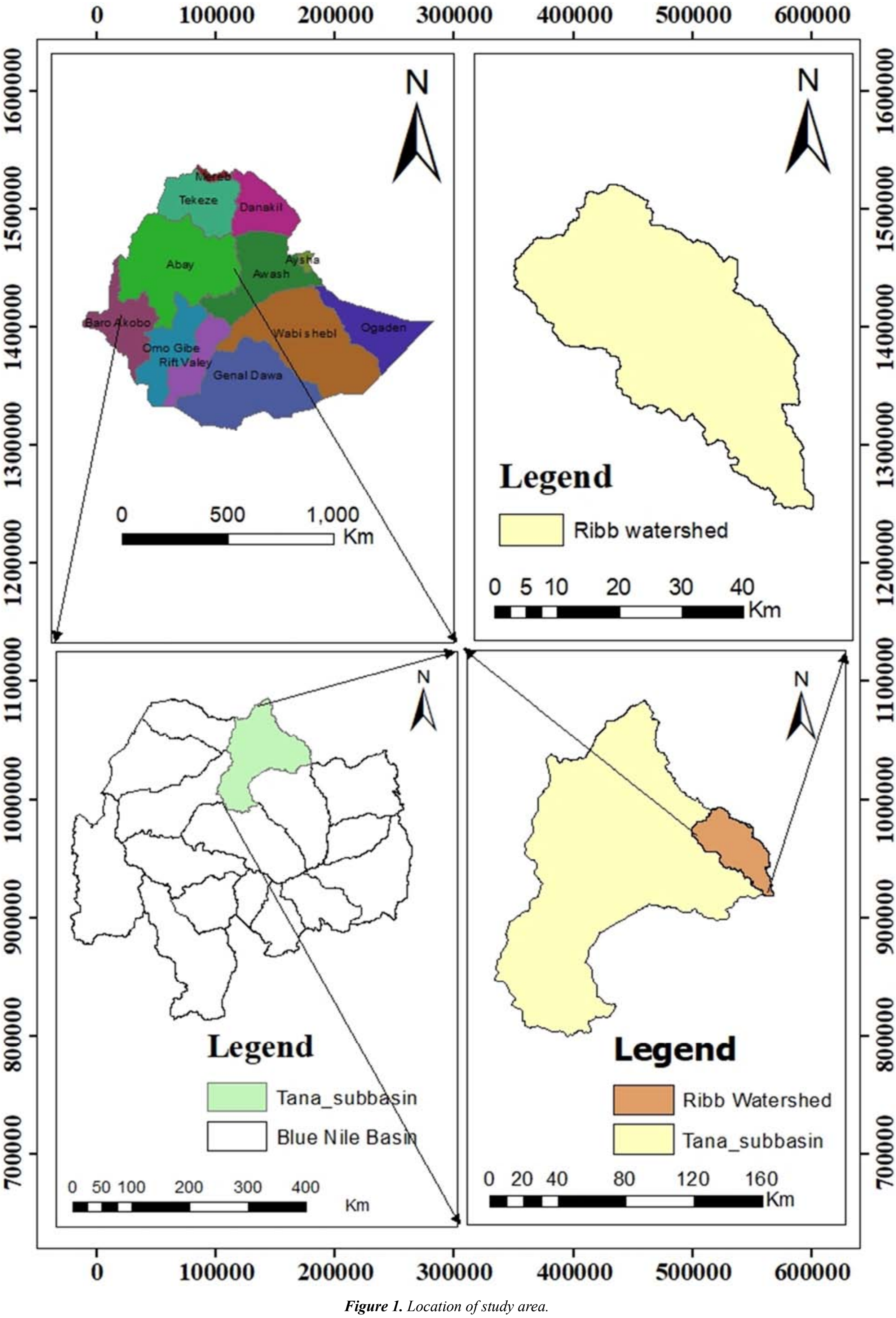


Figure 1. *Location of study area.*

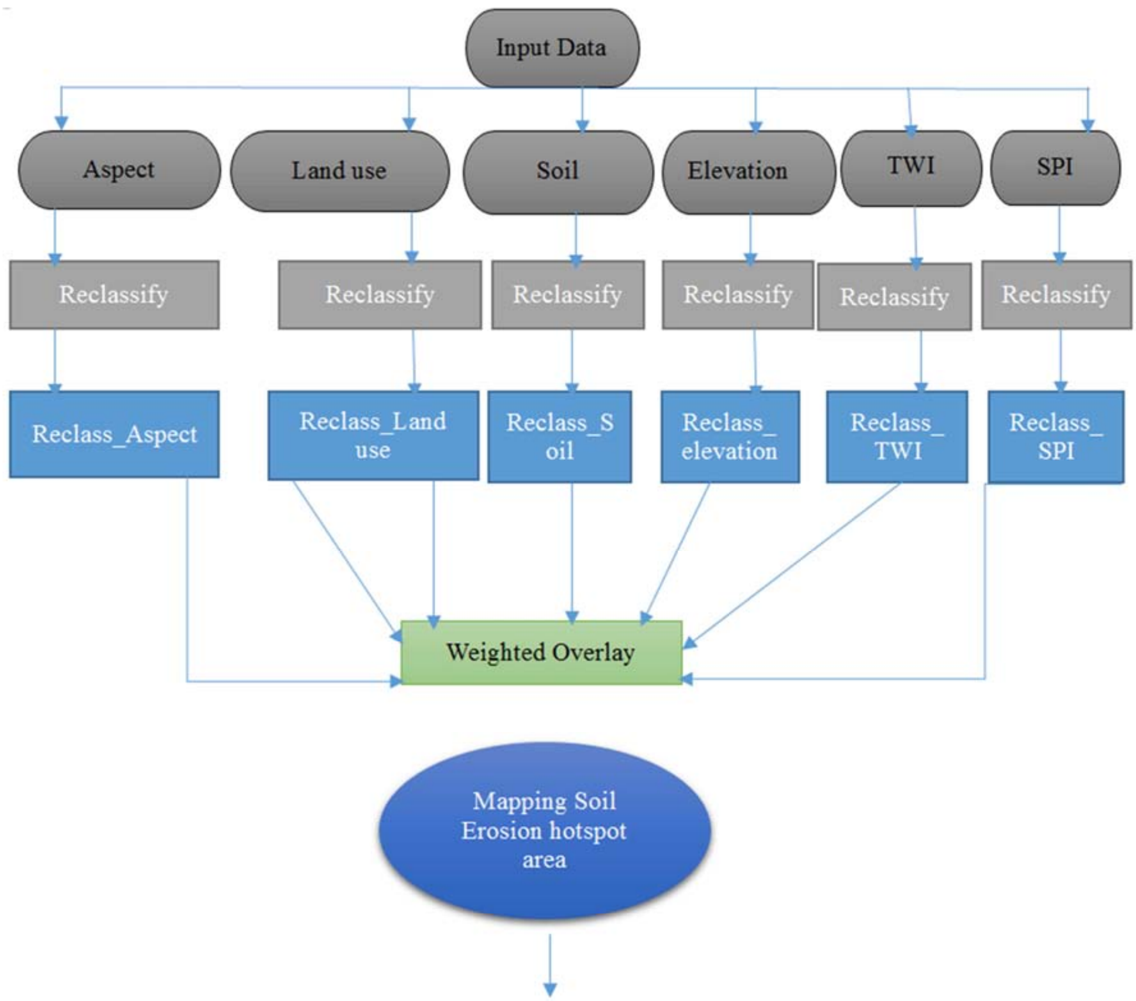


Figure 2. *Workflow of the criteria weighting using MCE in Arc GIS 10.3.*

2.3. Input for the Model

To carry out this study a 30m by 30m resolution Digital Elevation Model (DEM) for Ribb watershed (Figure 3) was downloaded from Shuttle Radar Topography Mission http://earthexplorer.usgs.gov website for creating aspect, Slope, Area description and altitude map analysis using Arc GIS 10.3 version.

2.4. Application of MCE

There are many tools used to combine different factors to obtain the expected outcome of the research. Hence, MCE technique was one of these tools selected for this study. It combines the selected five criteria or factor maps in GIS tool environment. Based on its contribution to soil erosion the first factor considered in the study area is the land cover factor. For this study, a Landsat satellite image with a spatial resolution of 30 meters was processed to record the land use status of the study area. Spatial data on the types of surface coverages allow us to estimate the resistance of topography units to surface protection erosion. The second criterion selected for this study was Soil types, which play an important role in erosion and sediment transport process. This is based on soil physical and chemical properties and sensitivity to erosion. Other layers considered as a contributing factor for this study are Topographic Witness Index, Slope and Altitudes. The ranks of those influencing factors for soil erosion were indicated as in (figure 4 below).

2.5. Multi Criteria Decision Analysis Evaluation

Assigning weight to each selected parameter involves a multi-criteria function. To assign a weight to the parameters, the logical and well-structured decision processes were followed to ignore the possible confusion. There are many MCDA methodologies available to solve complex decision problem with multiple criteria [32-33]. This study used the Analytical Hierarchy Process (AHP) according to [32]. This process uses simple and straightforward postulates in analysing multi criteria decision problems. However, the AHP always allows for some level of variations, which should not exceed a certain threshold [32]. The weights of each parameter were determined using the pairwise analysis of the parameter, based on the scale of relative importance [32]. The scale of 1 signifying equal value to 9 signifying extreme different was allocated to the pairwise parameter (Table 1). The pairwise matrix was then normalized and the eigenvalues of the normalized matrix representing the parameter weights were calculated (equation 3 below). The consistency of the assessment for this study was evaluated and confirmed using the Consistency Ratio (CR) and Consistency Index (CI) (equation 1 & 2 below) [32]. This measure examines the extent to which the submitted finding is consistent. The CI is zero if all the judgments are completely consistent.

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (1)$$

$$CR = \frac{CI}{RI} * 100\%, \quad (2)$$

$$\lambda_{max} = \sum_{i=1}^{n} X_{i,j} * W_{i,j} \quad (3)$$

Where CI is the Consistency Index
n is the number of parameters
RI is the random index using the [32] scale (Table 2).
λ_{max} is the average of the eigenvalues of the normalized comparison matrix computed using Equation (3)

Table 1. *The continuous rating scale [32].*

Rating scale								
1/9	**1/7**	**1/5**	**1/3**	**1**	**3**	**5**	**7**	**9**
Extremely	Very strongly	Strongly	moderately	Equally	Moderately	strongly	Very strongly	Extremely
Less important				More important				

2.6. Pairwise Analysis of the Parameters

The hierarchy in Table 3 below shows the relative impact of each factor to soil erosion. In allocating Soil erosion hotspot areas, land use was considered as the most influential factor, and it come on top of the hierarchy while Altitude was considered to have the least influential factor. The values in each cell represent the scale of relative importance for the given paired factors. The diagonal has the value of 1 throughout because the diagonal represent factors being compared to itself, and the scale equal importance "1" is assigned. In the lower diagonal the values of the scale are in fractions because the factors are being paired in the reverse order and the scale of relative importance is given as the reciprocal of the upper diagonal pairwise comparisons. From figure 3 below land use was ranked the 1st, Soil is ranked the 2nd, TWI the 3rd, SPI the 4th, Aspect 5th and Elevation 6th most important parameters in identifying erosion hotspot area in rib watershed.

Table 2. *Value of RI for the corresponding number of criteria/alternatives.*

Size	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 3. *Weights of paired factors concerning Hotspot area.*

	Land Use	Soil	TWI	SPI	Aspect	Elevation	Row total
Land Use	1.00	9	3	5	7	9	34.00
Soil	0.11	1.00	0.125	0.25	0.33	0.23	2.05
TWI	0.33	8.00	1.00	7	1	1	18.33
SPI	0.20	4.00	0.14	1.00	0.5	0.52	6.36
Aspect	0.14	3.03	1.00	2.00	1.00	0.56	7.73
Elevation	0.11	0.11	1.00	1.92	1.79	1.00	5.93
Column total	1.90	25.14	6.27	17.17	11.62	12.31	74.41

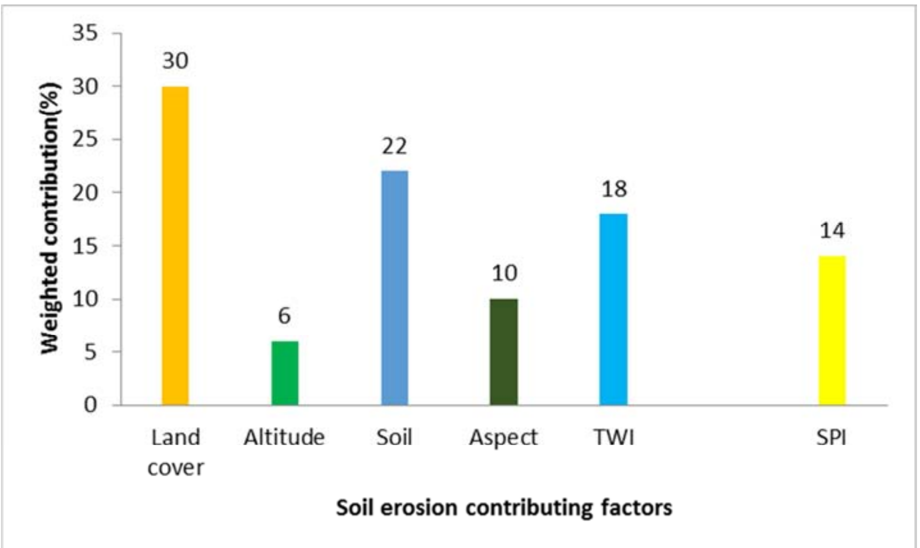


Figure 3. *Overall contribution of parameters for soil erosion.*

2.7. Description of Input Parameters

2.7.1. Land Cover Factor Map

Based on the Landsat image downloaded from http://earthexplorer.usgs.gov by analyzing in ERDAS 2014 then export to GIS environment, the land cover map was created in raster format. Depending on the specific cover type, the most important land cover types were classified into five land cover types as Urban, Plantation, Water body, Agricultural land and Pasture land. The five classes of cover types were reclassified according to their sensitivity to erosion (see Figure 6). Based on the knowledge of researchers and experts the priority prone to soil erosion has given to urban areas then Agricultural land, Pasture land, Plantation and water body.

2.7.2. Soil Factor Map

The soil types in the study area also considered as a major factors contributing for soil erosion. The Soil influences the choice of land management and land use practiced in a given area. From the soil map of Blue Nile basin in which our study area was found, the soil layer was extracted and created in raster format. Consequently the sensitivity of the soil to erosion was based on soil physical properties (texture and structure). These properties are also being studied by various organizations and their erosion sensitivity characteristics have been studied by various authors. There were six major soil types incorporated in the study area. These important soil types were reclassified depending on their sensitivity to soil erosion (see Figure 7).

2.7.3. Slope Factor Map

The slope is one of the most significant topographical features that impact degradation and production. The slope map was generated using GIS 10.3 tool from the DEM in raster format. The raster map of the slope consists of the slope class from 0 to greater than 30%. This slope range was reclassified to five major slope classes depending on the Food and Agriculture Organization (FAO) slope classification (Table 4). Each slope category was given an index for their prone to erosion (see figure 9 below).

2.7.4. Topographic Wetness Index (TWI) Factor

Another important element considered for identification of erosion hotspot area was TWI and called Compound Topographic Index (CTI) (Figure 4). It can be used to quantitatively simulate soil moisture conditions in a watershed and it is used as an indicator of static soil moisture content. It is also useful for distributed hydrological modelling, describes the effect of topography, mapping drainage, soil type, soil infiltration and crop or vegetation distribution, chemical, and physical properties of soil. In addition, it is important for soil/land evaluation for sustainable use, watershed management and hydrologic modelling, land use planning and management,. In this study the TWI was extracted from Digital Elevation Model (DEM) and it was calculated using the formula: TWI = ln (a/tanβ), where a is the contributing area in m^2 and β is the slope in degree calculated from the DEM. The TWI was calculated using raster calculator from Arc GIS 10.3 version. In this study, the TWI was extracted from Digital Elevation Model (DEM) and it was calculated using the formula:

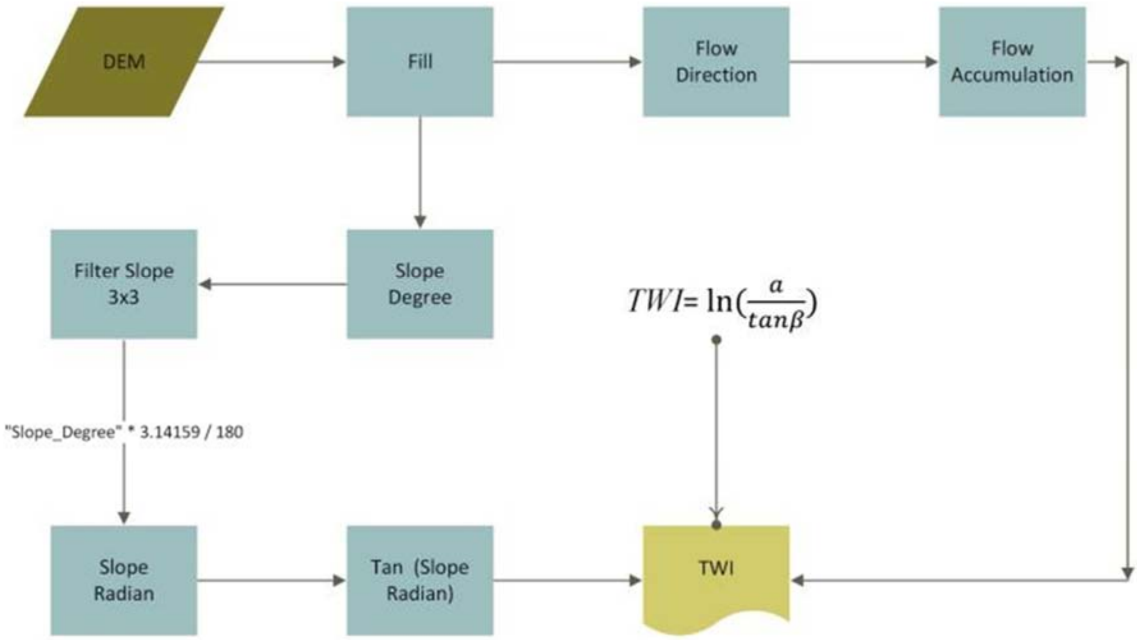


Figure 4. *Process flow diagram of TWI in ArcGIS environment.*

All criteria layers were obtained from MCE factor generation and reclassification and multiplied by applicable weight derived from pairwise comparison of criteria. This study used a pairwise comparison technique to allocate the weights of the decision factors since; it is less bias than other techniques like ranking technique. In pairwise comparison technique, each factor was in line head-to-head (one-to-one) with each other and a comparison matrix was arranged to express the relative importance [34]. A scale of significance was broken down from a value of 1 to 9. The highest value 9 links to absolute importance and reciprocal of all scaled ratios are entered in the transpose position (1/9 shows an absolute triviality) see [35]. For details (Table 1). After the complete comparison matrix, the weights of the factors were calculated by normalizing the respective eigenvector by the cumulative eigenvector. The weight of the decision factor was dispersed by equal interval ranging technique to the different classes of suitability.

3. Results and Discussion

The result of this study presents the selection of potential soil erosion hotspot areas by integrating multiple GIS layers, spatial analysis and multi-criteria assessment.

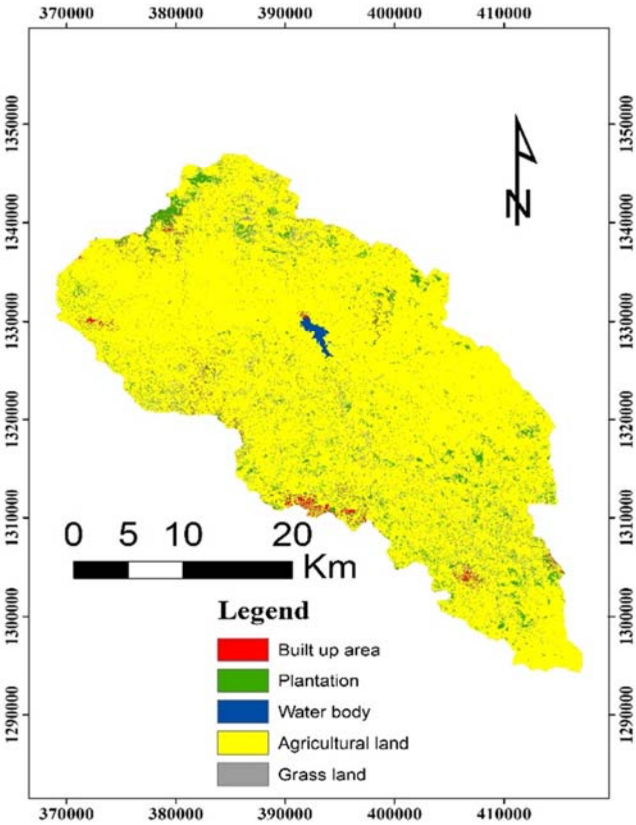
3.1. Impact of Land Use on Soil Erosion

As designated in the earlier methodological sections of this study the Land use land cover change factor was considered as the major factor contributed to soil erosion in the study area. Due to high increase of population density the demand for the land to cultivate was high. This increase in population density converts the Grass land and Forest land into cultivated lands (Agricultural lands), resulting in land degradation in the watershed. In this regard, the five types of land use/land cover were recognised in the study area. Land use/land cover classes were investigated and computed as presented in Figure 5a and Table 4 below. The outcome of classification was done by supervised and unsupervised land use classification method and maximum likelihood algorithm.

Percentage distribution of land use/cover and sensitive to erosion classes in Ribb Watershed presented in Table 5 below. As noted above the agricultural lands comprises about 86.27% of the entire area of the watershed. The re-classified land use map (Figure 5b) indicated that 8.88 km^2 (0.76%) of the land use is Very high sensitive; 1053.81km^2 (89.71%) Highly sensitive; 41.17 km^2 (3.51%) Moderate sensitive; 66.44 km^2 (5.66%) low sensitive and 4.44 km^2 (0.38%) Very low sensitive to soil erosion.

Table 4. *Land cover type in the Gumara catchment area.*

Land use	Area	Area (%)	Sensitivity
Urban	8.88	0.76	Very high
Plantation	66.44	5.66	Low
Water body	4.44	0.38	Very low
Agriculture land	1053.81	89.71	High
Pastureland	41.17	3.51	Moderate



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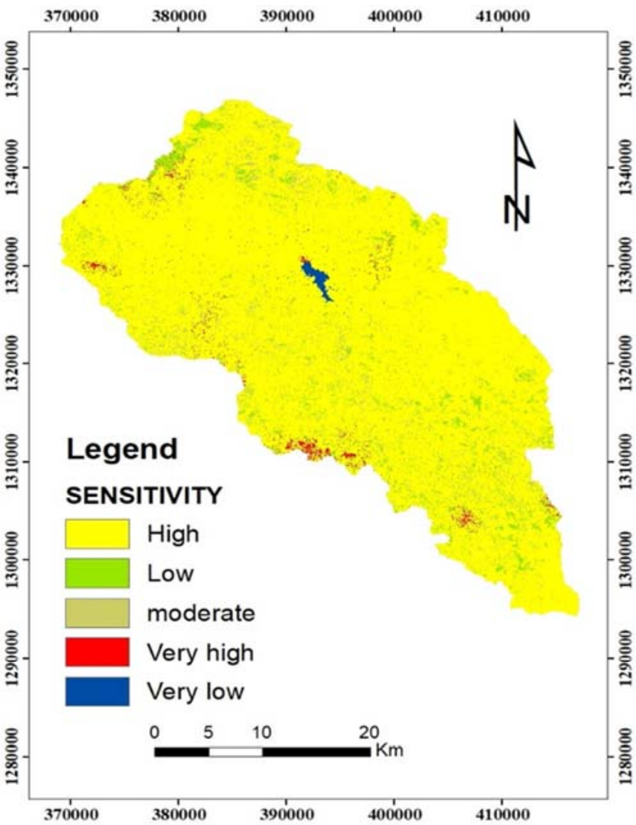


(b)

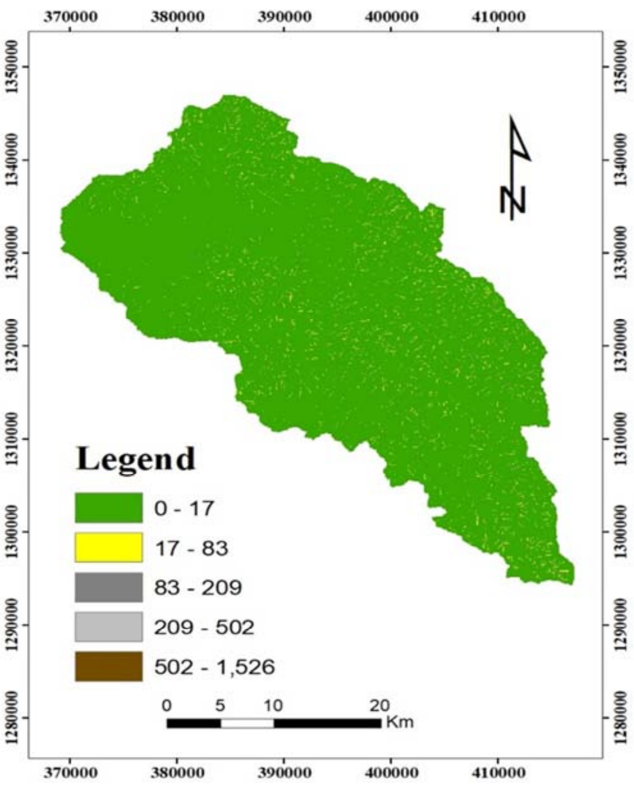
Figure 5. *(a) Land use map (b) Re-classified land use map.*

3.2. Impact of SPI on Soil Erosion

The Stream Power Index (SPI) is a measure of the erosive power of flowing water. SPI is calculated based upon slope and contributing area. SPI approximates locations where gullies might be more likely to form on the land-scape. SPI is calculated using the following equation: $SPI = (A_S * \tan\beta)$ where A_S = specific catchment area (m^2/m), β = slope gradient in deg. As designated in the earlier methodological sections of this study the Stream power index (SPI) factor was considered as the major factor contributed to soil erosion in the study area. It is the rate of the energy of flowing water expended on the bed and banks of a channel. It can be calculated on the cheap from DEM data because of the area discharge relationship. The re-classified SPI map (Figure 6 below and Table 5) indicated that 0.01 km^2 (0.001%) of the land use is Very high sensitive; 0.14 km^2 (0.012%) Highly sensitive; 1.21 km^2 (0.103%) Moderate sensitive; 11.59 km^2 (0.986%) low sensitive and 1161.77 km^2 (98.898%) Very low sensitive to soil erosion

Table 5. *SPI type in the Ribb catchment area.*

No	Sensitivity	Area (km^2)	Area (%)
1	High	0.14	0.012
2	Very high	0.01	0.001
3	Low	11.59	0.986
4	Moderate	1.21	0.103
5	Very low	1161.77	98.898
	Total	1174.71	100.000



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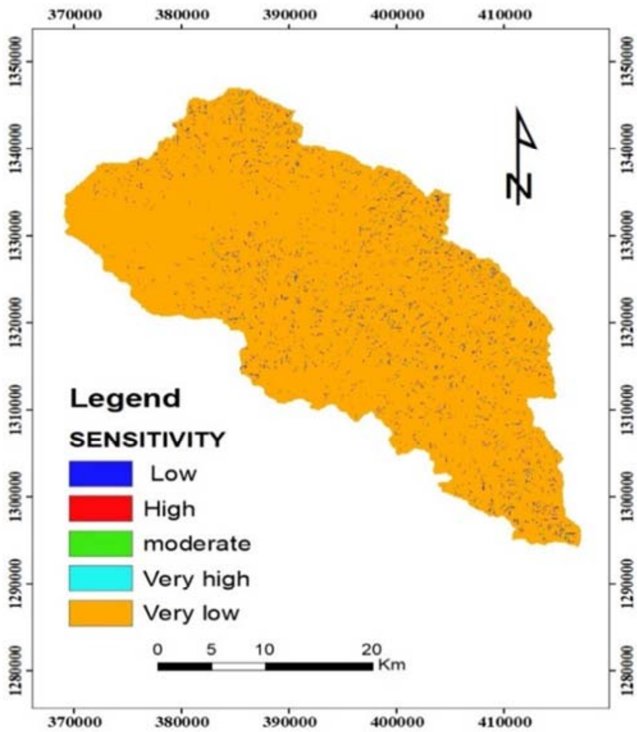


(b)

Figure 6. *(a) SPI (b) Reclassified SPI.*

3.3. Soil Type Impact on Erosion

Soil type is one of the key factors that affect erosion process depending on the physical and chemical characteristics. It controls detachability of soil, soil particle transport and infiltration of water into the soil. Soil texture is an important property which contributes to soil erodibility. The study watershed is dominated by Chromic Luvisols with an area of 505.79 km^2 (43.06%), followed by Eutric Leptosols 438.14 km^2 (37.30%), which are normally influenced by some form of water control and mainly by their topographic/physiographic location (Table 6 below). Figure 7a presented soil types in Ribb Watershed. The reclassified soil map (Figure 7b) indicated that 505.79 km^2 (43.06%) of the land use is Very high sensitive; 4.07 km^2 0.35%) Very high sensitive; 438.14 km^2 (37.30%) highly sensitive and 226.71 km^2 (19.30%) low sensitive to soil erosion

Table 6. *Soil type and percentage distribution.*

Major soil	Area (km^2)	Area (%)	Sensitivity to erosion
Eutric Leptosols	438.14	37.30	high
Chromic Luvisols	505.79	43.06	Very high
Eutric Fluvisols	226.71	19.30	low
Urban	4.07	0.35	Very high

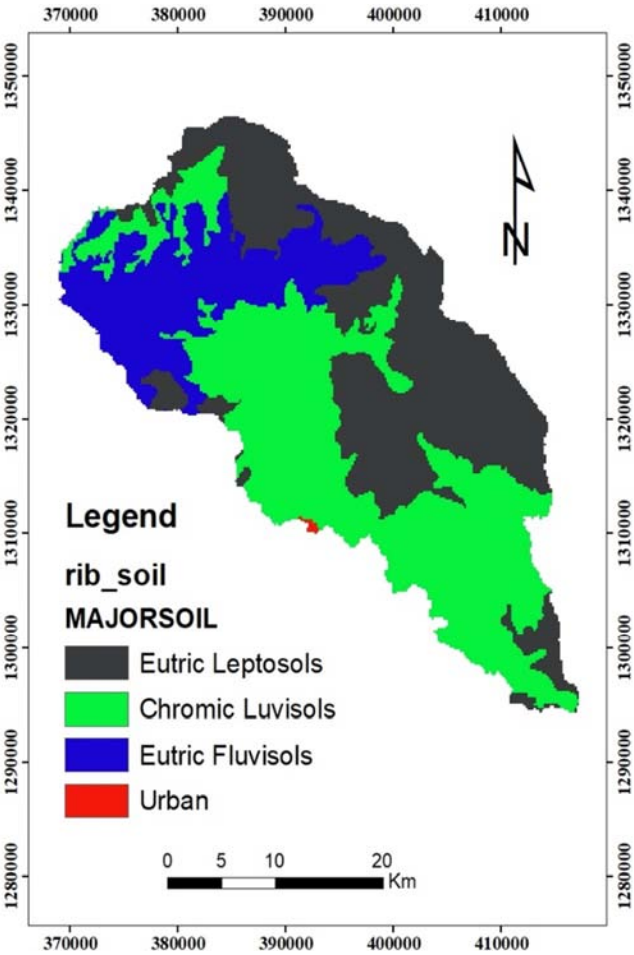
3.4. Impact of Aspect on Soil Erosion

Aspect identifies the downslope direction of the maximum rate of change in value from each cell to its neighbours. It can be thought of as the slope direction. The values of each cell in the output raster indicate the compass direction that the surface faces at that location. It is measured clockwise in degrees from 0 (due north) to 360 (again due north), coming full circle. Flat areas having no downslope direction are given a value of -1.(as shown in figure 8a). Aspect is used to calculate or identify areas of flat land or steep land in the study area.

The reclassified Aspect map (Figure 8b below) indicated that, 235.68km2 (20.06) very high sensitive, 230.54km^2 (19.62%) of the land use is highly sensitive; 188.22km^2 (16.02%) Moderate sensitive; 276.34km^2 (23.52%) Low sensitive and 243.95km^2 (20.77%) Very low sensitive to soil erosion (Table 7).

Table 7. *Aspects and percentage distribution.*

No	Sensitivity	Area (km2)	Area (%)
1	High	230.54	19.62
2	Moderate	188.22	16.02
3	Very high	235.68	20.06
4	Low	276.34	23.52
5	Very low	243.95	20.77
	Total	1174.71	100.00



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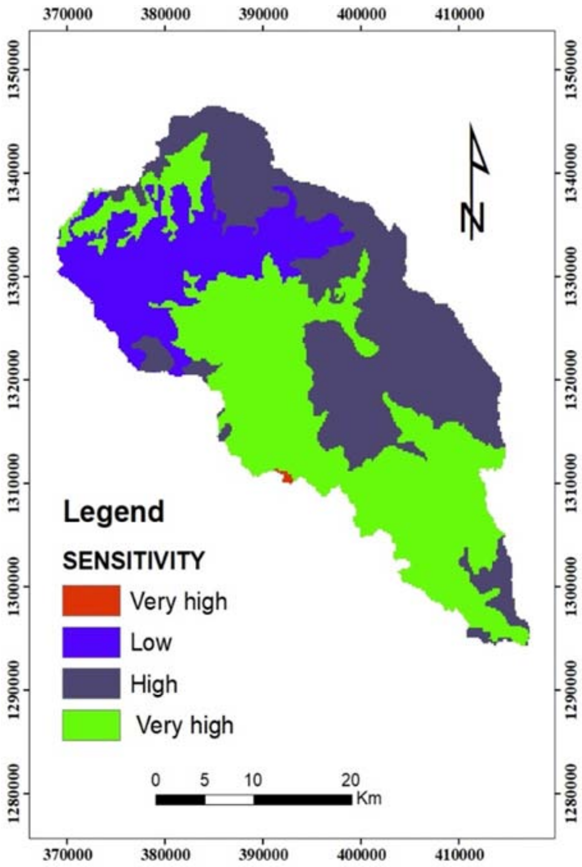

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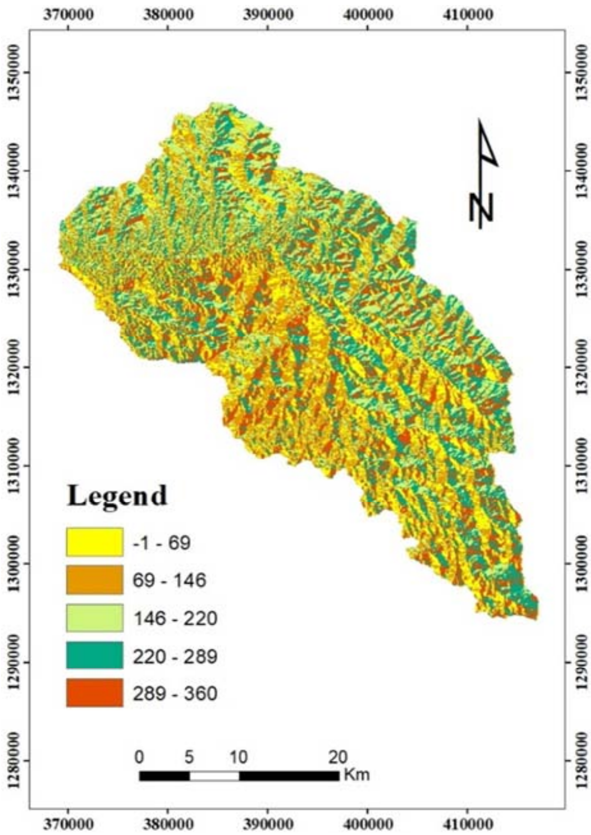
Figure 7. *(a) Soil map (b) Re-classified soil map.*



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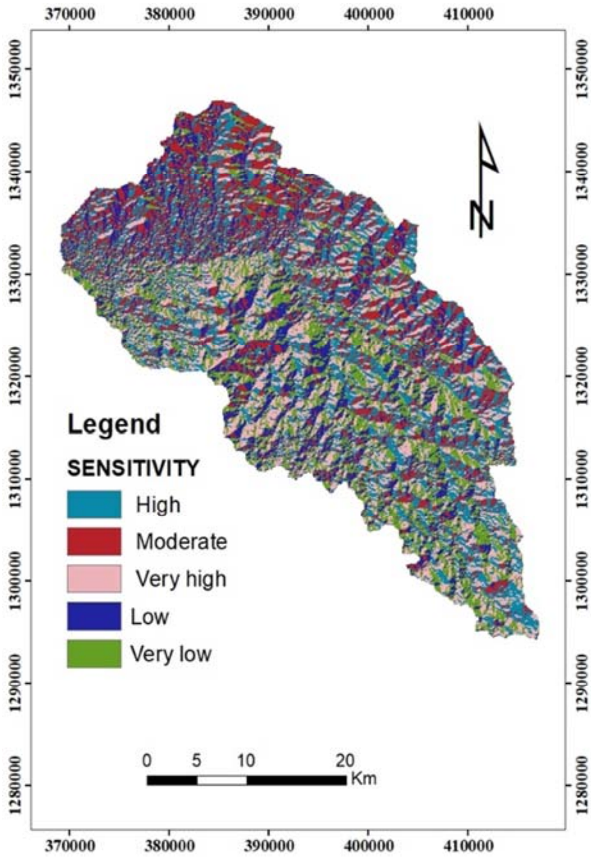


(b)

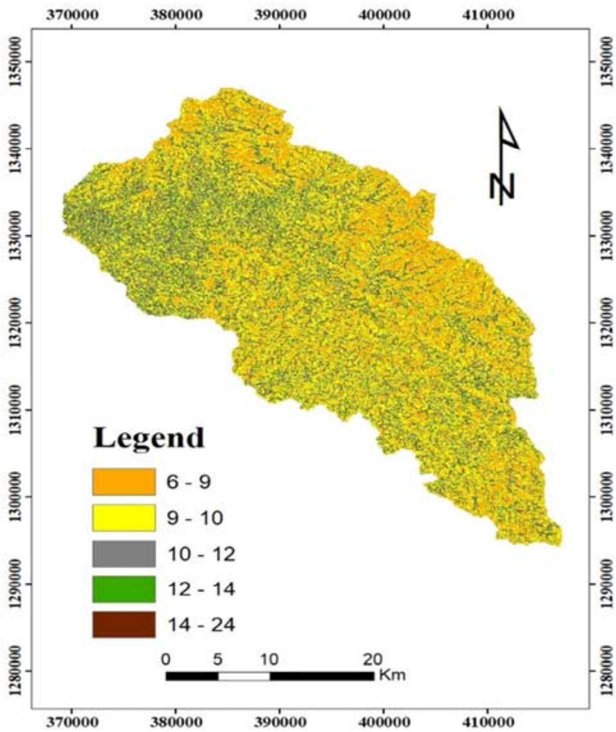
Figure 8. *(a) Aspect map (b) Re-classified aspect map.*

3.5. Impact of Topography on Erosion

Topography is the major surface parameter for soil erosion assessment. The Topographic Wetness Index (TWI), also called Compound Topographic Index (CTI), is a steady-state wetness index. It involves the upslope contributing area (Figure 9a), a slope raster, and a couple of geometric functions. The value of each cell in the output raster (the CTI raster) is the value in a flow accumulation raster for the corresponding DEM. The re-classified TWI map (Figure 9b below and Table 8) indicated that 110.66 km^2 (9.42%) of the land use is Very high sensitive; 292.35 km^2 (24.89%) Highly sensitive; 40.08 km^2 (3.41%) Moderate sensitive; 428.49 km^2 (36.48%) low sensitive and 262.68 km^2 (22.36%) Very low sensitive to soil erosion.

Table 8. *Topographic wetness index sensitivity class.*

TWI	area	Area (%)	Sensitivity group
6 - 9	262.68	22.36	Very low
9 - 10	428.49	36.48	Low
10 – 12	40.08	3.41	Moderate
12 – 14	292.35	24.89	High
14 - 24	110.66	9.42	Very high



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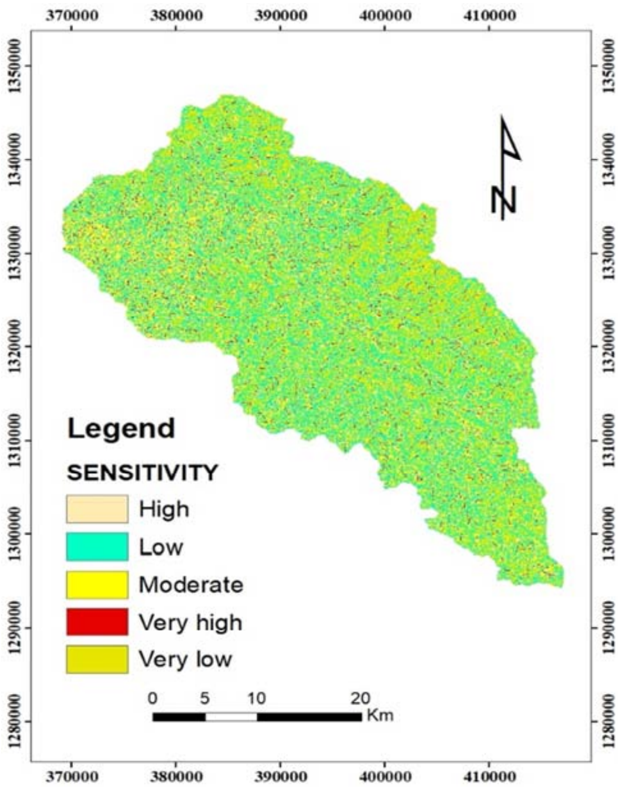
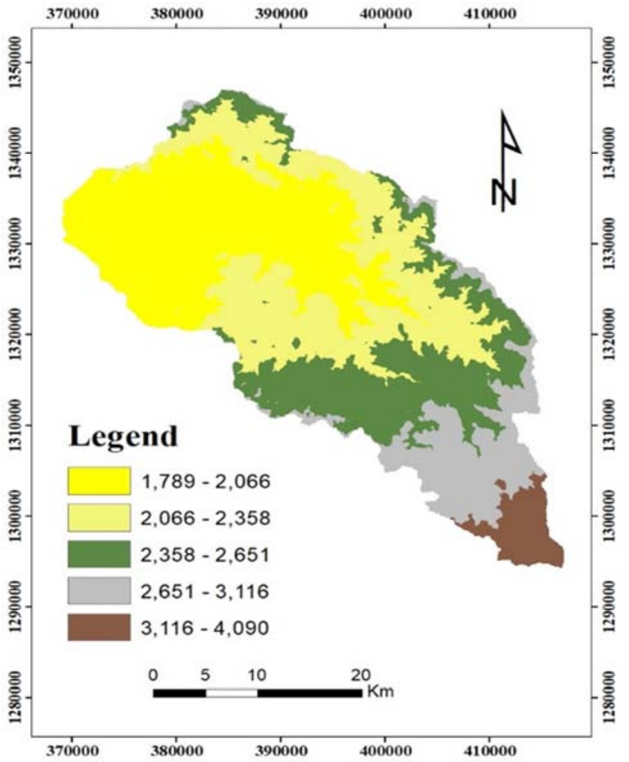


(b)

Figure 9. *(a) TWI map (b) Re-classified TWI map.*

3.6. Impact of Elevation on Erosion

Elevation is one of the best important factors determining the conditions on the microsite that influence plant distribution, morphology, physiology and growth [36]. The elevation map generated from the DEM by raster format. The reclassified Altitude map (Figure 10b below and Table 9) indicated that 87.78 km^2 (7.47%) of the land use is Very high sensitive; 311.06 km^2 (26.48%) Highly sensitive; 324.07 km^2 (27.59%) Moderate sensitive; 432.05 km^2 (36.78%) Low sensitive and 19.76 km^2 (1.68%) Very low sensitive to soil erosion.



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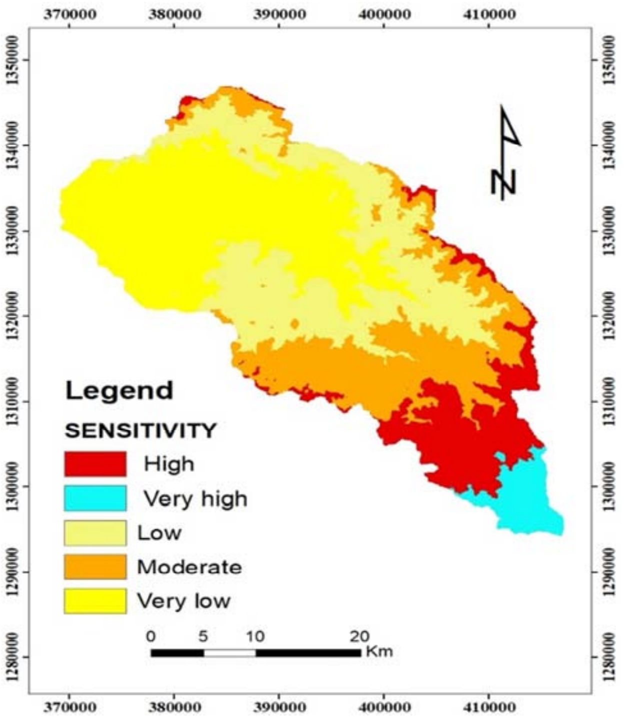

(b)

Figure 10. *(a) Elevation map (b) Re-classified Elevation map.*

Table 9. *Elevation and percentage distribution.*

No	Sensitivity	Area (km^2)	Area (%)
1	High	311.06	26.48
2	Moderate	324.07	27.59
3	Very high	87.78	7.47
4	Low	432.05	36.78
5	Very low	19.76	1.68
	Total	1174.71	100

3.7. Identification of Soil Erosion Hotspot Areas

Based on the methodology designed for identification of soil erosion hotspot area all selected factors were overlaid to identify the area sensitive to erosion as Very high, High, Moderate, Low and Very low. The sensitivity map (Figure 11) shows the relative ranking of the erosion potential sites, generated by weighted overlay mapping, according to the importance of concerned criteria. High sensitivity scores indicate that the site is highly sensitive for soil loss. According to the overall appropriateness score indicated as; 13.30 km^2 (1.13%), 95.31 km^2 (8.11%), 1037.75 km^2 (88.34%) and 28.41km^2 (2.42%) areas are High, Moderate, Low and Very low prone to soil erosion respectively. (See figure 11, 12 and Table 10). Very sensitive areas are concentrated mainly in the upper and lower part of the watershed. On the basis of this result, it is therefore important to facilitate planning and involvements to reduce soil erosion problems in the watershed. Therefore, this study has designed a roadmap for multi-criteria decision-makers to bring sustainable development into the study area.

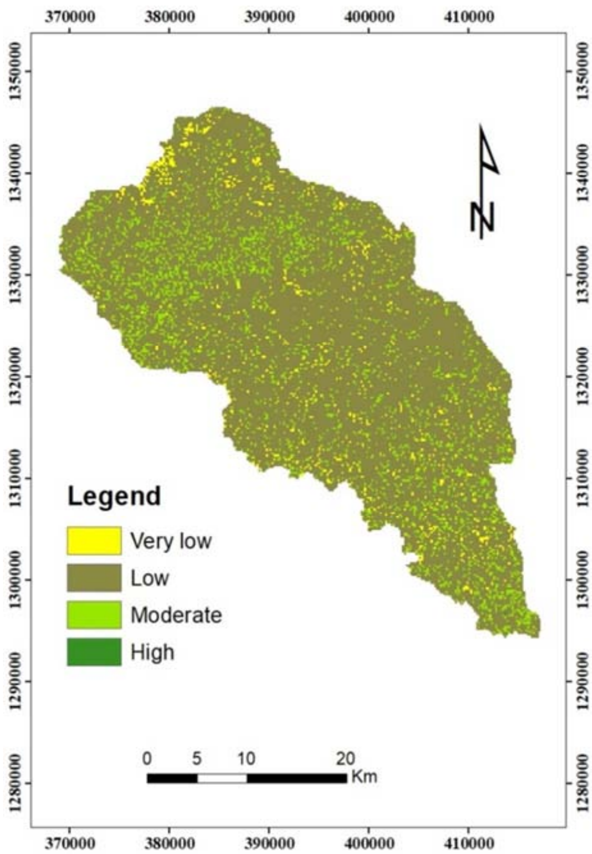

Figure 11. *Potential soil erosion vulnerable areas.*

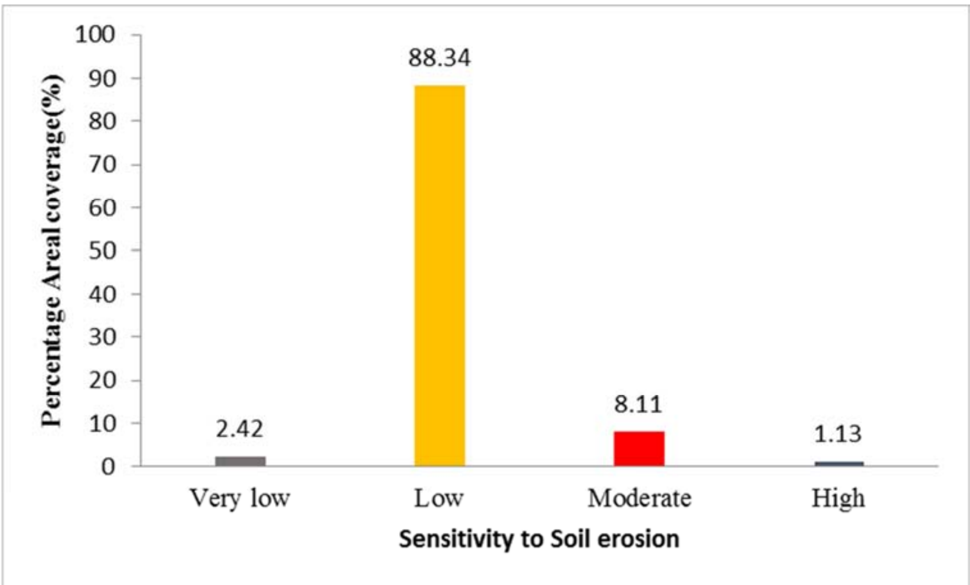

Figure 12. *Percentage coverage of relative sensitivity of soil erosion.*

Table 10. *Areas under soil erosion.*

No	Sensitivity	Area (km2)	Area (%)
1	Very low	28.41	2.42
2	Low	1037.75	88.34
3	Moderate	95.31	8.11
4	High	13.30	1.13
	Total	1174.76	100.00

4. Conclusion

The erosion risk map has been generated by considering five important parameters namely; land use, soil, altitude, slope and Topographic Wetness Index (TWI). With the benefit of GIS and MCE, there are many ways to improve soil and water resource assessment. The main objective of this study was to identify erosion soil hotspot areas in the Ribb watershed. In this study, MCE technique integrated within GIS environment was used to identify potential erosion zones in the Ribb watershed of the Blue Nile Basin of Ethiopia. The MCE result showed that land cover and soil factor are given high priority, suggesting that 30% and 22%, respectively, of the land area is sensitive to soil erosion. The map created using this approach showed significant areas of potential erosion. The results show that land use plays an important role in soil erosion and degradation. The results of this study can help planners and policy makers to take appropriate soil and water conservation measures to reduce the alarming problems of soil loss and depletion in the catchment area. Ultimately, it can be said that this model of spatial vulnerability of soil loss can help to decide whether the soil conservation plan should be given priority. Appropriate measures in critical erosion zones are essential to prevent the loss of sneaking, nutrient-rich topsoil in these agricultural areas.

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