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Mapping of Soil Erosion Hotspot Areas Using GIS Based-MCDA Techniques in South Gondar Zone, Amhara Region, Ethiopia

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ABSTRACT

In the highlands of the country in which the study area found was affected by soil erosion and desertification. This problem on the environment includes loss of soil fertility, reduction of the depth of water body (lakes, ponds, reservoirs etc), high water turbidity, flood hazard problems etc. This study focus on mapping of soil erosion prone areas in South Gondar zone (area: 14604 sq km), which comprises of Blue Nile river basin and Tekeze river basins. This study leads where the most effective soil conservation strategies should focus in the area. Based on GIS with the integration of the Multi Criteria Decision Analysis (MCDA), an attempt was made to combine a set of factors (Land use, Soil, Slope, Topographic Wetness Index, Stream Power Index, Elevation, and Curvature) to have a fruitful decision to fulfil to the stated objective. Raster based pairwise comparison method considering seven soil erosion motivating parameters have been done in Arc GIS environments. MCDA is used to quantify the raster based qualitative spatial erosion hotspot area which produced through pairwise comparison. Raster based spatial model tells that out of total watershed area, 39.31 sq km (0.27%), 33.40 sq km (0.23%), 2358.12 sq km (16.15%), 11027.76 sq km (75.51%) and 1145.60 sq km (7.84%) areas are very high, High, Medium, Low and Very low prone to soil erosion respectively. This study will serve as insight to Basins/watershed decision maker and planners to alleviate soil erosion problems and its related hazards.

Keywords: Causative factors, GIS, MCDA, Pairwise comparison, Raster calculator, Susceptibility mapping, South Gondar zone, Amhara Region

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1. INTRODUCTION

Soil erosion is a naturally occurring process that affects all landforms. In agriculture, soil erosion refers to the wearing a way of a field's topsoil by the natural physical forces of water. These problems reduce the productivity of agricultural lands in the highlands of Ethiopia [15, 16, 36]. It occurs through both anthropogenic and natural activities, such as storms, poor land-use practices, particularly inadequate management systems, soil protection measures and steep slopes. As a result, the phenomenon causes land degradation problems in the highlands of Ethiopia [25]. A huge amount of fertile soil are lost each year in the Country, and soil erosion and land degradation increase significantly due to the undulate and irregular topography of the area [12; 14]. 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 [21]. There are currently a lot of study soil compaction by effecting limiting root growth of plants. Plants are the source of life in the living world. They perform many ecological functions in their environment, and they shape the life of living things in the environment where they live. The life of living things in the world is directly or indirectly dependent on plants.

The ability of plants to fulfil their functions primarily depends on the availability of appropriate climatic and edaphic conditions. Therefore, soil is one of the absolutely necessary conditions for plant existence, which is essential for the life of living things. The soil is defined as "the part of the solid earth that has been altered by the loosening of the earth, humus formation and chemical decomposition, by the transport of humidification and chemical decomposition products". However, when it is examined in detail, the soil is a very complex structure and the biological and biochemical process in the soil is the basis of the terrestrial ecosystem. In this respect, it is very important to examine the structural change of the soil and to determine its relation with the plant. Some studies shows that it examined the change of the soil structure in the forests according to the tree species. An attempt to determine some soil characteristics based on tree species and depth of soil was made within the scope of the study. Soil is important for forest and landscape. Enzymes in the soil structure ensure that they are alive in forest areas [4, 10, 20, 30, 39].

Spatial information exploration is a new approach that can map, 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 MCDA, is 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 MCDA technique is used [42].

In order to achieve this, a ranking of alternatives and compromise alternatives according to their attractiveness must be produced [18]. In the last decade, MCDA has received renewed attention in the context of a GIS-based decision making [12, 17, 35]. Numerous researchers have been study using MCDA techniques in particular areas to conserve natural resources management [2, 3, 11, 13, 14, 23, 31, 34]. In this outcome, MCDA 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. GIS combines Land use, Soil, Slope, Topographic Wetness Index, Stream Power Index, Elevation and Curvature as impacts that contribute to the development of soil erosion. Maps of the above mentioned factors were ranked with different researchers [6, 24, 38].

For each evaluation criteria, weight is assigned which indicates importance relative to the other criteria that were under consideration [18]. Generally the main objective of this outcome was the delineation of vulnerable erosion areas by MCDA integrated with GIS extension tool.

2. METHODOLOGY

2. 1. Location of study area

Geographically the South Gondar zone (Fig. 1) is located between 11° 02' - 12° 33' N latitude and 37° 25' - 38° 43' E longitudes. The zone is bordered on the southwest by west Gojjam and Bahir Dar, on the south by east Gojjam, on the west by Lake Tana, on the northeast by Wag Hemra, on the north by north Gondar, on the east by north Wollo, and on the southeast by south Wollo; the Abbay River separates south Gondar from the two Gojjam Zones. In south Gondar zone, summer is the main rainy season with its peak in July (June to August) and Rainfall varies from 900 mm to1599 mm. The average annual rainfall in the zone is 1300 mm. Cultivation is the dominant types of Land use/land cover of the study area with an areal extent of 7596.16 km^2 followed by Shrub land 3988.77 km^2 of areal extent (Table 4). Eutric nitisols (1371.40 km^2) dominates the soil type of the area followed by Orthic luvisols (1321.04 km^2), Haplic xerosols773.59, Pellic vertisols 736.22 etc. (Table 5) The total area of South Gondar zone is approximately 14,604 km^2 (Figure 1).

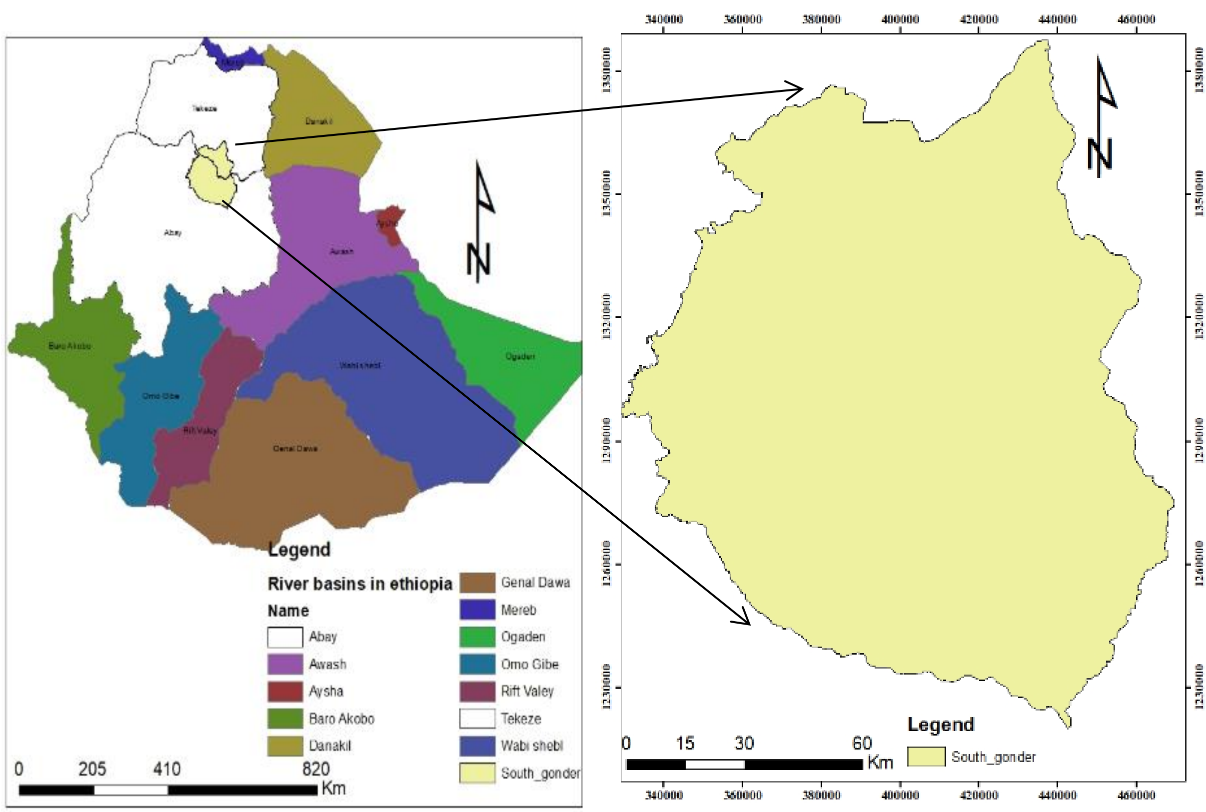


Fig. 1. Location map of study area

2. 2. Description of MCDA Model

GIS approach with the integration of MCDA techniques used to map 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 [42].

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 MCDA with IDRISI module was used.

The major factors selected for this study based on its contribution for soil erosion were Land use, Soil, Slope, TWI, SPI, Curvature and Elevation. 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 MCDA 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.

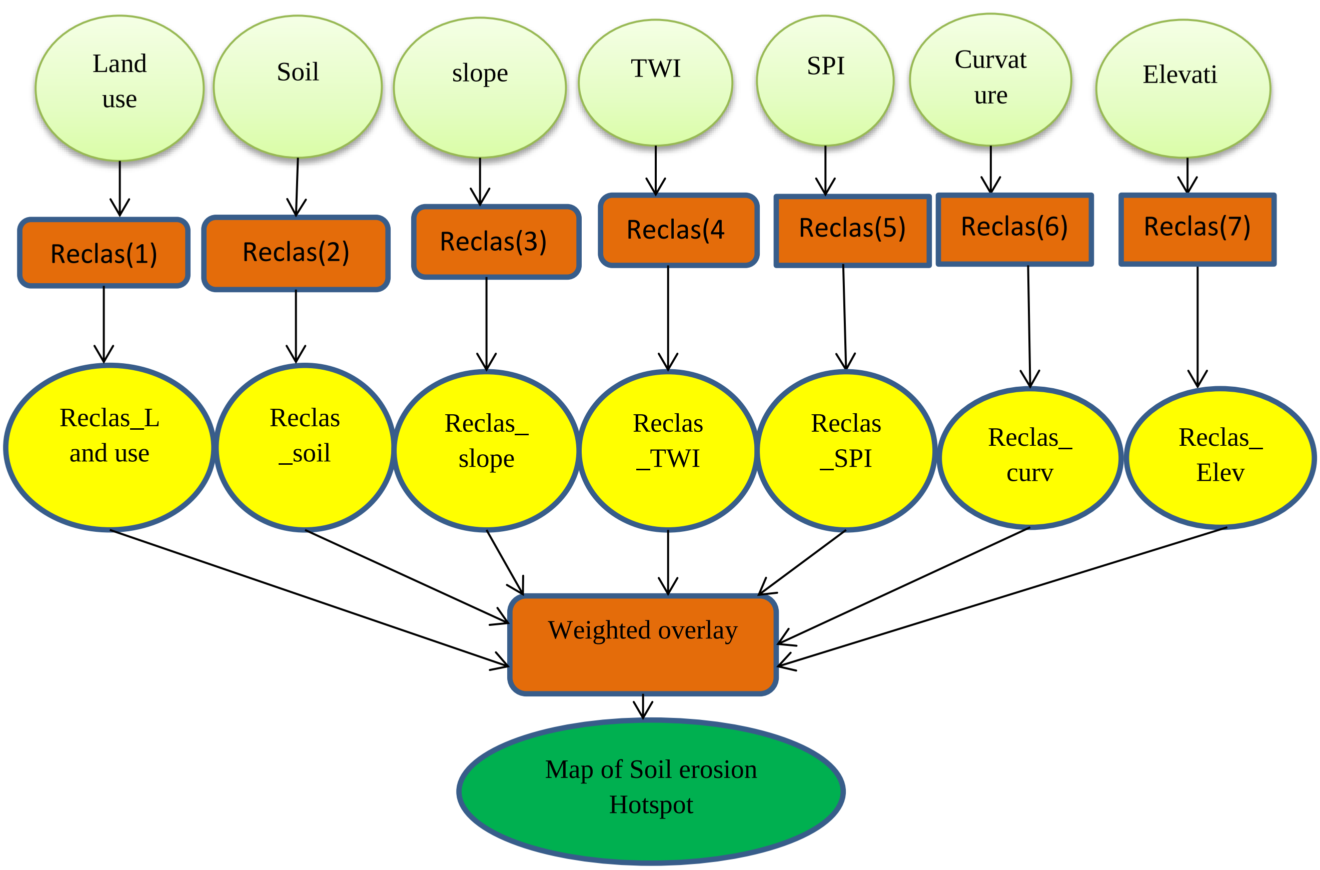


Fig. 2. Workflow of the analysis method

2. 3. Input for the model

To carry out this study a 30m by 30m resolution Digital Elevation Model (DEM) for South Gondar zone was downloaded from Shuttle Radar Topography Mission http://earthexplorer.usgs.gov website for creating, Slope, TWI, SPI, Elevation, Area description and Curvature map analysis using Arc GIS 10.3 version.

2. 4. Application of MCDA

There are many tools used to combine different factors to obtain the expected outcome of the research. Hence, MCDA technique was one of these tools selected for this study. It combines the selected seven 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 use factor. The second criterion selected for this study was Soil, which play an important role in erosion and sediment transport process. Other layers considered as a contributing factor for this study are Slope, TWI, SPI, Curvature and Elevation. The ranks of those influencing factors for soil erosion were indicated as in (Figure 3).

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 [27, 32, 40]. This study used the Analytical Hierarchy Process (AHP) according to T. L. Saaty [32]. The Analytical Hierarchy Process uses simple and straight forward 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]. The CR is acceptable if and only if CR< 10%. If the inconsistency is too large and unacceptable then the decision maker must revise their judgments. Hence for this study the value of CR was less than 10%. This measure examines the extent to which the submitted finding is consistent. The CI is zero if all the judgments are completely consistent.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{1}$$

$$CR = \frac{CI}{RI} * 100\%, \tag{2}$$

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

where: CI is the Consistency Index

- n is the number of parameters
- RI is the random index using the (Satty, 1990) 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 Elevation was considered to have the least influential factor. The highest value assigned for land cover types could be due to the fact that farmers dynamically changed their land use every year. This caused the initiation of soil erosion if it is accompanied by without proper land management practice. Soil is ranked the 2nd most important parameter in identifying erosion hotspot area. 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 1st, Soil 2nd, Slope 3rd, TWI 4th, SPI 5th, Curvature 6th and Elevation 7th most important parameters in mapping erosion hotspot area in south Gondar Zone. The criteria to rank the factors as contributing for soil erosion is the discussion with local expert, expert judgment and based on the topography of the area and as well as on the physical and chemical characteristic of soil types found in the study area.

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	Slope	Curvature	TWI	SPI	Elevation	Row total
Land use	1.00	7	3	5	7	9	5	37.00
Soil	0.14	1.00	0.125	0.25	0.33	0.23	0.25	2.33
Slope	0.33	56.00	1.00	7	1	1	1.2	67.53
Curvature	0.20	4.00	0.14	1.00	0.5	0.52	1.35	7.71
TWI	0.14	21.21	1.00	2.00	1.00	0.56	1.33	27.24
SPI	0.11	0.78	1.00	1.92	1.79	1.00	0.60	7.20
Elevation	0.20	0.57	0.28	0.15	0.11	0.19	1	
Column total	2.13	90.56	6.55	17.32	11.72	12.50	10.73	149.02

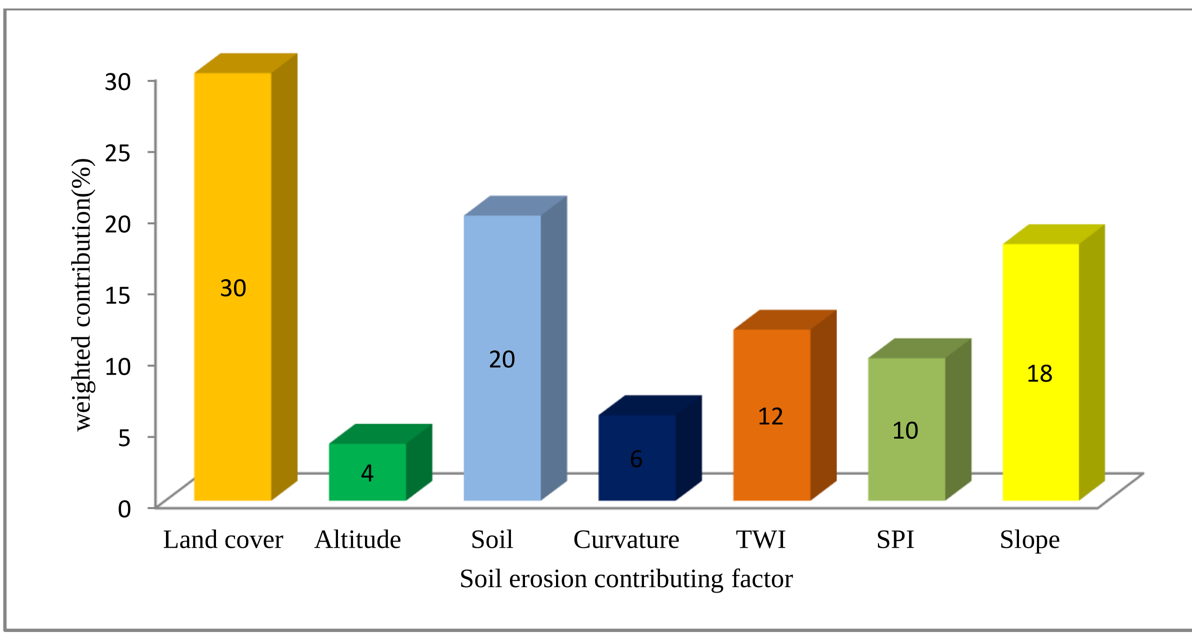


Fig. 3. Overall contribution of parameters for soil erosion

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 several classes. The eleven classes of cover types were reclassified according to their susceptibility to erosion (see Figure 6).

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 susceptibility characteristics have been studied by various authors. There were seventeen 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. Curvature factor map

The Digital Elevation Model (DEM) of 30m by 30m resolution was utilized in ArcGIS to determine hill slope gradient, aspect and curvature. The profile curvatures were the most significant variables for gully erosion prediction. Catchment morphology and drainage density are strongly influenced by curvature of hill slope processes. One of the most basic properties of a landscape is its degree of dissection, often expressed in terms of drainage density. The transition from straight or convex hill slopes to concave valley forms is widely understood to represent a transition in process dominance, but the nature of that transition has been debated. The susceptibility of the landform elements to erosion differs depending on the profile curvature, plan curvature and gradient of the hill slope.

2. 7. 4. 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 32%. 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 5 below).

2. 7. 5. Topographic Wetness Index (TWI) factor

Another important element considered for mapping of erosion hotspot area was TWI and also called Compound Topographic Index (CTI). 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. TWI indicates the amount of water accumulation at a point in watershed and trend of water to flow downslope by gravity [9]. According to Dube et al [7] described that TWI is a function of both slope and the upstream contributing area per unit width orthogonal to the flow direction. 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 [1], watershed management and hydrologic modelling, land use planning and management.

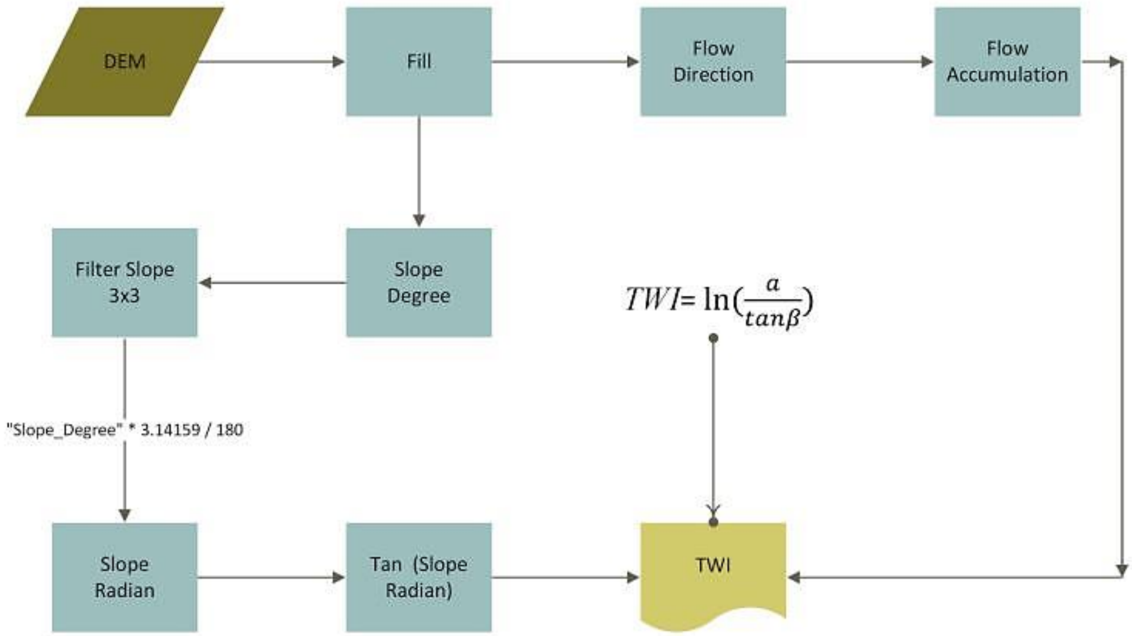


Figure 4. Process flow diagram of TWI in ArcGIS environment, where *a* is the contributing area in m^2 and β is the slope in degree calculated from the DEM. The TWI was calculated using raster calculator from Arc GIS 10.3 version.

2. 7. 6. Stream Power Index (SPI) factor map

Soil erosion caused by water is directly related to slope morphological factors of the areas [41]. SPI describes the erosive power of flowing water by assuming that the discharge is proportional to the specific catchment area and to the slope [26]. It is also an indicative of the potential energy available to entrain sediment [19]. The five classes of SPI were reclassified according to their susceptibility to erosion (see Figure 6). Based on the knowledge of researchers and experts the priority prone to soil erosion has given to the higher range to the lower range of SPI. The SPI can be calculated by using empirical equations of: $SPI = (A_S * \tan\beta)$ where A_S = specific catchment area (m^2/m), β = slope gradient in deg.

2. 7. 7. Altitude factor map

Elevation is often employed to study the effects of climatic variables on soil organic matter dynamics. Soil pH may also control biotic factors such as the activity and biomass composition. The change in altitudinal gradients influences soil organic matter by controlling soil water balance, soil erosion, geologic deposition processes, species and biomass production of the native vegetation and cultivated plants. The altitudinal gradient of mountain is characterized by variable temperature and different precipitation records.

All criteria layers were obtained from MCDA 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 [1]. 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 [28] 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

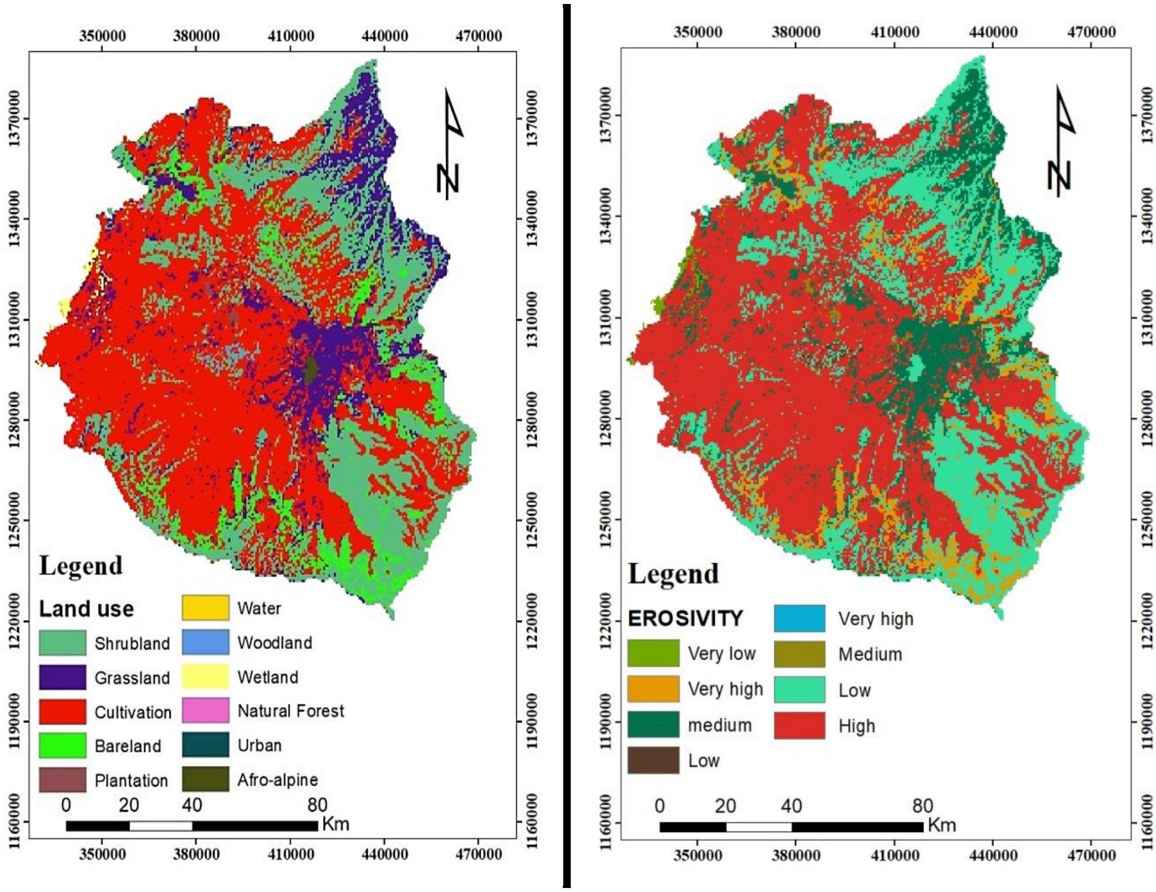
The result of this study presents the selection of potential soil erosion hotspot areas by integrating multiple GIS layers, spatial analysis and multi-criteria decision analysis.

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. Land use map is one of the most important factors that affect surface runoff and erosion in a study area. It enables to assess the resistance of terrain unit to erosion as a result of surface protection. High erosion and quick response to rainfall are resulted from poor surface cover. Due to high increase of population density the demand for the land to cultivate was high. In this regard, Eleven 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 6a and Table 5 below.

Table 4. Land use land cover types in South Gondar zone.

No	Land use types	Area (km^2)	Area (%)
1	Shrub land	3988.77	27.311
2	Grassland	1916.26	13.121
3	Cultivation	7596.16	52.011
4	Bare land	875.61	5.995
5	Plantation	66.28	0.454
6	Water	8.12	0.056
7	Woodland	60.11	0.412
8	Wetland	60.43	0.414
9	Natural Forest	4.55	0.031
10	Urban	0.97	0.007
11	Afro-alpine	27.62	0.189



(a) (b)

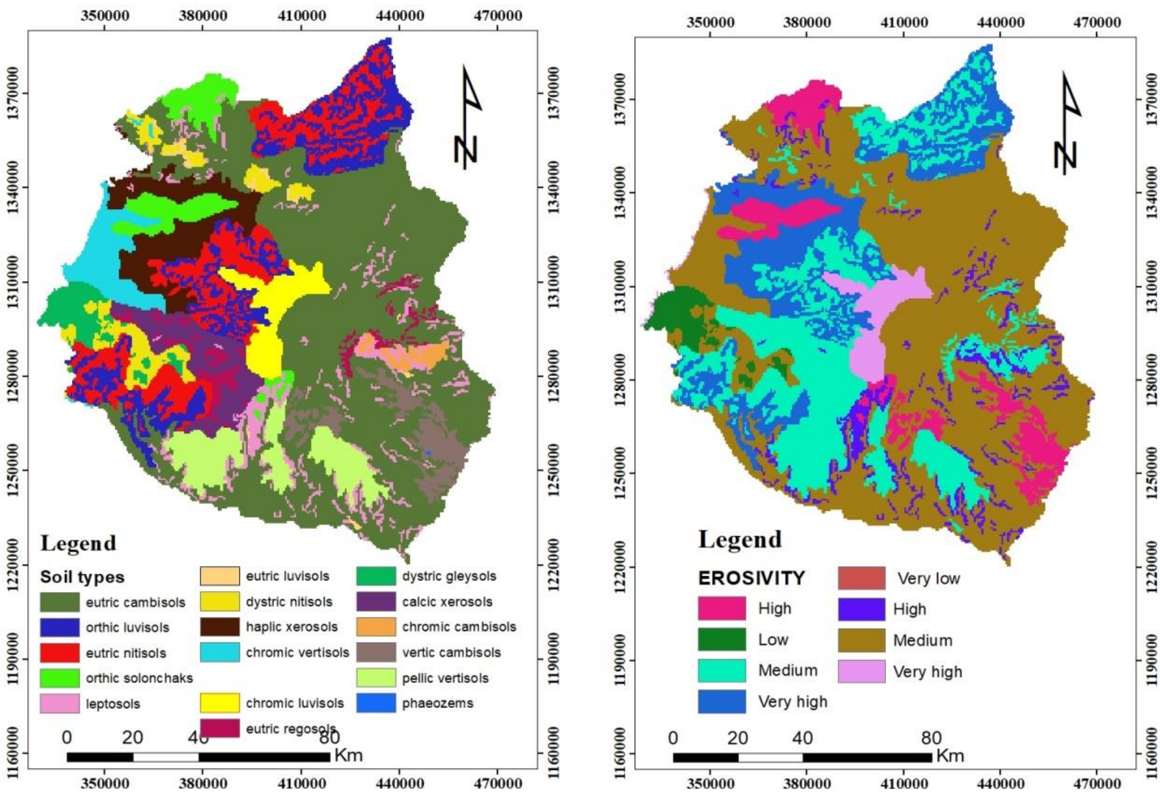
Fig. 5. (a) Land use map (b) Reclassified land use map

Percentage distribution of land use/cover and susceptible to erosion classes in South Gondar zone presented in Table 5 below. As noted above the cultivated lands comprises about 7596.16 km^2 (52.011%) of the entire area of the watershed. The re-classified land use map (Fig. 5b above) indicated that 4.85 km^2 (0.39%) of the land use is Very high susceptible; 1059.24 km^2 (86.27%) Highly susceptible; 45.06 km^2 (3.67%) medium susceptible; 116.49 km^2 (9.49%) low susceptible and 2.11 km^2 (0.17%) Very low susceptible to soil erosion.

3. 2. 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 [1]. Soil texture is an important property which contributes to soil erodibility. The study watershed is dominated by Eutric cambisols with an area of 5917.40 km^2 (40.59%), followed by Eutric nitisols 1371.40 km^2 (9.41%), which are normally influenced by some form of water control and mainly by their topographic/physiographic location (Table 5 below). Figure 6a presented soil types in South Gondar zone. The reclassified soil map (Fig.

6b) indicated that 22.41 km^2 (1.83%) of the land use is Very high susceptible; 114.43 km^2 (9.33%) Highly susceptible; 792.08 km^2 (64.57%) medium susceptible and 297.87 km^2 (24.28%) low susceptible to soil erosion.



(a) (b)

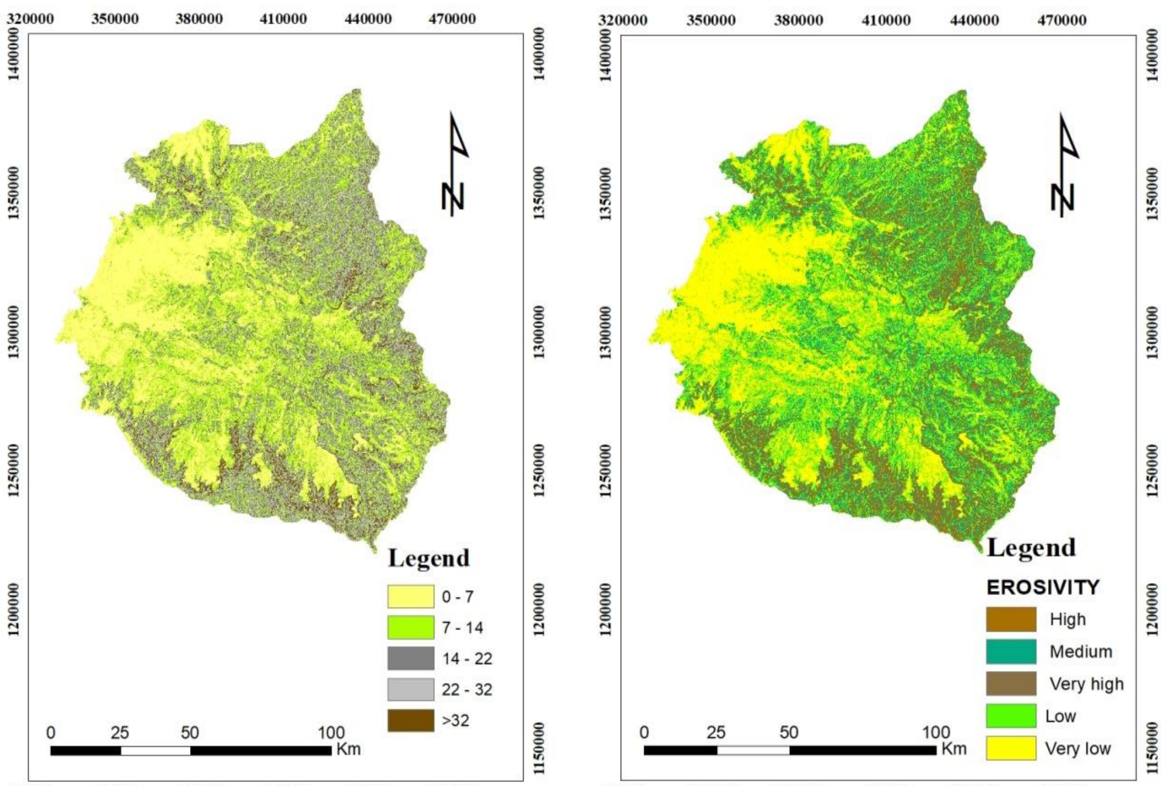
Fig. 6. (a) Soil map (b) Re-classified Soil map

Table 5. Soil type and percentage distribution.

No	Major soil types	Area (km^2)	Area (%)
1	Eutric cambisols	5917.40	40.59
2	Orthic luvisols	1321.04	9.06
3	Eutric nitisols	1371.40	9.41
4	Orthic solonchaks	563.70	3.87
5	Leptosols	726.15	4.98
6	Eutric luvisols	63.36	0.43

7	Dystric nitisols	443.16	3.04
8	Haplic xerosols	773.59	5.31
9	Chromic vertisols	477.28	3.27
10	Chromic luvisols	438.29	3.01
11	Eutric regosols	296.31	2.03
12	Dystric gleysols	316.45	2.17
13	Calcic xerosols	525.04	3.60
14	Chromic cambisols	118.59	0.81
15	Vertic cambisols	490.27	3.36
16	Pellic vertisols	736.22	5.05
17	Phaeozems	1.62	0.01

3. 3. Impact of slope on Erosion



(a) (b)

Fig. 7. (a) Slope map (b) Re-classified Slope map

The Slope gradient is one of the most vital factors affecting the surface flow erosion. The re-classified Slope map (Fig. 7b below and Table 6) indicated that 759.58 km^2 (5.20%) of the land use is Very high susceptible; 2064.91 km^2 (14.14%) Highly susceptible; 2968.15 km^2 (20.32%) Medium susceptible; 4088.41 km^2 (27.99%) Low susceptible and 4726.02 km^2 (32.35%) Very low susceptible to soil erosion.

Table 6. FAO slope categories and related susceptibility to soil erosion.

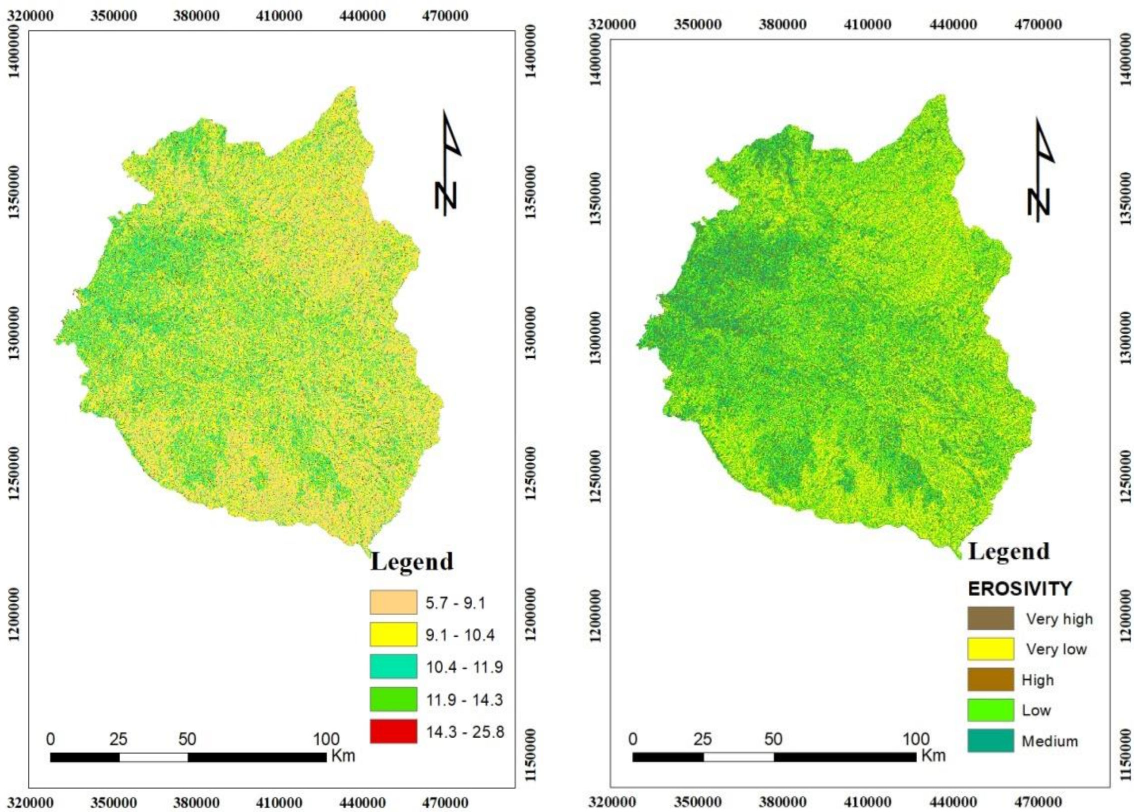
New class	Slope category	Characteristics	Area (km^2)	Area (%)	Susceptibility
1	0-7	Flat to gently undulating	4726.02	32.35	Very low
2	7-14	Undulating	4088.41	27.99	Low
3	14-22	Rolling	2968.15	20.32	Medium
4	22-32	Moderately steep	2064.91	14.14	High
5	>32	Steep	759.58	5.20	Very high

3. 4. 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. In some areas, TWI has been shown in some study areas to predict solum depth [8]. It involves the upslope contributing area (a), 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 (Fig. 8b below and Table 7) indicated that 443.46 km^2 (3.04%) of the land use is Very high susceptible; 1252.49 km^2 (8.57%) Highly susceptible; 3365.36 km^2 (23.04%) medium susceptible; 5693.27 km^2 (38.98%) low susceptible and 3852.53 km^2 (26.37%) Very low susceptible to soil erosion.

Table 7. Topographic wetness index susceptibility class.

TWI	Area(km^2)	Area (%)	Erosivity group
5.7 – 9.1	3852.53	26.37	Very low
9.1 – 10.4	5693.27	38.98	Low
10.4 – 11.9	3365.36	23.04	Medium
11.9 – 14.3	1252.49	8.57	High
14.3 – 25.8	443.46	3.04	Very high



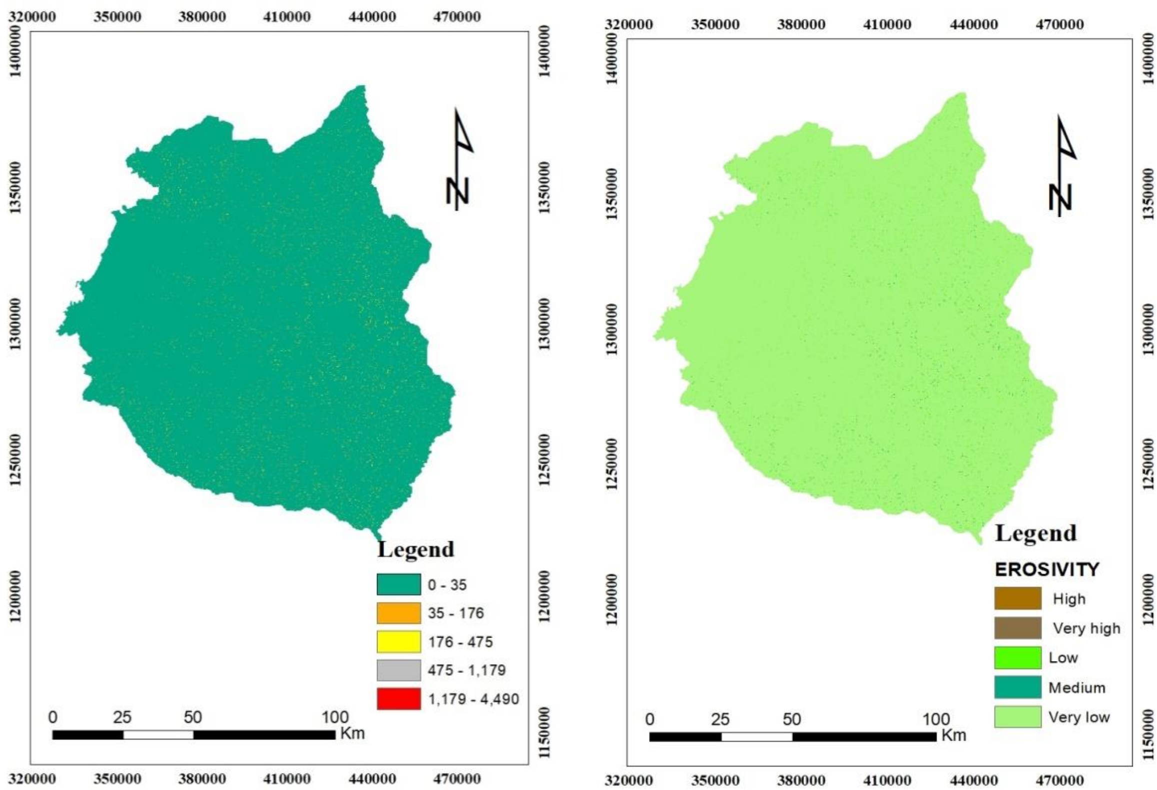
(a) (b)

Fig. 8. (a) TWI map (b) Re-classified TWI map

3. 5. 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 (Fig. 9 below and Table 8) indicated that 0.76 km^2 (0.01%) of the land use is Very high susceptible; 6.44 km^2 (0.04%) Highly susceptible; 37.53 km^2 (0.26%) medium susceptible; 206.15 km^2 (1.41%) low susceptible and 14356.51 km^2 (98.28%) Very low susceptible to soil erosion

Land use/land cover classes were investigated and computed as presented in Figure 7a and Table 5 below. Percentage distribution of land use/cover and susceptible to erosion classes in South Gondar zone presented in Table 6 below. As noted above the agricultural lands comprises about 86.27% of the entire area of the watershed. The re-classified land use map (Fig. 6b above) indicated that 4.85 km^2 (0.39%) of the land use is Very high susceptible; 1059.24 km^2 (86.27%) Highly susceptible; 45.06 km^2 (3.67%) medium susceptible; 116.49 km^2 (9.49%) low susceptible and 2.11 km^2 (0.17%) Very low susceptible to soil erosion.



(a) (b)

Fig. 9. (a) SPI (b) Reclassified SPI

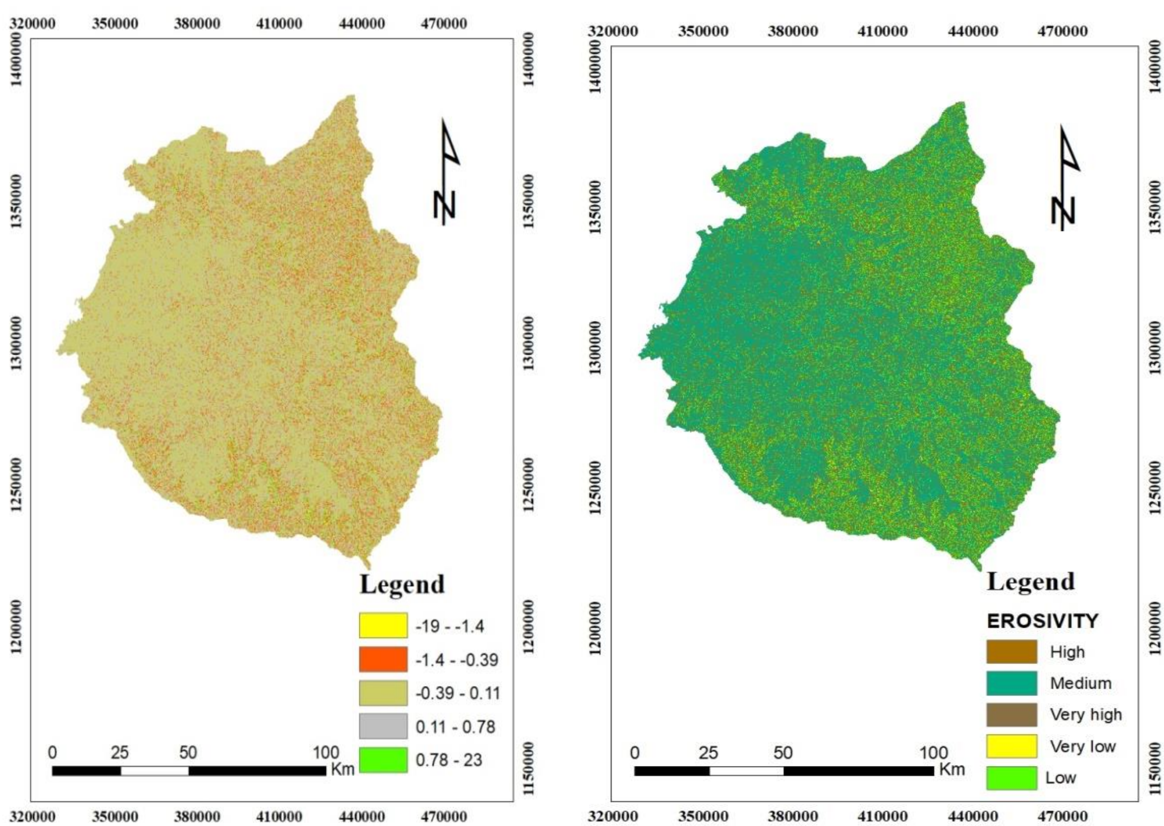
Table 8. SPI range in the South Gondar catchment area.

No	Erosivity	Area coverage (Km^2)	Area (%)
1.	High	6.44	0.04
2.	Very high	0.76	0.01
3.	Low	206.15	1.41
4.	Medium	37.53	0.26
5.	Very low	14356.51	98.28
	Total	14607.39	100

3. 6. Curvature Impact on Erosion

Curvature is a complex terrain derivative to compute, the equation that used depends on the resolution of input data. The Curvature tool calculates the second derivative value of the input surface on a cell-by-cell basis. For each cell, a fourth-order polynomial of the form: From an applied viewpoint, the output of the tool can be used to describe the physical characteristics of a drainage basin in an effort to understand erosion and runoff processes. The slope affects the overall rate of movement downslope. Unlike Aspect defines the direction of flow. The profile curvature affects the acceleration and deceleration of flow and, therefore, influences erosion and deposition. The plan form curvature influences convergence and divergence of flow.

Displaying contours over a raster may help with understanding and interpreting the data resulting from the execution of the Curvature tool. Table 9 and Figure 10a below presented the value of curvature profile. The reclassified curvature map (Fig. 10b) indicated that 491.67 km^2 (3.37%) of the land use of study area is Very high susceptible; 3714.96 km^2 (25.43%) Highly susceptible; 8472.10 km^2 (58%) medium susceptible and 1836.42 km^2 (12.57%) low susceptible and 92.03km2 (0.63%) very low susceptible to soil erosion.



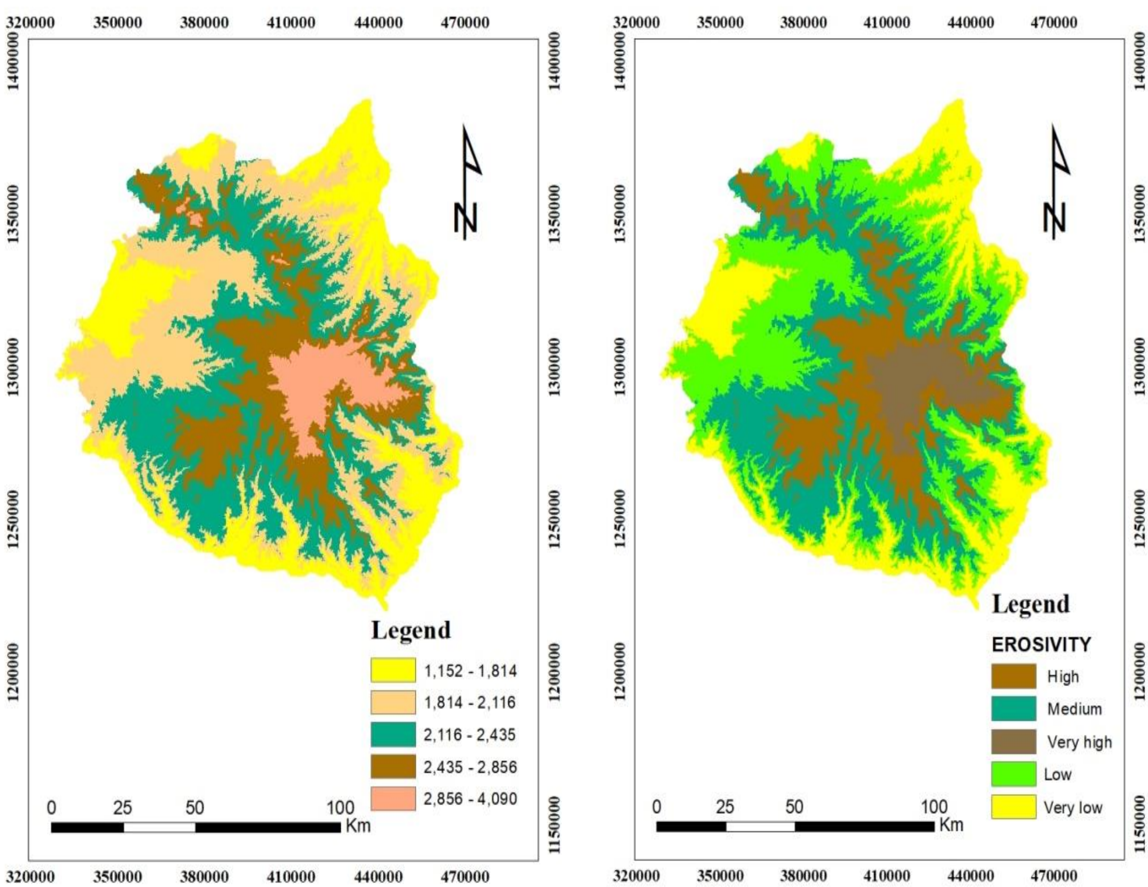
(a) (b)

Fig. 10. (a) Curvature map (b) Re-classified curvature map

Table 9. Curvature and percentage distribution.

No.	Erosivity	Area coverage (km^2)	Area %
1.	Medium	8472.10	58.00
2.	High	3714.96	25.43
3.	Low	1836.42	12.57
4.	Very High	491.67	3.37
5.	Very low	92.03	0.63
	Total	14607.39	100.00

3. 7. Impact of elevation on Erosion



(a) (b)

Fig. 11. (a) Elevation map (b) Re-classified Elevation map

Elevation is one of the best important factors determining the conditions on the microsite that influence plant distribution, morphology, physiology and growth [5]. The elevation map generated from the DEM by raster format. The reclassified Elevation map (Fig. 11b below) indicated that 883.10 km^2 (6.05%) of the land use is Very high susceptible; 2440.73 km^2 (16.71%) Highly susceptible; 3951.13 km^2 (27.05%) Medium susceptible; 4202.50 km^2 (28.77%) Low susceptible and 3129.92km^2 (21.43%) Very low susceptible to soil erosion (Table 10).

Table 10. Elevation and percentage distribution.

No.	Erosivity	Area coverage (Km.sq)	Area (%)
1.	High	2440.73	16.71
2.	Medium	3951.13	27.05
3.	Very high	883.10	6.05
4.	Low	4202.50	28.77
5.	Very low	3129.92	21.43
	Total	14607.39	100.00

3. 8. Mapping of soil erosion hotspot Areas

Based on the methodology designed for mapping of soil erosion hotspot area all selected factors were overlaid to map the area susceptible to erosion as Very high, High, Medium, Low and Very low. The susceptibility map (Fig. 12) shows the relative ranking of the erosion potential sites, generated by weighted overlay mapping, according to the importance of concerned criteria. High susceptibility scores indicate that the site is highly susceptible for soil loss. According to the overall appropriateness score indicated as; 0.00 km^2 (0.00%), 11.85 km^2 (0.08%), 4663.91 km^2 (31.93%), 9921.84 km^2 (67.93%) and 9.44 km^2 (0.06%) areas are very high, High, Medium, Low and Very low prone to soil erosion respectively. (See figure 12, 13 and Table 11).

Table 11. Areas under soil erosion.

No	Erosivity	Area (km^2)	Area (%)
1	Very low	1145.60	7.84
2	Low	11027.76	75.51
3	Medium	2358.12	16.15
4	High	33.14	0.23
5	Very high	39.31	0.27

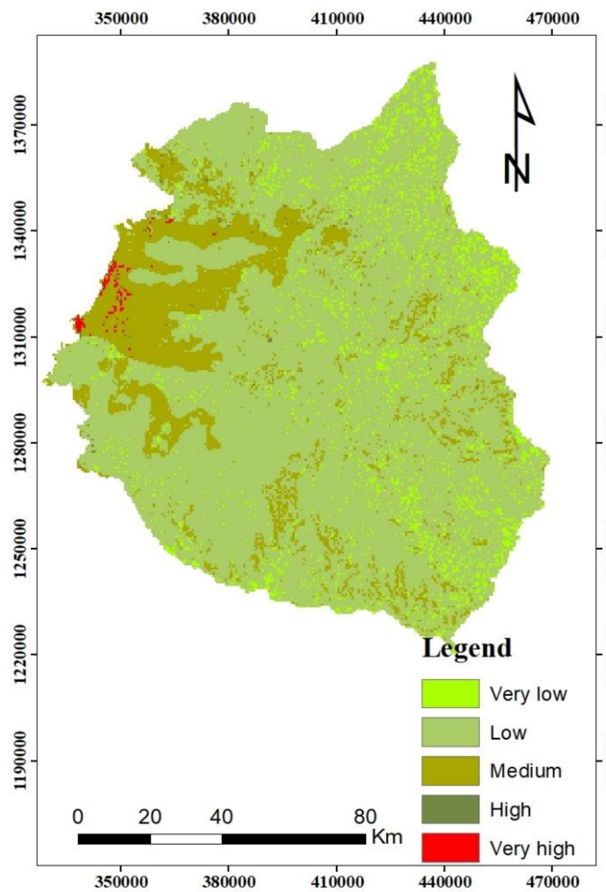


Fig. 12. Potential soil erosion vulnerable areas

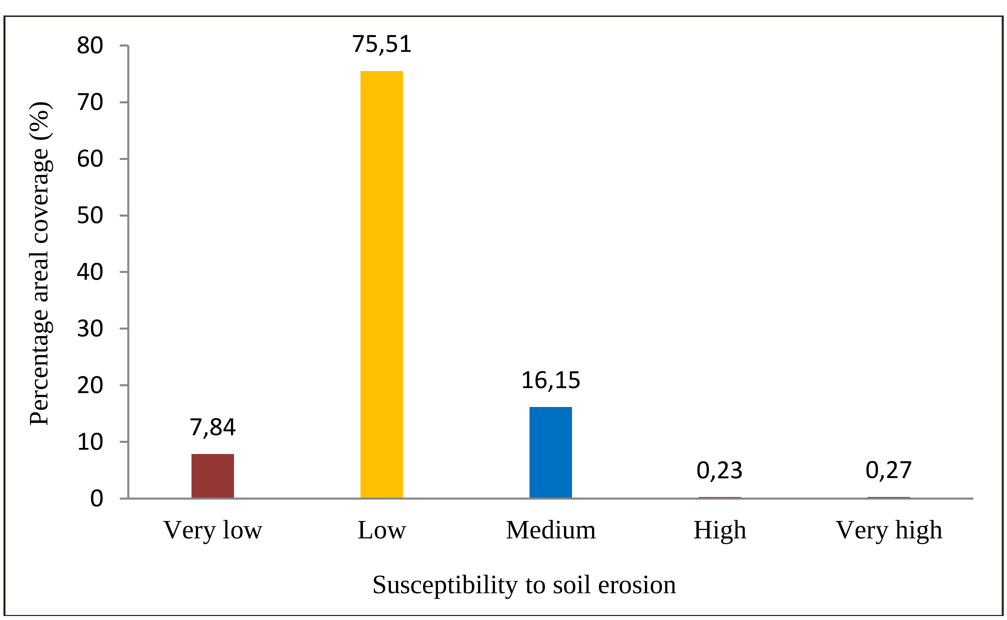


Fig. 13. Percentage coverage of relative susceptibility of soil erosion

Very susceptible 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.

4. CONCLUSIONS

The erosion risk map has been generated by considering six important parameters namely; Slope, Topographic Wetness Index, Stream Power Index, Elevation, Aspect and Curvature. With the benefit of GIS and MCDA, there are many ways to improve soil and water resource assessment. The main objective of this study was to map erosion soil hotspot areas in the South Gondar zone. In this study, MCDA technique integrated within GIS environment was used to map potential erosion zones in the South Gondar zone of the Blue Nile Basin of Ethiopia. The MCDA result showed that slope and TWI are given high priority, suggesting that 25% and 20%, 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 slope 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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