



# Application of geospatial technology coupled with fuzzy logic operations in mapping soil-erosion critical zones: the case of guder sub-basin, upper blue Nile basin, Ethiopia

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## Abstract

The study attempted to map soil-erosion critical zones in the Guder sub-basin in Ethiopia. To map soil erosion sensitive areas, a digital elevation model (12 m × 12 m spatial resolution), precipitation data covering 30 years, soil type, and land use were utilized as inputs. Fuzzy logic techniques based on Geographic Information Systems (GIS) were integrated and analyzed on the ArcGIS 10.5 platform. Five contributing variables were considered as potential causes associated to soil-erosion in the study. Slope, land use, soil type, rainfall, and compound topographic index are the variables. Fuzzy membership values were constructed to generate the rankings of each parameter and their subclasses. Researcher and expert judgment with a survey of the previous studies were used to determine the membership value for each thematic layer and their classes. As a result, the soil-erosion zone map revealed very high, high, moderate, low, and very low erosion susceptibility with areal percentage distribution of 4.96%, 67.48%, 25.41%, 1.88%, and 0.27%, respectively. The study's findings were validated using cross-relationship of the contributing elements and the final map, which revealed strong relationships. The study's findings would help decision-makers and policymakers plan and implement effective watershed management strategies in highly vulnerable locations to soil erosion. Fuzzy logic approaches, when combined with GIS, have been proven to be a basic tool for determining erosion important locations. The final soil erosion map revealed that the majority of the studied areas were prone to soil erosion as a result of agricultural practices, necessitating integrated soil and water conservation practices.

**Keywords** Erosion · Fuzzy · GIS · Guder watershed · Ethiopia

## Introduction

Soil degradation is a multifaceted, on-going, and pervasive phenomenon that affects the vast majority of the world's landforms. Soil erosion is the separation and transfer of topsoil induced by a variety of factors including wind and water (Pal and Shit 2017). Soil-erosion was exacerbated by poor land use, insufficient soil and water conservation, livestock grazing, thunderstorms, and abrupt slopes. Such incidences have led to complex land degradation problems in Ethiopia's plateaus (Mhired et al. 2019). Soil loss, reservoir siltation, downstream flooding, and soil productivity are all influenced by soil erosion (Pal and Shit 2017; Pal and Chakraborty

2019). Erosion of productive topsoil has become a key issue in Ethiopia's plateaus, resulting in lower agricultural production. As a result of land-use changes, soil erosion has become a major problem in Ethiopia (Hurni 1988; Asmamaw and Mohammed 2019). Urbanization, overgrazing, and poor land management hasten environmental degradation, siltation in downstream areas, and a significant decrease in agricultural products. Cultivated areas in the Upper Blue Nile, notably in the Guder watershed, expand year after year (Andualem and Gebremariam 2015; Andualem et al. 2018), hastening soil loss from the watershed. The undulated and irregular topography of Ethiopia's highland, according to Hurni (1989), is the root cause of enormous soil erosion and land degradation.

According to EHRS (1984) data, the loss of top productive soil due to land erosion will cost \$1.9 billion between 1985 and 2010. As a result, soil erosion necessitates the use of rapid sustainable water management strategies in order to preserve the physical state of the soil and increase

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its productivity. A spatial information inquiry is a novel method for locating, assessing, and managing complicated watersheds and catchment basins. Geographic information systems (GIS) have become an outstanding tool for making better decisions in the execution, design, and managing of land and water resource issues (Pal and Chakraborty 2019; Haile et al. 2022), despite objective disagreements and numerous criteria (Pal and Chakraborty 2019; Haile et al. 2022). Multi-criteria evaluation methods are a decision-making strategy that employs a large set of factors and criteria to enhance decision-making processes. The multi-criteria evaluation technique (MCET) is used to study a variety of scenarios including objective problems and multiple criteria (Aher et al. 2013).

A ranking of criteria based on their suitability and relation to the desired goal must be completed in order to carry out the planned study. MCET has been a significant tool for environmental resource management in the context of GIS-based decision making throughout the last decade (Burstein and Holsapple 2008; Haile et al. 2022). Many scholars have investigated the use of MCET in specific locations to aid in management of natural resources (Leskinen and Kangas 2005; Bello-Pineda et al. 2006; Chowdary et al. 2013).

The multi-criteria evaluation technique is commonly used to map soil erosion-prone sites by examining numerous possibilities based on predefined criteria. Gradient, land use, soil, precipitation, and the Topographic Wetness Score were all investigated as erosion contributing factors in this study. A unique themed map is used by the geographic information system (GIS) for the soil erosion contributing component. The geography and slope of a site determine its erosive potential. MCET takes into account soil erodibility, which has an impact on soil erosion. Soil erosion maps have been characterized in several researches based on the aforementioned parameters (Lulseged et al. 2005). Weights were allocated to the soil-erosion leading factor based on the relative significance of each parameter to the other. To avoid Guder Irrigation sedimentation, vulnerable soil erosion spots in the Guder watershed must be identified. As a result, the Guder dam's capacity for flood control and agricultural water needs will be enhanced. As a result, the purpose of this study is to identify erosion hotspots by combining the Fuzzy Logic technique with GIS to identify soil and water conservation priority areas, as well as to compute the cross-relationship between the leading factors and the final map. For factor map integration, fuzzy operators such as Fuzzy sum, Fuzzy product, and Fuzzy Gamma are employed. The final erosion critical area map was divided into groups based on the fuzzy value produced from map combination.

## Study methodology

### Description of the study area

The Guder sub-basin is situated in Ethiopia's Oromia regional state, in the southern part of the Upper Blue Nile basin. The study's watershed was undulating, with elevations ranging from 934 to 3323 m from the sub-basin exit to the outlet. The watershed for the study was defined at the mouth of the Guder River, with areal coverage of 7011 km<sup>2</sup> and coordinates ranging from 7°30' to 9°30' N latitudes and 37°00' to 39°00' E longitudes (Fig. 1). The Guder River's main tributaries are the Huluka, Tarantar, and Debis Rivers.

### Description of fuzzy logic model

The fuzzy logic technique is interesting since it is simple to understand and apply. It can be utilized with data from any measurement scale, and the expert has complete control over the evidence weighing. The fuzzy logic paradigm enables more flexible weighted map combinations and is easy to implement when utilizing a GIS modeling software (Pradhan et al. 2009). The evaluation of fuzzy membership values is required for a fuzzy model to function properly (Ebadi et al. 2001). The related value for each pixel (fuzzy membership value) in a fuzzy map illustrates the relative relevance of thematic layers as well as the relative values belonging to distinct parameters on the map region. Membership in fuzzy set theory can have any value between 0 and 1, expressing the level of certainty about a particular attribute of interest (Tangestani 2003).

Several fuzzy operators are included in the fuzzy logic model, including fuzzy AND, fuzzy OR, fuzzy algebraic product, fuzzy algebraic sum, and fuzzy gamma (Tangestani 2003). These procedures are used to build factor maps based on the influence of thematic maps and the rank of parameters within each thematic. Because multiplying a large number by a small number generates a very small number of integrated fuzzified values at each site, the fuzzy algebraic product operator would be an excellent combination operator for identifying ideal locations for artificial recharging (Saravi 2006). As a result, the fuzzy algebraic product was employed to identify erosion-prone areas in this study. This is how the fuzzy algebraic product is determined:

$$\mu_{\text{combination}} = \prod_{i=1}^n \mu_i$$

where  $\mu_i$  is the  $i$ -th map's fuzzy membership function.

The Fuzzy Membership has been assigned to the various theme maps depending on their vulnerability to soil erosion (slope, land use, soil, rainfall, and Topographic Wetness

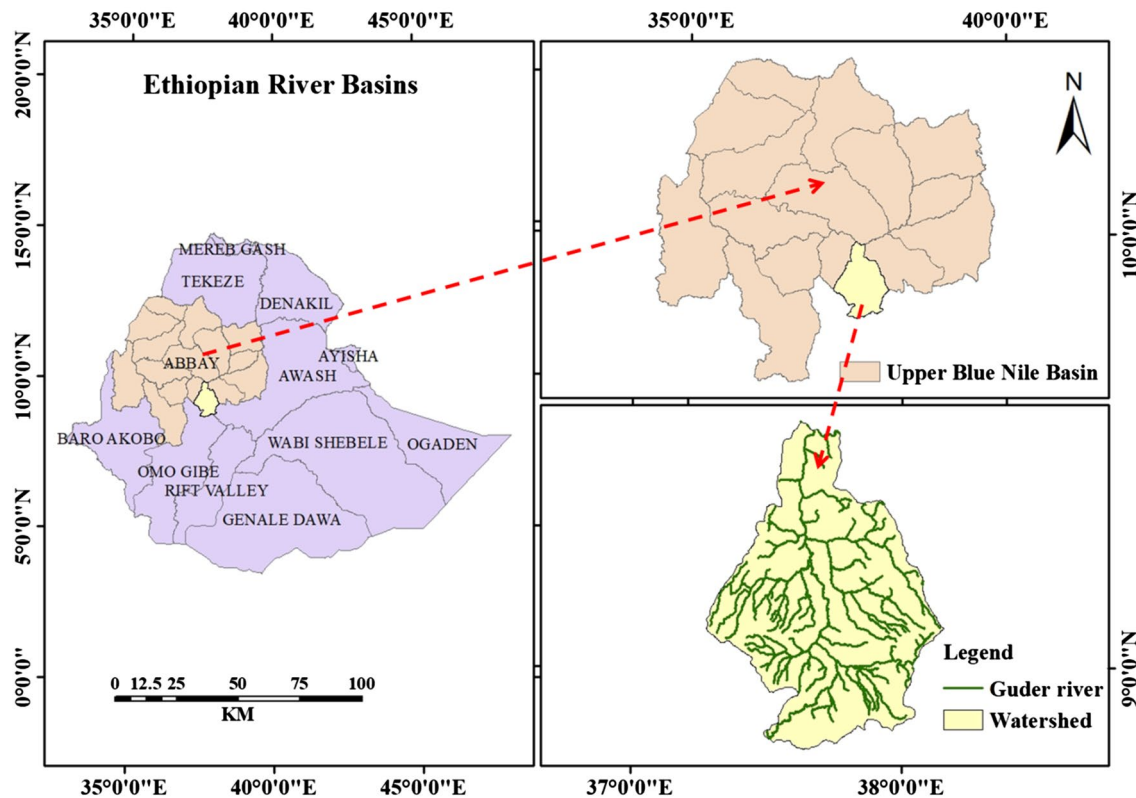


Fig. 1 Guder Sub-basin Map

Index). Various experts have attributed weightage to different classes. Based on their rank, all expert weight has been converted into a fuzzified value ranging from 0 to 1. Fuzzy membership of parameters was performed using expert judgment and literature.

**Factors classification approach**

The catchment's erosion sensitivity is classified into two categories based on the FAO (1981) land classification framework for irrigation purposes (sensitive and non-sensitive). Sensitive classes are further subdivided based on sensitivity degree, whereas resistant classes are separated into two

categories (temporarily and permanently non sensitive) (Table 1). Permanently unresponsive classes are proposed as an erosion limitation in this study.

**Important factors for soil erosion**

Five key elements that may influence erosion were investigated. The first component was land use, which affects soil particle detachability and mobility, as well as water infiltration into soil. The second aspect was geography, notably ground moisture. Soil types have an important influence in erosion and sediment transport processes due to their physiochemical properties.

**Table 1** FAO-based factor sensitivity class (FAO 1981)

Sensitivity category	Susceptibility to erosion	Description
S1	Highly vulnerable	Factors contribute greatly to erosion
S2	Moderately vulnerable	Factors are obviously sensitive, but there is an opportunity to decrease erosion
S3	Marginally vulnerable	Factors contribute greatly to erosion reduction
S4	Currently vulnerable	Factors that cannot be used to support erosion

## Preparation of criteria maps

### Slope gradient

One of the most major topographical factors that cause soil erosion is the slope. The slope map for the research area was created using the ArcGIS 10.5 environment and a 12.5 m resolution DEM (downloaded from <https://search.asf.alaska.edu/#/>). In the Guder sub-basin, the slope ranges from 0 to 56.853% (Fig. 2). When compared to a gentle slope, a steeper slope has a greater impact on soil erosion. Surface runoff accelerates with increasing slope, while soil erosion accelerates with increasing runoff. The amount of runoff and the quantity of particles taken away vary in proportion to the slope's gradient.

### Land use

The land use map was created by downloading a Landsat satellite image from Google Earth Engine land use 2020 (Sentinel-2) and classifying it using the ERDAS Imagine 2016 stratified supervised classification algorithm. The study area's land use classification revealed five major land use classes: water, vegetation, built area, barren land, and crop land. The land use types were classified based on their susceptibility to erosion (Fig. 3).

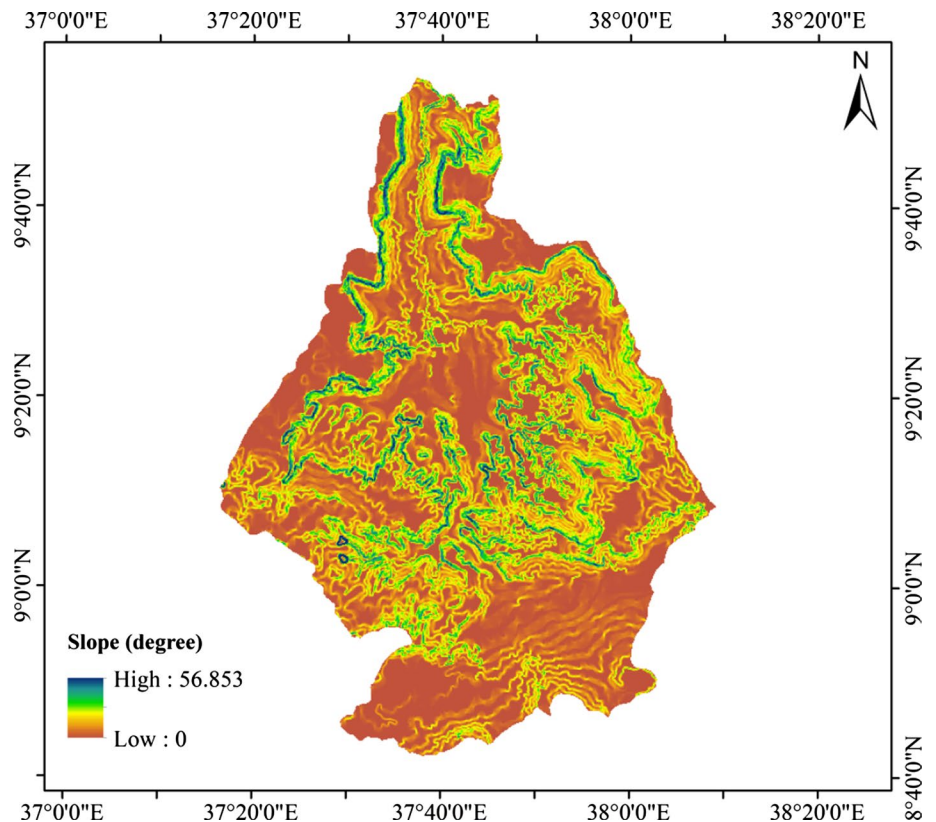
### Soil type

Another key feature that promotes soil degradation is soil type. Land use planning and management in the study area are influenced by soil type Fig. 4. Ethiopia's Ministry of Water and Energy provided the soil map. The vulnerability of the soil to erosion was considered based on its structure and texture. There are around ten major soil types in the Guder watershed, including land covered by a body of water (Fig. 4).

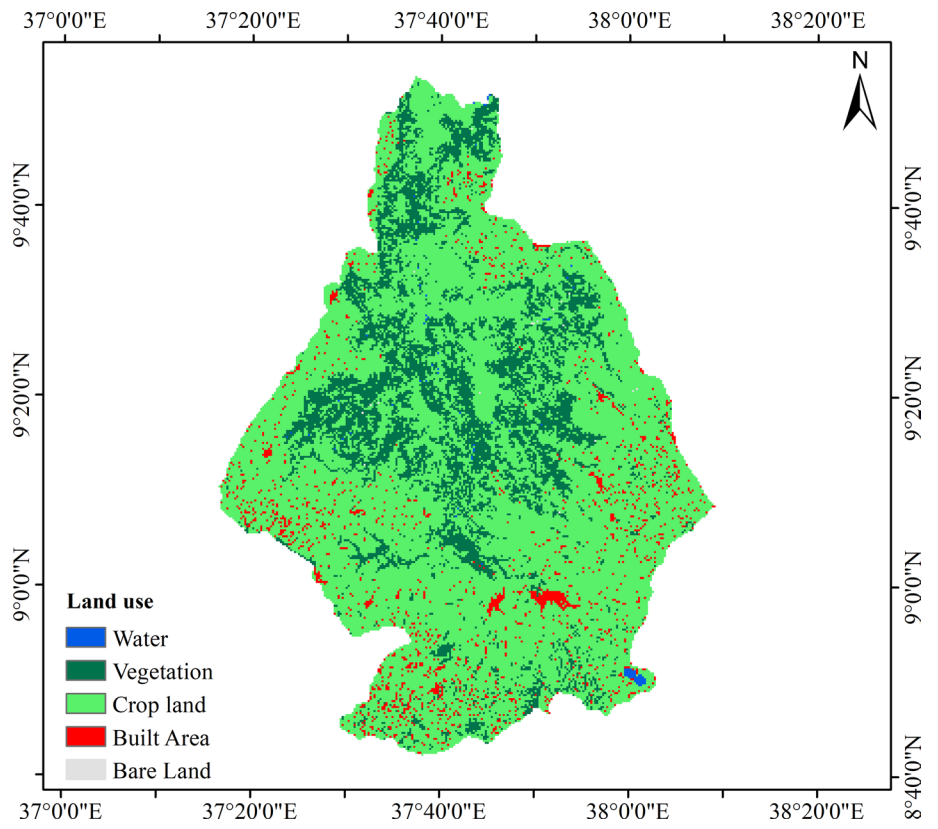
### Rainfall

The Ethiopian National Metrological Agency provided point precipitation records for the research area over 30 years (1987–2017) for 29 stations located in and around the Guder watershed. The areal rainfall map was created using the ArcGIS 10.5 environment and the inverse distance weightage (IDW) interpolation method. The amount, intensity, and period of rainfall all have an impact on soil erosion. Rainfall erosivity is caused by the kinetic energy of droplets striking the soil; the degree of kinetic energy varies with rainfall intensity, causing compaction and aggregate breakup Fig. 5. The rainfall erosivity factor evaluates the effect of rainfall intensity on erosion and necessitates significant continual rainfall data (Lala 1994). The amount of rainfall and maximum intensity prolonged over a long period of time are the

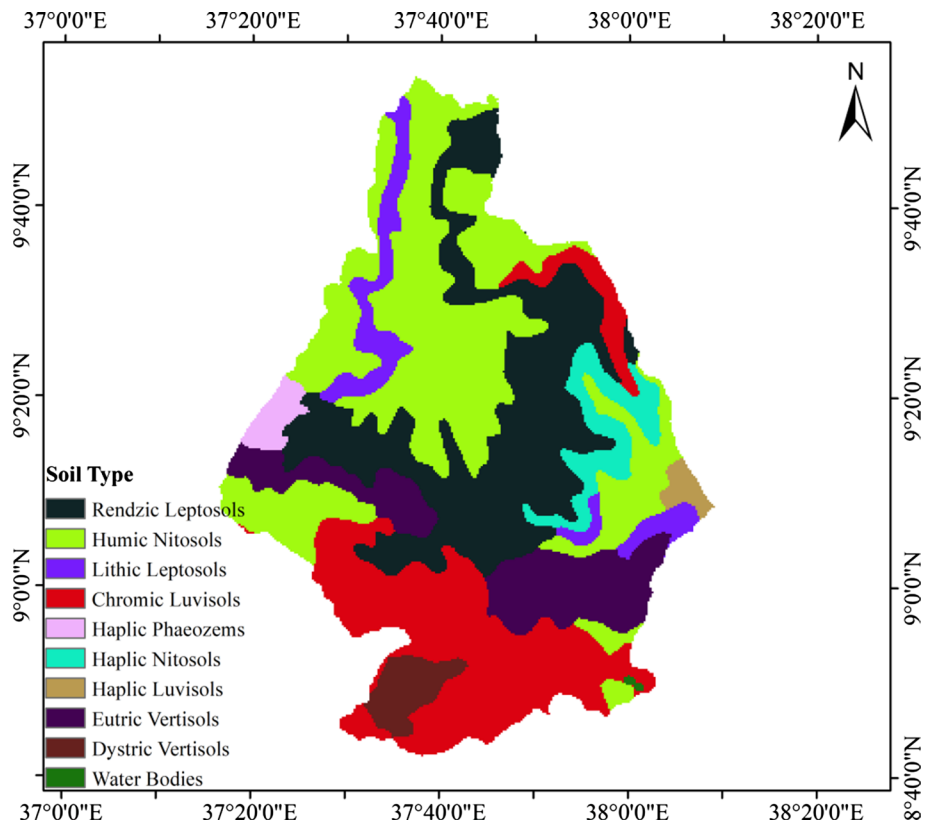
**Fig. 2** The slope of Guder Watershed



**Fig. 3** Land use of the Guder Watershed



**Fig. 4** Soil type of Guder Watershed



$$\text{Rainfall erosivity } (R) = 0.55P - 24.7$$

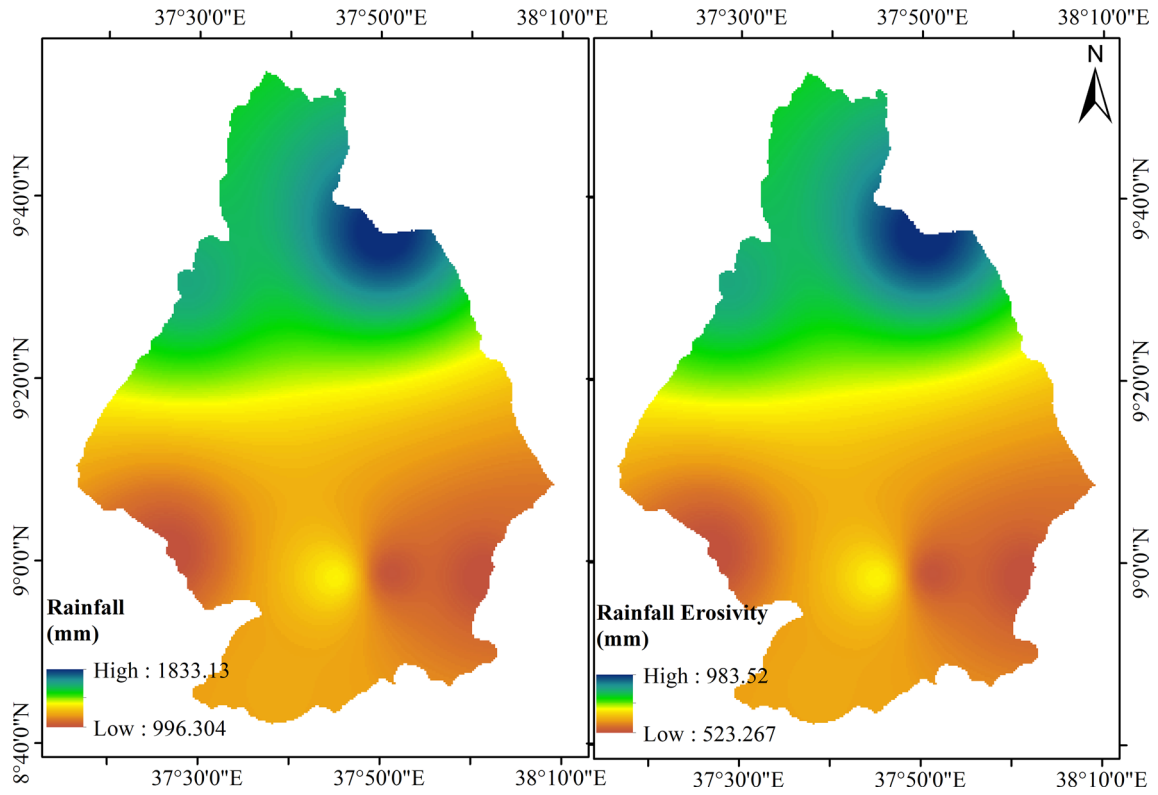
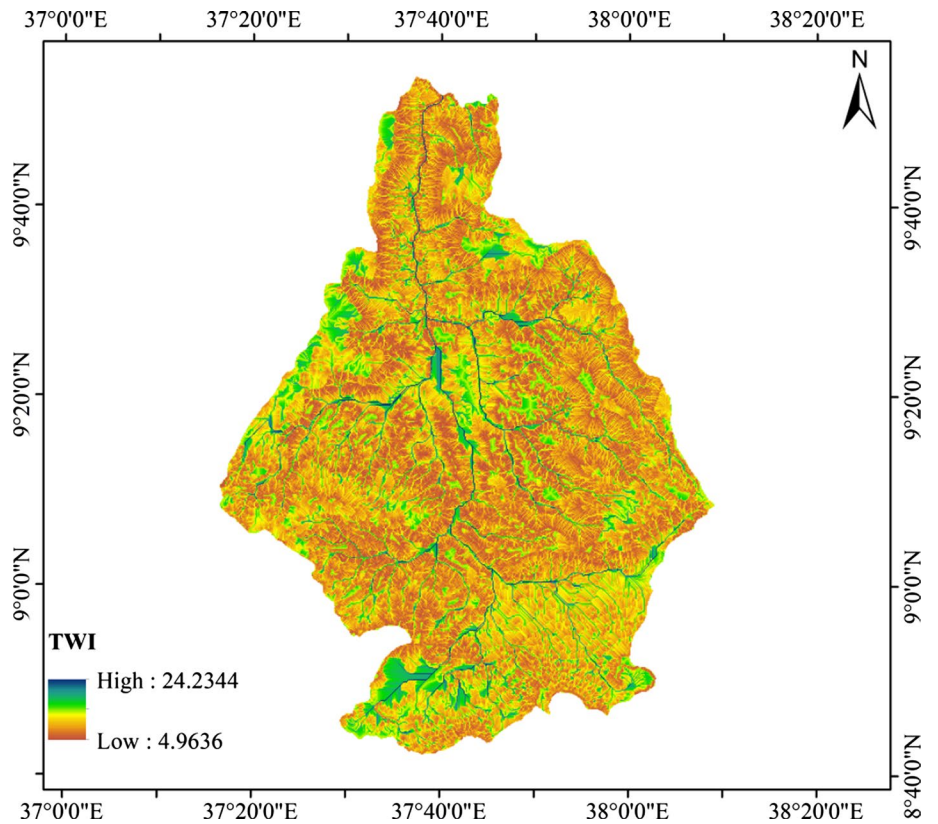


Fig. 5 Rainfall and Rainfall Erosivity of Guder Watershed

Fig. 6 Topographic Wetness Index of Guder Watershed



two most important characteristics of a storm that determine its erosivity. In erosion sensitivity studies, the rainfall erosivity factor value must measure the effect of raindrop impact while also indicating the quantity and rate of flow projected to be related with the rainfall. The erosivity map was constructed using precipitation (P) in mm data and the Ethiopian highlands formula (Hurni 1985).

$$\text{Rainfall erosivity}(R) = 0.55P - 24.7$$

### Topographic wetness index (TWI)

It may be used to determine soil moisture content in a drainage basin numerically as well as estimate static soil moisture. It is an important component in erosion and distributed hydrologic modeling, and it uses the saturating excess runoff generation process to demonstrate the effect of terrain in a watershed. It can also be used to map soil type, drainage, physicochemical soil properties and crop or vegetation coverage. It is also essential for future soil/land assessments (Fu et al. 2000), land use planning and administration, hydrologic modeling, and watershed planning (Western and Grayson, 1998). TWI may be calculated using the Digital Elevation Model (DEM) Fig. 6. The TWI will be determined using the following formula (Beven and Kirkby, 1979):

$$\text{TWI} = \ln(a / \tan \beta)$$

where *a* is the area contributing to the slope and *β* is the slope in degrees derived from the DEM. The TWI was estimated using ArcGIS 10.5's raster calculator.

## Study results and discussions

### Soil erosion versus slope gradient

The gradient of the slope is an important factor that determines erosion from the land's surface. The slope map was divided into five slope classes depending on the FAO slope definition and vulnerability to erosion (Table 2). Flat and moderate sloped areas were classed as very low to low prone to erosion (Table 2 and Fig. 7). Higher fuzzy membership

values are assigned to regions in the research area with a slope greater than 30°. The majority of the research area, 70%, is located in a very low erosion vulnerable area; in contrast, approximately 0.08% is located in a very high erosion vulnerable area.

### Soil erosion versus land use

The current land use of the region under consideration also plays an important role in erosion susceptibility analysis by contributing information about the extent of vegetative protection against erosion, and some study discovered land use to be a prominent factor in erosion sensitivity (Vuillez et al. 2018; Mandal and Mandal 2018; Abdulkareem et al. 2019). It is also one of the most important components influenced by humans, since it reflects human alteration of vegetation cover induced by logging, roadway clearing, and/or cultivation. As population density increased, so did the amount of land required for agriculture and shelter (Andualem et al. 2018). As population density increased, plantation land, grass land, and scrub land were converted into agriculture areas, causing soil erosion in the watershed.

In the Guder watershed, there are five fundamental forms of land cover, with agriculture accounting for more than 75.37% and being more prone to soil erosion. The land use types were categorized depending on their vulnerability to erosion (Table 3). For the fuzzy logic, the fuzzy membership value for each land use class was determined. Crop land and bare ground received the highest membership value due to soil structure disruption caused by tillage and construction operations, followed by built area, whilst vegetation and water received lower membership value (Fig. 8).

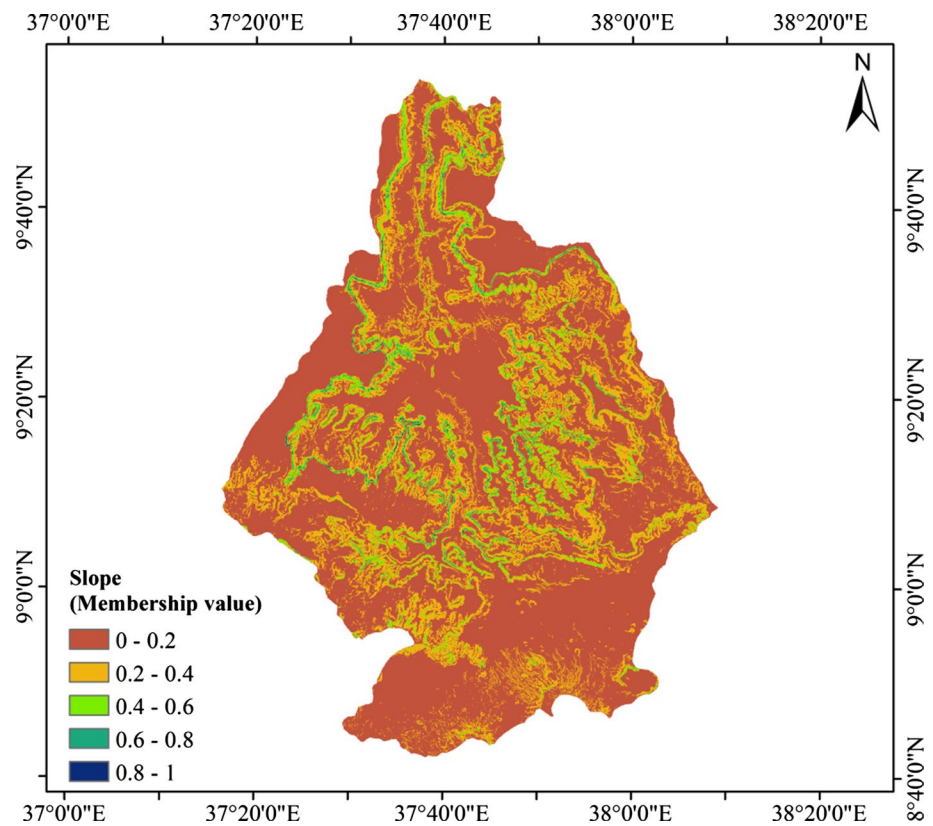
### Soil erosion versus soil type

Because of its physiochemical properties, soil type is one of the most important elements determining erosion. It regulates soil detachment, particle movement, and the rate of infiltration (Setegn et al. 2009). Soil texture has a significant impact on soil erodibility. The watershed is dominated by Humic Nitosols (31.88%), followed by Rendzic Leptosols (24.12%), both of which have moderately poor drainage grades (Table 4). The soil types of the Guder Watershed are represented in Fig. 9. The reclassified soil map (Table 4)

**Table 2** Slope membership value, distribution and sensitivity classes

Slope (%)	Membership value	Sensitivity class	Area (km <sup>2</sup> )	Coverage (%)
0–5	0–0.2	Very low	4909.10	70.02
5–10	0.2–0.4	Low	1612.69	23
10–15	0.4–0.6	Medium	395.93	5.65
15–30	0.6–0.8	High	87.97	1.25
> 30	0.8–1	Very high	5.71	0.08

**Fig. 7** Fuzzy membership value of slope classes



**Table 3** Land use sensitivity class membership value and areal coverage

Land use	Membership value	Sensitivity class	Area (km <sup>2</sup> )	Coverage (%)
Crop land	0.8–1	Very high	5284	75.37
Bare land	0.6–0.8	High	3	0.04
Built Area	0.4–0.6	Moderate	311	4.44
Vegetation	0.2–0.4	Low	1398	19.94
Water	0–0.2	Very low	15	0.21

indicates that 50.47% of the soil is very vulnerable, 5.02% is moderately vulnerable, 44.43% is slightly vulnerable, and 0.08% is resistant to erosion.

**Rainfall versus soil erosion**

The rainfall erosivity was computed using precipitation data from the area, which varied between 523 and 983 mm across the whole catchment. Erosivity is directly related to erosion since its amount of raindrops effects the stability of soil structure. High membership value and high sensitivity to erosion were assigned to regions with high erosivity value, and vice versa (Fig. 10 and Table 5).

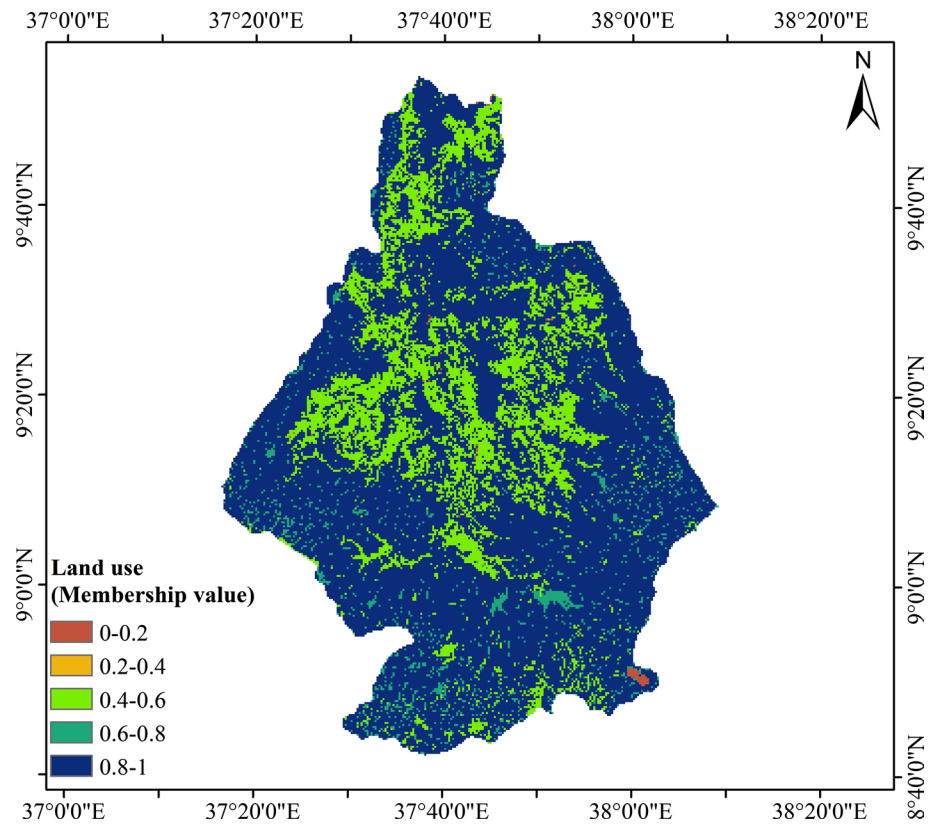
**TWI versus soil erosion**

To varied degrees, the variables discussed above all contribute to the terrain's vulnerability to erosion. Furthermore,

TWI produced from the DEM was used to account for the impact of water movement in the landscape on increasing susceptibility. TWI evaluates stable wetness and flow of water across the territory by accounting for upslope contributing area and slope (Pourghasemi et al. 2013a). Table 6 shows that the TWI obtained for the research region ranges from 4.96 to 24.23 and has been divided into five groups. Using TWI classes to determine the area's wetness potential, 40.58% of the research region was shown to have a low wetness index (4.96–8.21), 45.14% had a wetness index (8.21–10.25), and the remaining 14.28 percent had a high TWI value (> 10.5). Landslide and gully erosion susceptibility experiments performed at several locations were examined to account for the varying levels of TWI contributing to topography erosion vulnerability (Chen et al. 2017; Arabameri et al. 2018b);. Most studies have found that high TWI has a major impact on erosion, and in the current study, the fuzzy membership value of individual TWI



**Fig. 8** Fuzzy membership value of Land use classes



**Table 4** Soil type membership value, distribution and sensitivity classes

Soil type	Membership value	Sensitivity class	Area (km <sup>2</sup> )	Coverage (%)
Rendzic Leptosols	0.8–1	S1	1691	24.12
Humic Nitisols	0–0.4	S3	2235	31.88
Lithic Leptosols	0.7–1	S1	356	5.08
Chromic Luvisols	0.6–0.1	S1	1395	19.9
Haplic Luvisols	0.6–1	S1	96	1.37
Haplic Phaeozems	0.4–0.6	S2	291	4.15
Haplic Nitisols	0.4–0.6	S2	61	0.87
Eutric Vertisols	0–0.4	S3	708	10.1
Dystric Vertisols	0–0.4	S3	172	2.45
Water bodies	0	S4	6	0.08

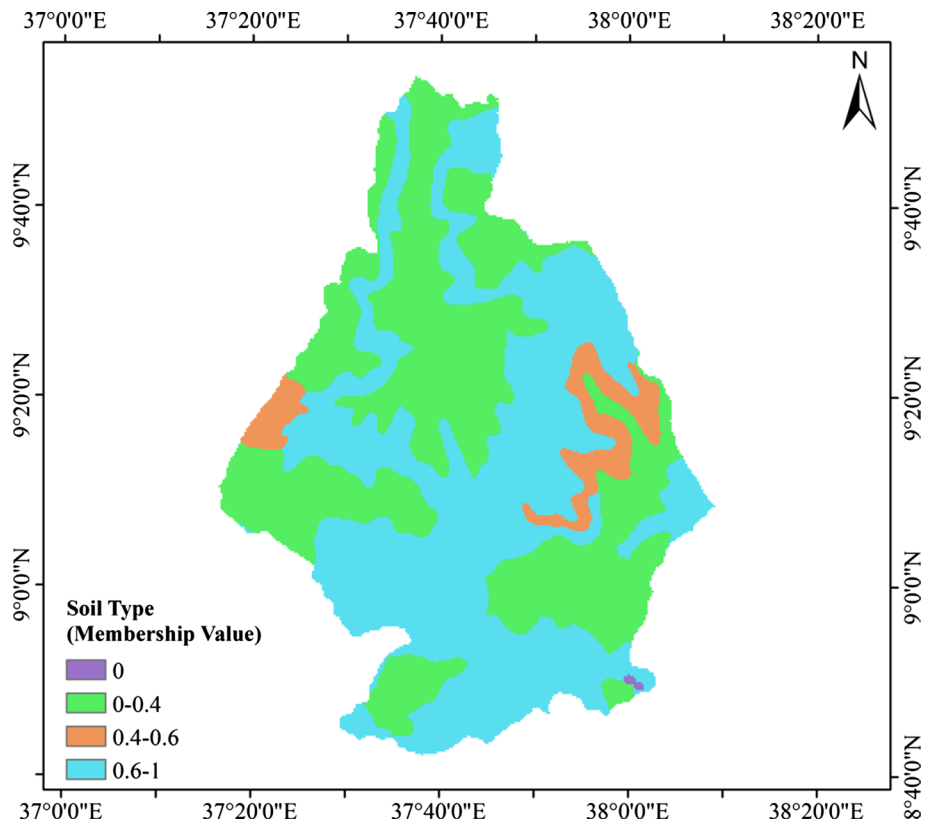
classes was assigned based on the TWI values, with smaller value assigned to low TWI and vice versa (Fig. 11).

**Soil erosion sensitive area mapping**

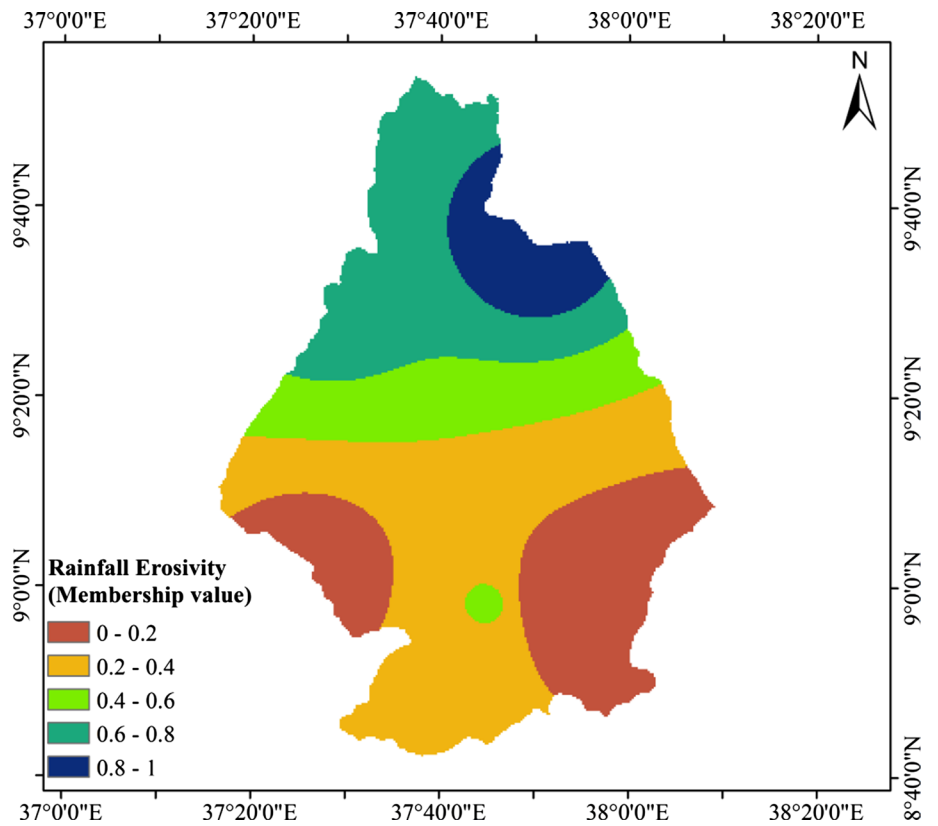
Erosion-vulnerable zones have been discovered by taking into account the erosion causing components (Chang and Bayes 2013; Chicas et al. 2016; Change et al. Chang et al. 2016). Jenks natural classification in the ArcGIS software was used to classify the overlaid maps based on erosion index values into separate soil erosion groups. The relevant components were overlaid using the ArcGIS

10.5 fuzzy overlay analysis tool based on the proportion of influence of each parameter. The outcomes of the fuzzy overlay analysis indicated the overall soil erosion hot-spot zone of the study region, and it was discovered that approximately 346 km<sup>2</sup> (4.96%) and 4705 km<sup>2</sup> (67.48%) of the research area are located in very high and high erosion susceptible zones, correspondingly (Table 7). The majority of the watershed's reaches were discovered to be highly vulnerable to soil erosion. This conclusion demonstrates the importance of promoting soil and water conservation methods in the watershed's most vulnerable parts (Fig. 12).

**Fig. 9** Fuzzy membership value of soil type classes



**Fig. 10** Fuzzy membership value of rainfall erosivity classes



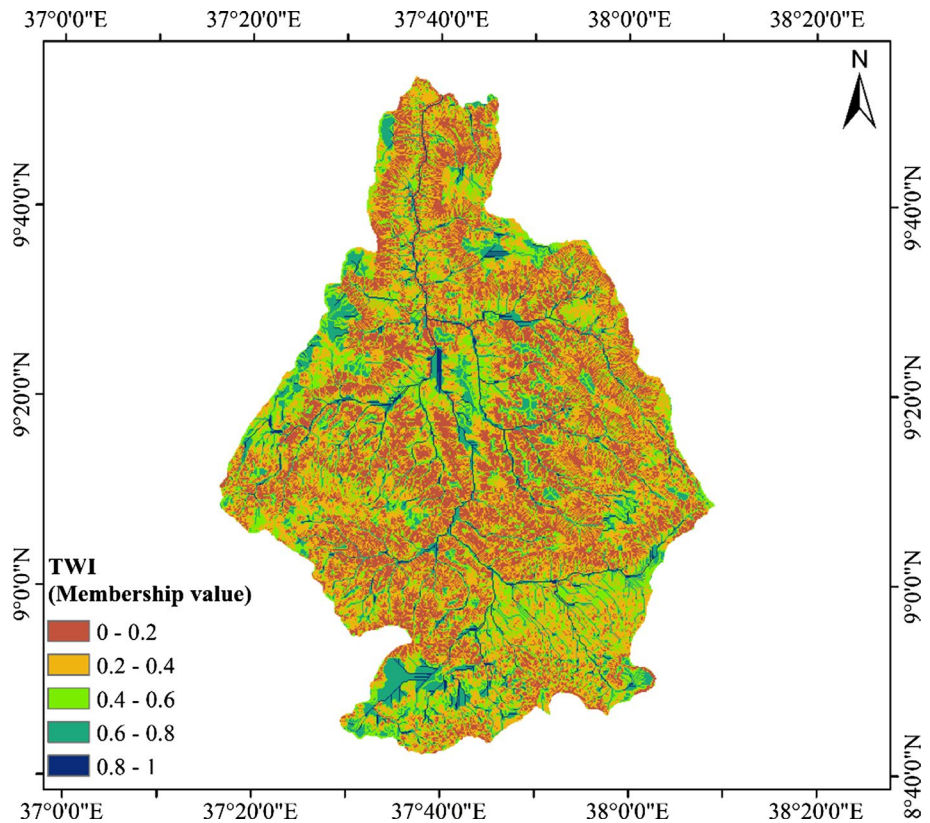
**Table 5** Rainfall erosivity membership value, distribution and sensitivity classes

Erosivity	Membership value	Sensitivity class	Area (km <sup>2</sup> )	Coverage (%)
523–604	0–0.2	Very low	1801.26	25.69
604–680	0.2–0.4	Low	2579.83	36.8
680–778	0.4–0.6	Moderate	807.02	11.51
778–877	0.6–0.8	High	1430.23	20.4
877–983	0.8–1	Very high	392.34	5.6

**Table 6** TWI membership value, distribution and sensitivity classes

TWI	Membership value	Sensitivity class	Area (km <sup>2</sup> )	Coverage (%)
4.96–8.21	0–0.2	Very low	2845.08	40.58
8.21–10.25	0.2–0.4	Low	3165.08	45.14
10.25–12.67	0.4–0.6	Moderate	852.40	12.16
12.67–16.0	0.6–0.8	High	127.68	1.82
16.0–24.23	0.8–1	Very high	20.80	0.3

**Fig. 11** Fuzzy membership value of TWI classes



**Cross-tabulation between erosion sensitive area and contributing elements**

The association between erosion hotspots and erosion factors involved has been determined using cross-tabulation.

**Cross-tabulation between erosion sensitive zone and slope**

The relationship between erosion and gradient was found by cross-tabulating final erosion outcomes with the slope

**Table 7** Fuzzy membership value of soil erosion critical zone classes

No	Erosion sensitive class	Area (km <sup>2</sup> )	Area percentage (%)
1	Very low	19	0.27
2	Low	131	1.88
3	Moderate	1772	25.41
4	High	4705	67.48
5	Very High	346	4.96

of the area. The results (Table 8) showed that very high and high erosion zones were observed in steeply step slopes of more than 15%. In contrast, flat and moderate slope zones have very low and low erosion sensitive areas (0–10%).

**Cross-tabulation between erosion sensitive area and land use**

The effects of land cover on erosion were demonstrated using cross-tabulation in the ArcGIS model. Crop areas were

**Table 8** Relationship between erosion sensitive area and slope

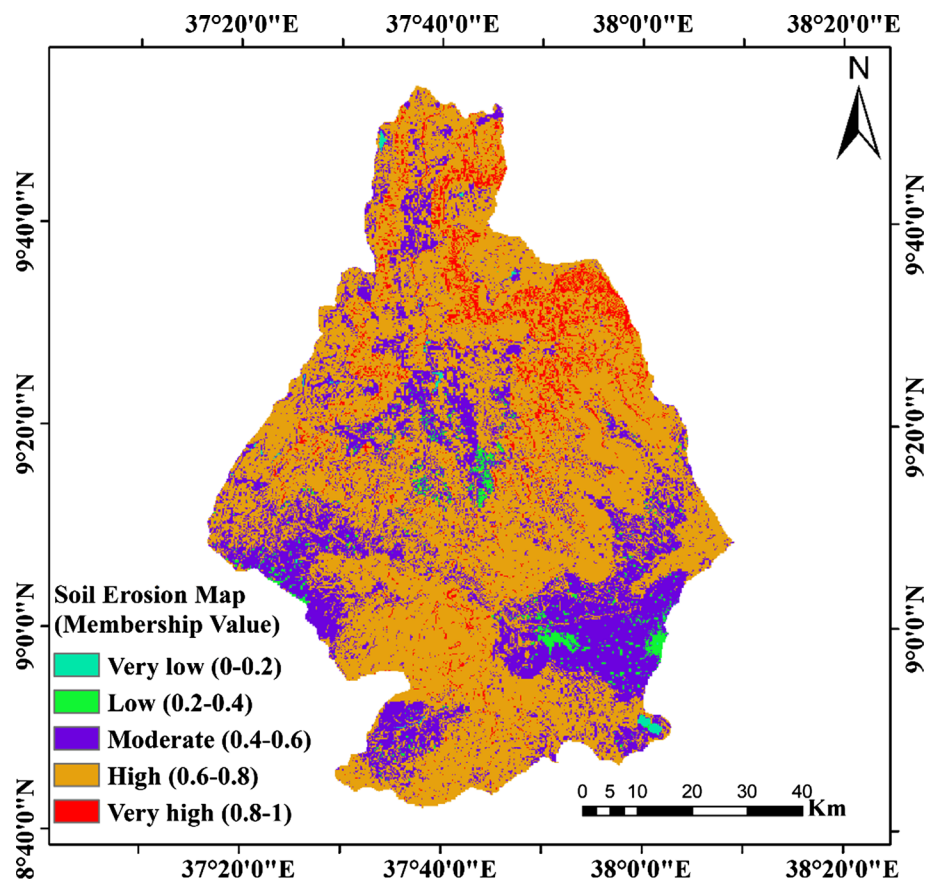
Erosion/Slope	Very low	Low	Moderate	High	Very high
0–5%	3116.52	1532.04	120.52	84.12	18.88
5–10%	167.64	1230.4	204.16	9.48	0
10–15%	0.04	1.2	291.76	70.04	31.4
15–30%	0	0	3.76	62.8	22.48
> 30%	0	0	0.2	3.8	1.92

**Table 9** Relationship between soil erosion and land cover

Erosion/land use	Very low	Low	Moderate	High	Very high
Water	7	1.04	4.17	2.23	0
Vegetation	0.89	779.46	545.31	62.11	7.89
Built area	0.15	50.2	157.14	98.46	0.89
Bare land	0	0	0.45	1.49	0.89
Crop land	10.72	10.72	330.08	1056.66	3845.62

home to the majority of the very high and high erosion prone zones, according to the cross-tabulation data. The majority of plant and water body locations, on the other hand, exhibited very low and minor erosion responses, respectively (Table 9).

**Fig. 12** Final Map of Soil Erosion Critical Zones



### Cross tabulation between erosion sensitive area and soil type

From cross-tabulation result 2823.32 km<sup>2</sup> and 317.72 km<sup>2</sup> area of the Guder watershed were high and very high erosive sensitive areas were found in Rendzic Leptosols and Chromic luvisols which are represented by S1 (Table 10). The majority of Humic Nitosols and Eutric Vertisols were less prone to erosion.

### Cross-tabulation between erosion sensitive area and erosivity

The soil erosion sensitive study included rainfall as an additional factor, and the cross-tabulation outcomes with erosion prone locations are displayed in Table 11. According to the cross-tabulation results, the majority of the very high and high erosion sensitive zones were situated in areas with very high and high rainfall erosivity. Alternatively, sites with very low and low rainfall erosivity displayed very low and low responses to erosion, respectively.

### Cross-tabulation between erosion and topographic wetness index (TWI)

The cross-tabulation of erosion prone zones and TWI has been investigated, and the results are shown in Table 12. The results demonstrate that the majority of the very high and high erosion sensitive zones are situated in areas with a high TWI. Areas with very low and low TWI, on the other hand, had very low and low responses to erosion.

**Table 10** Relationship between erosion and soil type

Erosion/ Soil type	Very low	Low	Moderate	High	Very high
S4	3.28	1.48	0.64	0	0
S3	130.08	1535.36	1394.84	21.56	10.32
S2	1.2	0	346.6	30.56	6.92
S1	5.92	0.48	342.88	2823.32	317.72

**Table 11** Relationship between soil erosion and erosivity

Erosion/Erosivity	Very low	Low	Moderate	High	Very high
523–604	886.68	818.48	77.64	8	5.04
604–680	37.6	1958.96	505.68	62.48	2.48
680–778	2.32	15.24	548.08	190.84	47.72
778–877	5.12	0.68	238.88	1015.12	155.04
877–983	1	0.04	17.68	296.44	75.92

### Conclusion

The application of fuzzy logic in combination with GIS has the potential to determine soil erosion-prone areas. When combined with appropriate cross-tabulation, the results provide further reliable erosion sensitivity projection. The overall findings of the indicated that the majority of erosion critical areas (more than 70% of erosion critical area) were found in the crop and lowland areas of the Guder catchment, implying that it is important to take into account saturated areas even during design and implementation interventions.

Identifying sensitive locations to soil erosion is critical for planning and implementing the optimal soil conservation strategies in the study region's rugged terrain. Strip farming, crop rotations, changing land cover arrangements, reforestation and afforestation, minoring of surface-shielding crops, terracing, check dam for flood regulating measures, and controlling overgrazing are major soil–water conservation measures that can aid reduction erosion in the Guder sub-basins. The study's findings will help planners and decision-makers design and implement effective watershed management strategies in particularly vulnerable soil erosion locations.

**Table 12** Relationship of soil erosion and topographic wetness index (TWI)

Erosion/TWI	Very low	Low	Moderate	High	Very high
4.96–8.21	10.8	6.08	1.04	0.6	0.4
8.21–10.25	51.04	72.04	7.88	0.24	0
10.25–12.67	21.08	203.48	847.8	696.64	2.56
12.67–16.0	87.8	2048.92	1984.4	569.32	14.84
16.0–24.23	3	17.4	58.96	101.2	165.64

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**Data availability** The datasets generated during and/or analyzed during this study are available from the corresponding author on reasonable request.

## Declarations

**Conflict of interest** The author declares that they have no conflict of interest.

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