Geo-Environmental Quality Assessment Study Based On Multivariate Data And Geospatial Approach For A Watershed of Central India

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Abstract

The present study accentuates the expediency of remote sensing (RS), Geographical Information System (GIS), and Spatial Multiple Criteria Evaluation Analysis (SMCE) in appraising the geo-environmental scenario of a watershed falling under the semi-arid region of India. In this study, the Bordi river basin, which falls partly under the Amravati and the Akola districts of Maharashtra state, Central India has been investigated in detail for identifying the existing environmental status of the region. This natural resource evaluation technique incorporates a set of 10 parameters which has significance in regional geo-environment sustainability. In the process, using expert knowledge, an integrated geo-environmental potential index (GPI) has been calculated and the same is used further to derive the final geo-environmental potential map (GEPM) illustrating four classes of geo-environmental resources *i.e.* high, moderate, low, and poor. The geo-environmental quality map overall shows a high level of geo-environmental resources in the maximum area (48.30%). The results are significant in protection, conservation, and planning management strategies of the geo-environment of the study area. Each geo-environmental potential unit is amenable to specific conservation techniques and hence appropriate conservation techniques are recommended to each of them. The work amply proves the applicability of RS, GIS, and SMCE techniques in the natural resource evaluation procedure. This technique is found to be suitable for areas with similar geo-environmental set-up elsewhere.

Introduction

In the current scenario of development, the natural resources are being exploited indiscriminately leading towards the degradation of the environmental ecosystem causing global warming, floods, and droughts across the world. The situation calls for the implementation of appropriate measures to restore and conserve the existing ecosystem. The importance of ecosystem services to human well-being for the present and future generations has been a matter of concern for land managers, environmental scientists, and decision-makers (De Groot et al. 2012; Wang et al. 2015; He et al. 2017). The issues of sustainable development are associated with the objectives of achieving desired growth for economic or social reasons on one hand with safeguarding the environment and maintaining a good quality of life on the other (Xiong et al. 2007; Kong et al. 2012; Chai and Lha 2018). In the process of development, the geo-environmental components may degrade and therefore needs to be addressed with adequate attention and proper reinstatement measures (Sarkar et al. 2007; Hickey et al. 2015).

In this regard, many researchers globally have concentrated on the development and evolution of appropriate methodologies for geo-environmental assessment studies. Some of the important methods are; the comprehensive evaluation (Goda and Matsuoka 1986), gray evaluation (Hao and Zhou 2002), landscape evaluation (Antonio et al. 2003; Song et al. 2012; Kangas et al. 2000), osculation value (Park et al. 2004), fuzzy evaluation (Dzeroski 2001; Adriaenssens and Baets 2004), artificial neural network evaluation (Enea and Salemi 2001; Hao and Zhou 2002; Xue et al. 2003; Xu et al. 2017), etc. A close review of the published literature on the derivation of various methods and models, however, illustrates a lack of multi-factor synthetic analysis, and involvement of complicated procedures (Rahman et al. 2014).

The assessment of regional environmental quality status of any region needs proper understanding of multiple factors along with consideration of appropriate spatial decision support system for obtaining the desired results, which are rarely defined in the earlier works (Kangas et al. 2000; Li et al. 2007; Xiong et al. 2007).

Therefore, the situation calls for the identification of target areas for implementing corrective measures. In this context, GIS plays a vital role as it facilitates the acquisition of data in digital format and can be used for the integration of multiple correlated spatial databases of all the controlling factors (Liu and Buheaosier 2000; Plummer 2000; Lillesand and Kiefer 2002; Wu et al. 2002). The environmental eco-system is governed by the set-up of natural resources that includes multiple databases. An attempt has been made in this study to derive a GIS-based model by considering spatial multi-criteria evaluation for natural resource estimation for a watershed of central India. In the current study, ten basic layers related to the soil, land, and water have been integrated to identify problem areas for a small watershed of Bordi river catchment of Maharashtra, Central India. The work is mainly aimed at guiding environmental protection and management of environmental resources in future sustainable development.

Study Area

The study was conducted in the Bordi watershed of the Purna sub-basin covered under the Amravati and Akola districts of Maharashtra state. The Purna sub-basin lies between north latitude $20^0$10’: $21^0$41’N and east longitude $76^0$0’:$77^0$55’ and covers an area of 18,300 km^2. About 2827 km^2 of the Purna sub-basin falls under the saline tract (Adyalkar 1962; Muthuraman et al. 1992; Raja et al. 2012). The Bordi watershed is a part of the Purna sub-basin and occupies an area of 449.60 km^2 and is covered under the Survey of India toposheet numbers 55 G/3, 55 G/4, 55 G/7, 55 G/8, and 55 H/1. The Bordi river is a tributary of river Shahanur, which emerges from the Satpura hill ranges and ultimately meets the main Purna river. The study area extent between 20°55’N to 21°18’N latitude and 77°05' E to 77°18' E longitude (Fig. 1). The area experiences a semi-arid climate and is characterized by a hot summer and general dryness throughout the year except during the south-west monsoon season, i.e. June to September. The minimum mean temperature in the area is 15.1°C in winter and the maximum mean temperature is 42.2°C in summer. Topographically, the area depicts a wide elevation difference between 270m to 900m (Fig. 2), wherein, nearly 42% of the total area represents the altitude of 320m to 400m. The slope analysis illustrates a total of 72.65%, 11.60%, and 15.74% area under the low, moderate, and high slope categories respectively.

Materials And Methods

The main objective of this study is to assess the various geo-environmental vulnerability grades within the study area using remote sensing, Geographical Information System (GIS), and multiple-criteria decision-making techniques. Recently, the approach of remote sensing has emerged as a powerful tool in understanding the spatial distribution of related parameters which has a direct bearing on geo-environmental status (MacMillan et al. 2004; Thakur and Raguwanshi 2008; Yu et al. 2011; Ma and Shi

2016). Many researchers have employed integrated Geographic Information Systems, remote sensing, and environmental evaluation models for obtaining the environmental management and monitoring plans e.g. Honnay et al. 2003; Lin et al. 2006; Mitsch and Day 2006; Chou et al. 2007; Fink and Mitsch 2007; Hernandez and Mitsch 2007; Tudes et al. 2012; Larsson and Hanberger 2015). Accordingly, in the present study, the spatial database on inter-related parameters of the study area has been generated by using remote sensing and GIS techniques. The adopted methodology is shown in the form of a flow chart in Fig. 3.

Regional geo-environmental quality assessment

The selection of appropriate factors i.e. natural and anthropogenic, affecting geo-environmental quality is essential to investigate for the geo-environmental evaluation studies of any area along with spatial database affecting geo-environment (Xu et al. 2017; Yu et al. 2011; Li et al. 2006, 2007). Many investigators have used different factors for such type of geo-environmental evaluation studies (Molden and Billharz 1997), amongst which land use/land cover and soil erosion are frequently used (Giaoutzi and Nijkamp 1993; Selman 1996).

The synthetic analysis of the geo-environment of the Bordi catchment area has been carried out using significant interrelated factors which have a direct bearing on the geo-environmental system, in which, ten (10) factors viz. land use, cropping pattern, geology, geomorphology, soil depth, soil texture, soil erosion, soil slope, groundwater quality, and groundwater fluctuation have been considered. Based on the analysis of these factors, the geo-environmental status in the area has been divided into three sub-systems of natural resources i.e. soil, land, and water (Table 1).

Table 1
Proposed ratings and weightage given to estimate geo-environmental resources

Category	Parameter	Data Source	Classes	Area (sq.km)	Rating	Weightage
Soil	Soil Depth	Ancillary data	Deep	273.141	3	3
			Moderate	144.623	2	
			Shallow	31.844	1	
	Soil Texture	Ancillary data	Gravelly clay loam	325.681	1	
			Gravelly sandy clay loam	108.427	2	
			Silty loam	15.5	3	
	Soil Slope	DEM	Less than 5 %	326.72	3	
			5–15%	52.192	2	
			Above 15%	70.696	1	
	Soil Erosion	Ancillary data	Slight	316.207	3	
			Moderate	114.32	2	
			Severe	19.081	1	
Land	Landuse	Remote Sensing	Agriculture	316.201	3	2
			Built-up	4.967	0	
			Forest	108.179	2	
			Wastelands	14.502	1	
			Waterbodies	5.759	0	
	Geomorphology	Remote Sensing	Alluvial Plain older	14.392	2	
			Alluvial Plain younger/lower	262.156	3	
			Bazada	55.062	1	
			Upper plateau	117.998	1	
	Geology	Remote Sensing	Deccan Trap	118.615	2	
			Alluvium	275.737	3	
			Bazada	55.256	1	
	Cropping	Remote	Citrus Wood land	2.639	3	

Category	Parameter	Data Source	Classes	Area (sq.km)	Rating	Weightage
	Pattern	Sensing	Current Fallow	1.188	2	
			Dense/Closed	96.274	2	
			Gullied/Ravenous Land	3.401	1	
			Kharif	235.614	2	
			Kharif + Rabi (Double Cropped)	97.510	3	
			Land with scrub	6.929	1	
			Land without scrub	4.17	1	
			Rabi	1.883	2	
Water	Groundwater Fluctuation	Ancillary data	Poor	213.679	3	3
			Moderate	134.57	2	
			High	101.359	1	
	Groundwater Quality	Ancillary data	Fresh	106.394	3	
			Brackish	273.827	2	
			Saline	69.387	1	

Criteria mapping

Initially, a criterion is established to rank various units in each theme with expert knowledge. After establishing the criteria, a raster map is prepared and linked to each criterion, where an individual pixel represents a suitability value. The criterion maps are prepared from basic raster GIS operations such as map overlay, spatial queries, buffering, distance mapping, etc. These maps show the spatial distribution of the criterion performance in achieving the goal. After criteria identification and mapping, each of the factors needs to be standardized to make factors comparable using rank order (RO) with expected value (EV) method (Li et al. 2007; Janssen and Herwijnen 1994; Rietveld 1980). The RO with EV method arranges the criteria in order of importance (high to low) and then it converts that order into the quantitative ranking. The weight, wk, for the criterion k is calculated according to Eq. (1),

$$Wk = \sum_{i=1}^{n+1-k} \frac{1}{n(n+1-i)} \qquad (1)$$

Where, n is the number of criteria. The weights fit the rank order of criteria defined by set S, meaning that w1 ≥ w2 ≥…≥ wn ≥ 0 (Janssen and Herwijnen 1994).

Design of the model

Once all the maps are obtained for each criterion and the factor weights are established (Table 1), it is necessary to integrate all the factors to evaluate the geo-environmental potential index of the region. In the present work, a weighted linear combination method is applied to derive the geo-environmental potential map in ArcGIS 9.3 software (Eq. 2, 3, and 4). The higher geo-environmental potential (GPI) index value indicates the greater geo-environmental resources in the region. The entire area is divided into four categories of suitability based upon the geo-environmental potential index values.

$S_j = \sum w_i$ (2)

Where, S_j represents the suitability for pixel j,

Wi represents the weight of factor I, and

$\mathbf{R_{eq} = \sum_{i=1}^{n} w_i}$ (3)

Where, R_{eq} = regional environmental quality index,

W_i= weight of factor i

n is the total number of factors

GPI = ∑ (weightage for each category) (4)

Results And Discussion

Geology

The geological map of the study area (Fig. 4) shows that it is covered by varied geological formations such as basaltic lava flows (Deccan trap of Upper Cretaceous to Eocene age) covering the northern part of the catchment area which are overlain by Quaternary sediments viz. Piedmont zone (Bazada zone) and the alluvium covering the southern part of the area (Tiwari et al. 2010; Saha and Asthana, 1990). Out of which, the majority of the basin area (61.33%) is covered with a thick pile of alluvial sediments.

Since geology plays a major role in controlling the groundwater as well as surface water resources, the area has been classified by assigning appropriate weights as per groundwater potential. Accordingly, a higher rating of three (3) is given to alluvial plain (older and younger) wherein the groundwater potential is expected to be very good to excellent. While least weightage (1) is given to the Bazada zone due to its poor groundwater potential since it acts as a groundwater run-off zone. The Deccan trap having moderate groundwater potential is allotted with the weightage value of two (2).

Geomorphology

Geomorphological processes reflect inter-relationship amongst the variables like climate, geology, soils, and vegetation; and thus, therefore, are an important aspect of environmental analysis and planning (Buol 1973; Blarzcsynski 1997). The geomorphological set-up of the study area is interpreted from the digitally enhanced satellite image and the results of the same are categorized into four different geomorphological units i.e. alluvial plain younger/lower, alluvial plain older, Piedmont zone (Bazada zone), and the upper basaltic plateau (Fig. 5). The thematic map on geomorphology reflects that the older alluvial plain, formed due to the deposition of river sediments, is widely distributed and has covered an extensive area of 262.15 km^2 (50.30% of the total area). The other geomorphological unit i.e. Piedmont zone (Bazada zone) trends from north to south and spreads in a 55.26 km^2 area. The least area of the basin is occupied by the younger alluvium plain unit, having about 14.39 km^2 spread (3.20% of the total area). The upper plateau developed over the Deccan trap is present exclusively in the northern part. The lowest occurred zone is the younger alluvium plain covering about 14.39 km^2 area and incorporating about 3.20% of the total catchment area. Based on their hydrological properties, the highest rating of three (3) is assigned to the alluvial plain (older and younger) whereas the lowest rating of one (1) is assigned to the Piedmont zone (Bazada zone).

Landuse/ Landcover

The existing land use in the area is a key factor to understand the land utilization process which has a direct bearing on groundwater situation and hence forms a base of designing the developmental plan for any region. The map on land use/land cover for the study area is prepared from the IRS-P6 LISS III satellite image data (acquisition in October 2015), by executing the maximum likelihood classification algorithm technique. The entire process of classification of the satellite image is performed in Arc-GIS 9.0 software. The map so obtained shows, five major classes, viz. agriculture, built-up, forest, wastelands, and water bodies (Fig. 6). During the process, the highest rating (3) is assigned to agriculture, whereas the lowest rating (0) is assigned to the built-up land and water bodies due to their lesser possibility of changing the existing land use pattern. The land use/land cover map of the study area shows the dominance of the agricultural area. The high altitude region encompasses the forest area. As agriculture is present over most of the area the need for water for crop cultivation is also demanding which anticipates overexploitation of groundwater.

Cropping Pattern

The thematic map pertaining cropping pattern has been prepared from the digitally enhanced image and analyzed further to obtain the results on the cropping pattern scenario. The results are categorized into nine (9) divisions of crop i.e. citrus plantation, current fallow land, dense closed forest, gullied/ravenous land, *Kharif*, *Kharif + Rabi* (double-cropped), land with scrub, land without scrub, and *Rabi* (Fig. 7). This map on the cropping pattern depicts the growth of dense forest over 96.28 km^2 (21.41%) area in the northern hilly region. Because of inadequate water availability, *Kharif* is the most cultivated crop in the area of 235.61 km^2 (52.40%); whereas, *Rabi* crop is least occurred and found scattered over 1.88 km^2 (0.42%) in the near central region. The presence of *Kharif + Rabi* (double-crop) is also remarkable in its presence and occupies 97.51 km^2 (21.69%) of the region. The highest rating (3) is assigned to *Citrus* along with *Kharif + Rabi* (double-cropped) as they show the productive lands whereas the lowest (1) rating is assigned to the gullied/ravenous land and scrubland where there is further scope for its development.

Groundwater Quality

The work on groundwater quality in the study area has been attempted earlier by various researchers. The available hydrochemical data generated by Jain and Tambe (2012) is modified and used further by applying the nearest neighbor interpolation technique in a GIS platform to derive the groundwater quality map for the Bordi watershed. Based on the distribution of total dissolved solid (TDS) values, the watershed area is categorized into three divisions, i.e. fresh, brackish, and saline water (Fig. 8). The freshwater (TDS < 1500) has occupied an area of 106.34 km^2 (23.67%) primarily in the northern-southern parts and few patches of the north-east region. The brackish water (TDS in between 1500–3000) has the maximum areal extent and is found mainly in the central region of 273.82 km^2 area (60.90%). The saline groundwater (TDS > 3000) is found distributed in the north-east and south-west regions and has 69.38 km^2 (15.43%) of aerial extent. The highest rating is assigned to freshwater whereas the lowest rating is assigned to the saline water category. This is because fresh water is more considerable over saline water from the geo-environmental point of view.

Groundwater Fluctuation

The studies on groundwater levels and their fluctuations over the period (i.e. pre and post-monsoon periods) are vital to understanding the groundwater regime of any area. The hydrogeological data of 66 inventory wells from the entire watershed were collected pre and post-monsoon season of the year 2012. The total depth of the existing wells ranged from 2.6 and 39.80 m below ground level (bgl). The pre-monsoon and post-monsoon water level vary from 1.4 and 39.60 m (bgl) and 0.9–39.50 m (bgl) respectively. The average seasonal fluctuation is around 0 to 6.90 m. The groundwater fluctuation map for the study area is derived based on water table data of the observation wells (Table 2). As per this, the map is categorized into three classes i.e. high, moderate, and poor (Fig. 9). Poor groundwater fluctuation is the most dominant category over 213.679 sq. km and comprises 47.52% of the total area. The highest rating (3) is assigned to poor fluctuation whereas the lowest rating (1) is assigned to a high fluctuation category according to the groundwater potential.

Table 2
Well inventory details of total sixty six (66) dug wells falling in the Bordi Watershed

Well No.	Location/ Village	Total Depth (mbgl)	Depth to Water Level (mgbl)		Groundwater Fluctuation (m)
			Pre-Monsoon	Post-Monsoon	
1.	Yeoda	9.94	6.25	4.8	1.45
2.	Yerandgaon	11.28	6.1	5.65	0.45
3.	Bambarda	7.84	4.27	1.2	3.07
4.	Pimplod	13.59	8.36	6.25	2.11
5.	Jainpur	8.36	8	7.4	0.6
6.	Adula	7.39	6.61	4.2	2.41
7.	Sagarvadi	7.72	5.97	2.5	3.47
8.	Jogarvadi	6.71	4.68	2.6	2.08
9.	Warudbedruk	7.01	7.32	5.7	1.62
10.	Warudbedruk	8.23	7.14	5.9	1.24
11.	Rajkheda	10.93	6.88	6.2	0.68
12.	Wadnergangai	10.54	7.67	5.6	2.07
13.	Wadnergangai	5.31	5.41	4.1	1.31
14.	Wadnergangai	7.59	6.88	5.25	1.63
15.	Wadnergangai	6.48	6.76	5.1	1.66
16.	Wadnergangai	11.25	8.18	6	2.18
17.	Wadnergangai	13.03	9.25	7.1	2.15
18.	Gavandgaon	11.91	12.29	8.5	3.79
19.	Hingani	12.1	9.58	6.5	3.08
20.	Kalgavan	28.23	20.48	17.6	2.88
21.	Kalgavan	20.7	21	20.45	0.55
22.	WadaliDeshmukh	20.25	20.9	20.5	0.4
23.	Bhuraskheda	18.25	18.55	18.55	0
24.	Nimkhed	39.62	35.05	35.05	0
25.	Nimkhed	28.66	24.38	24.38	0

Well No.	Location/ Village	Total Depth (mbgl)	Depth to Water Level (mbgl)		Groundwater Fluctuation (m)
			Pre-Monsoon	Post-Monsoon	
26.	Karla	32.2	29.1	28	1.1
27.	Bhandaraj	32.39	30.25	28.9	1.35
28.	Gavandgaon Bk.	7.48	10.2	7.6	2.6
29.	Sategaon	17.85	17.65	17.1	0.55
30.	Sategaon	21.92	22.37	22	0.37
31.	Rajapur	22.09	22.24	19.1	3.14
32.	Rajapur	15.4	15.9	15.25	0.65
33.	Jawardi	26.8	21.76	20	1.76
34.	Dhanwadi	30	30	29.5	0.5
35.	Adgaon	39.7	39	38.8	0.2
36.	Murtijapur	41	39.6	39.5	0.1
37.	Malkapur	28.95	25.7	25.4	0.3
38.	Malkapur	25.18	25.5	25.3	0.2
39.	Adgaon	39.8	38.5	38.3	0.2
40.	Karla	30.7	28.35	26.4	1.95
41.	Panaj	29.7	30	27.35	2.65
42.	WadaliDeshmukh	33.63	26.9	20	6.9
43.	Ruikhed	26.1	19.1	13.8	5.3
44.	Mahagaon (Gadhi)	6	4.9	3	1.9
45.	Mahagaon (Gadhi)	2.6	1.4	0.9	0.5
46.	Rajura	7.95	5.7	2.9	2.8
47.	Vastapur	7.78	3.2	1.4	1.8
48.	JanunaBedruk	5.4	4.5	1.5	3
49.	Jhingapur	12.35	12.6	6.4	6.2
50.	Menghat	6.4	6	1.4	4.6

Well No.	Location/ Village	Total Depth (mbgl)	Depth to Water Level (mgbl)		Groundwater Fluctuation (m)
			Pre-Monsoon	Post-Monsoon	
51.	Khirkundkhurd	4.9	3.2	2.35	0.85
52.	Mardi	8.8	5.6	1.85	3.75
53.	Ruikhed	31.7	21.5	18.7	2.8
54.	Chausala	35.6	35	34.8	0.2
55.	Chinchona	29.2	20	17.2	2.8
56.	Nimkhed Bazar	24.35	21.5	18.8	2.7
57.	Hirapur	26.3	24.7	21.7	3
58.	Palaskhed	9.35	6.7	3.5	3.2
59.	Khirada	23.6	24	22.2	1.8
60.	Lakhar	36.45	35.2	35	0.2
61.	Hasnapur	29.1	28.15	27	1.15
62.	Anjangaon	24.9	24.5	22.5	2
63.	Selgaon	28.95	27.15	24.4	2.75
64.	Dhari	11.95	9.3	5.9	3.4
65.	Dahigaon	28.8	24	18.2	5.8
66.	Garajdari	6.0	5.0	1.5	3.5
Range		2.6–39.80	1.4–39.60	0.9–39.50	0-6.90

Soil Depth

The soil formed in topographic sequence under specific geo-pedological environmental conditions has great influence of different geomorphic features in conjunction with the type of parent materials (Kantor and Schwertmann 1974). For digital soil depth database creation, the soil map developed by the National Bureau of Soil Sciences & Land Use Pattern (NBSS & LUP) is used in this study and the obtained results are categorized into three classes *i.e.* deep, moderate, and shallow depths (Fig. 10). The soils of the Bordi watershed show a wide variation in their depths because of their physiographical set-up. The soils on hills and slopes are having shallow to medium depth while in the low lying areas and river valleys deep soils are observed. Soil depth map depicts shallow soil (< 25cm) at the high altitude regions particularly in the northern part, moderate soil (25-50cm) mostly in the valley fills around the shallow depth region, and deep soil (> 50cm) in the central and entire southern region of the watershed. The ratings are assigned according to the importance of soil depth as per its erodable nature, in which, the highest rating (3) is assigned to the deep soil which is least prone to erosion, whereas, the lowest rating (1) is assigned to shallow soil that is highly susceptible to erosion.

Soil Texture

Soil texture is one of the important factors in development planning as it governs the infiltration characteristic of soil (Varade et al. 2013). The soil map depicted mainly three types of soil textural classes i.e. gravelly clay loam, gravelly sandy clay loam, and silty loam (Fig. 11). The major portion of the study area is occupied by gravelly clay loam 325.68 km^2 (72.43% of the total area) as apparent from the map. The poorly drained clay soils have a high runoff, while sandy soils generate less runoff (Aller et al. 1987). Considering this, the highest weightage of three (3) is given to silty loam, while weightage of two (2) is given to gravelly sandy clay loam and one (1) weightage is provided to gravelly clay loam.

Slope

The slope or topographic features of an area are important as they affect the run-off process, soil erosion, and land use planning. By considering it, the slope map of the watershed was generated by using the Cartosat-1 DEM and Survey of India topographical maps. The topography of the area is distributed as the low slope (less than 5%) over the entire alluvial region towards the mid-lower portion, moderate slope (5–15%) occurs in a piedmont zone in the northern side, and high slope (> 15%) seen in the extreme northern boundary (Fig. 12). It is found that the majority of the study area falls under the low slope class (Table-1). The highest rating of three (3) is assigned to the low slope category due to its favorable situation for agricultural, plantation, and developmental activities. All land with low to moderate topographical location was rated high for sustainable geo-environmental protection and development.

Soil Erosion

Soil erosion is a process of removing the earth material (both rock debris and soil) and its further transportation to a longer distance by the various erosive agents (Singh 1998). The studies on soil erosion are essential to predict soil erosion rates under land-use conditions vis-à-vis geo-environmental situation. The soil erosion data extracted from the soil map of NBSS & LUP depicts three divisions viz. slight, moderate, and severe erosion types (Fig. 13). Because of the planer topography, slight erosion is observed in most of the central and lower reaches covering 316.207 sq. km area (70.33%). Moderate erosion is observed mostly in the highlands of the Deccan trap region due to its resistive nature, whereas severe erosion is remarkably observed only along the stream channels and a few places in the highlands of weathered nature. The highest rating is assigned to slight erosion whereas the lowest rating is assigned to severely eroded areas. This is because slight erosion is much considerable over severe erosion from the geo-environmental point of view.

Integrated Regional Geo-environmental Quality Evaluation

The status of the physical environmental condition discussed above reveals the environmental quality scenario, thus indicate towards limited choices of land use/land cover, soil erosion, infertility of soils, and paucity of potable water, etc. Similarly, the long-term use of improper agricultural practices has exploited land and water resources in the basin and poses the problems of sensitivity, fragility, and environmental changes. The geo-environmental potential index (GPI) of the Bordi River basin is calculated based on the above ten factors. The GPI values of the basin range between 3 to 30. Subsequently, these values are reclassified into four classes as follows: (a) poor resources (< 9), (b) low resources (9–16), (c) moderate resources (16–23), (d) high resources (> 23) (Table-3) and the spatial distributions of regional geo-environmental resources are given in Fig. 14. The categorization of geo-environmental resources in the study area is discussed below;

Area with high geo-environmental resources

The areas with the high geo-environmental resources are distributed in the southern part of the Bordi watershed. The geo-environmental potential index map shows that approximately 48.30% of the study area is classified under high geo-environmental quality with GPI index values ranging between 23 to 30. The region shows good vegetation cover, a weak and slight intensity of soil erosion. The sound quality of the geo-environment in this portion is due to high vegetation cover, rich nutrients in the soil, fewer disturbances by human beings, and good soil penetrability. The high geo-potential of the area indicates that this area is very suitable for development through agricultural practices and thus is likely to be overexploited which may lead to degradation of the environment. Therefore the area needs the implementation of conservation measures on a large scale mainly to retain sustainability.

Area with moderate geo-environmental resources

The moderately geo-environmental resources zone accounts for 25.75% of the whole study area with its values ranging between 16 and 23. It is distributed in the north and south-west of the study area (The landform is characterized by high mountains and leveled lands), of which the ecosystem is composed of dense forest in the uplands. Areas with moderate eco-environmental quality have strong eco-sensitivity, less human interferences, and important ecosystem service included the whole of Chikhaldara, mid, western, and northern parts of the Bordi basin. The major region is occupied by farmland, forest, along with some grassland. The human activities are relatively less, thus making the environment quality of this part better. This area is also likely to deteriorate due to the exploitation of forest resources as well as high erosion due to steep slopes and thin soil cover. To protect the area from further deterioration it is necessary to implement soil and forest conservation techniques in this area.

Area with low geo-environmental resources

The low geo-environmental resources zone is mainly concentrated in the northern part of the Bordi watershed. It constitutes 23.98% of the basin area with GPI index values ranging between 9 and 16. The major land-use types in this area are agriculture and forestland. The eco-environment of the area appears to be affected by human activity more seriously, and the eco-environment quality is only generic.

Area with poor geo-environmental resources

The areas with poor geo-environmental resources are located in the northern area in the form of scattered patches of 8.88 km^2 only accounted for a very small proportion (2%) of the study area. The areas are in the vicinity of small towns with a hard surface and limited vegetation cover (Schotten et al. 2001). The GPI index has values is below nine (< 9). This area since located close to human settlement is more prone to degradation due to their activities thus requires measures for restoration of soil and vegetation cover.

Table 3
Geo-environmental quality categories of study area

Class	GPI Index	Area (km^2)	Area (%)
High resources	> 23	217.18	48.30
Moderate resources	16–23	115.79	25.75
Low resources	9–16	107.84	23.98
Poor resources	< 9	8.88	2
		449.608	100%

Conclusion And Recommendations

This study describes a methodological approach for synthetic evaluation of regional geo-environmental resources of the Bordi River based on the integrated use of spatial database through remote sensing, GIS, and Multi-Criteria Decision Analysis (MCDA) techniques. The results of this study revealed that the geo-environment in the area is at a high level, but some area shows low to the poor condition of GPI. The results of the evaluation could be useful in planning and management strategies of the geo-environment of the area. Accordingly, the areas with GPI Index above 23 require immediate attention for the protection of a sustainable environment in the long term as these areas are likely to be adversely affected in the process of development because of over-exploitation. Similarly, attention is also required to areas of low GPI Index because of their vulnerability to soil erosion, and measures such as afforestation, conservation of forest need to be implemented in such areas. The paper highlights GIS and MCDA approach in environmental research analysis and ecosystem services evaluation as it takes care of all the relevant factors (natural and human influence) which have a direct bearing on the environmental situation in an area. The concept envisages the adoption of the holistic approach of development in which no single resource is over/under-exploited and thus facilitates maintenance of ecological balance.

Declarations

Acknowledgments

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Figures

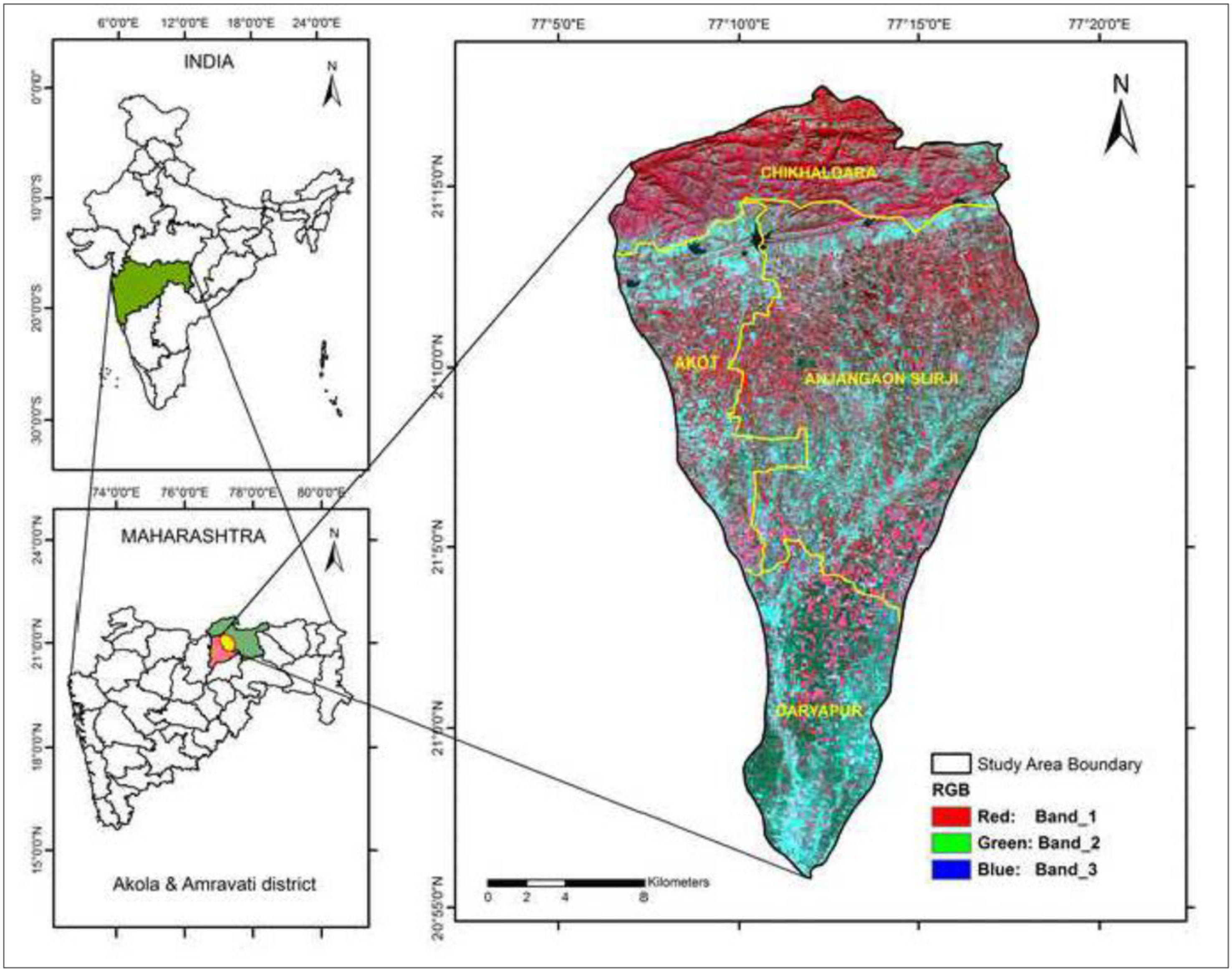

Figure 1

Index Map of the study area

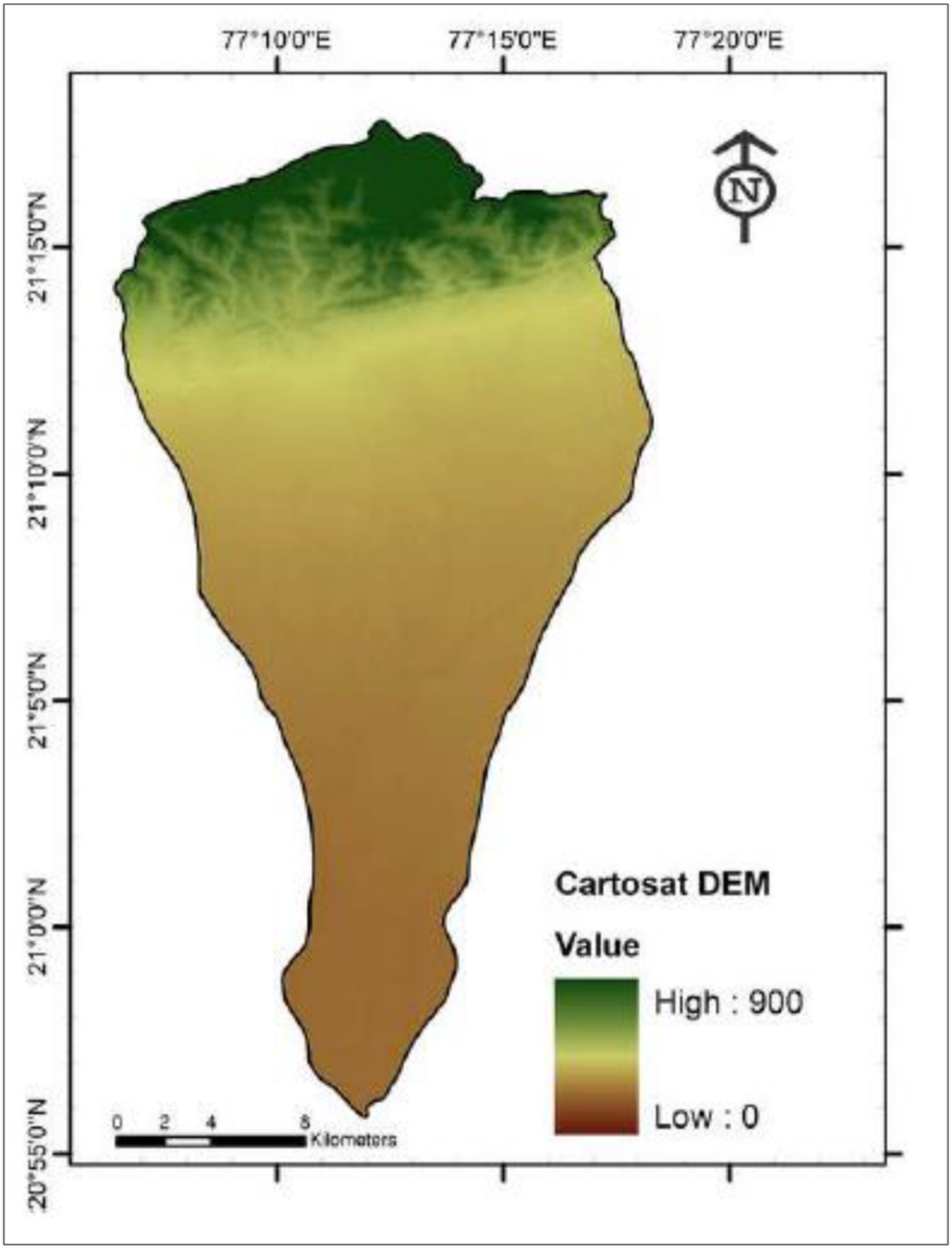

Figure 2

DEM for the study area

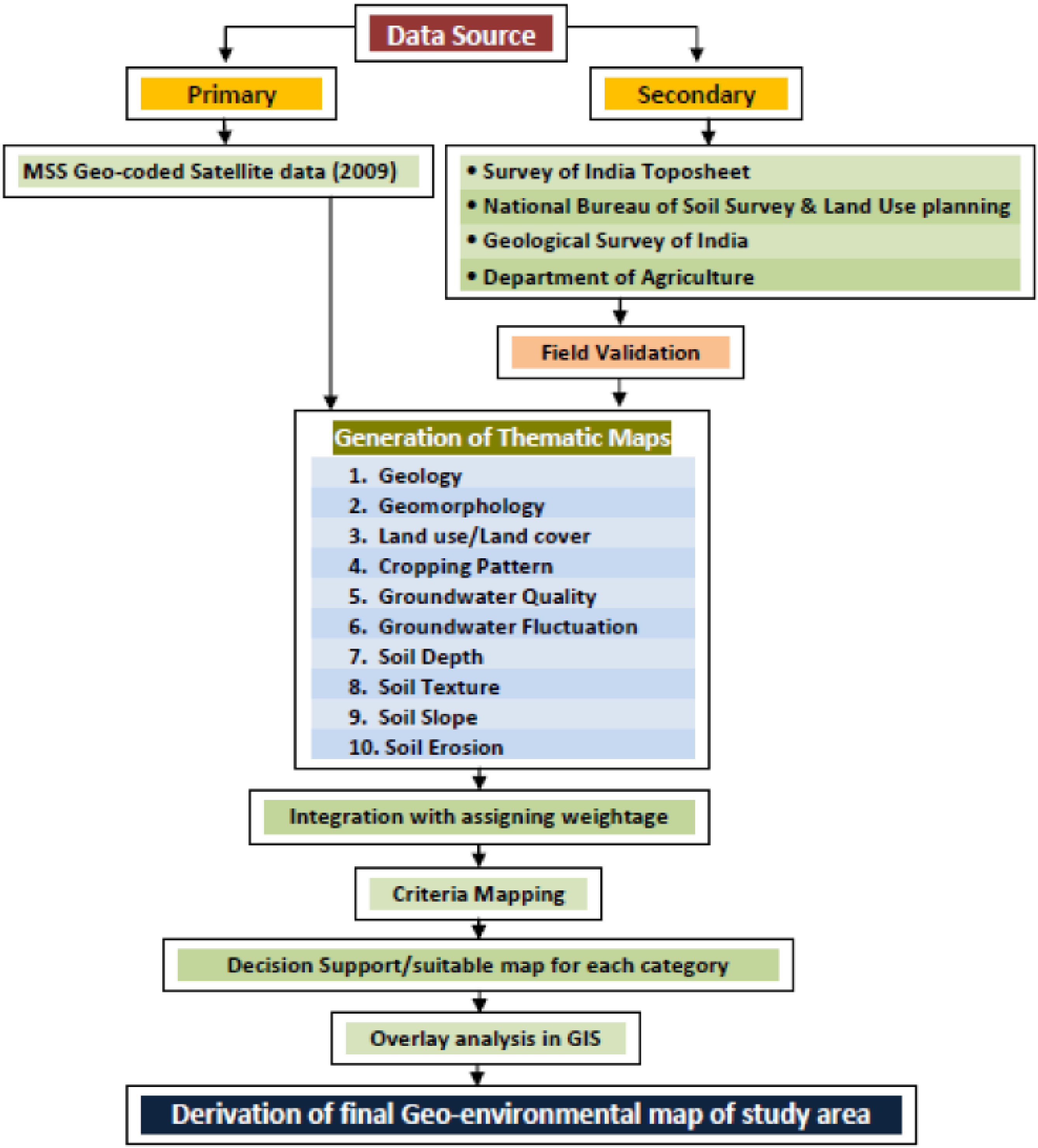

Figure 3

Flow chart showing methodology adopted in the work

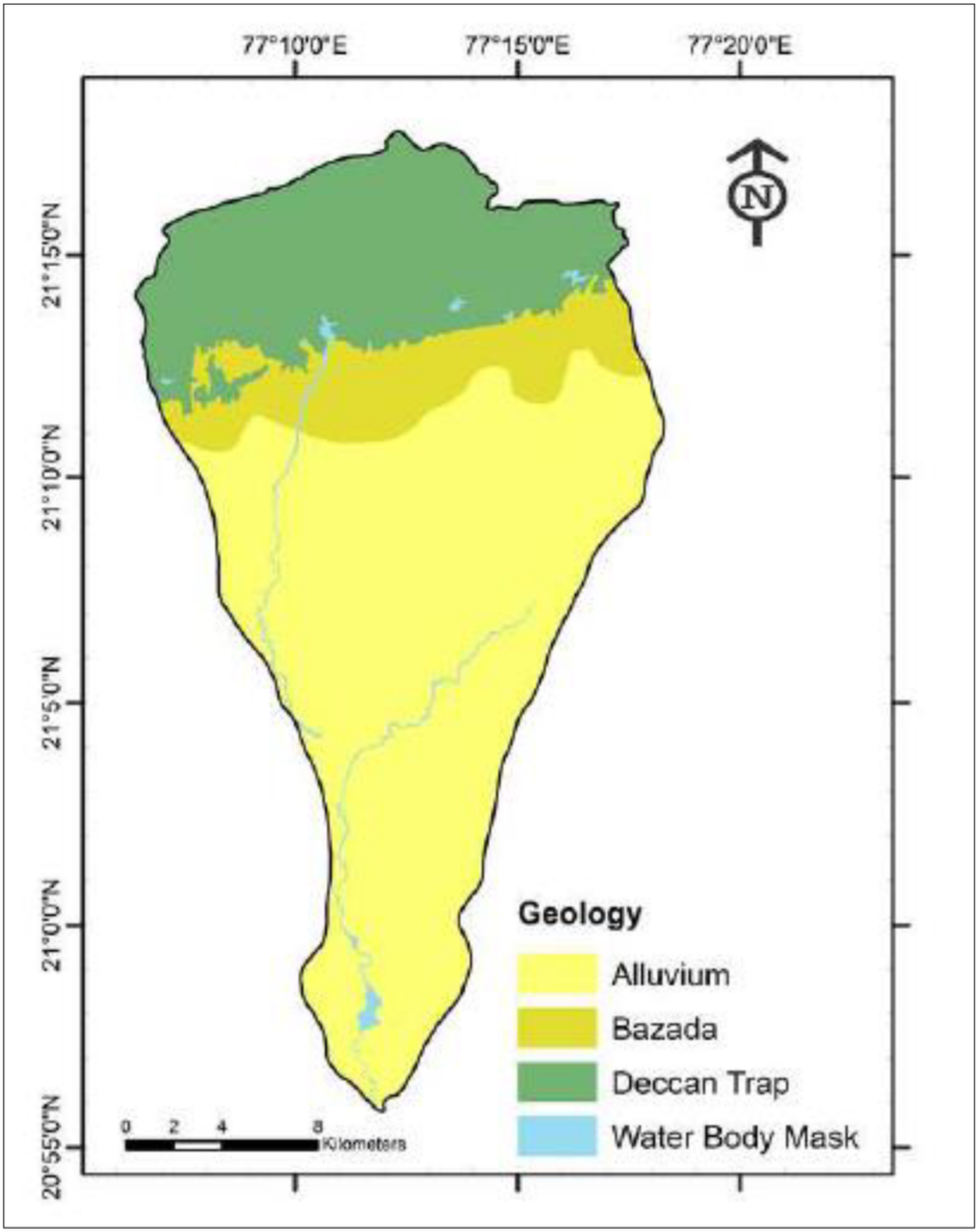

Figure 4

Geology distribution

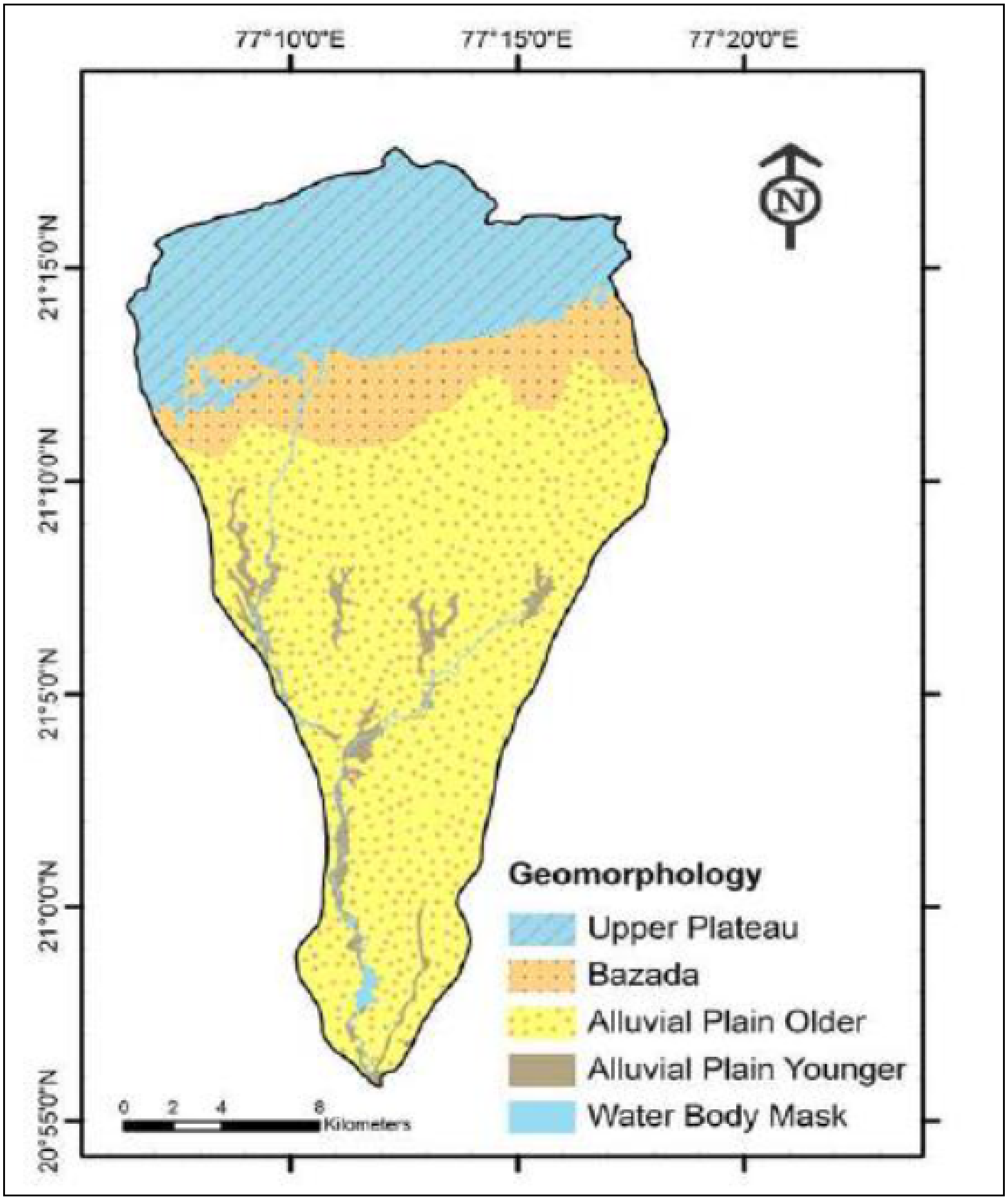

Figure 5

Geomorphology distribution

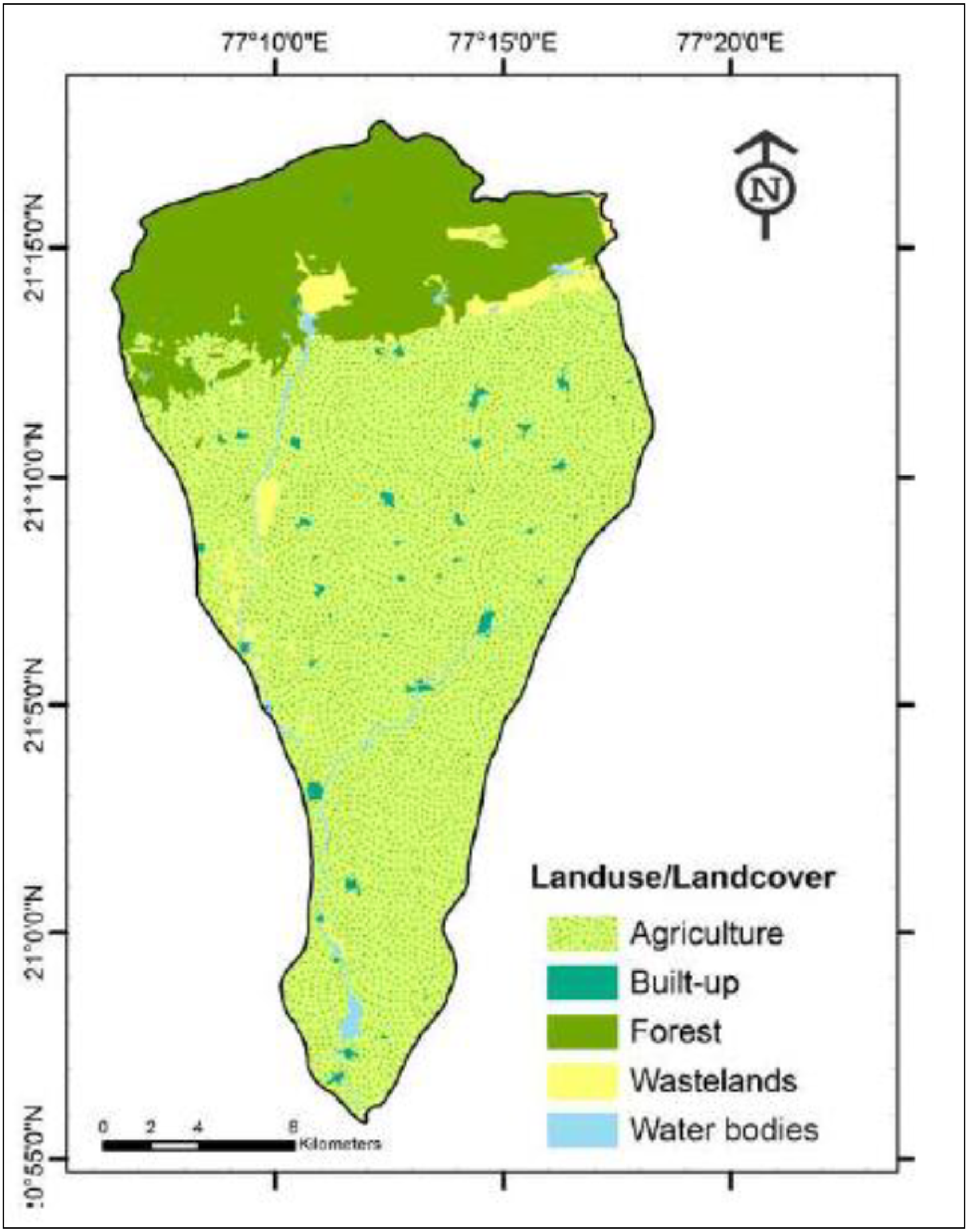

Figure 6

Land use/ land cover classification

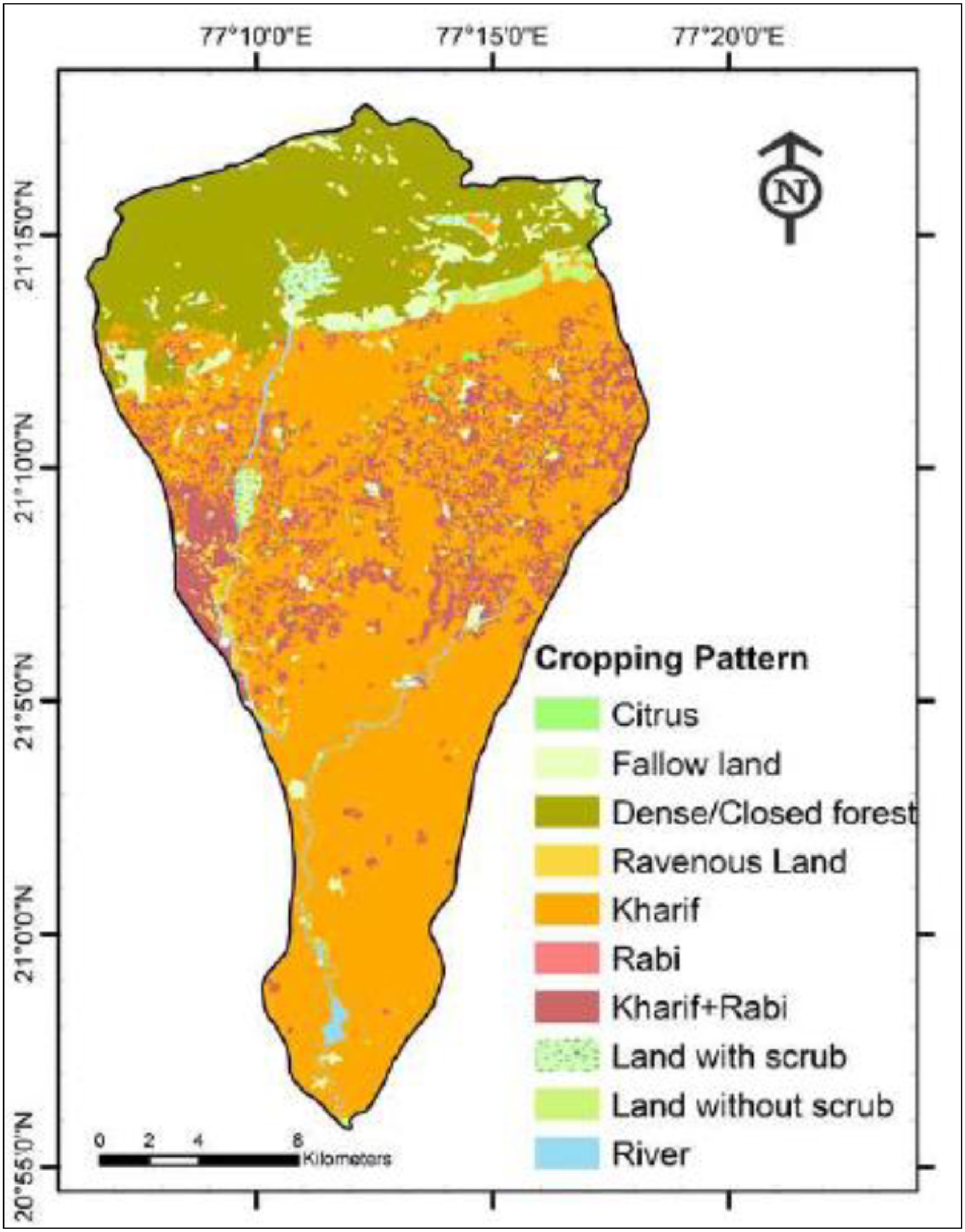

Figure 7

Cropping pattern distribution

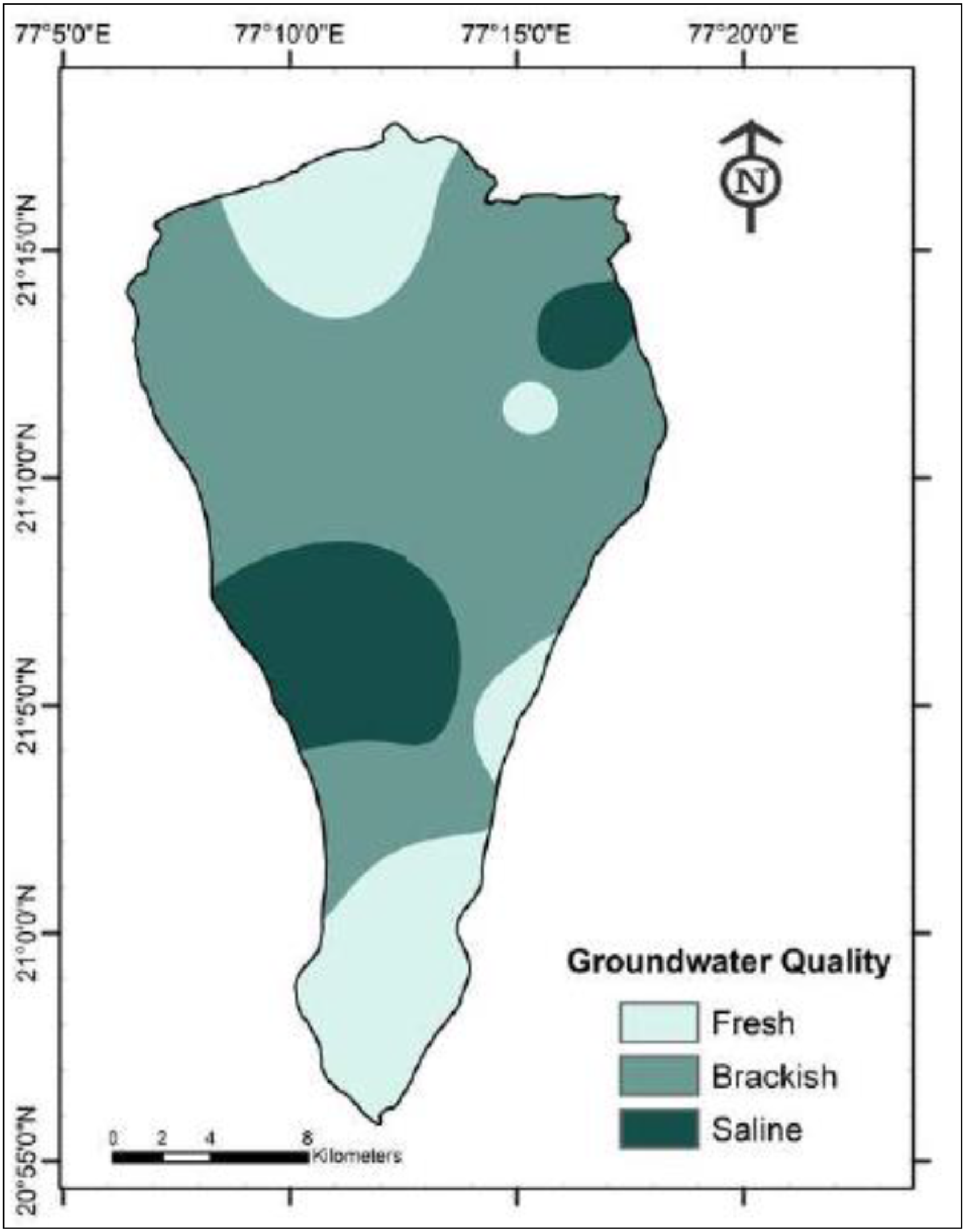

Figure 8

Groundwater quality distribution

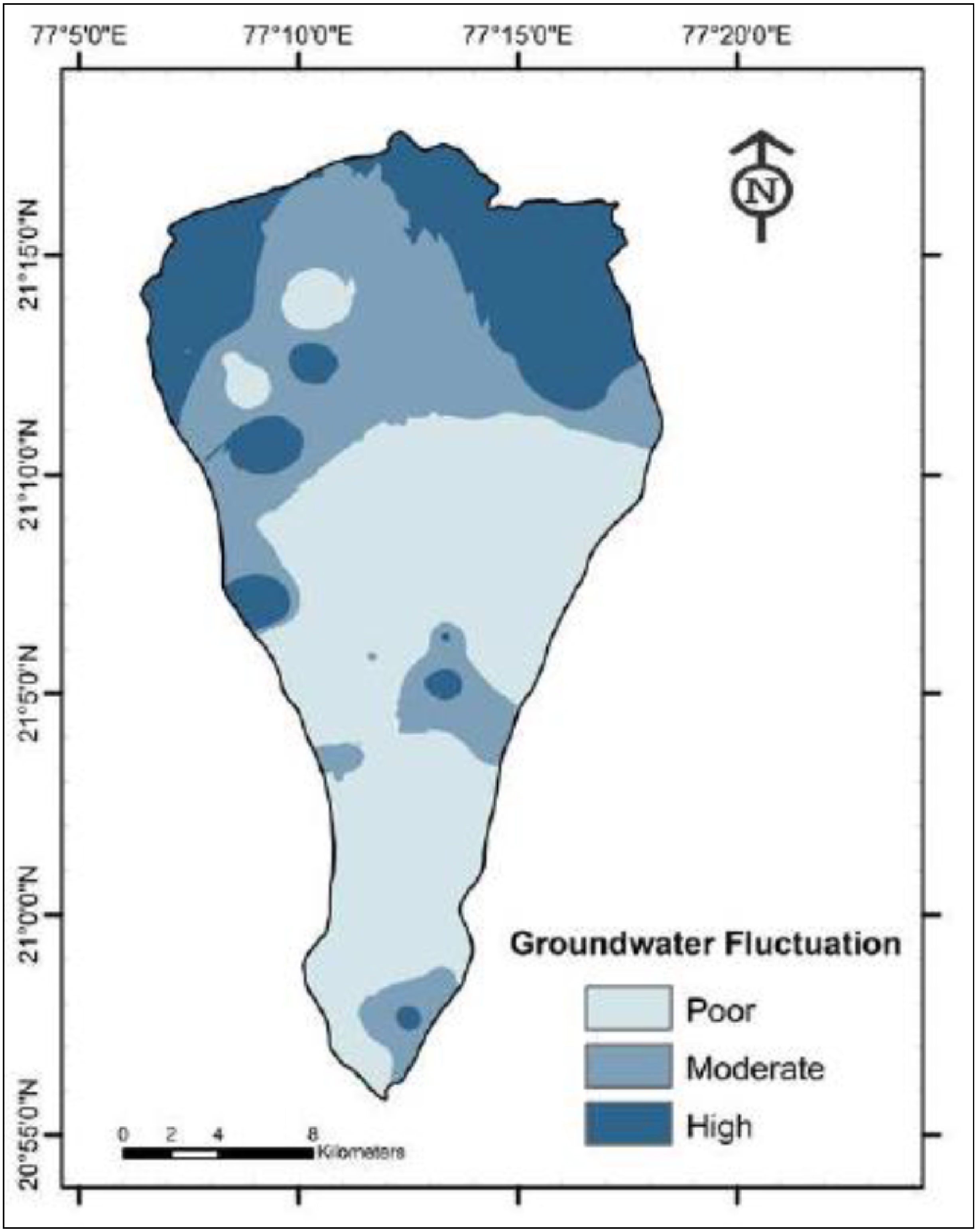

Figure 9

Groundwater fluctuation distribution

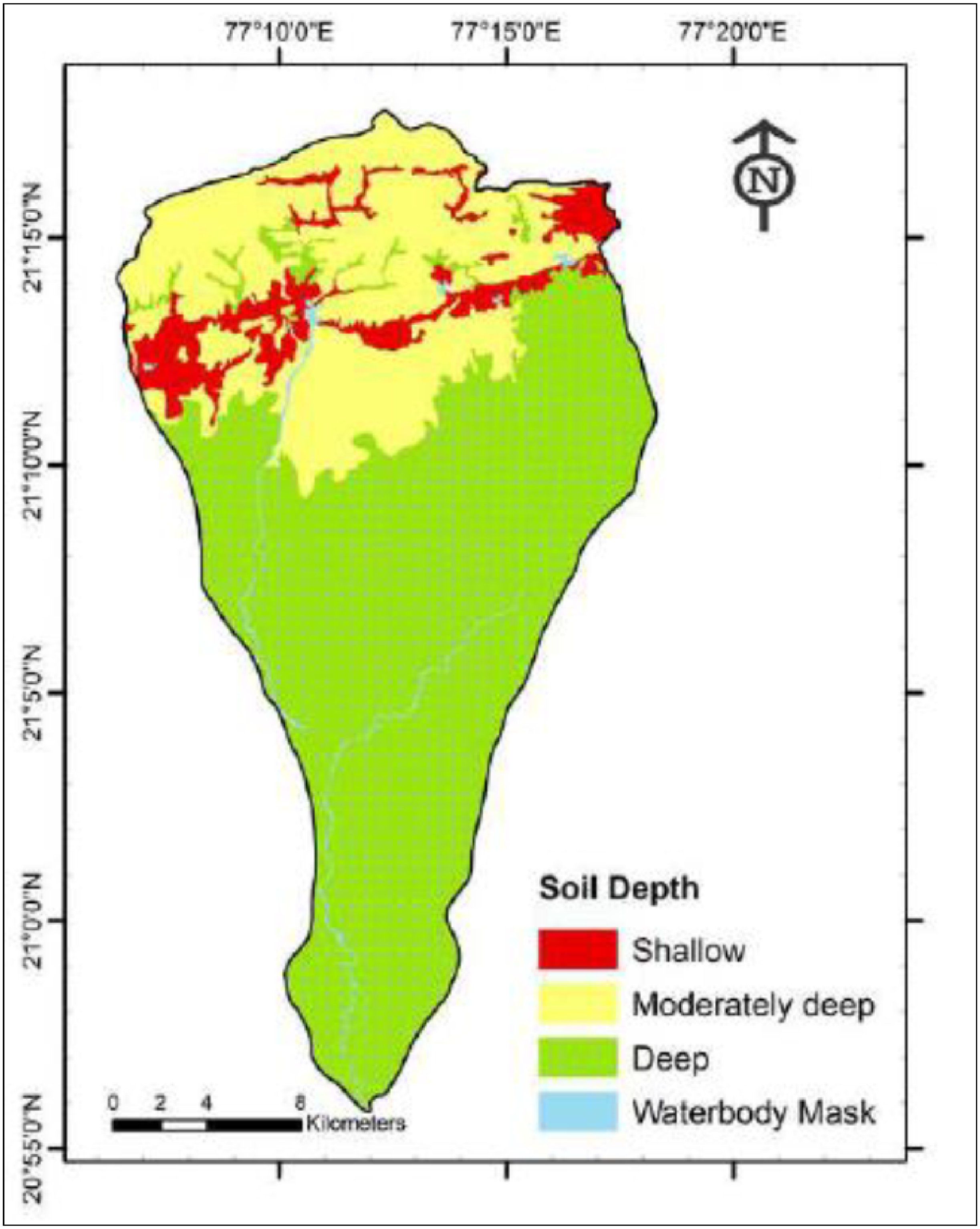

Figure 10

Soil depth distribution

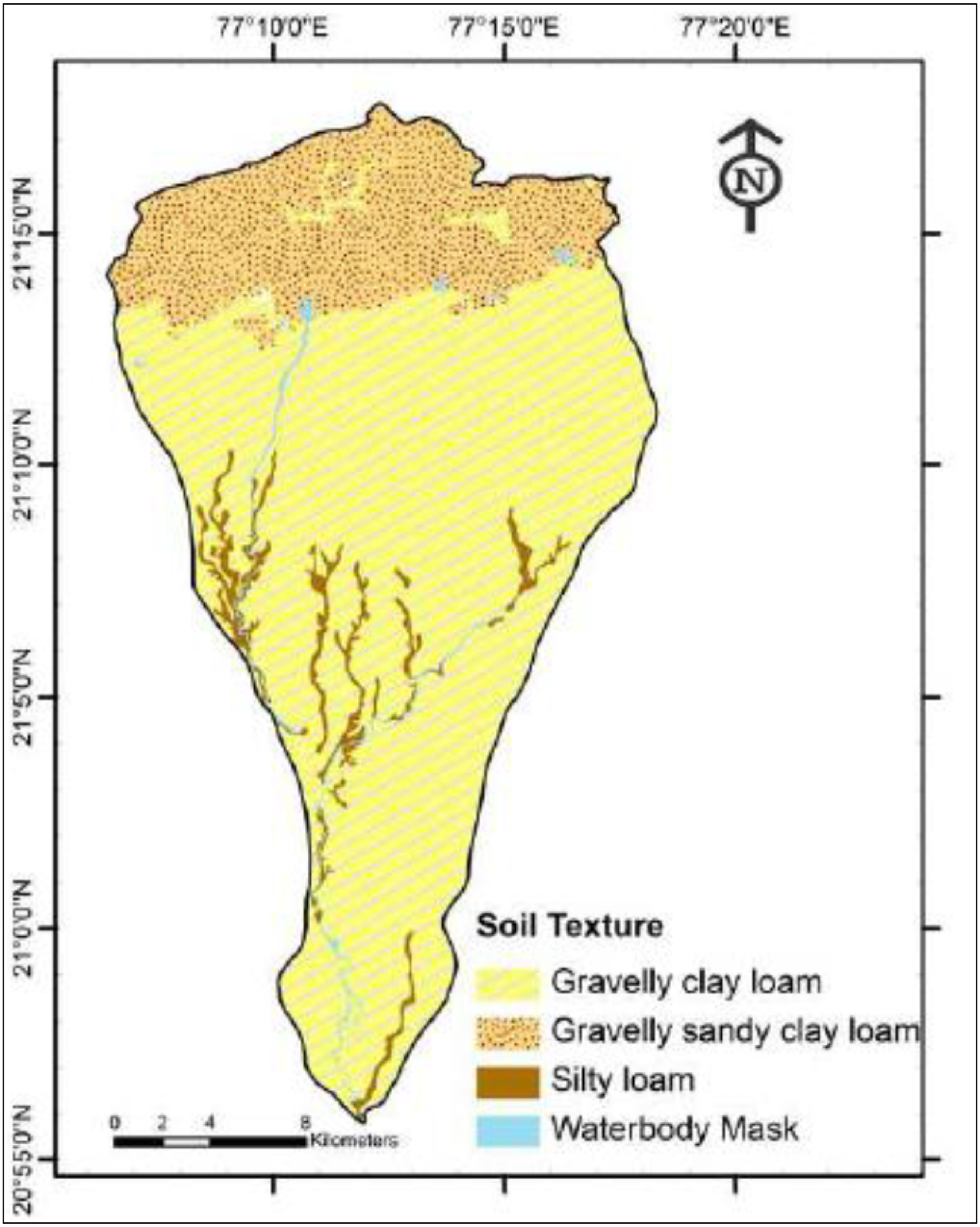

Figure 11

Soil texture distribution

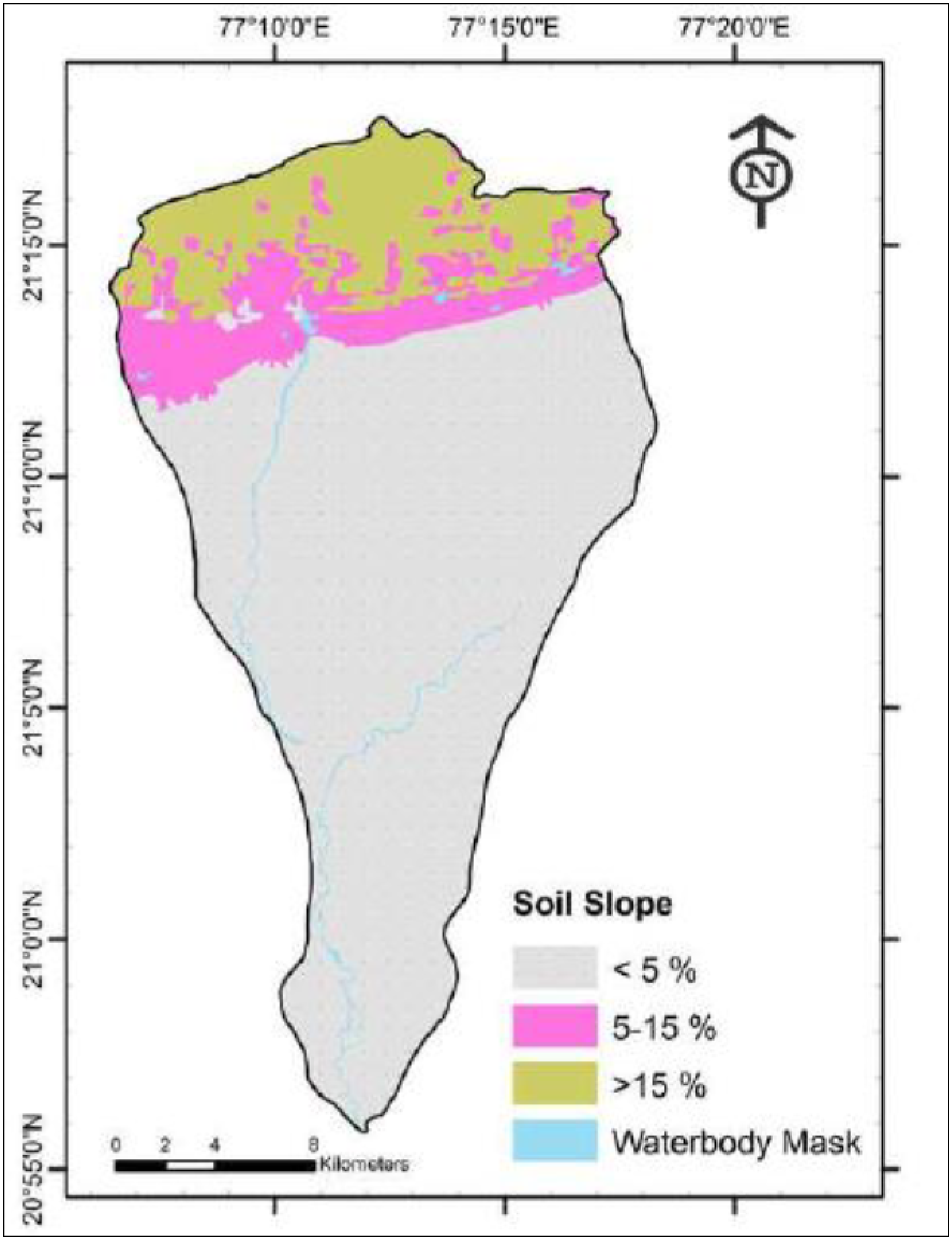

Figure 12

Soil slope distribution

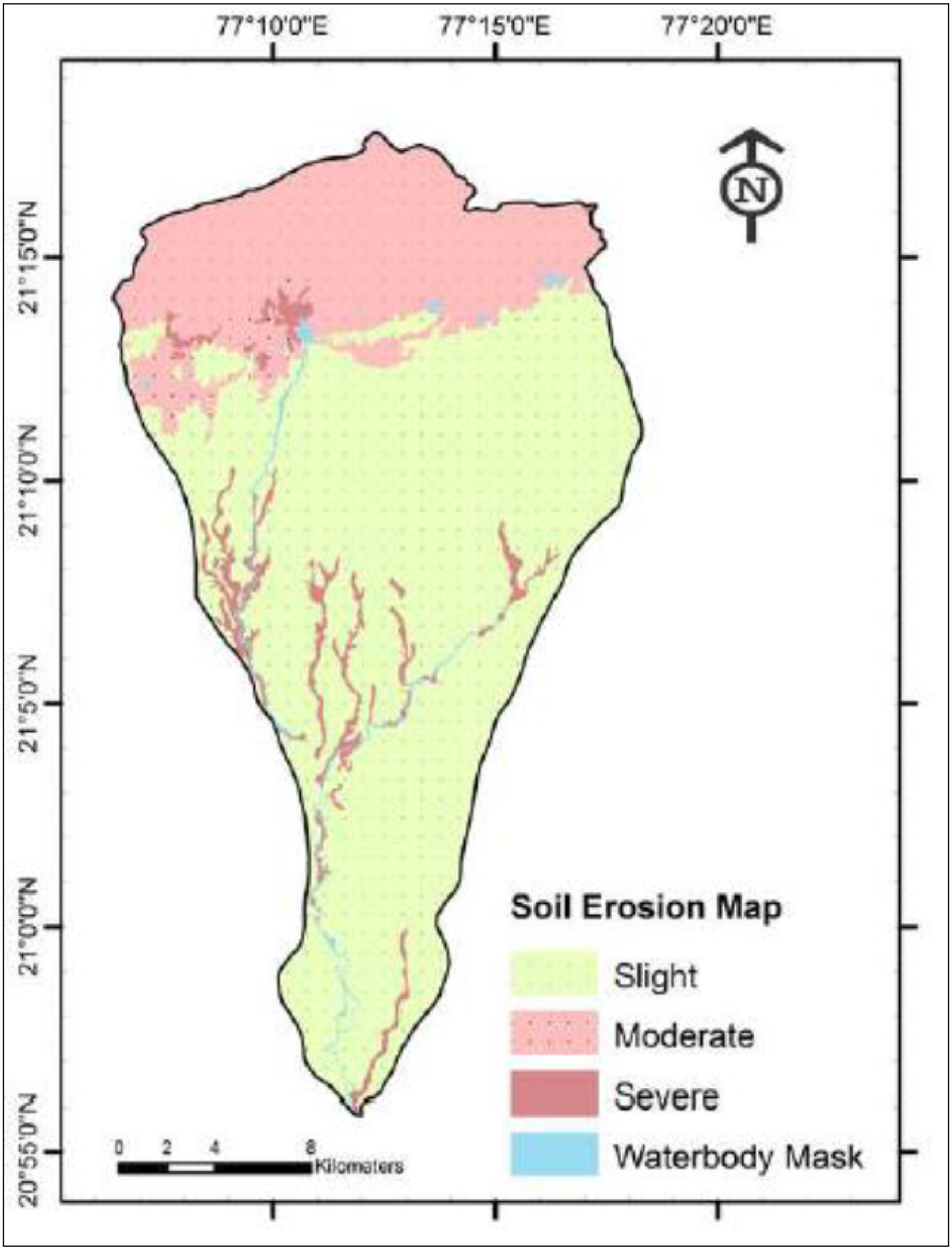

Figure 13

Soil erosion distribution

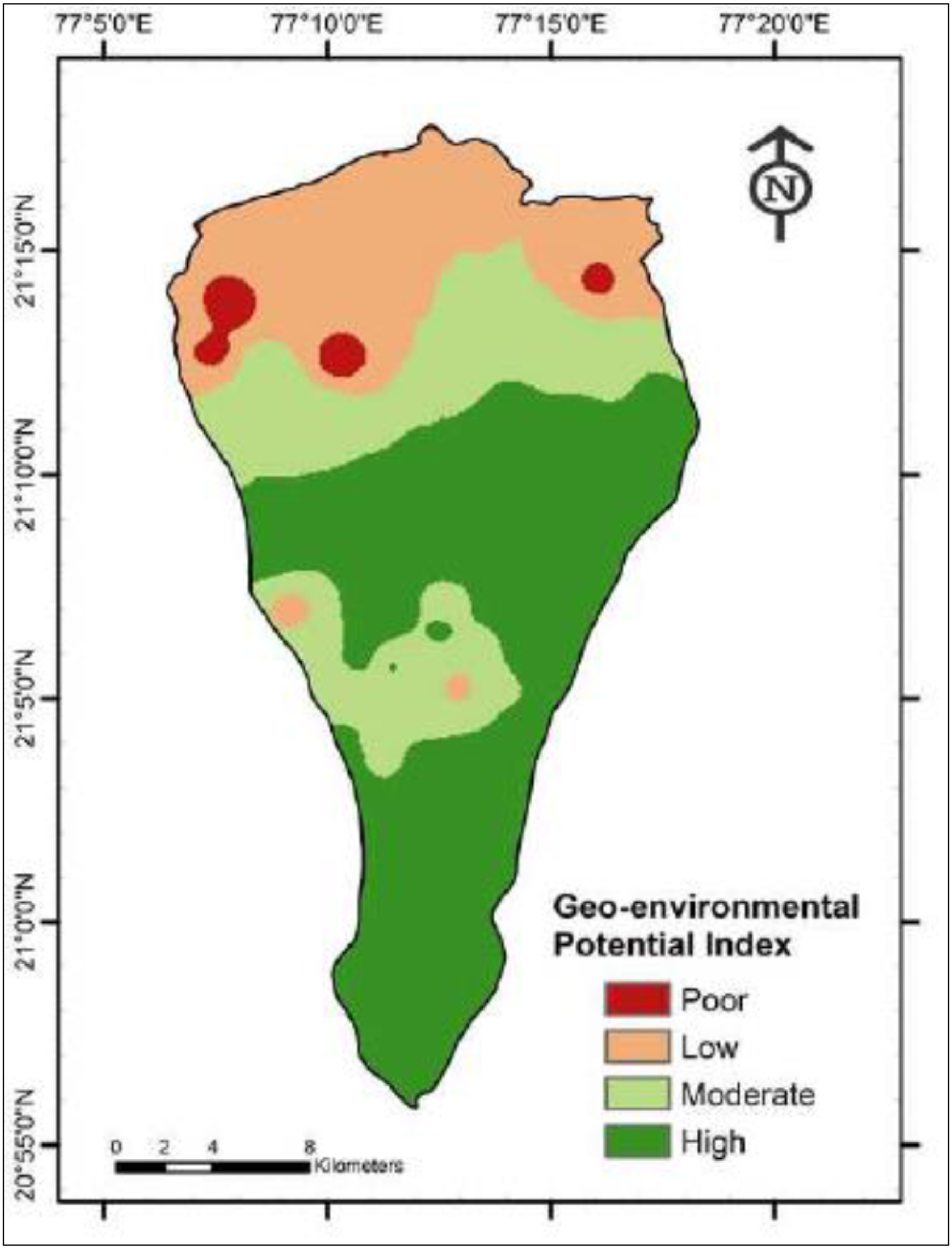

Figure 14

Geo-environmental category comprehensive evaluation classification map