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ORIGINAL ARTICLE

An assessment of geo-environmental quality using physical data and a geospatial approach: an example for a watershed in Central India

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Abstract
A spatial multiple criteria evaluation analysis (SMCE) was undertaken using GIS and remote sensing techniques with spatial datasets to identify the geo-environmental values for a watershed in central India. All the geo-environmental values were estimated based on this dataset for the development of an ecological system. We have investigated the resources of an environmental status of the region using this methodology. A set of ten natural resource parameters were evaluated using a combination of remote sensing information, GIS technologies and field data, which has significance in regional geo-environment sustainability. An integrated geo-environmental potential index (GPI) has been calculated and the same is used further to derived 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 of study area are significant for identifying the protection, conservation, and planning management strategies that would be needed to protect the geo-environmental values of the river basin area. The geo-environmental potential zones that were identified are potentially manageable using conservation techniques. The work amply proves the applicability of RS, GIS, and SMCE techniques in the natural resource evaluation procedure.

Keywords Geo-environmental quality · Spatial multi-criteria evaluation · Remote sensing · GIS · Central India

Introduction

Currently, the excessive use of natural resources and poorly planned land development is leading to environmental degradation throughout the world (Pande et al. 2022; Orimoloye et al. 2022). The situation calls for the implementation of appropriate measures to restore and conserve the remaining ecosystems in many parts of the world (Rajesh et al. 2022). 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 (DeGroot 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). The process of development may also cause the loss of soil and the degradation of other geo-environmental components of a landscape which also need to be addressed with appropriate restoration 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 used for these studies are: the comprehensive evaluation method (Goda and Matsuoka

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1986); the gray evaluation method (Hao and Zhou 2002); the landscape evaluation method (Antonio et al. 2003; Song et al. 2012; Kangas et al. 2000); the osculation value method (Park et al. 2004); the fuzzy evaluation method (Dzeroski 2001; Adriaenssens and Baets 2004); and the artificial neural network evaluation (Enea and Salemi 2001; Hao and Zhou 2002; Xue et al. 2003; Xu et al. 2017; Elbeltagi et al. 2022a, b). A detailed review of the published literature on the derivation of various methods and models, however, illustrates a lack of multi-factor synthetic analysis, and of the involvement of complicated procedures (Rahman et al. 2014). The assessment of the environmental quality status of any region needs a proper understanding of multiple factors along with the consideration of an appropriate spatial decision support system for compiling these data into new indices that are measures of the degree of degradation of a landscape. These factors were rarely defined in earlier geo-environmental studies (Kangas et al. 2000; Li et al. 2007; Xiong et al. 2007; Shahid et al. 2021).

Therefore, the situation calls for the identification of target areas for implementing corrective measures. In this context, GIS plays a vital role for facilitating the acquisition of data in digital format and it 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 quality of an ecosystem in a given region is determined by a range of factors, and information about these is often available in multiple databases.

Agriculture is the major livelihood in the study area, and hence these areas are often prone to water scarcity and land degradation due to heavy groundwater withdrawal and the excessive use of fertilizers. The primary aim of the present work is to derive a GIS-based model of the quality of natural resources, primarily groundwater and land resources, in a watershed of central India using a multi-criteria evaluation process. In the current study, ten basic layers related to soil, land, and water information 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 the management of environmental resources for the sustainable development of the region.

Physical characteristics of the study area

The study was conducted in the Bordi watershed of the Purna sub-basin in the Amravati and Akola districts of Maharashtra state. The Bordi River basin is located in the Amravati and the Akola districts of Maharashtra state but the study was mostly undertaken in the Amravati (district) of Central India. The Purna sub-basin lies between north latitude 20°10´: 21°41´ N and east longitude 76°0´: 77°55´ and covers an area of 18,300 km^2. About 2827 km^2 of the Purna sub-basin is underlain by saline land (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 is located in between 20°55´ to 21°18´ N latitude and 77°05′ to 77°18′ E longitude (Fig. 1). The area has 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 is 15.1 °C in winter and the maximum mean temperature is 42.2 °C in summer in the area. The elevation of land varies between 270 and 900 m in the study area (Fig. 2), but nearly 42% of the total area has an elevation of between 320 and 400 m. The slope analysis illustrates a total of 72.65%, 11.60%, and 15.74% area under the low, moderate, and high slope categories respectively. Data from Indian Meteorological Department indicate that the average annual rainfall in the study area is in the range of 800–1400 mm/year.

The geological map of the area shows that the Deccan lava flows of the Upper Cretaceous to Eocene age cover the northern part of the study area. These flows are very hard and compact and lack primary porosity. While the Bajada zone or Piedmont zone covers the foothill region of the watershed and consists of large boulders and cobbles and hence acts as a run-off zone and is not suitable for groundwater storage. Alluvial deposits covering the southern valley's significant portion consist of alternate layers of clay and sand (Tiwari et al. 2010). The area is favorable for groundwater recharge, movement, and storage due to the terrain's sandy nature and gentle slope.

Materials and methods

The main objective of this study was to assess the various geo-environmental vulnerability grades within the study area using remote sensing, a Geographical Information System (GIS), and multiple-criteria decision-making techniques (Pande et al. 2021). 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; Pande et al. 2020). Many researchers have employed integrated Geographic Information Systems, remote sensing, and environmental evaluation models for developing

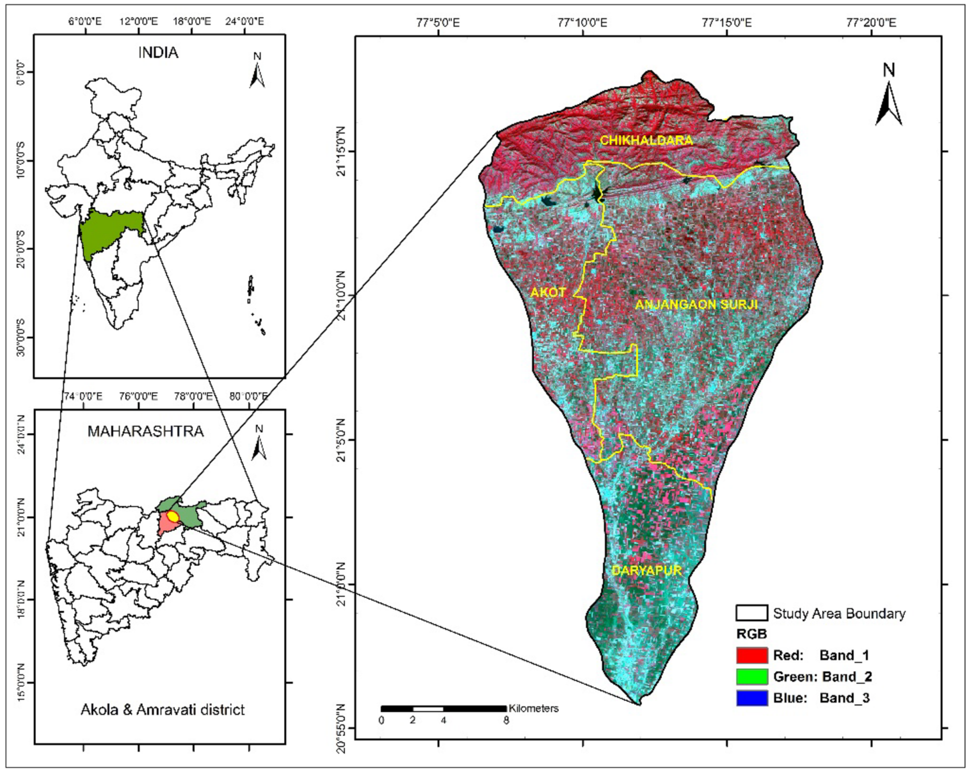

Fig. 1 Index Map of the study area

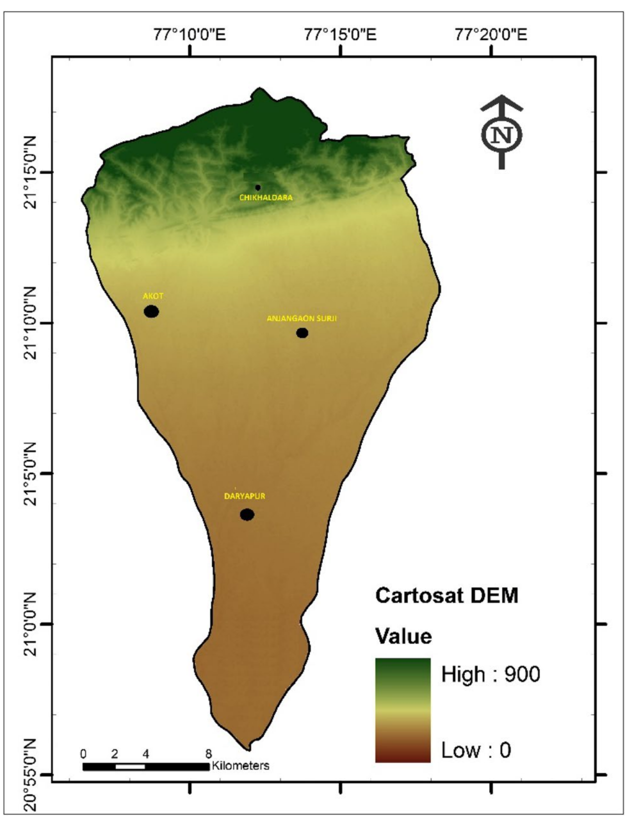

Fig. 2 DEM for the study area

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, a spatial database on inter-related parameters of the study area has been generated 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 natural and anthropogenic factors that affect geo-environmental quality is essential for determining the degree of natural resource degradation of any area, together with the availability spatial databases that are relevant for geo-environmental assessments (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), among 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 ten (10) factors. These are: land use; agricultural cropping pattern; geology; geomorphology; soil depth; soil texture; degree of soil erosion; land surface slope, groundwater quality; and groundwater fluctuation have been considered. Based on the

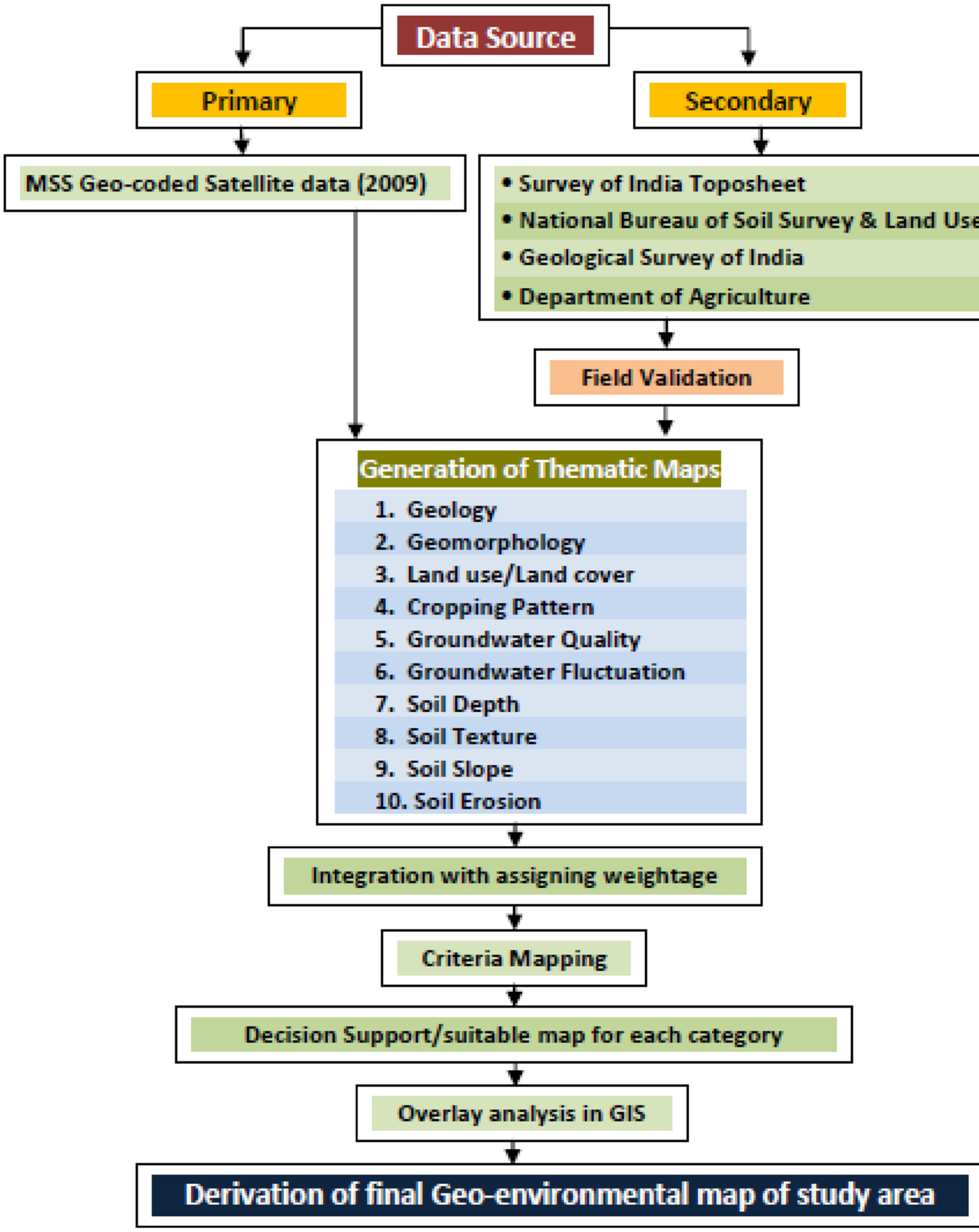

Fig. 3 Flow chart showing methodology adopted in the work

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 sub-systems (Table 1).

Criteria mapping

Initially, a criterion was established to rank various parameters in each theme based on an expert knowledge assessment of the parameter using a numerical scoring system. After establishing the criteria, a raster map was prepared and linked to each criterion, where an individual pixel represents a suitability value. The criterion maps were prepared from basic raster GIS operations, such as the use of map overlay methods, spatial queries, buffering, and distance mapping. These maps show the spatial distribution of each criterion and their relative importance in determining the overall environmental quality score.

After criteria identification and mapping, each of the factors needs was standardized to make the factors comparable using the rank order (RO) with expected value (EV) method (Li et al. 2007; Janssen and Herwijnen 1994; Rietveld 1980). The RO with EV method arranges

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 Pattern	Remote Sensing	Citrus Wood land	2.639	3	
			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	

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* was calculated according to Eq. (1),

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

where, *n* is the number of criteria. The weights fit the rank order of criteria defined by set S, meaning that $w1 \geq w2 \geq \cdots \geq wn \geq 0$ (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 was applied to derive the geo-environmental potential map using Arc-GIS 9.3 software (Eqs. 2, 3, and 4). A higher geo-environmental potential (GPI) index value indicates a greater quality of the geo-environmental resources in the region. The entire area was divided into four categories of suitability based upon the geo-environmental potential index values.

$$S_j = \sum w_i, \tag{2}$$

where, S_j represents the suitability for pixel j, Wi represents the weight of factor I, and

$$R_{\mathrm{eq}} = \sum_{i=1}^{n} w_i, \tag{3}$$

where, R_{eq} is the regional environmental quality index, W_i is the weight of factor i, n is the total number of factors

$$\mathrm{GPI} = \sum (\text{weightage for each category}). \tag{4}$$

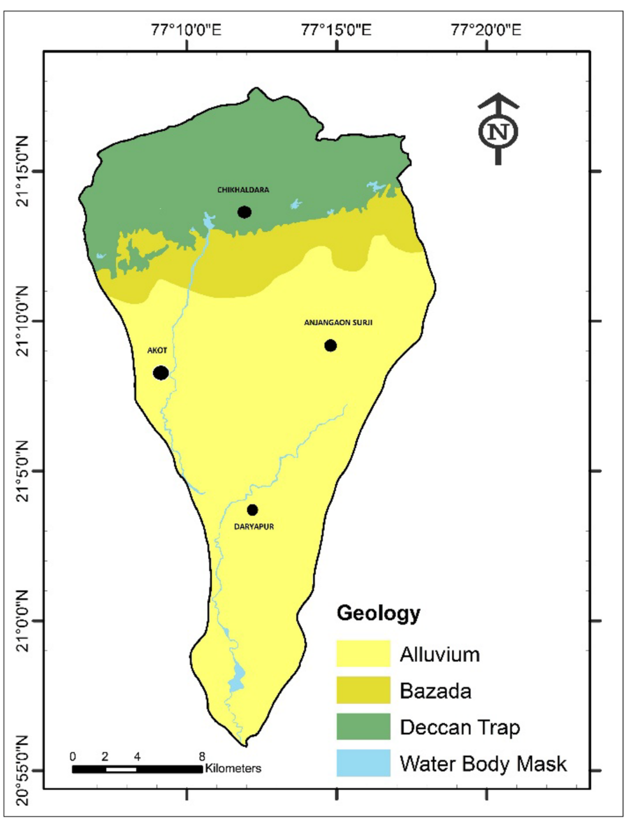

Fig. 4 Geology distribution

Results and discussion

Geology

The geological map of the study area (Fig. 4) shows that it is covered by varied geological formations. These include basaltic lava flows (Deccan trap flows of Upper Cretaceous to Eocene age) which cover the northern part of the catchment area. These basalt flows are overlain by Quaternary sediments (viz. the Piedmont zone also known as the Bazada zone) and the alluvium that covers the southern part of the area (Tiwari et al. 2010; Saha and Asthana, 1990). About 61% of the study area is covered with alluvial sediments that are up to approximately 400 m in thickness (Tiwari et al. 2010). The geological situation of the area controls the groundwater recharge. Therefore, the watershed has been classified in different classes of groundwater situation, and weightages are given accordingly. Thus, the most favorable for groundwater storage, the alluvium, is assigned the highest weightage. While the Bajada zone, a run-off zone, has been allotted with the least weightage of one (1). The groundwater area has a moderate groundwater potential; hence weight value of two (2) is assigned to it.

Geomorphology

Geomorphological processes reflect the inter-relationship between factors, such as climate, geology, soils, and vegetation and therefore, are an important aspect of environmental analysis and planning (Buol et al. 1973; Blarzcsynski 1997). The geomorphological characteristics of the study area were interpreted from a digitally enhanced satellite image and were categorized into four different geomorphological units. These were: alluvial plains comprising both the deeper older alluvium and the shallower younger alluvium; the Piedmont zone (Bazada zone); and the upper basaltic plateau (Fig. 5). The thematic map on geomorphology indicates that the older alluvial plain is widely distributed and covers an area of about 262 km^2 (about 50% of the total area). The Piedmont zone (Bazada zone) trends from north to south and an area of about 55km^2 area. However, the younger alluvium plain unit, only underlies about 14.39 km^2 of the study area (or about 3% of the total area). The upper plateau developed over the Deccan trap basalt flows is only present in the northern part of the study area.

Land use/Landcover

The existing land use in the area is a key factor for determining the environmental quality of a landscape and for assessing whether a groundwater resource is likely to be under stress. The map on land use/land cover for the study area

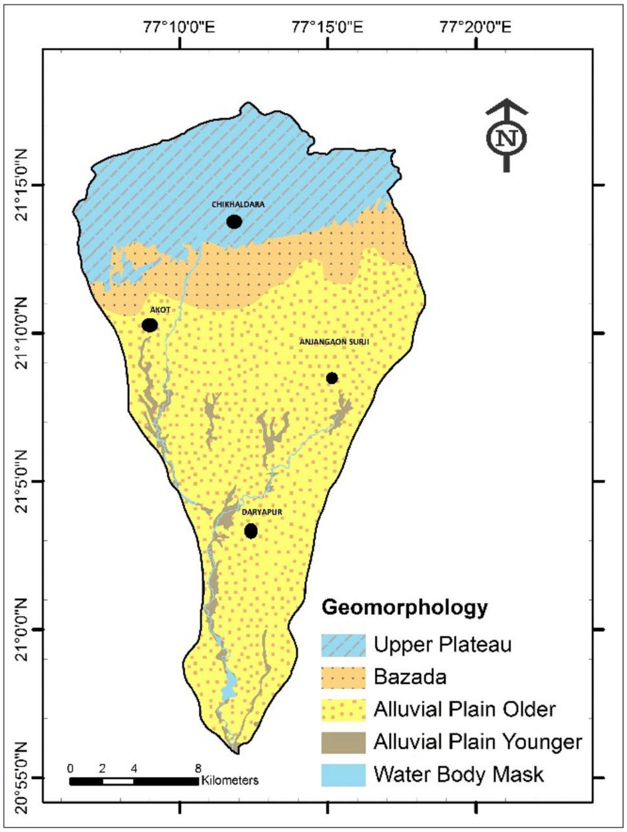

Fig. 5 Geomorphology distribution

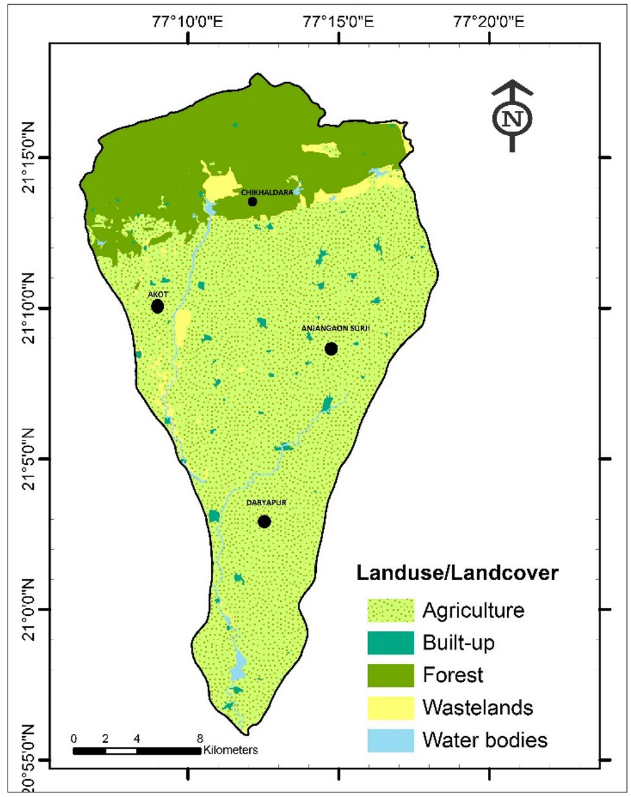

Fig. 6 Land use/land cover classification

was prepared from the IRS-P6 LISS III satellite image data (acquisition in October 2015) using the maximum likelihood classification algorithm technique. The entire process of classifying the satellite image was performed in Arc-GIS 9.0 software. The map that was obtained included five major land use/land cover classes. These were: agriculture land use, built-up areas, forest, wastelands, and water bodies (Fig. 6). During the classification process, the highest rating (3) was assigned to agriculture due to good environmental quality in terms of thick soil cover and good groundwater potential. On the other hand, to isolate built-up areas and water bodies from future development programs, the lowest rating (0) was assigned to these land use/land cover categories. The land use/land cover map of the study area shows that agriculture is the dominant land use in the study area. Forests are mostly confined to steep land in elevated parts of the landscape. As most of the study area is used for irrigated agriculture there is also likely to be a large demand for water, which indicates that there is a risk of excessive groundwater use.

Vegetation cover

The thematic map for vegetation cover was prepared from the digitally enhanced image and was analyzed further. Nine categories of vegetation cover were identified. These were: citrus plantations; currently fallow land; dense closed forest, eroded and gullied land, *Kharif*, *Kharif* + *Rabi* (double-cropped land), land with scrub, land without scrub, and *Rabi* (Fig. 7). This map indicates that dense forest covers an area of 96.28 km^2 (about 21% of the study area) in the northern hilly part of the study area. Because of the limited water availability, *Kharif* is the most important agricultural land use, covering an area of 235.61 km^2 or about 52% of the study area. By contrast, *Rabi* crops cover the least land (an area of 1.88 km^2 or about 0.42% of the study area) in the central part of the study area. *Kharif* + *Rabi* (double-cropped land) occupies 97.51 km^2 (about 22%) of the study area. The highest rating (3) was assigned to *Citrus* along with *Kharif* + *Rabi* (double-cropped) as they show the productive lands whereas the lowest (1) rating was assigned to the gullied/eroded land and scrubland where there is further scope for its development.

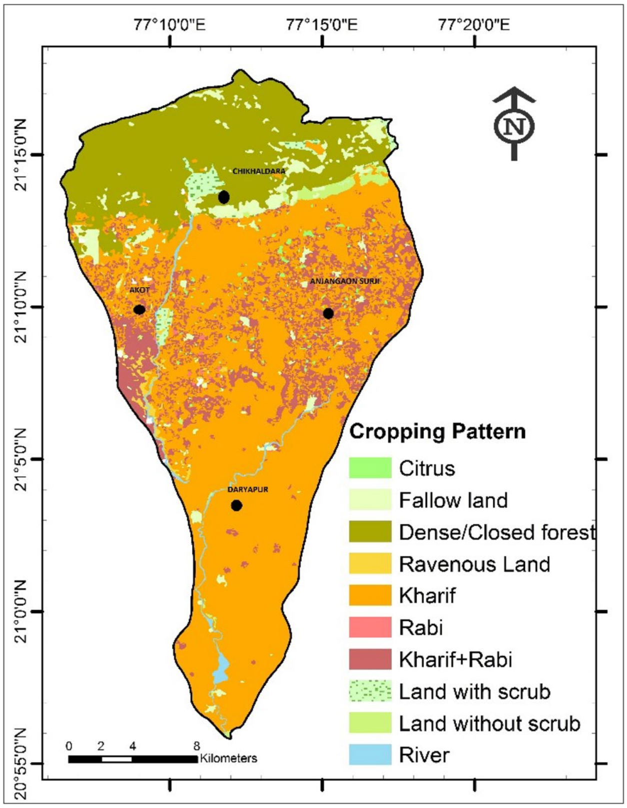

Fig. 7 Cropping pattern distribution

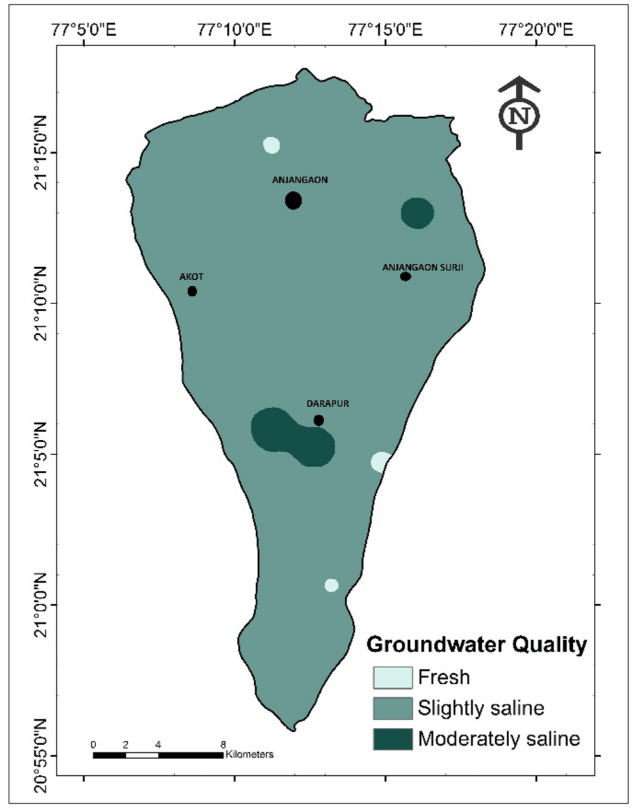

Fig. 8 Groundwater quality distribution

Groundwater quality

Previous investigations of groundwater quality in the study area have been undertaken. The available hydro-chemical data generated by Jain and Tambe (2012) were modified and used further by applying the nearest neighbor interpolation technique in a GIS platform to derive a groundwater quality map for the Bordi watershed. Based on the distribution of total dissolved solid (TDS) values, the watershed area was categorized into three categories, i.e., fresh, brackish, and saline water (Fig. 8). Fresh groundwater (TDS < 1500) occupies an area of about 106 km^2 (about 24% of the study area). Most of the study area is underlain by brackish groundwater (TDS in between 1500 and 3000 mg/L). Brackish groundwater is found mainly in the central part of the study area, and comprises about 274 km^2 area, or about 61% of the study area. Saline groundwater (TDS > 3000 mg/L) underlies the north-eastern and south-western parts of the study area and covers an area of about 69 km^2 (or about15%) of the area. The highest rating was assigned to freshwater, whereas the lowest rating was assigned to the saline water category. This is because a low water salinity has a higher value both from a land development perspective, and from an environmental perspective.

Groundwater fluctuations

The studies on groundwater levels and their seasonal fluctuations (i.e., during the pre- and post-monsoon periods) are vital to understanding the groundwater regime of any area. The hydrogeological data from 66 wells in the entire watershed were collected both during the pre- and post-monsoon season of the year 2012. The total depths of the existing wells ranged from 2.6 and 39.80 m below ground level (bgl). The pre-monsoon and post-monsoon water levels vary from 1.4 and 39.60 m (bgl) and 0.9–39.50 m (bgl) respectively. The average seasonal fluctuation is around 0–6.90 m. The groundwater fluctuation map for the study area was derived based on water table data of the observation wells (Table 2). Based on this, groundwater level variations were categorized into three classes, i.e., high, moderate, and low (Fig. 9). Low groundwater fluctuations were the most dominant category over 213 sq. km and comprise about 48% of the total area. The highest rating (3) was assigned to small groundwater fluctuations, whereas the lowest rating (1) was assigned to the 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
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

Table 2 (continued)

Well no	Location/Village	Total depth (mbgl)	Depth to water level (mgbl)		Groundwater fluctuation (m)
			Pre-Monsoon	Post-Monsoon	
50	Menghat	6.4	6	1.4	4.6
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

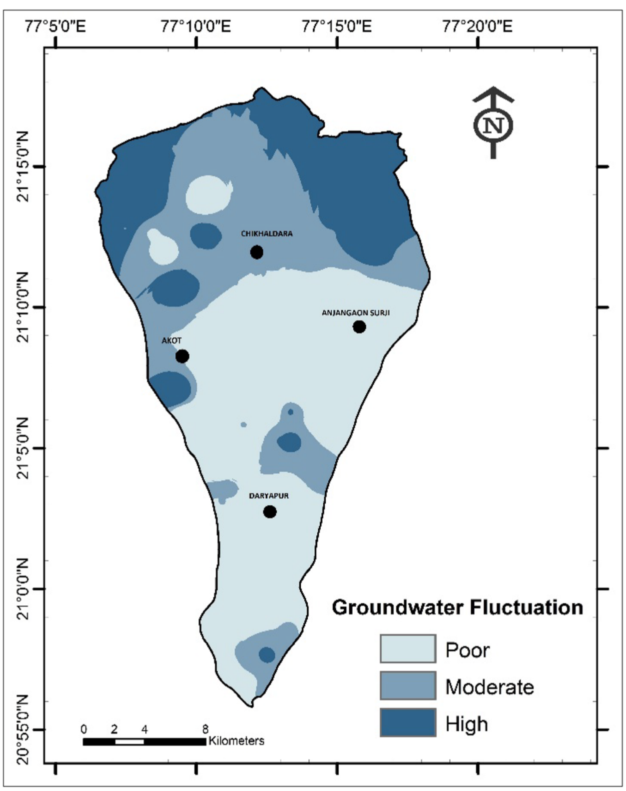

Fig. 9 Groundwater fluctuation distribution

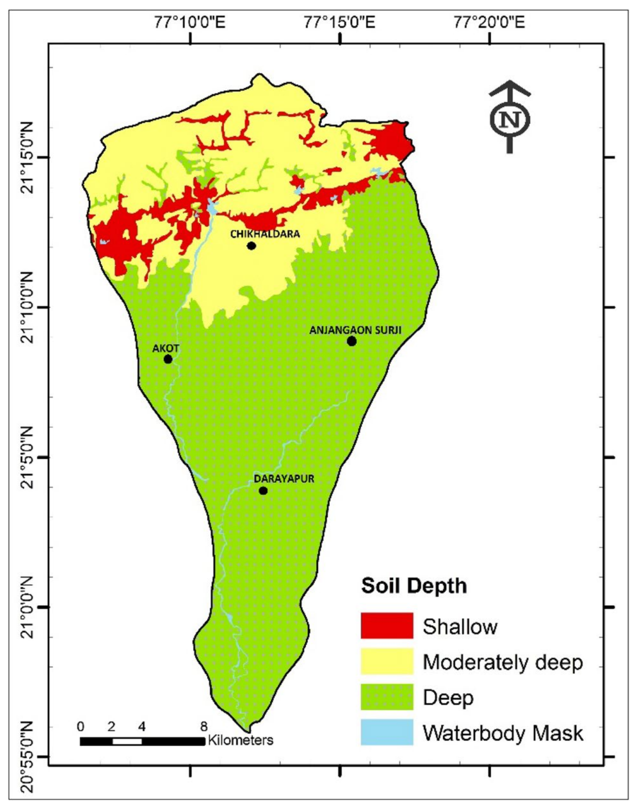

Fig. 10 Soil depth distribution

Soil thickness

The soil formed in topographic sequence under specific geo-pedological environmental conditions (in conjunction with the lithology of underlying rocks) has a great influence on the geomorphological characteristics of a region (Kantor and Schwertmann 1974).

In this study, a digital soil thickness database was created. Information for this was obtained from the soil map developed by the National Bureau of Soil Sciences & Land Use Pattern (NBSS & LUP). The obtained soil thickness results were categorized into three classes, which were deep soils (more than 150 cm), moderately thick soils (50–90 cm), and shallow soils (25–50 cm) (Fig. 10). The soils of the Bordi watershed show a wide variation in their thicknesses because of the variation of land elevations in the area. The soils on steeply sloping land on hills were found to be shallow to medium thickness soils, whereas in the low-lying areas and in river valleys deep soils are observed. The soil thickness map indicates that shallow soil (< 25 cm thick) occurs in elevated parts of the landscape, particularly in the northern part of the study area, moderately thick soil (25–50 cm thick) occurs mostly in the valley fills, and deep soil (> 50 cm thick) occurs in the central and southern parts of the watershed. The ratings were assigned according to the importance of soil thickness as per its erodible 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 an important factor for considering the availability of groundwater resources, as it governs the infiltration characteristics of soil (Varade et al. 2013). In this study, the soil map indicated that there were three dominant soil textural classes, i.e., gravelly clay loams, gravelly sandy clay loams, and silty loams (Fig. 11). The major portion of the study area is covered by gravelly clay loam. Soils in this textural category cover an area of 325.68 km^2, or about 72% of the total area. Typically, soils with a clayey texture are poorly drained and produce a large amount of run-off, while sandy soils generate less run-off and allow a greater amount of infiltration (Aller et al. 1987). Considering this, the highest weighting of three (3) was given to silty loams, while a weighting of two (2) is given to gravelly sandy clay loam and a weighting of one is provided to gravelly clay loams.

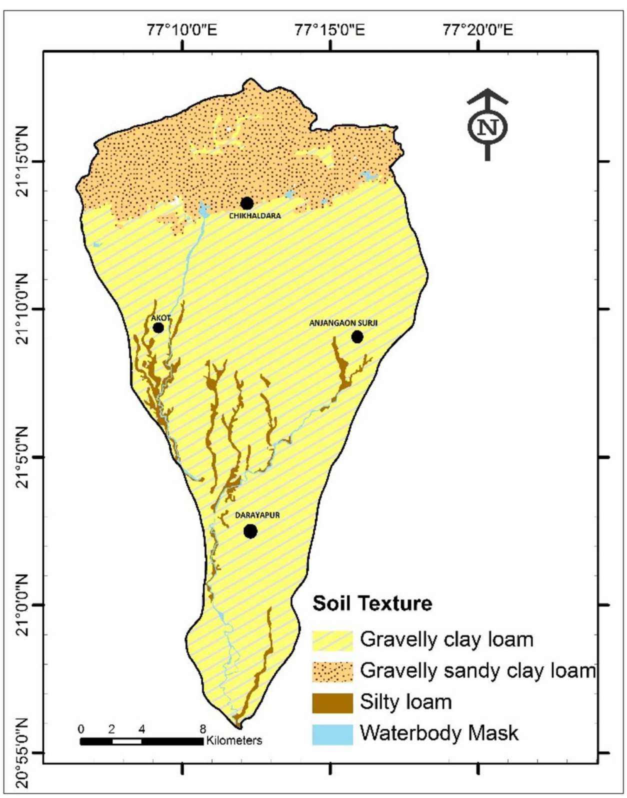

Fig. 11 Soil texture distribution

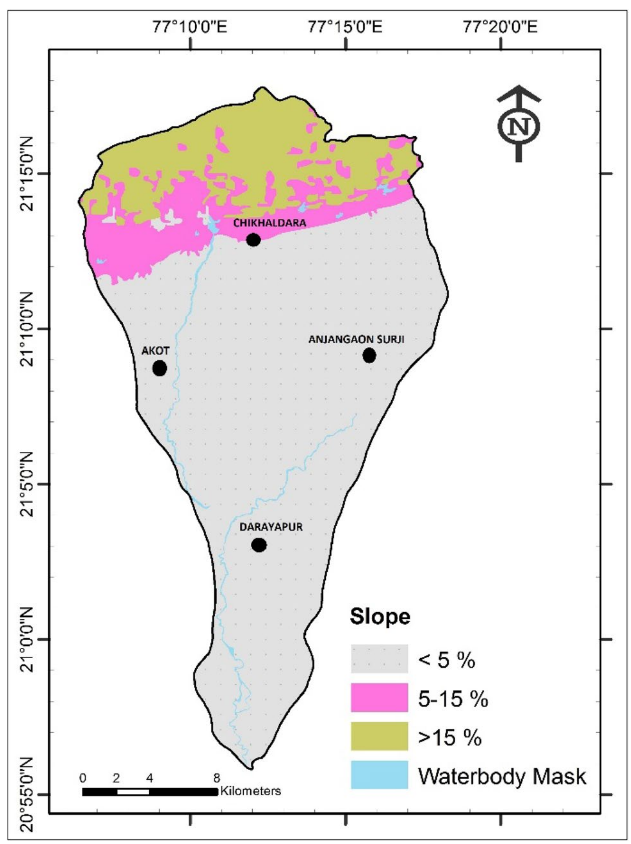

Fig. 12 Soil slope distribution

Slope

The slope or the topographic relief of an area is important as they affect the run-off process, soil erosion, and land use planning. In this study, a slope map of the watershed was generated using the Cartosat-1 DEM and Survey of India topographical maps. Much of the area was classified as having a low slope (less than 5% gradient). Land with this characteristic occurred in the alluvial plains. Land with a moderate slope (5–15% gradient) occurs in a piedmont zone in the northern part of the study area, and land with a high slope (> 15% gradient) occurs near the northern boundary of the study area (Fig. 12). It was found that most of the study area falls under the low slope class (Table 1). The highest rating of three (3) was assigned to the low slope category due to its favorable situation for agricultural, plantation, and developmental activities. This is also corroborated from the fact that there are no records of major floods in the area. All land with low to moderate topographical location was rated as having a high potential for further development.

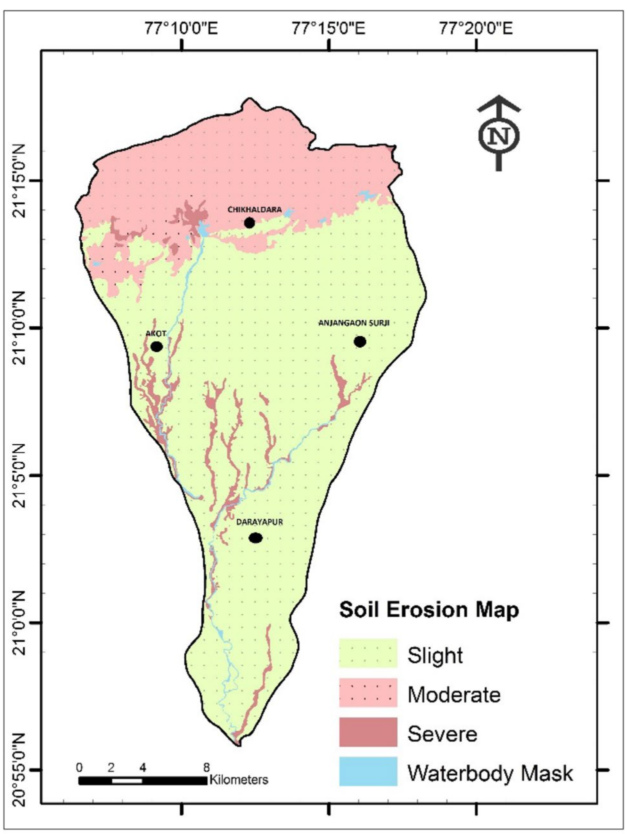

Fig. 13 Soil erosion distribution

Soil erosion

Soil erosion is a process of removing the earth material (both rock debris and soil) and its further transportation downslope by various erosive agents (Singh 1998). Investigations of soil erosion are often required to predict soil erosion rates under particular land-use conditions. The soil erosion data extracted from the soil map of NBSS & LUP were categorized into three classes, namely: slight, moderate and severe erosion (Fig. 13). Because of the flat topography, only slight erosion is observed in most of the central and lower reaches of the study area, and this category cover an area of 316.2 sq. km., or about 70% of the study area. Moderate erosion is observed mostly in the highlands of the Deccan trap region due to the thin soils, steep slopes, and the resistive nature of bedrock. Severe erosion is observed only along the stream channels and in some areas of steep land. The highest rating is assigned to slight erosion, whereas the lowest rating is assigned to severely eroded areas.

Integrated regional geo-environmental quality evaluation

The status of the physical environmental condition discussed above can indicate the extent to which environmental degradation has taken place in the watershed, and determine the constraints that exist for the further development of land and water resources in the area. The geo-environmental potential index (GPI) of the Bordi River basin was calculated based on the above ten factors. The GPI values of the basin range between 3 and 30. Subsequently, these values were 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% of the study area is classified as having a high geo-environmental quality index with GPI values ranging between 23 and 30. The region shows a good vegetation cover and limited soil erosion. The high GPI values in this part of the study area are due to the high vegetation cover, limited disturbance by human beings, and good soil penetrability. The high geo-potential of the area indicates that this area is likely to be susceptible for agricultural development and thus there is a high risk that it will be overexploited

Table 3 Geo-environmental quality categories of study area

Class	GPI Index	Area (km2)	Area (%)	Characteristics of the area	Geo-environmental resources potential of the area
High resources	> 23	217.18	48.30	Gentle slope, sandy formation, high porosity and permeability, low seasonal fluctuation	Sustainable Geo-environment
Moderate resources	16–23	115.79	25.75	Gentle slope, less aquifer thickness, moderate porosity and permeability, moderate seasonal fluctuation	Geo-environment under threat in the event of drought and over-exploitation
Low resources	9–16	107.84	23.98	Moderate slope, thin soil cover, moderate to poor permeability due to presence of Basaltic formation	Disturbed Geo-environment prone to land degradation. Target area for restoration of ecosystem through adoption of conservative measures
Poor resources	< 9	8.88	2	Moderate to steep slope predominantly run-off area, very thin soil cover	Highly disturbed Geo-environment. Prime target area for restoration of ecosystem through adoption of conservative measures
		449.608	100%		

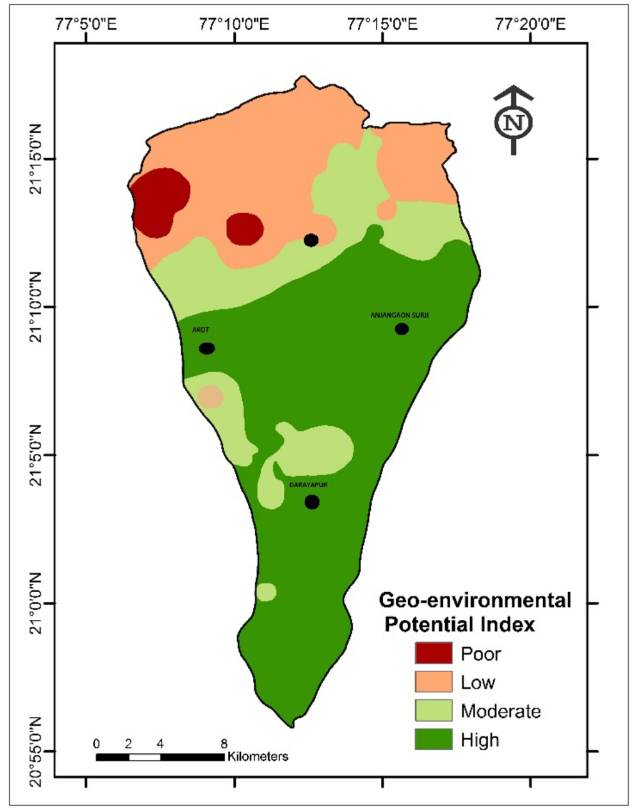

Fig. 14 Geo-environmental category comprehensive evaluation classification map

which may lead to degradation of the environment. Therefore, the area needs the implementation of conservation measures on a large scale mainly to retain its 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 southwest of the study area (The landform is characterized by both steep hills and land with little relief), where remnants of dense forest occur in upland areas. Areas with moderate eco-environmental quality are highly vulnerable to damage from human interference, and cover the whole of Chikhaldara, and some areas in the center and western and northern parts of the Bordi basin. Most of the region is occupied by farmland, forest, along with some grassland. There is limited land use in this category, which improves its biodiversity. This area is also susceptible to deterioration due to the exploitation of forest resources as well as high erosion rates due to steep slopes and the thin soil cover. To protect the area from further deterioration it is necessary to implement soil and forest conservation management 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 about 24% 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.

Area with poor geo-environmental resources

The areas with poor geo-environmental resources are located in the northern part of the study area in the form of scattered patches. This category covers an area of about 9 km^2 and only accounts 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 of below nine (< 9). Land in this category that is located close to human settlement is more prone to degradation due to human land uses, and thus requires ongoing management to restore soils and vegetation cover.

Conclusion and recommendations

This study describes a methodological approach for the evaluation of the regional geo-environmental resources of the Bordi River region based on the integrated use of spatial databases with remote sensing, GIS, and Multi-Criteria Decision Analysis (MCDA) techniques. The present study results indicate that a significant part of the area has good geo-environmental values as the values of the resources are > 23. However, some parts of the watershed have a low geo-environment values as the values are less than < 16. Therefore, these areas need land and water conservation programs to restore the geo-environment system. 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 environmental values 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 the combined use of GIS and MCDA techniques in environmental research analysis are useful for identifying 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.

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Declarations

Conflict of interest The authors declare that they have no
conflict of interest.

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