International Journal of Environment and Climate Change

Volume 14, Issue 10, Page 285-305, 2024; Article no.IJECC.124404
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Assessment of Groundwater Potential Zones in the Konkan Region Using Geospatial Techniques

Aniket A. Kale [a++*], R. T. Thokal [a#], P. M. Ingle [a†], H. N. Bhange [b‡], N. A. Meshram [c^], Akanksha D. Salvi [a++] and Mrunalini Lokhande [d##]

[a] Department of Irrigation and Drainage Engineering, CAET, Dr. BSKKV, Dapoli, India.
[b] Department of Soil and Water Conservation Engineering, CAET, Dr. BSKKV, Dapoli, India.
[c] Department of Soil Science & Agril Chemistry, COA, Dr. BSKKV, Dapoli, India.
[d] Groundwater Survey and Development Agencies, Navi Mumbai, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijecc/2024/v14i104487

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/124404

Original Research Article

Received: 21/07/2024
Accepted: 25/09/2024
Published: 30/09/2024

[++] *PG Scholar;*
[#] *Professor and Head;*
[†] *Professor;*
[‡] *Associate Professor;*
[^] *Assistance Professor;*
[##] *Junior Geologist;*
**Corresponding author: E-mail: aniketkale782@gmail.com;*

Cite as: *Kale, Aniket A., R. T. Thokal, P. M. Ingle, H. N. Bhange, N. A. Meshram, Akanksha D. Salvi, and Mrunalini Lokhande. 2024. "Assessment of Groundwater Potential Zones in the Konkan Region Using Geospatial Techniques". International Journal of Environment and Climate Change 14 (10):285-305. https://doi.org/10.9734/ijecc/2024/v14i104487.*

ABSTRACT

Groundwater is considered as the major and secure the source of water supply all over the world and it is a precious natural resource. As populations grow and surface water sources become increasingly strained or contaminated, the reliance on groundwater intensifies. This study was conducted to assess the groundwater potential zones across Konkan region, Maharashtra, India for the future sustainable water resource development in the region. To spatially identified the groundwater potential zones using integrated Remote Sensing (RS) and GIS with Analytical Hierarchy Process (AHP). Several influencing factors such as geology, geomorphology, rainfall, soil, slope, groundwater depth, land use land cover and lineament density are assessed individually. All the factors and their features have been assigned weights according to their relative importance and their normalized weights were calculated using Analytical Hierarchy Process. Groundwater potential zone map has been prepared through weighted sum model in GIS environment after integrating all the thematic layers. The entire region has been classified into five different groundwater potential zones viz., Very Good, Good, Moderate, Poor and Very Poor. A major part of the region was found about 44.19% in moderate groundwater potential zones followed by poor groundwater potential zones 27.23%. The good zones also contribute 19.82% area of the region, as well as the very poor zones contributes 4.43% area of the region. Least area found in the very good potential zones which is about 4.33%. Therefore, the high area coverage of groundwater potential zones, ranging from moderate to very good, provides critical insights for sustainable groundwater management and planning in the Konkan region.

Keywords: Konkan; groundwater potential; water resources; RS and GIS, AHP.

1. INTRODUCTION

“Rapid industrial development, urbanization, and increase in agricultural production have led to freshwater shortages in many parts of the world” [1]. “Groundwater is an essential global resource in the world as a freshwater supply source. Groundwater has many characteristics compared to surface water: it is mostly of higher quality, better protected from microbial and chemical pollutants, less subject to perennial and seasonal fluctuations, and more spread over large regions than surface water” [1,2]. “Groundwater is replenishable, less contaminated and can be easily extracted. Records show that 80% of the rural population and 50% of urban population use groundwater for domestic purposes [3]. This rate may increase further in the future. But nowadays due to drastic changes in climatic conditions and the dynamic development of land surface features, there are fluctuations in water levels and shifts in ground water zones” [2].

The Central Groundwater Board (CGWB) [3] reports that because of the 230 billion-meter cube (BCM) of groundwater that is removed each year to irrigate agricultural lands, many parts of India are suffering an increasing groundwater scarcity. An estimated 122-199 BCM of groundwater has been lost in India [3]. Groundwater in Maharashtra, a state in western India, plays a crucial role in meeting the water demands of its population, agriculture, and industries. Maharashtra has a diverse geological composition, resulting in various types of aquifers. The state comprises hard rock areas, alluvial plains, and basaltic formations, which influence the occurrence and availability of groundwater. Maharashtra is known for its recurring water scarcity issues, particularly during the dry seasons and drought periods. Inadequate rainfall and limited surface water sources necessitate heavy reliance on groundwater to meet agricultural and domestic water requirements. Excessive and unregulated groundwater extraction has resulted in the depletion of aquifers in several parts of Maharashtra.

“The state's projected annual groundwater recharge is 32.76 BCM, whereas its annual extractable groundwater resources are 30.95 BCM. The total yearly extraction of groundwater is 16.66 BCM, of which 15.28 BCM is removed for irrigation, 0.03 BCM for industrial use and 1.36 BCM for domestic use, and the extraction stage is 53.83%. The Annual Ground Water Recharge and Annual Extractable Ground Water Resources in 2023 have slightly increased from 32.29 BCM to 32.76 BCM and from 30.45 to 30.95 BCM, respectively, in comparison to the 2022 assessment. The Annual Ground Water Extraction has remained relatively unchanged. There has been a little decline in the Stage of

Ground Water Extraction from 54.68% to 53.83%" [4].

"The Konkan extends throughout the western beachfront of Maharashtra, Goa, and Karnataka. There is 25970 groundwater- grounded sources that feed the drinking and domestic water requirements in 7 sections that represent the Konkan region" [5]. While the region sees heavy rainfall, ground water is scarce during the summer months, leading to lowering of water situations and drying of wells in certain pastoral areas of its area. Central groundwater board has attributed this scarcity to high sub-surface and surface runoff due to hilly topography and high permeability of the phreatic aquifer.

"The issue of assessment of groundwater potential is an important aspect of groundwater development and management. In many cases the groundwater potential estimated by the Central Ground Water Board of India (CGWB) deviates from reality if examined at regional levels. There are instances where CGWB estimates are on the high side. As a consequence, water scarcity and over-exploitation of groundwater resources are common in several parts of India. Also, the Konkan region faces water scarcity during the months of summer season. This research work focuses on groundwater potential and potential sites of groundwater recharge for groundwater potential for sustainability in irrigation" [3].

"Groundwater evaluation has been usually conducted using field surveys which is not feasible in terms of time and resources. Researches shows that remote sensing and GIS have opened a new path in Groundwater studies [5,6]. Remote sensing is the technology of acquiring information about the Earth's surface without in reality being in contact with it. A Geographic Information System (GIS) is a computer-based information system designed to accept large volumes of spatial data derived from variety of sources and to efficiently store, retrieve, analyze, model, and display output of these data according to user-defined specifications" [4]. In recent studies, researchers such as [5,6,7,8,9] "used Remote sensing and GIS for delineation of groundwater potential zones". The main reason is the availability of satellite data which makes the analysis easier compared to the traditional techniques such as ground drilling geophysical assessment of lineaments and field observations [6]. Hence, an attempt has been made in this study to assess different groundwater potential zones in the Konkan region by using GIS and AHP techniques (Analytical Hierarchy Process).

2. MATERIALS AND METHODS

2.1 Study Area

Konkan region is the further western part of Maharashtra, featuring with the coast of Arabian seat at the West and Sahyadri hills at the East. Most of the part of the region falls in Western Ghat. The total geographical area of the Konkan region is 3.08 Mha and agroclimatic featured as hilly topography with high rainfall (2500-3500 mm). The soils in the region are medium black soil in Northern part with low infiltration and lateritic soils in Southern part with high infiltration rate. Konkan region extends throughout the western coasts of Maharashtra, Goa and Karnataka. It extends between 16° 30' *and* 19° 30' N Latitudes and 72° 00' *and* 75° 00' E. Fig. 1 shows the Location map of the study area. Konkan region constitutes 10 percent of the geographic area of Maharashtra state (30728 Km^2). The region comprises Palghar, Thane, Raigad, Ratnagiri, Sindhudurg and Mumbai districts. During this study Mumbai district was skipped due to its high urbanization. The region is featured with undulated topography with a range in hills 7 to 35 percent.

2.2 Geospatial Database

Table 1 shows various groundwater influencing factors and their data sources. Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) with a resolution of 30 m was obtained from the United States Geological Survey (USGS) to generate the slope layer of the Konkan region. The thematic layers of geology, lineaments and geomorphology were prepared using data derived from Bhukosh, Survey of India (SOI). The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) provided digital soil maps at a scale of 1:250,000 for continents and significant regions. Accordingly, the NBSS digital soil map data used to generate the soil map of the study are. The land use land classification with 10 m resolution was obtained from ESRI. Groundwater depth data (1994-2023) for different well locations spread all over the region was procured from the Groundwater Survey and Development Agencies, Navi Mumbai, Maharashtra (GSDA). The rainfall data

(1994–2023) was procured from the Hydrology Project, Hydrology Data User Group (HDUG), Nashik, Maharashtra. In this study, groundwater potential zoning was carried out using various thematic layers such as, rainfall, groundwater depth, geology, geomorphology, lineament density, soil, slope and land use land cover in ArcGIS 10.3 version.

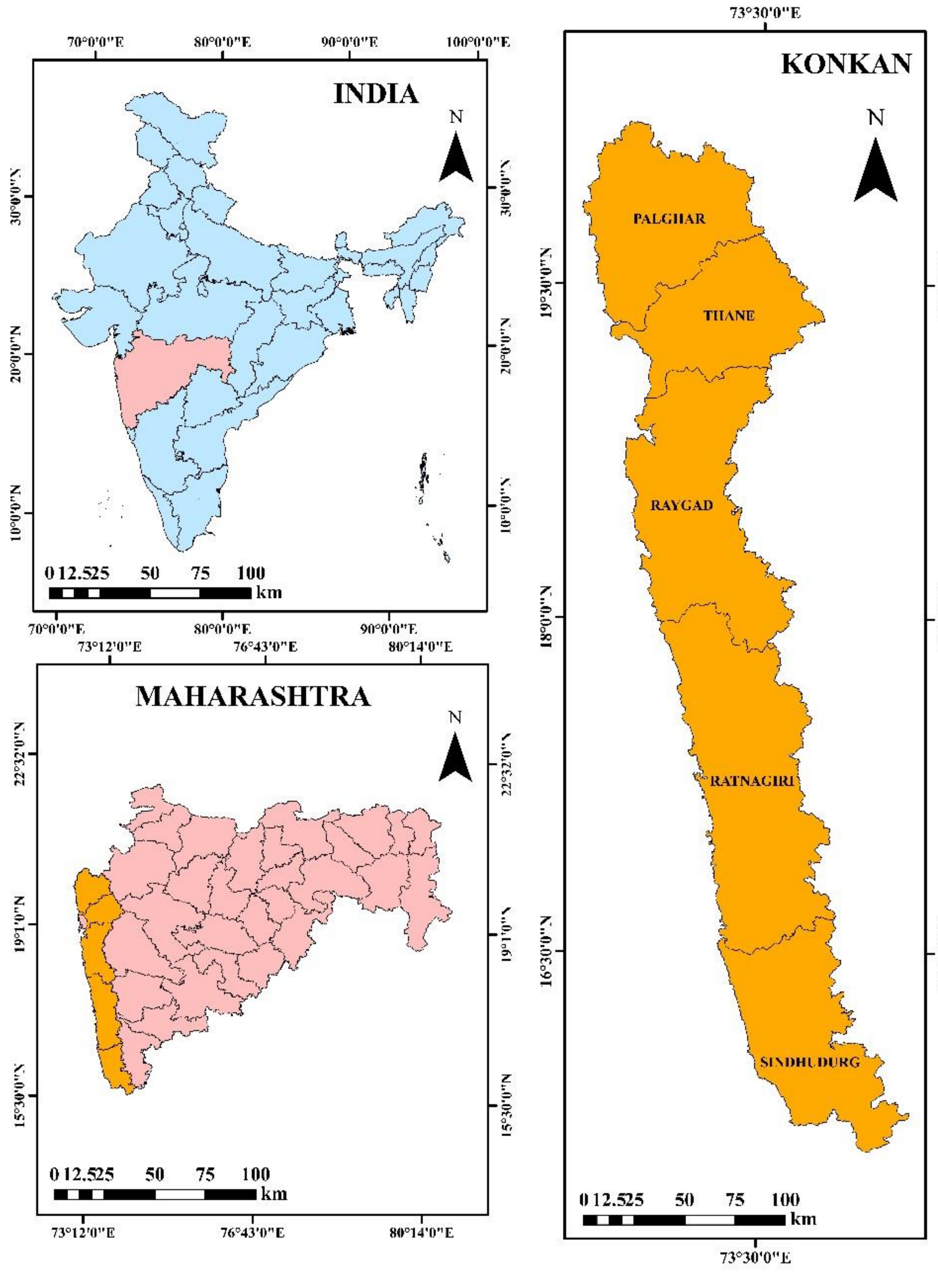

Fig. 1. Location map of the study area (Konkan Region)

Table 1. Data required for study, its period, and source

Sr. No.	Data	Duration	Retrieving Date	Source
1	Groundwater Level	1994-2023 (30 Years)	28.11.2023	Groundwater Survey and Development Agencies
2	Rainfall Data	1994-2023 (30 Years)	03.09.2023	Hydrology Project, Nashik. Hydrology Data User Group
3	Soil Data and Soil Map	-	10.09.2023	National Bureau of Soil Survey and Land Use (NBSS&LUP)
4	Digital Elevation Model (DEM) SRTM 30 m Resolution	-	05.04.2024	United States Geological Survey (USGS) https://earthexplorer.usgs.gov/
5	Land Use Land Cover Map, Sentinel 2 (10m)	2022	15.04.2024	ESRI Database Portal https://livingatlas.arcgis.com
6	Geology, Lineament, Geomorphology	-	21.04.2024	Survey of India (Bhukosh) https://bhukosh.gsi.gov.in

2.3 Methodology for Assessment of the Groundwater Potential Zones

The first stage includes a base map and various thematic map preparation. The slope map was prepared by analyzing the SRTM – Digital Elevation Model (DEM) with 30 m resolution. Soil, Geology, Geomorphology and Lineament Density map were digitized using *ArcGIS 10.3.* Land-Use Land cover map was classified into five classes. Collected average monsoon rainfall data and Groundwater depth of the past 30 years were imported into ArcGIS software to find out the overall rainfall and groundwater depth variation in the region using the Inverse Distance Weightage (IDW) tool. All the groundwater influencing factors mentioned above and iterated in Table 1. were transformed in raster format, using the Polygon to raster (spatial analyst) conversion tool for converting polygon feature to raster data, Linedensity (3D analyst) conversion tool used for converting line feature to raster data. All the converted data sets were projected to UTM Zone 43 N and then resampled to the same cell size of 10*10 m using ArcGIS software. All the thematic layers have been assigned weights and based on their influence on groundwater-bearing capacity by using Analytical Hierarchy Process (AHP) presented in Fig. 2.

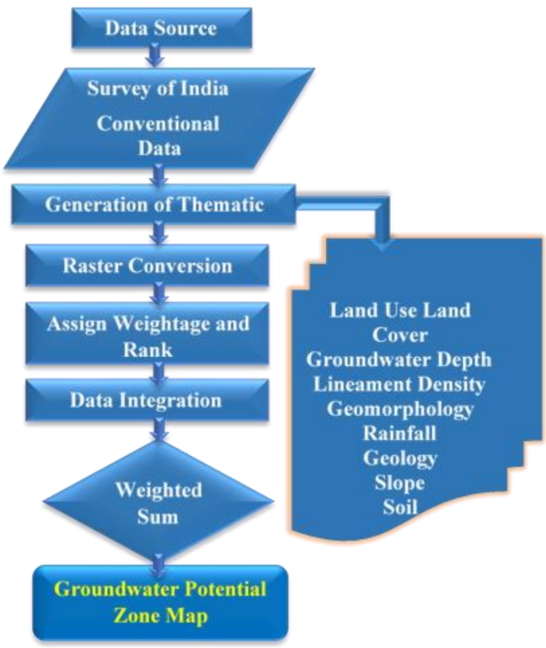

Fig. 2. Flow chart showing steps for preparation of groundwater potential map

2.4 Assessment of the Groundwater Potential Zones

The effect of various parameters like rainfall, slope, geology, geomorphology, lineament density, groundwater depth, land use land cover and soil type (texture) on groundwater potential zones were examined and assigned appropriate weightage and rank to each parameter using AHP. Every factor had divergent influence in different areas. Therefore, every factor was assigned a weight depending upon their involvement towards groundwater potentiality. The analytical hierarchy process (AHP) is a highly flexible and well-structured method capable of addressing complex decision-making problems involving multiple [10]. The AHP is a measurement theory based on pairwise comparisons and relies on expert judgments to establish priority scales. Comparisons are made using a numerical scale from 1 to 9, indicating the relative importance of one layer over another [11].

In this study the ranks were finalized considering the weights suggested by various experts and the weights used in earlier studies [5] as well as from local experience. After that, a normalized pairwise comparison matrix was developed by calculating individual weights and criteria weights (CW) for each thematic factor. The obtained matrix was checked for consistency and if consistency ratio < 0.1, and then the criteria weights therefore derived were employed for analysis. To check the consistency of assigned weights, the Consistency Ratio (CR) as suggested by Saaty (1980) was computed using Equation 1 and 2. The procedure for calculation of consistency ratio is given below.

Consistency Ratio (CR):

$$CR = \frac{CI}{RI} \quad \ldots\ldots.. \quad (1)$$

Where, CI = Consistency Index
RI = Random Index

Consistency Index (CI):

$$CI = \frac{\lambda\max - n}{n-1} \quad \ldots\ldots.. \quad (2)$$

Where, λ_{max} = average of the ratio of weighted sum/criteria weight

n = matrix size

The consistency ratio (CR) is accepted into this study if the value is not more than 0.1 and this value is reasonable to map groundwater potential zones. If the value of CR is found more than 0.1, then the value is readjusted by assigning different values in the pairwise comparison matrix according to Saaty (2008).

To accomplish the next step, a weighted sum matrix was established by calculating the modified weight for individual factors given in Table 2. Then ratio of weighted sum (WS) and criteria weight (CW) calculated for each of the thematic factors which is important to estimate the λmax. The value of λmax was found 8.85 by calculating the average (mean) value of the ratio of weighted sum and criteria weight. Afterward, the consistency index (CI) was calculated and found to be 0.12. In the final stet, the consistency ratio (CR) was estimated and found to be 0.086. The obtained consistency ratio (CR) is less than 0.1 which is an acceptable condition. Similar weightage and ranks were assigned by [5,9,12,13].

Table 2. Weightage and ranking for different thematic maps by AHP

Sr. No	Theme	Subclass	Rank	Weight age(%)
1	LULC	Water Body	5	23
		Forest	3	
		Flooded Vegetation	5	
		Agriculture	4	
		Built-Up	1	
		Barren Land	2	
2	Slope %	<10	5	16
		10-20	4	
		20-30	3	
		30-40	2	
		>40	1	
3	Post Monsoon GWD (m bgl)	0.26-1	5	12
		1-3	4	

Sr. No	Theme	Subclass	Rank	Weight age(%)
		3-5	3	
		5-7	2	
		7-13	1	
4	Geology	Badami Gp. (Kaladgi SGp.)	1	13
		Goa Gp. (Dharwar SGp.)	2	
		Deccan Trap	4	
		Laterite	3	
		Alluvium	5	
5	GM	Alluvial Plain	4	13
		Dissected Hills and Valleys	1	
		Dissected Plateau	3	
		Pediment Pediplain Complex	4	
		Waterbodies	5	
6	Rainfall (mm)	500-1000	1	10
		1001-2000	2	
		2001-3000	3	
		3001-4000	4	
		4001-5000	5	
7	Soil Texture	Sandy Clay Loam	2	6
		Clay Loam	2	
		Loam	3	
		Sandy Loam	4	
		Clay	1	
8	L.D (km/sq.km)	0-0.0693	1	7
		0.0694-0.188	2	
		0.189-0.342	3	
		0.343-0.563	4	
		0.564-1.04	5	
Total				**100**

The assigned ranks were integrated into the raster of all thematic maps. The reclassified thematic maps with ranking values were integrated with the help “weighted sum” tool in Arc GIS Software to obtain groundwater potential zones. The generated map indicates the very good, good, moderate, poor, and very poor groundwater potential zones.

3. RESULTS AND DISCUSSION

3.1 Geology

Geology plays a crucial role in the movement and occurrence of groundwater in a region, which significantly influencing groundwater potential studies. In the study area, five major geological groups are identified namely, Alluvium, Badami Group (Kaladagi sgp.), Deccan Trap, Goa Group (Dharwar sgp.) and Laterite. The succession of geological formations is represented in Table 3 and spatial distribution of different geological formations over the study area is depicted in Fig. 3.

The region is predominantly composed of deccan trap, covering 72.66% of the geographic area. The most common type is a dark green or nearly black basalt. The porosity of fractured basalt ranges between 5 to 30% and for vesicular basalt, it ranges between 10 and 40%. The porosity of vesicular basalt is a result of the degree of void creation during the solidification process [14]. Konkan region is distinguished in Maharashtra for the presence of Lateritic rocks and soils, which cover approximately 13.92% and are characterized by a pebbly crust formed due to the alternating dry and wet periods. Laterite is typically rusty red in color due to its high iron oxide content. Laterite formation is unconsolidated sediment and dominantly consists silt having porosity between 35 and 50% and clay having porosity range of 45 to 55% [15]. The Goa group of geological formations cover 7.90% of the region, consisting of quartzite, phyllites, schist and gneiss. The weathered granite and gneiss, which are igneous and metamorphic rock in the Goa group formation have a porosity between 5 to 25%. Alluvium, which accounts for 4.74%

of the area, consists of geologically young unconsolidated sediment made up of silt, sand, clay, and gravel left by rivers and floods. It often contains significant organic matter and minerals, giving it a dark color. Badami group, which consolidated sediment containing sandstone, limestone, and shale has a porosity between 1 to 30%. This sediment covered 0.79% of the study area.

Table 3. Geological formations and their area distribution in the Konkan region

Sr No.	Geological Group	Area, km^2	Percent Area
1	Badami Gp. (Kaladgi SGp.)	236.627	0.79
2	Goa Gp. (Dharwar SGp.)	2363.856	7.90
3	Deccan Trap	21741.573	72.66
4	Laterite	4164.668	13.92
5	Alluvium	1417.576	4.74

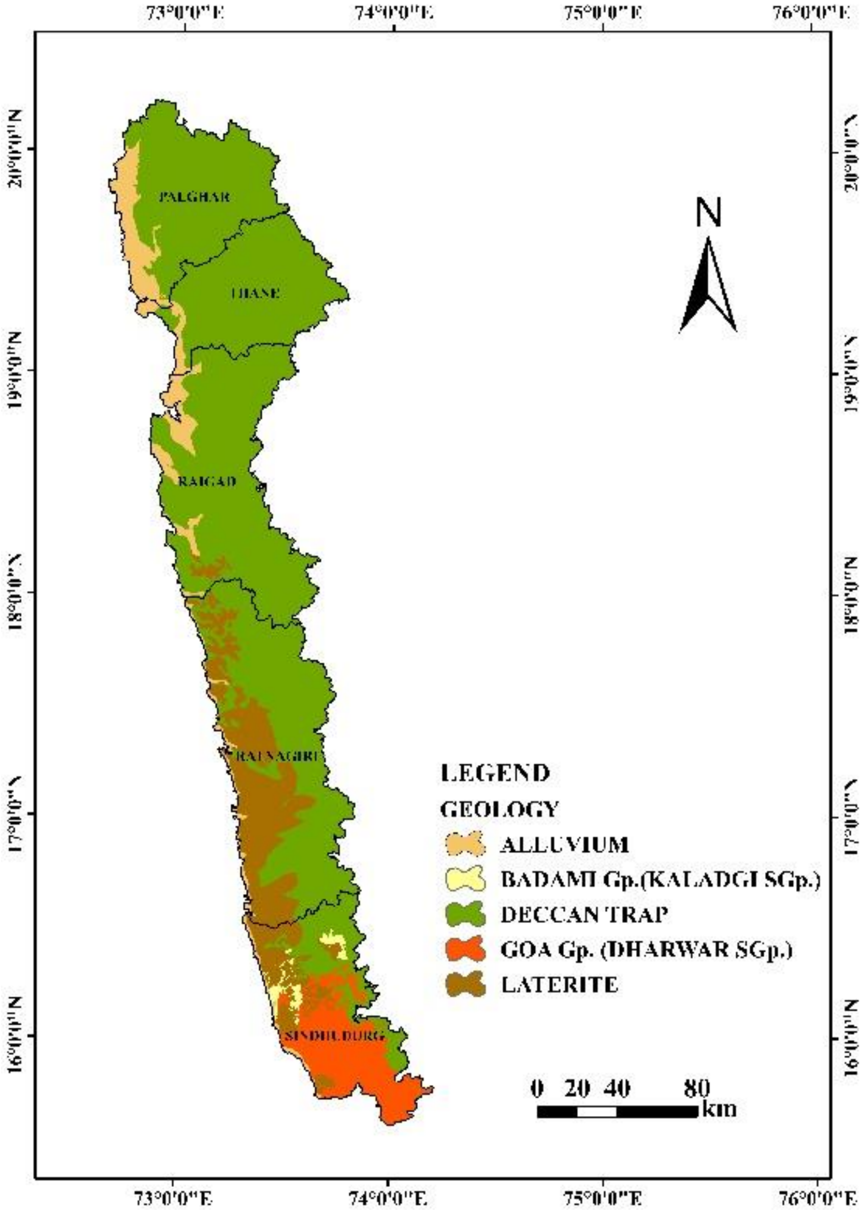

Fig. 3. Spatial distribution map of geology

Table 4. Distribution of geomorphological units in the Konkan region

Sr. No	Geomorphological Units	Area, km^2	Percent Area
1	Alluvial Plain	2518.354	8.42
2	Dissected Hills and Valleys	754.05	2.52
3	Dissected Plateau	15803.3	52.81
4	Pediment Pediplain Complex	10305.353	34.44
5	Waterbodies	543.246	1.81

Alluvium deposits are found along both banks of the main river and in coastal areas. These deposits also occur in Patalganga, Ulhas, Vaitarna, Amba and other basins in varying proportions, covering an area of 1417.58 km^2, which accounts for 4.74% of the region, mainly in North Konkan. In the eastern part, the alluvium is mixed with gravel, while near the coastal areas, it is mixed with sand. Lateritic capping over the basaltic flows has been observed rarely at plateau-type areas in Ambika, Auranga Nar par Damanganga and streams between Damanganga and Vaitarna.

3.2 Geomorphology

In the study area, five geomorphic units were identified namely, Alluvial Plain, Dissected Hills and Valleys, Dissected Plateau, Pediment Pediplain Complex and Waterbodies which are shown in Table 4. The spatial map of the geomorphology of the Konkan region was illustrated in Fig. 4.

Dissected plateau and Pediment-Pediplain complex equally dominate the study area at more than 70%, followed by Alluvial plain and Dissected hills and valleys at 8.42% and 2.52%. The pediment-pediplain complex is ideal for groundwater recharge because of the weathered material and gently undulating plains [16]. A good to moderate groundwater potential zone can be found in the pediment and pediplain areas associated with agricultural land [17]. However, water bodies, which serve as a recharge zone for the region's groundwater, are given the highest weight, but the water bodies occupied only 0.22% of the total area.

Out of total 5 geomorphological formations, the major part of the study area is covered by the Dissected Plateau (52.81%), followed by the Pediment Pediplain Complex (34.44%). The smallest area covered by (2.52%) Dissected Hills and Valleys and followed by Water bodies (1.81%). Dissected plateau formed by basalt, the primary porosity is found in the form of vesicles, but to a limited extent, normally water flow is only available in secondary fractures and joints of open nature making it poor-moderate site of groundwater recharge. Thus, the areas with dissected plateaus are poor to moderate character for groundwater recharge. On the contrary, the pockets in the study area with the Pediment Pediplain complex may have a good zone of groundwater potential.

3.3 Lineament Density

Lineaments are structurally controlled linear or curvilinear features that indicate the zone of structural weakness in the form of faults, dyke and joints or fractures and hence normally carry groundwater. Lineament density and its coverage area are presented in (Table 5) and the spatial map of Lineament density is presented in Fig. 5.

The highest area (about 48% of the total area) in the Konkan region is occupied by a lineament density of 0 – 0.0693 km/km^2, indicating very low groundwater potential, followed by about 26% area with a range of 0.0694 to 0.188 km/km^2 suggesting the area with more groundwater recharge. The smallest area is occupied by the higher lineament values indicating the very high groundwater potential through the secondary porosity of fractures, faults and joints of rocks. Structural ridges are poor groundwater recharge zones, whereas subsurface fractures and joints qualify as good groundwater recharge zones [18]. Lineaments represent the zones of faulting and fracturing resulting in increased secondary porosity and permeability, which determine groundwater occurrence and movement in hard rock terrain [19]. These factors are hydro-geologically very important as they provide the pathways for groundwater movement. Lineament density of an area can indirectly reveal the groundwater potential, since the presence of lineaments usually denotes a permeable zone. Groundwater potential increases with increasing lineament density values [20].

The spatial distribution of lineament density shows that the higher densities are concentrated in the eastern parts of the Palghar and Thane districts (Fig. 5), suggesting the high to very high groundwater potential as compared to other parts of the region. In contrast, Raigad, Ratnagiri and Sindhudurg districts exhibit lower lineament density values, indicating comparatively lower groundwater potential. Based on this distribution, Palghar district is likely to have the highest groundwater potential, while Sindhudurg district may have the lowest.

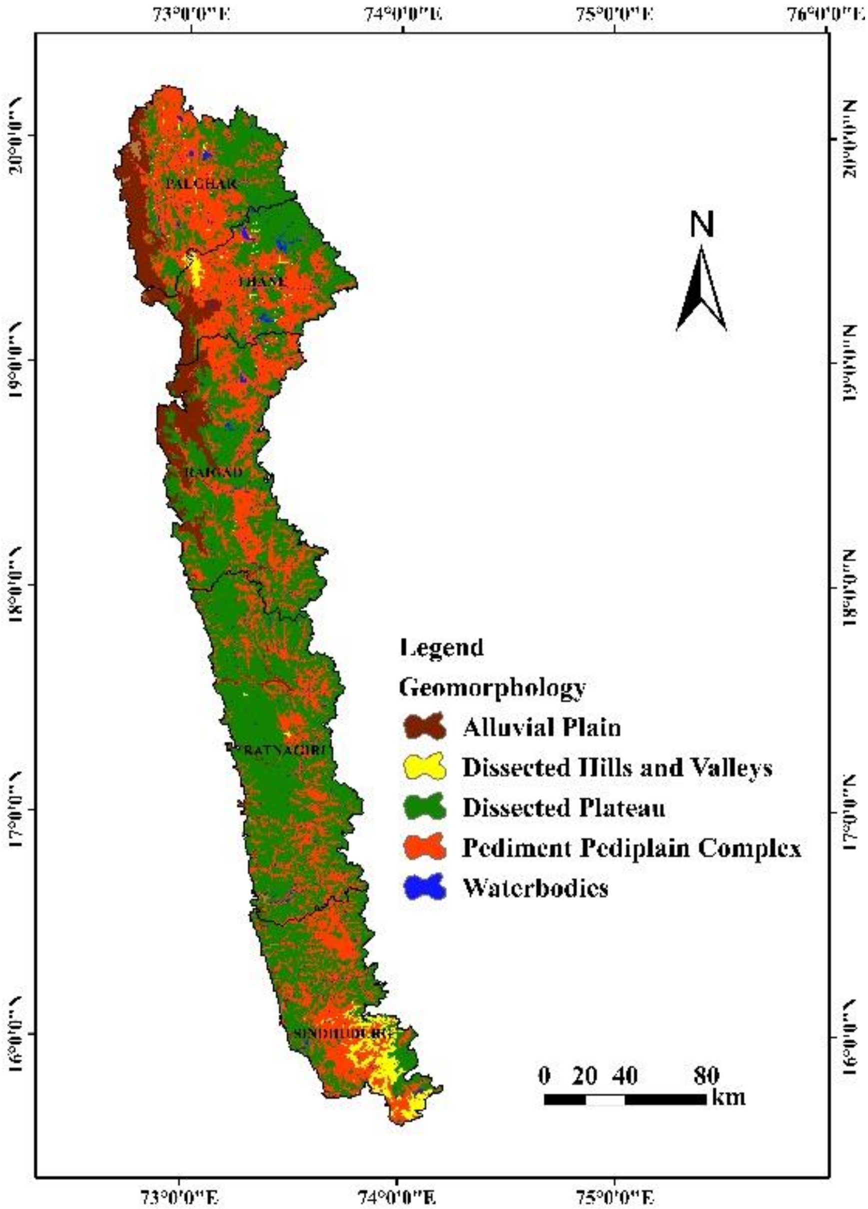

Fig. 4. Spatial distribution map of geomorphology

Table 5. Lineament density and its distribution in the Konkan region

Sr. No	Lineament Density (km/km^2)	Area, km^2	Percent Area
1	0-0.0693	14248.900	47.62
2	0.0694-0.188	7756.830	25.92
3	0.189-0.342	4761.100	15.91
4	0.343-0.563	2276.700	7.61
5	0.564-1.04	880.706	2.94

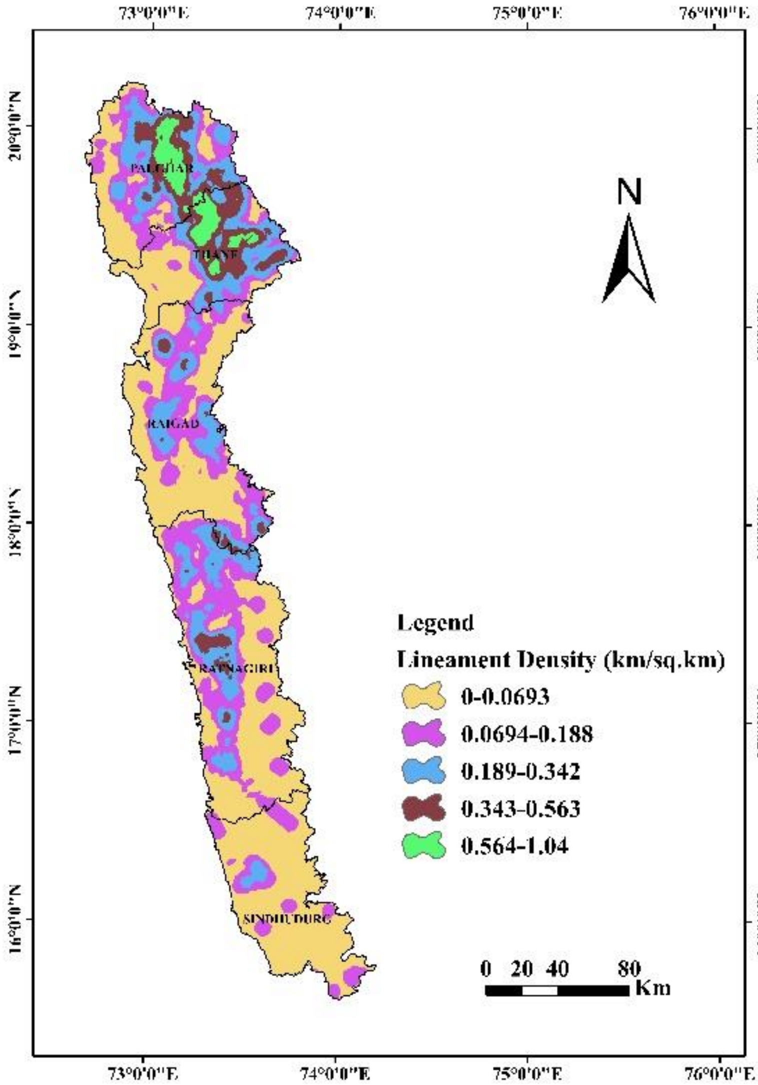

Fig. 5. Spatial distribution map of lineament density

Table 6. Areal distribution of soil texture

Sr. No	Soil Texture	Area, km^2	Percent Area
1	Sandy Clay Loam	5976.190	19.97
2	Loam	13692.662	45.76
3	Clay Loam	10157.170	33.94
4	Sandy Loam	31.310	0.10
5	Clay	66.964	0.22

3.4 Soil Texture

Soils are the resultant product of weathering parent rocks caused by differences in temperature and hydration effect. Soil texture is the most evident factor which influences the groundwater prospect mapping in any area. A total of five major textural classes of soil were found in the region namely sandy clay loam, loam, clay loam, sandy loam and clay which is given in Fig 6. The areal distribution of soil texture in the study area is presented in Table 6. It was observed that the loamy soil covered major part of the region (45.76%) followed by clay loam soil (33.94%). The smallest portion of the region was associated with the sandy loam (0.10%).

3.5 Slope Ranges

The slope of a surface, representing the elevation change, influences the movement of water due to gravity and therefore a critical factor in assessing groundwater potential zone. Slope regulates water infiltration into the subsurface, making it a strong indicator of potential groundwater resources. Generally, slope and infiltration rate are inversely proportional [19]. The degree of slope impacts the rate of water percolation and infiltration into the ground [21]. Areas with lower slopes are more conducive to groundwater potential, while higher slope areas are considered less suitable [22]. In this study, a slope map was generated from SRTM DEM using ArcGIS software. The study area was classified into five categories, with the distribution and area occupied by each category presented in Table 7. The spatial distribution of slope ranges shown in Fig. 7.

The slope values were classified into five categories: very steep (> 40%), steep (30-40%), moderate (20-30%), low or gentle (10-20%) and very low or flat (0-10%). The flat slope category dominated the study area, covering 15569.7 km^2, indicating that a significant portion of the region has slopes favorable to water retention. Areas with flat or gentle slopes are ideal for good recharge, as they minimize runoff and allow a longer time of concentration for surface water percolation. Therefore, highest weight was assigned to these areas [23]. Similar classes were also observed by Bhange et al., 2016; Keskar et al., 2023; and Gavit et.al. 2024.

The eastern side of the Konkan region, occupied by Sahyadri hills, is dominantly characterized by very steep to steep slopes across all districts. In contrast, the coastal areas generally feature flat slopes. The flat slope is more concentrated in the Palghar district, followed by the Thane and Raigad districts, particularly on the western side near the Arabian Sea. Ratnagiri district has the least amount of flat slope areas compared to other districts. As a result, Thus, Palghar district is likely to have higher groundwater recharge potential, while Ratnagiri district may have the lowest.

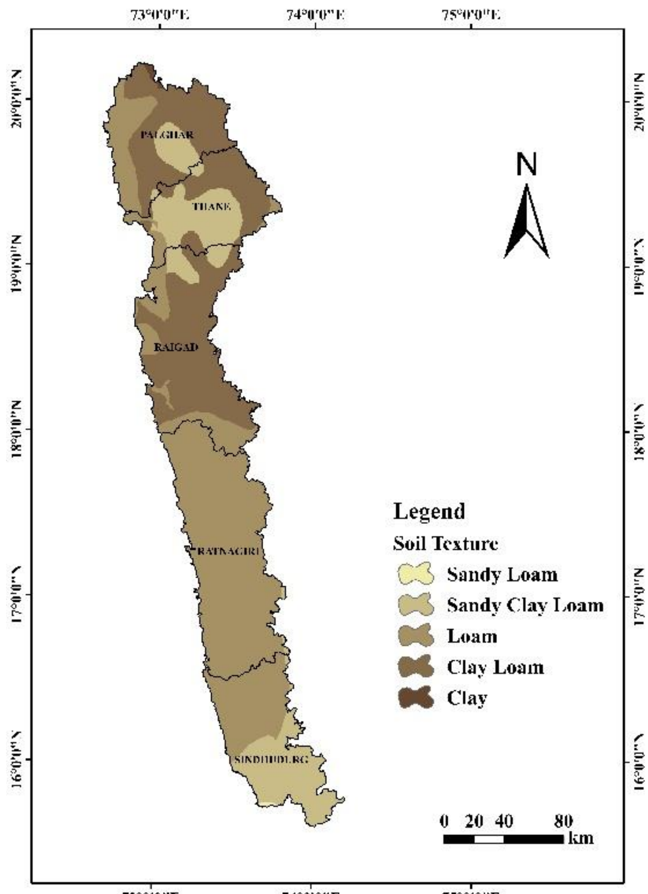

Fig. 6. Spatial distribution map of soil texture

Table 7. Distribution of slope categories and their area coverage in the Konkan region

Sr. No	Slope (%)	Area, km^2	Percent Area
1	< 10	15569.70	52.03
2	10-20	6435.56	21.51
3	20-30	3706.92	12.39
4	30-40	2023.56	6.76
5	>40	2188.51	7.31

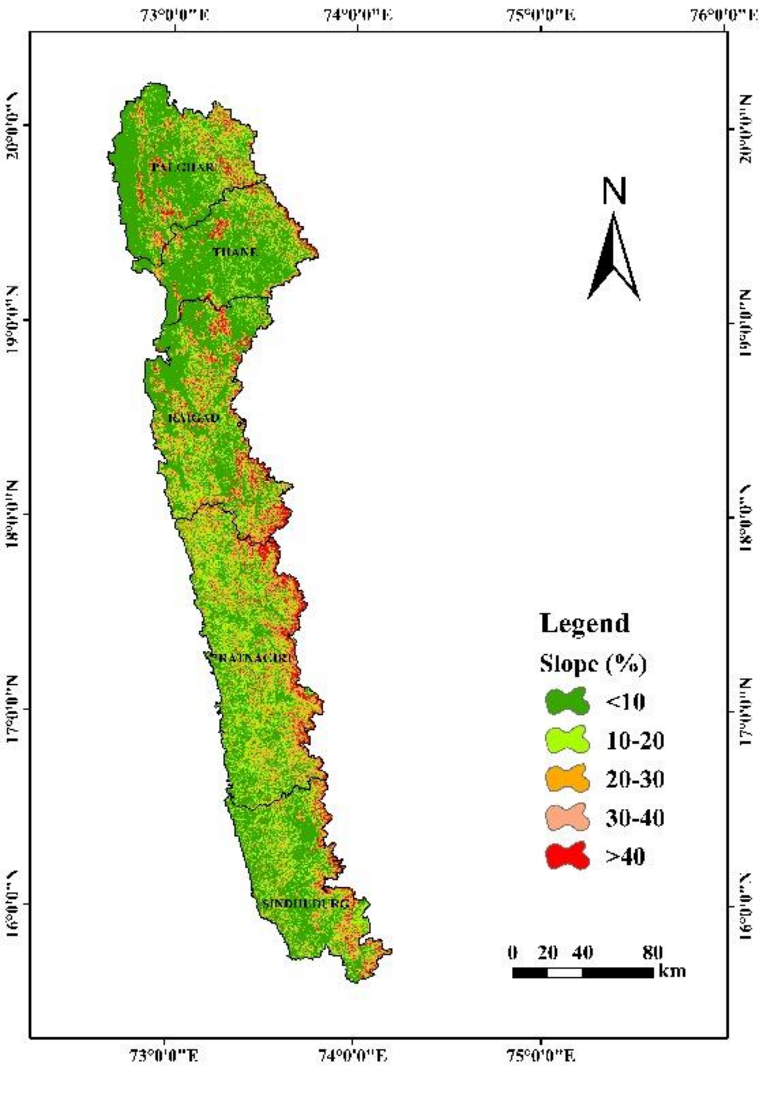

Fig. 7. Spatial distribution of slope categories in the Konkan region

3.6 Rainfall

Rainfall is a crucial component of the hydrological cycle and directly influences the amount of groundwater recharge in a given area. Higher rainfall in a region typically increases the likelihood of groundwater recharge [24]. Given that the region typically experiences heavy rainfall, the majority of the area (over 90%) falls within the 2001 to 4000mm rainfall range. The average rainfall data was interpolated and grouped into five categories from 500 to 5000 mm, with an area occupied by each range of rainfall is presented in (Table 8.). Fig. 8 illustrates the distribution of rainfall across five districts of the Konkan region. Rainfall has been reclassified into five categories ranging from 500-1000mm, 1001-2000mm, 2001-3000mm, 3001 to 4000mm and 4001 to 5000mm.

Table 8. Annual rainfall and its distribution in the study area

Sr. No	Rainfall (mm)	Area, km^2	Percent Area
1	500-1000	7.112	0.02
2	1001-2000	49.737	0.16
3	2001-3000	12315.376	41.15
4	3001-4000	15241.134	50.93
5	4001-5000	2310.944	7.72

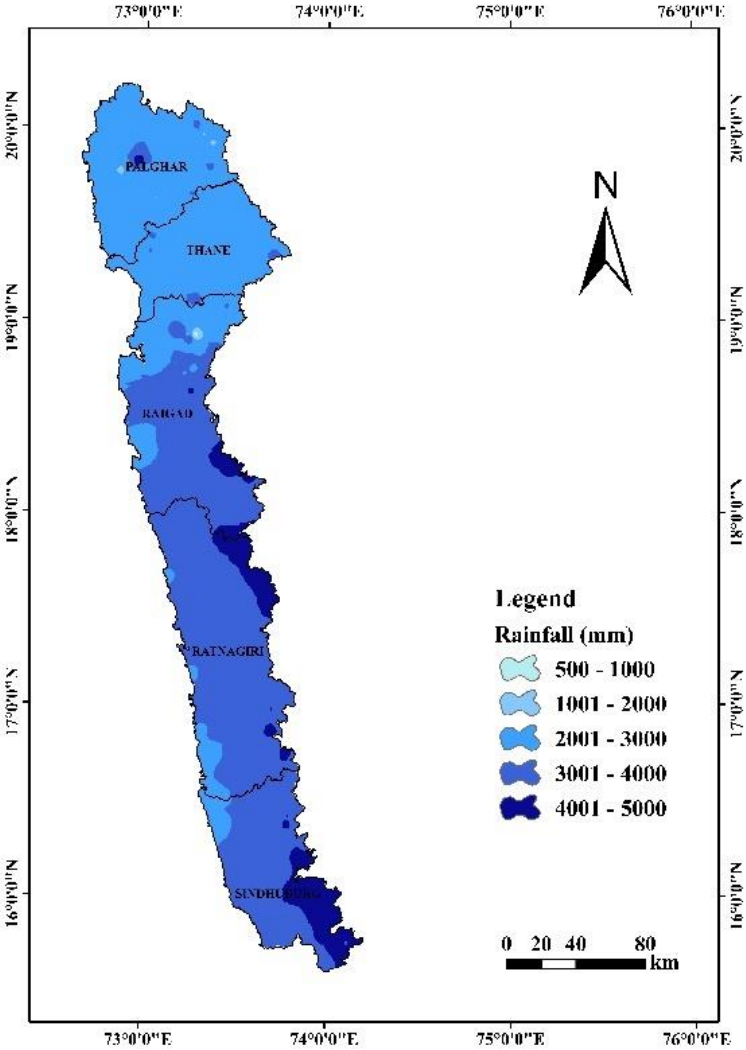

Fig. 8. Annual rainfall distribution in the Konkan region

3.7 Land Use Land Cover

Land use refers to human activities on land and the various purposes for which land is utilized, while land cover denotes the natural features present, such as vegetation, water bodies, rock/soil, and artificial structures resulting from land transformation [25]. Land Use and Land Cover (LULC) data provide crucial insights into factors like moisture, infiltration, surface water, and other water resources, as well as indicators of groundwater demand. The LULC map highlights the extent of impervious surfaces, which correlates with the availability of water for percolating [26]. Groundwater depletion is more likely in areas with wastelands and dense populations, while forested areas tend to see a rise in the water table due to low runoff and high subsurface infiltration [27]. Similarly, surfaces with dense vegetation have a higher infiltration capacity than barren lands, making groundwater potential high in forested and agricultural areas [28].

The LULC map of the region includes various classes such as water bodies, forests, flooded vegetation, agriculture, built-up area, and barren land and their area distribution is presented in Table 9.

The LULC pattern in the Konkan region, as presented in Table 9, reveals a contrasting distribution of land cover: approximately 40% of the area is occupied by forests, while another 40% area consists of barren land. Agriculture accounts for only 10% of the area, with built-up areas covering 6% and water bodies spanning 926.38 km^2 (3.1%). Forests dominate a significant portion of the region, covering 12052.711 km^2, while agricultural land occupies 3036.906 km^2. The infiltration rate increases as vegetation holds onto rainwater for longer periods, facilitating groundwater recharge. Forested areas, croplands and plantations have moderate runoff and high infiltration rates, contributing to enhanced groundwater recharge [29]. Water bodies are assigned the highest weight as they are principal recharge zones, followed by forests, plantations and croplands. In contrast, barren and built-up lands have impervious surfaces that increase storm runoff and reduce infiltration capacity, resulting in lower weights being assigned to these classes. The map showing the spatial distribution of LULC across all districts of the Konkan region is displayed in Fig. 9. Similar classes were also observed by Bhange et al., 2016; Keskar et al., 2023; and Gavit et.al. 2024.

3.8 Groundwater Depth Fluctuation

The groundwater depth map was based on data collected from monitoring well locations and groundwater levels. The fluctuation map was categorized into appropriate depth ranges, with weights assigned according to their relative importance in terms of groundwater recharge. The distribution of groundwater depth across the study area during pre and monsoon seasons is presented in Table 10.

Based on groundwater data from observation wells, the data was regrouped and classified into eight categories for pre-monsoon observations below ground level. The results in Table 10 show that the depth range of 4 to 6 m bgl occupies 40.77% of the area, followed by the 2 to 4m bgl and 6 to 8 m bgl ranges. Together, these three depth ranges account for over 90% of the total area in the region. Only 9.25% area has the water table depth in the range between 8 m bgl and 16 m bgl, and just 0.25% of the area had this water table depth before the monsoon. Post-monsoon observations indicate that more than 70% of the area has a groundwater depth of 0.26 to 3 m bgl, indicating adequate recharge in these regions. Groundwater potential is higher in areas with less water level fluctuation than in the regions with greater fluctuation [30].

Conversely, the remaining 30% of the area has a depth of more than 3 m bgl, suggesting that these areas may not be suitable for groundwater recharge, resulting in inadequate recharge. Consequently, areas with faster recharge i.e., areas with shallow depths were assigned the highest rank, while the areas with deeper groundwater depths were given the lowest rank. The distribution of groundwater fluctuation during pre-monsoon and post-monsoon seasons, as shown in Fig. 10, indicates that most of the areas in Palghar, Thane and Raigad districts experience significant recharge after the monsoon. However, certain areas in the central part of Ratnagiri district and the southern part of Sindhudurg districts do not receive adequate recharge, despite receiving over 3000 mm of annual rainfall during the monsoon season.

Table 9. Area occupied by different Land Use Land Cover (LULC) classes in the Konkan region

Sr. No	Class	Area, km^2	Percent Area
1	Water Body	926.377	3.10
2	Forest	12052.711	40.28
3	Flooded Vegetation	136.880	0.46
4	Agriculture	3036.906	10.15
5	Built-Up	1818.923	6.08
6	Barren Land	11946.097	39.94

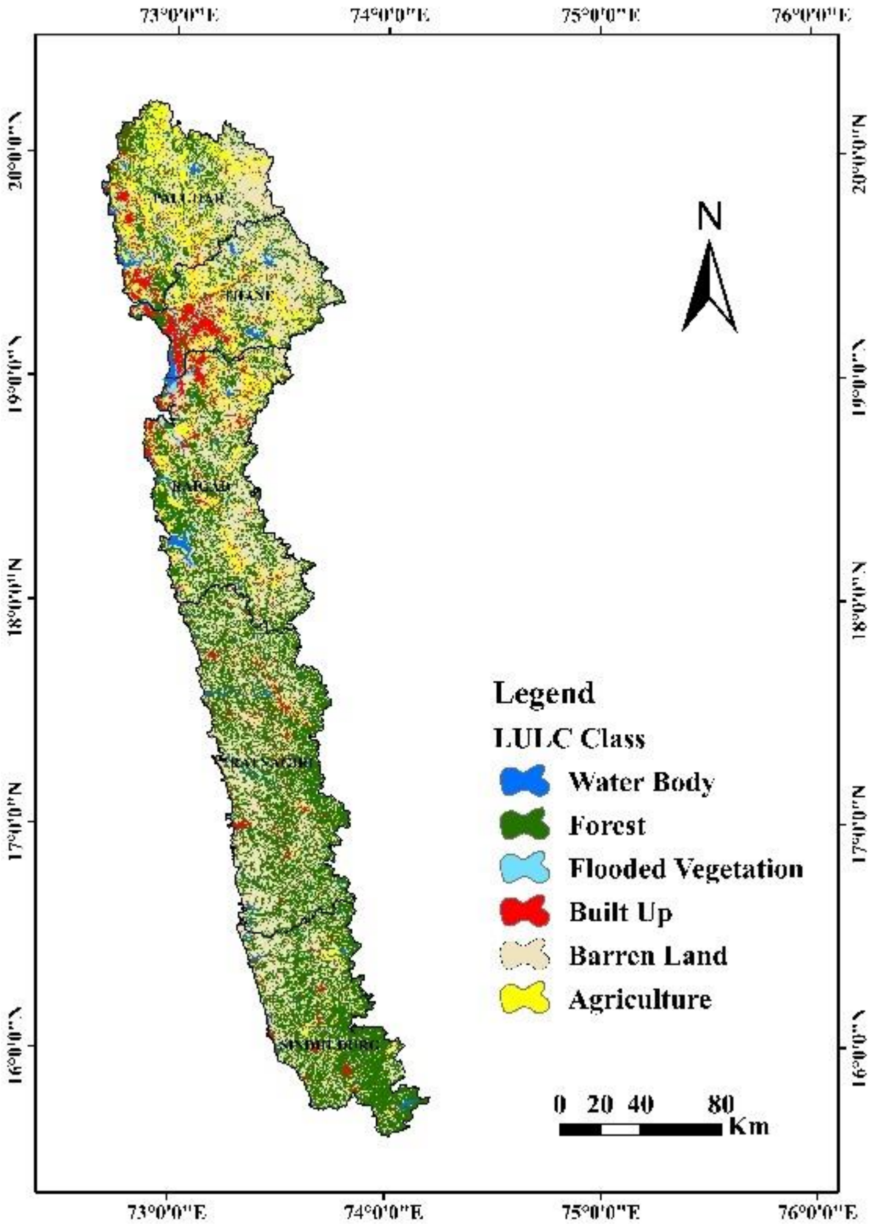

Fig. 9. Spread of LULC classes across all districts of the Konkan region

Table 10. Distribution of area under different groundwater depths in the study area

Groundwater depth below ground level (m bgl) and its distribution					
Pre-monsoon period			Post monsoon period		
GW depth (m bgl)	Area occupied, km^2	Percent area	GW depth (m bgl)	Area occupied, km^2	Percent area
0.69-2	224.61	0.75	0.26-1	7016.41	23.44
2-4	8422.14	28.14	1-3	13930.70	46.54
4-6	12198.80	40.77	3-5	6455.74	21.57
6-8	6369.34	21.28	5-7	1890.67	6.32
8-10	1970.38	6.58	7-13	638.27	2.13
10-12	540.02	1.8			
12-14	155.76	0.52			
14-16	43.17	0.14			

Table 11. Distribution of groundwater potential zones (GWPZ) in the Konkan region

Sr. No	Class	Area, km^2	Percent Area
1	Very Poor	1326.38	4.43
2	Poor	8148.22	27.23
3	Moderate	13224.26	44.19
4	Good	5929.61	19.82
5	Very Good	1295.84	4.33

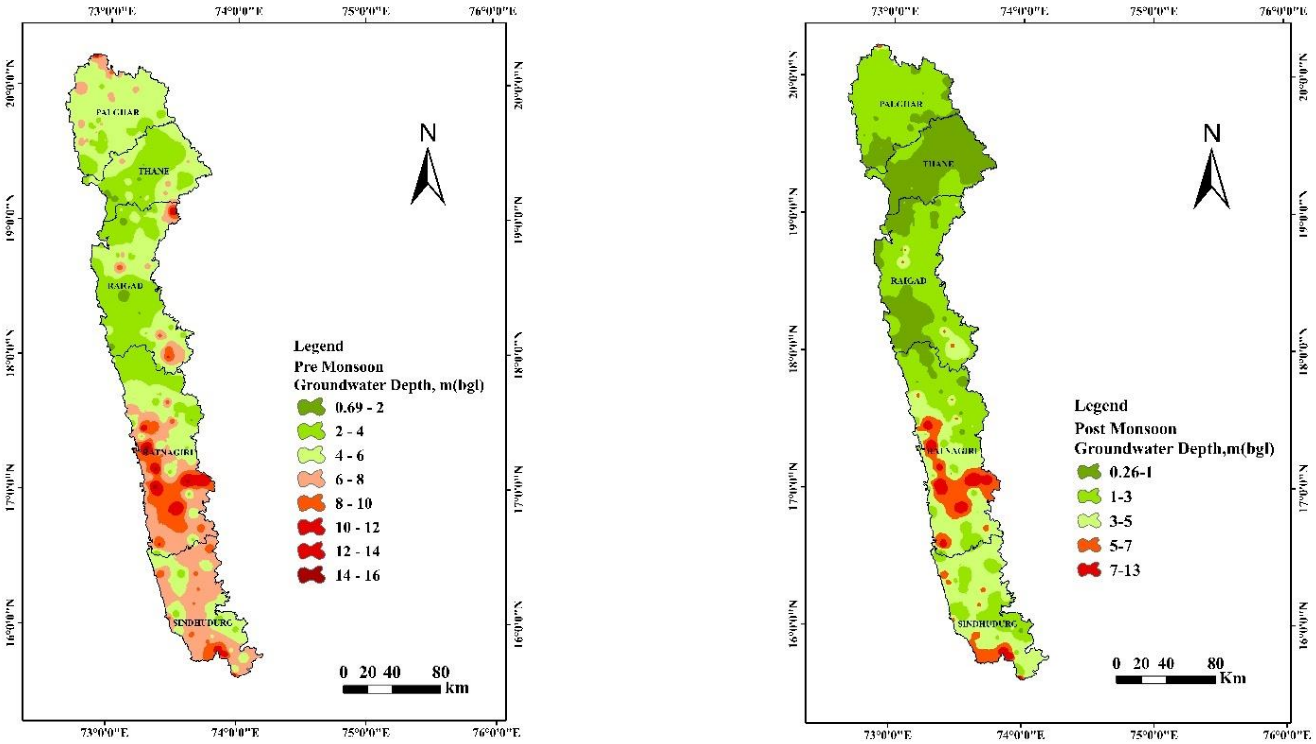

Fig. 10. Spatial distribution of groundwater depth during pre- and post-monsoon periods in the Konkan region

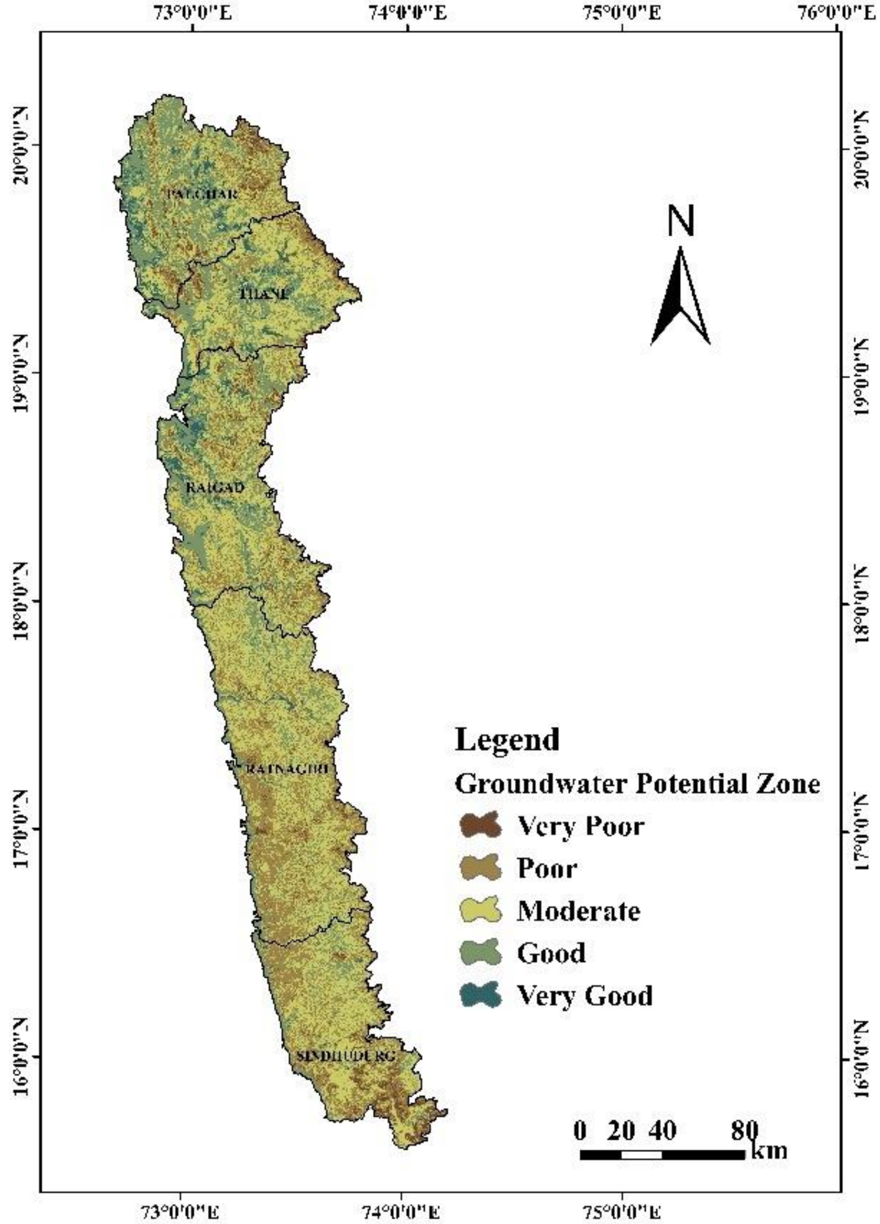

Fig. 11. Spatial distribution map of groundwater potential

3.9 Groundwater Potential

The results of the groundwater potential zones map through the AHP technique and weighted sum method divided the region into five classes, viz., very poor, poor, moderately poor, good and very good zones. Areal distribution of groundwater potential zones is presented in Table 11. A major part of the region found at about 44.19% in moderate groundwater potential zones followed by poor groundwater potential zones at 27.23%. The groundwater potential map of the region is shown in Fig 11. The good groundwater potential zones also contribute 19.82% area of the region, as well as the very poor groundwater potential zones also contribute to 4.43% area of the region. The least area found in the very good potential zones which is about 4.33%. Similar results were also observed by [5,9,13].

4. CONCLUSION

In this study, the integration of Remote Sensing and GIS with the Analytical Hierarchy Process (AHP) technique has proven to be an effective method for identifying groundwater potential zones within the study area. The area has been categorized into five distinct groundwater potential zones, with the majority of the region exhibiting a range from moderately poor to good groundwater potential. By combining factors such as rainfall, geology, geomorphology, lineament density, groundwater depth, land use and land cover, slope, and soil, this approach provides valuable preliminary information for planners and decision-makers involved in water resource development, enabling them to create economically viable plans.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology.

ACKNOWLEDGEMENT

The authors are greatfull to the Groundwater Survey and Development Agencies (GSDA), Navi Mumbai and Hydrology Project (HDUG) Nashik, Maharashtra for their extensive help and support during data collection and field survey.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFRENCES

1. Jarvis T, Giordano M, Puri S, Matsumoto K, Wolf A. International borders groundwater flow and hydroschizophrenia. Groundwater. 2005;43(5):764-770. Available:https://doi.org/10.1111/j.1745-6584.2005.00069.x
2. Pandey K, Kumar S, Malik A, Kuriqi A. Artificial neural network optimized with genetic algorithm for seasonal groundwater table depth prediction in Uttar Pradesh, India. Sustainability. 2020;12(21): 8932. Available:https://doi.org/10.1016/j.ecolind.2019.01.034
3. CGWB. National Compilation on Dynamic Ground Water Resources of India; 2019. Available: www.cgwb.gov.in
4. CGWB. National Compilation on dynamic ground water resources of India; 2023a. Available: www.cgwb.gov.in
5. Bhange HN, Singh PK, Purohit RC, Yadav KK, Jain HK, Jain S. Use of remote sensing and GIS techniques in delineation of groundwater potential zones. Int. Res. J. Earth Sci.. 2016;4(9): 1-6. Available: https://www.isca.me/EARTH_SCI/Archive/v4/i9/1.ISCA-IRJES-2016-032.pdf
6. Das S, Pardeshi SD. Integration of different influencing factors in GIS to delineate groundwater potential areas using IF and FR techniques: A study of Pravara basin, Maharashtra, India. Applied Water Science. 2018; 8(7): 197. Available: https://link.springer.com/content/pdf/10.1007/s13201-018-0848-x.pdf
7. Patle D, Awasthi MK. Groundwater potential zoning in Tikamgarh District of Bundelkhand using remote sensing and GIS. International Journal of Agriculture, Environment and Biotechnology.2019; 12(4): 311-318. Available:https://doi.org/10.30954/0974-1712.12.2019.3.
8. Pawar U, Suppawimut W. Rathnayake Mapping of groundwater potential zones in a drought prone Marathwada Region using frequency ratio and statistical index methods, India. Results in Engineering. 2024;22:101994. Available: https://pdf.sciencedirectassets.com/320278/1-s2.0-S2590123024X0002X/
9. Gavit SB, Bhange HN, Ayare BL, Patil ST, Kolhe PR. Identification of groundwater potential zones in Wakawali watershed using remote sensing and geographic information system (GIS). International Journal of Environment and Climate Change. 2024;14(8):333–346. Available: https://doi.org/10.9734/ijecc/2024/v14i84354
10. Saaty TL. The analytic hierarchy processes. McGraw-Hill, New York; 1980. Available: https://www.sciencedirect.com/science/article/pii/0270025587904738
11. Saaty. Decision making with the analytic hierarchy process. International Journal of Services Sciences. 2008;1(1):83-98. Available:https://www.sciencedirect.com/science
12. Landage OP, Bhange HN, Tharkar MH, Kolhe PR, Bansode PB, Ayare BL.

Application of geospatial technology for estimation of groundwater potential zone. 2021;200-210.
Available: https://www.researchgate.net/publication/363212084_Application_of_geospatial_technology_for_estimation_of_groundwater potential_zone

13. Keskar PR, Ayare BL, Bhange HN, Ingle PM, and Kolhe PR. Identification of groundwater potential zones in Kajali River basin using remote sensing and GIS. The Pharma Innovation Journal. 2023; 12(10): 2137-2144.
Available:https://www.thepharmajournal.com/specialissue?year=2023&vol=12&issue=10S&ArticleId=23835

14. Woessner WW, Eileen PP. Hydrogeologic properties of earth materials and principles of groundwater flow. The Groundwater Project, Guelph, Ontario, Canada; 2020.
Available:https://www.un-igrac.org/sites/default/files/resources/files/hydrogeologic-properties-of-earth-materials-and-principles-of-groundwater-flow.pdf

15. Prasad TK, Parthasarathy GR. Laterite and laterization-a geomorphological review. International Journal of Science and Research (IJSR). 2018;7(4):578-583.
Available:https://www.ijsr.net/archive/v7i4/ART20181444.pdf

16. Murmu P, Kumar M, Lal D, Sonker I, Singh SK. Delineation of groundwater potential zones using geospatial techniques and analytical hierarchy process in Dumka district, Jharkhand, India. Groundwater for Sustainable Development. 2019;9:100239.
Available:https://www.sciencedirect.com/science/article/abs/pii/S2352801X18302339

17. Thapa R, Gupta S, Guin S, Kaur H. Assessment of groundwater potential zones using multi-influencing factor (MIF) and GIS: A case study from Birbhum district, West Bengal. Applied Water Science. 2017;7:4117-4131.
Available:https://link.springer.com/article/10.1007/s13201-017-0571-z

18. Goitsemang T, Das DM, Raul SK, Subudhi CR, Panigrahi B. Assessment of groundwater potential in the Kalahandi District of Odisha (India) using remote sensing, geographic information system and analytical hierarchy process. Journal of the Indian Society of Remote Sensing. 2020;48:1739–1753.
Available: https://doi.org/ 10.1007/s12524-020-01188-3.

19. Satapathy I, Syed TH. Characterization of groundwater potential and artificial recharge sites in Bokaro District, Jharkhand (India), using remote sensing and GIS-based techniques. Environmental Earth Science. 2015;745(74):4215–4232.
Available:https://doi.org/ 10.1007/s12665-015-4474-8

20. Varade AM, Khare YD, Yadav P, Doad AP, Das S, Kanetkar M, Golekar RB. 'Lineaments' the potential groundwater zones in hard rock area: A case study of Basaltic Terrain of WGKKC-2 Watershed from Kalmeswar Tehsil of Nagpur District, Central India. Journal of the Indian Society of Remote Sensing. 2018;46:539-549.
Available: https://doi.org/ 10.1007/s12524-017-0716-4

21. Siva G, Nasir N, Selvakumar R. Delineation of groundwater potential zone in Sengipatti for Thanjavur District using analytical hierarchy process. IOP Conference Series: Earth and Environmental Science. 2017; 80:012063.
Available:https://doi.org/10.1088/1755-1315/80/1/012063

22. Shao Z, Huq ME, Cai B, Altan O, Li Y. Integrated remote sensing and GIS approach using Fuzzy-AHP to delineate and identify groundwater potential zones in semi-arid Shanxi Province, China. Environmental Modelling and Software. 2020;134:104868.
Available: https://doi.org/10.1016/J.ENVSOFT.2020.104868

23. Kumar A, Krishna AP. Assessment of groundwater potential zones in coal mining impacted hard-rock terrain of India by integrating geospatial and analytic hierarchy process (AHP) approach. Geospatial Intelligence. 2016;33:105129.
Available:https://doi.org/ 10.1080/10106049.2016.1232314.

24. Machiwal D, Jha MK, Mal BC. Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. Water Resource Management. 2011; 25:1359–1386.
Available:https://doi.org/10. 1007/s11269-010-9749-y.

25. Balchandar D, Alaguraja P, Sundaraj P, Rutharveimurthy K, Kumaraswamy K. Application of remote sensing and GIS for artificial recharge zone in Sivganga District. Tamilnadu, India. International

Journal of Geomatics and Geoscience. 2010; 1(1): 84-96.
Available:https://www.researchgate.net/publication/334945416_Application_of_Remote_Sensing_and_GIS_for_Artificial_Recharge_Zone_in_Sivaganga_District_Tamilnadu_India

26. Patil SG, Mohite NM. Identification of groundwater recharge potential zones for a watershed using remote sensing and GIS. International Journal of Geomatics and Geosciences. 2014;4:485–498.
Available:https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=2286d72bff7a8aa1fc74670bbe4b95e1507f69fe
27. Sahoo S, Munusamy SB, Dhar A, Kar A, Ram P. Appraising the accuracy of multi-class frequency ratio and weights of evidence method for delineation of regional groundwater potential zones in canal command system. Water Resource Management. 2017;3114(31): 4399–4413.
Available: https://doi.org/10.1007/ S11269-017-1754-Y
28. Li W, Macbean N, Ciais P, Defourny P, Lamarche C, Bontemps S, Houghton RA, Peng S. Gross and net land cover changes in the main plant functional types derived from the annual ESA CCI land cover maps (1992–2015). Earth System Science Data. 2018;10:219–234.
Available: https://doi.org/10.5194/essd-10-219-2018
29. Saravanan S, Saranya T, Abijith D, Jacinth JJ, Singh L. Delineation of groundwater potential zones for Arkavathi sub-watershed, Karnataka, India using remote sensing and GIS. Environmental Challenges. 2021; 5:100380.
Available:https://doi.org/10.1016/j.envc.2021.100380
30. Bera A., Mukhopadhyay B. P., and Barua S. Delineation of groundwater potential zones in Karha river basin, Maharashtra, India, using AHP and geospatial techniques. Arabian Journal of Geosciences. 2020;13(15):693.
Available: https://doi.org/10.1007/s12517-020-05702-2

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/124404