Original Research Article

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

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.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.As populations grow and surface water sources become increasingly strained or contaminated, the reliance on groundwater intensifies.This study was conducted in Konkan region, Maharashtra, India. To spatially identified the groundwater potential zones using integrated Remote Sensing (RS) and GIS with Analytical Hierarchy Process (AHP). Several influencing factors in which groundwater potential of a region entirely and partially depends 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%.It shows that the applied technique produces considerably reliable results for this study which may facilitate the decision makers to formulate an effective plan for the 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. Groundwater is an essential global resourceas 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 showthat 80% of the rural population and 50% of the urban population use groundwater for domestic purposes. This rate may increase further in the future. But nowadays due to drastic changes in climatic conditions and the dynamic development ofland surface features, there are fluctuations in water levels and shiftsin ground water zones.

The Central Groundwater Board (CGWB)reports that because ofthe 230 billion ~~metre~~ metercube (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 ~~have~~ 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 ~~ground water~~ 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].

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The Konkan extends throughout the western beachfront~~s~~ of Maharashtra, Goa, and Karnataka.There ~~are~~ is25970 ~~groundwater- grounded~~groundwater-grounded sources ~~which~~ thatfeed ~~to~~ the drinking and domestic water requirements in 7 sections ~~which~~ thatrepresent the Konkan region. While the region sees heavy rainfall, ~~ground water~~groundwater is scarce during the summer months, leading to a 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 ~~ground water~~ groundwater potential and potential sites of groundwater recharge for groundwater potential for sustainability in irrigation.

Groundwater evaluation has been usually conducted using field ~~survey~~ surveyswhich is not feasible in terms of time and ~~resource~~ resources. Researches show~~s~~ that remote sensing and GIS ~~has~~ haveopened a new path in Groundwater studies. 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 a variety of sources and to efficiently store, retrieve, ~~analyse~~analyze, model, and displayoutput of these data according to ~~user defined~~user-defined specifications. 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).~~Several environmental criteria such as rainfall, soil, slope, land use land cover, lineament density, geology, geomorphology and groundwater depth have been evaluated to prepare the groundwater potential zone maps for future planning,management, utilization and conservation of groundwater resources in the Konkan Region.~~

2. Study area

Maharashtra is the western part of India comprising a geographical area of 30.08 Mha and divided into four geographical divisions. Konkan region is the further western part of ~~the~~ Maharashtra, ~~featured~~ featuringwith 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. ~~Total~~ The totalgeographical area of the Konkan region is 3.08 Mha and ~~agroclimatical~~agroclimatic~~ly~~ featured as hilly topography with high rainfall (2500-3500 mm). The soils in the region are medium black soil in the Northern part with low infiltration and lateritic soils in the 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 ~~per cent~~percent of the geographic area of Maharashtra state (30728 Km^2). The region ~~comprising~~ comprisesPalghar, Thane, Raigad, Ratnagiri, Sindhudurg, and Mumbai districts. During this study,the 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.

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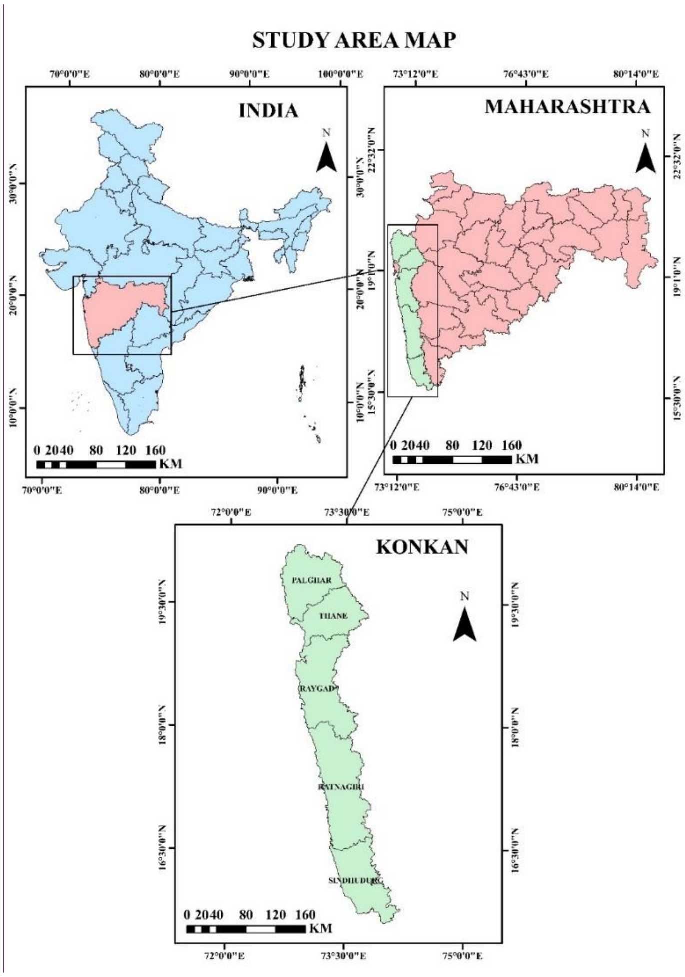

Fig. 1. Location map of study area

3. ~~Database and methodology~~ Materials and methods

~~3.1 Geospatial~~3.1 Geospatialdatabase

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 a 10 m resolutionwas obtainedfrom 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 zoningwas 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.

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3. Materials and Methods;
3.1Study area;
3.2 materials/ Geospatial database;
3.3Methods;
3.3.1Thematic Layers and Geospatial Techniques
3.3.2Analytical Hierarchy Process (AHP) and Weighed
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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

3.1 Methodology for assessment of the groundwater potential zones

The first stage includes a base map and various thematic ~~maps~~ mapspreparation.The ~~S~~slope map~~were~~ wasprepared by ~~analysing~~ analyzingthe SRTM – Digital Elevation Model (DEM) with 30 m resolution. Soil, Geology, Geomorphology, and Lineament Density ~~map~~ mapswere 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 ~~and~~ tofind out the overall rainfall and groundwater depth variation in the region using the Inverse Distance Weightage (IDW) tool.All the groundwater influencing factors~~above mentioned~~mentioned above and iterated in Table 1~~.was~~ weretransformed in raster format,using the Polygon to raster (spatial analyst) conversion tool for converting polygon feature to raster data, ~~Line density~~Linedensity (3D analyst) conversion tool ~~is~~ used for converting line feature to raster data.All the converted data ~~set~~ setswere 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 ~~weightages~~ weightsand ~~ranks~~ based on~~depending upon~~ their influence on ~~groundwater bearing~~groundwater-bearing capacity by using Analytical Hierarchy Process (AHP) presented in Fig 2.

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

3.2 Assessment of the ~~groundwater potential zones~~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 ~~ground water~~groundwater potential zones were examined and assigned appropriate weightage and rank to each parameter using AHP. Every factor had divergent influence in different ~~area~~areas. Therefore, every factor was assigned a weight depending upon their involvement towards ~~ground water~~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 the 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~~ Equations 1 and 2. The procedure for the calculation of the consistency ratio is given below.

Consistency Ratio (CR):

$$CR = CI/RI \qquad \text{……..(1)}$$

Where, CI = Consistency Index

RI = Random Index

Consistency Index (CI):

$$CI = \frac{\lambda\max - n}{n-1} \qquad \text{……..(2)}$$

Where, λ_{max}= average of the ratio of weighted ~~sum / criteria~~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 ~~pair wise~~pairwise comparison matrix according to Saaty (2008).

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

Sr. No	Theme	Subclass	Rank	~~Weightage(~~Weightage (%)
1	LULC	Water Body	5	23
		Forest	3	
		Flooded Vegetation	5	
		Agriculture	4	
		~~Built Up~~Built-Up	1	
		Barren Land	2	
2	Slope %	0-10	5	16
		10-20	4	
		20-30	3	
		30-40	2	
		40-395	1	
3	Post Monsoon GWD (m bgl)	0.26-1	5	12
		1-3	4	
		3-5	3	
		5-7	2	
		7-13	1	
4	Geology	Badami Gp. (KaladgiSGp.)	1	
		Goa Gp. (DharwarSGp.)	2	

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		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
		1000-2000	2	
		2000-3000	3	
		3000-4000	4	
		4000-7000	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
		0.0693-0.188	2	
		0.188-0.342	3	
		0.342-0.563	4	
		0.563-1.04	5	
	Total			**100**

To accomplish the next step, a weighted sum matrix was established by calculating the modified weight for individual ~~factor~~ factorsgiven in Table 2. Then ratio of weighted sum (WS) and criteria weight (CW) is calculated for each of the thematic ~~factor~~ factorswhich 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. ~~Afterword~~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 byBhange et al., 2016;Landage et al., 2021Keskar et al., 2023 and Gavit et al., 2024.

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 ~~zone~~zones. The generated map ~~indicating~~ indicatesthe very good, good, moderate, poor, and very poor groundwater potential zones.

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4. Result and discussion

4.1 Geology

Geology plays a crucial role in the movement and occurrence of groundwater in a region, which significantly ~~influencing~~ influencesgroundwater potential studies. The geology map of the Konkan region is developed from ~~rectifies~~ rectifieddigitized vector shapefile in GIS software. In the study area, five major geological groups are identified namely, Alluvium, Badami Group (Kaladagisgp.), Deccan Trap, Goa Group (Dharwarsgp.), and Laterite. The succession of geological ~~formation~~ formationsis represented in Table 3 and spatial distribution of different geological formations over the study area is depicted in Fig 3.

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

Sr No.	Geological Group	Area,km^2	~~Per cent~~PercentArea
1	Badami Gp. (KaladgiSGp.)	236.627	0.79
2	Goa Gp. (DharwarSGp.)	2363.856	7.90
3	Deccan Trap	21741.573	72.66
4	Laterite	4164.668	13.92
5	Alluvium	1417.576	4.74

The region is predominantly composed of ~~deccan~~ Deccantrap, ~~comprise~~ comprisinga series of basaltic lava flows of individual ~~thickness~~ thicknessesof 8 to 48 m with very fine-grained textures, covering 72.66% of the geographic area. The most common type is a dark green or nearly black basalt. ~~Porosity~~ The

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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 ~~covers~~ cover approximately 13.92% and ~~is~~ are characterized by a pebbly crust formed due to the alternating dry and wet periods. Laterite is typically rusty red in ~~colour~~ color due to its high iron oxide content. Laterite formation is unconsolidated sediment and dominantly consists of silt having porosity between 35 and 50% and clay having a porosity range of 45 to 55%. The Goa group of geological ~~formation~~ formations ~~covers~~ 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 ~~a~~ significant organic matter and minerals, giving it a dark ~~colour~~ color. Badami group, which consolidated sediment containing sandstone, limestone, and shale ~~have~~ has a porosity between 1 to 30%. This sediment ~~has~~ covered 0.79% of the study area.

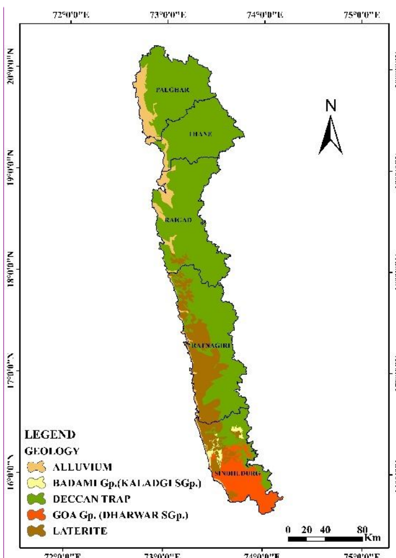

Fig. 3. Spatial distribution map of geology

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 ~~gravels~~ gravel, while near the coastal areas, it is mixed with sand. Lateritic capping over the basaltic flows has been observed rarely at ~~plateau type~~ plateau-type areas in Ambika, Auranga Nar par Damanganga, and streams between Damanganga and Vaitarna.

4.2 Geomorphology

Geomorphology has a direct relationship with the groundwater movement and its occurrence in ~~the~~ a particular region. ~~Geomorphology~~ The geomorphology map of the Konkan region was developed from a digitized vector shape file of the geomorphology in GIS software. 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 illustrate~~ is illustrated in Fig. 4.

Table 4.Distribution of geomorphological units in the Konkan region

Sr. No	Geomorphological Units	Area, km^2	~~Per cent~~ 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

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Moderately dissected plain and Pediment-Pediplain complex equally dominate the study area at more than 70%, followed by a highly ~~dissected plateau and coastal plain at~~ 15% and 8%~~. The pediment-~~ pediplaincomplex is ideal for groundwater recharge because of the weathered material and gently undulating plains [15]. A good to moderate groundwater potential ~~zones~~ zonecan be found in the pediment and ~~pediplain~~Pedi plain areas associated with agricultural land [16]. 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 a total of 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~~least~~ 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 a poor-moderate site of groundwater recharge. Thus, the areas with dissected ~~plateau~~ plateausmay be poor to moderate character for groundwater recharge. On the contrary, the pockets in the study area with the Pediment Pediplain complex may havea good zone of groundwater potential.

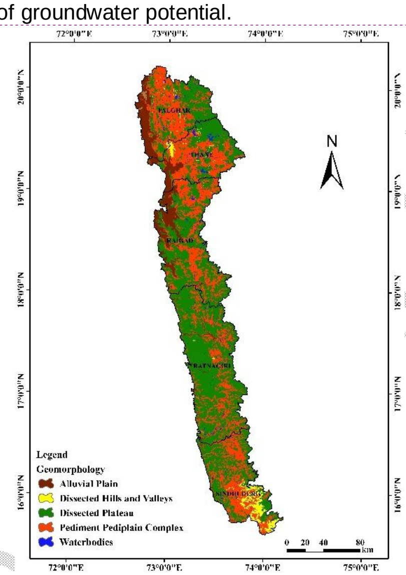

Fig. 4. Spatial distribution map of geomorphology

4.3 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. Structural ridges are poor groundwater recharge zones, whereas subsurface fractures and joints qualify as good groundwater recharge zones [17]. 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 [18]. These factors are hydro-geologically very important as they provide the ~~path ways~~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 [19]. Lineament density and its coverage area ~~is~~ arepresented in (Table 5) and the spatial map of Lineament density ~~was~~ ispresented in Fig. 5.

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

Sr. No	Lineament Density km/km^2	Area, km^2	~~Per cent~~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

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~~Highest~~ The highestarea (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 ~~the~~ arange of 0.0694 to 0.188 km/km^2 suggesting the area with more groundwater recharge. The lsmallest~~east~~ 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.

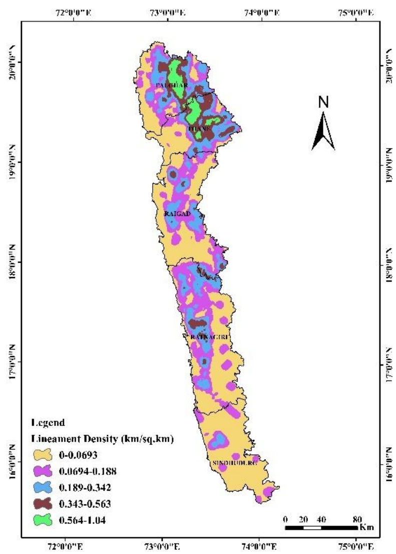

Fig. 5. Spatial distribution map of lineament density

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.

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4.4 Soil texture

Soils are the resultant product of weathering parent rocks caused by ~~difference~~ differencesin temperature and hydration effect. Soil texture is the most evident factor which influences the groundwater prospect mapping in any area. ~~Total~~A totalof 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 a major part of the region (45.76%) followed by clay loam soil (33.94%). The smallest~~least~~ portion of the region was associated with the sandy loam (0.10%).

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Table 6. Areal distribution of soil texture

Sr. No	Soil Texture	Area,km^2	~~Per cent~~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

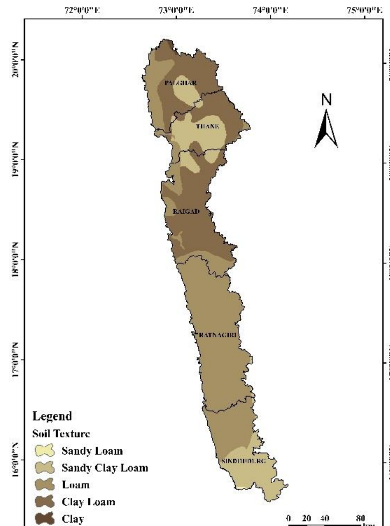

Fig. 6. Spatial distribution map of soil texture

4.5 Sloperanges

~~Slope~~ 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 [18]. The degree of slope impacts the rate of water percolation and infiltration into the ground [20]. Areas with lower ~~slope~~ slopesare more conducive to groundwater potential, while higher slope areas are considered less suitable [21]. In this study, a slope map was generated from SRTM DEM using ~~Arc-GIS~~ArcGIS software. The study area was classified into five categories, with the distribution and area occupied by each category ~~are~~ presented in Table 7.

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

Sr. No	Slope (%)	Area, km^2	~~Per cent~~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

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 ~~favourable~~ favorableto 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, the highest weight was assigned to these areas [22].~~Spatial~~ The spatialdistribution of slope rangesis shown in Fig. 7.Similar classes were also observed by Bhange et al., 2016; Keskar et al., 2023; and Gavit et.al. 2024.

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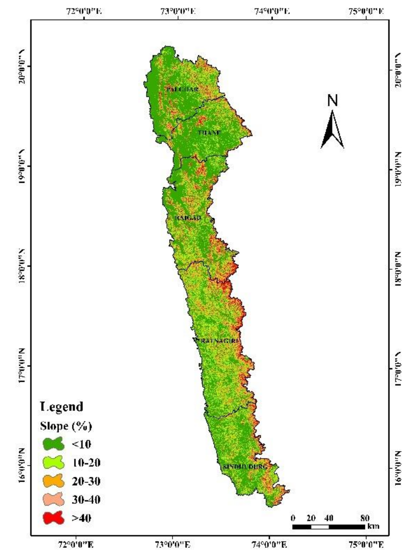

Fig. 7.Spatial distribution of slope categories in Konkan region

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. ~~Flat~~ The flatslope is more concentrated in the Palghar district, followed by the Thane and Raigad districts, particularly on the western side near the Arabian ~~sea~~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.

4.6 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 [23]. 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~~.~~).~~and Fig.~~Fig8 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	~~Per cent~~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

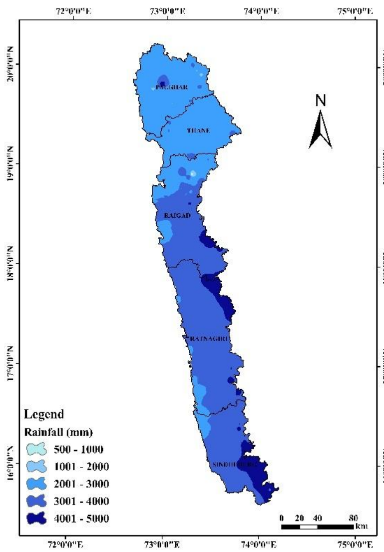

Fig. 8.Annual rainfall distribution in Konkan region

4.7 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 [24]. 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 [25]. 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 [26]. Similarly, surfaces with dense vegetation have a higher infiltration capacity than barren lands, making groundwater potential high in forested and agricultural areas [27].

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

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

Sr. No	Class	Area, km^2	~~Per cent~~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

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 [28]. 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.

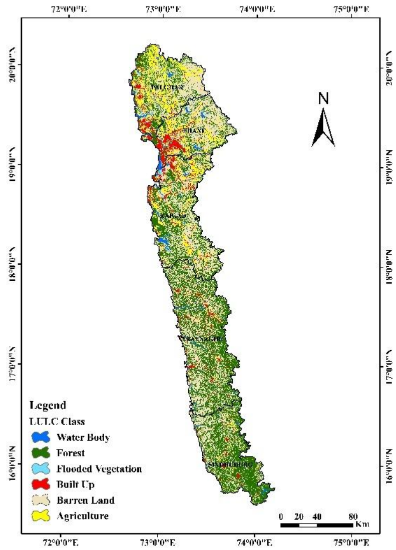

Fig. 9.Spread of LULC classes across all districts of Konkan region

4.8 Groundwater depthfluctuation

The fluctuation in groundwater depth between the Pre-Monsoon and post-Monsoon periods was ~~analysed~~analyzed, and a groundwater level fluctuation map was created using GIS software. This map was based on data collected from monitoring well locations and groundwater levels. The fluctuation data was categorized into appropriate depth ranges, with ~~weightages~~ weightsassigned 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 Table10.

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	~~Per cent~~Percent area	GW depth (m bgl)	Area occupied, km^2	~~Per cent~~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			

Based on groundwater data from observation wells, the data was regrouped and classified ~~in~~ intoeight categories for pre-monsoon observations below ground level: 0.69-2 m ~~bgl,~~ 2-4 m ~~bgl~~, 4-6 m ~~bg~~l, 6-8 m bgl, 8-10 m bgl, 10-12 m bgl, 12-14 m bgl and 14-16 m bgl. For post-monsoon observations, five categories were used: 0.26 to 1 m bgl, 1 to 3 m bgl, 3 to 5 m bgl, 5 to 7 m bgl and 7 to 13 m bgl. 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

Comment [ET45]: Its appropriate place is in the methods section.

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these regions. Groundwater potential is higher in areas with less water level fluctuation than in the regions with greater fluctuation [29].

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.

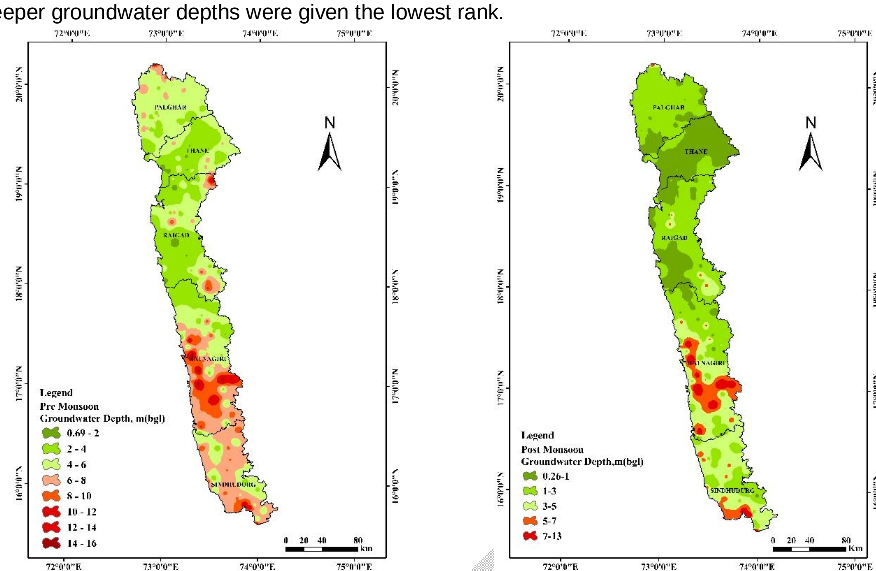

Fig. 10. Spatial distribution of groundwater depth during pre- and post-monsoon periods in Konkan region

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.

Comment [ET50]: Bring it before fig. 10

4.9 Groundwater potential

The ~~resulted~~ results ofthe 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~~ The realdistribution of groundwater potential zones is presented in Fig 12. A major part of the region ~~was~~ found at about 44.19% in moderate groundwater potential zones followed by poor groundwater potential zones at 27.23%. ~~the~~ The groundwater potential map of the region is shown in Fig 11. The good groundwater potential zones also contribute to 19.82% area of the region, as well as the very poor groundwater potential zones also ~~contributes~~ contributeto 4.43% area of the region. ~~Least~~ The leastarea found in the very good potential zones which is about 4.33%. Similar results were also observed by Bhange et al., 2016;Keskar et al., 2023; and Gavit et.al. 2024.

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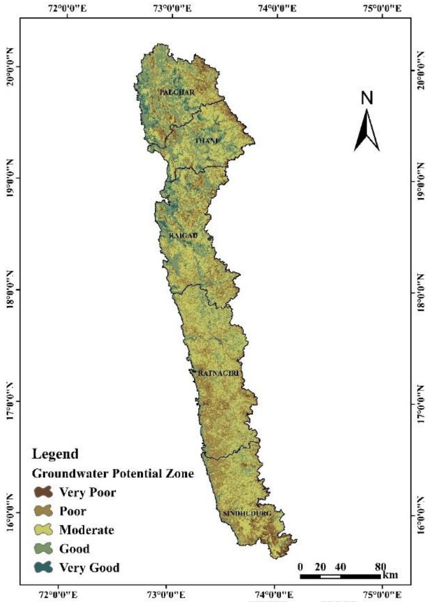

Fig. 11. Spatial distribution map of groundwater potential

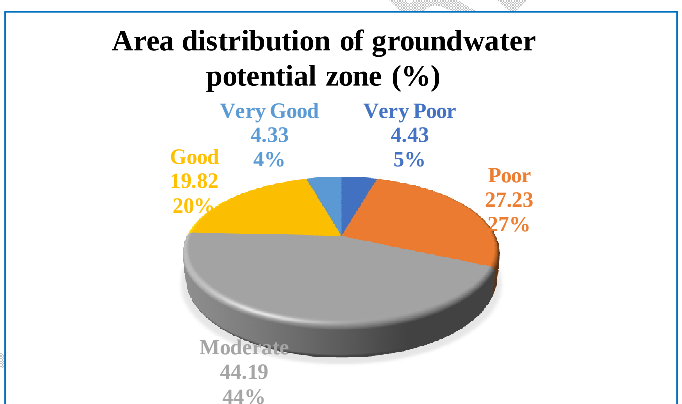

Fig 12. Areal distribution of groundwater potential zones

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5. 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.

Comment [ET53]: This should briefly state the major findings of the study. So, write the correct conclusion, please.

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Comment [ET54]: Use this format of the reference:
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