Identification of Groundwater Potential Zones in the Akole Taluka Watershed Using Geospatial Techniques and Analytical Hierarchy Process (AHP)

Abstract

This study focuses on identifying groundwater potential zones in the Akole taluka watershed, Ahmednagar District, Maharashtra, India, using an integrated approach combining Remote Sensing (RS) and Geographic Information Systems (GIS). Groundwater is a key source of freshwater, stored beneath the Earth's surface in the saturated zone, filling the gaps and spaces within soil and geological formations. It forms when rainwater or melting snow seeps into the soil and filters down into the underlying rock layers. Key thematic layers such as slope, drainage density, lithology, lineament density, geomorphology, rainfall, soil, and land use/land cover, were derived using SRTM DEM (30 m resolution) and conventional datasets. Each layer was assigned weights based on its influence on groundwater potential, calculated and normalized using AHP. The layers were integrated using the "weighted sum" tool in Arc GIS to create a comprehensive groundwater potential map. The study area was classified into five groundwater potential zones: very poor, poor, moderate, good, and very good, covering 6.47%, 19.91%, 32.11%, 25.67%, and 15.85% of the area, respectively. The findings highlight that a significant portion of the region has moderate to very good groundwater potential, providing critical insights for sustainable water resource development and management. By incorporating factors such as rainfall, lithology, geomorphology, drainage density, land use and land cover, slope, and soil, this method offers valuable preliminary insights for planners and decision-makers in water resource development, facilitating the formulation of economically viable strategies.

Keywords: Remote Sensing, Groundwater Potential Zone, geomorphology, hydrological characteristics s

1. INTRODUCTION

Water scarcity is increasing throughout the world due to the effects of increasing groundwater abstraction and climatic change. One of the most important resources on earth, groundwater accounts for around 34% of the world's freshwater supply. It is the primary water source and is regarded as less contaminated than other sources. A few years ago, groundwater was considered as a safe water supply. However, in recent years, the state of water has revealed that groundwater is extremely sensitive to inanition in many places around the world, particularly in developing countries. Soil and water are essential natural resources, fundamental for agricultural production [26-28]. The presence of water is needed for all the life on Earth including the lives of plants and organisms in the soil. According to Dr. H. H. Bennett, "soil without water is a desert and water without soil is useless"[1]. Various forms of precipitation contribute to different water sources, with the largest freshwater reservoir being underground. Groundwater is a key source of freshwater, stored beneath the Earth's surface in the saturated zone, filling the gaps and spaces within soil and geological formations. It forms when rainwater or melting snow seeps into the soil and filters down into the underlying rock layers [2]. Simply put, groundwater is the water located beneath the Earth's surface in the spaces between soil particles and the cracks within rocks. Areas of the Earth's crust that contain water and facilitate its movement and storage are called groundwater potential zones. These zones can be identified by analysing visible terrain features such as geology, landforms, and hydrological characteristics, without needing direct access to water sources [2]. Groundwater potential zone modeling is critical for sustainable water resource management since it helps to allocate this key resource more efficiently for agriculture, industry, and home usage. It permits the identification of locations appropriate for groundwater extraction while preserving the resource, guaranteeing long-term growth and resilience in the face of droughts or climate change [29-31]. Groundwater provides approximately 80% of the drinking water supply. However, growing demand for agricultural products, driven by population growth and economic development, has intensified competition for freshwater in recent years[3, 4, 5]. In regions where water levels fluctuate annually, rainfall is crucial for replenishing groundwater supplies. To ensure sustainable groundwater use, accurately assessing its availability is essential, and efficient rainwater management is key to preventing water shortages.

In 2023, the country's total annual groundwater withdrawal was estimated at 241.34 billion cubic meters (bcm). The agricultural sector emerged as the largest consumer, utilizing 87% of the total groundwater resources, which equates to 209.74 bcm. Domestic use accounted for 11% (27.57 bcm), while industrial use constituted 2% (4.03 bcm) [6]. The rising demand for agricultural products both for food and non-food purposes combined with population growth and economic progress, has intensified competition for freshwater resources in recent years. Consequently, identifying and mapping groundwater potential zones has become increasingly crucial [7].

The state anticipates an annual groundwater recharge of 32.76 billion cubic meters. Of this, 30.95 billion cubic meters are available for use each year. Currently, 16.66 billion cubic meters of groundwater are extracted annually. This total includes 15.28 billion cubic meters for irrigation, 0.03 billion cubic meters for industrial purposes, and 1.36 billion cubic meters for domestic use. The groundwater extraction level stands at 53.83% [6]. Groundwater is a hidden natural resource that is hard to find, and charting it can be challenging. It is influenced, directly or indirectly, by terrain features such as geomorphology, stream density, topography, and water bodies. These surface hydrological characteristics play a crucial role in the process of groundwater replenishment [8]. The widespread acceptance of the AHP model, combined with RS and GIS techniques, has made its application increasingly popular worldwide. Numerous research studies utilizing this model have yielded outstanding results in groundwater assessment. In the current study, groundwater potential zones of Akole taluka watershed were identified through the preparation and analysis of various thematic layers [9, 10].

2. MATERIALS AND METHODS

2.1 Study Area

Akole taluka watershed is situated in Ahmednagar District of Maharashtra and covers a total Geographical area of 1983.86 ha. The Research location is located between latitude 19^{0}32'N and longitude 73^{0}58'E. Fig.1 shows the Location map of the study area map of Akole taluka watershed.

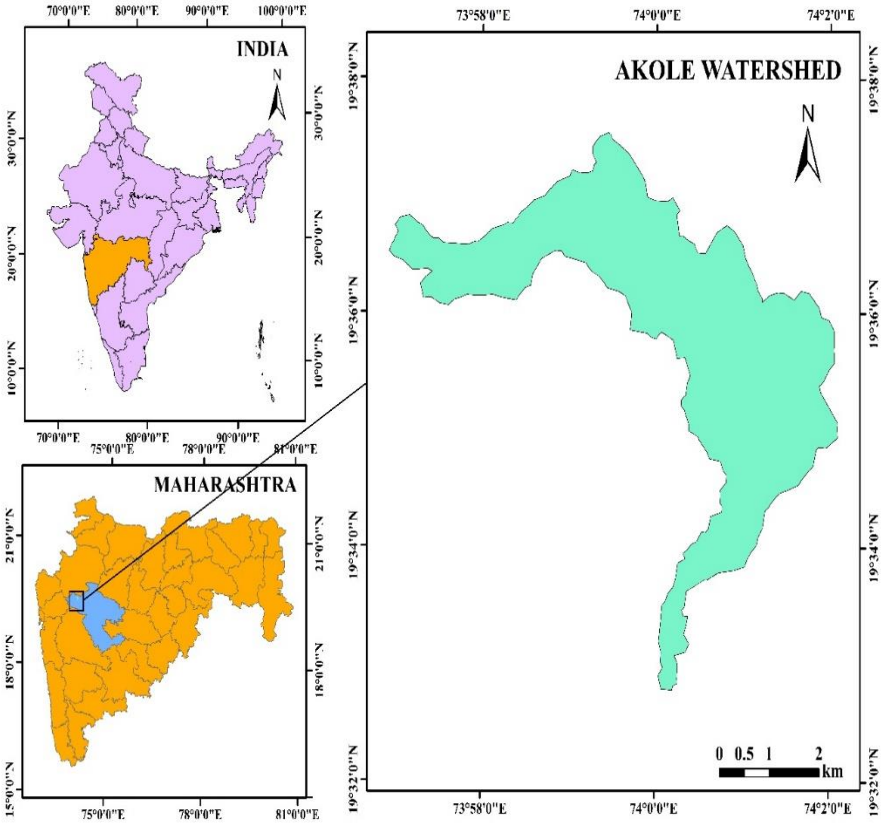

Fig.1 Map showing study location

2.2 Materials

The village vies shape file are obtained from Survey of India (SOI) (https://onlinemaps.surveyofindia.gov.in/) portal, study area boundary which is shown in fig. 1. Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) with resolution of 30 m was downloaded from (http://earthexplorer.usgs.gov/) to prepare the slope map, stream order map, drainage density and lineament density map of Akole taluka watershed. Geomorphology and lithology data were obtained from Bhukosh portal (https://bhukosh.gsi.gov.in/). The MSL Level-1C Sentinel 2-B satellite imagery (10m resolution) was used to generate the land use land cover map of the Akole taluka watershed downloaded from Copernicus Data Space Ecosystem portal (https://dataspace.copernicus.eu/). Land use and land cover maps were produced using ERDAS IMAGINE software with supervised classification technique. The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) provides 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 Akole taluka watershed. The rainfall data (1991-2023) was downloaded from NASA power Portal, and the rainfall map was generated from inverse distance weighted tool of Arc GIS, and the soil map of the study area was generated using Arc GIS Software.

2.3 Methodology for Assessment of the Groundwater Potential Zones

The Analytical Hierarchy Process (AHP) is a method for determining weightages through pairwise comparisons, using a numerical scale from 1 to 9 to indicate the relative importance of one factor over another [11]. This technique is widely used by researchers globally, particularly in studies focused on identifying groundwater potential mapping [12, 13]. The initial phase involved the preparation of a base map along with various thematic maps. For this study, eight thematic maps were prepared. Slope map was created by analyzing the SRTM Digital Elevation Model (DEM) with a 30-meter resolution. Thematic maps such as soil, geology, lineament density, drainage density and geomorphology map were digitized using Arc GIS 10.3. Additionally, average monsoon rainfall data from the past 30 years were imported into Arc GIS software to analyze the regional variations of rainfall in the study area. The analysis utilized the Inverse Distance Weighting (IDW) tool. Land use and land cover maps of the study area were produced using ERDAS IMAGINE software with a supervised classification technique. All thematic layers were assigned weights based on their respective influence on groundwater-bearing capacity, determined using the Analytical Hierarchy Process (AHP), as illustrated in Fig. 2.

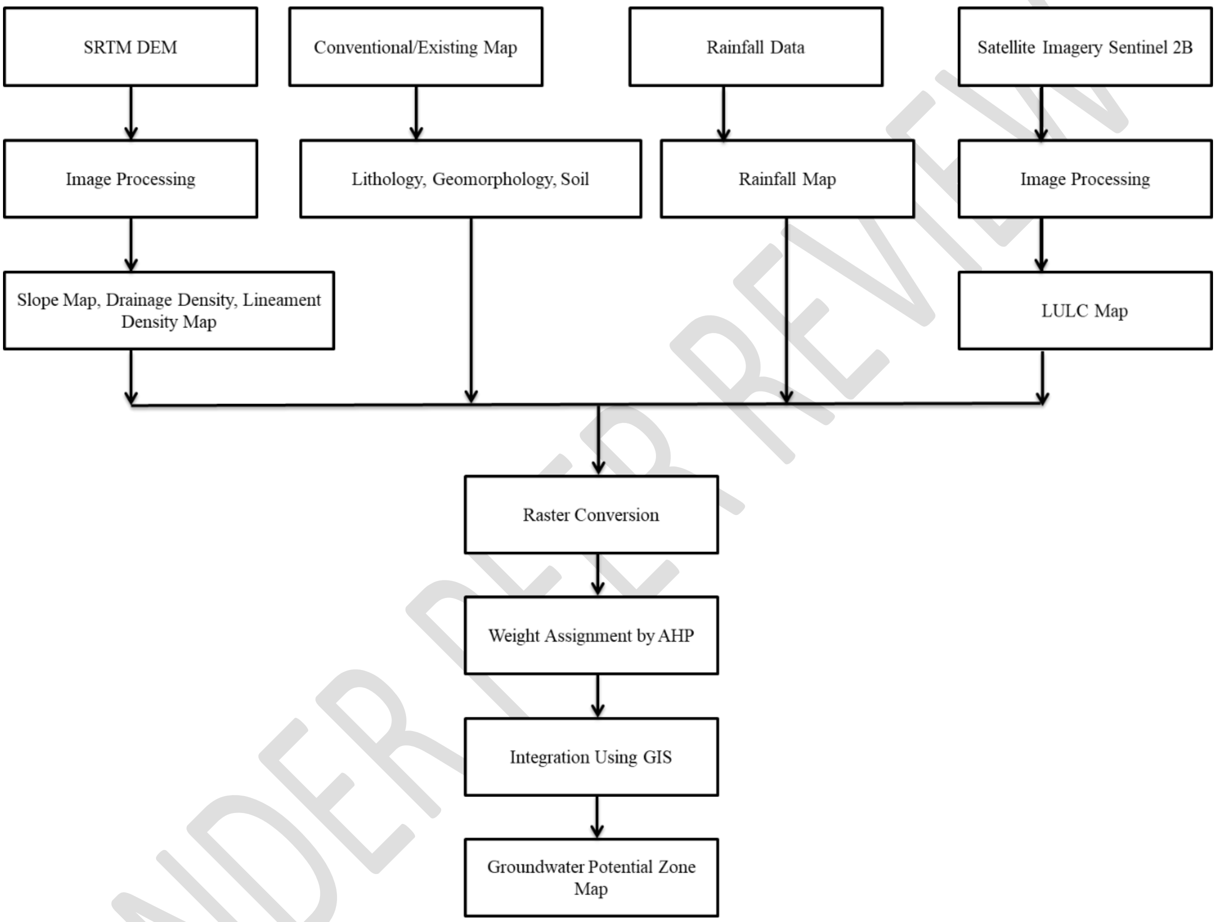

Fig. 2. Flow chart for groundwater potential zone map

2.4 Identification of Groundwater Potential Zones

The influence of various factors, including rainfall, slope, geology, geomorphology, drainage density, lineament density, land use and land cover, and soil texture, on groundwater potential zones was analysed. Each parameter was assigned appropriate weights and ranks based on its significance using the Analytical Hierarchy Process (AHP) [11]. The Analytical Hierarchy Process (AHP) assigns weights through pairwise comparisons, using a numerical scale from 1 to 9 to indicate the relative importance of one layer compared to other factors [14]. Each thematic layer was assigned a specific weight, and each characteristic was ranked accordingly. The influence of each factor varied across different areas, and weights were assigned based on their contribution to groundwater potentials [11].

In this study, the ranks were determined based on weights recommended by experts, insights from previous studies, and knowledge derived from local experience [8]. A normalized

pairwise comparison matrix was then created by calculating the individual and criteria weights (CW) for each thematic factor. The matrix was evaluated for consistency, ensuring a Consistency Ratio (CR) of less than 0.1. If this criterion was met, the derived criteria weights were used for analysis. The Consistency Ratio, as proposed by Saaty (1980), was calculated using Equations 1 and 2. The procedure for determining the consistency ratio is outlined below.
Consistency Ratio (CR):

$$CR = \frac{CI}{RCI} \qquad \text{................. (1)}$$

Where,
CI = Consistency Index
RCI = Random Consistency Index

Consistency Index (CI):

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

Where,
λmax = average of the ratio of weighted sum/criteria weight
n = matrix size

In this study, the Consistency Ratio (CR) is deemed acceptable if it does not exceed 0.1, as this threshold is considered suitable for mapping groundwater potential zones. If the CR exceeds 0.1, the values in the pairwise comparison matrix are adjusted by assigning different weights, following the guidelines provided by Saaty (2008). In the next step, a weighted sum matrix was established by calculating the modified weight for individual factors given in Table 1. Then ratio of weighted sum (WS) and criteria weight (CW) is calculated for each of the thematic factors which is important to calculate 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 0.012. In the final step, the consistency ratio (CR) was calculated 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 [8, 15, 16, 17].

Table 1. Weightage and ranking for different thematic maps are assigned using Saaty's Analytical Hierarchy Process (Saaty, 1980)

Sr. No.	Theme	Sub-Class	Rank	Weight (%)
1	Land use Land cover	Water Body	5	23
		Agriculture	4	
		Barren Land	3	
		Forest	2	
		Built Up	1	
2	Slope %	0 to 5	1	16
		5 to 10	2	
		10 to 15	3	
		15 to 20	4	
		>20	5	
3	Drainage density (km/km^2)	<1.1	5	12
		1.2-3.2	4	
		3.3-5.5	3	

		5.6-7.6	2	
		>11	1	
4	Rainfall (mm)	400-500	1	13
		500-600	2	
		600-700	3	
		700-800	4	
		>800	5	
5	Soil	Clay loam	3	6
6	Lithology	Basalt	3	10
7	Geomorphology	Water Body	5	13
		Moderately Dissected Plateau	3	
		Pediment Pediplain Complex	4	
8	Lineament density	<0.5	1	7
		0.5-1.5	2	
		1.5-2.5	3	
		2.5-3.5	4	
		>3.5	5	
	Total			**100**

The assigned ranks were applied to the raster layers of all thematic maps. The reclassified thematic maps, with their respective ranking values, were combined using the "Weighted Sum" tool in Arc GIS software to identify groundwater potential zones. The resulting map highlights areas classified as very good, good, moderate, poor, and very poor in terms of groundwater potential zones.

3. RESULTS AND DISCUSSION

3.1 Slope

The slope of a surface denotes the steepest change in elevation within a specific region of that surface. The potential for runoff becomes more pronounced as the slope becomes steeper [18]. The slope map was created from a SRTM DEM using Arc-GIS software. The slope of Akole taluka watershed varies from 0 to 20 %. The slope of the watershed was divided into five classes namely gentle, moderately gentle, steep, moderately steep and very steep, similar results were also observed by [8, 15, 16, and 18]. Approximately 68% of the watershed area falls within a gentle to moderately gentle slope range. Table 2 provides the areal extent of these slope categories across the study area, while Fig. 3 illustrates the spatial distribution of the various slope classes.

Table 2. Areal extent of slope

Sr. No	Slope Range	Slope Class	Area (ha)	Percent of total area
1.	0-5	Gentle	914.68	46.11
2.	5-10	Moderately Gentle	437.37	22.05
3.	10-15	Steep	248.99	12.55
4	15-20	Moderately Steep	167.87	8.46
5	> 20	Very Steep	214.94	10.83
Total			**1983.86**	**100**

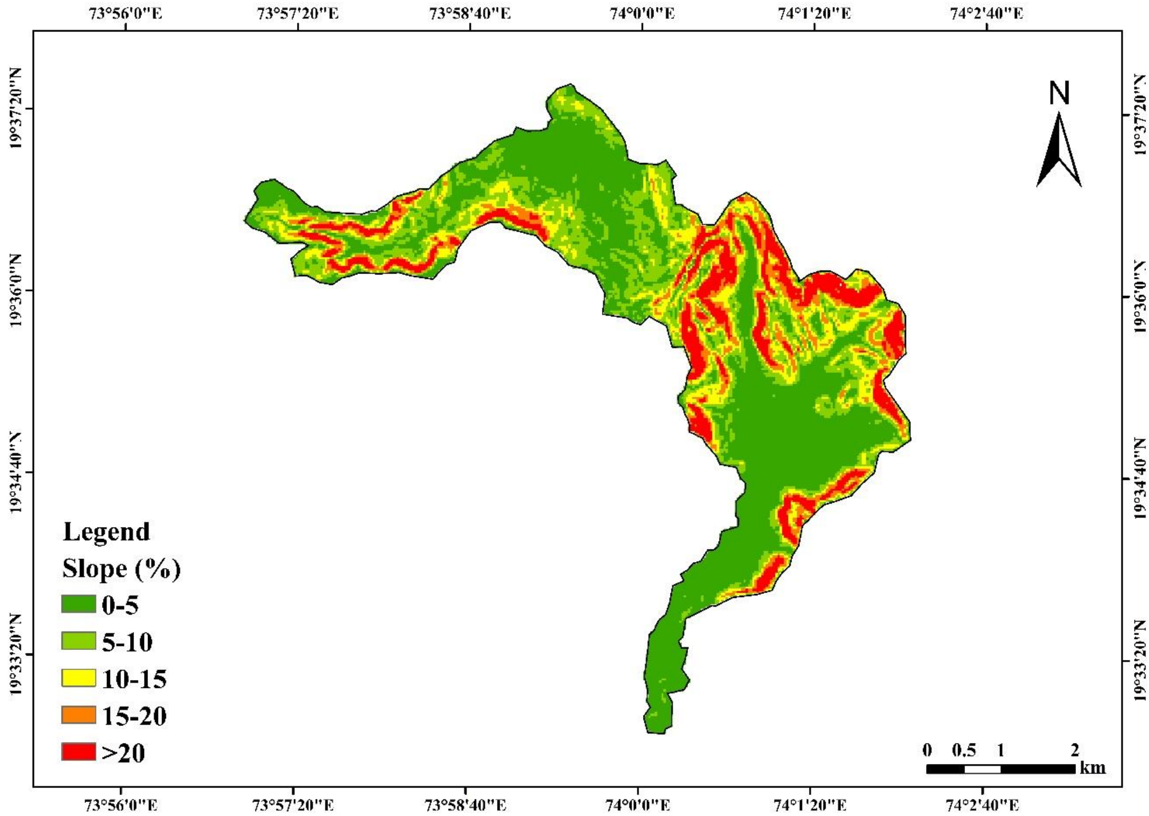

Fig. 3. Spatial distribution map of slope

3.2 Drainage Density (DD)

Drainage density is the ratio of the total length of all streams of all orders within a watershed to the total area of the watershed. For the preparation of drainage map of the Akole taluka watershed, was developed using stream order map through Arc-GIS software. If drainage density is higher, less will be infiltration and more will be runoff [16, 20]. The area with low drainage density, probability of groundwater potential zone is high. The drainage density of the Akole taluka watershed is classified into five categories: <1.1 km/km², 1.2-3.2 km/km², 3.3-5.5 km/km², 5.6-7.6 km/km², and >11 km/km². Based on these classifications, the drainage density is rated as very good, good, moderate, poor, and very poor in terms of groundwater significance [17, 18]. Drainage map and drainage density area distribution of the basin is shown in Fig.4. And Table 3 respectively.

Table 3 Drainage density area distribution of basin

Sr. No.	Drainage Density (km/km^2)	Category	Area (ha)	Area (%)
1	<1.1	Very Good	833.19	42.00
2	1.2-3.2	Good	360.27	18.16
3	3.3-5.5	Moderate	398.31	20.08
4	5.6-7.6	Poor	289.94	14.62

5	>11	Very Poor	102.15	5.15
	Total		**1983.86**	**100**

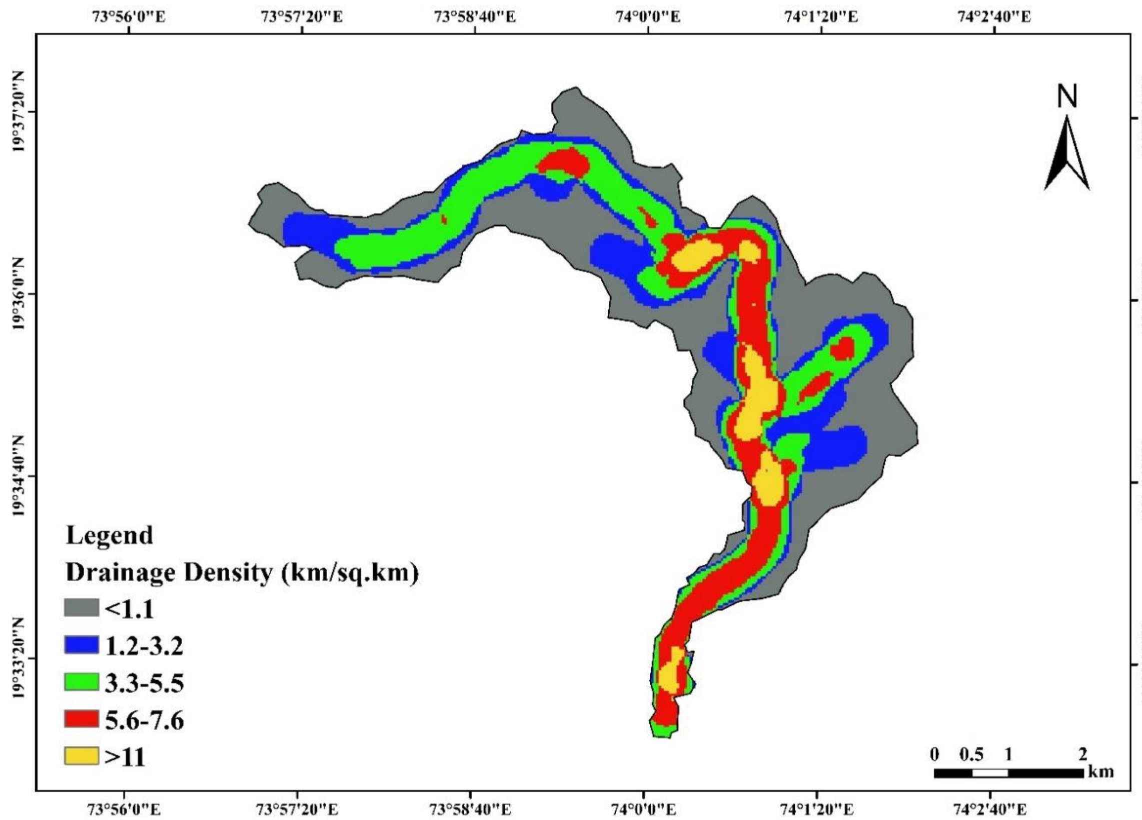

Fig.4 Drainage density map of basin

3.3 Lithology

Lithology plays a crucial role in determining groundwater potential zones. Lithology is vital in assessing groundwater potential, as rock properties like porosity and permeability influence infiltration and groundwater flow [19, 20]. The Akole taluka watershed fall under one group of geological formation, which is Basalt. The areal distribution of basalt over the study area spatial distribution is depicted in Fig.5. In the study area around 100% of total area is basalt rock formation of total area has moderate water holding ability therefore runoff generated will be more and infiltration less which considered as moderate category for groundwater significance. Similar results were found by Das et al. 2018.

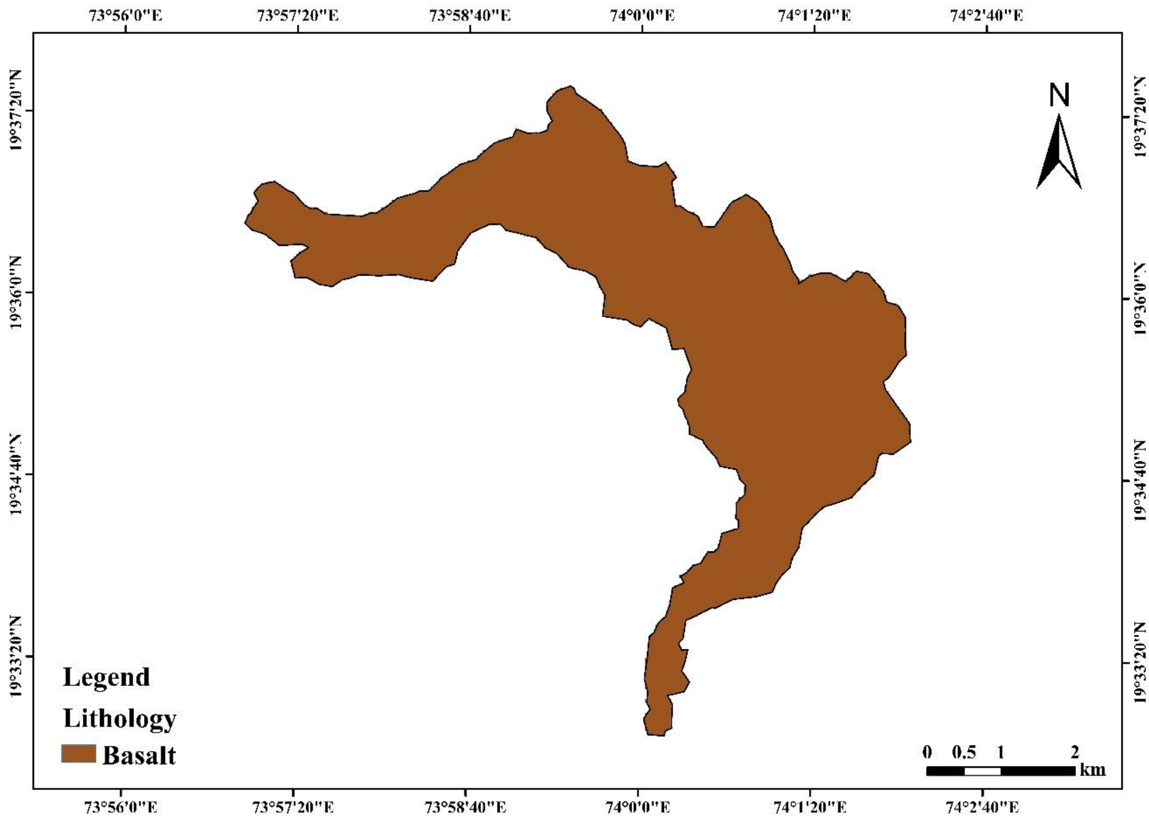

Fig 5 spatial distribution map of lithology

3.4 Geomorphology

Geomorphology, coupled with information about soil, water, and vegetation, now plays a vital role in the planning of various development projects. The geomorphology of the region is influenced by the structural evolution of its geological formations, reflecting a diverse range of landforms and structural characteristics [21, 22]. In the study area, only three geomorphic units were identified namely water body, moderately dissected plateau and pediment pediplain complex their areal distribution is presented in Table 4. The spatial map of geomorphology of the Akole taluka watershed is illustrated in Fig. 6. Major portion of the study area was covered by the moderately dissected plateau (68.34%) and the remaining portion was covered by pediment pediplain complex (29.36%) and water body (2.31), similar results were found by Das et al. 2018.

Table 4 Areal distribution of geomorphology

Sr. No.	Geomorphological Units	Area (ha)	Area (%)
1	Water body	45.73	2.31
2	Moderately Dissected Plateau	1355.76	68.34
3	Pediment Pediplain complex	582.37	29.36
	Total	**1983.86**	**100**

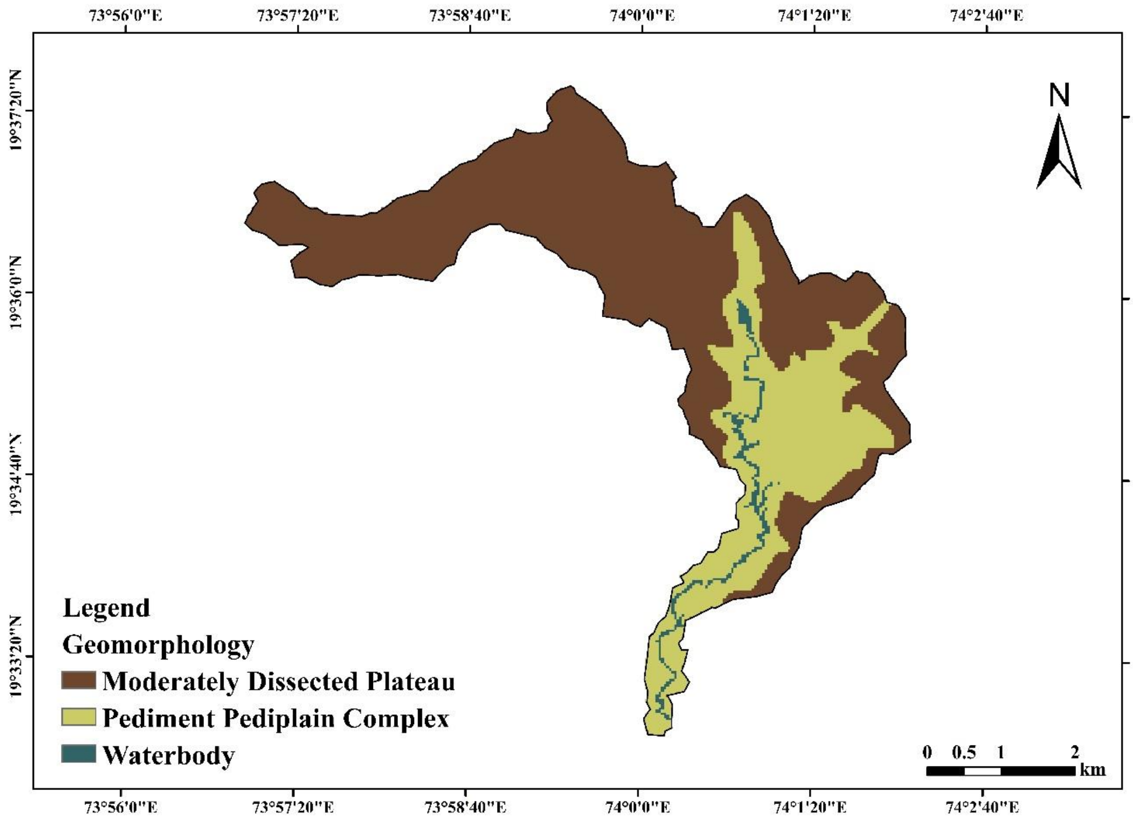

Fig 6 spatial distribution map of geomorphology

3.5 Soil Texture

Soil texture is a key factor that significantly influences groundwater prospect mapping in any area. The initial infiltration and transmission of surface water into an aquifer system is a function of soil type and its texture [23]. A textural class of soil found in the Akole taluka watershed is clay loam which is given in Fig 7. It was observed the total (100 %) area is covered by clay loam soil. Similar results were found by Das et al. 2018.

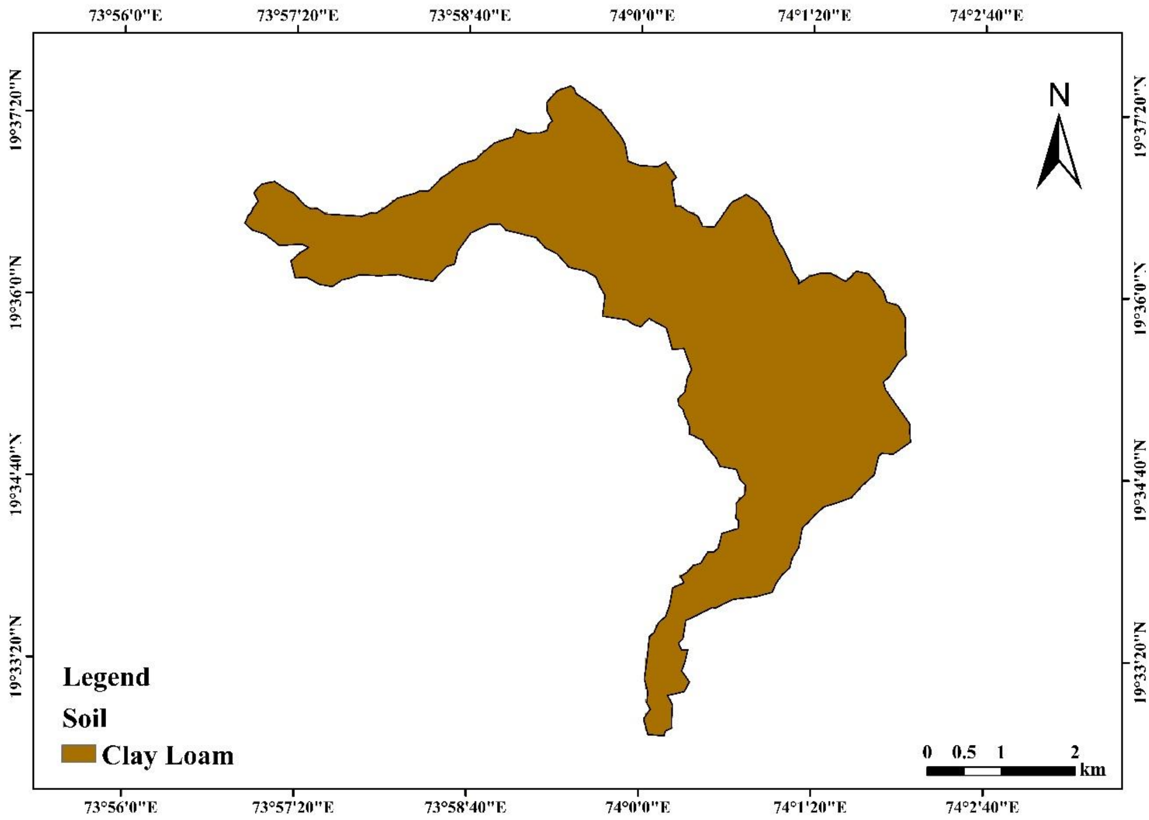

Fig 7 spatial distribution map of soil texture

3.6 Rainfall

Rainfall is the primary source of surface water and plays a crucial role in recharging groundwater in a region [15, 16]. The monsoon rainfall map of the study area ranged from 800 mm to 1300 mm. The resulted, rainfall map was classified into five classes which are mentioned in Table 5. The Akole taluka watershed contains a major of 46.26% area covered by rainfall ranging 800 mm to 1300 mm followed by 600 mm to 700 mm (about 17.62%). Similar results were found by Das et al. 2018. The Spatial distribution map of rainfall in the study area which is depicted in Fig. 8

Table 5 Areal distribution of rainfall

Sr. No.	Rainfall Range (mm)	Area (ha)	Area (%)
1	400-500	172.97	8.72
2	500-600	299.92	15.12
3	600-700	349.60	17.62
4	700-800	243.72	12.29
5	>800	917.65	46.26
	Total	**1983.86**	**100**

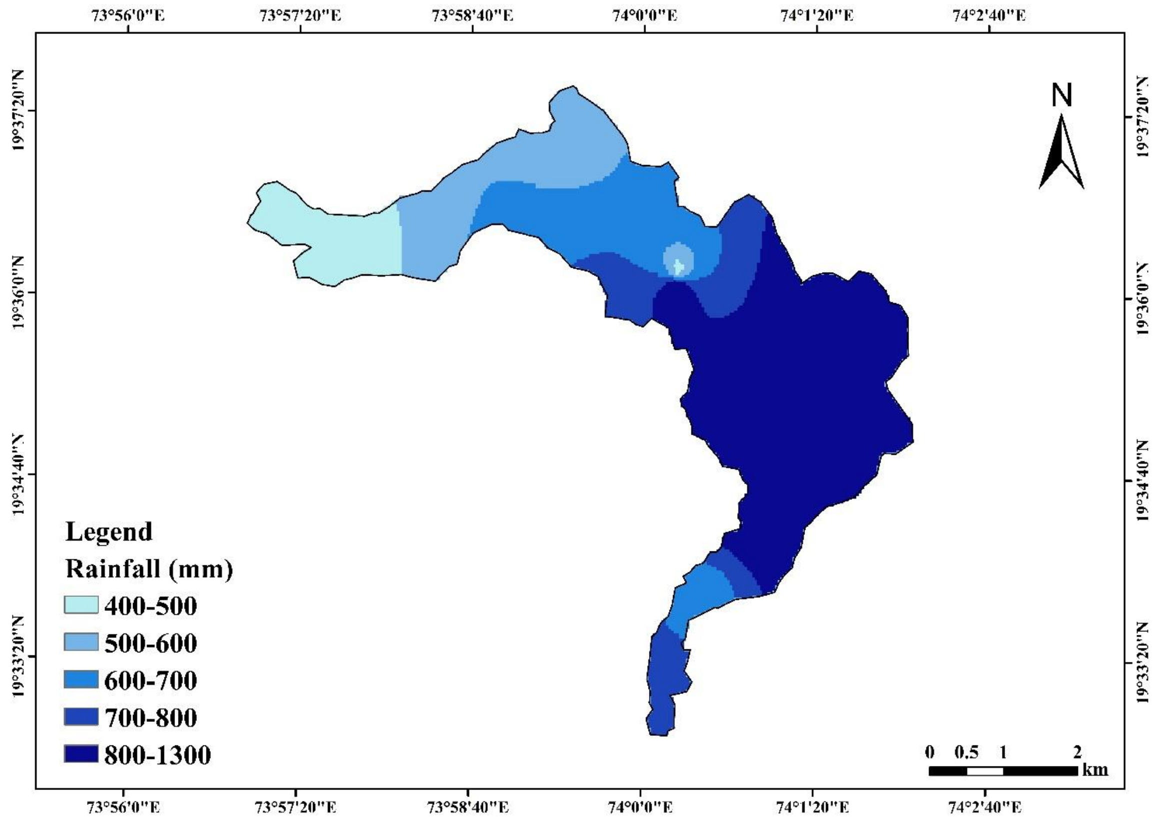

Fig 8 Spatial distribution map of rainfall

3.7 Land Use Land Cover (LULC)

Land use refers to the ways humans utilize land for various activities and purposes, while land cover describes the natural features present on the surface, such as vegetation, water bodies, soil, rocks, or artificial structures created through land modification. Land use and land cover (LULC) play a crucial role in influencing runoff generation and the availability of groundwater resources [24]. In this study, the land use land cover map was classified into five major categories: water bodies, agricultural land, barren land, forest, and built-up areas, as shown in Fig. 9 Similar land use land cover classifications were developed by Nandgude et al. 2018. The areal distribution of these land use classes within the Akole taluka watershed is presented in Table 6. It was found that barren land cover accounts for the largest portion of the watershed (40.75%), followed by forest (22.02%). The smallest portion of the watershed consists of water bodies, making up just 0.34%.

Table 6 Areal distribution of land use land cover

Sr. No.	Land use land cover classes	Area (ha)	Area (%)
1	Water Body	6.79	0.34
2	Agriculture Land	395.81	19.95
3	Forest	436.80	22.02
4	Barren Land	808.47	40.75
5	Built Up	335.99	16.94
	Total	**1983.86**	**100**

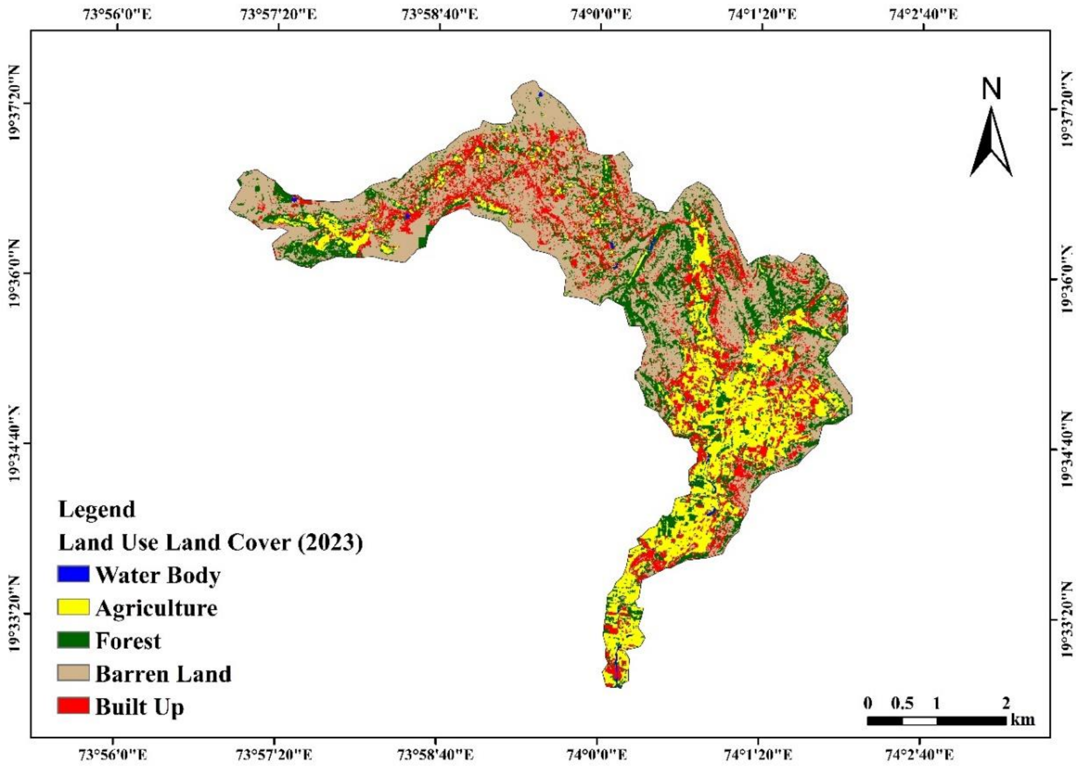

Fig. 9. Spatial distribution map land use land cover

3.8 Lineament density

Lineaments are the weaknesses of topography such as joints, cracks, faults and shears. In hard-rock lithology due to the lower porosity of terrain, groundwater potentiality generally depends on other structural features. Hence, lineaments play a fundamental role in groundwater potential as the structural weakness increases the infiltration capacity. Areas having a higher density of lineaments are having a good groundwater potential. [16]. For the preparation of the drainage map of the Akole taluka watershed, was developed using DEM through Arc-GIS software. The Lineament density of the Akole taluka watershed is classified into five categories: <0.5 km/sq.km, 0.5-1.5 km/sq.km, 1.5-2.5 km/sq.km, 2.5-3.5 km/sq.km, and >3.5km/sq.km. The lineament density map and lineament density areal distribution of the basin shown in fig 10 and Table 7 respectively.

Table 7 Areal distribution of lineament density

Sr. no.	Lineament classes	Area (ha)	Area (%)
1	<0.5	508.207	25.62
2	0.5-1.5	388.991	19.61
3	1.5-2.5	248.056	12.51
4	2.5-3.5	204.615	10.32
5	>3.5	633.592	31.94
	Total	**1983.86**	**100**

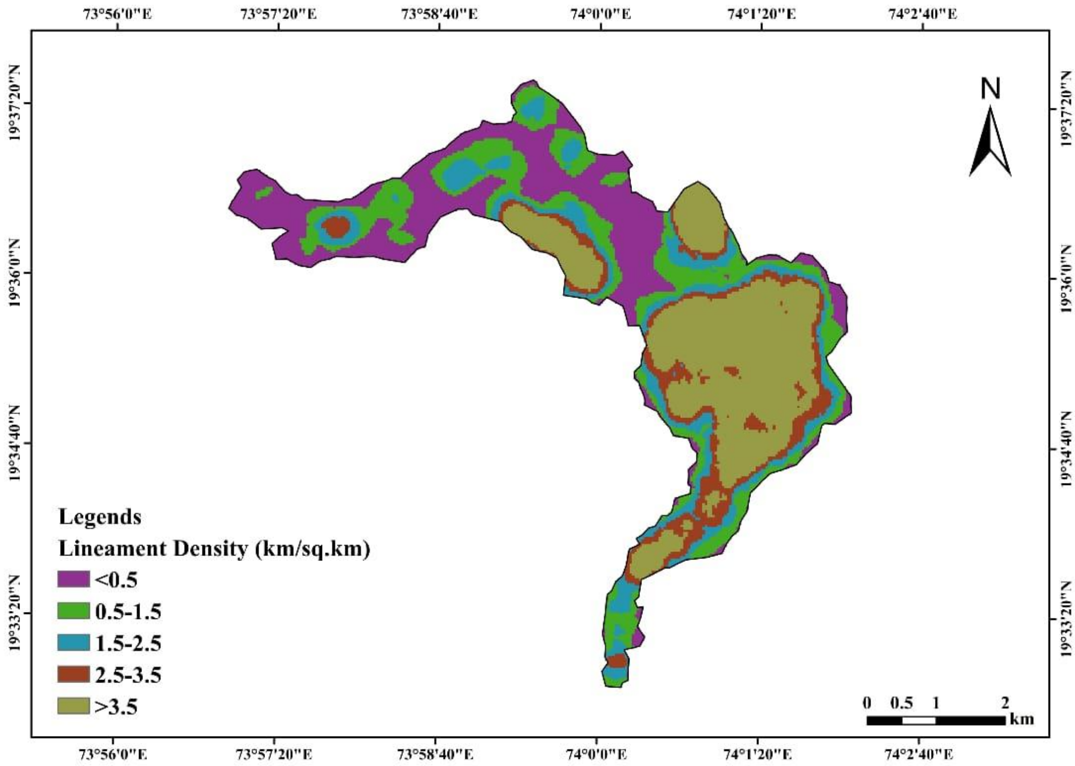

Fig.10. Spatial distribution map of lineament density

3.8 Groundwater Potential Zone

The outcomes of groundwater potential zones map through AHP technique and weighted sum method, the study area is divided into five classes, viz., very poor, poor, moderately, good and very good zones contributing to 128.27 ha. (6.47%), 394.92 ha. (19.91%), 637.02 ha. (32.11%), 509.26 ha. (25.67%) and 314.40 ha. (15.85%) respectively. Similar results were also observed by Das et al. 2018. Fig.11 shows the groundwater potential zone map of Akole taluka watershed.

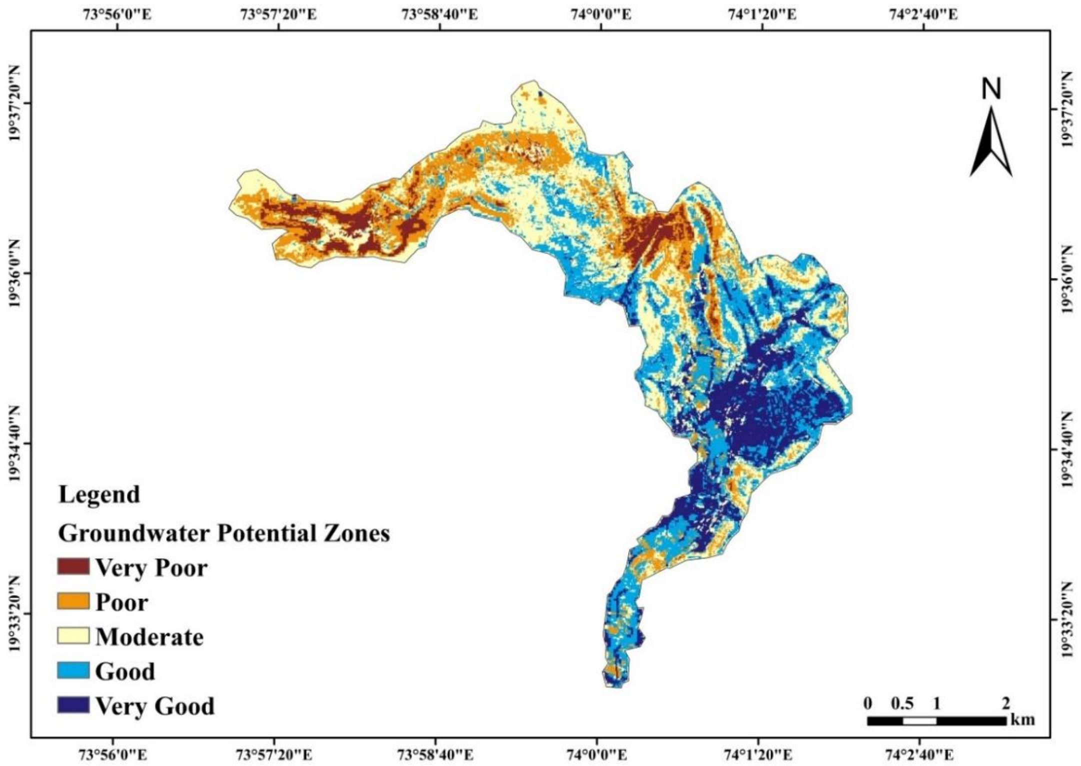

Fig. 11. Groundwater potential zone map of Akole taluka watershed

4. CONCLUSION

This study demonstrates that integrating Remote Sensing and GIS with the Analytical Hierarchy Process (AHP) is an effective approach for identifying groundwater potential zones within the study area. The region has been classified into five distinct groundwater potential zones, with most areas ranging from moderately poor to good potential. By incorporating factors such as rainfall, lithology, geomorphology, drainage density, land use and land cover, slope, and soil, this method offers valuable preliminary insights for planners and decision-makers in water resource development, facilitating the formulation of economically viable strategies.

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