



Identification of groundwater potential zones using multi-influencing factor method, GIS and remote sensing techniques in the hard rock terrain of Madurai district, southern India

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Abstract

The development of groundwater resources has been challenged due to an increase in water demand. An irregular climate and overpopulation have contributed to the groundwater crisis in recent years, resulting in overexploitation and overstressed aquifers. This work was carried out in the hard rock terrain of Madurai district, Tamil Nadu, India. The purpose of this study is to identify suitable groundwater recharge zones to satisfy this region's water resource demand. Each feature's weighting and ranking were calculated using the multi-influencing factor method and literature review. A number of thematic maps were prepared with ArcGIS software as part of this study. Groundwater potential zone is delineated by seven influencing factors including geology, geomorphology, soil, land use/land cover, slope, lineament and drainage density. In this study, groundwater potential maps were obtained using GIS and remote sensing techniques by weighted overlay analysis. Groundwater potential is influenced by land use, geomorphology and geology. According to results, groundwater potential zones were found to be covering this region in increasing order such as high groundwater potential, low groundwater potential, and medium groundwater potential. With the help of groundwater level data, a groundwater potential zone was validated. In the future, it will be very useful to identify new locations for good groundwater resources as well as to manage water resources sustainably.

Keywords Groundwater potential · Multi-influencing factors · Overlay analysis · Remote sensing · Southern India

Introduction

The long-term plan for water sustainable development requires consideration of the present as well as the future. The sustainability of water resources depends on being able to meet changing demands now and in the future without water system degradation. Research is essential to making water resources sustainable practices if they are to be effective. Although surface water occurs on land, it is not sufficient to meet the world's water supply demands for domestic, industrial, and agricultural use. Most countries are relying on groundwater to meet their water needs, and 50% of the global population drinks water from groundwater

(UNWWAP 2015). The groundwater supply is crucial for food security and economic development, but nowadays environmental changes are being caused by the rapid growth of the world's population. Groundwater is more susceptible to depletion when it is pumped in an unscientific manner and in excessive amounts (Barua et al. 2021). Geographic information systems (GIS) and remote sensing have become increasingly important for groundwater studies. In recent years, population growth, agricultural activities, and industrialization have made groundwater the most important renewable resource. Due to a lack of direct observation methods, groundwater studies have remained more insecure despite extensive research and technological advancement. The presence or absence of groundwater can only be indirectly determined by various parameters including geology, soil, slope, land use, lineament, drainage and geomorphology (Jha et al. 2010). Due to their natural and environmental conditions, these parameters control groundwater occurrence differently in different regions, resulting in differences in groundwater potential. Wide area coverage and multispectral characteristics of remote sensing data

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provide a cost-effective means of identifying and mapping most factors (Anbarasu et al. 2020). The integration of these factors with the available well and ancillary data in a GIS environment provides a better understanding of how potential groundwater zones are identified. By narrowing down target areas, detailed hydrological and geophysical surveys can be conducted on the ground, and eventually the drilling site can be located (Mahesh et al. 2012). This has resulted in increased research on both groundwater resources and locating high-quality groundwater for human consumption (Jha et al. 2007). Data from multiple sources and over a long period of time can be collected using geospatial and remote sensing data for water resource development. For hydrogeological monitoring and investigation, remote sensing data provides spatial and temporal information that is necessary for analysis, prediction, and validation. As satellite images are available, lithological, structural, and geomorphological maps at regional and small scales can be prepared using these data. Synoptic coverage and multispectral capability of these data enable them to reveal major rock types and structural features such as folds, faults, lineaments, fractures, and landforms. Groundwater potential is assessed using several thematic layers, such as geomorphology (Achu et al. 2019), land use and land cover, soil, and lineaments (Gopinath et al. 2017), geology (Silwal and Pathak 2018) and drainage density (Rajaveni et al. 2013). In order to determine groundwater potential, satellite imagery, toposheet data, and conventional data are used (Jha et al. 2007; Preeja et al. 2011; Anbarasu et al. 2020). In recent years, several researchers have investigated how geophysical data can be integrated with remote sensing and GIS (Jha et al. 2010; Anbazhagan and Jothibasu 2016; Kanagaraj et al. 2018; Oladunjoye et al. 2019). Different methodologies were applied, including multiple-criteria decision analysis (Duan et al. 2016; Das and Mukhopadhyay 2018), evidential belief function (Pourghasemi and Beheshtirad 2015), fuzzy logic (Aouragh et al. 2017; Mohamed and Elmahdy 2017), artificial neural network (Lee et al. 2018), principal component analysis (Mahato and Pal 2018), bivariate statistical methods (Falah et al. 2017), weights-of-evidence (Lee et al. 2012; Ghorbani Nejad et al. 2017), analytic hierarchy process (Andualem and Demeke 2019; Murmu et al. 2019; Senapathi and Kumar Das 2022) frequency ratio (Oh et al. 2011; Razandi et al. 2015; Yadav et al. 2019), Shannon's entropy model (Naghibi et al. 2015), Random Forest Model (Rahmati et al. 2016; Golkarian et al. 2018) and weighted linear combination (Senanayake et al. 2016), all of which have been integrated with GIS techniques. Although several methods are available to estimate groundwater potential, the multi-influencing factor (MIF) method is most commonly used due to its simplicity and reliability (Suganthi et al. 2014; Fagbohun 2018; Anbarasu et al. 2020). MIF emphasizes the interrelationship between each factor. During the monsoon season, the river in

Madurai district flows water, but during the rest of the year, it is dry. As reported by Tamil Nadu Water Supply and Drainage Board (TWAD 2018), Madurai district is overexploited in Usilampatti, Muthuvarpatti, Palamedu and A.Vellalapatti areas, while Madurai west, Kokkulam and Sedapatti areas are critically exploited, and Madurai east, Athipatti, Peraiyur and Thirumangalam areas are semi-critically exploited. In Madurai district, there are major problems with unbalanced water development, salinity, and the mixing of wastewater with existing surface and groundwater (CGWB 2007). To meet the district's water needs for drinking, irrigation, and industrial purposes in the future, it must manage sustainable water resources and find suitable groundwater potential. A hard rock terrain characterizes Madurai district, Tamil Nadu, India, which has potential groundwater development zones.

Material and methods

The study area

Madurai district is located in the southern part of Tamil Nadu, India. It covers a total area of about 3696 km² and is the third largest city in Tamil Nadu. It lies within the latitude range of 9°30'0" N to 10°30'0" N and the longitude range of 77°0'0" E to 78°30'0" E (Fig. 1). The boundaries of the district are bordered by Dindigul and Trichy districts in the north, Virudhunagar district in the south, Sivagangai district in the east and Theni district in the west. The study region of Madurai district includes seven taluks: Madurai North, Madurai South, Vadipatti, Melur, Thirumangalam, Peraiyur and Usilampatti. The main tributaries are Vaigai and Gundar in the central region, Pambar in the northern region and Vaippar in the southern region. The annual average rainfall is about 850 mm and of which 47% of rainfall contributes from the northeast monsoon, 32% of rainfall contributes from the southwest monsoon and the remaining 21% of rainfall contributes from the summer and winter. This region experiences a semiarid climate with temperature ranges from 15 to 41 °C. The study region is dominated by crystalline formation and alluvium is found only along the river course (CGWB 2007). Groundwater occurs under phreatic aquifers and semi-confined to confined conditions. The groundwater level fluctuation ranges from 5 to 20 m bgl (below ground level). Water yielding capacity of rock types in the study area is given in Table 1 (GEC 2015; TWAD 2018; Anbarasu et al. 2022). Water yield in this region ranges from 45 to 135 L/min (liter per minute) in hard rock and 315 to 1080 L/min in alluvial formation. The fractures occur commonly ranging from 30 to 175 m (CGWB 2007). This district has a population of 3,038,252, including 1,526,475 males and 1,511,777 females. It is estimated that 61% of groundwater is used for agricultural purposes, and 6.3% for domestic and industrial

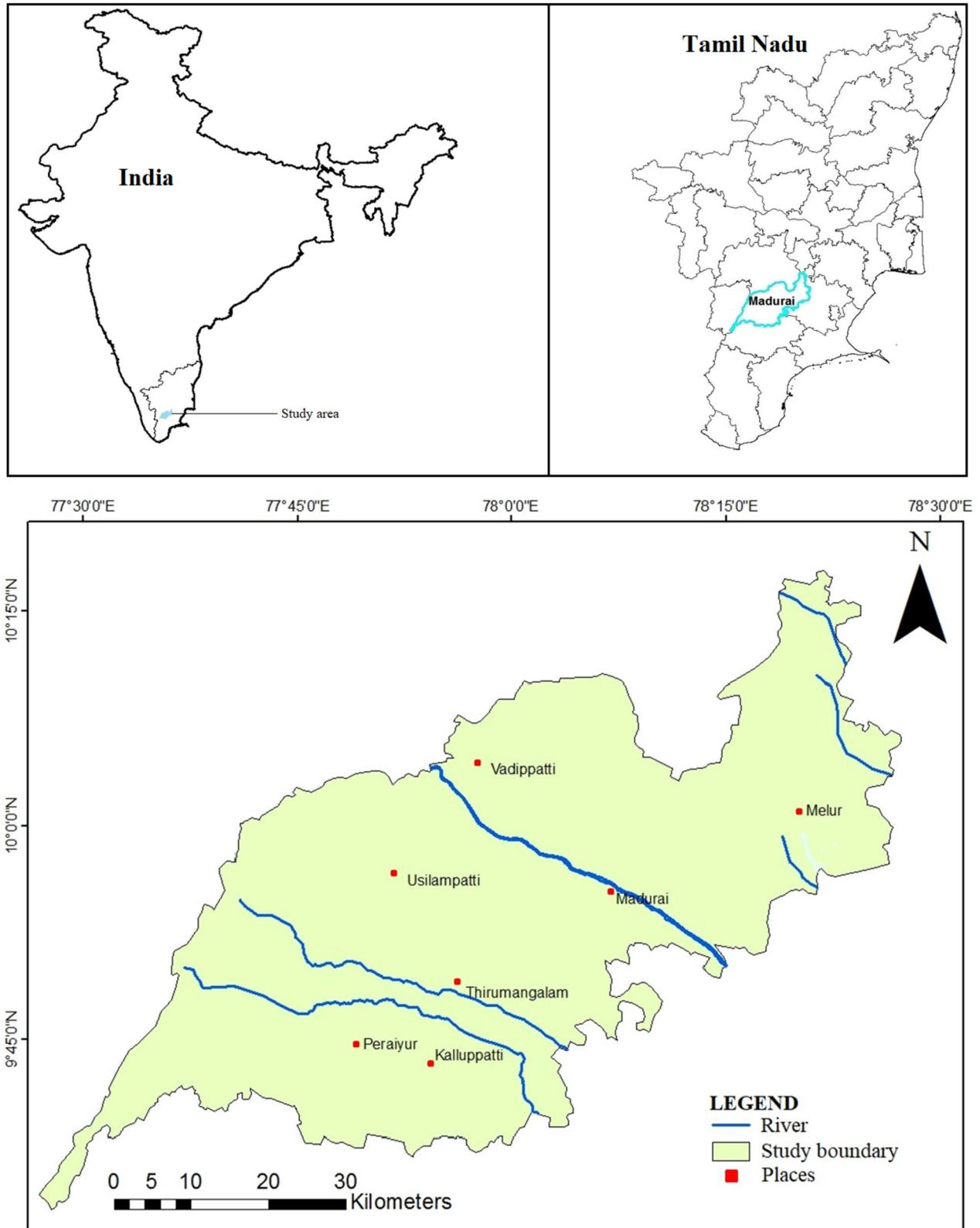


Fig. 1 The study area map

Table 1 Water yielding capacity in the rock formation

Rock types	Weathering intensity	Water yielding capacity (%)
Khondalite and migmatite	Highly weathered	1–2
	Medium weathered	0–1
	Fractured	0.5–1.5
Charnockite	Highly weathered	4–8
	Medium weathered	2–4
	Fractured	3–6
Alluvium and quaternary sediment	Highly weathered	8–16
	Medium weathered	4–10
	Fractured	6–14

uses. There are different types of crops grown during kharif (paddy, sorghum, cotton, sugarcane, and groundnut), during rabi (paddy, sorghum, cotton, green gram, maize, and groundnut), during summer (paddy), and vegetables (all seasons). Transmissivity (T) of the study region ranges from 15 to 60 (m²/day) in hard rock and 210 to 1500 (m²/day) in alluvial formation. Permeability (K) of the study region ranges from 0.98 to 2.45 (m/day) in hard rock and 19.5 to 48.9 (m/day) in alluvial formation (TWAD 2018).

Data collection

The methodology of this study is given in the flow chart (Fig. 2), which explains the following steps in the study. The geology map was digitized using ArcGIS software and collected from Geological Survey of India (GSI, scale 1:50,000), Chennai. Using ArcGIS software, the geology map was digitized and which was collected from the Geological Survey of India (GSI, scale 1:50,000), Chennai. The base map of the study region was generated based on toposheets (58 K/1, K/02, K/05, G/14, G/13, G/9, F/16, J/08, J/04, J/05, J/07, G/09, G/07). The scale of the toposheet was 1:50,000 and it was collected from the Survey of India (SOI). Shuttle Radar Topography Mission (SRTM) and Digital Elevation Model (DEM) data were used to derive a slope map after image processing using ArcGIS software. The spatial resolution of this map is 30 m. Linear Imaging Self-Scanning Sensor III was used to prepare geomorphology, lineaments and from the Indian Remote Sensing Satellite P6 (Resourcesat-1) and its spatial resolution was 23.5 m (IRS P6 LISS III, 1:50,000 scale, geocoded with UTM projections, WGS 84 and North zone 44). Land use and land cover map was digitized using Landsat 8 data. Before preparing the map, these were images processed using ArcGIS software. ArcGIS line density tools were used to calculate lineament density and drainage density. Land use and land cover, geomorphology and lineament maps were collected from the National

Remote Sensing Centre (NRSC 2005–2006). The soil map was digitized using ArcGIS software after being collected from the Geological Survey of India (scale 1:50,000). With the help of field data, these thematic maps were verified. The processed data and various thematic maps were used to derive groundwater potential through a multi-influencing factor method. The ground truth data include groundwater levels, transmissivity, permeability, and rainfall, which were collected from various agencies including CGWB, TWAD, and GEC.

Multi-influencing factor method

A variety of factors are considered when determining groundwater potential zones, including soil type, drainage, geology, slope, geomorphology, land use, land cover, and lineament. The weightage for each factor was calculated using the multi-influencing factor (MIF) method. The relationship between each factor is considered to assign a weightage. The interrelationship between each factor and its effects is shown in Fig. 3. According to their capacity for holding water, characteristics of the surface and subsurface features, the study region was classified into major effects and minor effects. The values of 1 and 0.5 for each influencing factor were assigned as a major factor and a minor factor (Table 2). In terms of influence on groundwater sources, the major factor shows greater influence and the minor factor shows less influence. Using the given equation, the MIF weight is calculated by combining the major and minor effect values for each factor.

$$MIF = \frac{(A + B)}{\sum(A + B)} * 100 \quad (1)$$

where the effect of A on the two factors is the maximum and the effect of B is the minimum.

Overlay analysis

In the study area, influencing factors such as soil, drainage, geology, slope, geomorphology, land use and lineaments have been used to delineate the groundwater potential zones. Groundwater potential zones for this region were derived through the weighted overlay analysis method. The weightage for each layer was derived using the multi-influencing factor method (MIF method). Ranks for each feature within a layer were assigned for overlay analysis and which is calculated based on literature review and local knowledge of the area (Jasmin and Mallikarjuna 2011; Rajaveni et al. 2015; Gnanachandrasamy et al. 2018; Anbarasu et al. 2020). There have been a number of studies that use the weights and ranks of the various layers to derive groundwater potential indices around the world (Muhammad et al.

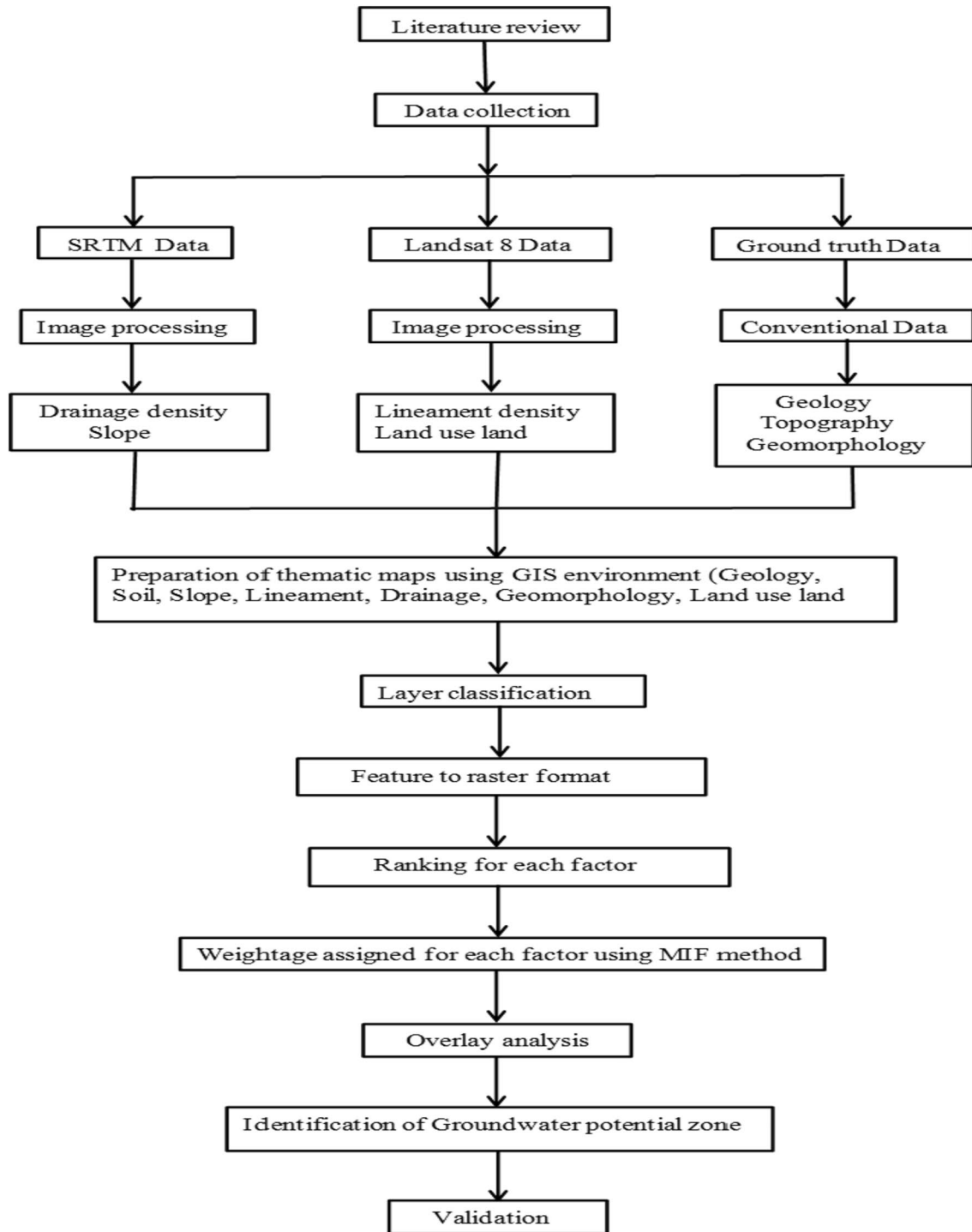


Fig. 2 Methodology adopted for this study

2018; Babatunde 2018; Abijith et al. 2020; Anbarasu et al. 2020). To calculate the groundwater potential index, each layer is assigned the ranks and weights, which are then integrated by the formula. The weightage and ranks calculated

for each layer of the study area are shown in Table 3. The weightage and ranks calculated for each layer of the study area are shown in Table 3. The groundwater potential index is given below.

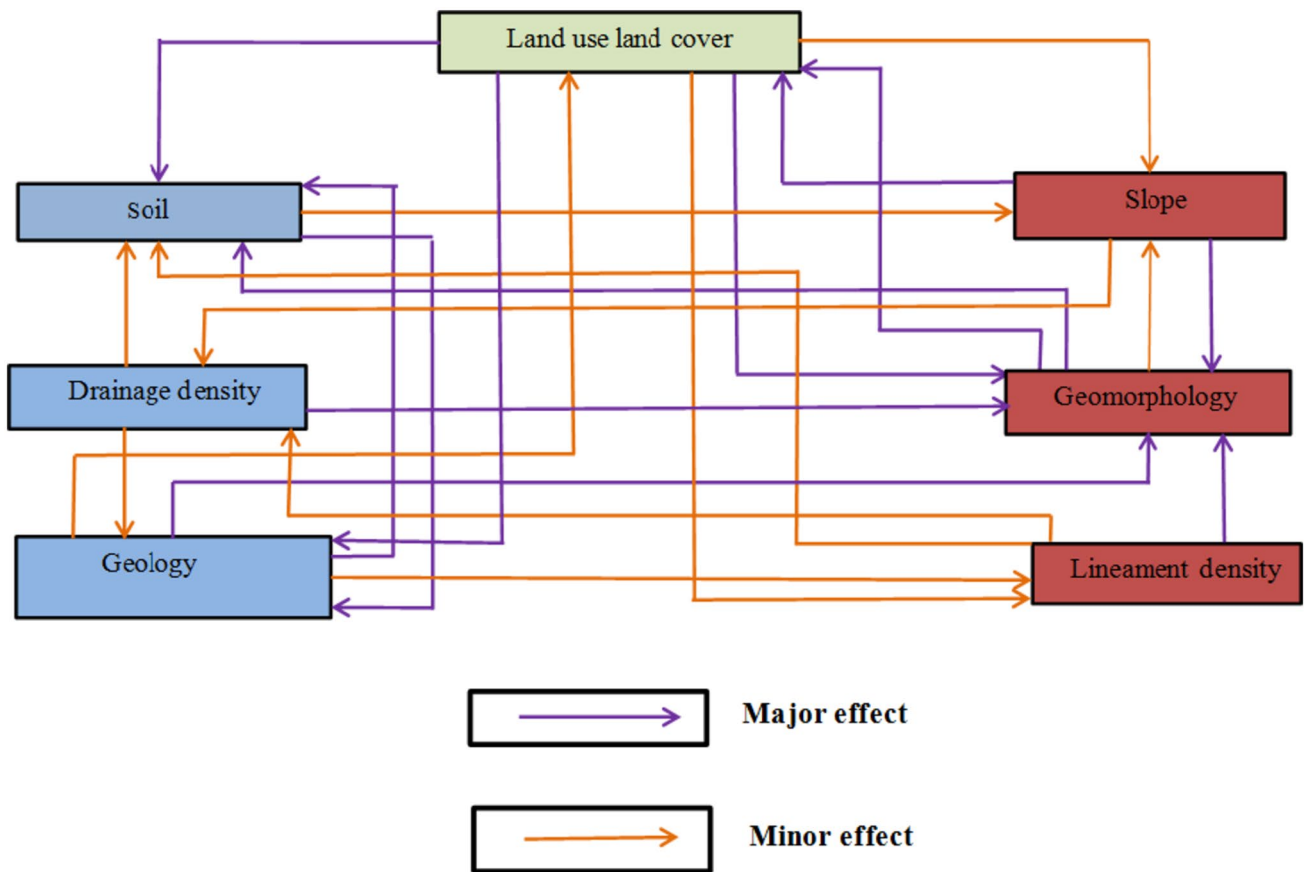


Fig. 3 Interrelationship between major and minor effects of each factor

Table 2 Proposed rates and score for each influencing factor using MIF

Influencing factor	Major effect (A)	Minor effect (B)	Proposed relative rates (A + B)	Proposed score of each influencing factor
Soil	1	0.5	1.5	10
Drainage density	1	0.5+0.5	2	12
Geology	1+1	0.5+0.5	3	16
Slope	1+1	0.5	2.5	14
Geomorphology	1+1	0.5+0.5	3	16
Land use	1+1+1	0.5+0.5	4	20
Lineament density	1	0.5+0.5	2	12
			Σ18	Σ100

$$\text{Groundwater potential index} = (\text{SO}_w \times \text{SO}_r) + (\text{DD}_w \times \text{DD}_r) + (\text{G}_w \times \text{G}_r) + (\text{SL}_w \times \text{SL}_r) + (\text{GM}_w \times \text{GM}_r) + (\text{LU}_w \times \text{LU}_r) + (\text{LD}_w \times \text{LD}_r) \tag{2}$$

where SO is soil; DD is drainage density; G is geology; SL is slope; GM is geomorphology; LU is land use; LD is lineament density; r is feature rank within a layer; w is layer

weight and it was calculated using MIF method. The study area was classified according to the groundwater potential index values: low groundwater potential zone, medium

Table 3 Classification of weightage and rank for each sub feature within a thematic layer

Factor	Sub class	Weightage	Rank
Soil	Red soil	1	1
	Brown soil	2	2
	Black soil	3	3
	Alluvial soil	4	4
Drainage density (km/km ²)	Low drainage	6	3
	Medium drainage	4	2
	High drainage	2	1
Geology	Alluvial quaternary	8	3
	Charnockite	6	2
	Khondalite and migmatite	2	1
Slope	0–5	8	3
	5–15	4	2
	> 15	2	1
Geomorphology	Bazada	8	1
	Pediment	16	4
	Duri crust	6	1
	Flood and delta plain	12	3
	Structural hill	4	1
	Valley fill	10	2
Land use/land cover	Buildup land	2	1
	Crop land	20	4
	Plantation	17	3
	Fallow land	8	2
	Reserve forest	5	3
	Open scrub	11	1
	Barren land	14	2
	Water bodies	20	4
Lineament density (km/km ²)	0–0.2	2	1
	0.2–0.6	4	2
	> 0.6	6	3

groundwater potential zone, and high groundwater potential zone. Groundwater level data was collected from CGWB for 38 wells and these data were validated with groundwater potential zone.

Results and discussion

The groundwater resource is dependent on surface and subsurface features. Various influencing features like soil, drainage density, geology, slope, geomorphology, land use, land cover and lineament density are used to demarcate the groundwater potential zones in the study region using weighted overlay analysis through multi-influencing factors.

Soil

Plant growth, surface water recharge, and groundwater recharge are all dependent on soil. A soil layer is the

uppermost layer of the earth's surface, which contains fine particles, disintegrated rocks, minerals, organic matter, and bacteria. Soil may control water infiltration because it depends on grain shape, bulk density, grain size and porosity (Anbarasu et al. 2020). In general, soil is an unconsolidated, or loose, combination of inorganic and organic materials. Soil plays a critical role in rainwater recharge, which is a key parameter for groundwater development. Red soil, reserve forest soil, alluvial soil, brown soil, and black soil are among the most important soil types. The soil map is given in Fig. 4a. The soil distribution in the study region is covered mostly by red soil (44%), black soil (23%) and is followed by reserve forest (15%), brown soil (15%) and alluvial soil (3%) (Table 4). Alluvial soil is considered to be high rank because this region has more porosity and permeability. Red soil is considered to be low rank and this soil has low water holding capacity (Table 3).

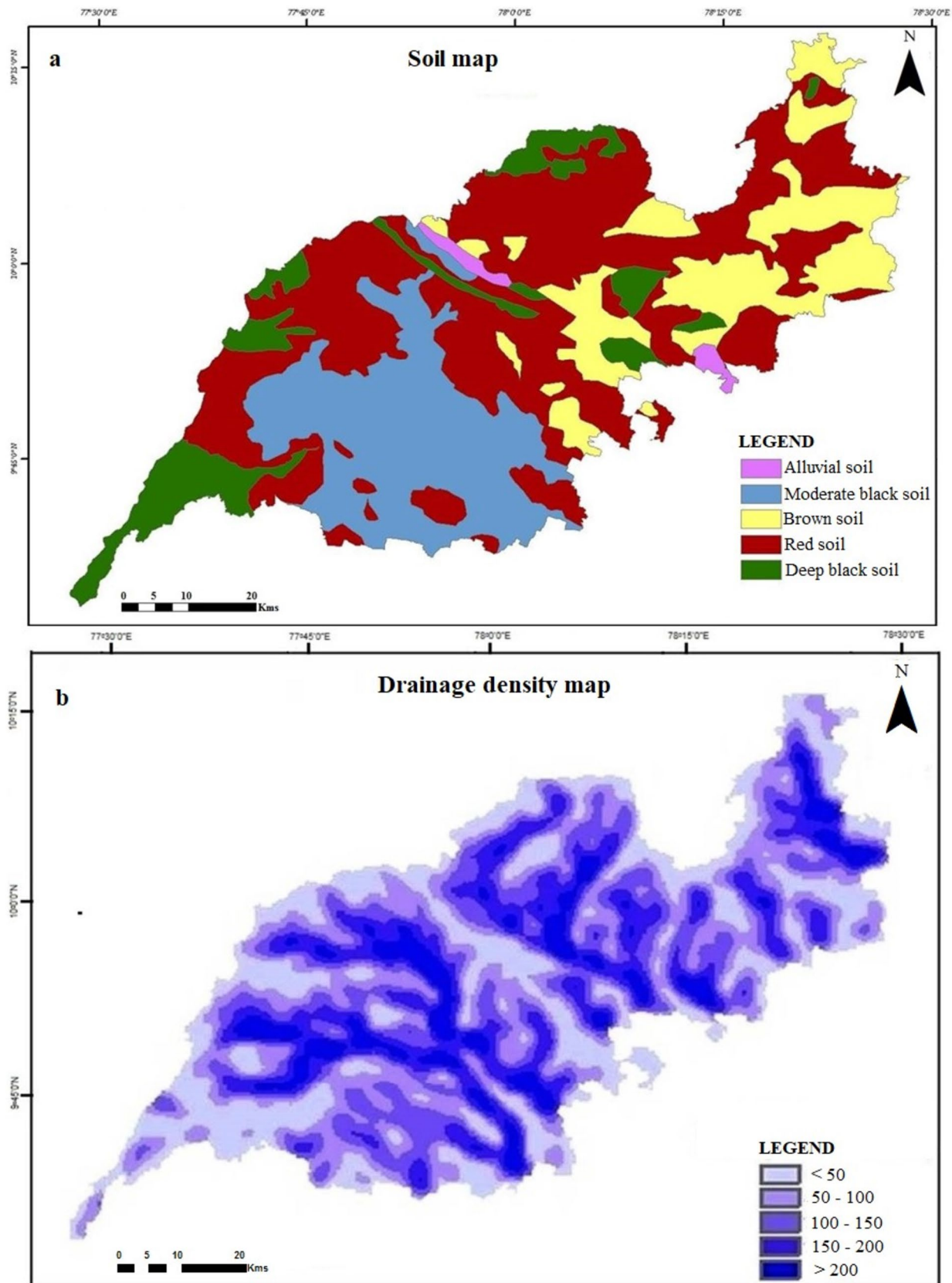


Fig. 4 a Soil, b drainage density map of the study area

Table 4 Areal distribution of each parameter in the study region

Feature	Range	Area in km ²	Percentage
Soils	Red soil	1610.24	44
	Deep black soil	571.75	15
	Alluvial soil	118.66	3
	Brown soil	560.45	15
	Moderate black soil	835.7	23
Drainage density (km/km ²)	<0.2	295.7	8
	0.2–0.6	2281	62
	>0.6	1120.1	30
Geology	Alluvial and quaternary sediment	158.92	4.3
	Charnockite	1663.2	45
	Khondalite	77.6	2.1
	Migmatite	1796.2	48.6
Slope (°)	Low slope (<5)	2649.8	72
	Medium slope (5–15)	882.5	24
	High slope (>15)	164.5	4
Geomorphology	Bazada	73.1	2
	Pediment	2831	77
	Duri crust	56.1	1
	Flood and delta plain	103.6	3
	Structural hill	514.9	14
	Valley fill	118.2	3
Land use	Build up land	416.52	11.35
	Crop land	301.29	8.15
	Plantation	524.95	14.2
	Fallow land	1193.28	32.25
	Reserve forest	289.35	7.8
	Open scrub	474.19	12.8
	Barren land	435.48	11.78
	Water bodies	61.74	1.67
Lineament density (km/km ²)	<0.2	295.7	8
	0.2–0.6	2281	62
	>0.6	1120.1	30

Drainage density

By controlling permeability and surface runoff, drainage density is an important feature of groundwater resources. An area's drainage density is determined by how many streams are present per unit area. Drainage density is determined by categorizing the study region into low drainage density, medium drainage density, and high drainage density. In Arcgis, the drainage density of the study region was prepared using the line density tool by first digitizing drainage on toposheets (Fig. 4b). The major streams in the study region like Vaigai, Gundar, Vaippur and Pambar are occurring. Water flows mostly during the rainy season and a dendritic drainage pattern is found throughout the study region. This region is covered mostly by medium drainage (53%), high drainage (31%) and low drainage (16%) (Table 4). As a result of low relief, more runoff time, and

greater rainwater recharge on the flat land in this region, low drainage density is considered high rank. High drainage density is considered as low rank, while this region has a steeper slope and less runoff time (Table 3). Low drainage density can be seen in the river coarse and high drainage density found in the northern and southern part of the study area.

Geology

Geology plays an essential role in the movement of water, defining the quality of water and occurrence of water. The geologic map in Fig. 5a was prepared with the aid of the GSI map (GSI 1995). A major part of this region is composed of alluvium, quaternary sediments, charnockite, khondalite, and migmatite, while a minor part contains hornblende biotite gneiss, granite and anorthosite. In the late archaean

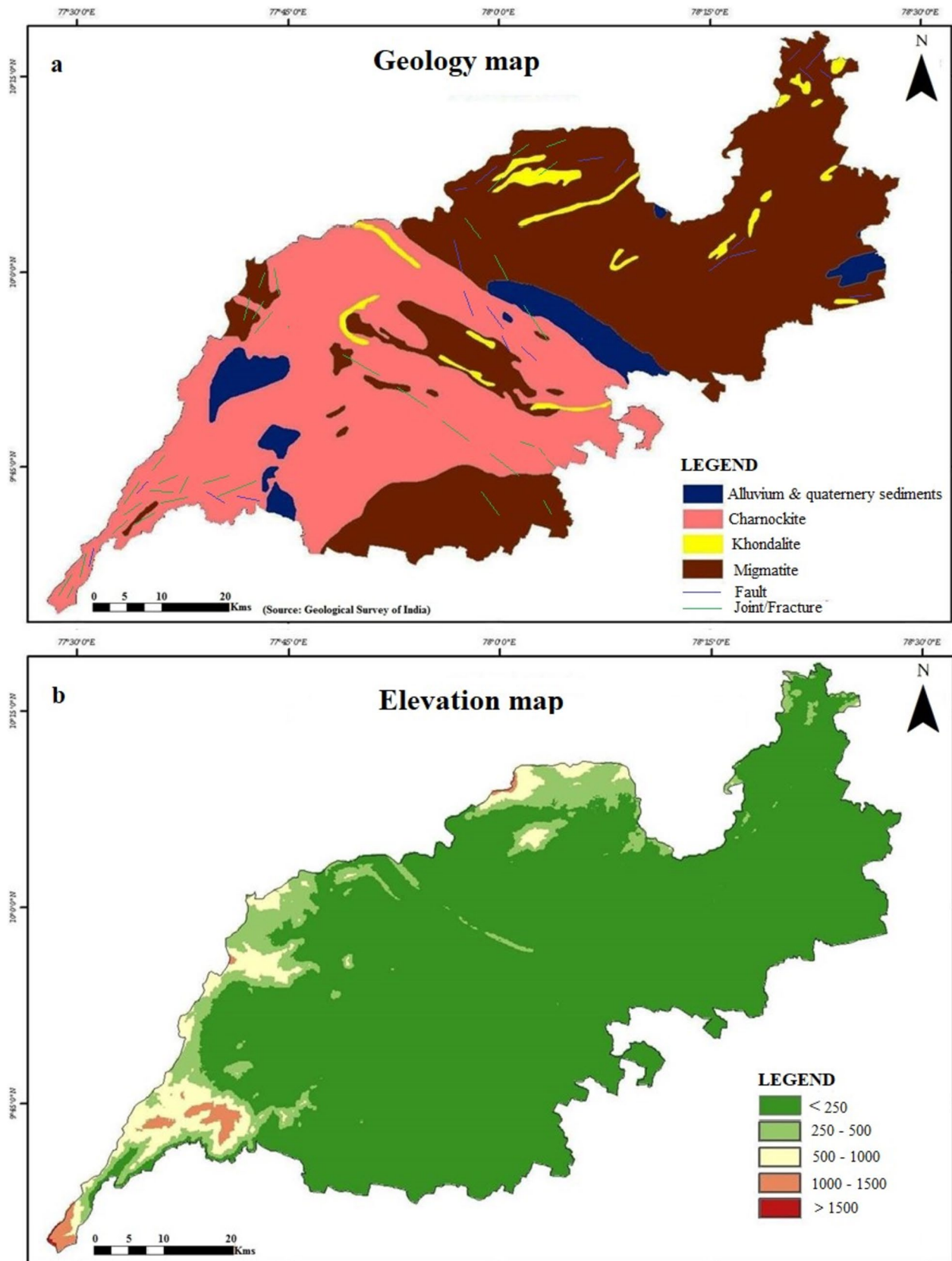


Fig. 5 a Geology and b elevation map of the study area

period (2.6 billion years ago), charnockite, khondalite, and migmatite were formed, while alluvium and sediments were formed in the quaternary period (0.9 billion years ago). Alluvium and quaternary sediments are considered to be high rank (Table 3). Quaternary sediments are composed of calcareous mud, calcareous sandy clay, gritty sandstone, and clay. Rainwater infiltration capacity and permeability are greater in alluvium and quaternary sediments. A khondalite or migmatite with less porosity and permeability is considered to be low rank because there are no fractured rocks present. Most of the study region is covered by migmatite (48.6%), charnockite (45%), alluvium with quaternary sediments (4.3%) and Khondalite (2.1%) (Table 4).

Slope

The slope is one of the important features on the earth's surface to identify the groundwater potential zone, which controls the infiltration rate and it plays a major role in the formation of landforms and hydrological conditions. Recharge of rainwater varies depending on the slope of the region. The slope map was derived from elevation data and elevation in this region ranges from 101 to 1500 m msl (Fig. 5b). Maximum elevation is found in the southwestern and northern, minimum elevation in the eastern part of the study region. Slope of the study region is given in Fig. 6a. In relation to slope degree, the study region can be divided into low slope (less than 5°), medium slope (5–15°), and high slope (more than 15°). Low slope regions are considered to be higher rank. There is a high groundwater recharge rate in low slope areas, which is due to the fact that surface runoff takes more time to travel and a greater amount of water is recharged. High slope region is considered to be lower rank while run off time in steeper region is very short, increase of erosion rate and very less amount of recharge (Table 3). Groundwater recharge is generally low in high slope areas, and rainwater recharge reduces in steeper slope regions. The study region is covered by low slope (72%), medium slope (24) and high slope (4%) (Table 4). The steep slope can be found in the southwest, western and northern part of the study area and the gentle slope can be found in the central, southern and eastern part of the study area.

Geomorphology

The geomorphological features are formed by various processes like physical, chemical and biological through the water, wind, glacier, river and tectonic activities. Geomorphology plays an important role in the identification of favorable zones for groundwater development. The geomorphic features in the study region are identified as bazada, flood plain, buried pediment, buried shallow pediment, buried moderate pediment, dissected upland,

duricrust, valley fill, structural hill, residual hills, paleo-deltaic plain and old deltaic plain (Fig. 6b). Flood plain and valley fills are considered to be high rank. Good groundwater is found in flood plains, alluvial fans, and valley fills. They are associated with thick alluvial and weathered materials, which have high porosity and permeability. Structural and residual hills are considered to be lower rank because of these features are reducing recharge of rainwater into subsurface due to the steeper slope, fast runoff and uneven surface (Table 3). The pediment is considered to be medium rank, which is covered mostly by water bodies and agricultural land and this is having good groundwater potential. The distribution of geomorphological features in the study region is covered mostly by a pediment (77%), structural and residual hill (14%), and is followed by valley fill (3%), flood and deltaic plain (3%), Bazada (2%) and duricrust (1%) (Table 4).

Land use and land cover

Various land use patterns in this region are identified. This map shows the land use in Fig. 7a and is digitized using ArcGIS software. Land use is covered dominantly by fallow land (32%) and followed by plantation (14.2%), open scrub (12.8%), barren land (11.7%), buildup land (11.3%), crop land (8.1%), reserve forest (7.8%), and water bodies (1.7%) (Table 4). Cropland and water bodies are considered to be high rank due to more recharge in the extension of plain terrain. Buildup land, barren land and open scrub are considered to be lower rank, which are having less groundwater potential and these are less recharge area due to non-availability of space to infiltrate rainwater (Table 3). Crop land can be seen in the northern and central part of the study area, built up land can be seen in the south central part of the study area, reserve forest and barren land can be seen in the southwest, western, central and northern part of the study area.

Lineament density

Lineament features are very essential in groundwater development to identify faults, folds and fractures in the rock. Faults, folds and fractures are indirect evidence of good groundwater potential. As shown in Fig. 7b, the line density map was prepared using ArcGIS line density tools. Based on the lineament density, the study region is classified into low lineament (<0.2 km²), medium lineament (0.2–0.6 km²) and high lineament (>0.6 km²). The study area is covered by medium lineament (62%), high lineament (30%) and low lineament (8%) (Table 4). As a result of fractured rocks, the study region is getting more recharge through high lineation. The low lineament region is considered to be lower rank and

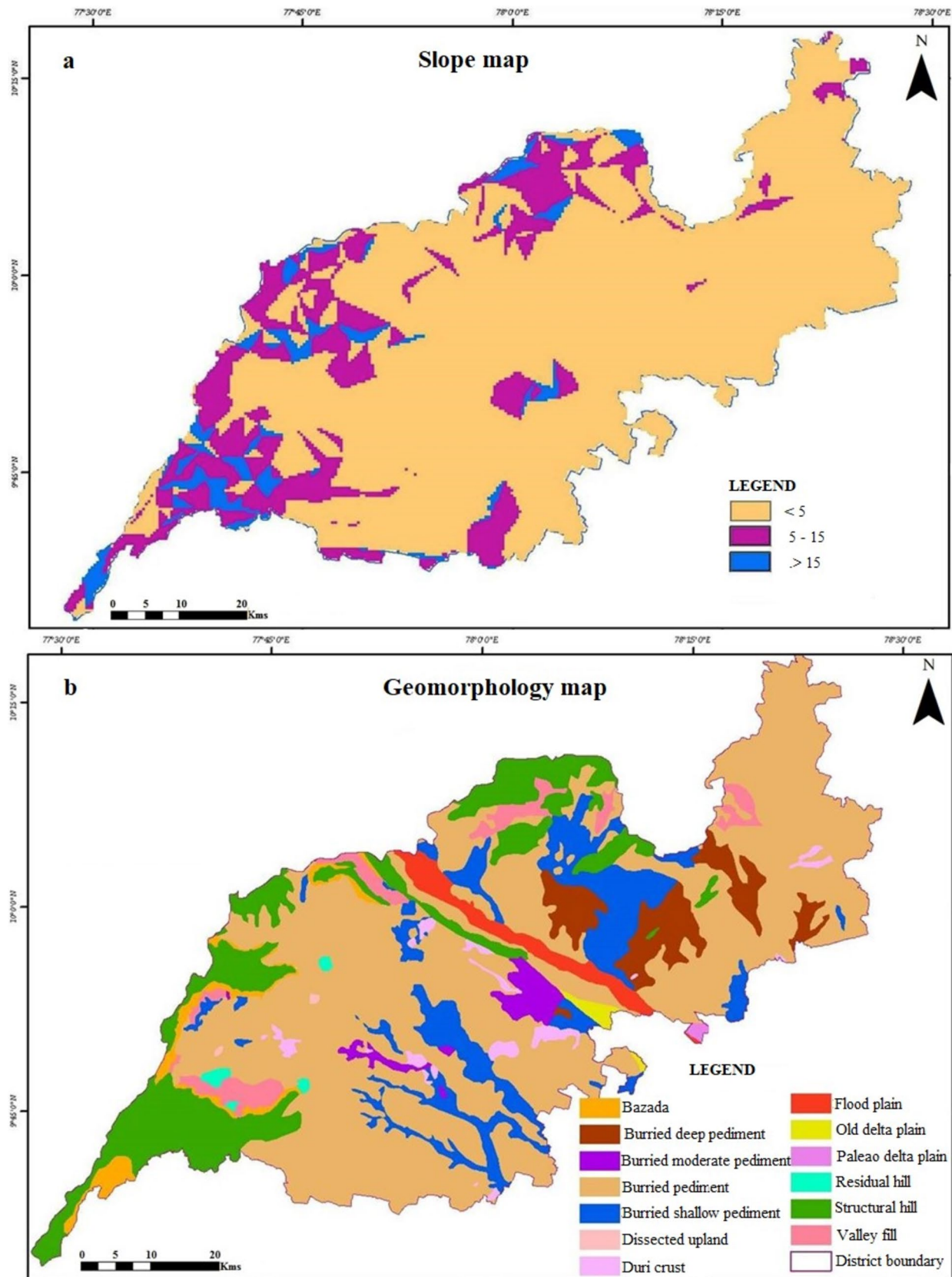


Fig. 6 a Slope, b the geomorphology of the study area

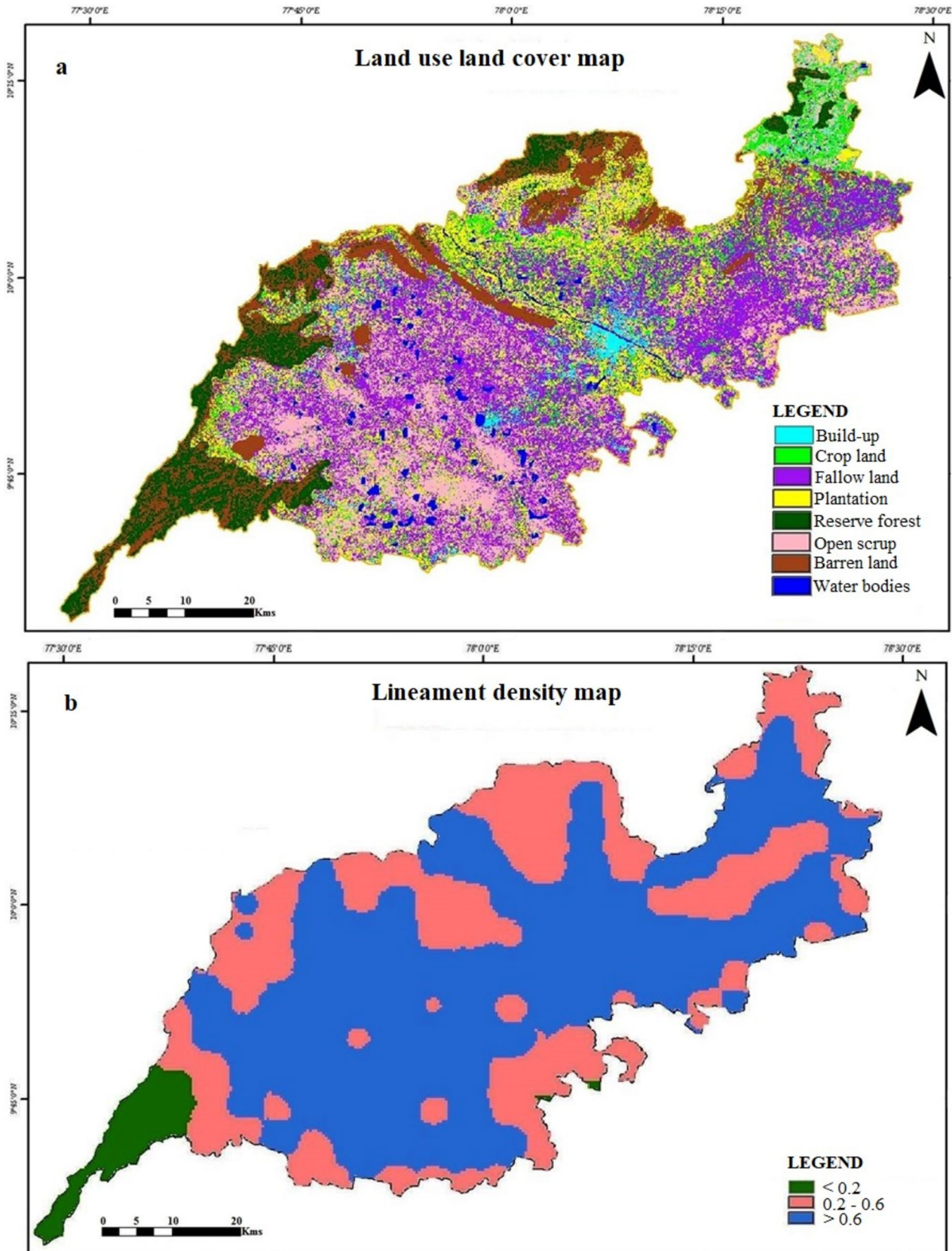


Fig. 7 a Land use, b lineament density in the study area

this region has less groundwater potential due to the absence or less recharge of rainwater (Table 3).

Identification of groundwater potential zone

Groundwater potential for the study area was derived using various thematic maps like soil, drainage, geology, slope, geomorphology, land use and lineament in ArcGIS 10.4.

The weightage for each factor was calculated using a multi-influencing factor method. Ranks and scores for each factor were derived from previous studies. To derive the groundwater potential index for the study region, seven influencing factors such as slope, geology, land use, lineament, drainage, soil and geomorphology were integrated through the weighted overlay analysis method. Groundwater potential index values for low, medium and high groundwater potential

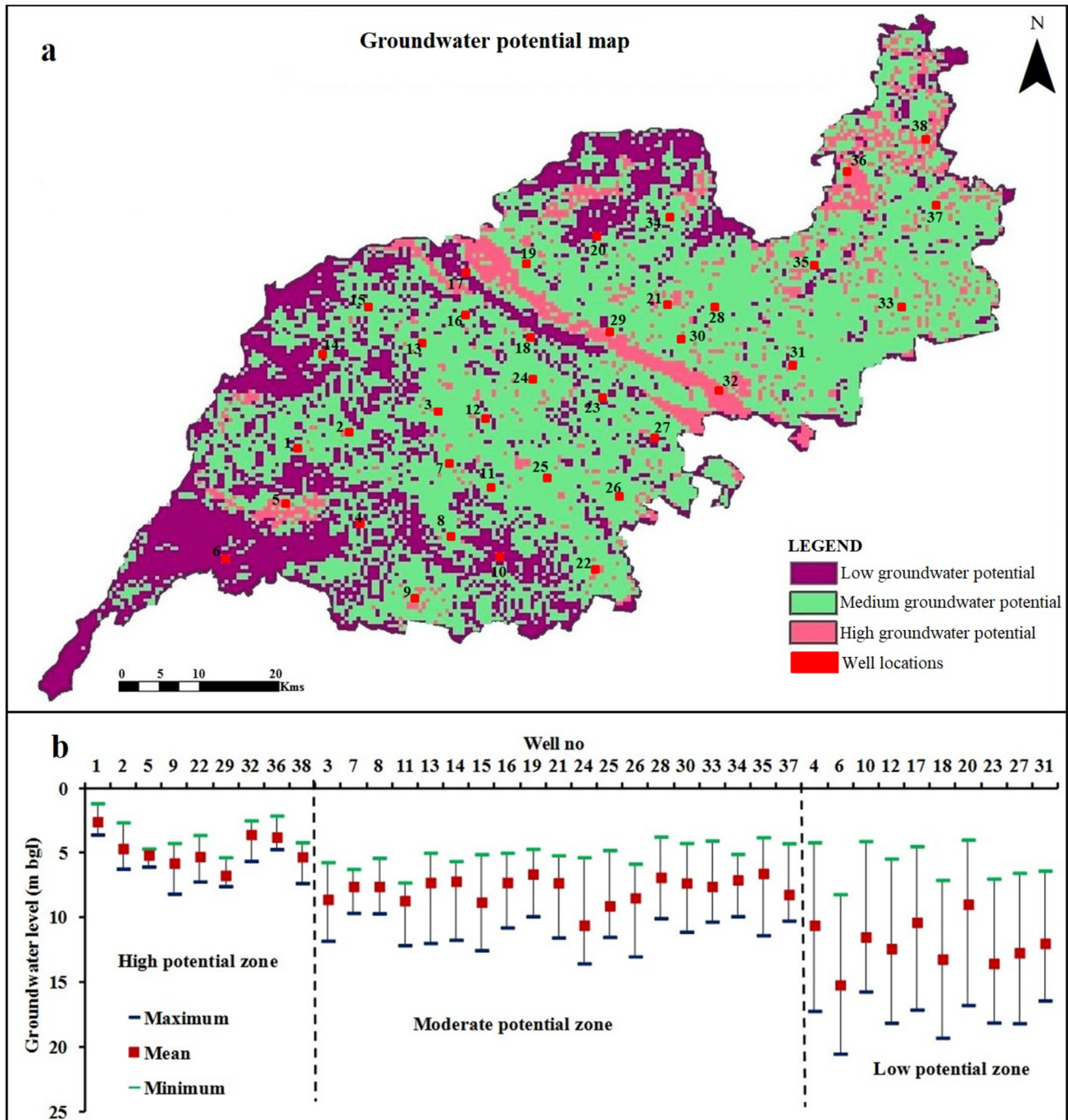


Fig. 8 a The study area shows groundwater potential. b Fluctuations in groundwater levels at low, medium and high potential wells

zones were derived as from 100 to 160, 161 to 225 and 226 to 300, respectively. The spatial variation of the groundwater potential zone in the study region was shown in Fig. 8a. Groundwater potential zones can be classified into three categories: low, medium and high groundwater potential. Results of groundwater potential in the study region indicate that about 11% (406.5 square kilometers) of the area was covered by high groundwater potential. Alluvium, low drainage, low slope, pediment, delta plain, crop land, water bodies, and high lineament density have a high groundwater potential. High groundwater potential is due to more surface runoff time, flat land, alluvium sediment and water bodies. About 64% of the study area has medium groundwater potential (2365.5 square kilometers) and is located in the black soil, medium drainage, medium slope, valley fill, plantation, barren land and medium lineament density. About 25% of the study area (924 square kilometers) was found to be low groundwater potential, because of red soil, high drainage density, khondalite, migmatite, high slope, structural hill, low lineament density and buildup land. The low groundwater potential zone is formed due to the steep slope, fast runoff time, less available space for rainwater infiltration and forest area. Geology, land use, land cover and geomorphology features have played an essential role in high groundwater potential zones. Drainage, lineament and soil types have played a major role in low groundwater potential zones. The alluvial and quaternary sediments of the geological formation showed a high groundwater potential zone.

Validation

Groundwater level data was collected from CGWB for 38 wells in 2016 to 2017. On the basis of low, medium, and high groundwater potential zones, the groundwater level was validated. In Fig. 8b, groundwater levels fluctuate in zones with low, medium, and high groundwater potential. Groundwater levels in high groundwater potential zones varied from 1.13 to 8.16 m below ground level with a mean value of 3.5 m in the study area. Low groundwater potential zones had groundwater levels ranging from 3.1 to 23.3 m with a mean value of 8.4 m below ground level, whereas medium groundwater potential zones had groundwater levels ranging from 2.76 to 13.5 m with a mean value of 5.6 m below ground level. During groundwater level fluctuations, low and medium potential zones have experienced higher fluctuations than high potential zones. The result indicates that high potential zones can yield a larger volume of groundwater for various uses.

Conclusion

Groundwater potential zones were identified in the hard rock terrain of Madurai district, southern India, using a multi-influencing factor method, remote sensing and mapping techniques. Based on toposheets, satellite images, and conventional data, thematic maps were prepared for the study area. The MIF method was used to assign weightage to each factor and rank was assigned based on local knowledge and literature. The overlay analysis method was integrated with each influencing factor to derive the groundwater potential index using ArcGIS software. Based on the groundwater potential map, the study area in Madurai district is divided into three classes such as low, medium and high groundwater potential. A high groundwater potential zone was found on flat land, water bodies, low slopes, croplands, delta plains and alluvial soils. The study areas have a high groundwater potential in around 11% of them, and geology, geomorphology, and land use are all important factors. It was found that black soil, valley fill, medium slopes, charnockite rock, and barren land had medium groundwater potential. About 64% of the study area had a medium groundwater potential. A low groundwater potential zone was found in the build up land, hill region, waste land, khondalite and migmatite. In 25% of the study area, the groundwater potential was low. The study aims to identify future groundwater resources that may be to manage water sustainably. In this region, new locations with reliable groundwater sources can be identified based on this information. The future groundwater depletion can be reduced by adding recharge structures, including check dams and percolation ponds, around high groundwater potential zones and medium groundwater potential zones.

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Declarations

Conflict of interest The authors declare that they have no known competing financial interest.

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