



Multi-influencing factor method for delineation of groundwater potential zones using remote sensing and GIS techniques in the western part of Perambalur district, southern India

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Abstract

Identification of groundwater recharge zones in an area is important to properly utilize and safeguard the groundwater resources. The objective of this study is to delineate the groundwater potential zones in the Chinnar River basin of Perambalur district, southern India, using remote sensing and GIS methods. Toposheets and satellite imageries were used to prepare various thematic maps such as geology, soil, drainage density, slope, lineament density, geomorphology, and land use. These data were combined with the weighted overlay method to demarcate the groundwater potential zones. Multi-influencing factor (MIF) method was used to derive the weights for the seven layers, and ranks were assigned to the features within the layers based on local knowledge and from literature. The study suggests that the geology, slope, land use, and geomorphology features play a major role in determining the availability of groundwater in the study area. The groundwater potential was high in 54%, medium in 21%, and low in 25% of the study area. The groundwater level fluctuation that varies based on the rainfall and different rock types was used to validate the groundwater potential map. Areas with high groundwater potential had the lowest groundwater fluctuation compared with the medium and low groundwater potential areas. Sensitivity analysis showed that excluding the land use and geomorphology features will have the highest impact on identifying the groundwater potential zones. Determination of effective weights indicated that land use, geomorphology, and slope have higher weights than the assigned weights. The results show that the delineated groundwater potential zones can be used in the future for groundwater resource management in the study area.

Keywords Multi-criteria analysis · Multi-influencing factor · Recharge areas · Rainfall · Water resources management · Sensitivity analysis · Perambalur · Tamil Nadu

Introduction

Groundwater forms an important source of water for sustaining livelihood in most parts of India. In the recent years, groundwater is continuously declining in some places and the major reasons for this are over exploitation, population growth, industrialization, intensification of agriculture, and

climate change. The annual replenishable groundwater resources of the country has been estimated as 431 km³, and the estimated net annual groundwater availability is 396 km³ (as of March 2009) (CGWB 2011). The groundwater development in India is not uniform and some regions of the country have declining groundwater level due to excessive pumping. The annual average rainfall contribution to the groundwater resources in the country is about 68%, and other resources such as tanks, ponds, irrigation return flow, and water storage structures contribute to about 32% (GEC 2017). However, due to uneven distribution of rainfall events over space and time, there is large variation in the groundwater availability and extraction. Of the 5842 assessment units in the country, 802 units are over-exploited, 523 are semi-critical, and 169 are critical (CGWB 2011). Hence, the sustainable management of this limited freshwater resource requires detailed assessment, proper planning, and stringent

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implementation measures. For this, as a first step, it is essential to identify the potential zones for groundwater recharge.

Traditional hydrogeological approaches of groundwater exploration through visual, geological, geophysical, and drilling methods are expensive, time-consuming, and requires skilled staff (Jha et al. 2010; Mahato and Pal 2018). Geospatial methods have been used as an effective tool for a long period of time for assessment, monitoring, and sustainable management of the groundwater resources (Fagbohun 2018; Mokadem et al. 2018; Rajaveni et al. 2015; Suganthi et al. 2014). Remote sensing data that can be used in a geographic information systems (GIS) platform is nowadays inexpensive and in many cases hosted in an open-access portal for public use. Hence, these data provide valuable information on the groundwater resources, and on the factors influencing the groundwater occurrence and distribution. Key advantages of remote sensing and GIS are the spatial, spectral, and temporal availability of the data, and the ability to produce quick results (Jha et al. 2010; Misi et al. 2018). Large and inaccessible areas can also be examined through satellite imageries.

Common practice for identification of the groundwater potential zones is to combine the different surface features derived from satellite imagery and toposheets using weighted overlay analysis (Jha et al. 2006; Preeja et al. 2011; Sener et al. 2004). Studies have adopted this basic idea and have improvised by combining with other techniques to obtain reliable results. Researchers have integrated geophysical data with remote sensing and GIS resources (Anbazhagan and Jothibasur 2016; Jha et al. 2010; Oladunjoye et al. 2019). Multiple-criteria decision-making/analysis (Das and Mukhopadhyay 2018; Machiwal et al. 2011; Pradhan 2009), analytic hierarchy process (Andualem and Demeke 2019; Murmu et al. 2019), 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 (Ghorbani Nejad et al. 2017; Lee et al. 2012), evidential belief function (Mogaji et al. 2016; Pourghasemi and Beheshtirad 2015), frequency ratio (Oh et al. 2011; Razandi et al. 2015), and weighted linear combination (Senanayake et al. 2016) are some of the wide array of methods integrated with GIS for groundwater potential mapping. Among these methods, multi-influencing factor (MIF) method has gained more attention recently as it is comparatively simple and reliable (Etikala et al. 2019; Fagbohun 2018). A comparison of the existing approaches have also been carried out to determine the consistency of the results

from various methods (Arabameri et al. 2019; Cui et al. 2017; Pham et al. 2019).

In Perambalur district located in Tamil Nadu, southern India, agriculture is intensively practiced, and groundwater is the main source for irrigation, drinking, and domestic purposes. Nearly 60% of the extracted groundwater is used for agriculture (CGWB 2009). Perambalur district experienced 71% deficit in rainfall in December 2016 (CGWB 2017), and 79% of the monitored wells showed decline in water table between May 2016 and January 2017. Decline in groundwater level in comparison with the decadal mean (2006 to 2015) was recorded in 20%, 93%, and 90% of the monitoring wells in May 2016, November 2016, and January 2017, respectively. As per Central Ground Water Board (CGWB), the entire district was categorized as over-exploited on March 2011. In view of these reports, it is necessary to demarcate the groundwater potential zones for proper planning and for safeguarding the resource for future water supply. Previous studies in this region are restricted to the assessment of groundwater quality and identification of the hydrogeochemical processes (Ahamed et al. 2013; Anbarasu and Elango 2016). A clear understanding and delineation of the groundwater recharge areas that should be protected are not available. Therefore, the present study aims at demarcating the groundwater potential zones in the western part of Perambalur district using modern techniques of remote sensing and GIS and identifying the areas that require more focused management during water crisis.

Study area

The study region covers an areal extent of ~ 220 km² and is located in the Chinnar River basin, Perambalur district, Tamil Nadu, India (Fig. 1). Most part of the study area is covered by the Eastern Ghats (Pachamalai). This area experiences an arid to semi-arid climate and has high humidity. The maximum temperature is about 40 °C during the summer (April to June), and the minimum temperature is 22 °C during winter (December to February). Annual average rainfall is about 950 mm. Most of the rainfall occurs during the northeast monsoon (October to December) and the southwest monsoon (July to September) contributes to a lesser extent. This region is comprised of weathered and fractured gneissic rocks along with charnockite which is mostly covered by agricultural lands. The major water-bearing formations are the weathered gneiss (CGWB 2009). The water-yielding capacities of the rock formations in the

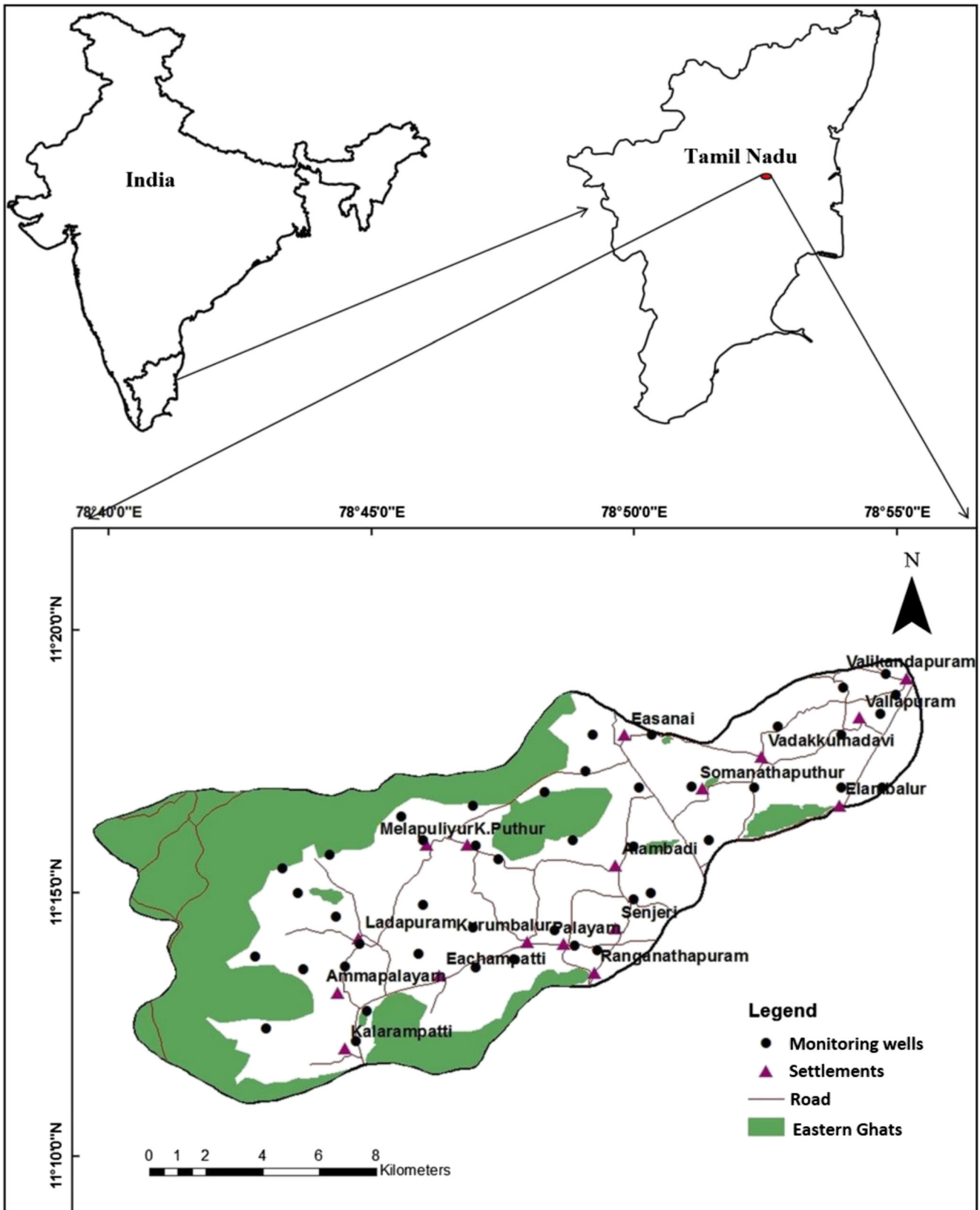


Fig. 1 Location of the study area with monitoring wells

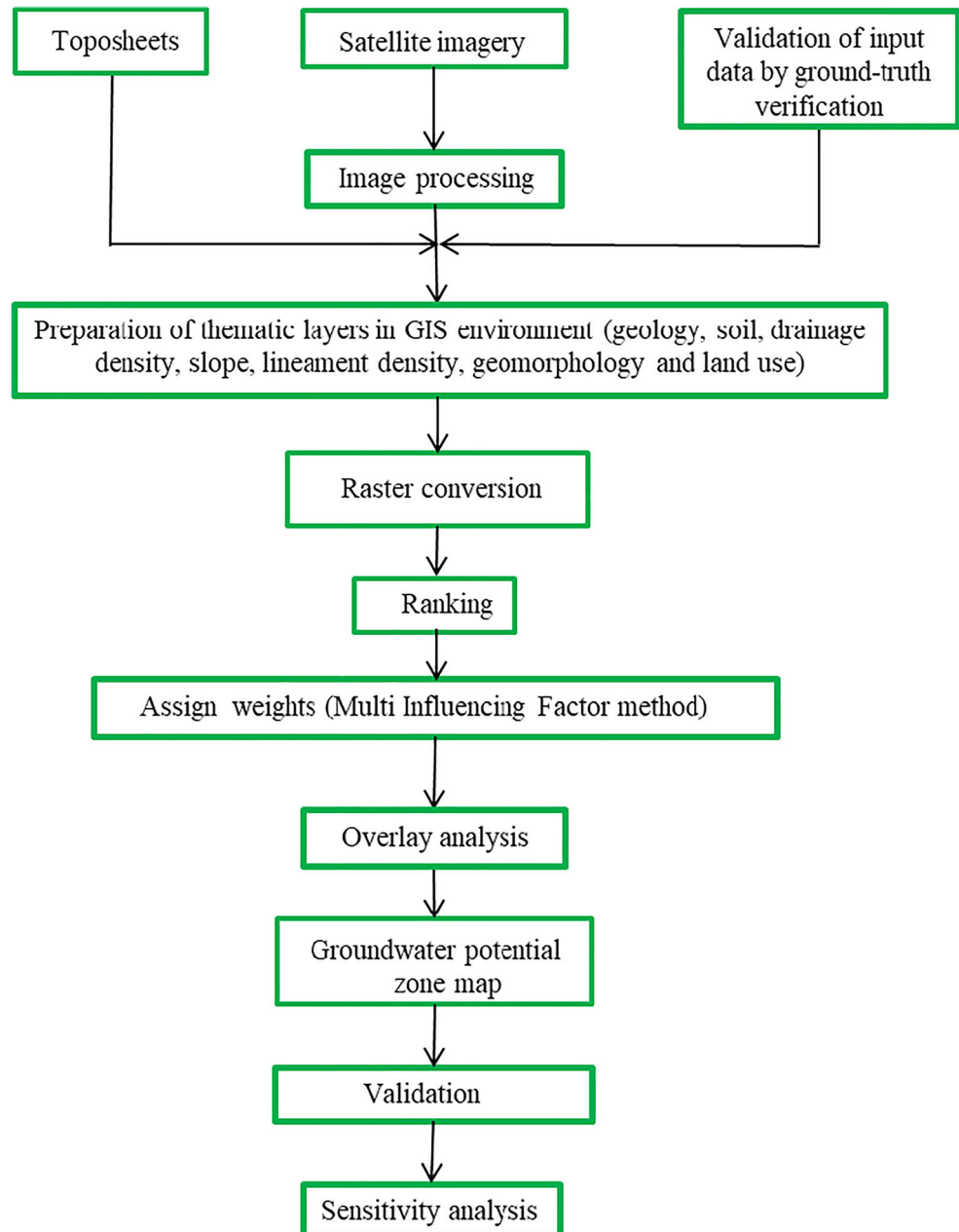
Table 1 Water yielding capacities (specific yield %) of the rock formations in the study area

Rock type	Intensity of weathering	Water yielding capacities (specific yield %)
Charnockite	Highly weathered (soil)	4–8
	Medium weathered	2–4
	Fractured	3–6
Gneissic rock	Highly weathered (soil)	10–12
	Medium weathered	4–7
	Fractured	5–10

area are given in Table 1 (GEC 2017; Ministry of Environment Forest and Climate Change 2018). The depth of groundwater level ranges from 3 to 15 m

bg1 (TWAD 2018). Groundwater recharge occurs mostly by rainfall, surface water bodies (river and ponds), and irrigation return flow during the monsoon period. The yield of

Fig. 2 Methodology adopted in the present study



wells range from 80 to 120 lpm in the hard rock formations (TWAD 2018). As the pumping rate is increasing in the recent years, the groundwater table is going very deep, and there are instances wherein the wells get dried-up because of the high rate of evaporation and very less rainfall (CGWB 2017; TWAD 2018). Irrigation is the chief activity in the region.

Methodology

Preparation of input data

The methodology adopted is given as a flow chart in Fig. 2. Base map of the western part of Perambalur district and the drainage pattern in the area was demarcated from the Survey of India toposheets (1:50,000 scale) (Survey of India 1995). Slope was derived for the year 2014 from the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) with 30 m spatial resolution. Geology, soil, lineaments, geomorphology, and land use were generated from the Indian Remote Sensing satellite P6 (Resourcesat-1) Linear Imaging Self-Scanning Sensor III (IRS P6 LISS III) images of the year 2014 with a spatial resolution of 24 m (1:50,000 scale geocoded with UTM projection, WGS 84 and North zone 44). Geology map was verified with the map from the Geological Survey of India (1:50,000 scale) (GSI 1995). The prepared thematic layers were cross-checked with the data collected during the field work for ground-truth verification. Processing the data, generating the thematic layers, and analyzing the data through MIF method was carried out in a GIS environment using the ArcMap 10.4 program. For the

validation of the groundwater potential map, the groundwater level was measured in selected monitoring wells (44 wells) in the study area for the period from 2015 to 2018.

Weightage from multi-influencing factor method

Geology, soil, drainage, slope, lineament, geomorphology, and land use, considered as the influencing factors in facilitating groundwater recharge are combined to delineate the potential zones. The weightage of each factor is computed by the MIF method where the strong and weak relationship between the influential factors are considered to assign the weight. Figure 3 shows that the interrelationship and interdependency between these factors and their effects. Major effect represents direct influence of one factor over another, and minor effect represents indirect influence. The major and minor effects are classified based on their holding capacity and the characteristics of the surface and subsurface features. The major factor is assigned a value of 1 and minor factor is given 0.5 value. These values are combined to calculate the MIF weight of each layer using the following equation:

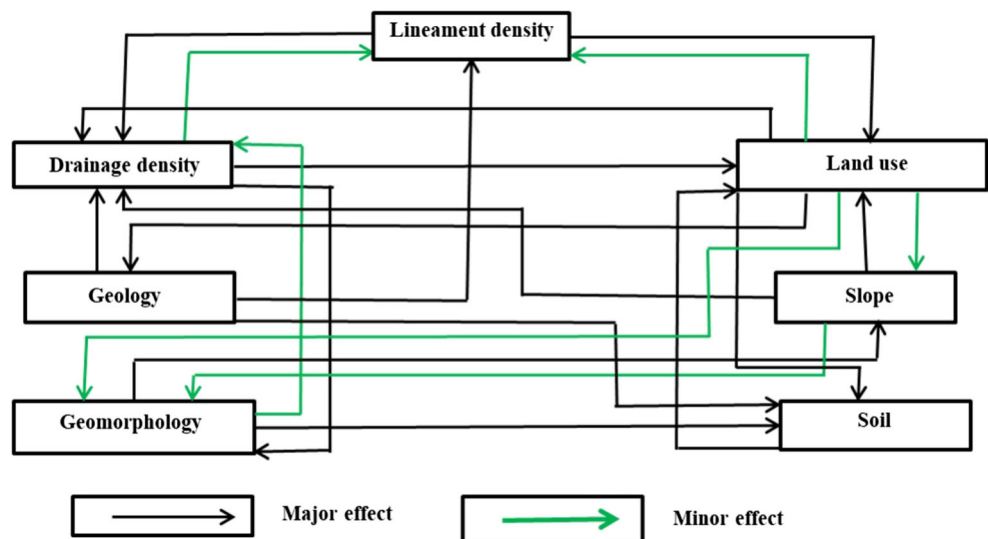
$$MIF = \frac{(A + B)}{\sum(A + B)} \times 100 \tag{1}$$

where A is the major effect between the two factors, and B is the minor effect between the two factors.

Overlay analysis

Seven factors influencing the groundwater occurrence in the study area were used to delineate the groundwater

Fig. 3 Interrelationship between the multi-influencing factors that are considered in mapping the groundwater potential



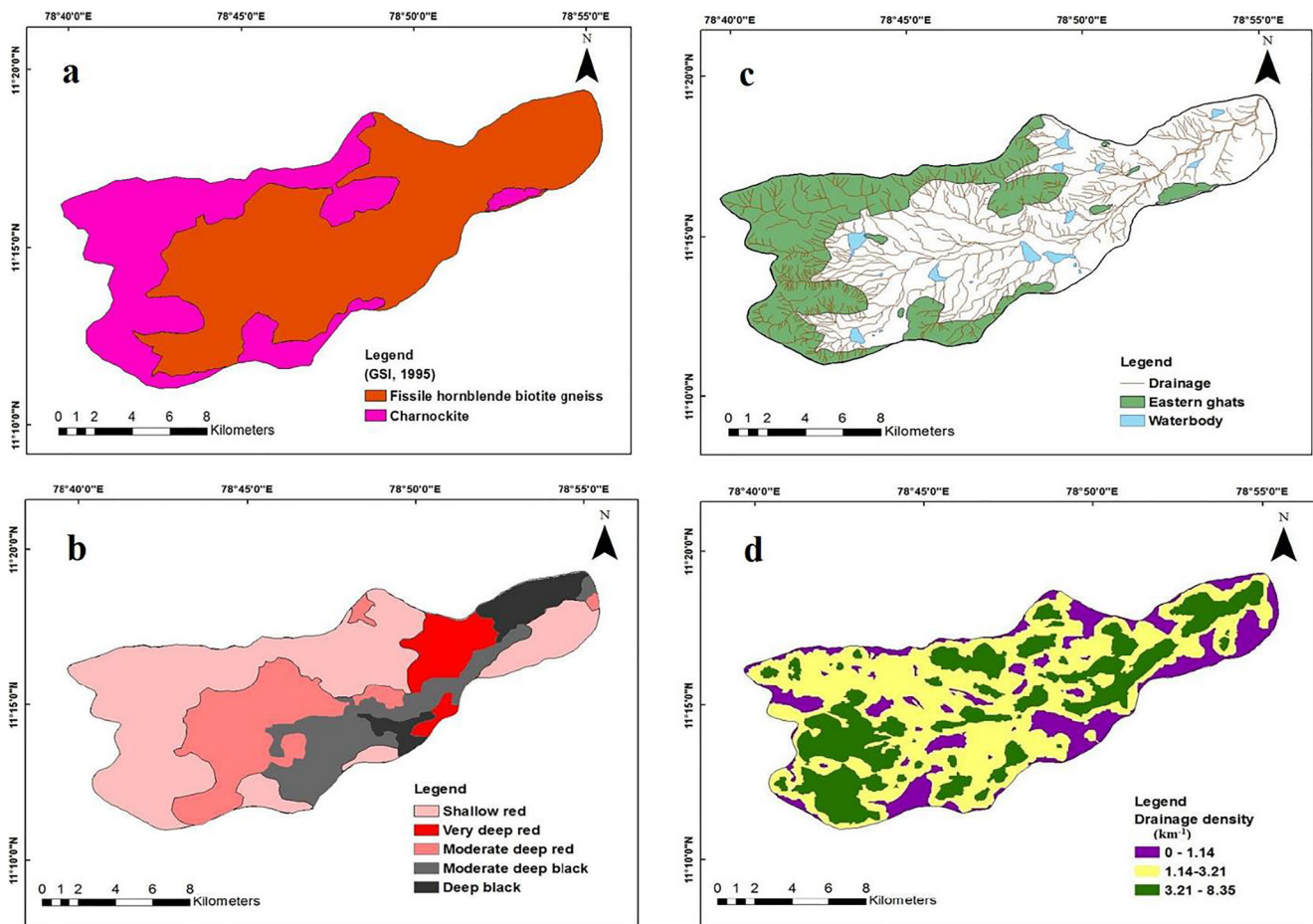


Fig. 4 Features of the study area. **a** Geology. **b** Soil. **c** Drainage. **d** Drainage density

potential zones. These potential zones were generated by the weighted overlay analysis method. The weights for the layers were derived from MIF method as described earlier. The features within each layer were assigned ranks based on local knowledge about the area and from literature (Avtar et al. 2010; Chaudhary and Kumar 2018; Gnanachandrasamy et al. 2018; Jasmin and Mallikarjuna 2011; Patra et al. 2018; Rajaveni et al. 2015). The layers assigned with the ranks and weights were integrated using the equation given below to arrive at the groundwater potential index.

Groundwater potential index

$$\begin{aligned}
 &= (G_w \times G_r) + (SO_w \times SO_r) + (DD_w \times DD_r) \\
 &+ (SL_w \times SL_r) + (LD_w \times LD_r) + (GM_w \times GM_r) \\
 &+ (LU_w \times LU_r)
 \end{aligned} \quad (2)$$

where G represents the geology, SO represents the soil, DD represents the drainage density, SL represents the slope, LD represents the lineament density, GM represents the

geomorphology, LU represents the land use, r represents the feature rank within a layer, and w represents the layer weight calculated using MIF method.

Sensitivity analysis

Sensitivity of the parameters used in the groundwater potential index calculation can be analysed using the map removal analysis and single parameter analysis. Map removal sensitivity analysis is carried out by removing one parameter or multiple parameter at a time from the index (Lodwick et al. 1990). This is calculated using

$$S = \frac{|(GWPI/N) - (gwpi/n)|}{GWPI} \times 100 \quad (3)$$

where S is the sensitivity measure, $GWPI$ is the unperturbed groundwater potential index computed with all the parameters, $gwpi$ is the perturbed groundwater potential index computed by removing one or more layers, N is the number of layers used to compute $GWPI$, and n is the number of layers used to compute $gwpi$.

Single parameter sensitivity measure also helps to identify the influence of the layers on the groundwater potential index. This is used to compare the theoretical weights assigned to the input layers with actual or effective weights (Babiker et al. 2005). This can be calculated using the following equation given by Napolitano and Fabbri (1996).

$$W = \frac{(P_r P_w)}{GWPI} \times 100 \tag{4}$$

where, *W* is the effective weight of a parameter, *P_r* is the rank of the feature within a layer, *P_w* is the weight of each layer, and *GWPI* is the groundwater potential index.

Results and discussion

Groundwater availability depends on several surface and sub-surface features. Accuracy of predicting the groundwater

potential zone depends on the quality of the thematic layers and the number of features considered in the study.

Geology

Geological formations play an important role in determining the quality, occurrence, and movement of groundwater. Geological map was prepared with the help of the GSI map and LISS III images (Fig. 4a). The study area is largely covered by fissile hornblende biotite gneiss especially in the plains (65%), and remaining part of the area is covered by charnockite rock in the mountainous region (Table 2). The hard rock formation of fissile hornblende biotite gneissic rock is comprised of amphibolite, granulite, granite, hornblende, granodiorite, garnetiferous gneiss, gneiss, weathered biotite, weathered granite, and weathered garnetiferous gneiss with coarse to medium texture, melano- and mesocratic color. The fissile hornblende biotite gneiss

Table 2 Areal extend of each feature in the study area

Layer	Range/ Feature	Area in km ²	Percentage
Geology	Charnockite	77.2	35
	Fissile hornblende biotite gneiss	142.7	65
Soil	Moderately black	31.5	14
	Deep black	15.1	7
	Shallow red	111.5	51
	Moderately red	45.6	21
	Very deep red	16.2	7
	Drainage density (km ⁻¹)	Low density	34.8
	Medium density	116.7	53
	High density	68.4	31
Slope (°)	Low slope (< 8)	158.4	72
	Medium slope (8–20)	35.8	16
	High slope (> 20)	25.7	12
Lineament density (km ⁻¹)	< 0.49	161.2	73
	0.49–1.32	52	24
	1.32–1.96	3.5	2
	> 1.96	3.1	1
Geomorphology	Structural origin low dissected hills and valleys	0.1	0
	Structural origin moderately dissected lower plateau	9.9	5
	Denudational origin lower dissected hills and valleys	6.7	3
	Denudational origin pediment and pediplain complex	149.3	68
	Structural origin moderately dissected hills and valleys	53.8	24
Land use	Wetland and water bodies	13.7	6
	Waste land, scrub land and barren land	19.7	9
	Forest	66.4	30
	Built-up	3.5	2
	Agriculture	116.6	53

is comparatively more weathered than the charnockites. Hence, the rainfall recharge in the gneissic rocks is more than the charnockites. Thus, the fissile hornblende biotite gneiss are assigned a higher rank and charnockites have lower rank (Table 3).

Soil

Soil controls the infiltration of water in an area and depends on several characteristics such as grain size, grain shape, soil texture, porosity, and bulk density. Soils in the study area have formed from the weathering of the parent rock. Black soil and red soil are major soil types in this region (Fig. 4b). Black soils found at a depth of 30–200 cm, are deep gray to black in color and clayey loam in texture. These soils have high water holding capacity with medium infiltration, exchangeable bases and alkaline soil pH. Black soil covers 21% of the study region (Table 2), which is considered suitable for groundwater development. Red soils have shallow to medium depth and light texture. These soils have low water holding capacity, thus unsuitable as a groundwater potential zone, and 79% of the study area is covered by red soil. Black soils were allotted a

higher rank and red soils were given lower rank (Table 3).

Drainage density

Drainage density is the total length of streams and rivers per unit area in a drainage basin. This feature is an indirect function of permeability and surface runoff. Drainage was initially digitized from the toposheets (Fig. 4c), and the drainage density map was generated using the line density tool (Fig. 4d). A small stream is found in this area, where water flows only during the rainy season (from October to December). Most of the study region is covered by dendritic drainage pattern, and the remaining area is covered by sub-trellis drainage pattern (Fig. 4c). Based on the drainage density, the study area has been classified into three types: low drainage density ($< 1.14 \text{ km}^{-1}$) (16%), medium drainage density (1.14 to 3.21 km^{-1}) (53%), and high drainage density ($> 3.21 \text{ km}^{-1}$) (31%) (Table 2, 3). Low drainage density has good potential for groundwater augmentation, since this area is usually flat and slow surface runoff facilitates more recharge. Whereas, high drainage density areas have a steeper slope, and infiltration is low due to fast runoff, thus offering poor chances for

Table 3 Rank assigned for each feature within a thematic layer

Layer	Range/ Feature	Rank
Geology	Charnockite	1
	Fissile hornblende biotite gneiss	2
Soil	Moderate deep black, deep black	3
	Moderate black, shallow red	2
	Moderate red, very deep red	1
Drainage density (km^{-1})	< 1.14	3
	1.14–3.21	2
	3.21–8.35	2
Slope ($^{\circ}$)	0–8	3
	8–20	2
	20–38	1
Lineament density (km^{-1})	< 1.32	1
	1.32–1.96	2
	> 1.96	3
Geomorphology	Structural lower dissected hills and valleys	1
	Denudational lower dissected hills and valleys	2
	Structural moderate dissected lower plateau	3
	Denudational pediment and pediplain complex	4
Land use	Waste land, built-up land	1
	Forest	2
	Wetlands and water body	3
	Agricultural area	4

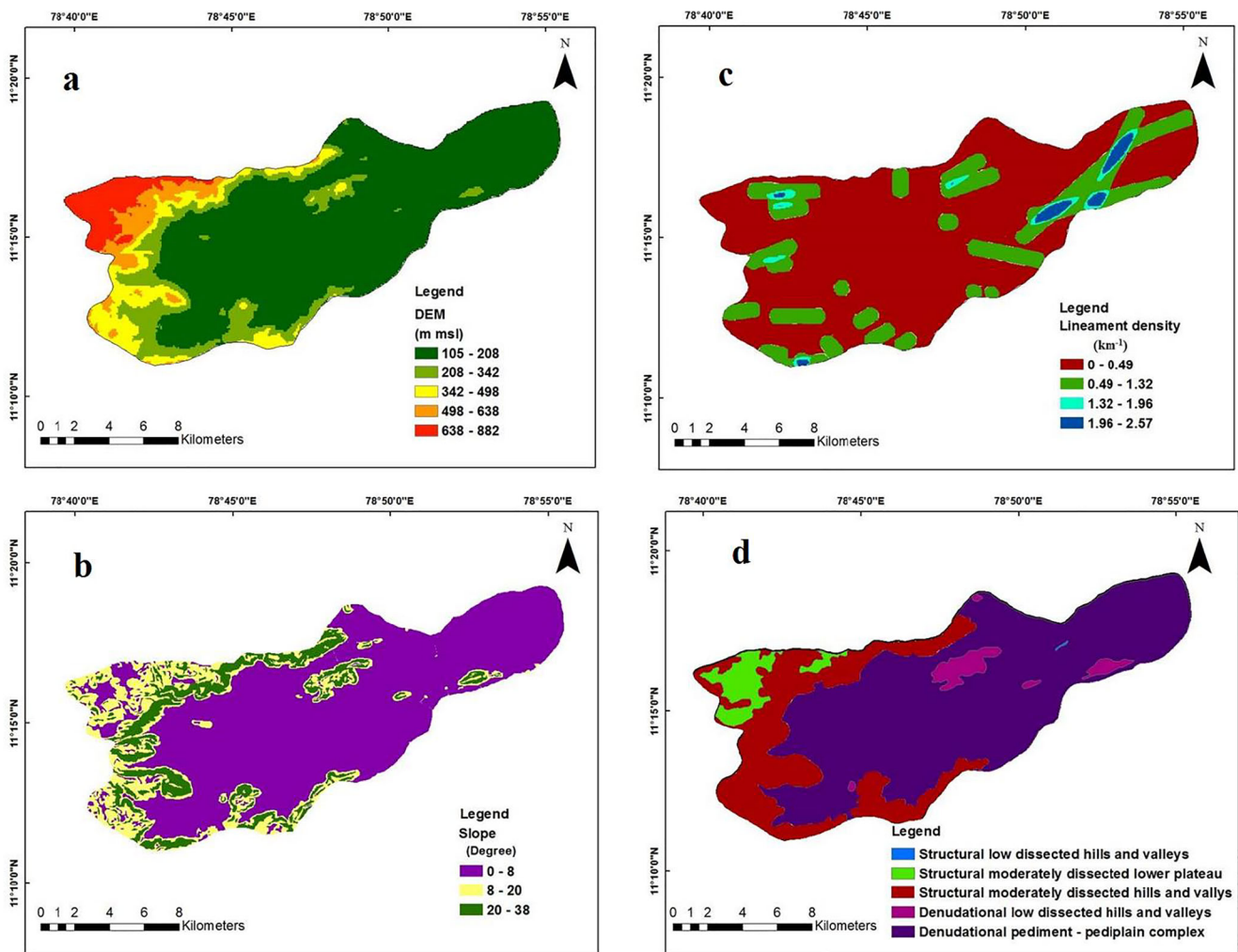


Fig. 5 Features of the study area. a Topography. b Slope. c Lineament density. d Geomorphology

groundwater development. Low drainage and high drainage areas were assigned a high and low rank, respectively (Table 3).

Slope

Topography plays an important role in understanding the runoff and occurrence of groundwater resources. Slope of a region is derived from the topography. So, the topography was first prepared from the satellite imageries (Fig. 5a). Major part of the study region is covered by gentle slope, moderate undulating discontinuous hills, and flat land (Fig. 5b). Steep slope implies low groundwater potential, because of faster runoff, whereas the gentle slope has high groundwater potential. Areas with lesser gradient favor infiltration of rainfall by offering more time. Based on the slope degree, the groundwater potential is classified into three

classes: $< 8^\circ$ (low slope), 8 to 20° (medium slope), and $> 20^\circ$ (higher slope) (Table 2). The study region comprised largely of flat area (72%), gentle slope (16%), and steep slope (12%). Higher ranks were given to flat and gentle slope and lower ranks for higher slope (Table 3).

Lineament density

A lineament is a linear feature on the earth, which is an indirect evidence for geological structures such as faults and fractures. These features indicate increase in secondary porosity and permeability and are main conduits for transit and storage of groundwater. Thus, lineaments represent the faulting and fracturing zones, which are also indicators for the groundwater potential zones. Lineament density map was prepared from the line density tool in GIS platform (Fig. 5c). Lineament length in the study region ranges from 0 to 2.57 km^{-1} , trending in the SSW-NNE direction. Based on the

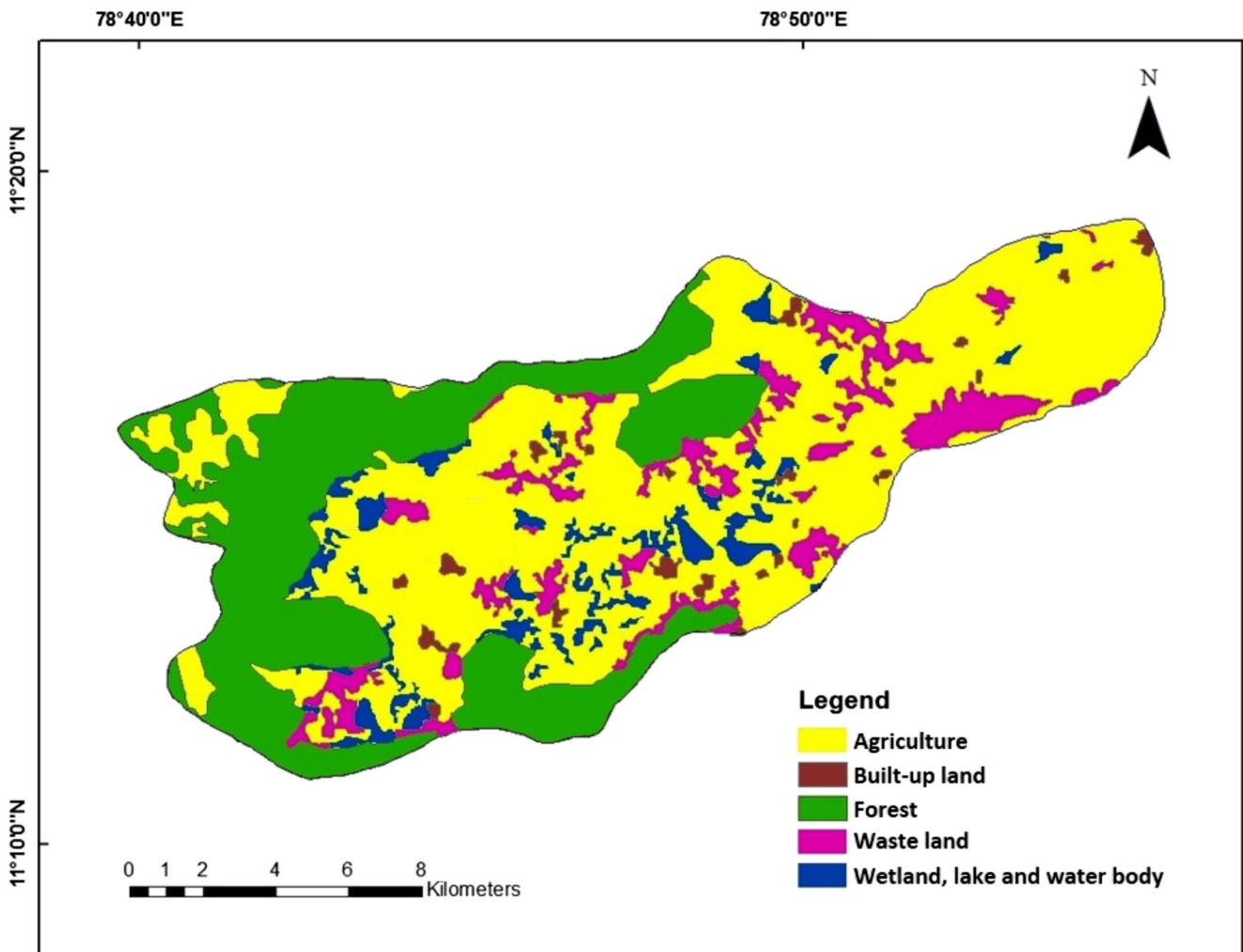


Fig. 6 Land use in the study area

lineament density, the study area was classified into four classes: low ($< 0.49 \text{ km}^{-1}$), medium ($0.49\text{--}1.32 \text{ km}^{-1}$), high ($1.32\text{--}1.96 \text{ km}^{-1}$), and very high ($> 1.96 \text{ km}^{-1}$). About 73% of the study area fall in low lineament density (Table 2), which is considered as

poor groundwater potential, and these areas are assigned a lower rank (Table 3). Nearly 3% of area fall in the high lineament density zone, and these areas occur mostly in the middle and lower part of the study region (Fig. 5c).

Table 4 Relative rates and score for each influencing factor calculated using the MIF technique

Influencing factor	Major effect (A)	Minor effect (B)	Proposed relative rates (A + B)	Proposed score of each influencing factor
Drainage density	1	0.5	1.5	9
Slope	1 + 1	0.5	2.5	14
Lineament density	1 + 1	0	2	12
Soil	1	0	1	6
Geology	1 + 1 + 1	0	3	18
Geomorphology	1 + 1	0.5 + 0.5	3	18
Land use	1 + 1 + 1	0.5 + 0.5	4	23
			$\Sigma 17$	$\Sigma 100$

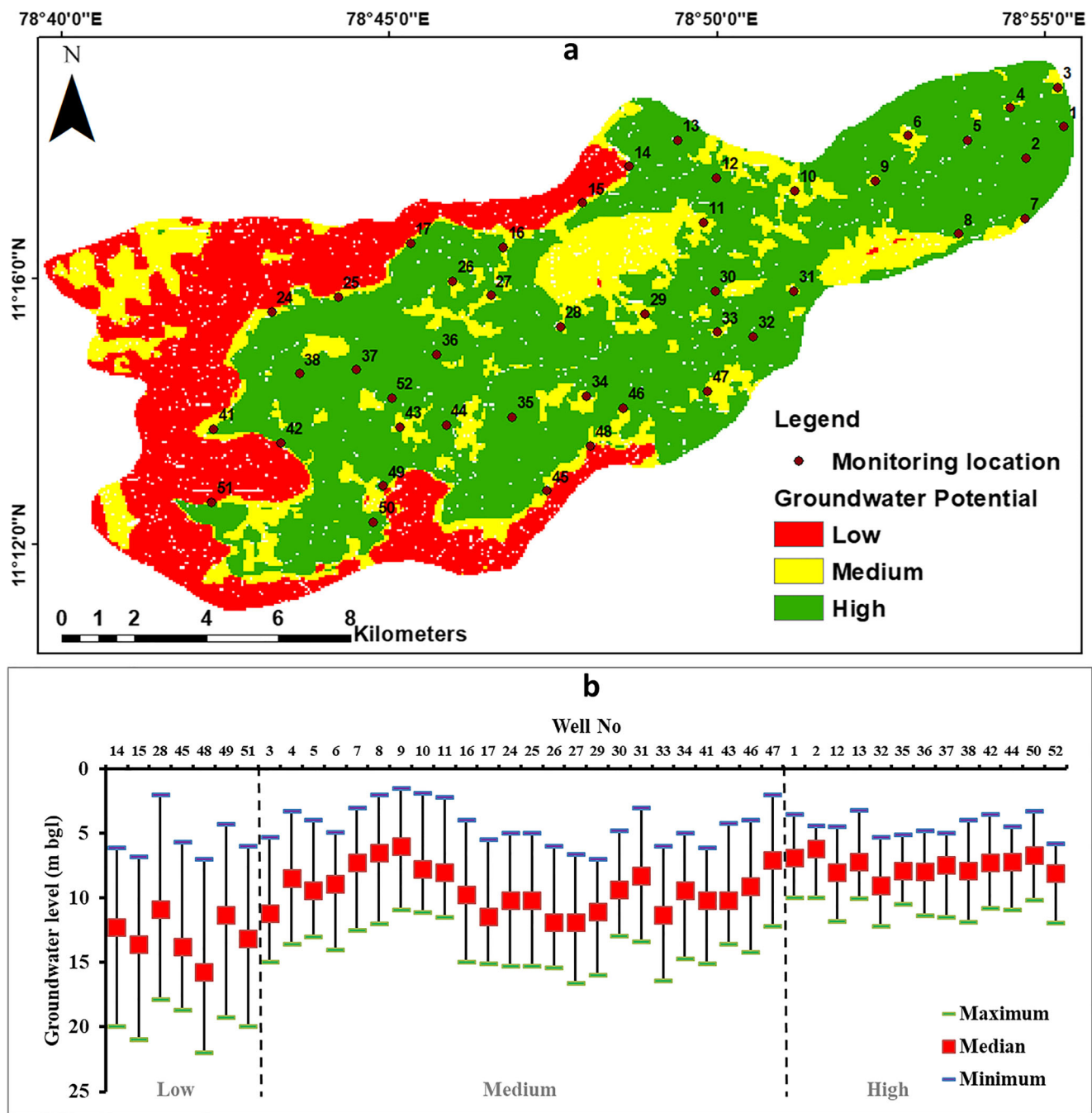


Fig. 7 a Groundwater potential zones identified through the MIF method. b Groundwater level fluctuation in different groundwater potential zones

Geomorphology

Various geomorphic features of the earth are formed by different processes such as the action of waves, wind, chemical reaction, groundwater movement, surface water flow, tectonism, and glacial action. The geomorphological features controlling the movement of groundwater was derived from LISS III image. Various features identified in the study area are structural, denudational dissected hills and valleys, lower plateau, pediment and pediplain

(Fig. 5d). The study area comprises mostly of pediment and pediplain (68%) followed by structurally dissected hills with valleys (24%), moderately dissected lower plateau (5%), and lower dissected hills with valleys (3%) (Table 2). Pediplain is covered by an extensive plain of agricultural land with water bodies and is naturally suitable for groundwater development due to the high recharge rates. Moderately dissected lower plateau has slow runoff with moderate groundwater potential. Structurally dissected hills and valleys are considered as low groundwater potential zones due to the high elevation, steep

Table 5 Water holding capacity of various surface and subsurface features based on the groundwater potential zones

Layer	High	Medium	Low
Drainage density	< 1.14 km ⁻¹	1.14–3.21 km ⁻¹	> 3.21 km ⁻¹
Slope	< 8°	8–20°	> 20°
Lineament density	> 1.96 km ⁻¹	0.49–1.96 km ⁻¹	< 0.49 km ⁻¹
Soil	Deep black, moderate-ly black	Moderately black, shallow red	Moderately red, very deep red
Geology	Fissile hornblende biotite gneiss	Fissile hornblende biotite gneiss, charnockite	Charnockite
Geomorphology	Pediplain, pediment	Dissected lower plateau	Dissected hills and valleys
Land use	Agriculture, water bodies	Forest	Wasteland, built-up area
Groundwater range measured in the monitoring wells	1.9–12.4 m	1.5–16.4 m	2–22.5 m
Groundwater potential values based on the 7 layers	248 to 311	185 to 247	120 to 184
Total area	118.9 km ²	46.1 km ²	54.7 km ²

topography, faster runoff, and subsequently low infiltration rate. Therefore, pediplain is assigned a higher rank, and the structural dissected hills and valleys are assigned a lower rank (Table 3).

Land use

Land use is one of the key features that control groundwater recharge. LISS III satellite imagery was used to derive the various land use patterns in this region. The study area had diverse land use, such as agricultural land, water bodies, forest, waste land, and built-up areas (Fig. 6). Agriculture is the major activity in this region, with 53% of the land being used

Table 6 Groundwater potential areas in different land use

Land use	Low (km ²)	Medium (km ²)	High (km ²)
Wetland and water body	0.0	2.0	11.7
Wasteland	0.4	19.3	0.0
Forest	56.2	10.2	0.0
Built-up land	0.0	3.1	0.5
Agriculture	0.0	6.4	110.2

for cultivation (Table 2). Paddy, shallots, groundnut, maize, sweet corn, cotton, sunflower, fruits, vegetables, and flowers are cultivated as major crops in this region. Agricultural lands and water bodies function as good groundwater potential areas because of more recharge in the flat areas. Wetland and water body contains 6% of the study area; these are considered as having good groundwater potential. Forest occupies 30% of the study area, even though there is recharge in these areas, it is comparatively less and hence is considered to have medium groundwater potential (Table 3). Wasteland (9%) and built-up area (2%) have low recharge due to non-availability of space to infiltrate the rainwater, and thus have the lowest groundwater potential.

Delineation of groundwater potential zones

The weightage of each factor is computed by the MIF method. The minor and major effects of one influencing factor over another was calculated and is given in Table 4. The groundwater potential map indicating its spatial variation is given in Fig. 7a. High groundwater potential occurs in the plains as it comprises mostly of agricultural land, low slope, low drainage density, and pediplain (Table 5). About 54% of the study region was covered by high groundwater potential. Geology, slope, land use, and geomorphology have played an important role in the high groundwater potential zone. The medium groundwater potential occurs around the forest areas with medium drainage and medium slope, black and red soils. Geological formation in the high groundwater potential area is mostly coarse sand, amphibolite, and garnetiferous gneiss. About 21% of the study area is covered by the medium groundwater potential. Low groundwater potential was found out in the low, medium dissected hills and valleys with high slope, high drainage density, and low lineament feature (Table 5). Infiltration of this area is very low due to fast runoff with steep slopes, waste land, and built-up area that were reducing recharge of the water into the subsurface. Low groundwater potential was noticed in 25% of the study area. The groundwater potential in the study area compared with the different land use is given in Table 6.

Validation

The groundwater potential zone of low, medium, and high was validated with groundwater level data in the study area to understand the recharge of rainwater into the aquifers. The groundwater level was monitored every 3 months in 44 wells

Table 7 Single parameter sensitivity measure

Removed influencing layer	Minimum	Maximum	Average	Standard deviation
Land use	0.0	6.4	2.2	1.2
Geomorphology	0.0	5.1	1.7	1.1
Soil	0.1	2.0	1.4	0.3
Lineament density	0.0	1.7	1.0	0.5
Drainage density	0.0	1.9	1.0	0.5
Slope	0.0	2.8	0.6	0.5
Geology	0.0	2.2	0.5	0.3

from 2015 to 2018 (Fig. 7a). This groundwater level information was used to validate the groundwater potential map. The groundwater level fluctuation in low groundwater potential zones ranged from 2 to 22.5 m with an average value of 7.5 m, in medium groundwater potential zones from 1.5 to 16.4 m with an average value of 4.85 m, and in high groundwater potential zones from 1.9 to 12.4 m with an average value of 3.1 m (Fig. 7b). The results show that groundwater level fluctuation was very shallow in the high groundwater potential zone than in the medium and low groundwater potential zones in the study region. Thus, the delineated groundwater potential map is validated with the measured groundwater levels from the study area.

Sensitivity analysis

All the parameters used for the groundwater potential index are inter-related, and removing one or more parameters will indicate the sensitivity of the removed parameters in demarcating the potential zones. Table 7 indicates the sensitivity of the index when one layer is removed during the index calculation, and Table 8 indicates the sensitivity when one or more layers are removed at the same time of index calculation. Most influence on the groundwater potential index is exerted by the land use parameter. This is followed by geomorphology, soil, lineament density, drainage density, slope, and geology.

Though geology and geomorphology layers have the same weight assigned using the MIF method (i.e., 18), geomorphology has a higher influence on the groundwater potential index than the geology. Table 8 indicates that removing more layers increases the variation in the potential index. The removal of layers were carried out based on the influence of the layers identified in Table 7. Removal of any one of the layers has a great impact on the identified groundwater recharge areas. This shows the importance of including these parameters in the delineation of groundwater potential areas.

The effective weights identified through the sensitivity analysis is compared with the theoretical weights assigned through the MIF method (Table 9). It is clear that the effective weights do not make a perfect match with the assigned weights for few parameters. Land use, geomorphology, and slope have higher average effective weights than the assigned weights. Drainage density and soil have the same average effective weights and assigned weights. All other parameters have lower effective weights. This shows the importance of assigning weights to the layers in overlay and index studies such as this for identifying the groundwater potential zones. These weights cannot be universally applied to these layers and should be combined with knowledge of the study region. This study also shows that these layers cannot be excluded in any

Table 8 Single or more parameter removal sensitivity measure

Influencing layer(s) used	Minimum	Maximum	Average	Standard deviation
LU, GM, S, LD, DD, SL, G	0	0	0	0
LU, GM, S, LD, DD, SL	0.0	2.2	0.5	0.3
LU, GM, S, LD, DD	0.0	5.0	0.8	0.7
LU, GM, S, LD	0.0	6.2	1.9	1.1
LU, GM, S	0.0	11.3	4.1	2.3
LU, GM	0.0	21.5	10.2	4.0
LU	0.1	38.3	13.1	7.0

LU land use, GM geomorphology, S soil, LD lineament density, DD drainage density, SL slope, G geology

Table 9 Statistical summary of single parameter sensitivity measure by calculating the effective weight

Influencing layer	Theoretical weight (%)	Effective weight (%)			
		Minimum	Maximum	Average	Standard deviation
Drainage density	9	3.0	21.8	8.6	3.7
Slope	14	5.2	31.3	15.5	4.2
Lineament density	12	4.0	24.5	8.7	4.1
Soil	6	2.0	13.8	5.8	2.1
Geology	18	6.0	27.7	12.4	3.3
Geomorphology	18	7.2	45.0	22.8	8.9
Land use	23	9.1	52.6	26.2	8.9

groundwater potential studies, and sensitivity analysis should be included to identify the influence of these layers in a region.

Conclusion

The groundwater potential zones were identified using remote sensing and GIS methods in the western part of Perambalur district, Tamil Nadu. The various thematic layers like geology, soil, geomorphology, drainage density, slope, lineament density, and land use were prepared using satellite imagery, toposheets, and conventional data. The various thematic layers were assigned a weightage based on the MIF method, and ranks were assigned to features within the layers based on the local knowledge about the region. The high groundwater potential zone is found around the agricultural land, low slope, and pediplain areas. Medium groundwater potential was found in wetland areas, medium slope, plateau, and soils, whereas the low groundwater potential zones occurred in hills, valleys, waste land, and built-up areas. High groundwater potential zone occurs in 54% of this region; 21% is in the medium groundwater potential zone, and 25% falls in the low groundwater potential zone. Weathered gneissic rock, low slope, pediplain, high lineament, and water body played an important role in increasing the groundwater recharge in this region. The groundwater level data was used to validate the groundwater potential areas in the study region, which indicated that groundwater level fluctuation was more at low and medium groundwater potential zones than the high groundwater potential zone. This was due to the low recharge rate in the low and medium groundwater potential zones and high recharge in the high groundwater potential zone. Sensitivity analysis was carried out to analyse the importance of one layer over another. Land use was the significant parameter that influenced the delineation of the groundwater potential

areas. This study shows that the groundwater potential areas identified by integrating features of the various layers can be used to identify the locations for exploration of groundwater. This groundwater potential zone map may assist stakeholders and decision-makers in groundwater development activities in the region.

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