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Identification of groundwater potential in hard rock aquifer systems using Remote Sensing, GIS and Magnetic Survey in Veppanthattai, Perambalur, Tamilnadu

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Abstract: Water is an essential natural resource without which life wouldn' t exist. The study aims to identify groundwater potential areas in Vepapanthattai taluk of Perambalur district, Tamil Nadu, India, using analytic hierarchy process (AHP) model. Remote sensing and magnetic parameters have been used to determine the evaluation indicators for groundwater occurrence under the ArcGIS environment. Groundwater occurrence is linked to structural porosity and permeability over the predominantly hard rock terrain, making magnetic data more relevant for locating groundwater potential zones in the research area. NE-SW and NW-SE trending magnetic breaks derived from reduction to pole map are found to be more significant for groundwater exploration. The lineaments rose diagram indicates the general trend of the fracture to be in the NE-SW direction. Assigned normalised criteria weights acquired using the AHP model was used to reclassify the thematic layers. As a result, the taluk's low, moderate, and high potential zones cover 25.08%, 25.68% and 49.24% of the study area, respectively. The high potential zones exhibit characteristics favourable for groundwater infiltration and storage, with factors as gentle slope of <3°, high lineament densities, magnetic breaks, magnetic low zones as indicative of dykes and cracks, lithology as colluvial deposits and land surface with dense vegetation. The depth of the fracture zones was estimated using power spectrum and Euler Deconvolution method. The groundwater potential mapping results were validated using groundwater level data measured from the wells, which indicated that the groundwater potential zoning results are consistent with the data derived from the real world.

Keywords: Groundwater exploration; Remote Sensing and GIS; Magnetic data; Hard rock terrain; Analytical hierarchy process; Radially averaged power spectrum

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Introduction

Groundwater is a significant natural resource that flows through the cracks in fractured bedrock and pore spaces in soil (Simlandy, 2015). It is a major freshwater resource in hard-rock semi-arid terrain in India, which covers two thirds of India (Prasad et al. 2008). Being an agricultural country, India has heavily relied on the precipitation from monsoons for crop irrigation. It is reported that the summer monsoon precipitation (June to September) over India has declined by around six percent from 1951 to 2015, with notable decreases over the Indo-Gangetic Plains and the Western Ghats and there are more frequent dry spells (27% higher between 1981–2011 than 1951–1980) and more intense wet spells during the summer monsoon season in recent years (Krishnan et al. 2020). However, as a result of periodic monsoon failure, an increasing number of people are relying on groundwater for irrigation. Current study area, Veppanthattai taluk, had already been categorized as an over exploited block by Central Ground Water Board (CGWB), as the existing draft for all uses (15 416.01 Ha·m) was more than the net groundwater availability (10 201.77 Ha·m) by over 51%, as of 31st March 2007, especially for the purpose of irrigation. Over 75% of the area is covered by agricultural fields and plan-

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tations. Maize and cotton are the important crops of the region as these do not require much water like rice and paddy. The lack of sufficient water for irrigation can bring the lives of people in this region to a standstill and cause severe economic impoverishment. Thus, it is important to deduce groundwater potential zones for the efficient management, sustainable utilization and conservation of the resources.

In semi-arid regions, groundwater recharge takes place during the rainy season by means of direct infiltration into the soft mantle overlying the hard rocks and into the exposed network of fissures and fractures. It also depends on the interactions of various factors such as lithological variation, slope, rainfall pattern, topographical features on the surface, soil texture, drainage density, structural features, the profile of the underlying hard rock, type of vegetation and land use pattern. Several researchers have applied remote sensing and GIS in delineating potential groundwater zones in hard rock terrain (Singh et al. 2013; Das, 2017; Saraf and Choudhury, 1998; Prasad et al. 2008). Muthamilselvan et al. (2019) have delineated hard rock aquifer system for Perambalur taluk using remote sensing technique which confirms that remote sensing and GIS serve as dynamic tools in groundwater exploration with its cost-effective and rapid localization of the potential zones. GIS is a decision-making tool for groundwater management. GIS can be used in image processing, which includes extracting necessary information from satellite data and integrating thematic layers. It has the capability to transform spatial data according to the modelling requirements (Ashraf and Ahmad, 2012). The recent advancements in remote sensing, Geoinformatics, and spatial data availability have resulted in accurate mapping of natural resources and better environmental modelling.

In areas of hard rock terrain such as that of the study area, due to overexploitation, the level of groundwater has fallen below weathered zones into the underlying fractured zones above the bedrock (Chandra et al. 2019). For this reason, aquifers are mainly being associated with fractures, faults, shear zones, joints and fissures. The identification of such features becomes difficult with conventional methods that are designed for sedimentary aquifers. Geophysical methods such as magnetic, gravity, geoelectric and resistivity methods have been employed to understand these subsurface structural features (Araffa, 2013; Anbazhagan and Jotibasu, 2016; Muthamilselvan et al. 2017; Chandra et al. 2019). Magnetic prospecting used to investigate subsurface geology is based on anomalies in the Earth's magnetic field resulting from the magnetic properties of the underlying rocks, and is an ideal method in this scenario. The fractures and fissures usually show a magnetic low due to the weathering and dissolution of magnetic minerals present in them (Kumar and Krishnamurthy, 2006). The depth to the fractured zones can be identified after processing the magnetic data which gives us a rough idea of the spatial extent of the aquifers. The different thematic layers necessary to locate the suitable zones for groundwater exploration were weighed by AHP and integrated using the weighted linear combination method. The AHP provides a systematic approach in decision making by helps in prioritizing the importance of multiple factors over one another and helps in choosing the best alternative. Further, we check the consistency of the weights we have obtained, which has been assigned based on the judgements of experts and other references. This helps measure the consistency of the decision maker's judgment. Several researchers have carried out the manipulation of remote sensing, GIS and AHP for identifying the potential groundwater zones (Khodaei and Nassery, 2013; Dar et al. 2020; Mohammadi-Behzad et al. 2019; Kumar et al. 2020; Mallick et al. 2019). In hard rock terrain, the occurrence of groundwater would be associated with fractures, which has not been studied in existing researches. In this study, we make an effort to identify the fracture zones through magnetic data and integrate to obtain a more efficient result. Thus, the objective of the study is to identify and integrate the factors controlling groundwater occurrence using the methods of remote sensing, geoinformatics and magnetic survey, to obtain a map that produces a proper assessment of hard rock aquifer systems with resources potential in the Veppanthattai taluk, Perambalur district, Tamil Nadu, India, and to validate the result using the well locations.

1 Study area

Veppanthattai is one of the four taluks in Perambalur district of Tamil Nadu, India. The taluk is located between 11°27′ to 11°52′ North latitudes and between 78°63′ to 78°99′ East longitudes, at an elevation of 169 m above the sea level (Fig. 1). It has an area of 574 km^2. The taluk is bounded by Villupuram district to the North, Salem district to the Northeast, Tiruchirappalli district to the East, Perambalur taluk to the South, Kunnam taluk to the West and Cuddalore district to the Northwest. The study area falls within Sur-

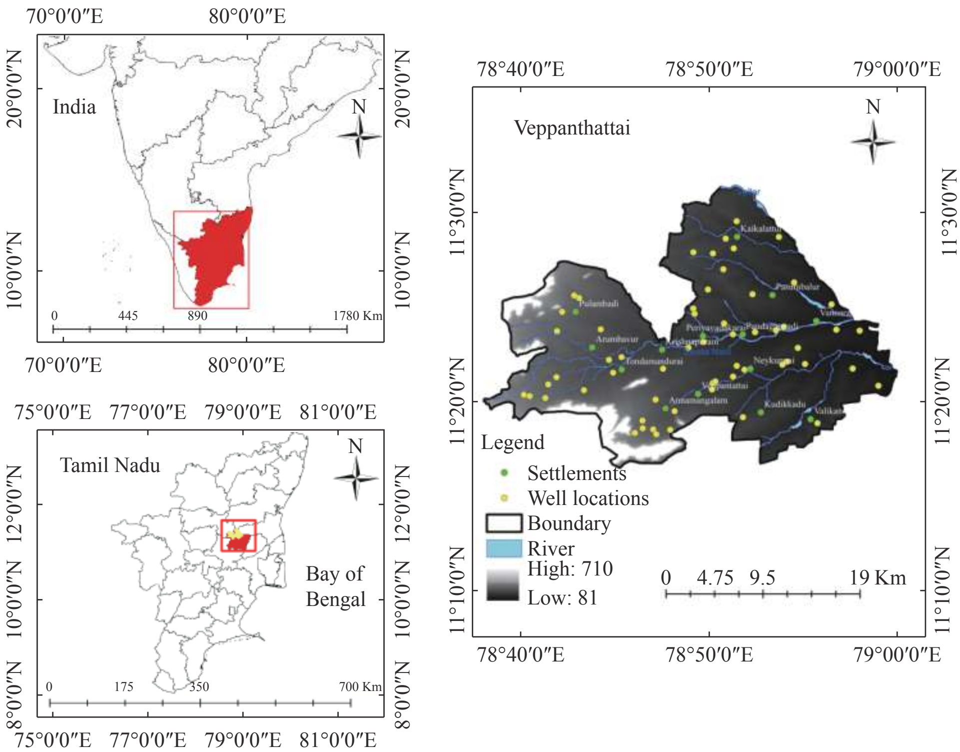

Fig. 1 Location of the study area

vey of India (SOI) Toposheets 58 I/11, 58 I/14 and 58 I/15, which are used in this study. The climate is mainly semi-arid tropic. The mean annual rainfall is 927 mm and the area receives the highest rainfall during the months of October to December as an effect of the northeast monsoon. The mean maximum temperature is 31.4°C and the minimum temperature is 21.6°C. The average mean relative humidity is 66.5%. The tributaries of the Vellar River-Swethanadhi and Kallar River flow through the taluk towards the East. Swetha Nadhi drains Pachamalai and Kolli hills[①].

2 Methodology and data

2.1 Methodology

In order to identify the potential groundwater zones of Veppanthattai taluk, the factors influencing the occurrence of groundwater were identified and mapped. By interpretation of satellite imagery, various thematic layers, such as the geomorphology, lineaments and its derivative map, land use/land cover, slope, tasselled cap–wetness map, normalized difference vegetation index (NDVI) and land surface temperature (LST) maps, were created. The lithology and soil texture is digitized from published sources. A magnetic survey was carried out. Using Geosoft software, the total magnetic strength, reduction to magnetic equator, regional anomalies, and residual anomalies of the study area were produced. The obtained maps were examined, and the breaks which could be used as prospective locations for groundwater occurrences were deduced from them. Euler Deconvolution and spectral analysis were used to derive the depth of the fracture zones. The depth to the groundwater level in the taluk was also measured as part of this study, and it was later used to validate the results. The semi-arid environment and the presence of groundwater in structural features were taken into consideration when choosing these layers. AHP was used in assigning weights based on its priority between the factors in contributing to the occurrence of groundwater. The AHP is a multi-criteria decision making approach which involves matrix based pair-wise comparison. The thematic layers are reclassified based on the assigned normalised criteria weights and integrated. Fig. 2 illustrates the methodology employed in this study.

2.2 Data and data products

The base map and the drainage map are digitized from the Survey of India toposheets on a scale of 1:50 000. The satellite images of Landsat 8 OLI (Operational Land Imager) with 30 meters spatial

①District Survey Report for Sand, 2019

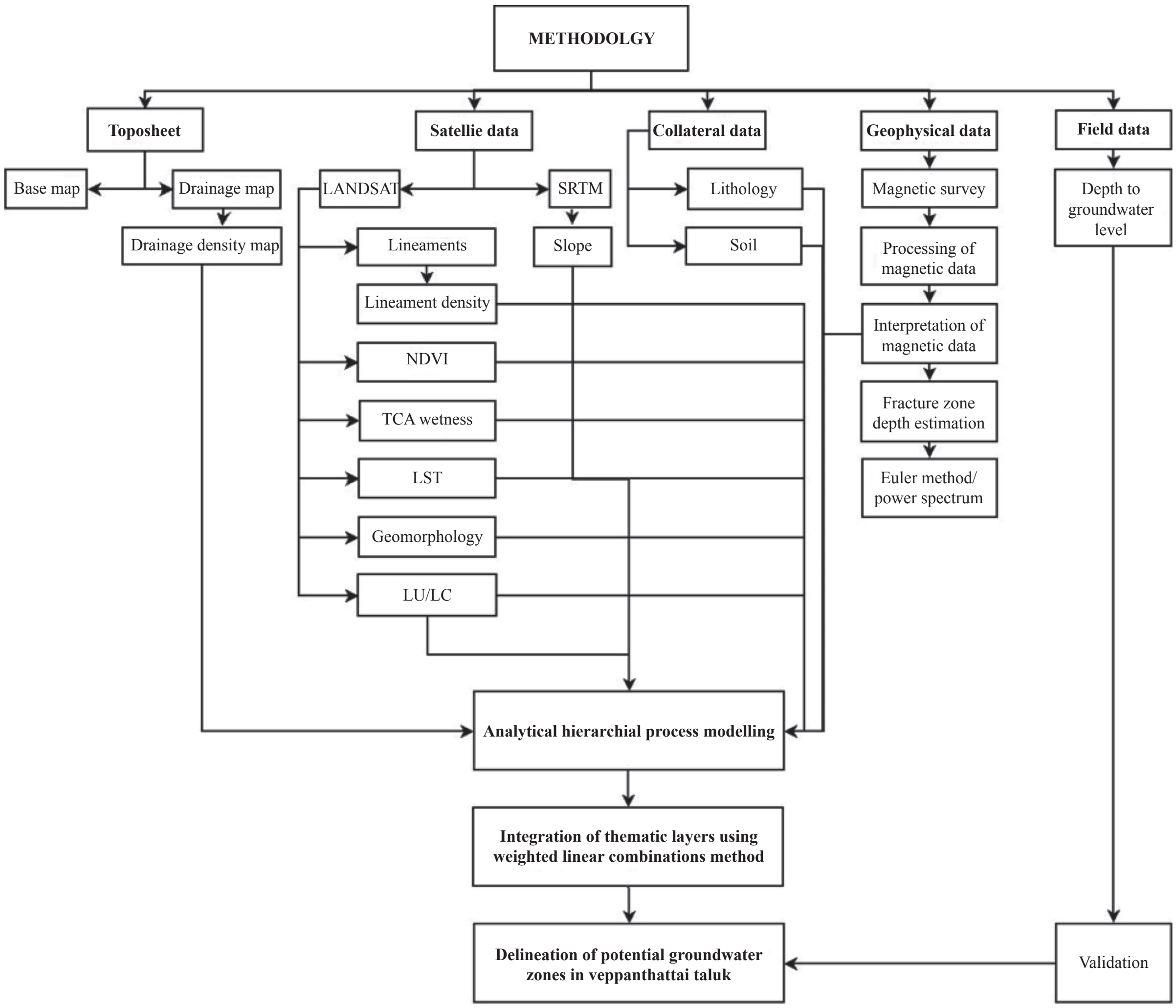

Fig. 2 Methodology flowchart

resolution acquired on 6th March 2019, of path 143 and row 52 with UTM projection, of datum WGS84, Zone 44 North and SRTM (Shuttle Radar Topography Mission) digital elevation model data of resolution 1 (arc) second (30 meters) were used. The lithology map is obtained from the District Resource Map of the Perambalur district published of the scale 1:250 000. The soil texture is digitized from the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) map of India which are published on a scale of 1:500 000 in the year of 1996.

By interpretation of satellite imagery, various thematic layers are created. Geomorphology, lineaments map and land use/land cover were manually digitized from the satellite datasets. Tasselled cap–wetness map, normalized difference vegetation index (NDVI) and land surface temperature (LST) maps were created by processing the same datasets. The lineament density and drainage density maps were generated using the density tool in ArcTool Box. The slope map was generated from the DEM data. These maps were created using ArcGIS 10.4 and ENVI 5.3.

The field survey was conducted during the 22nd to 27th of February, 2020. The magnetic survey was conducted during this period. The depths to groundwater level were also measured at the wells in the taluk during this period. The magnetic data was collected using the proton precession magnetometer. Other equipment used to accomplish the survey were the handheld GPS and the Brunton compass to locate the magnetic data sample points and in the alignment of the magnetometer in the North–South direction during the survey. Euler Deconvolution and the spectral analysis were used to derive the depth of the fracture zones.

3 Results and discussion

3.1 Lineament density

The occurrence of groundwater in the study area is chiefly associated with fractures which show effective secondary porosity in underlying charnockites and gneisses and acts as major conduits for the movement and storage of groundwater in fractured rock aquifers. In the hard rock terrains, lineaments are usually surface manifestation of the fracture network. The lineaments were mapped from the FCC image of Landsat 8 data using image interpretation techniques like tonal and texture variations, change in vegetation pattern and sudden change in drainage course. SRTM DEM data was used to enhance the interpretation. On the raster DEM imagery, the azimuth angles were changed in order to highlight the lineaments with various trends. At 50° azimuth angle, the northwest-southeast direction lineaments were highlighted and so as at 330° for the northeast-southwest trending ones. The lineament density values vary from < 0.466 km/km^2 to 2.087 km/km^2 (Table 1). The high lineament density zones indicate areas with high groundwater occurrence zones which covers about 26% of the study area as seen in Fig. 3.

Table 1 Lineament density and its areal size

Density range (km/km^2)	Density grade	Size (km^2)
0.00 – 0.46	Very low	145
0.46 – 0.77	Low	144
0.77 – 1.06	Moderate	132
1.06 – 1.39	High	100
1.39 – 2.08	Very High	48

3.2 Rose diagram

The orientation of the lineaments can be studied via the rose diagram. The rose petals show the frequency of the lineaments in that particular direction with a petal width of 15°. It can be seen from Fig. 4 that the majority of the lineaments are trending in the northeast-southwest direction. This analysis of the orientation of lineaments indirectly confirms the groundwater flow in the area (Prabu and Rajagopal, 2013).

3.3 Drainage density

A drainage system that develops on regional surface is controlled by the slope of the surface and the type of the underlying features like fractures or lineaments (Nilawar et al. 2014). The drainage map was digitized from the toposheets. The streams and rivers in this area are seasonal as rainwater is its only source. Veppanthattai is drained by hundreds of streams which belong to the Swetha and Chinnar rivers which are tributaries of the Vellar River flows from west to east and drains into the Bay of Bengal. Drainage density is inversely proportional to the rate of infiltration and the vegetative cover. Drainage density map of the study area was prepared using the line density tool under the spatial analyst tools in Arc Toolbox. The cell size was given as 10 m × 10 m and the search radius was given as 1 500 m. Density is calculated

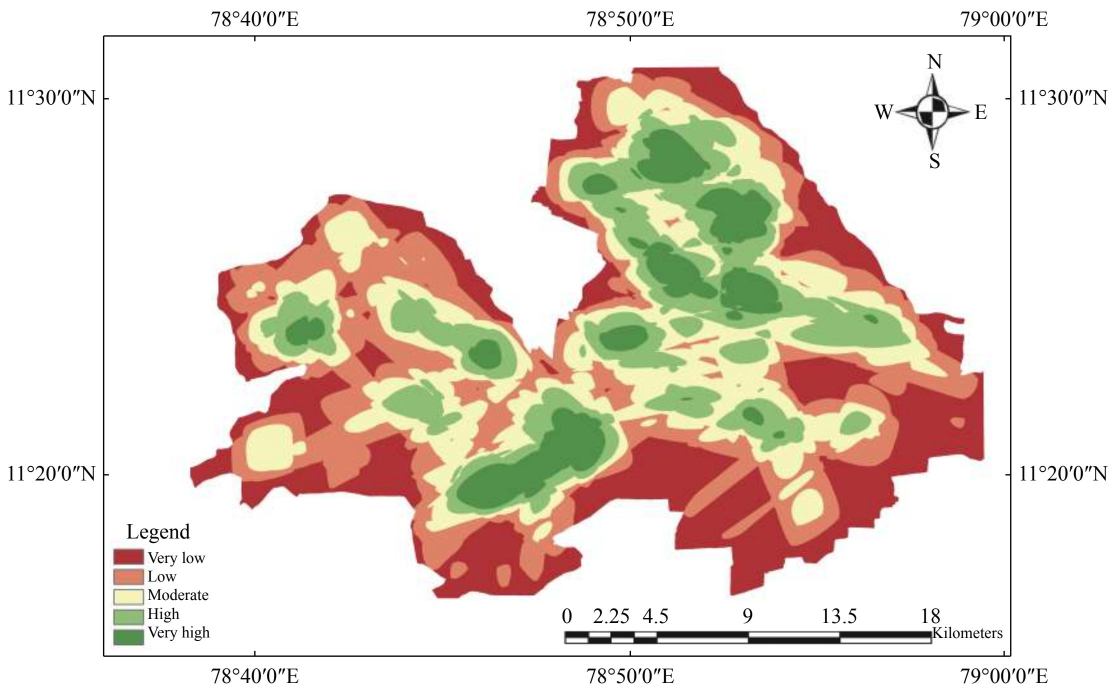

Fig. 3 Lineament Density map

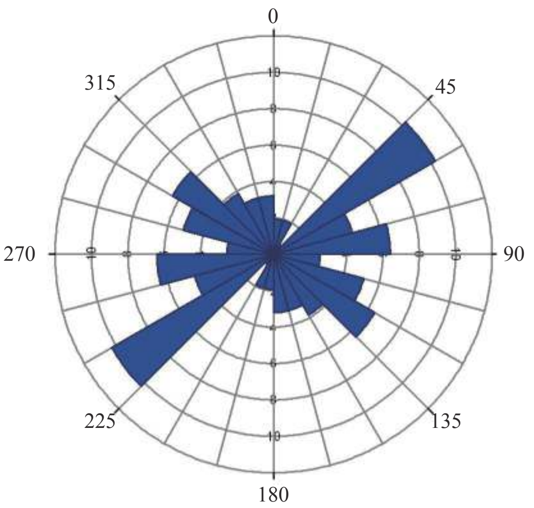

Fig. 4 Rose diagram of lineaments

in units of drainage length per unit of area (as km/km^2) as shown in (Fig. 5). It is divided into five categories as in Table 2.

3.4 Slope map

Slope is one of the important terrain parameters which can be perceived from the horizontal spacing of contours. The slope map was prepared from the SRTM imagery. The slope quantity ranging from 0° to 38° shows that the study area is dominated by gently sloping plains, except for a few hillocks on the western and south western parts (Fig. 5). In the plain slope area (0°–3°), the surface runoff water is slow allowing more time for rainwater to percolate and can be considered as a good groundwater potential zone. The plain comprises 91.7% of the area, whereas steep slope areas (35°–38°) facilitate high runoff water allowing less time for rainwater infiltration and hence comparatively less groundwater potential. The present study follows the classification of Slope by national remote sensing centre (NRSC).

3.5 Lithology

Geologically, the study area is covered by Precambrian metamorphic rocks of the Archean system. Since groundwater occurrence is related to the fractures, fissures and joints in the hard rocks, geology plays an inevitable role in groundwater recharge in the hard rock terrains. The major rock types in the study area are charnockite and pyroxene granulite of the Charnockite Group, and pink migmatite and fissile hornblende biotite gneiss of the Bhavani Group. Among them, the fissile hornblende biotite gneiss overlies the other rock formations as it is younger in age. The gneiss covers about 84.66% of the total area and has a more favourable condition

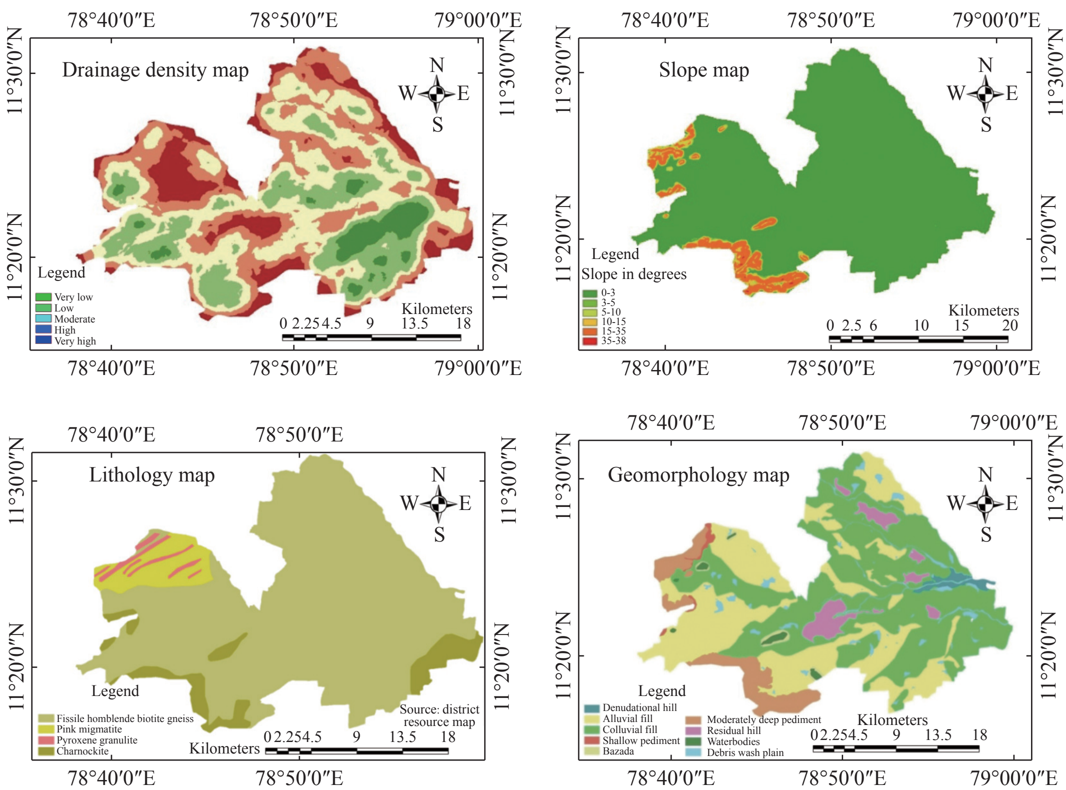

Fig. 5 Drainage density, slope, geomorphology and lithology maps (clockwise from the top left)

Table 2 Drainage density and its areal size

Density range (km/km^2)	Density grade	Size (km^2)
0.12 – 1.34	Very Low	81
1.34 – 2.03	Low	161
2.03 – 2.69	Moderate	185
2.69 – 3.49	High	115
3.49 – 5.15	Very High	32

for water infiltration than the other rock types due to its fissile nature. Charnockite covers 7.49% of the area which is seen along the hilly regions. Pink migmatite and pyroxene granulite cover 6.09% and 1.56% of the area, respectively, and expose on the north-western part of the taluk (Fig. 5).

3.6 Geomorphology

Geomorphological features which are identified in the study area through interpretation of satellite images include denudational hills, residual hills, alluvial deposits, colluvial deposits, shallow pediments, moderately deep pediments, bazada (alluvial fans), water bodies and debris wash plains (Fig. 5). Denudational hills area, identified in the satellite image as massive structural-less, shapeless and size-less features, cover around 7.25% of the study area. Due to high porosity and permeability, the colluvial sediments has a high rate of infiltration and can be a potential site for groundwater recharge if the water accumulates in an aquifer below and covers about 33.95% of the area. Almost 47.74% of the study area is covered by shallow pediments. The water holding capacity would directly depend on the thickness and type of regolith and the extent to which the bedrock is fractured. Alluvial plains, bazada and debris wash plains covers a small portion of the study area.

3.7 Soil

The texture and moisture content of soil heavily influences the infiltration of the water (Ma et al. 2016). The porosity and permeability of soil are directly related to the texture of soil. The study area is predominantly covered with clayey soil and has relatively thin. The soil types in the Veppanthattai taluk can be classified as calcareous clay, gravelly clay and loamy clay. Water is isolated and trapped between the pores in clayey soil due to its low permeability, very fine texture and small particle size (less than 0.002 mm). Comparatively, gravelly clay has a higher infiltration rate followed by loamy clay and calcareous clay. Calcareous clay, gravelly clay and loamy clay cover 74.86%, 21.78% and 3.33% of the area, respectively (Fig. 6).

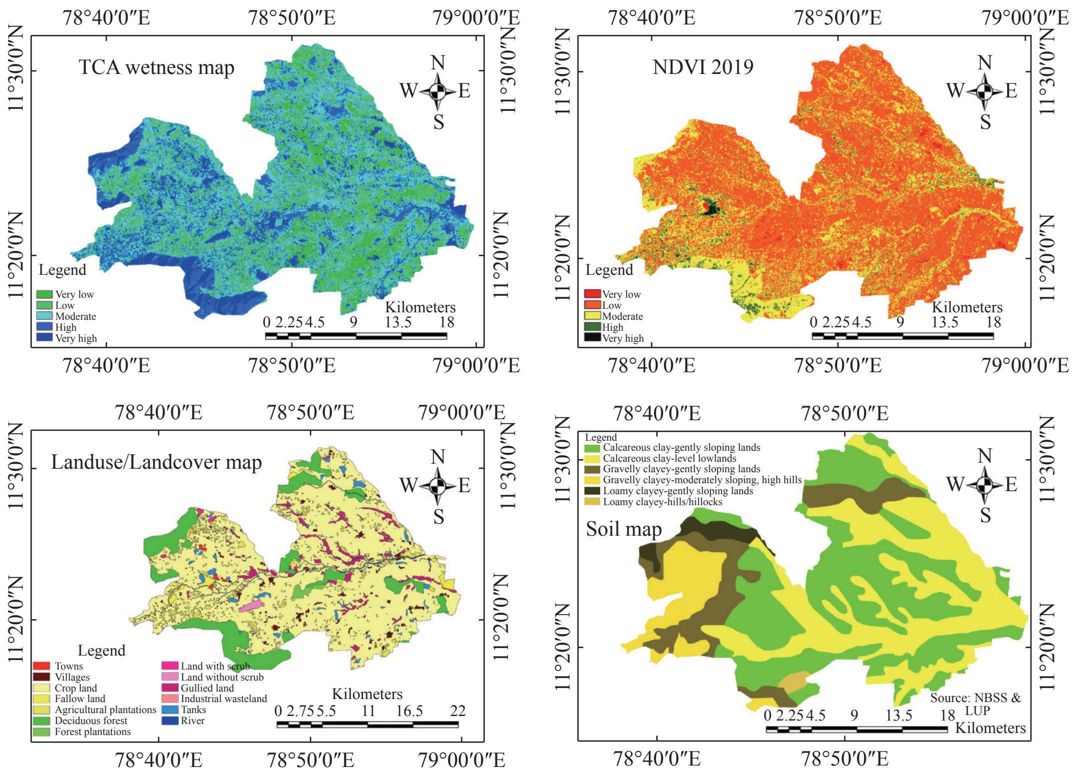

Fig. 6 TCA Wetness Map, NDVI Map, Soil Map and LU/LC Map (clockwise from top left)

3.8 Land use/Land cover map

The land use/land cover (LULC) map plays a vital role in planning, management and monitoring of natural resources. The occurrence of groundwater and its development is greatly influenced by the land use/land cover pattern of that region. Land use/land cover features of the study area are delineated from the FCC image which is the combination of bands 5 (Near Infrared), 4 (Red) and 3 (Green) of the Landsat 8 OLI data, using image interpretation elements like tone, texture, drainage and relief, with field verification. The LULC classification is carried out based on NRSC level II classification. Different types of features affect the rate of infiltration and runoff of water differently. Forests, croplands, plantations and surface near the water bodies show an increased rate of infiltration of water while built-up areas, fallow lands, scrublands, gullied land and barren rocky areas show increased run off rather than infiltration. With agriculture being the main occupation in Veppanthattai, agricultural lands covers about 77.97% of the area, forest land covers 13.97% of the area, the built-up area accounts for about 1.74%, wasteland covers 4.14% and the water bodies cover 2.15% of the area (Fig. 6).

3.9 Tasseled cap transformation

Tasselled cap transformation is generated on the basis of spectral information with minimal information loss which was initially developed by Kauth and Thomas in 1976. Out of the three maps the wetness map is considered in studying groundwater occurrence as it highlights the plant and soil moisture content (Liu et al. 2014). SWIR bands are sensitive to the soil moisture than the visible and near infrared bands, highlighting the moisture content. Moisture content in the soil influences the infiltration of water into the subsurface. When the soil is dry there is an increased rate of infiltration and when it is wet there is only meagre amount of infiltration taking place. The wetness values ranges from −0.540–0.025 which were further classified (Fig. 6).

3.10 Magnetic survey

The magnetic data is collected using a Proton Precession Magnetometer which measures the scalar intensity of the local magnetic field. The study area of 574 km^2 was divided into square grids with each side of 2 km. The intensity of the time-varying local magnetic fields was recorded at 128 points across the area. The collected data have been preprocessed to remove the regional and residual effect on the magnetic field. This is done by using the IGRF and diurnal correction. The IGRF is a collaborative model of the Earth's Magnetic field produced by geomagnetists from around the world which was endorsed by the International Association of Geomagnetism and Aeronomy (IAGA) (Zmuda, 1971).

3.11 Total magnetic intensity

The total magnetic intensity map of the Veppanthattai taluk has a grid cell size of 0.001 unit and the amplitudes of the magnetic anomalies ranging from 41 270 nT to 41 330 nT (Fig. 7). These values were then corrected using the IGRF model that describes the field from 1900 to 2025. The depth, geometry and magnetic properties of rocks affect the amplitude of magnetic anomalies (Nakamura and Miligan, 2015).

3.12 Reduction to magnetic equator

Magnetic anomalies caused by ore bodies or entrenched geological conditions tend to be positioned vertically above their actual locations only at the polar regions of very high latitudes (Malczewski, 1999; Aina, 1986). The study area is located along lower latitudes (11°) which is closer to the magnetic equator than to the poles. At the locations far away from the poles, the anomalies tend to be shifted horizontally instead of being vertically above their actual locations due to the effect of magnetic inclination. Reduction to magnetic equator is a modified version of reduction to pole method. It positions the magnetic anomaly midway between the North Pole and the South Pole, that is, the magnetic equator and thus making it devoid of effects of magnetic inclination and magnetic declination.

Magnetic breaks can be identified by closely spaced contours which show a sharp change in values from positive to negative or vice versa, depending upon the viewer. Linear breaks in magnetic data may indicate positions of complex structures or linear anomalies like rift zones or fracture zones, especially where the breaks are correlated with the features from other datasets. Several linear breaks identified in the study area using different mathematical manipulations have been superimposed on the RTE map for a better understanding (Fig. 8). One magnetic break trending along N-S

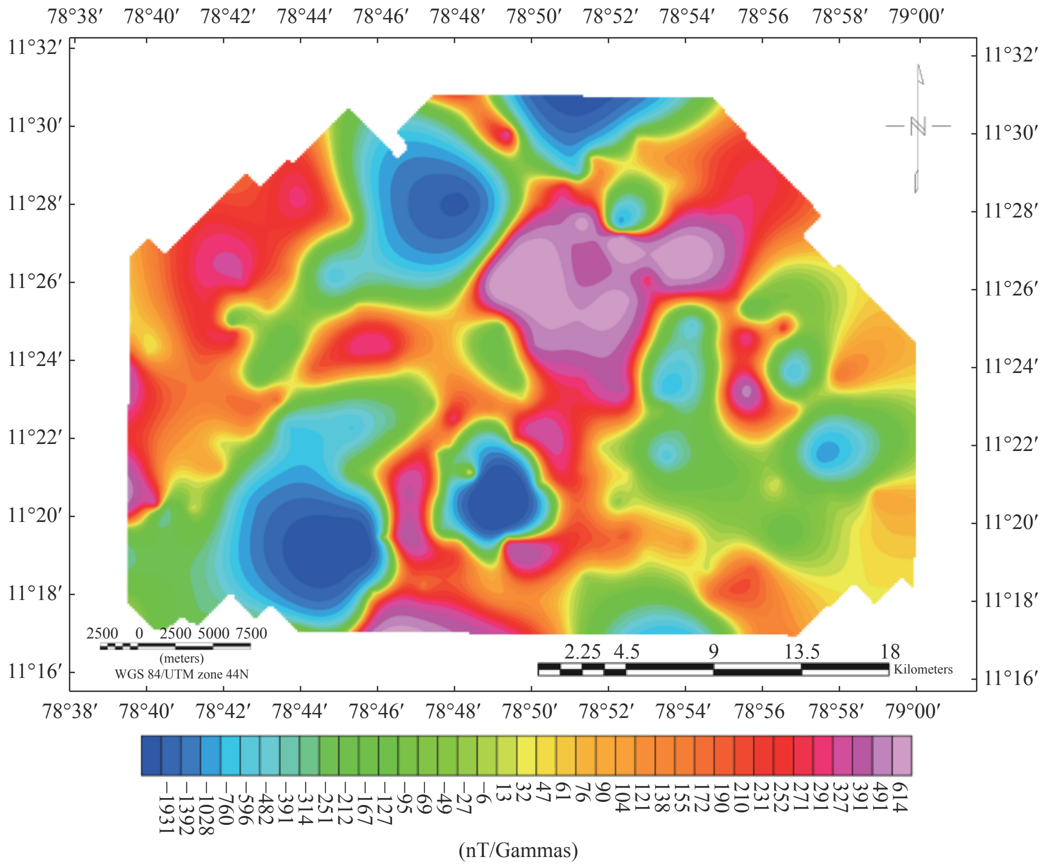

Fig. 7 Total magnetic intensity map

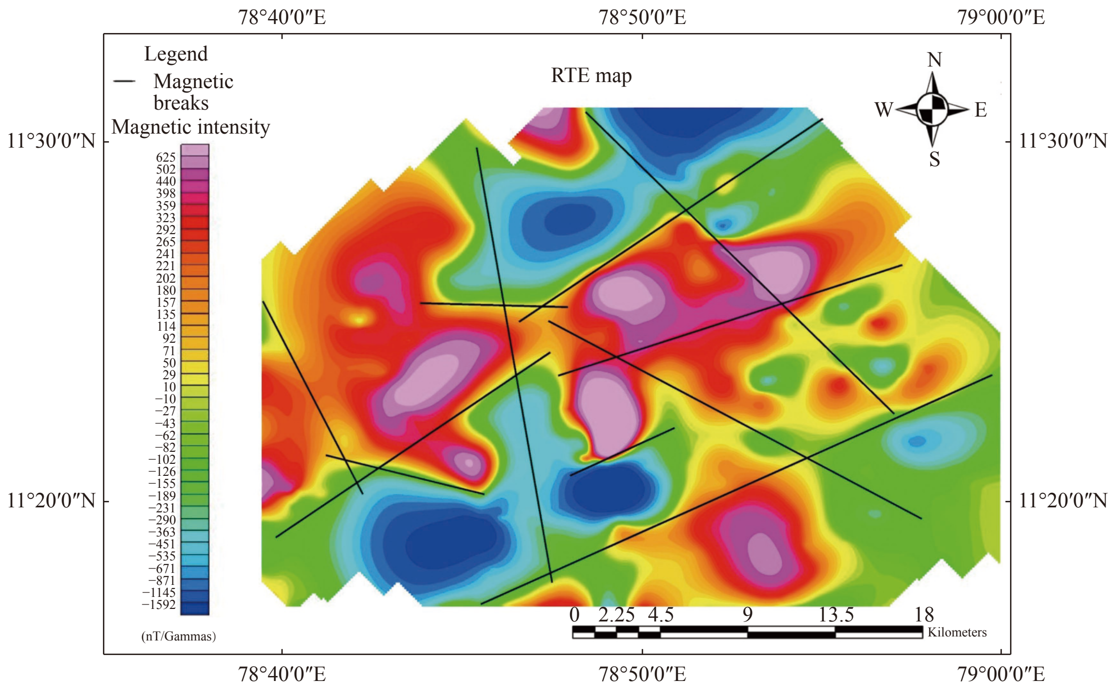

Fig. 8 Reduction to magnetic equator with magnetic breaks map

and two along NE–SW are mapped from the magnetic maps. It indicates that the breaks are the reflections of deep structures and are significant in groundwater and mineral exploration.

4 Analytical hierarchy process (AHP)

The analytical hierarchy process model is a qualitative and quantitative multi decision-making method which has been effectively implemented in various fields, originally developed by Thomas Saaty in 1980. The AHP method breaks down the complex multi-criteria decision problem into a hierarchy based on a pair-wise comparison of the importance of different criteria and sub-criteria (Saaty, 2014). The AHP method helps in finding the finest solution and understanding the issues for the decision-makers (Chandio et al. 2013). The primary step underlying this method is to run down the decision problem into a hierarchy, i.e. to define a goal and identify criteria and sub-criteria relevant for groundwater targeting. The second is the pairwise comparison matrix (Table 3) in which each factor is rated against every other factor based on the Saaty's scale of relative importance (Table 4) ranging from 1 (equal importance) to 9 (extreme importance). The highest ranks were given to the layers which have shown greater influence in the groundwater potentiality. The next step is to normalise the matrix which is essential as it transforms the input data into comparable data (Table 5). Finally the normalised weights are validated by calculating the consistency ratio (CR). When the consistency ratio is less than 0.1 the assigned ranks are said to be consistent. CR is the ratio between consistency index (CI) and the random index (RI). For calculating the consistency index the principal eigenvalue must be calculated by multiplying the pair wise comparison matrix with the normalised weights and their sum is obtained. Further, these values are divided by the respective normalised weights and the average is taken as the largest eigenvalue, λ_{max}. "n" represents the order of the matrix. The value of RI is taken with respect to the n value.

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (1)$$

4.1 Normalised weights of the layers

The ranks of the thematic layers were assigned based on expert's opinion and by reviewing relevant literature. In this study, high ranks were given to lineament density and magnetic breaks. The thematic layers were analysed in the pairwise comparison matrix and the normalised weights were obtained. The average value of λ_{max} is 10.064. The CR ratio is less than 0.1, verifying that the results of the comparison are acceptable. The normalised weights for LULC, NDVI and wetness layers are 0.06, respectively. The weight for lineament density is 0.22, for distance from the magnetic breaks layers is 0.23, drainage density and geomorphology is 0.12, lithology and slope layers is 0.03

Table 3 Pairwise comparison matrix rating

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one over another
5	Strong importance	Experience and judgement strongly favour one over another
7	Very strong importance	Activity is strongly favoured and its dominance is demonstrated
9	Absolute importance	Importance of one over another affirmed on the highest possible order
2,4,6,8	Intermediate values	Used to represent compromise between priorities listed above
Reciprocal of above non-zero numbers	If activity I has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	

Table 4 Pairwise Comparison Matrix

Item Description	LULC	NDVI	Wetness	LD	DD	Lithology	Soil	Slope	Dist to Magnetic Breaks	Geomorphology
LULC	1.00	1.00	1.00	0.25	0.50	2.00	3.00	2.00	0.25	0.50
NDVI	1.00	1.00	1.00	0.25	0.50	2.00	3.00	2.00	0.25	0.50
Wetness	1.00	1.00	1.00	0.25	0.50	2.00	3.00	2.00	0.25	0.50
Lineament density	4.00	4.00	4.00	1.00	2.00	6.00	7.00	6.00	1.00	2.00
Drainage density	2.00	2.00	2.00	0.50	1.00	4.00	5.00	4.00	0.50	1.00
Lithology	0.50	0.50	0.50	0.17	0.25	1.00	2.00	1.00	0.16	0.25
Soil	0.33	0.33	0.33	0.14	0.20	0.50	1.00	0.50	0.14	0.20
Slope	0.50	0.50	0.50	0.17	0.25	1.00	2.00	1.00	0.16	0.25
Dist to Magnetic Breaks	4.00	4.00	4.00	1.00	2.00	6.25	7.14	6.25	1.00	2.00
Geomorphology	2.00	2.00	2.00	0.50	1.00	4.00	5.00	4.00	0.50	1.00

Table 5 Normalized matrix with criteria weights

Item description	LULC	NDVI	Wetness	LD	DD	Lithology	Soil	Slope	Distance to magnetic breaks	Geomorphology	Criteria weights
LULC	0.061	0.061	0.061	0.059	0.061	0.070	0.079	0.070	0.059	0.061	0.064
NDVI	0.061	0.061	0.061	0.059	0.061	0.070	0.079	0.070	0.059	0.061	0.064
Wetness	0.061	0.061	0.061	0.059	0.061	0.070	0.079	0.070	0.059	0.061	0.064
Lineament density	0.245	0.245	0.245	0.237	0.244	0.209	0.184	0.209	0.238	0.244	0.230
Drainage density	0.122	0.122	0.122	0.118	0.122	0.139	0.131	0.139	0.119	0.122	0.126
Lithology	0.031	0.031	0.031	0.039	0.030	0.035	0.052	0.035	0.038	0.030	0.035
Soil	0.020	0.020	0.020	0.034	0.024	0.017	0.026	0.017	0.033	0.024	0.024
Slope	0.031	0.031	0.031	0.039	0.030	0.035	0.052	0.035	0.038	0.030	0.035
Distance to Magnetic breaks	0.245	0.245	0.245	0.237	0.244	0.217	0.187	0.217	0.238	0.244	0.232
Geomorphology	0.122	0.122	0.122	0.118	0.122	0.139	0.131	0.139	0.119	0.122	0.126

and soil layer 0.02 (Table 5).

4.2 Groundwater potential zone mapping

The potential zones were identified by integrating the thematic layers of lithology, soil, drainage density, lineament density, LULC, NDVI, distance from the magnetic breaks, slope, wetness and geomorphology using the weighted linear combination method (WLC). The WLC method is employed when addressing multiple attributes (Malczewski, 1999). The results are multi-attribute spatial features with high values indicating high potential zones for groundwater occurrence.

$$GWPI = \sum_{i=1}^{n}\sum_{w=1}^{m}(W_i \times X_j) \qquad (2)$$

Where: W_i represents the normalised weights of the i^{th} thematic layer, X_j is the rank value of each class with respect to the j^{th} layer, m is the total number of thematic layers and n is the total number of classes in a thematic layer.

4.3 Groundwater potential map analysis

Through the acquisition and interpretation of magnetic and remote sensing data and its integration by GIS using the AHP technique, a systematic analysis was carried out on the weighted parameters to obtain a groundwater potential zone map (Fig. 9). The values were classified into five categories as very low, low, moderate, high and very high groundwater potential zones. Out of 21 settlements, 8 are located within the very high zones, 11 within high and moderate zones while the remaining 3 fall in low and very low zones. The settlements that are within the very high zone are Kaikalattur, Nuttappur, Nerkonam, Pasumbalur, Vannarampundi, Periyavadakarai, Mettur and Annamangalam. The three settlements located in the low and very low zones are Kallapatti, Pulambadi and Kudikkadu (Fig. 9). The low, moderate and high potential zones cover 25.08%, 25.68% and 49.24% of the area, respectively. The low potential zones is seen along the eastern and south western region, it is also seen as small patches in the northern and north western parts of the taluk. Moderate zones are characteristic of denudational hills with greater slope, low to moderate lineament density zones, calcareous clay and high drainage density zones. Thus these features result in more surface runoff and less infiltration of water. The high groundwater potential zones are seen in small patches all around the taluk. These areas show favourable conditions for groundwater infiltration and storage such as gentle slope of lower than 3°, high lineament density, magnetic low zones indicating the presence of fractures and dykes, low drainage density, colluvial fills and densely vegetated area. The depth to water level data has been collected during the survey which is used for validation. Out of 60 wells surveyed, 26 fall within the very high and high categories. 16 wells having shallow water level depth account for about 61.5% of the wells within the very high and high zones, showing that potential zoning results are reasonably consistent with the actual environment. Magnetic breaks along the northeast-southwest direction in the northern part of the taluk and almost along north-south direction in the western part of the taluk correlate with the lineament density high zones. This indicates the extension of surface lineaments into the subsurface. These zones are taken into

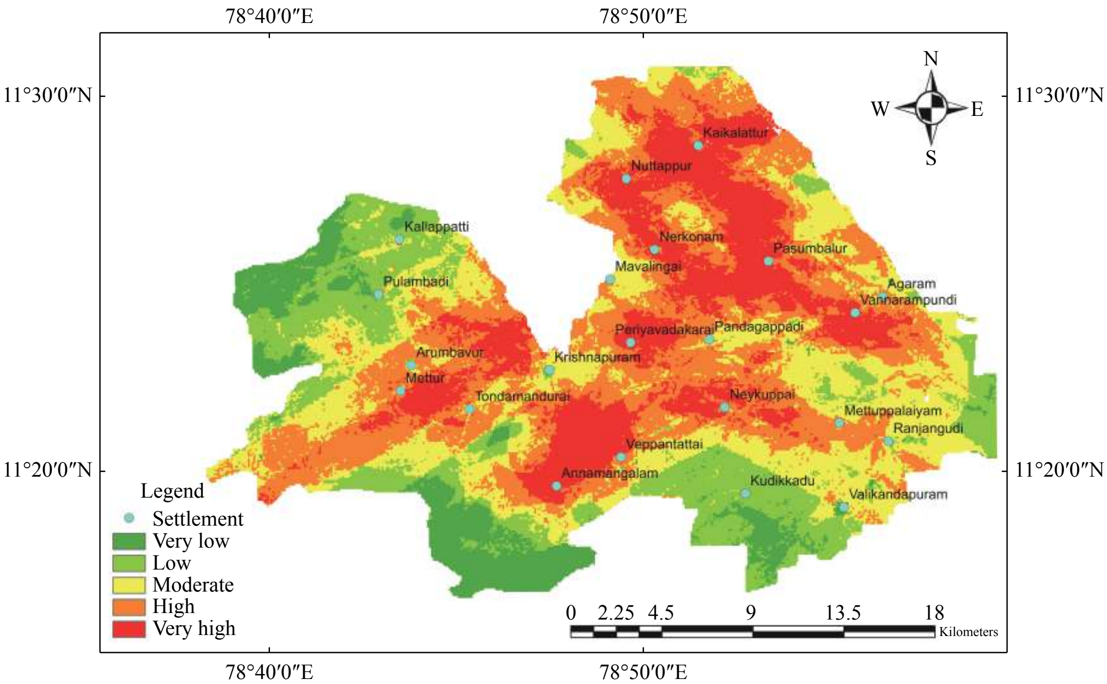

Fig. 9 Groundwater potential zonation map

consideration for groundwater potential zone mapping.

5 Conclusion

The present study was conducted to delineate the groundwater potential zones of the semiarid Veppanthattai taluk of Perambalur district in Tamil Nadu, India, using a combination of remote sensing, GIS and magnetic surveys. The AHP method is once more proved to be a scientific approach in decision-making by assisting in determining the relative importance of various criteria and in the selection of the optimal factors influencing groundwater occurrence. 49.24% of the area falls in high zone and this was validated with the groundwater levels at 60 well locations within the study area. Magnetic breaks and the lineaments are majorly seen in the NE-SW direction which indicates that there is an extension of the surface structural features to greater depths forming high potential zones. Thus, using magnetic data has brought more assertion in identifying groundwater potential zones in the areas of hard rock terrain.

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