S. I. – CEC FRAMEWORK

Identification of groundwater potential zones using geospatial approach in Sivagangai district, South India

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Abstract

The study area, Sivagangai district is considered as one of the drought prone districts of south India. Hence, there is a need of study to identify the groundwater potential zones in this region. Firstly, thematic layers (geomorphology, geology, drainage, lineament, slope, and soil) were produced using satellite images in Arc GIS platform. Analytical hierarchy processes (AHP) was done to compute the weightage for each layer with respect to the relative importance of groundwater potential index. All the thematic layers were reclassified according to their water-bearing properties with the weightages derived by AHP. The consistency of derived weightage is evaluated as 0.082 which is below the standard consistency ratio of 0.1 and is consistent. Through overlying analysis of all thematic layers, a groundwater potential map was produced using geographic information system (GIS). Four major groundwater potential zones were identified as very good, good, moderate, and poor. Majority of the study area were classified as moderate (38.2%) and good (30.8%) groundwater potential zones. Groundwater level map was used to validate the groundwater potential zone. The groundwater potential map can be used to identify the appropriate locations for artificial recharge. Artificial recharging structures such as percolation ponds, recharge shaft, and farm ponds have to be implemented to improve the water level in the region. The outcome of this study strengthens the knowledge of geospatial analysis for groundwater vulnerability and also allows policymakers in this drought-prone area to sustainably manage water supplies.

Keywords Groundwater vulnerability · Thematic layers · Satellite data · GIS and AHP

Introduction

Since the beginning of the twenty-first century, the availability of surface water (rivers and lakes) is reduced by deficit rainfall due to global climate change, rapid urbanization, and industrial developments, which induced the need for the identification of groundwater potential zone (Metwaly et al. 2012; Selvam et al., 2015; Gnanachandrasamy et al. 2018). Groundwater is an alternate resource to the surface water that is available throughout the year for extraction, subjected to the specific groundwater condition (Prabakaran et al. 2020). However, the identification of potential groundwater zones is very complicated due to the heterogeneity of underlying formations. Many techniques have evolved by the hydrogeologists to find the groundwater potential beneath the earth surface. Electrical resistivity method is a traditionally used technique in different parts of the world (Jatau et al. 2013; Fadele et al. 2013; Ravindran et al. 2018). In recent years, airborne electromagnetic surveys (AEM) are emerging in groundwater flow path identification at fractured crystalline hard rock (Chandra et al.

2019). However, the heterogeneity of the earth's subsurface increases the uncertainty of identifying groundwater potential zone even employing these cost-effective techniques that are applicable only for small scale explorations. Some of the earth surface features can be used to identify the groundwater availability directly or indirectly with the help of remotely sensed satellite images (Das et al. 1997; Dar et al. 2010). Satellite images are widely and successfully used for groundwater potential zone mapping at regional scale which is a cost-effective technique (Fenta et al. 2014; Arumaikkani et al., 2017; Pinto et al. 2017; Kanagaraj et al., 2019). Remote sensing integrated with GIS is more efficient in the identification of groundwater potential zones (Basavaraj and Nijagunappa 2011; Fenta et al. 2014; Jung et al. 2020).

Geospatial and remote sensing techniques are compressive methods for groundwater occurrence, restoration, evaluation, vulnerability mapping, and risk assessment (Bahuguna et al. 2003; Jha et al. 2007; Mondal et al. 2018; Ajay Kumar et al. 2020). The combination of satellite and remote detection information offers data on the various impact components of groundwater occurrence such as geology, geomorphology, soil, land use and land cover, drainage patterns, rainfall, slope, depth to water, net groundwater recharge, lineage density, and climate (Nyeko 2012; Jha et al. 2007; Murthy and Mamo 2009; Elewa and Qaddah 2011; Andualem and Demeke 2019). Such variables play a critical role in determining effective groundwater potential zones . However, the identification of more favorable zone for groundwater potential is still a complicated process (Pandey et al. 2013). Assigning the weightage to each layers based on their relative importance in determining the groundwater occurrence is blindly followed by many researchers (Arkoprovo et al., 2012; Fenta et al. 2014; Selvam et al. 2015; Kanagaraj et al. 2019). To address this issue, structured techniques such as analytical hierarchy process (AHP), artificial neural network (ANN), and Fuzzy logic can be adopted in assigning weightage to the thematic layers (Venkatramanan et al. 2015; Ajay Kumar et al. 2020; Dikshit et al., 2020). AHP is a widely used multi-criteria weighting technique for spatial decision making (Wu et al. 2017). In complex decision-making, AHP is applicable on the basis of mathematical formulation, which organizes and analyses the relative value of the variable set (Triantaphyllou and Mann 1995). Hoque et al. (2020) have successfully developed and evaluated a multi-criteria integrated spatial drought vulnerability mapping system that integrates all drought categories using AHP and geospatial techniques in the northwestern part of Bangladesh. However, limited studies have used AHP in drought vulnerability assessment, particularly in the present study area. Hence, the current research was done to evaluate the AHP-based groundwater potential zone in a drought-affected region of Tamilnadu, South India.

Sivagangai district was selected for this study in southern India which has hot, humid climate, and inadequate rainfall leads to groundwater scarcity and poor socio-economic condition in this region (CCC&AR and TNSCCC 2015). Due to the above factors, including anthropogenic impacts, groundwater level gets declined in most of the places in this region. It was found that the district has patches of brackish content in the formation water (CGWB 2008). So, there is a need of studies for sustainable management of groundwater resources in the district. A preliminary study was carried out by Balachandar et al. (2010) to identify the artificial recharge sites in this region. However, this research concentrated more on creating different thematic maps with lesser interpretation of the results. Since then, no studies have been conducted on groundwater potential in this region. Hence, the present study aims a detailed investigation on groundwater potential zone by adopting remote sensing and GIS technique with analytical hierarchy process. This study also helps to identify the suitable locations, where artificial recharge structures can be implemented for sustainable management of this vulnerable groundwater resource.

Although the research focuses on particular region of South India, but the lessons are universal. Other parts of South India can also experience water shortage and quality problems due to over usage and rainfall variability due to climate change. Thus, the outcomes and the methods applied in this study can be used by other researchers worldwide.

Study area

Sivagangai is one of the drought-prone districts of Tamil Nadu, India as declared by the state government in order MS No.91 dated 04.02.2019. It is situated between the northern latitudes of 9° 32′ and 10° 18′ and eastern longitudes between 78° 08′ and 79° 01′ (Fig. 1). The neighboring districts are Madurai in the west, Pudukottai and Tiruchirappalli in the north, and Ramanathapuram in the south. The total area of district is about 4189 km^2 and the average elevation is 102 meters above mean sea level. District's tropical climate condition makes the April to June period generally hot and dry with the summer temperature ranging from 30 to 36 °C (CCC&AR and TNSCCC 2015). The normal annual rainfall over the district varies from about 861.8 mm to 988.6 mm. The normal south west monsoon rainfall varies from 275.8 to 401.1 mm while during north east monsoon, the normal seasonal rainfall varies from 382.5 to 442.8 mm. The groundwater level in shallow aquifer is ranging from 30 to 32 meters below ground level (mbgl) in sedimentary formation, whereas 15 to 20 mbgl in hard rock. In deeper aquifer of sedimentary formations, the groundwater level is ranging from 150 to 325 mbgl, whereas 65 to 200 mbgl in hard rock (CGWB 2008). The district is part of Kanyakumari to Cauvery Basin and parts of Kottakaraiyar, Tirumanimuttar, Vaigai, and Pambar sub basins (CGWB 2008). Fluvio-marine sediments (Alluvial) of quaternary period is the
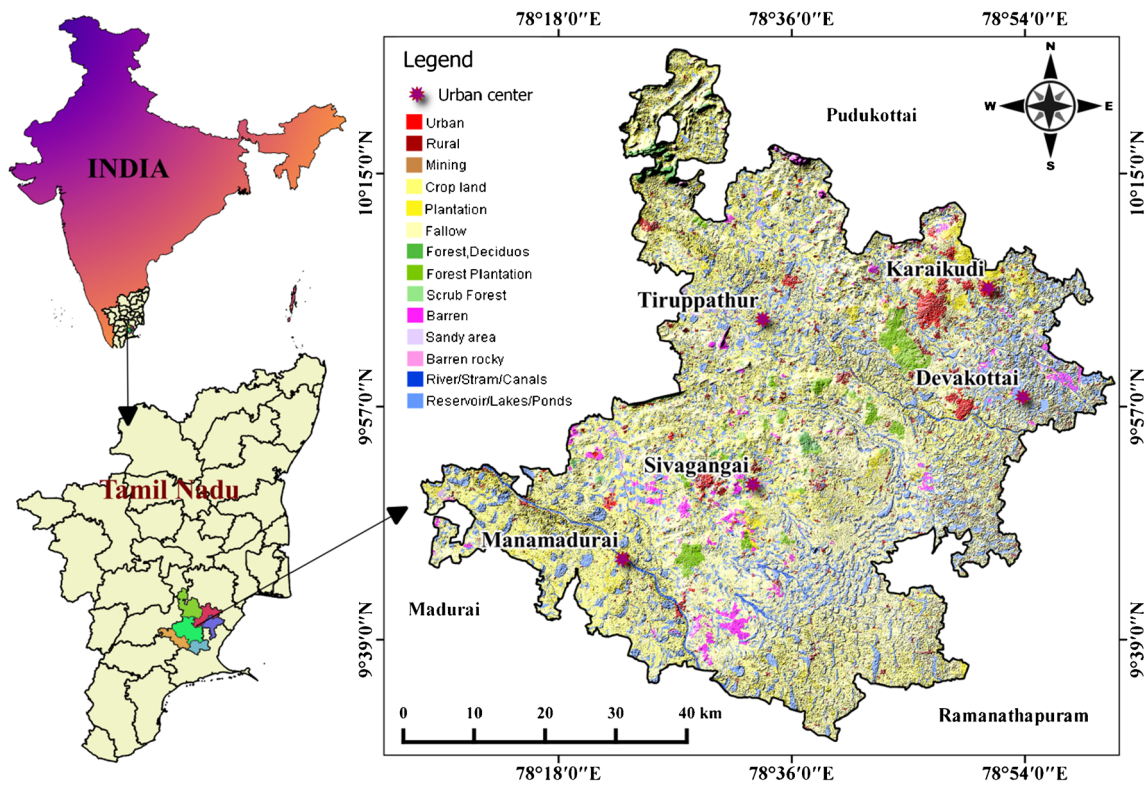
Fig. 1 Location map of the study area with the land use details

predominant formation found in the study area, followed by Archaean intrusive quartz veins. The other predominant rock formations are sandstones of carboniferous-pliocene, granite, and granitoid gneisses of Precambrian and clay deposits of recent quaternary period. Groundwater occurs generally in both weathered crystalline and porous sedimentary rocks of the study area. Aquifer transmissivity in crystalline formation is ranging from < 1 to 25 m^2/day, whereas in sedimentary

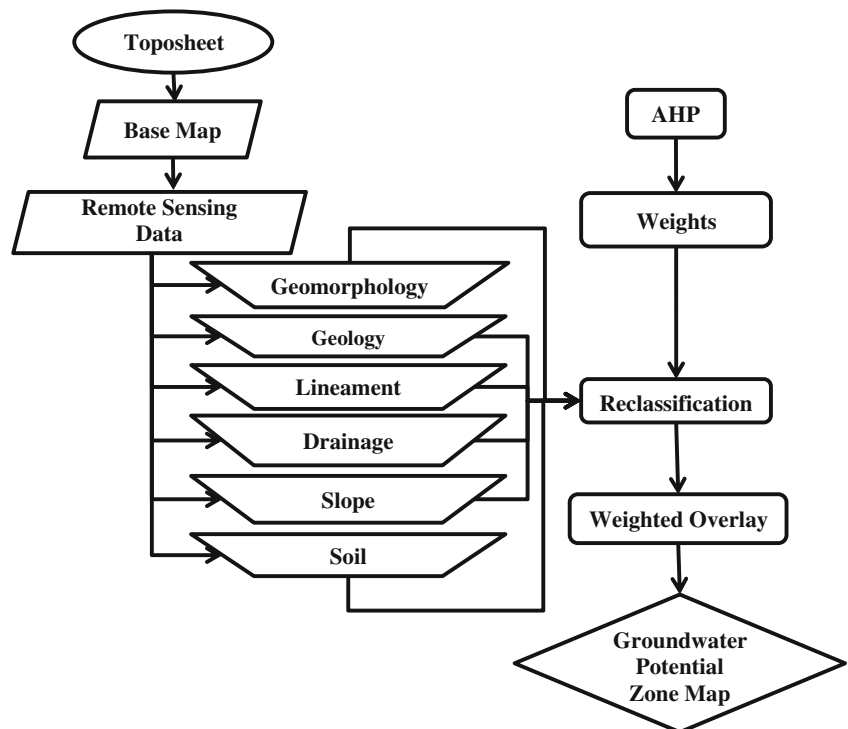**Fig. 2** Flowchart depicts the methodology adapted in this study

Table 1 Pairwise comparison matrix of the six thematic layers

Layers	Geomorphology	Geology	Drainage density	Lineament density	Degree of slope	Soil
Geomorphology	1.000	0.333	0.143	0.111	0.333	0.333
Geology	3.000	1.000	0.333	0.200	0.333	0.333
Drainage Density	7.000	3.000	1.000	0.333	0.333	3.000
Lineament Density	9.000	5.000	3.000	1.000	3.000	5.000
Degree of slope	3.000	3.000	3.000	0.333	1.000	3.000
Soil	3.000	3.000	0.333	0.200	0.333	1.000
Sum	26.000	15.333	7.810	2.178	5.333	12.667

formations, it is ranging between 1 and 500 m²/day (CGWB 2008). Storativity ranges from 7.6×10^{-5} to 3.59×10^{-4} in sedimentary formation, whereas 2.16×10^{-5} to 4.9×10^{-5} in hard rock. The specific yield is 12% in sedimentary formation and 1.5% in hard rock (CGWB 2008). Pediplains are major geomorphological feature followed by alluvial plains that are found in the eastern and southern part. Uplands, flood plains, lateritic plain, structural, and denudational hills are also occurring in the study area. The order of abundant soils is sandy-loam, sandy-clay-loam, clay, sandy-clay, loamy-sand, sand, clay-loam and loam.

Methodology

Groundwater potential zone mapping requires the following thematic layers which are Geomorphology, Geology, Drainage Density, Lineament Density, Slope, and Soil type. From the toposheet, a base map was prepared to the study area and remote sensing data were used to produce all other thematic layers. Further, the thematic layers are reclassified and the methodology adapted for this study has been illustrated as flowchart in Fig. 2. Survey of India toposheets of 1:50000 scale were used to prepare the base map of the study area and IRS P6 LISS IV MX satellite data captured on 10th of March 2017, with SRTM DEM of 50 m resolution data were used to produce the thematic layers that are relevant to groundwater occurrence (Narendra et al. 2013). These thematic layers are having more probability in groundwater potential

zone mapping, though it controls the runoff, infiltration, recharge, and groundwater movement. Geomorphology of any study area is controlled by the subsurface lithology and its structural characteristics. The structural features and different land forms can be identified and delineated by the visual interpretation technique on processed satellite images for geomorphological mapping (Jaiswal et al. 2003; Chowdhury et al. 2009; Machiwal et al. 2011; Fashae et al. 2014; Fenta et al. 2014). The mutual relation between the occurrence of groundwater and the geomorphological features is based on rate of infiltration, runoff, drainage pattern, and flow of the stream (Ahmad and Singh 2002). The rocky outcrop's litho nature is very much important for groundwater recharge though it makes the aquifer media by the development of secondary porosity due to weathering and fracturing. So, the geology of the study area has been taken into consideration with other layers due to its control on water percolation and influence in groundwater availability (Mukherjee et al. 2012).

Drainage represents both the surface characteristics and sub-surface lithology. Unit for the drainage density is denoted by km/km2 and it reveals the distance between each channel (Prasad et al. 2008). SRTM Dem data were processed to delineate the drainage, watershed, and its parameters. The following equation was used to calculate the drainage densities (DD) of the produced drainage map (Murthy 2000).

$$DD = \sum LWS / AWS$$

Where,

Table 2 The normalized principal eigenvector for comparison matrix

Layers	Geomorphology	Geology	Drainage density	Lineament density	Degree of slope	Soil	Weights
Geomorphology	0.038	0.022	0.018	0.051	0.063	0.026	0.036
Geology	0.115	0.065	0.043	0.092	0.063	0.026	0.067
Drainage Density	0.269	0.196	0.128	0.153	0.063	0.237	0.174
Lineament Density	0.346	0.326	0.384	0.459	0.563	0.395	0.412
Degree of slope	0.115	0.196	0.384	0.153	0.188	0.237	0.212
Soil	0.115	0.196	0.043	0.092	0.063	0.079	0.098
Eigenvector	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Table 3 Randomly generated consistency index by Saaty (1980)

Random consistency index table

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.53	0.9	1.12	1.24	1.32	1.41	1.45	1.49

N number of criteria, *RI* random index

Table 4 The evaluation of consistency for derived criteria weights

Consistency of criteria weights	
λmax	6.509
CI	0.102
CR	0.082

CR < 0.10, so the criteria weights are consistent

LWS   total length of streams in watershed
AWS   Area of the watershed

The complex mutual relationships of fracture zones, joints space, litho-contacts, faults, and shear zones that generally controls the aquifer dynamics and the groundwater movement (Chandra et al. 2019). Aquifer permeable zone can be identified through the presence of lineaments and higher lineament density gives good groundwater potential (Prasanta et al. 2016). High pass and low pass filter techniques were used for edge enhancement to delineate the lineaments of the study area and also the lineament densities were found in the basis of proximity of lineaments (Jasmin and Mallikarjuna 2011). Degree of slope is one of the controlling factors of groundwater to infiltrate into the sub-surface; hence, it indicates the potential zone of groundwater (Pandiyan and Annadurai 2013). In steep slope, the precipitation runoff will be quicker, whereas in gentle gradient, the runoff will be slower which
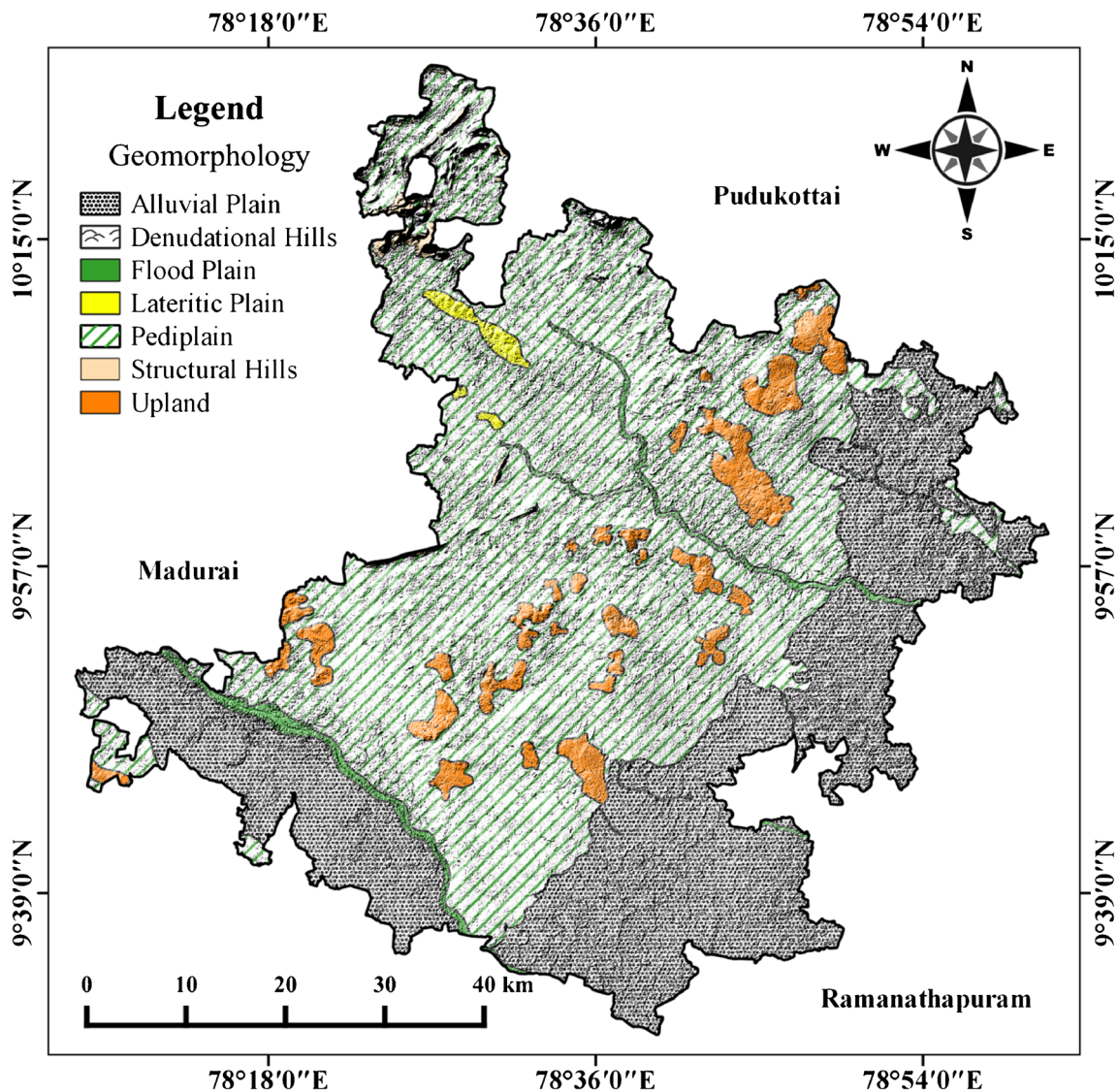

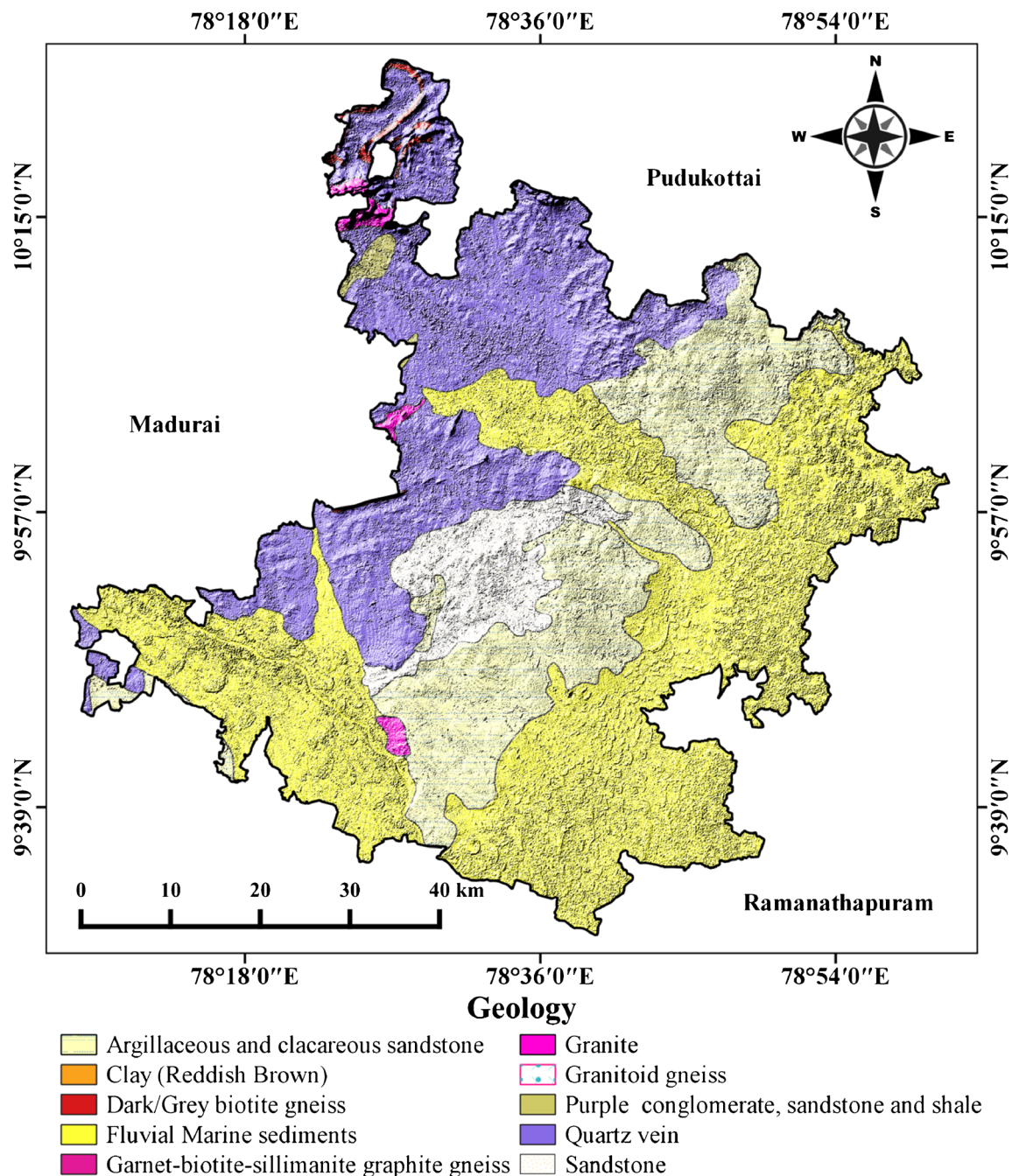**Fig. 3** Geomorphological features of the study area

Fig. 4 Geological features of the study area

will increase the infiltration by accommodating the precipitated water for longer period in the surface of the slope (Pandiyan and Annadurai 2013; Bagyaraj et al. 2013; Kanagaraj et al. 2019). The amount of ability of soil to infiltrate the water in certain time period is said as infiltration rate of soils (Arab et al. 2014). Infiltration is the initial process where the rain water begins to move toward the groundwater due to gravity and capillary force from the soil surface which makes it one of the important criteria for potential zone identification. The following factors affecting the infiltration are

conditions at soil surface, soil texture and structure, soil density, soil-moisture content, biological crusts, type of vegetative cover, soil temperature, and anthropogenic activities on soil surface (Mangala et al. 2016).

All the major features are marked by definite symbols and mapped to produce various thematic maps of the study area using ArcGIS platform (Arkoprovo et al. 2012). The digital image processing and statistical spatial analysis were carried out using the GIS software, ERDAS IMAGINE:8.7, and ArcGIS:10.2. Ground control points (GCP) were extracted from
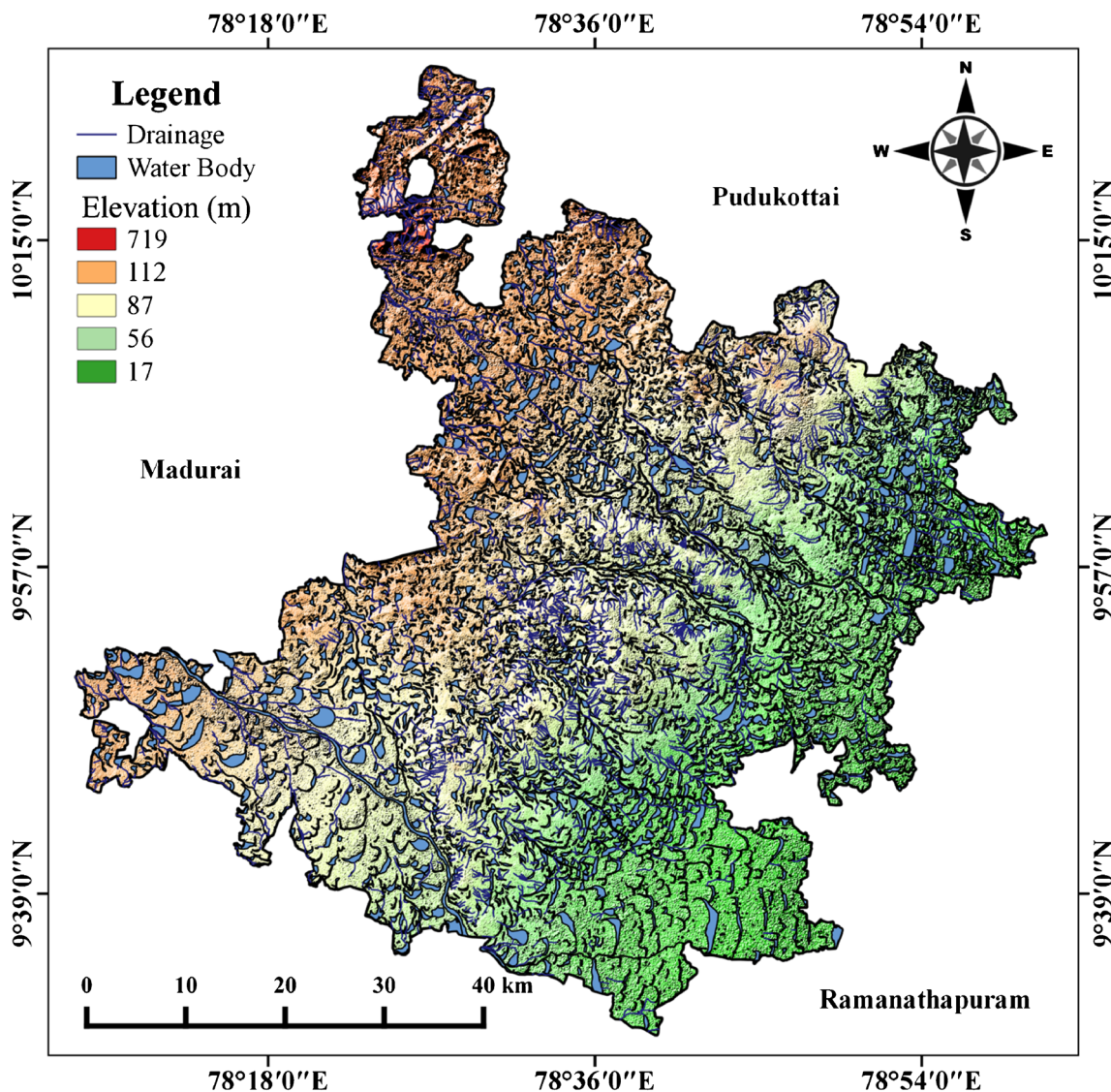
Fig. 5 Drainage patterns map of the study area

the base map for geometrical rectification of satellite data. Analytical hierarchical processing (AHP) was done to determine the weights for each layers based on their relative importance in groundwater identification (Saaty 1980; Hoque et al. 2020). Pairwise comparison process is used to identify the comparatively more preferred layer based on their properties which controls the infiltration, surface runoff, and the groundwater movement. Pairwise comparison matrix was constructed (Table 1) followed by Saaty (1980) and evaluated for consistency using the following equations (Eqs. 1 to 6)(Triantaphyllou and Mann 1995; Cabrera and Lee Han, 2019). The normalized principal Eigen vector for the pairwise comparison matrix is given in the Table 2. The eigenvalue is generally denoted by "λ" and it defines the changes in a vector of linear transformation by a scalar factor. The maximum eigenvalue approximation for each layer was calculated using the Eq. 4(Hoque et al. 2020).

$$Xi = \frac{Ci}{\sum_{i=1}^{n} Ci} \tag{1}$$

$$Wi = \frac{\sum_{i=1}^{n} Xi}{n} \tag{2}$$

$$Cj = \frac{\sum_{i=1}(Ci \times Wi)}{Wi} \tag{3}$$

$$\lambda max = \frac{\sum Cj}{n} \tag{4}$$

$$CI = \frac{\lambda max - n}{n-1} \tag{5}$$
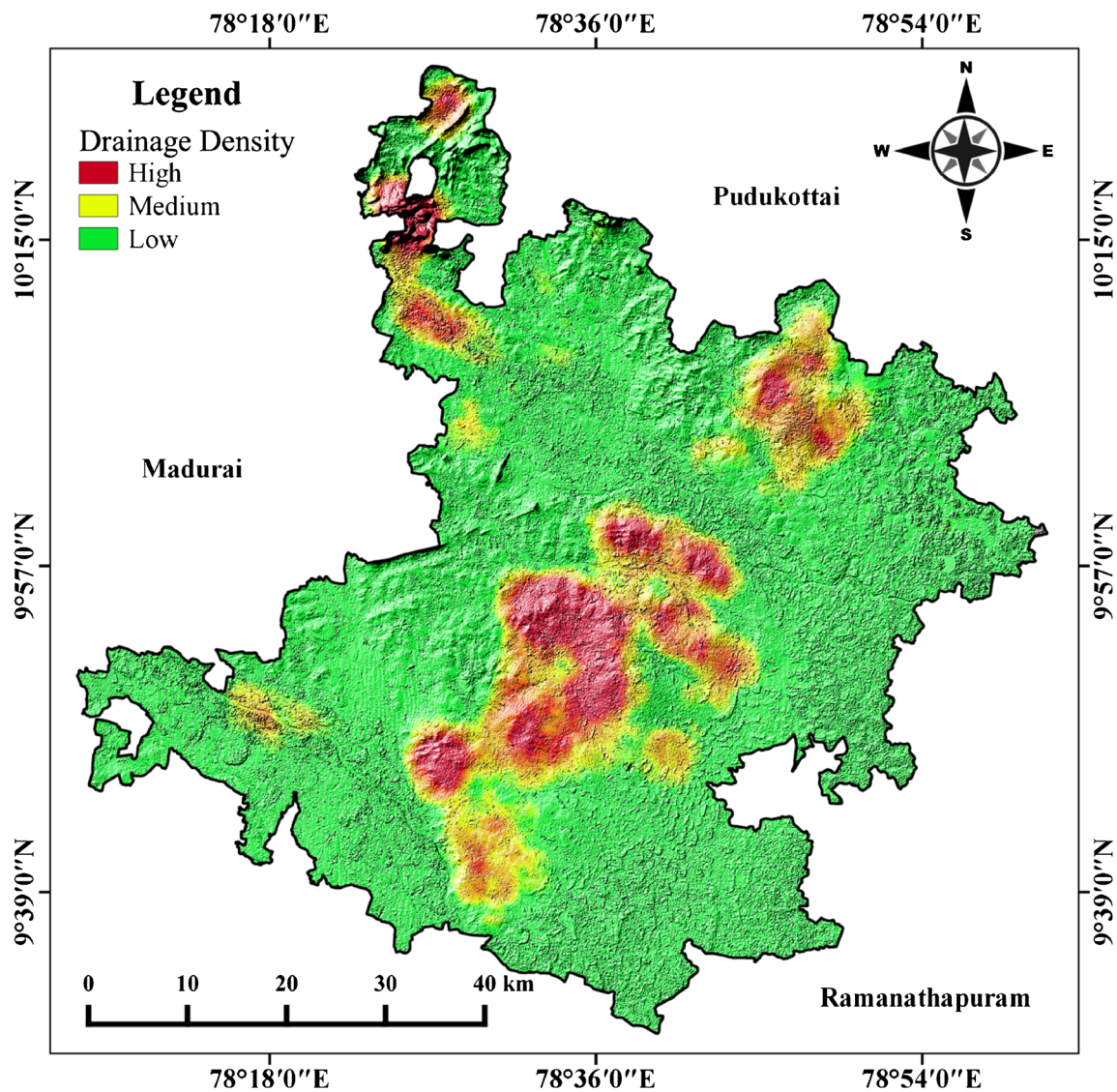
$$CR = \frac{CI}{RI} \tag{6}$$

Where

Fig. 6 Drainage density variation map of the study area

Ci   is the indicator value assigned in the pairwise comparison matrix

Xi   is the normalized value of pairwise comparison matrix

Wi   is calculated weight for each criterion from the pairwise comparison matrix

Cj   is the consistency measurement factor

λmax   is the maximum eigenvalue approximation

n   is the number of criteria

CI, RI, and CR are denoted for consistency index, random index (Table 3)(Saaty 1980), and consistency ratio of derived weights.

The calculated consistency ratio for the derived criteria weights is 0.082 (Table 4) which is below 0.10 as proposed by Saaty (1980). It shows that derived weights for each criterion is consistent and can be applied for weighted linear combination.

Following Eq. (7) of weighted linear combination method has been used to calculate the groundwater potential index (Basavaraj and Nijagunappa 2011; Selvam et al. 2015; Gnanachandrasamy et al. 2018).

$$\text{GWPI} = \sum_{i=1}^{n} (\text{GMw.wi}, \text{GGw.wi}, \text{DDw.wi}, \text{LDw.wi}, \text{SLw.wi}, \text{STw.wi})$$

$$(7)$$

Here, GWPI denotes the groundwater potential index, Geomorphology as GM, Geology as GG, Drainage density as DD, Lineament Density as LD, Slope as SL, and Soil type as ST. The normalized weights of layer are given as subscript "w" and the normalized weights in each thematic layer are given as subscript "wi." With respect to the range of GWPI values, the groundwater potential zone is further classified as very good, good (higher value), moderate (medium value), and poor (least value) type (Bagyaraj et al. 2013; Selvam et al. 2015;
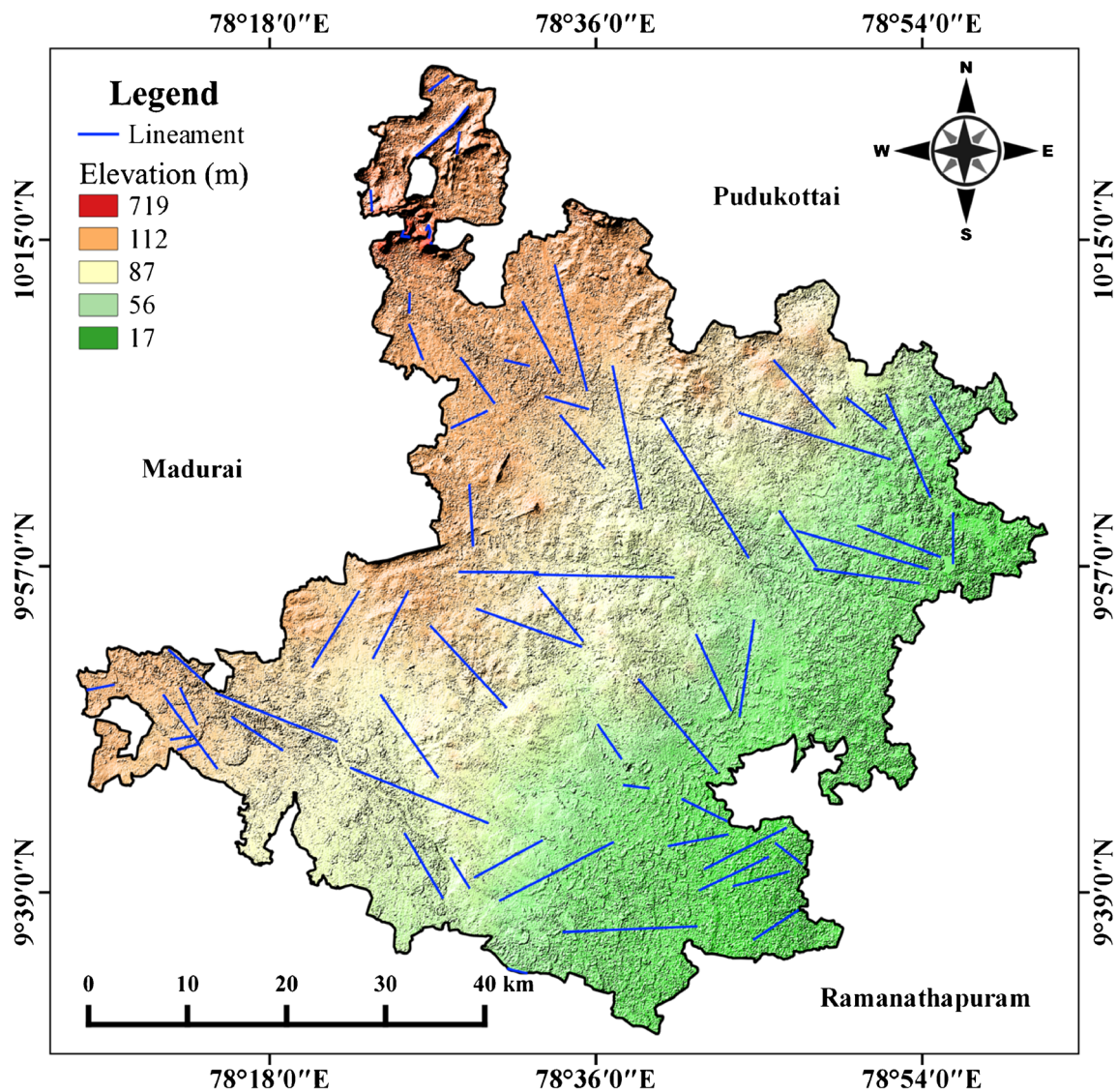
Fig. 7 Lineaments trend map of the study area

Gnanachandrasamy et al. 2018). Further, the groundwater potential index is converted into GIS database file in order to produce the groundwater potential zone map. Random field scouting was done for ground truthing the results.

Results

Geomorphology

Geomorphological map (Fig. 3) is classified into seven zones such as alluvial plain, denudational hills, flood plain, lateritic plain, pediplain, structural hills, and upland. Major part of the study area is occupied by pediplain (58.3%) and followed by alluvial plain (32.8%), upland (5.8%), flood plain (1.8%), lateritic plain (0.6%), structural hills (0.6%), and denudational hills (0.2%). Small part of the north western region of the

study area is occupied by the denudational and structural hills. Based on land forms and water holding capacity, ranking is assigned for all the zones as the following order; pediplain > lateritic plain > alluvial plain > flood plain > upland > structural hills > denudational hills (Gnanachandrasamy et al. 2018; Kanagaraj et al. 2019).

Geology

There are four major distinct lithological layers of fluvial marine sediments (Alluvial deposit) (45.46%), quartz vein deposits (26%), Argillaceous-calcareous sandstone (20.67%), and sandstone (5.54) are present in the study area. In addition to the major lithology, few smaller patches of granite (0.93), dark/grey biotite gneiss (0.56%), purple conglomerate (0.49), granitoid gneiss (0.21%), garnet biotite gneiss (0.08), and reddish brown clay (0.05) are found in
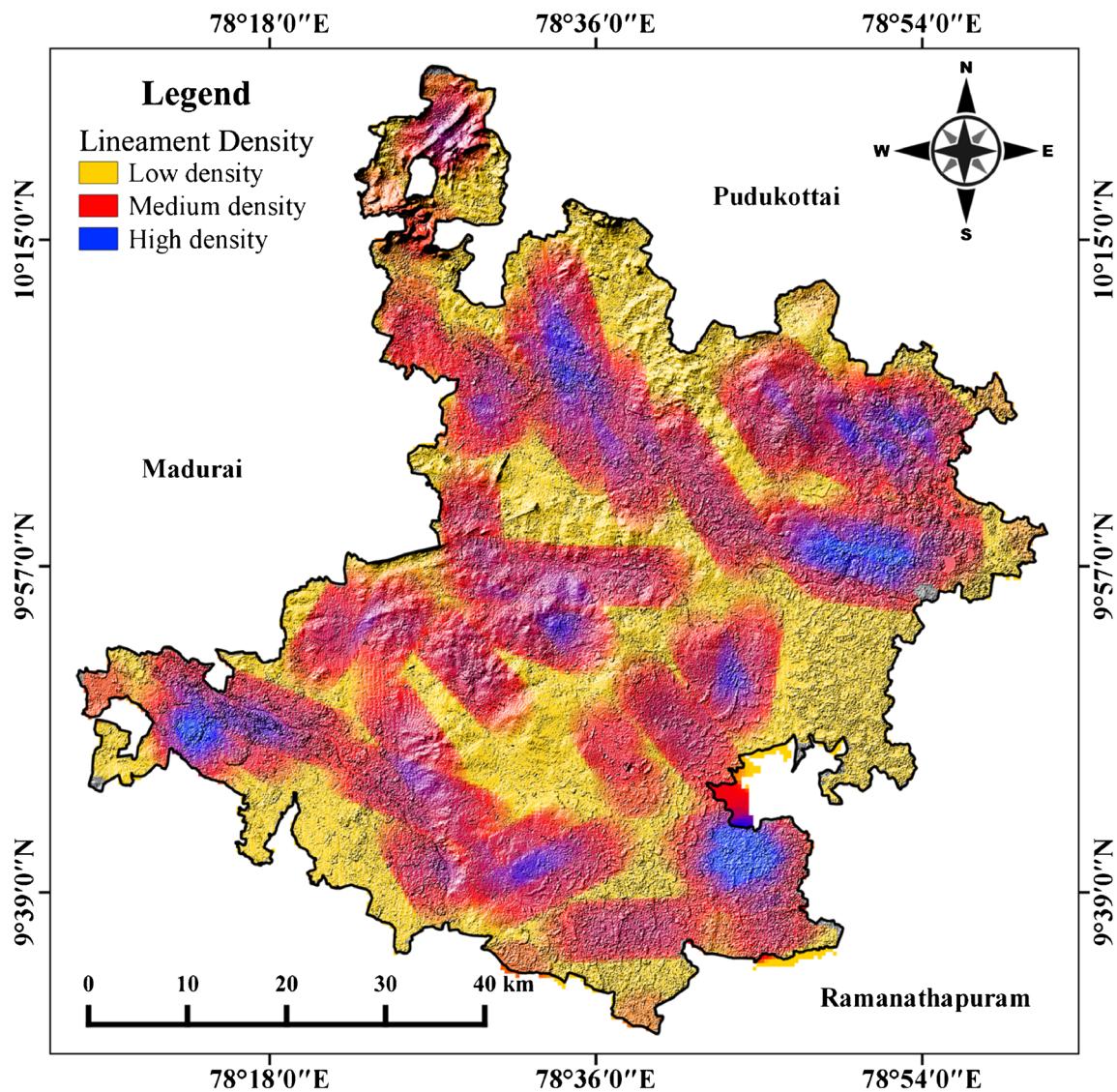
Fig. 8 Lineaments density variation map of the study area

north western parts of the study area (Fig. 4). The predominant water-bearing formations of the study area are fluvial marine sediments, sandstone, and clayey-sandstone. Ranking for different rock formations is assigned based on their water yielding properties (CGWB 2008; Fenta et al. 2014; Pinto et al. 2017; Gnanachandrasamy et al. 2018; Kanagaraj et al. 2019).

Drainage and drainage density

Geologically and structurally controlled drainages show dentritic and sub-dentritic pattern in most part of the study area (Fig. 5). The drainage density is classified as three zones with respect to the proximity of the streams, which are high, moderate, and low. High and moderate drainage density is found almost all over the study area and some parts in the south and north having

low drainage density (Fig. 6). The hydrological factor of drainage density is defined as denser drainage increases surface runoff and does not give enough time to infiltration and recharge groundwater. So, relatively lesser drainage density is preferred for the groundwater recharge and potential zone identification (Pandiyan and Annadurai 2013; Bagyaraj et al. 2013; Roy et al. 2019).

Lineament and lineament density

The lineaments are like conduit for groundwater flow and equally distributed in the study area (Fig. 7). Based on the lineament density, it is categorized as low, moderate, and high. Ranking has been given accordingly to the category that is higher density possess higher ranking followed by moderate and low densities (Selvam et al. 2015; Gnanachandrasamy et al. 2018; Kanagaraj et al. 2019). Low lineament density is

found in all part the study area (Fig. 8), whereas moderate density and high density of lineaments found in the central and north eastern part of the study area respectively.

Degree of slope

Hilly terrain at north-western region make steep surface slopes of above 45% and the rest of the study area is gentle (< 10%) to moderately (10–45%) sloping (Fig. 9), in which the rainwater can percolate into sub surface aquifers. So, the degree of slope is very important to estimate the runoff and infiltration capacity of a terrain. The more the slope is, the more will be the runoff, which causes lesser infiltration and gentle slope infiltrates more water.

Soil type

The order of abundance of soil type is as follows: sandy-loam (30.53%) > sandy-clay-loam (20.27%) > clay (19.28%) > sandy-clay (17.66%) > loamy-sand (6.83%) > sand (3.13%) > clay-loam (2.25%) > loam (0.04%). The central portion of the study area is occupied by loamy-sand and the sand dominates in northern and north eastern region of the study area (Fig. 10). Southern part of the study area is filled with shrinking/swelling clay minerals. Some patches of loam soil are found all over the study area except in the south eastern region. Generally, the sand layer at the surface has more infiltration rate compared to the other soil types. Based on the soil infiltration capacity, the following order of ranking is given to the soils; sand > loam > sandy-loam > loamy-sand > clay > sandy-clay clay-loam > sand-clay-loam(Selvam et al. 2015).
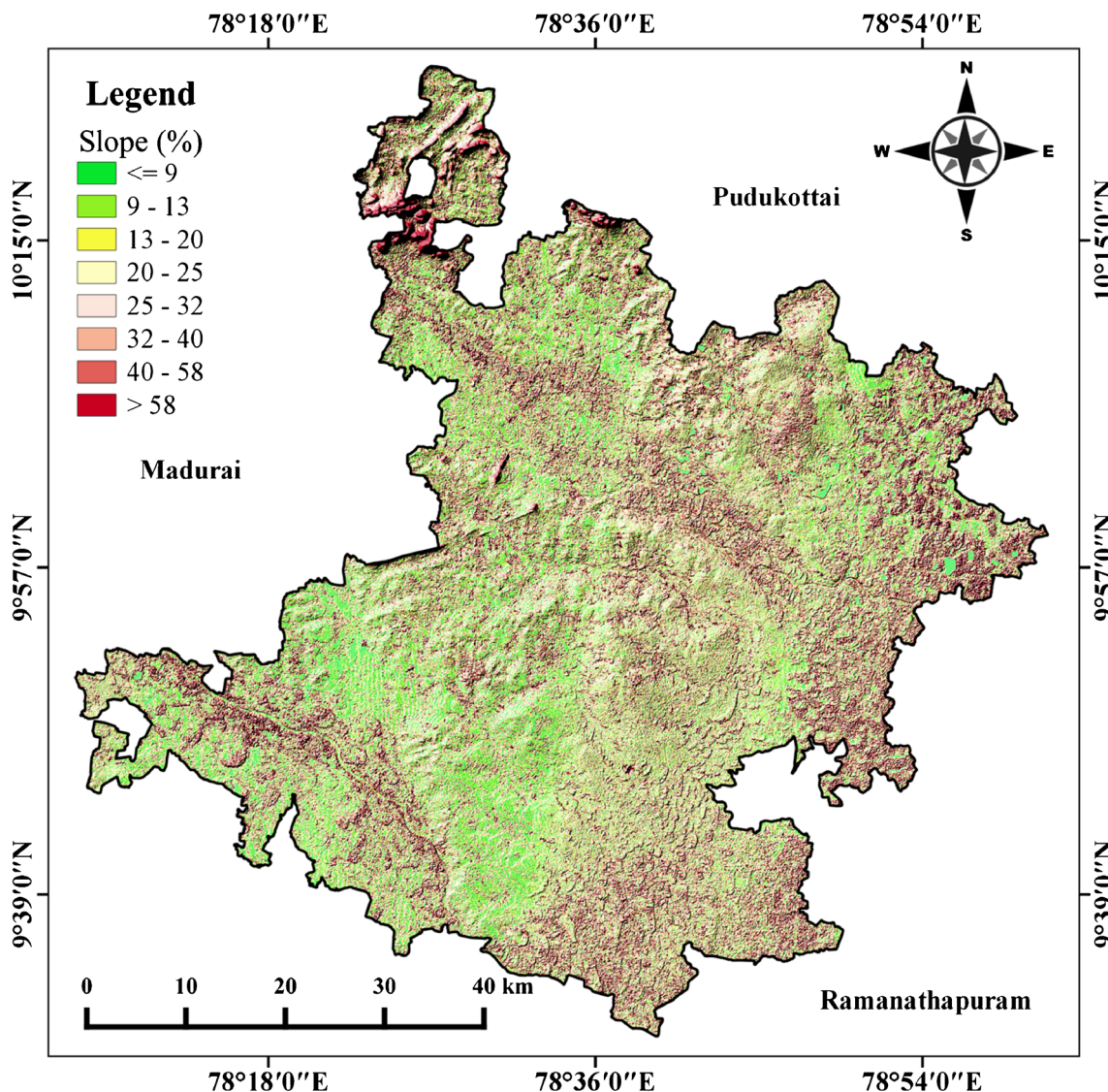

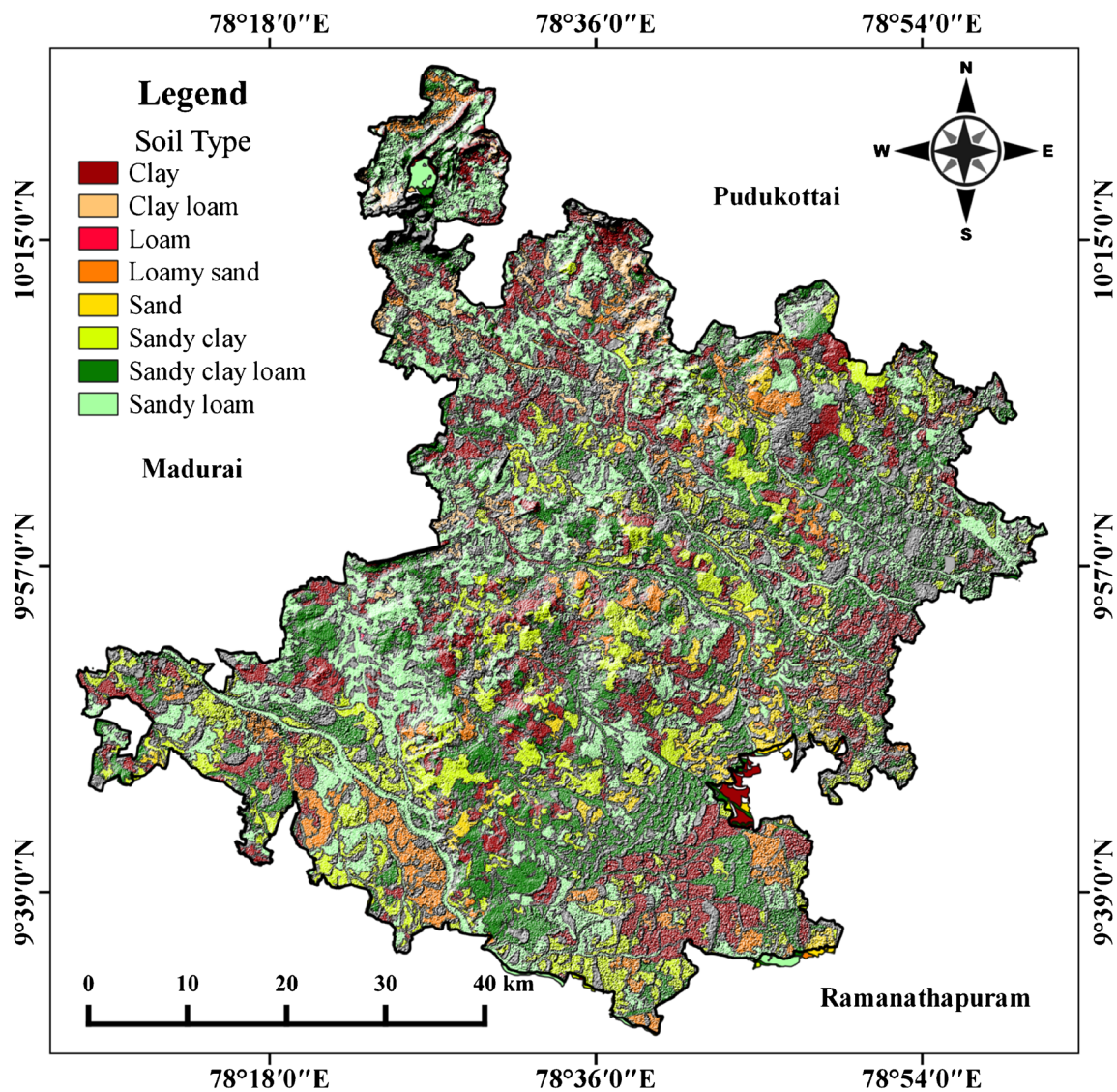**Fig. 9** Slope trend map of the study area

Fig. 10 Soil types map of the study area

Discussions

The classes of each thematic layer were reclassified with respective of ranks assigned to them based on their water holding capacity (Table 5). Weighted overlay analysis of cumulative weight percentages that are assigned for geomorphology, geology, drainage density, lineaments density, slope, and soil maps were used to produce the groundwater potential map (Fig. 11). Higher weightage represents the higher water holding capacity and lower weightage represents the lower water holding capacity. From the weighted overlay analysis, the groundwater potential map of the study area is categorized with four zones that are very good, good, moderate, and poor potential. The moderate potential zone is occupied with 38.2%, followed by 30.8% of good potential, 20.3% by poor potential, and 10.6% by very good potential zone in the study

area (Table 6). The bar chart represents the relative percentage of each zone in Fig. 12. The central and northern parts of the study area having very good to good potential and the peripheral part of the study area is showing moderate potential of groundwater zones (Fig. 11). Poor potential zone of groundwater found as some small patches in the north-west, south-west, and central portion of the study area. Most part of the study area is fall under the good, very good, and moderate potential of groundwater zone.

The produced groundwater potential map was validated by correlating with the groundwater level map of the study area which is the direct evidence for its potential availability. The groundwater potential maps are also correlated with the number of wells tapping the aquifer (Annadasankar et al. 2019). Groundwater level data of 32 dug wells during 2018 were collected from the Central Groundwater Board (CGWB),

Table 5 Weightage and score for each class of thematic layers

Sl. No	Parameters	Classes	Rank	Weights	Area (%)
1	Geomorphology	Pediplain	3	0.036	58.34
2		Lateritic plain	3	0.036	0.55
3		Alluvial plain	2	0.036	32.75
4		Flood plain	1	0.036	1.77
5		Upland	1	0.036	5.80
6		Structural hills	1	0.036	0.62
7		Denudational hills	1	0.036	0.17
8	Geology	Purple conglomerate, sandstone and shale	3	0.067	0.49
9		Sandstone	3	0.067	5.54
10		Argi & cal sandstone	2	0.067	20.67
11		Fluvial marine sediments (Alluvium)	2	0.067	45.46
12		Dark/Grey biotite gneiss	2	0.067	0.56
13		Garnet-biotite gneiss	2	0.067	0.08
14		Granite	2	0.067	0.93
15		Granitoid gneiss	2	0.067	0.21
16		Clay (reddish brown)	1	0.067	0.05
17		Quartz vein	1	0.067	26.00
18	Drainage density	Low	3	0.174	2.79
19		Moderate	2	0.174	25.29
20		High	1	0.174	71.93
21	Lineament density	High	3	0.412	1.10
22		Moderate	2	0.412	14.16
23		Low	1	0.412	84.75
24	Degree of slope	0–15(gentle slope)	3	0.212	29.84
25		15–45(moderate slope)	2	0.212	49.91
26		> 45(steep slope)	1	0.212	20.25
28	Soil	Sand	3	0.098	3.13
29		Loam	3	0.098	0.04
30		Sandy-loam	2	0.098	30.53
31		Loamy-sand	2	0.098	6.83
32		Clay	1	0.098	19.28
33		Sandy-clay	1	0.098	17.66
34		Clay-loam	1	0.098	2.25
35		Sand-clay-loam	1	0.098	20.27

Tamilnadu. Spatial map of groundwater level data is produced using the inverse distance weights (IDW) interpolation technique in spatial analysis tool. The spatial map illustrates the groundwater level in different parts of the study area, where the south, central, and north western parts having shallow level of groundwater (Fig. 13). But, deeper groundwater level is observed in northeastern part of the study area due to over exploitation. The two main cities, Karaikudi and Devakottai, in northeastern part with high-density population consumes large amount of groundwater for their drinking, domestic, irrigation, and small-scale industrial purposes (Mariappan et al. 2000; Lalitha et al. 2019).

It was observed that the groundwater potential zones are well correlated with the groundwater level map. Similar observation was made by Ajay kumar et al. (2020), in which the cross-correlation between water level and rainfall is well related to the groundwater potential zone. Pediplain in the central and western part of the study area may act as recharge catchment to the underlying sandstones and fluvio-marine sediments of central to northeast part which results in the good and moderate potential zone. This was also supported by the poor drainage density around the central part and high lineament density in the western part of the study area. Poor potential zone in the northwestern region may be attributed by the presence of denudational hills and rock outcrops. The underlying formation of the northwestern region is composed of granitic and gneissic rocks with quartz veins that hardly weathered and does not hold water in it which makes this
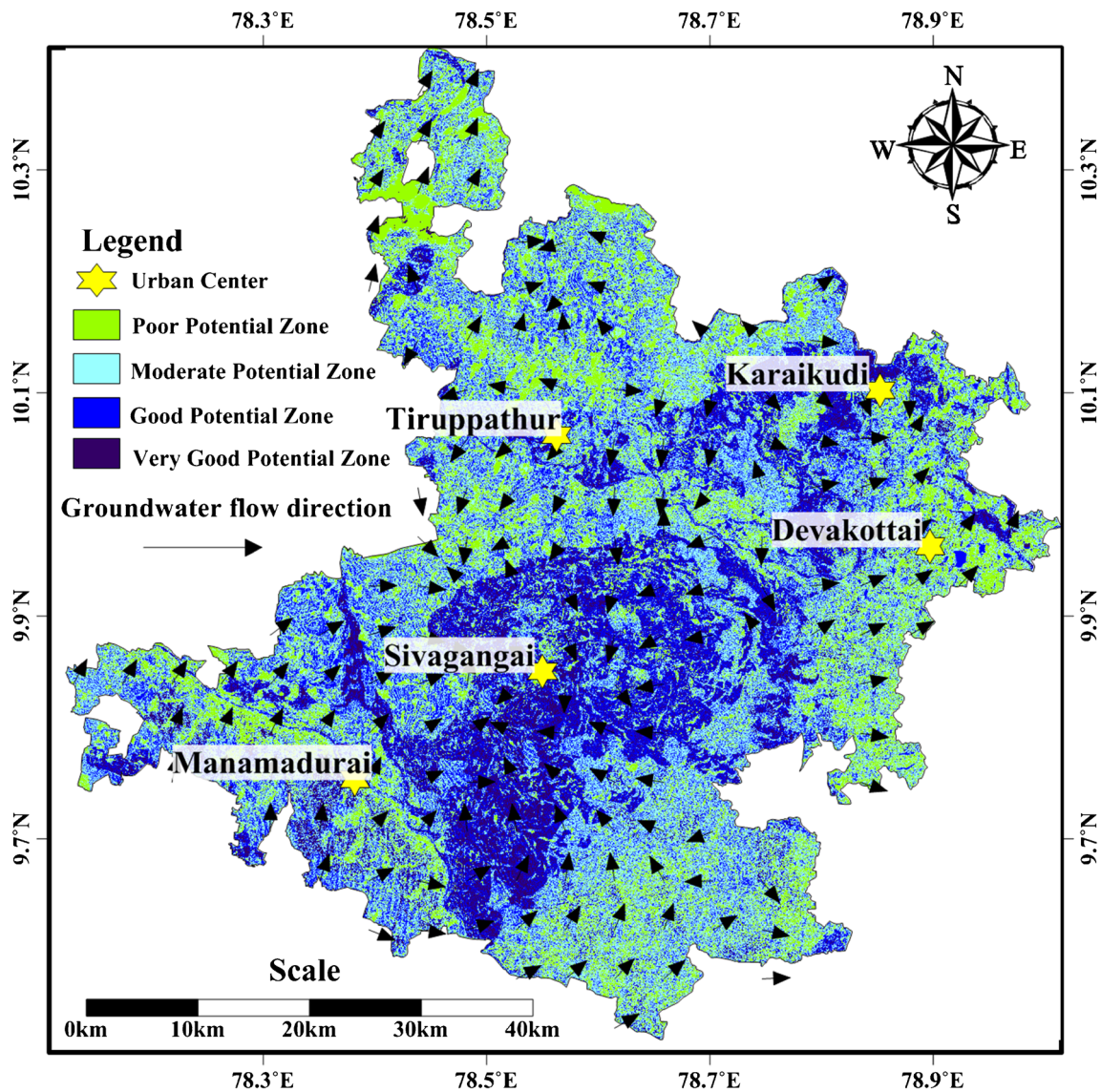
Fig. 11 Spatial representation of groundwater potential zones in Sivagangai district

region as poor potential zone. Hence, the results of this study has proven that AHP is a powerful tool in assessing the spatial groundwater vulnerability of Sivagangai district, as argued in the introduction section.

To improve the groundwater level in poor potential zones as identified in groundwater potential map, artificial recharging is required in the study area. Artificial recharge is

Table 6 Calculated area of each zones in groundwater potential GWPZ map

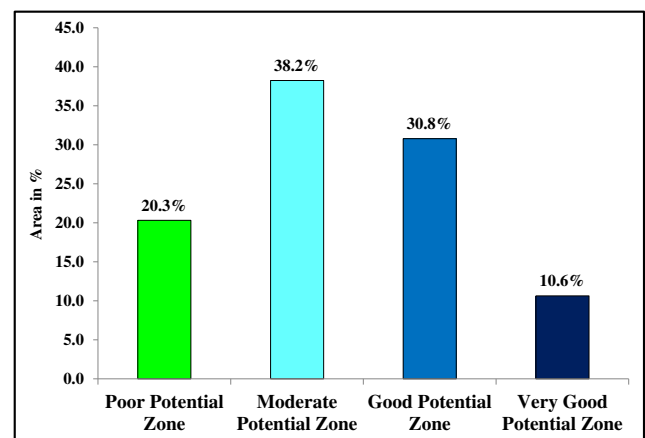| Zone	Description	Area in km^2	Area in %
1	Poor potential zone	851	20.3
2	Moderate potential zone	1601	38.2
3	Good potential zone	1290	30.8
4	Very good potential zone	444	10.6

Fig. 12 Histogram shows the relative percentage of each groundwater potential zone
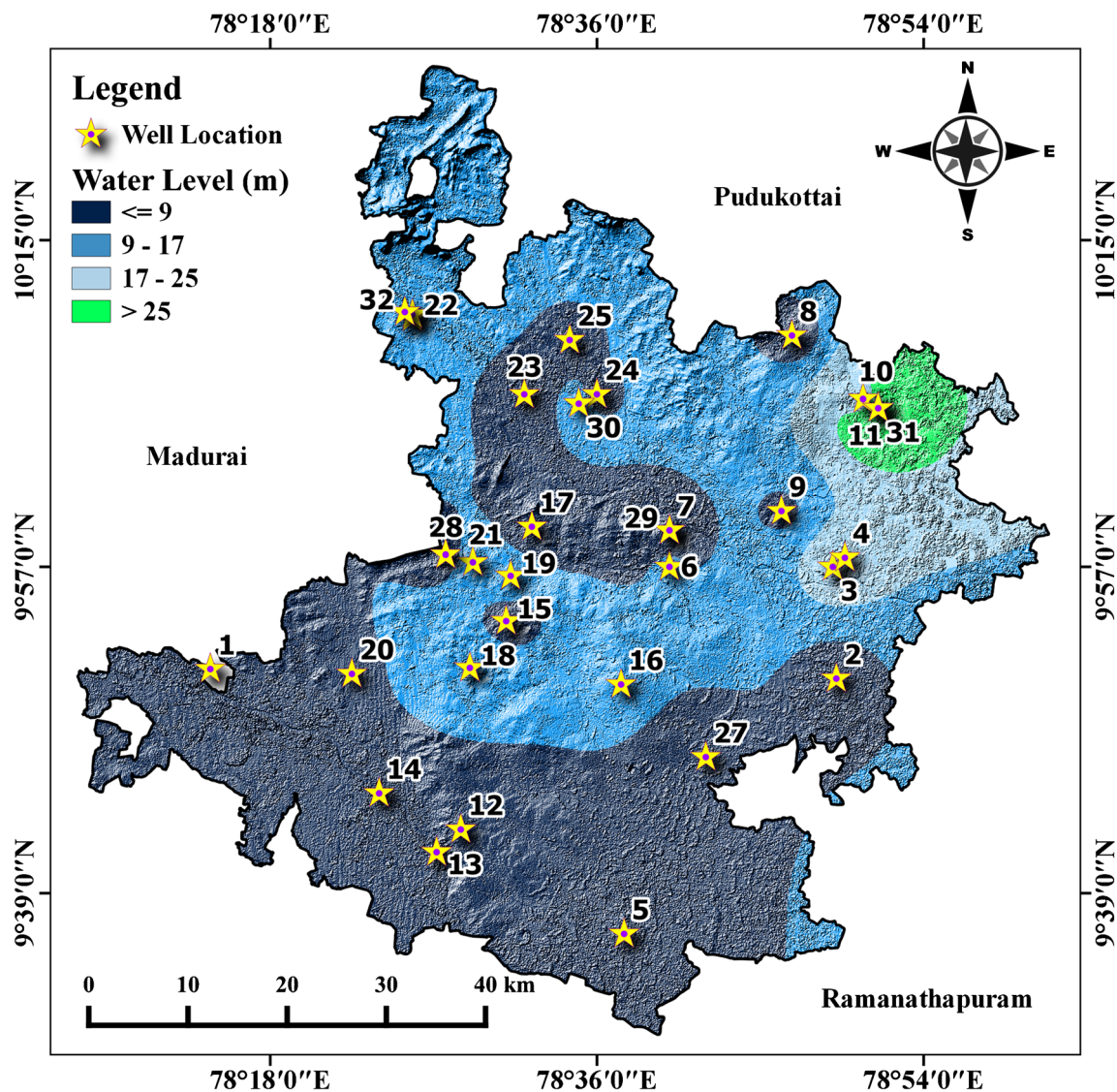
Fig. 13 Groundwater level map of the study area

the process of replenishing groundwater by augmenting the natural infiltration of surface water into sub surface aquifers through various methods, including artificial recharge structures such as check dams, percolation ponds, and percolations wells (Sukhija et al. 1997; Jothiprakash et al. 2002). It was found that percolation pond with percolation wells were more effective in recharging the surface water including rainwater into the aquifer, and also the groundwater quality was improved based on the analysis of water quality parameters (Abraham and Mohan 2015). Through the groundwater potential map, it was inferred that the higher water holding capacity was present in the central part of the study area. In order to maintain the groundwater level and recharge the rainwater and surface water into aquifers of this region, percolation ponds or percolation wells are the suitable artificial recharge structures based on geology, topography, drainage, lineament, and soil conditions.

Conclusion

In this study, identification of groundwater potential zones in the drought prone area (Sivagangai district) is successfully carried out using geospatial technique. Pre-processed satellite images were used to produce various thematic layers such as geomorphology, geology, drainage and drainage density, lineament and lineament density, slope, and soil for groundwater prospecting. GIS with AHP method was efficiently used to derive four categories of groundwater potential zones, which are very good, good, moderate, and poor. AHP was successfully applied to derive the weightage for each selected layers and the weighing values are evaluated as consistent to apply for groundwater potential zone investigation. The central and northern parts of the study area having very good to good potential and the peripheral part of the study area is showing moderate potential of groundwater zones. Most part of the

study area is classified between good and moderate groundwater potential. Groundwater potential zone map was validated using groundwater level data, and it correlates well. Suitable artificial recharge structures such as percolation ponds and percolation wells are recommended to improve the existing groundwater level. This study proves that GIS with AHP in groundwater potential zone identification is very successful which helps to decrease the uncertainty of demarking the available groundwater resources and to identify the vulnerable zones that need attention to implement artificial recharge structures. The outcome of this research would also be useful for policymakers in this drought-prone area to handle water supplies in a sustainable way. In addition, other researchers could use this method if they are interested in groundwater vulnerability mapping in drought-prone regions using geospatial technique.

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