



# Delineation of groundwater potential zones and recommendation of artificial recharge structures for augmentation of groundwater resources in Vattamalaikarai Basin, South India

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## Abstract

Nowadays, GIS and remote sensing techniques are effectively used to find groundwater prospect zones in various trouble-some landscapes throughout the world. In the present work, groundwater potential zonation mapping was carried out for the Vattamalaikarai River basin in South India by overlaying ten thematic maps such as soil, drainage density, lineament density, geology, slope, land use/land cover, geomorphology, topographic position index, rainfall and groundwater level by giving appropriate weightages to each significant parameter with respect to its influence on groundwater. As the basin mainly depends on the groundwater resources, it is necessary to assess the groundwater prospect for the better management of aquifer system. Groundwater potential zonation map illustrates that more than 50% of the basin region falls under moderate to low groundwater potential category. Highly influential thematic layers were integrated to generate groundwater recharge zonation map. Based on this output, artificial recharge sites were selected to replenish the groundwater resources in the basin. Three check dam sites were suggested across the third- and fourth-order streams. Four suitable sites for the construction of percolation ponds and ten locations for the construction of recharge pits were also identified. Four injection well sites were recommended to augment groundwater in the aquifer present under the black cotton soil regions in the western part of the basin.

**Keywords** Groundwater potential · Recharge zones · Artificial recharge structures · Vattamalaikarai River basin

## Introduction

Groundwater is generally perceived as a tried and true well-spring of water to meet the needs of household, water system and mechanical segments everywhere throughout the world

(Gorgij et al. 2019; Li et al. 2019; Li and Qian 2018a, b; Wu et al. 2015, 2019; He and Wu 2019a; He et al. 2019). However, irrational and unplanned groundwater resources development and enhanced human activities such as mining, industry and agriculture have resulted in groundwater pollution, groundwater over-extraction and land quality degradation problems (Li et al. 2018a, b, c; Wu et al. 2014). Groundwater is of significance in India, as a result of the expanding populace and urbanization, for the most part in regions with deficient surface water supply plans. It is estimated that about half of the urban and over 85% of rural populace relies upon groundwater for their drinking purposes and around 60% of the aggregate water system in the nation relies upon the same. CGWB (2011) reports that out of the 5723 pieces/watershed surveyed in the nation, 839 are considered as completely misused, 226 as risky and 30 are tainted with saline groundwater.

Groundwater potential is largely determined by natural factors such as geology, hydrogeology and geomorphology, but nowadays it is increasingly impacted by human activities because human activities can change land

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use/land cover, affect groundwater level variation and groundwater quality (Li et al. 2016a, b, 2017), making it hard to assess the groundwater potential zone effectively. As of now, GIS and remote detecting procedures are effectively being connected to find groundwater potential zones in various and troublesome landscapes everywhere throughout the world (He and Wu 2019b; Thilagavathi et al. 2015a, b). A point by point examination of every single topographic articulation such as alleviation highlights, geomorphic variations, soil dampness zones, topographic and vegetation markers can help in the fruitful outline of forthcoming groundwater potential zones in a locale. GIS is basically a database that features connection between these segments. For delineation of groundwater potential zones, GIS provides systematic approach over the secondary data sets along with the hydrogeological investigation through a rapid and cost-effective way (Imran et al. 2011). GIS is one of the propelled data frameworks utilized as a part of logical investigations and innovative work. The utilization of various devices and modules, for example, Arc GIS with other programming, empowers rapid and moderately mistake-free investigation which would have otherwise been generally dull and tedious. Uses of geospatial technologies for investigation of groundwater prospect zones are done by various specialists all around the globe, and it was discovered that the factors included in deciding the groundwater potential zones were unique, and thus the outcomes fluctuate in a like manner. Teeuw (1995) depended just on the lineaments for groundwater investigation and others combined diverse parameters separated from lineaments such as seepage thickness, geomorphology, topography, slant, arrive utilize, precipitation force and soil surface (Sander et al. 1996; Sener et al. 2005). The inferences are observed to be agreeable in view of field overview and fluctuates from area to district as a result of changed geonatural conditions. Abuse of groundwater assets has expanded in the previous decades, prompting over-utilization of groundwater, which in the long run has caused a progression of geonatural issues, for example, diminished groundwater levels, water level exhaustion, and contamination and weakening of water quality and so forth.

Water supply for drinking and irrigation practices in the study area mainly depends on the available groundwater resources. As this basin receives less precipitation and the surface water resources are not adequate to fulfill the demand, groundwater is indiscriminately extracted in many parts. Therefore, proper planning is needed in the basin for the conservation and management of groundwater resources. Considering this aspect, in the present study remote sensing and GIS were used for delineation of groundwater potential zones and identification of artificial recharge structures.

Ten thematic layers such as drainage density, soil, lineament density, geology, geomorphology, slope, land use/land cover, topographic position index, rainfall and groundwater level were overlaid by giving appropriate weightages to each significant parameter with respect to its influence on groundwater.

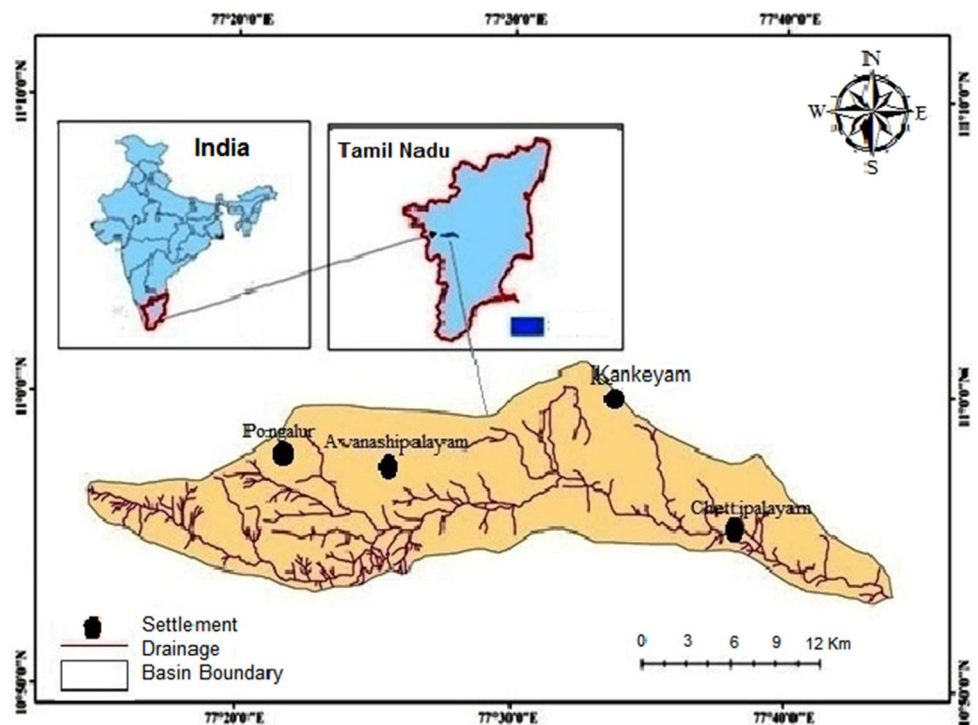
## Study area

The study area largely falls under Tiruppur and some parts of Erode districts of the state Tamil Nadu. Vattamalaikarai River basin lies between the latitudes  $10^{\circ} 53' N$  and  $11^{\circ} 01' N$  and the longitudes  $77^{\circ} 15' E$  and  $77^{\circ} 45' E$  with geographical area of 434.28 sq km (Fig. 1). The basin covered in the Survey of India Toposheet No. 58 E/12, 58 F/9 and 58 F/5. Vattamalaikarai River is the tributary of Amaravathi River. This is a non-perennial river which is drained toward east and confluences with the Amaravati River. The study area falls under the rain shadow region (CGWB 1979; Anandakumar et al. 2008). The highest elevation of the study area is 427 m above the mean sea level. The annual average rainfall of the basin is 571 mm. The basin receives maximum rainfall during the northeast (NE) monsoon season (around 53%). The southwest (SW) monsoon contributes nearly 24%, and the pre-monsoon contributes nearly 22% of rainfall in the basin. Negligible precipitation occurs during the post-monsoon seasons, which is around 1% (Vennila et al. 2007). Precipitation is the ultimate source for groundwater replenishment in this basin. The normal maximum temperature received during the month of April is  $39^{\circ} C$  and the minimum mean temperature is  $20^{\circ} C$  observed during the month of January. Hornblende–biotite gneiss and charnockite are the major geological formations in the basin. The depth of groundwater (below ground level) in the basin ranges from 2 to 25 m. As the ground slope increases toward west, the depth of groundwater table is also low in the western part of the basin. The well inventory survey indicates unconsolidated, weathered and fractured formations form the aquifer system. Groundwater occurs under phreatic condition in the weathered formation, and the thickness of the aquifer extends up to 30 m in most of the places. Groundwater is under semi-confined condition in the fractured and jointed formations.

## Data used and methodology

The data sources used in the present work is depicted in Table 1. Data needed for the study were collected from various government departments, field surveys and the satellite imageries freely available in the USGS Earth Explorer website. Since the satellite imageries and digital elevation

**Fig. 1** Location map of Vattamalaikarai River basin, Tamil Nadu, India



**Table 1** Details of data sources used for thematic layers preparation

S. no.	Thematic layers	Data sources
1	Geomorphology	IRS-P6
2	Landuse/land cover	Landsat
3	Geology	GSI, 1995
4	Soil	Tamil Nadu Agricultural Department
5	Slope	SRTM data
6	Drainage density	SRTM data
7	Lineament density	IRS-P6
8	Rainfall distribution	PWD
9	Topographic position index	Landsat
10	Depth to water level	Field survey & PWD

model (DEM) were available in 30 m resolution, and spatial resolution of 30 m was chosen in this study (Basvarajappa et al. 2015; Thilagavathi et al. 2015a, b; Golla et al. 2018; Andualem and Demeke 2019). Ten different thematic layers such as geology, soil, geomorphology, drainage density, lineament density, land use/land cover, slope, topographic position index, depth to water level and rainfall were processed through weighted overlay analysis using ArcGIS to generate a groundwater prospect map. These ten parameters were selected because they have good control over groundwater flow and recharge in hard rock aquifers (Thilagavathi et al. 2015a, b). These parameters have played vital roles in several stages of this analysis. Since the river is a non-perennial

one, the aquifer gets recharged from the rainwater infiltration. In the hard rock areas geomorphological land forms, soil types, geological formations, land use pattern and lineaments have major and direct impact over groundwater movement and storage. Geomorphology represents the nature of landforms in the basin and their significance over groundwater recharge. As geomorphology is considered for assessment, it indirectly shows the influence over several morphometric parameters such as topographical position, slope of the terrain, precipitation availability, vegetation and drainage (Bashe 2017; Anand et al. 2017). The nature of various rocks and soils present in this region helps to figure out the infiltration and horizontal movement through the fractures and weathered zone into the aquifer system. For the groundwater extraction, the land use evaluation shows an impact on various socioeconomic parameters and landform conditions. The lineaments present in this basin act as a conduit for the movement of groundwater. Hence, the incorporation of all the ten parameters characterizes specific role in the groundwater potential assessment. These influencing parameters selected for the analysis are interdependent of each other.

Saaty (1980) introduced the analytical hierarchy process (AHP), which can be used as a decision-making tool in the field of groundwater prospecting. It is a pairwise comparison method for evaluating a criterion through the weighted ranking hierarchical approach. The groundwater potential influencing factors were evaluated by giving numerical scores to each criterion with respect to the hydrogeological conditions of the basin and also based on our field investigations. It is

a most reliable and consistent way for reducing complexity in synthesizing results (Arulbalaji et al. 2019). Higher ranks given to a theme illustrate the high impact and a lower rank illustrates its low impact over groundwater potential. In recent times, several researchers have adopted the AHP method for groundwater potential delineation (Kaliraj et al. 2014; Al-shabeeb 2016; Song and Kang 2016; Hazra et al. 2018; Andualem and Demeke 2019).

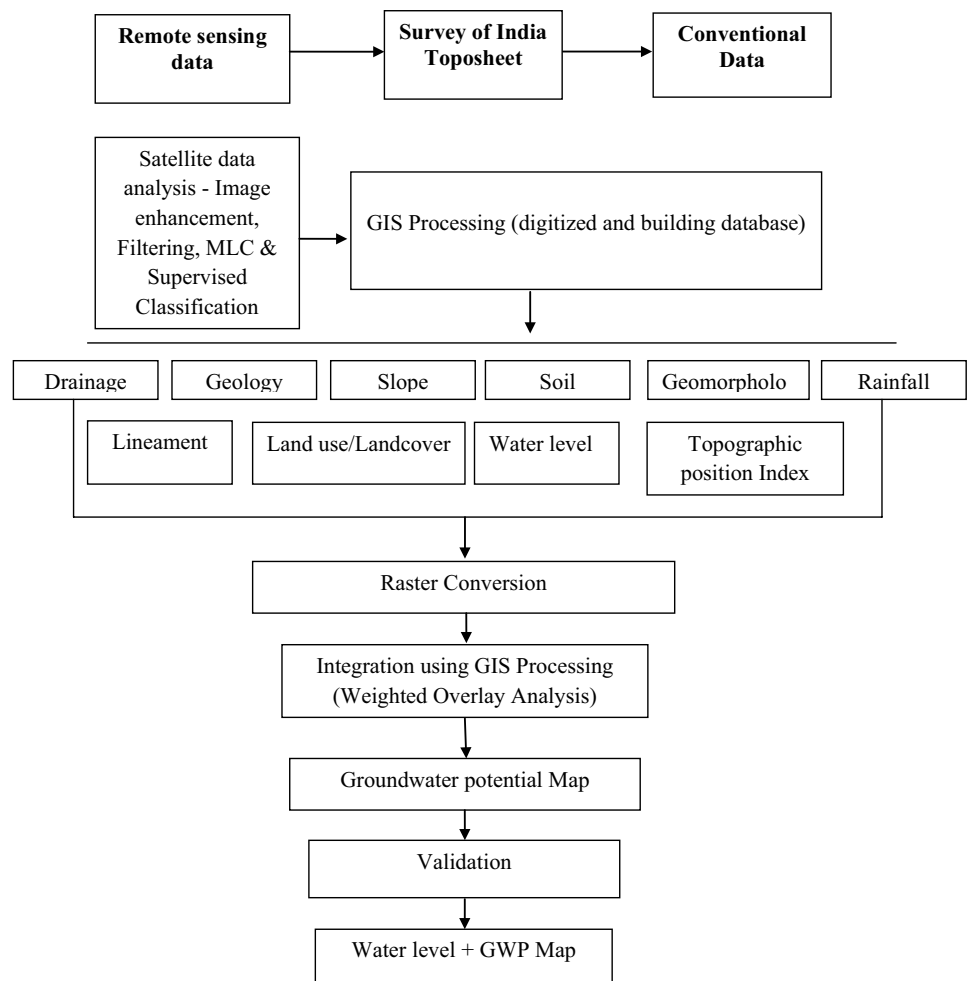
Each thematic layer was ranked on a scale of 1–5 by considering its influence on the groundwater occurrence and movement. The weighted overlay method (Hema et al. 2017; Thilagavathi et al. 2015a, b) was used to assign ranks for the thematic layers. The weightages were given to different components of each theme according to their influence on the occurrence of groundwater. The different features of a given theme were evaluated with low, moderate and high after a qualitative valuation. To delineate the groundwater potential zones, after assigning weights and ranks, the ten layers were integrated using spatial analyst tool in ArcGIS

software. The following equation was used to integrate all the themes for obtaining the groundwater potential zone map (Rao and Kishore 1991).

$$GWPZ = \left[ \begin{aligned} &(Gm_w) (Gm_{wi}) + (Ge_w) (Ge_{wi}) + (SoG_w) (So_{wi}) \\ &+ (Lc_w) (Lc_{wi}) + (DdM_w) (Dd_{wi}) \\ &+ (Ld_w) (Ld_{wi}) + (El_w) (El_{wi}) + (Tp_w) (Tp_{wi}) \\ &+ (Rd_w) (Rd_{wi}) + (Wl_w) (Wl_{wi}) + (Sl_w) (Sl_{wi}) \end{aligned} \right]$$

where GWPZ is the groundwater potential zone, Gm is the geomorphology, Ge is the geology, So is the soil type, Lc is the land use/land cover, Ld is the lineament density, Tp is the topographic position index, Dd is the drainage density, Rd is the rainfall distribution, Wl is the depth to water level, Sl is the slope and the subscripts 'w' and 'wi' refer to the normalized weight of a theme and the normalized weight of the individual features of the theme, respectively. The methodology flowchart is illustrated in Fig. 2.

Fig. 2 Methodology flowchart



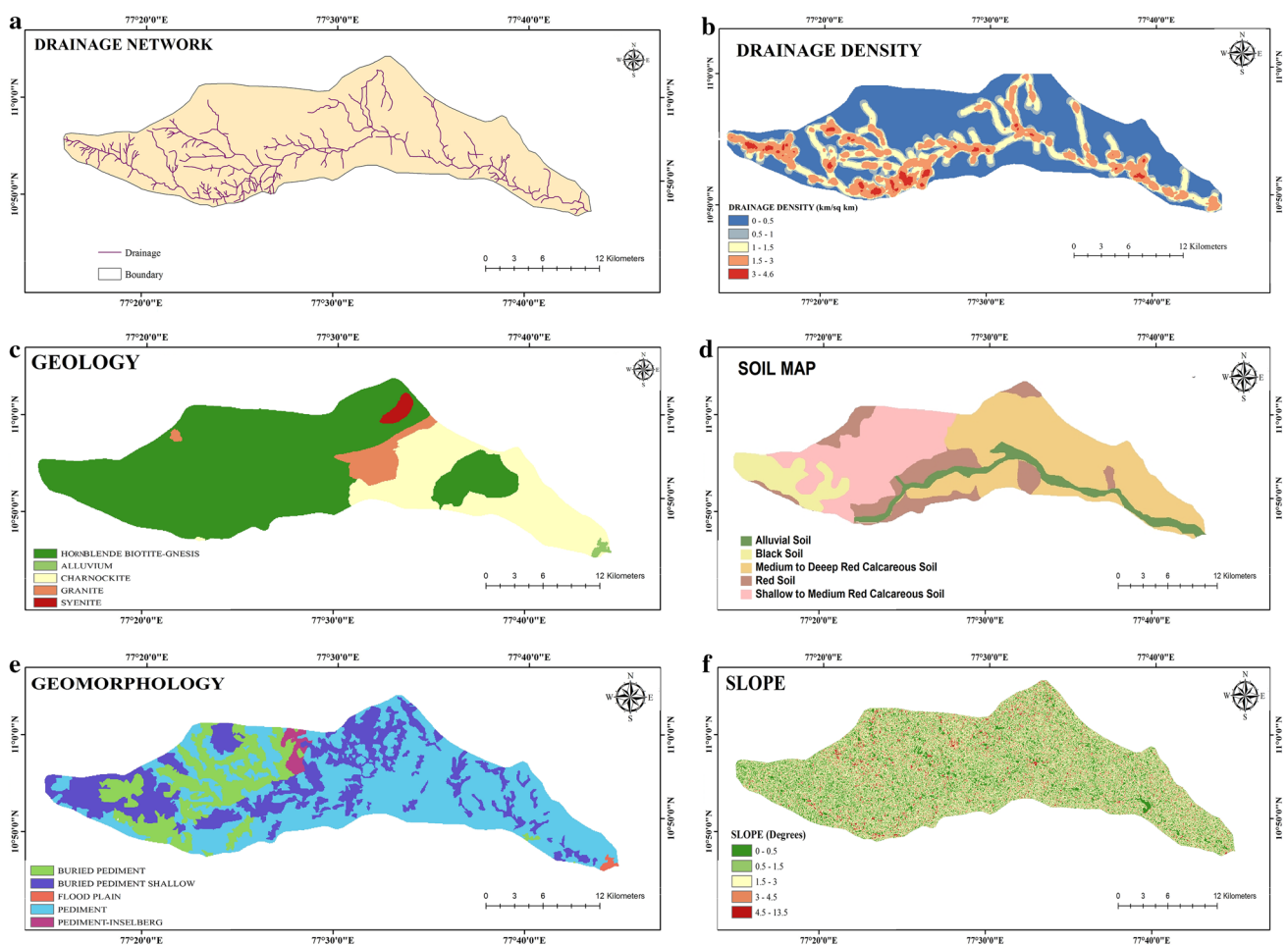
## Results and discussion

### Drainage density

The drainage map of a terrain gives details on porosity of rocks and groundwater availability (Wisler and Brater 1959; Subramani et al. 2013). The drainage map of Vattamalakarai basin was derived by digitizing the Survey of India toposheets on a 1:50,000 scale (Fig. 3a). Drainage density is considered as one of the important parameters in groundwater prospecting, as it shows an inverse function with hydraulic conductivity. The drainage density of the basin area was computed as  $Dd = L/A$ , where  $Dd$  is the drainage density of basin, ‘ $L$ ’ is the total drainage channel length of the basin (km) and ‘ $A$ ’ is the total basin area (km<sup>2</sup>). The less permeable the rock, the less does rainfall infiltrates. This creates a well-developed and fine drainage pattern.

Since the drainage density depends indirectly on the groundwater prospect due to its correlation with surface

runoff and permeability, it is considered as one of the significant indicators of a groundwater potential zone (Sedhuraman et al. 2014; Subramani et al. 2015). High drainage density indicates the surface runoff due to the underlying less permeable layer and hence possesses lesser groundwater potential. The area that comes under a high drainage density is unsuitable for groundwater occurrence. An area with moderate drainage density indicates medium groundwater potential, and the low drainage density area indicates high groundwater prospect (Todd and Mays 2005). Coarse drainage pattern reveals the existence of hard and permeable rocks, while the fine drainage pattern implies soft and impermeable rock (Karanth 1989). For groundwater prospecting, higher ranks were allocated to low drainage density zones, and lower ranks were assigned to high drainage density zones. The western and eastern part of the basin show fine and coarse drainage patterns. The drainage density of the basin (Fig. 3b) varies from 0 to 4.6 km/km<sup>2</sup>.



**Fig. 3** Thematic maps integrated for groundwater potential zonation mapping

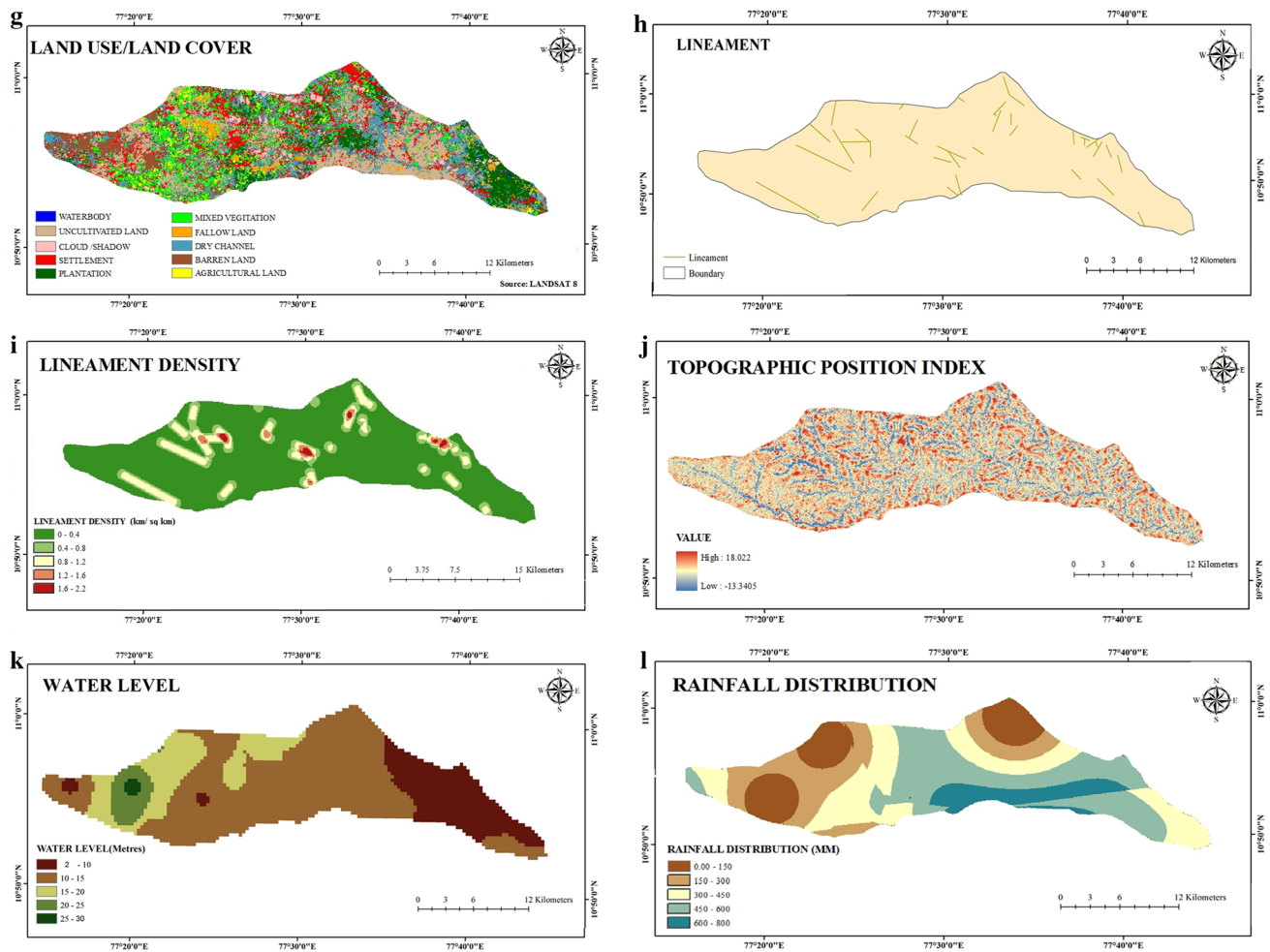


Fig. 3 (continued)

## Geology

Hema et al. (2017) reported that the groundwater occurrence and flow highly influence the porous and permeable hydrogeological zone, so that it can store and transmit water easily. The geological setting of the study area is underlain by crystalline rocks of the Peninsular Gneissic Complex comprising hornblende–biotite gneiss and charnockite. Granite, syenite and magnetite–quartzite were found as patches in the study area (Fig. 3c). The western, northern and south-eastern parts comprise hornblende–biotite gneiss and the eastern part mainly comprises charnockitic formations. The weathered formations and the secondary openings present on the hard rock act as a conduit for groundwater passage and recharge. Hence the hard rock present in the area has moderate rate of groundwater recharge. Alluvium found in the south-eastern portion of the basin has high groundwater potential zone.

## Soil

The soil zone manages the entry of surface water into the subsurface aquifer system, and also decides the rate of percolation and hydraulic conductivity (Arivalagan et al. 2014). Soil formation is influenced by geological, climatic and physiographic features. Five major soil types were identified in Vattamalaikarai basin such as alluvial soil, black soil, medium to deep red calcareous soil, shallow to medium calcareous soil and red soil (Fig. 3d). The alluvial soil is mainly found along the river course, which acts as a high groundwater potential zone. Black soil acts as poor permeable zone, and red soil is moderately permeable for groundwater recharge.

## Geomorphology

The geomorphological setting of a region may impact on the groundwater occurrence to a great extent. To understand the groundwater mechanism of a basin, correlation of the

geomorphological components with other hydrological factors is needed (Thomas et al. 2009). The flow and storage of groundwater were highly controlled by the geomorphologic units in the study area. The slope, weathering, thickness of alluvium and the different landforms are the result of the long-term denudation by the fluvial process. The various hydrogeomorphologic units present in the study area are buried pediments, shallow pediments, flood plains and pediment inselberg complexes (Fig. 3e). Weightages were given to each parameter in accordance with its influence over groundwater occurrence. Flood plain possesses high groundwater potential, whereas the other geomorphic units have moderate influence on groundwater occurrence.

### Slope

Slope is an important factor that controls the infiltration of groundwater into underground formations; hence, it serves as an indicator for demarcating the groundwater potential zone. A high relief terrain enables higher runoff and lower infiltration rate and hence those areas show less groundwater prospects with respect to the low slope areas. The slope map of the basin was prepared from digital elevation model (DEM) derived from SRTM data of 30 m resolution (Fig. 3f). Percolation of surface water will be high in the flat terrain, whereas runoff will be more in sloppy areas. The flow speed depends on the gradient (slope) in the groundwater table and the permeability of the soil. More weightages were assigned to the low and moderate slope areas, whereas less weightages were given to the steep slope areas to delineate the groundwater potential zones. The slope of the basin is classified into five categories, namely 00–0.50 (very low), 0.50–1.50 (low), 1.50–30 (moderate), 30–4.50 (high) and 4.50–13.50 (very high).

### Land use/land cover

Land use/land cover is a significant parameter in hydrological studies because it imparts major indication of the extent of groundwater necessity and usage (He and Wu 2019b). Multispectral remote sensing has been utilized for preparing map of land use/land cover (Thilagavathi et al. 2015a, b). The map was prepared using supervised classification technique from the Landsat-8 satellite imagery. Todd and Mays (2005) reported that land with vegetation is an admirable site for groundwater investigation. The places covered with water bodies are good zones for groundwater recharge, and the existence of fallow land indicates less groundwater prospecting zone (Chowdary et al. 2008). The major land use categories determined in the present study are plantation, settlement, agricultural land, mixed vegetation, fallow land, barren land and water body (Fig. 3g). Settlements mostly restrict the infiltration of rainwater and

movement of groundwater. Agricultural land particularly intensively irrigated areas posse high groundwater potential.

### Lineaments

Lineaments indicate the tectonically originating linear features, which are observed as long slender and straight tonal orientation in satellite imageries. It may refer to continuous fracture, a fault, master joint or intrusions. Straight stream courses and alignment of vegetation may result due to fault or fracture in the country rock, and hence it is generally implied as the areas of high porosity and permeability in hard rock regions. Lineaments are the most prominent parameters in groundwater prospecting studies, because they act as secondary aquifers in hard rock regions (Fig. 3h). The lineament intersections in an area help the groundwater movement and infiltration. Therefore, these areas act as high prospect zones of groundwater occurrence. The lineament density map of the basin area was prepared from the satellite imagery using GIS as shown in (Fig. 3i). High lineament density of a region proves the availability of more groundwater. In hard rock areas, the lineament intersections indicate the most productive zones for groundwater.

### Topographic position index

Topographic position index (TPI) implies the analysis of topographic landscape terrain units into the upper, middle and lower parts. TPI evaluates the elevation of every cell in a DEM to the mean elevation of specified vicinity around that cell. The mean elevation is subtracted from the elevation value at the center:

$$TPI_i = M_0 - \sum_{n=1} \frac{M_n}{n},$$

where  $M_0$  is the elevation of the model point under evaluation,  $M_n$  is the elevation of grid, and  $n$  is the the total number of surrounding points employed in the evaluation (Guisan et al. 1999; Weiss 2001; Jenness 2006). The areas near the peak of the hills exhibit high index values, while the foot of hills shows low index values. The flat ground surface or the mid sloppy region shows index value near zero. The areas with low TPI values were given higher ranks (Hema et al. 2017). The topographic position index map of Vattamalakarai basin is given in Fig. 3j.

### Water level

Groundwater level represents the top surface of the saturated zone. Any fact that creates a variation in the pressure of groundwater will induce a deviation in the groundwater level. Rainfall plays a major role in the fluctuation of water

level. Water entering the water table is referred to as the recharge from precipitation to the aquifer. The water level fluctuations of a terrain are mainly governed by variation in rainfall occurrence, groundwater recharge and discharge (Arya and Subramani 2015; Anand et al. 2019). Water table depth with respect to ground surface was measured in 70 observation wells during field visits. The groundwater level in Vattamalaikarai basin varies from 2 to 30 m (Fig. 3k). The map shows a gradual decrease in the groundwater head toward the downstream side in the study area.

### Rainfall distribution

The rainfall distribution map of Vattamalaikarai basin was prepared from the data collected from government departments (Fig. 3l). The infiltration rate of water has direct impact over the rainfall occurrence along with the slope of the terrain. Therefore, it controls the existence of groundwater in an area.

### Demarcation of groundwater potential zones

The groundwater potential zonation map was generated by integrating all the thematic layers through the weighted index overlay method. The ranking assigned for each theme is based on its influence on groundwater occurrence. In the present study, ten themes were perused for demarcating the groundwater potential zones in Vattamalaikarai River basin. The determination of weightage for each category in a theme is most decisive in integrated analysis, because the output profoundly depends on the weightages and ranks assigned. The influences of different hydrogeological and geomorphic units on groundwater occurrence were considered during weightage allocation. After integrating all the thematic layers with proper weightages and ranks (Table 2), the groundwater potential zonation map of Vattamalaikarai basin was delineated using GIS (Fig. 4).

The groundwater potential map of the study area generated using GIS was categorized into four zones such as 'low', 'moderate', 'high' and 'very high'. Very high groundwater potential zones are found in alluvial formations and in the highly weathered and fractured rocks. The map shows that a high potential zone occurs in the low drainage density areas. About 20.77% of the basin area falls under low potential zone category; 31.08% area falls under moderate category; 32.15% area falls under high potential category; and 15.99% area represents very high potential category. The 3D perspective view of the groundwater potential zones was also generated using GIS.

The groundwater potential zones delineated using GIS were finally validated with the groundwater levels measured

in 70 observations spread over the entire Vattamalaikarai River basin (Arya et al. 2018) (Fig. 5). It shows a nearly 95% accuracy. The depth of groundwater level ranged from 2 to 25.4 m with reference to the belowground level (bgl). To verify the accuracy of potential zones, water level data were overlaid with the groundwater potential map. The three-dimensional perspective view of the depth of water levels in wells are also illustrated in the map (Fig. 5). The height of lines illustrates the depth of water level. The wells located in the high potential zones have shallow groundwater level (2–5 m) represented by short lines, whereas the moderate potential areas have water level ranges from 5 to 15 m, which are indicated by medium height lines. In the poor potential zones, the depth of water level varies from 15 to 30 m, which is illustrated by longer lines. The majority of the wells located in eastern part of the basin (high groundwater potential areas) possess shallow depth of water level, whereas the wells in the western part of the basin (poor groundwater potential areas) possess deeper water level. It was also noticed during the field investigations that the areas with poor potential lacked wells. Therefore, the validation of the final output satisfactorily matches with the groundwater level data.

### Delineation of favorable zones for artificial recharge

For the sustainable groundwater resource management, artificial recharge structures play a vital role in hard rock regions. Generally in regions receiving low rainfall, people have to depend on groundwater for domestic and irrigation purposes due to the non-availability of surface water sources. Hence, the depletion of undergroundwater due to overexploitation makes the situation very alarming in several parts of the world. Now, the identification of recharge zones by using remote sensing technique incorporated with indirect analysis of directly observable topographic components like hydrogeological and geomorphic features proves to be an easy and cost-effective method for artificial recharge.

Application of geospatial technologies for the water resources mapping and management proves to have a prominent tool. People of Vattamalaikarai basin mainly depend on groundwater resources for drinking and irrigation purposes. However, the infiltration of rainwater varies from place to place and also the changes occur within the same basin due to several terrain factors and rainfall availability. Poor groundwater potential and overexploitation create serious groundwater scarcity during the summer season. Therefore, proper planning is needed in the regional and local scale for the conservation of groundwater resources through artificial recharge structures. By considering this aspect, zones favorable for artificial recharge of groundwater were

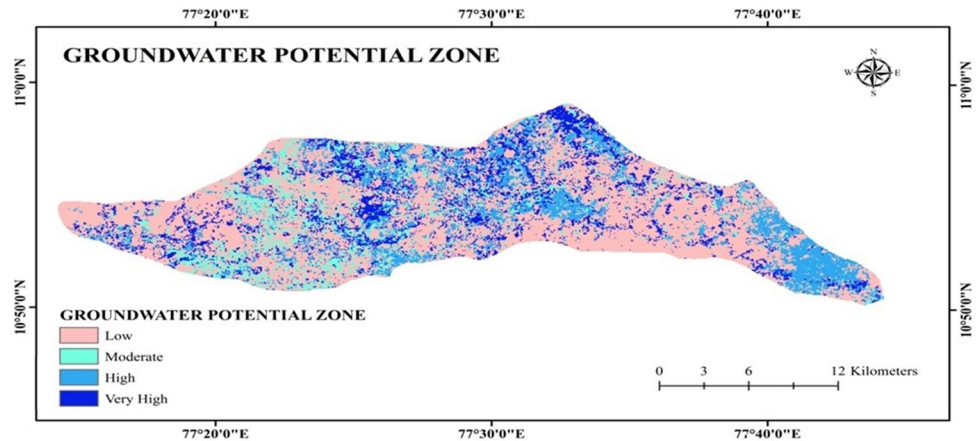
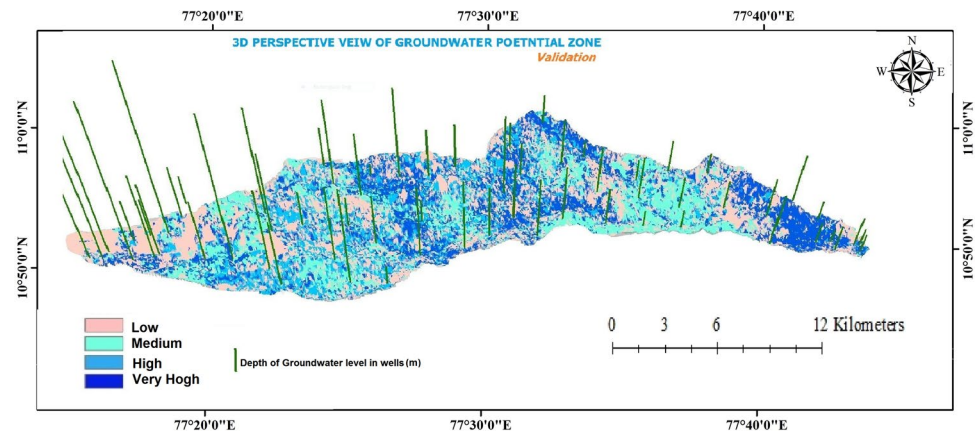


**Table 2** Ranks and weightages assigned for various themes and parameters

Themes	Parameters	Ranks	Weightages
Drainage density (km/km <sup>2</sup> )	0.0–0.5	4	5
	0.5–1		4
	1–1.5		3
	1.5–3		2
	3–4.6		1
Geology	Charnockite	8	4
	Granite		1
	Alluvium		5
	Syenite		2
	Hornblende–biotite gnesis		3
Soil	Red soil	5	4
	Black soil		1
	Alluvial soil		5
	Shallow to medium red calcareous		2
	Medium to deep red calcareous		1
Geomorphology	Buried pediment	10	4
	Buried pediment shallow		3
	Flood plain		5
	Pediment		1
	Pediment Inselberg		2
Slope (degrees)	0–0.5	6	5
	0.5–1.5		4
	1.5–3		3
	3–4.5		2
	> 4.5		1
Land use/land cover	Barren land	9	1
	Agricultural land		4
	Fallow land		3
	Water body		5
	Uncultivated land		2
	Mixed vegetation		3
	Plantation		4
	Settlement		1
Lineament density (km/km <sup>2</sup> )	0–0.2	7	1
	0.2–0.8		2
	0.8–1.4		3
	1.4–2		4
	2–2.65		5
Topographic position index (TPI)	– 13.34 to –2.69	6	5
	–2.69 to 0		4
	0 to 3.57		3
	3.57 to 10		2
	10 to 18.03		1
Water level (m)	2–10	6	5
	10–15		4
	15–20		3
	20–25		2
	25–30		1

**Table 2** (continued)

Themes	Parameters	Ranks	Weightages
Rainfall (mm)	0–150	6	1
	150–300		2
	300–450		3
	450–600		4
	600–800		5

**Fig. 4** Map showing groundwater potential zones**Fig. 5** Validation of groundwater potential zones with water levels

demarcated. In addition to the geological and hydrogeomorphological parameters, soil, land use/land cover, lineament, slope and drainage were also considered. Thorough analysis of the heterogeneous condition of underground terrain features present in the basin were studied for recharge zone delineation. As the study area falls in the hard rock terrain, the availability of primary porosity and permeability in the underlying lithological formations is very less. Lineaments also play an important role in the groundwater movement in the basin. Proper weightages and ranks were assigned based on each parameter on their role in recharge capability (Raviraj et al. 2017). The map highlights three zones, namely, 'low', 'medium' and 'high'. The category 'high' is

more favorable for artificial recharge structure construction, and possesses good water-retaining capacity and storativity. The high artificial recharge zone possesses areas with surface water bodies, flat to gentle slope, irrigation channels, lineament intersections and buried pediplains.

### Recommendation of artificial recharge structures

Artificial recharge structures aid to augment the surface water into the aquifer layers. The suggestion of suitable artificial recharge structure depends on geologic, hydrologic, hydrogeomorphic and topographic parameters (Bhowmick et al. 2014). In hard rock areas, the rainfall

runoff can be stored in the aquifers for future extraction through infiltration of water artificially. Therefore, site selection for artificial recharging highly considers the porosity, permeability and hydrogeologic parameters of the aquifers present in the area. The best artificial recharging site has the specific property of absorbing a huge quantum of water and does not transmit quickly (CGWB 2000). Based on the artificial recharge potential zone map, the favorable artificial recharge sites were selected in the basin. Four types of recharge structures, namely percolation tanks/ponds, check dams, recharge pits and injection wells/recharge wells were suggested to augment the groundwater resources (Fig. 6). Suitable areas for the construction of these artificial recharge structures were also identified.

Check dams are generally constructed across the downstream side of higher-order streams. These structures help to avoid scouring from excess runoff by enabling the percolation of water into the subsurface aquifers (CGWB 2000). Check dams were recommended at three locations across the third- and fourth-order streams in the runoff zones accompanied by low to moderate slope. Percolation ponds are normally large tanks of manmade or natural area surrounded by a bank, which stores the rainwater and infiltrates into the deeper aquifers. These structures are suggested in the low potential zones with medium to high water table fluctuations (Bhowmick et al. 2014). Four favorable sites were identified for the construction of percolation ponds in Vattamalaikarai basin to facilitate more recharge. Recharge pits allow the rainwater to replenish the groundwater in the subsurface aquifer. These pits are generally filled with stones, which facilitate the passage of water to reach the aquifer system. Ten sites were identified for the construction of recharge pits to artificially recharge the groundwater in the basin. Injection wells were mainly used to recharge the aquifer lying beneath

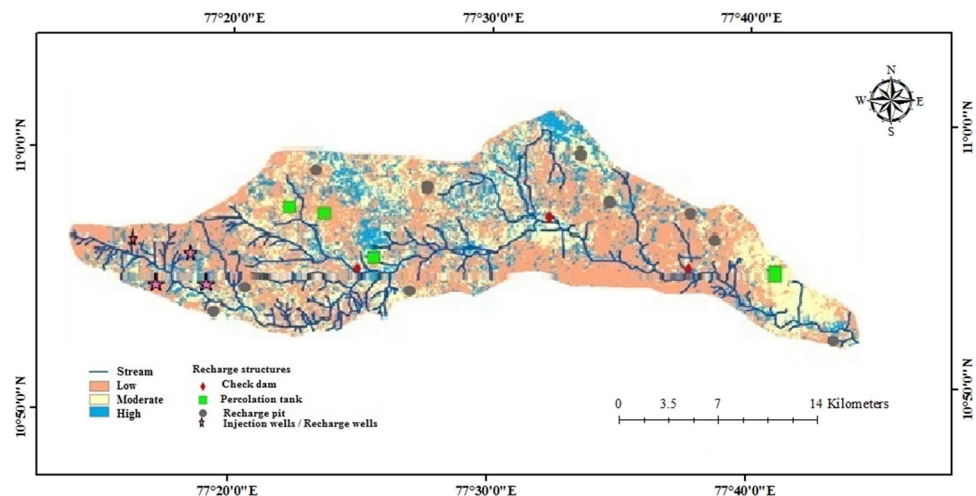
an impermeable layer (CGWB 2000). Normally, the abandoned wells in an area can be used as a recharge well. In such a situation, the depth of groundwater can be raised through injection wells/recharge wells. As the western part of the study area consists of black cotton soil with low permeability, recharge wells are required to inject rainwater into the aquifers. Therefore, four suitable locations were identified for the construction of injection wells/recharge wells.

### Conclusions

The groundwater potential zonation map was generated using remote sensing and GIS technologies by assigning proper ranks and weightages to ten themes such as geology, drainage density, soil, lineament density, geomorphology, land use/land cover, slope, topographic position index, rainfall occurrence and groundwater level. The zonation map has four categories such as ‘low’, ‘moderate’, ‘high’ and ‘very high’. Very high groundwater potential zone occupies only 16% (69.44 km<sup>2</sup>) of the total area. High groundwater potential zone occupies 32% (139.63 km<sup>2</sup>), whereas moderate and low potential zones occupy 52% (225.18 km<sup>2</sup>) of the total area. The groundwater potential map prepared using geospatial techniques was validated with the help of the available groundwater level data. It was found that the accuracy level was around 95%.

As the Vattamalaikarai Basin depends on the groundwater resources for drinking and irrigation purposes, it is required to evaluate the groundwater prospect for the better management of water resources. The less availability of groundwater and overexploitation cause serious groundwater scarcity during summer season. Therefore, favorable recharge zones were identified using geospatial techniques for artificial recharge of groundwater. Eventually, suitable sites were

**Fig. 6** Map showing groundwater recharge zones with artificial recharge structures



opted for the construction of artificial recharge structures to augment groundwater resources. Three sites across the third- and fourth-order streams in the runoff zones were chosen for the construction of check dams. Four favorable sites and ten locations were selected for the construction of percolation ponds and recharge pits, respectively. By considering the existence of low permeable soil and high fluctuation of groundwater in the western portion of the basin, four locations were suggested to construct injection/recharge wells.

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