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Groundwater potential mapping and natural remediation through artificial recharge structures in Vellore District, Tamil Nadu, India using geospatial techniques

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ABSTRACT

The main objective of the present study is groundwater potential mapping and natural remediation through artificial recharge structures in Vellore District, Tamil Nadu, India using geospatial techniques. Water is an important essential renewal resource, without which life cannot exist on the earth. Water scarcity problems are increasing day by day throughout the Vellore District due to the increasing needs for various applications like domestic, agriculture and industries. Unpredictable variation in the occurrence of precipitation with respect to space and time creates droughts and floods in many places. In the Vellore District delineating groundwater potential zones with the aid of geospatial techniques and suggestion of suitable sites and structures for artificial recharge of groundwater is much important. According to research, the area of groundwater occurrence in good water is 382 km^2, moderate water is 736.3 km^2, and 18 villages have 'poor' occurrences of 586.7 km^2, which require immediate attention to improve the scenario through artificial recharge. Because rainfall recharge dilutes ion concentrations in groundwater during the NE and SW monsoon seasons, the study recommends implementing artificial recharge techniques such as constructing a percolation tank across a Palar River stream, constructing a check dam across a Palar River channel, and introducing injection wells to place fluid underground into porous geologic formations in this region.

Keywords: Artificial recharge structures; Geospatial techniques; Groundwater potential; India; Natural remediation; Vellore District

1. Introduction

In groundwater research, remote sensing techniques (RST) and geographic information system (GIS) have created new directions [1–3]. Remote sensing has become a very useful method, with its advantages of spatial, spectral and temporal availability of data covering wide and inaccessible areas within a short time in gathering, transforming, storing, retrieving, analyzing and displaying spatial data [38]. It is used for a range of purposes, such as recharge site viability, surface and groundwater resources assessment, hazardous site detection, etc. [40]. Satellite images offer useful and quick baseline information on the

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themes like geology, lineaments, geomorphology, land use/land cover, drainage etc., [4,5]. RST and GIS approaches have been successfully used to target and recharge groundwater [6–8].

Groundwater potential zones can be easily demarcated using integrated techniques of remote sensing and GIS [9–12]. Used various thematic maps prepared using geospatial techniques for the measurement of groundwater resources in the basin of the Chithar River, Tamil Nadu, India [13–15]. In hard rock regions, groundwater availability is of limited extent. Groundwater occurrence in hard rock aquifers is essentially restricted to fractured and weathered horizons [16,17].

Water supply for drinking and irrigation practices in the study area mainly depends on the available groundwater resources [18–20]. As this basin receives less precipitation and the surface water resources are not adequate to fulfil 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 [39–41].

2. Experimental section

2.1. Study area

The Study area is located in the north of Tamil Nadu, South India. The available Survey of India (SOI) Toposheet (SOI, 2011) Number is 57 L/8, 57 L/9, 57 L/10 and 57 L/11 with latitude 12°35′0″ - 12°55′0″ N and longitude 78°30′00″ - 78°50′00″ E (Fig. 1). The complete geographical area is 1,727 km^2.The common elevation ranges from 220 to 351 m above the mean sea level (MSL) [21,22]. The city has a semi-arid climate, 135 km west of the state capital Chennai. Vellore lies in the Eastern Ghats region and Palar River basin. The topography is almost plain with slopes from west to east. The temperature ranges from 13°C (55°F) to 39.4°C (102.9°F). Like the rest of the state, April to June are the hottest months and December to January are the coldest. The most common types of hard rock formations in this area are the Gneisses and Charnockites. The Gneissic formations are found in almost all the taluks of the district but lack uniformly both in composition and texture. Different names are attributed to the Gneissic formation based on its mineral content. The sedimentary or the quarternary alluvial deposits which are the transported sediments by the river and streams stretch mainly along the Palar River course as thin isolated patches. These formations overlie the hard rock formation [23].

2.2. Materials and methods

The groundwater potential zones in the study area were demarcated by integrating different thematic maps using remote sensing and GIS techniques. Geological map of the area was prepared from the geological quadrangle map published by the Geological Survey of India (GSI). Other thematic maps such as geomorphology, drainage, lineament, land use/land cover, soil and slope were prepared from the satellite data (LANDSAT image of Path: 102 and Row: 125, 2018, Earth Explorer and SRTM) using GIS. By integrating all the thematic layers groundwater potential zone map was generated. Integration of various thematic maps was carried out using GIS in the following three steps:

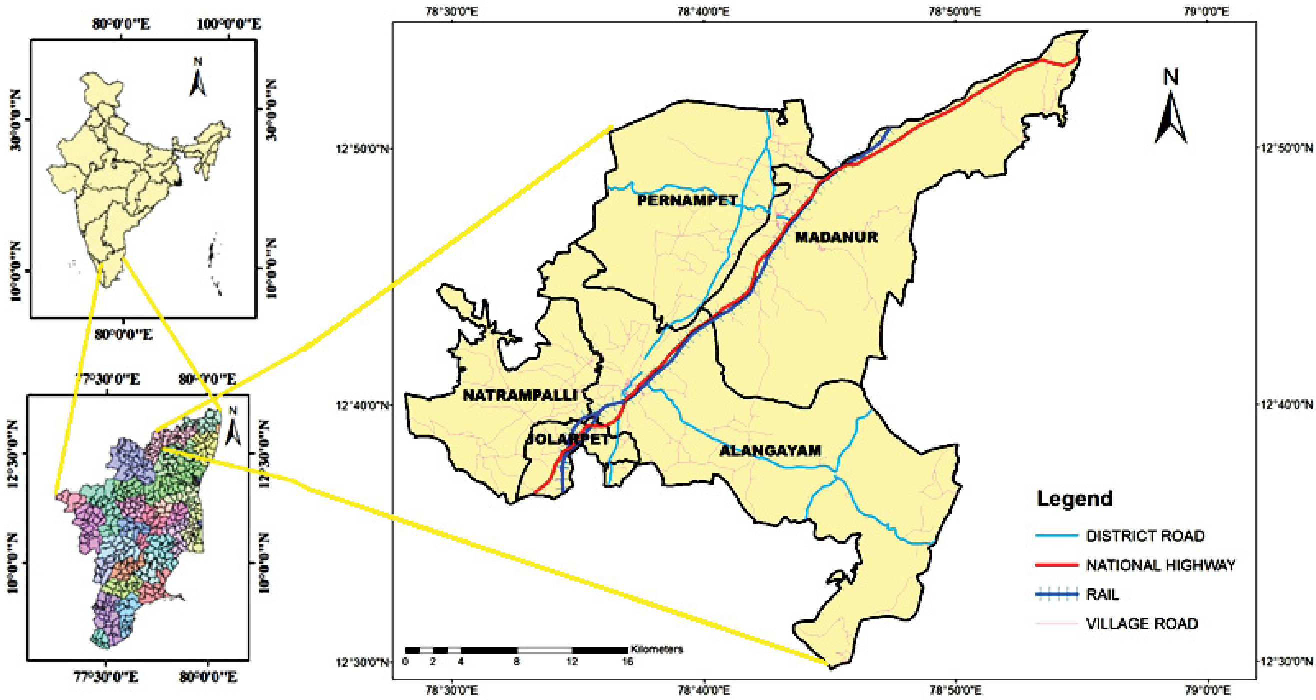

Fig. 1. Study area map.

2.2.1. Spatial database building

By digitizing scanned maps, editing for errors, topology building, attribute assignment, and projection, all the thematic maps were generated using GIS software [24–26].

2.2.2. Spatial data analysis

The groundwater prospect map was prepared for the study area by incorporating the hydrogeomorphic, linear, geological, slope, and soil maps along with drainage patterns. Based on its degree of impact on groundwater recharge and storage, each theme was considered and assigned a weightage. Groundwater prospect maps were prepared by combining all these thematic maps and adding restricted groundwater level data. Different geological formations that develop a range of landforms such as structural hills, pediments, buried pediments, and valley fills have different water keeping abilities that show varied qualities of aquifers [27,28].

2.2.3. Data integration

Each thematic map provides some information on the occurrence of groundwater, such as geology, geomorphology, drainage, drainage density, line, line density, soil, slope, and land use/land cover. To find the intersecting polygons, each theme was overlaid on another theme. A new map was obtained by combining two thematic maps in this way. This composite map was subsequently overlaid, and so on, on a third thematic map. So there was a final composite map made. Weighting was allocated to each polygon in the final map using a basic arithmetic model, and the possible groundwater zones were demarcated and classified into three zones: (i) Good, (ii) Moderate, and (iii) Bad. The methodology followed in this study is depicted in Fig. 2 [29,30].

3. Results and discussion

3.1. Geology

The study area is rocky in nature, which is chiefly made up of gneisic and charnokite formations. Alkali rocks and acid intrusions are also noticed in few places. Alluvial formations are seen all along the river course (Geological Survey of India 1995). The geological map of the study region is shown in Fig. 3a [31–34]. Aerial extent of different rock types, ranks and weightages assigned to each rock type are presented in Table 1. In this area having 414.48 km^2 (24%) of Charnockite group and assigned rank of 4,131.943 km^2 (7.64%) of alluvial formation and assigned rank of 5,998.20 km^2 (57.8%) of Peninsular Gneiss and assigned rank of 414.67 km^2 (0.85%) of acid intrusions and migmatite complex and assigned rank of

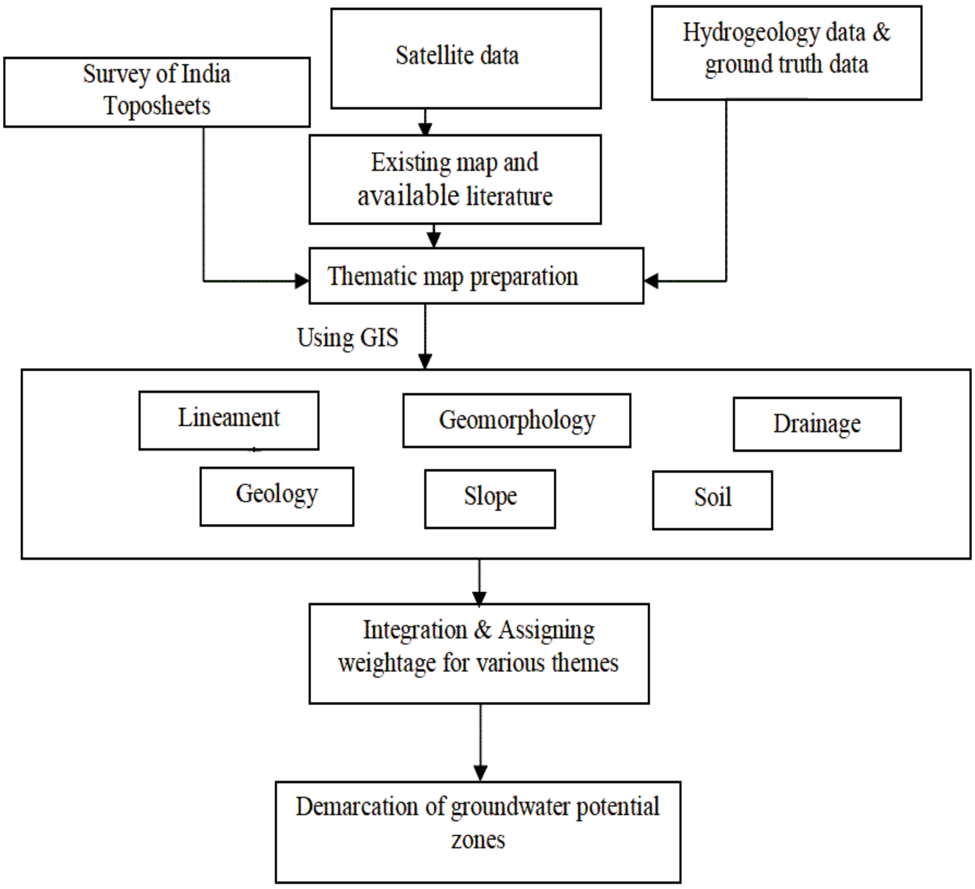

Fig. 2. Methodology flowchart for groundwater potential zonation mapping.

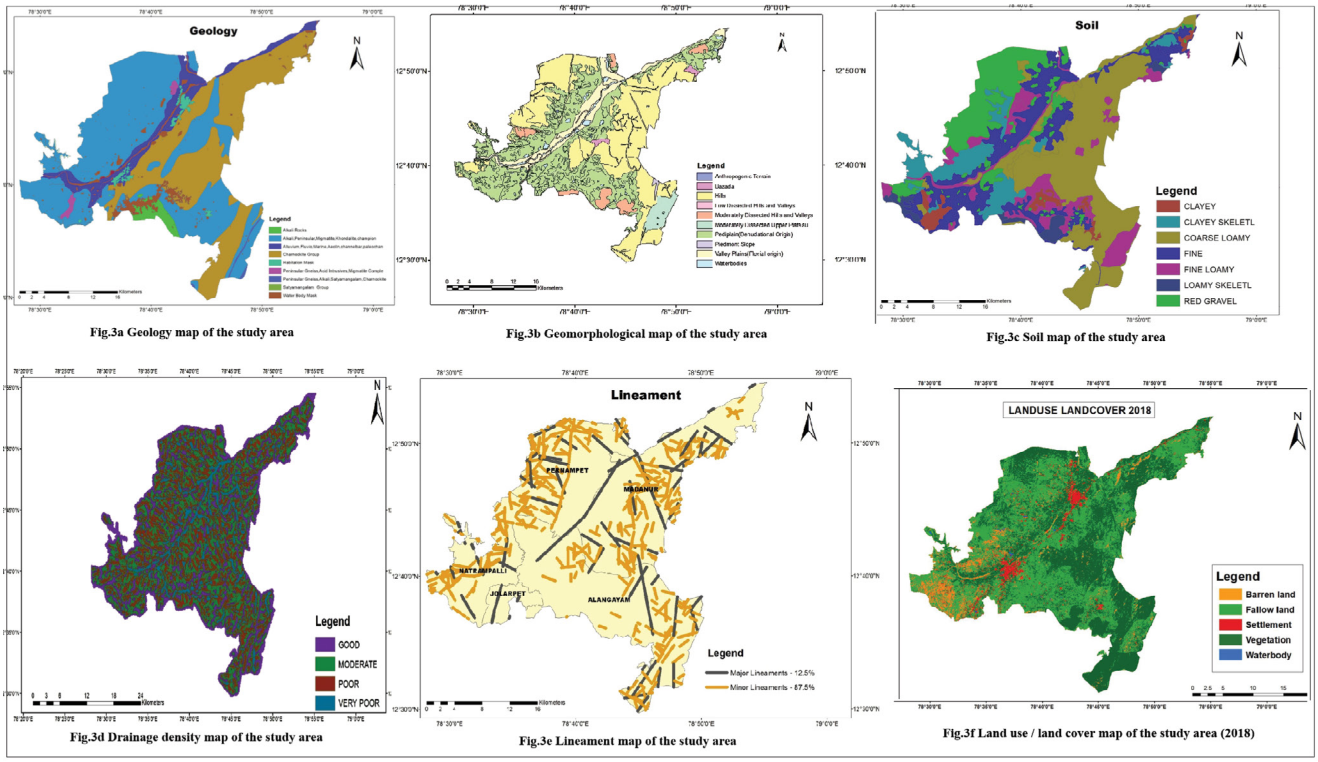

Fig. 3. Geology, geomorphological, soil, drainage density, lineament, land use/land cover map of the study area.

2,114.837 km² (6.65%) of alkali rocks and assigned rank of 1 and 52.24 km² (3.06%) of Sathyamangalam group here assigned rank of 3.

3.2. Geomorphology

Various geomorphic landforms in the study area were identified from the LANDSAT imageries. The study region is classified into two major physiographic divisions viz., (i) hilly terrain noticed all along the eastern boundary and in the north western part and (ii) plain regions in the central and south-western parts. The major hill ranges in this region belong to Jawadu hills. The landscape in the hilly terrain is undulating to rugged, flanked by hill ranges belonging to Eastern Ghats. Undulating plains are having isolated hillocks with sharply rising peaks. The hills are mostly sloping towards east. The various geomorphic features in the study area are illustrated in the Fig. 3b Ranks and weightages assigned for different geomorphic features are given in Table 1. In this area having 3.63 km² (0.21%) of Bazada and assigned rank of 5,177.28 km² (10.3%) of valley plains (fluvial origin) and assigned rank of 521.6 km² (1.25%) of Piedmont slope and assigned rank of 222 km² (1.3%) of water bodies and assigned rank of 2,527.92 km² (30.6%) of hills and assigned rank of 12.41 km² (0.14%) of low dissected hills and valleys and assigned rank of 2,837.22 km² (48.5%) of pediplain (denudational origin) and assigned rank of 358.71 km² (3.4%) of moderately dissected hills and valleys and assigned rank of 416.23 km² (0.94%) of moderately dissected upper plateau and assigned rank of 1 and 60 km² (3.4%) of settlement/ industries and assigned rank of 2.

3.3. Soil

Soils in the study area were classified into seven categories viz., (1) clayey, (2) clayey skeletal, (3) coarse loamy, (4) fine (silt), (5) fine loamy, (6) loamy skeletal and (7) red gravel (Fig. 3c). Aerial occurrences, weightages and ranks assigned for various soil categories are given in Table 1. In this area having 199.12 km² (11.53%) of fine soil (silt) and assigned rank of 3,132.11 km² (7.65%) of red gravel and assigned rank of 5,217.42 km² (12.59%) of fine loamy and assigned rank of 41,050.4 km² (60.82%) of coarse loamy and assigned rank of 371.56 km² (4.15%) of clayey skeletal and assigned rank of 218.74 km² (1.08%) of clayey and assigned rank of 1 and 37.65 km² (2.18%) of loamy skeletal and assigned rank of 4.

3.4. Drainage density

Subsurface hydrogeological conditions of any area is mostly controlled by the drainage characteristics of the basin that leads to decipher the groundwater condition. Drainage density influences the following factors such as initial slope, differences in rock resistance, structural controls and morphological history of the basin [35]. It is also useful for the analysis of geomorphic features and for tracing landform evolution.

For the study area, the drainage map was initially prepared along with different tributaries from the Survey of India (SOI) topographical maps on 1:50,000 scale and revised with the help of satellite pictures (Fig. 3d).

Due to its relationship to surface runoff and infiltration, the drainage density may indirectly indicate the groundwater potential of an area [36]. More drainage density is an

Table 1
Ranks and weightages assigned for different features

Ranks and weightages assigned for different geological formations				
S. No	Type weightage assigned = 20	Area in %	Area in km^2	Rank
1	Charnockite group	24	414.48	4
2	Alluvial formation	7.64	131.943	5
3	Peninsular Gneiss	57.8	998.20	4
4	Acid intrusions and migmatite complex	0.85	14.67	2
5	Alkali rocks	6.65	114.837	1
6	Sathyamangalam group	3.06	52.24	3
Ranks and weightages assigned for different geomorphological features				
S. No	Type weightage assigned = 15	Area in %	Area in km^2	Rank
1	Bazada	0.21	3.63	5
2	Valley plains (fluvial origin)	10.3	177.28	5
3	Piedmont slope	1.25	21.6	2
4	Water bodies	1.3	22	2
5	Hills	30.6	527.92	1
6	Low dissected hills and valleys	0.14	2.41	2
7	Pediplain (denudational origin)	48.5	837.22	3
8	Moderately dissected hills and valleys	3.4	58.71	4
9	Moderately dissected upper plateau	0.94	16.23	1
10	Settlement/Industries	3.5	60	2
Ranks and weightages assigned for different soil types in the study area				
S. No	Type weightage assigned = 15	Area in %	Area in km^2	Rank
1	Fine soil (silt)	11.53	199.12	3
2	Red gravel	7.65	132.11	5
3	Fine loamy	12.59	217.42	4
4	Coarse loamy	60.82	1,050.4	3
5	Clayey skeletal	4.15	71.56	2
6	Clayey	1.08	18.74	1
7	Loamy skeletal	2.18	37.65	4
Ranks and weightages assigned for different drainage density categories				
S. No.	Range weightage assigned = 20	Groundwater potential	Rank	
1	<50	Good	1	
2	50–100	Moderate	2	
3	100–150	Poor	3	
4	>150	Very poor	4	
Ranks and weightages assigned for different lineament densities				
S. No.	Type weightage assigned = 10	Area in %	Area in km^2	Rank
1	Minor	87.5	1,513.16	1
2	Major	12.5	213.84	2
Ranks and weightages assigned for different land use/land cover categories				
S. No.	Type weightage assigned = 10	Area in %	Area in km^2	Rank
1	Vegetation	40.5	700	5
2	Settlement	3.5	60	2
3	Water body	1.3	22	1
4	Fallow land	37.3	644	4
5	Barren land	17.4	301	3
Ranks and weightages assigned for different slope categories				
S. No.	Range weightage assigned = 10	Groundwater potential	Rank	
1	0°–5°	Very Good	5	
2	5°–10°	Good	4	
3	10°–20°	Moderate	3	
4	20°–30°	Poor	2	
5	30°–60°	Very Poor	1	

Table 2
Villages falling under various groundwaters potential categories

Good	Moderate	Poor
Pullur	Mallangunda	Naickanoor
Ambalur	Nayanaseruvu	Bheemakulam
Govindapuram	Chinnamottur	Nekkanamalai
Vaniyambadi	Ponneri	Nacharkuppam
Kannadikuppam	Thekkupattu	Kallaparai
Minnur	Jolarpet	Asanampattu
Alankuppam	Kalendira	Thenpudipattu
Solur	Vallipattu	Nayakaneri
Vengili	Reddiyur	Kuppampalayam
Madanur	Kothakottai	Arimalai
Kammiyambattu	Vellakuttai	Kommeswaram
	Alangayam	Palur
	Poongulam	Thirumalaikuppam
	Periyankuppam	Madakadappa
	Somalapuram	Chinthagambenta
	Kilmurungai	Peddur
	Gollamangalam	Pernampet
	Pallikuppam	Gudiyatham
	Thollapalli	
	Nattrampalli	
	Kollapalli	
	Thumberi	
	Velathigamanibenta	
	Elayanagaram	

indicator of more surface runoff whereas less drainage density is an indicator of more infiltration. Ranks and weightages were assigned to different drainage density categories as shown in Table 1.

3.5. Lineament density

Lineaments are long direct common surface and subsurface cracks, with significant highlights of secondary porosity in hard rock areas. These lineaments are remarkably useful for the groundwater occurrence and movement. Lineaments of the study area were mapped from the satellite imageries. In the eastern and southwestern part of the study area, most of the lineaments are in the NE-SW trend, whereas in the central part, both NE-SW and NW-SE trending lineaments are identified (Fig. 3e). Ranks and weightages were assigned to different lineament density categories as shown in Table 1. High lineament density will promote more groundwater recharge whereas low density will promote less recharge.

3.6. Land use/land cover

Land use/land cover map of 2018 was prepared from the satellite data using supervised classification technique. Five major categories are included in the map such as barren land, fallow land, settlements including industries, vegetation including unwanted bushes and water bodies (Fig. 3f). The aerial occupancy of different land use/land cover categories and the ranks and weightages assigned to them are shown in Table 1.

3.7. Slope

Slope map of the study area was prepared from the SRTM satellite data and rechecked with topographical (SOI) maps (Fig. 4a). Slope is one of the important controlling factor for surface runoff and infiltration. Therefore, groundwater occurrence depends on the topographical variations. Less slope is more favourable and steep slope is least favourable for groundwater prospecting. According to this, ranks and weightages were assigned to different categories of slope (Table 1).

3.8. Weighted index overlay analysis

The identification of possible groundwater zones requires an integrated method that takes different parameters such as geomorphology, drainage density, line density, slope and soil into account [37].

Thematic data for the assessment of possible groundwater zones in the study area has been incorporated, by using remote sensing and GIS techniques. In a variety of landforms such as structural hills, pediments, submerged pediments, and valley fills, various geological characteristics have different abilities to retain water, demonstrating differing qualities of aquifers. Weighted index overlay analysis (WIOA) is an easy and straightforward way to evaluate multi-class maps in combination. The value of this approach is that this research can be combined with human judgment. The relative significance of a parameter and the purpose are expressed by a weight. For a simple weighted overlay system, there is no standard scale. For this reason, the analysis criteria are specified and each parameter is given its proper significance. Geology, geomorphology, line density, drainage density, land use/land cover, slope, and soil thematic maps provide useful groundwater occurrence information. In order to unify all this information, it is necessary to integrate this data with the correct factor, and this information can also be manually superimposed. Therefore, numerically, through the application of GIS, this information is integrated. On the basis of assigned weighting, various thematic maps are reclassified. Groundwater potential zones were delineated to evaluate the groundwater availability in the study area using remote sensing and GIS techniques on the basis of the groundwater potential index (GWPI) value. Using ArcGIS 10.3 software, seven different thematic layers were integrated to generate the GWPI for the study area. This method is related to the locations of geographical phenomena being studied together with their spatial dimension and associated attributes. A composite GWPI for the study area is therefore generated using raster calculator tools in ArcGIS on the basis of which the final groundwater potential zonation map has been generated. The following formulae Eq. (1) has been used for the calculation of GWPI:

$$\mathrm{GWPI} = \frac{\begin{pmatrix} \mathrm{Gg}^{w}\mathrm{Gg}^{r} + \mathrm{Gm}^{w}\mathrm{Gm}^{r} + \mathrm{Dd}^{w}\mathrm{Dd}^{r} + \mathrm{Ld}^{w}\mathrm{Ld}^{r} + \\ \mathrm{LULC}^{w}\mathrm{LULC}^{r} + \mathrm{SL}^{w}\mathrm{SL}^{r} + \mathrm{ST}^{w}\mathrm{ST}^{r} \end{pmatrix}}{\text{Total Weightage}} \quad (1)$$

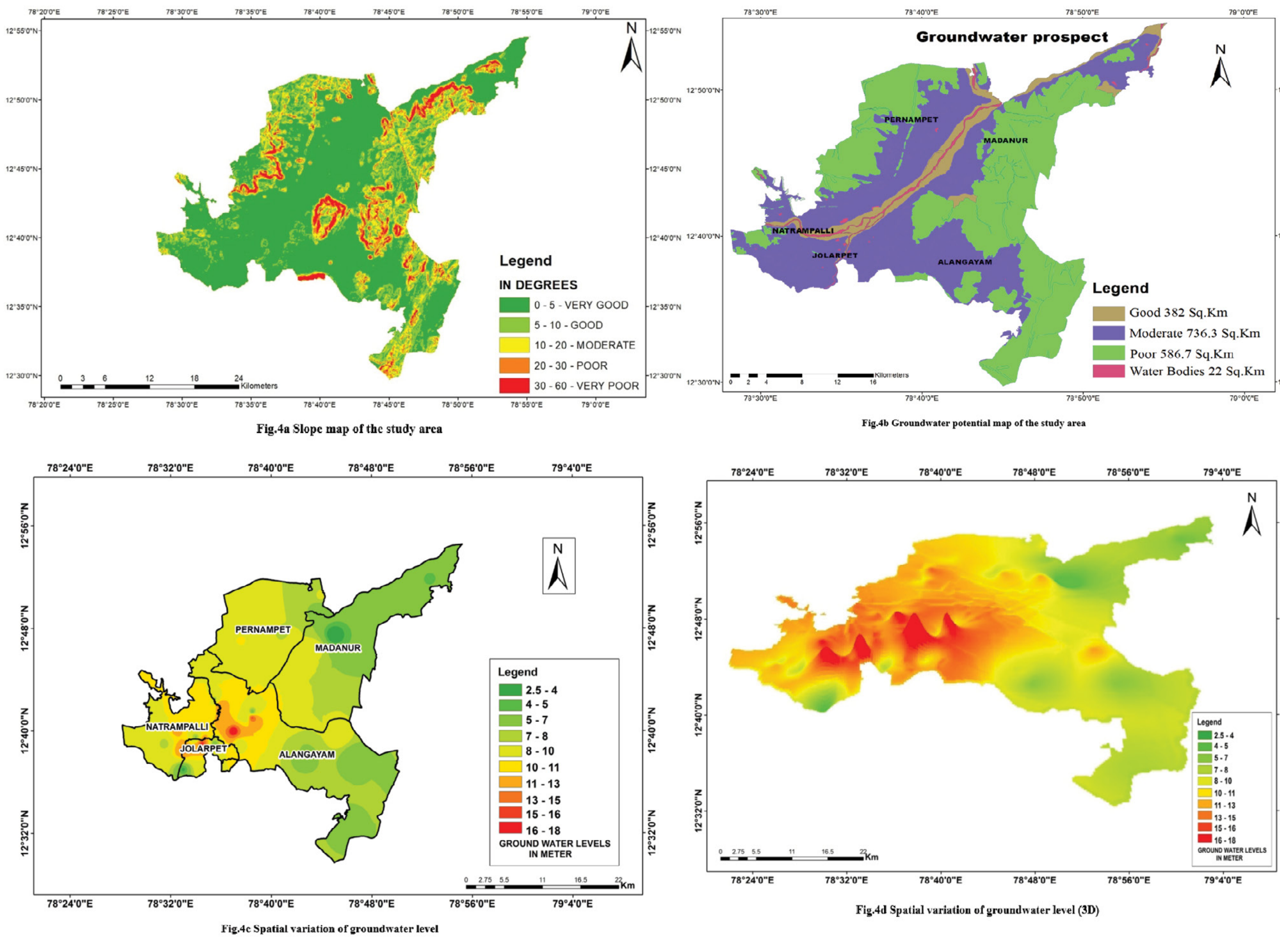

Fig. 4. Slope, groundwater potential, spatial variation of groundwater level, spatial variation of groundwater level (3D).

Due to the heterogeneous existence of the rock formations exhibiting varying composition, compaction, and degree of weathering, the groundwater conditions in crystalline hard rock terrain are multivariate.

3.9. Groundwater potential zones

For the Study Area, groundwater potential map was created by integrating various themes using GIS. Three categories namely good, moderate and poor were suggested in the output (Fig. 4b).

Good groundwater potential zones are mostly associated with the river bed. Moderate potential zones fall in the plain areas whereas poor potential areas are mostly in the hilly regions. The study also identified the major villages falling under different categories of groundwater occurrence (Table 2). There are 18 villages falling under poor occurrence of groundwater, which need immediate attention to improve the scenario. 24 and 11 villages are representing moderate and good groundwater potential categories respectively.

Groundwater levels were measured during field investigations. The average shallow depth of groundwater in the study area is 2.5 m whereas the maximum depth is noticed up to 18 m in the open wells. The spatial variation of groundwater levels with respect to ground surface was plotted using GIS (Fig. 4c). It is also represented in 3D using GIS (Fig. 4d). Water level data is not perfectly matching with the groundwater potential map because extensive pumping is done in the alluvial formations adjunct to the river bed for drinking water supply and agricultural purposes. Therefore, water level is much lowered wherever groundwater occurrence and yield are good.

3.10. Artificial recharge structures

The alluvial formations, bajada zones and deep pediments are the most suitable locations for artificial recharge of groundwater in hard rock areas. Lineament intersections are also favorable for injection wells. In the present study suitable sites were identified for the different artificial recharge structures such as injection wells, percolation tanks and check dams (Fig. 5). These structures will not only improve the groundwater potential but also enhance the quality of the groundwater. It is the best and natural remediation for improving groundwater quality and quantity.

4. Conclusions

Groundwater potential studies carried out using geospatial techniques indicate that groundwater occurrence is good all along the Palar River course. Eighteen villages have been

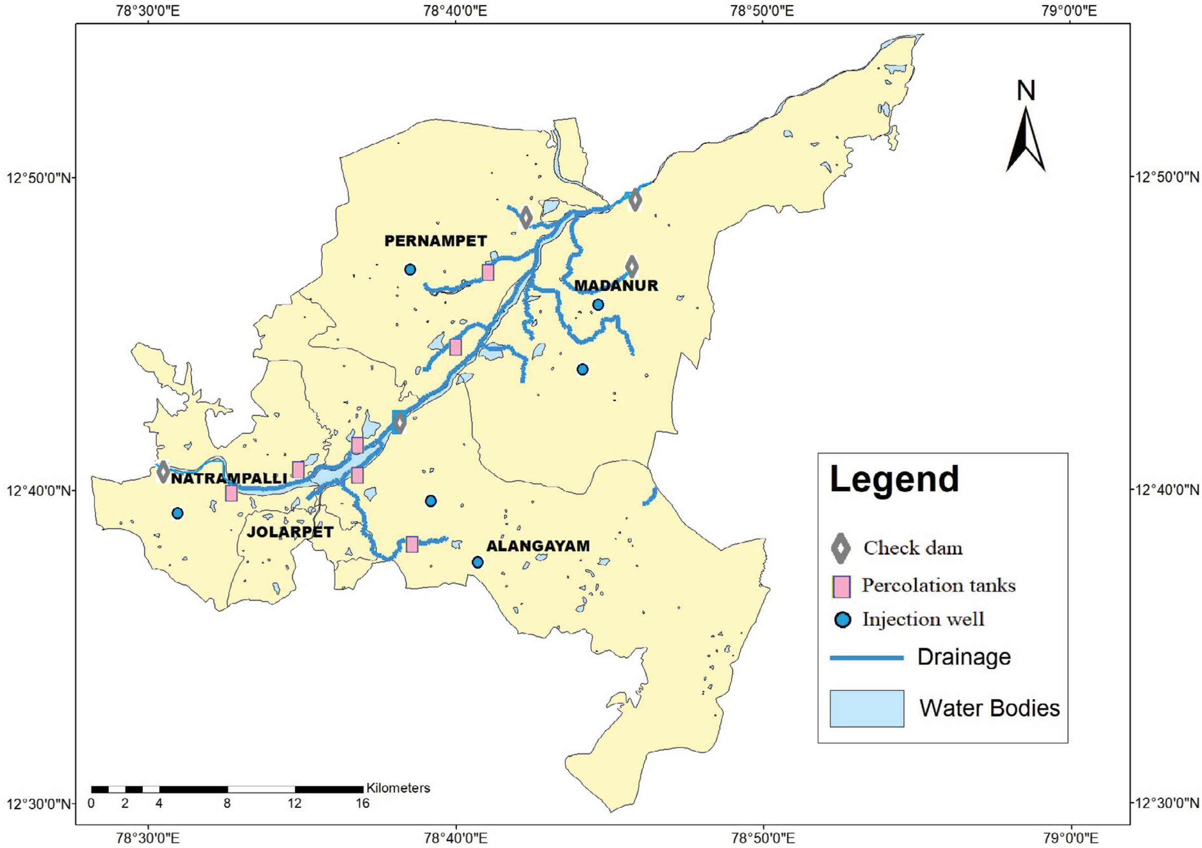

Fig. 5. Locations of different artificial recharge structures for augmentation of groundwater.

identified as 'poor' occurrence of groundwater, which need immediate attention to improve the scenario. Twenty-four and eleven villages are possessing 'moderate' and 'good' groundwater potentials respectively. As the groundwater quality is naturally improved in this region by the infiltration of NE and SW monsoon rains suitable sites for the construction of artificial recharge structures (check dams, percolation tanks and injection wells) have been identified. The study finally recommends the artificial recharge of groundwater as one of the best natural remedy for improving groundwater quality and quantity.

Author contributions

V G: conceived, designed, conducted, analysis interpretation of data and drafted the manuscript.

S T: conducted the literature search and drafted the manuscript. J S: drafted the manuscript. S G: was involved in the analysis interpretation of data. All authors read and approved the final manuscript.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2021.111238.

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