Mapping Of Groundwater Potential Zones In Pulampatti Watershed, Dharmapuri District – A Geospatial Approach

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Abstract

The estimation of groundwater resources for the district has shown that under over exploited category. Hence, there is a need for demarcation of potential groundwater zones. The present study deals with the utilization of GIS based analytical hierarchy process (AHP) technique for identification of the groundwater potential zones in Pulampatti watershed, Dharmapuri district. Various thematic layers that influence the groundwater occurrence in an area are lithology, geomorphology, lineaments density, drainage density, slope, landuse/land cover, soil, and elevation. All these themes and their individual features are then assigned weights according to their relative importance in groundwater occurrence and the corresponding normalized weights were obtained based on the analytical hierarchy process. Finally, all the thematic layers were integrated using weighted overlay analysis in GIS environment to generate a groundwater potential map of the study area, viz., good, moderate and poor. It has been concluded that about 629.79 km^2 area has good groundwater potential which is 37.20% of the total study area. However, the area having moderate and poor groundwater potential is about 58.33 km^2 and 1005.02 km^2 respectively. Finally, the groundwater potential map was verified using the well yield data of 39 pumping wells with average potential yield value of ≥44 m^3/h, and the result was found satisfactory. The produced groundwater potential map could be used to formulate an efficient groundwater management plan for the study area so as to ensure sustainable utilization of scarce groundwater resources.

Keywords: Groundwater Potential Zone, analytical hierarchy process, GIS, Pulampatti watershed.

1. Introduction

Groundwater is one of the most valuable natural resources, and supports human life, economic development and ecological diversity. The main source for ground water is precipitation resulting in drainage flows through fracture zone on the earth surface. In the world scenario, the availability of groundwater is reducing gradually due to over exploitation, and the lack of groundwater management. In India, more than 90% of the rural and nearly 30% of the urban population depend on groundwater for meeting their drinking and domestic requirements (Reddy et al., 1996). Hence, it is necessary to understand the methods and way to approach towards groundwater potential zones and surface water conservation and to improve the groundwater level at the national, regional, and local scale for sustainable livelihood. Groundwater studies have become crucial not only for targeting groundwater potential zone, but also for monitoring and conserving this vital resource.

Geospatial technology, with its advantages of spatial, spectral and temporal availability of data covering large and inaccessible areas within a short time, has emerged as a very useful tool for the assessment, monitoring and management of groundwater resources (Singh et al. 2013). Geospatial techniques provide a rapid and cost effective tool for generating valuable geo-data (geology, geomorphology, landuse/land cover, lineaments/structures and slope, etc.) both directly and indirectly, that can be used in deciphering groundwater potential zones (Dar et al. 2011; Singh et al. 2014). Recently, there are several research study were conducted on groundwater targeting with successful results through different methodologies. Remote sensing and GIS techniques have been effectively utilized as a tool to delineate groundwater potential zones in various parts of India (Ramasamy et al. 1989; Anbazhagan et al. 2001; Neelakantan and Yuvaraj 2012; Gnanachandrasamy et al. 2018). Multi-criteria decision analysis (MCDA) is effective tools for providing a framework for groundwater resource management (Pietersen

2006; Madrucci et al. 2008; Jha et al. 2010). The AHP method is one of the most widely used MCDA models, which has also been to obtain spatial plan, resource allocation etc. Additionally, the AHP tool is a suitable technique for evaluating the consistency of the result, consequently reducing the bias in the decision making process (Saaty 1990). AHP has been accepted by the international scientific community as a very useful tool for dealing with complex decision problems. Its major innovation was the introduction of pair-wise comparisons. AHP technique analyzes the multiple datasets in a pair-wise comparison matrix, which is used to calculate the geometric mean and normalized weight of parameters (Omid Rahmati et al. 2015; Vijay Prabhu et al. 2016; Aenumula Mallikarjun et al. 2018; Arulbalaji et al. 2019). The AHP has been successfully applied in several studies of water resource management by integrating MCDA with RS and GIS techniques (Shashank Shekhar and Arvind Chandra Pandey 2014; Muralitharan and Palanivel 2015; Jothibasu and Anbazhagan 2016; Domingos Pinto et al. 2017; Biswajit Das et al. 2018).

In the present study, analytic hierarchy process and GIS technique used to determine the ground water potential zones in pulampatti watershed. Development of groundwater in the study area is through construction of dug wells. The groundwater is being continuously exploited for drinking and irrigation purposes, it is essential to delineate the groundwater potential zones. Therefore, the various thematic layers, such as geomorphology, lithology, drainage density, lineament density, landuse/land cover, slope, soil, and elevation were prepared using remote sensing and GIS technique and identifying groundwater potential zones.

2. Study area

Pulamapatti watershed is located in Dharmapuri district, Tamil Nadu with an area of 1,701.69 km^2. It is located between 78°00' to 78°35'E longitude and 12°00' to 12°31'N latitude and covers SOI toposheets 57L/2, L/3, L/4, L/7, L/8 and L/12 on 1:50,000 scale (Fig.1). The main River is Ponnaiyar and split into Pulampatti and Semmandakuppam River at near Kambainellur. The River originates and flowing towards south eastern side of watershed. Physiographically the study area is covered by undulating plain and upland plateau. The watershed is predominantly covered with Archaean crystalline formations of Charnockite and gneissic rocks. The average annual rainfall is around 978mm. The lowest temperature is reached in January is about 19°C. April and May are the hottest months of the temperature of about 37°C.

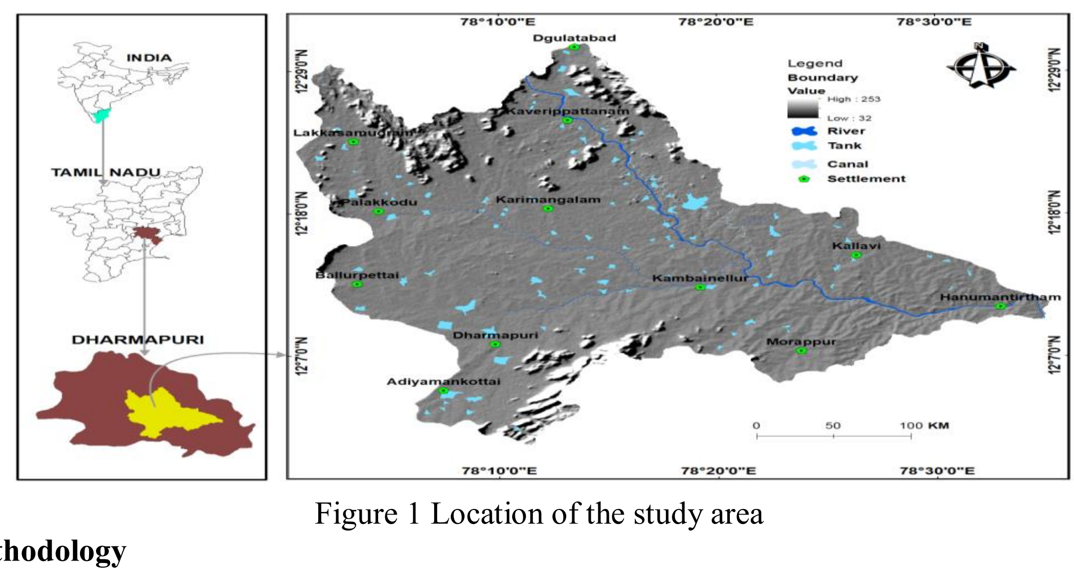

Figure 1 Location of the study area

3. Methodology

To identify the groundwater potential zone in the study area, thematic layers of geomorphology, lithology, lineament density, slope, land use / land cover, drainage density, soil and elevation were generated using topographic maps, satellite image, existing maps and field data in GIS environment.

3.1 Groundwater parameters

3.1.1 Geomorphology

Geomorphology of an area is one of the most important features in evaluating the groundwater potential and prospect. The geomorphology, as such, controls the surface water and subsurface movement of the groundwater. The geomorphologic features of the study area identify the IRS LISS III satellite imagery by visual interpretation techniques (Fig.2). The major geomorphologic features of the study area include shallow buried pediment, flood plain and buried pediment, which are potential zones for groundwater storage.

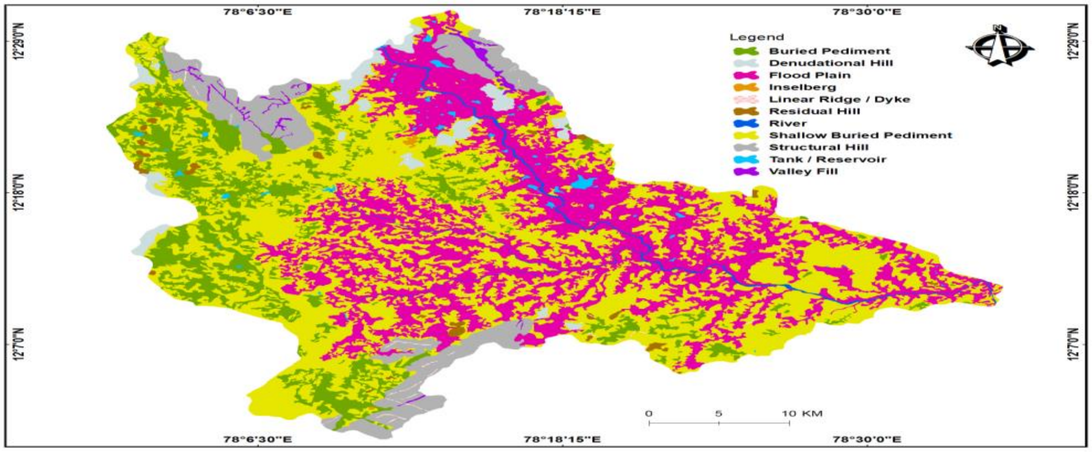

Figure 2 Geomorphology of the study area

3.1.2 Lithology

The lithology map published by Geological Survey of India (1995) is referred in the present study (Fig.3). Geologically, the watershed consists of Charnockite, Epidote-hornblende gneiss and Pink migmatite of the Archaean age.

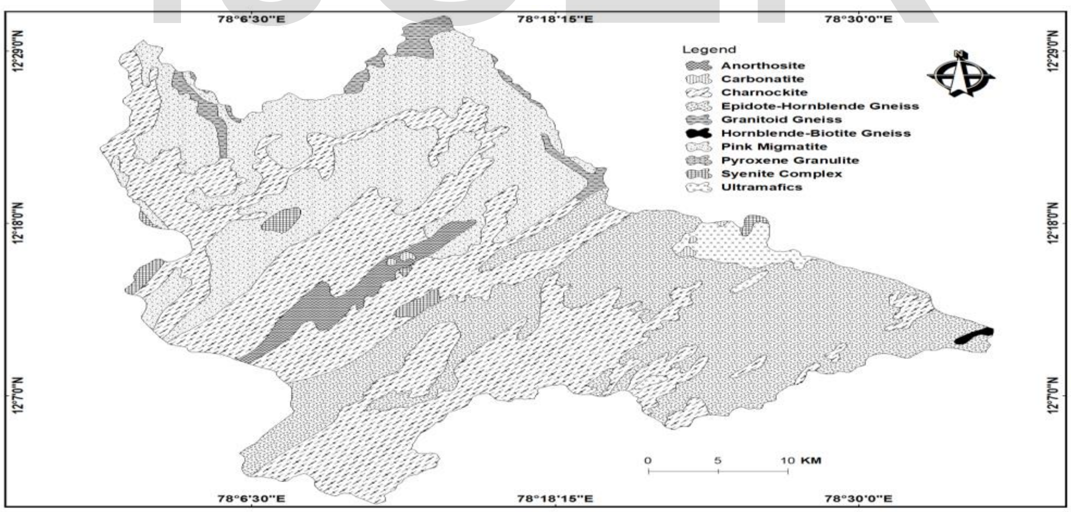

Figure 3 Lithology of the study area

3.1.3 Lineament Density

Lineaments represent the zones of faulting and fracturing resulting in increased secondary porosity and permeability. Areas with high lineament density are good for groundwater potential zones (Haridas et al.1998). Lineament density is classified as very high followed by high, medium and low categories (Fig.4). Very high lineament density is in the southeastern part of the study area with a value range from 117.75 to 157 km/km^2.

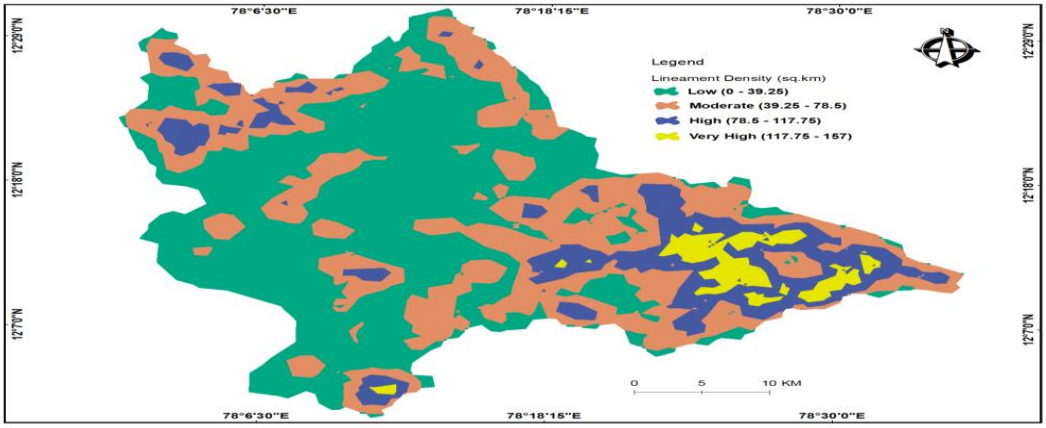

Figure 4 Lineament density of the study area

3.1.4 Slope (Degree)

Slope determines the rate of infiltration and run-off of surface water (Nassif and Wilson, 1975). The slope map of the study area is produced using the SRTM data with 90m resolution. On the basis of slope, the study area is divided into four classes, which are 0–10.72º, 10.72–21.44º, 21.44-32.16º and 32.16–42.88º. The study area is dominated by slope of >10º, which indicates almost flat topography and runoff is slow, allowing more time for rainwater to percolate and consider good groundwater potential zone (Fig.5).

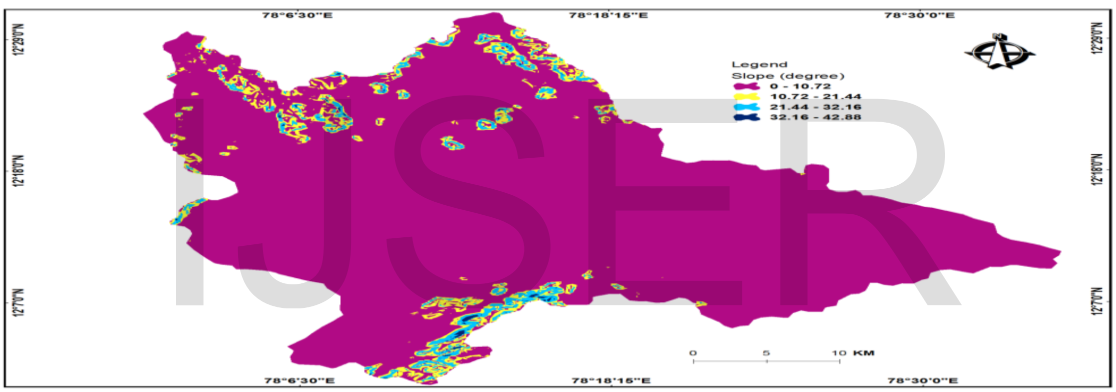

Figure 5 Slope (Degree) of the study area

3.1.5 Land use / Land cover

The fundamental approach to any watershed planning is to determine the present situation of land use / land cover pattern. Different land use / land cover patterns obstruct the run-off, reduce evaporation of surface and ground water and hence have an impact on groundwater resources. Agricultural land has very good groundwater potential because of enough void space for groundwater recharge and built up area showing very low groundwater potential because of very low groundwater recharge. The land use/land cover map was created using LISS-III satellite image by visual interpretation technique and classified it into eleven classes. The study area is almost covered by crop land and land with scrub in all directions. Classification of land use/land cover for weighted analysis was decided based on the land use type and properties to infiltrate water, and their characteristics to hold water on the ground surface (Fig.6).

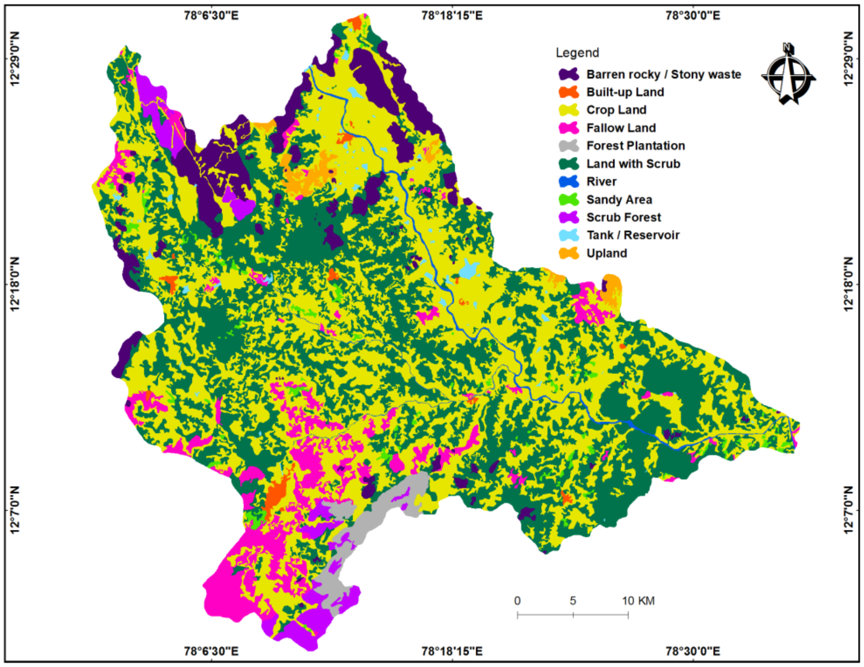

Figure 6 Land use / Land cover of the study area

3.1.6 Drainage density

Drainage density is an inverse function of permeability, and therefore it is an important parameter in evaluating the groundwater zone. The drainage map prepared from the SOI published toposheets of the study area is used for obtaining the drainage density map. Higher weightage were given to low drainage density regions causes more infiltration and results in good groundwater potential zones as compared to a high drainage density region. High drainage density values are favorable for run-off, and hence indicates low groundwater potential zone. Drainage density value was classified into four classes viz; low (0-97.61 km/km^2), moderate (97.61-195.21 km/km^2), high (195.21-292.82 km/km^2) and very high (292.82-390.42 km/km^2) groundwater potential respectively (Fig.7).

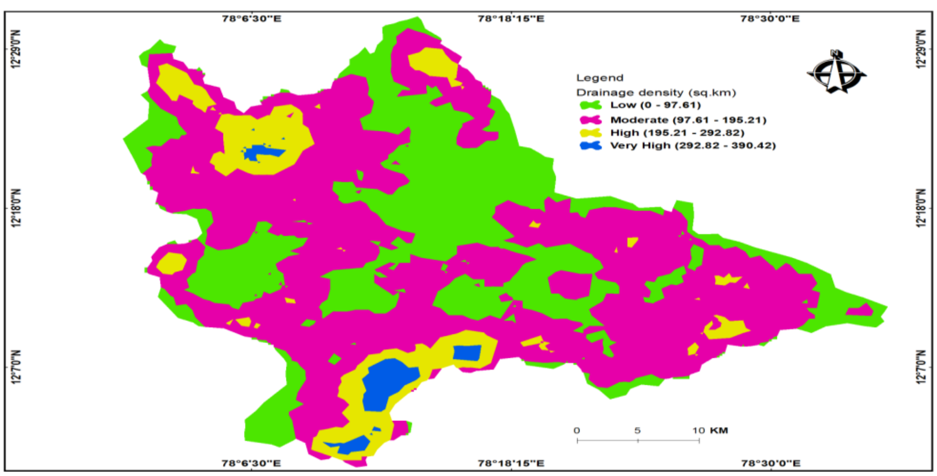

Figure 7 Drainage density of the study area

3.1.7 Soil

The movement of ground water and infiltration of surface water into ground is based on the porosity and permeability of soil. Therefore the study of soil is important to determine the amount of ground water of Pulamapatti watershed. The soil data were collected from soil survey and landuse board and the same data was digitized in GIS platforms. The soil for the watershed reveals three main soil categories namely red gravelly soil, red loamy soil and red sandy soil (Fig.8).

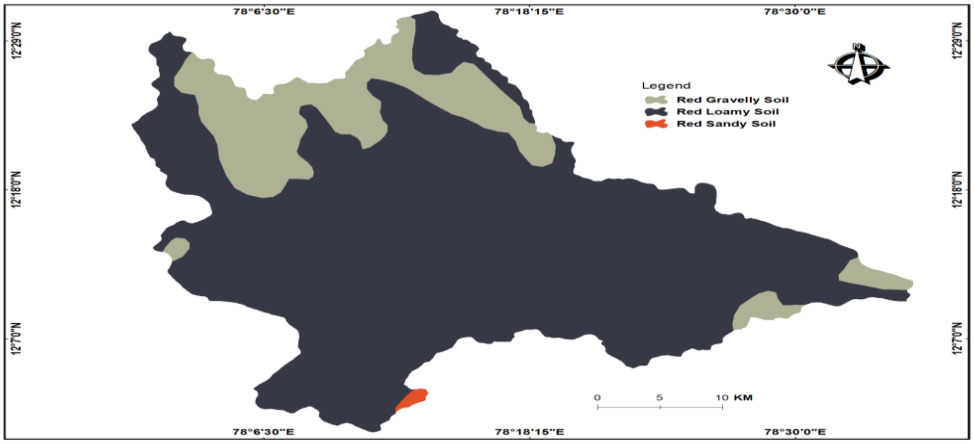

Figure 8 Soil of the study area

3.1.8 Elevation

Water tends to store at lower topography rather than the higher topography. Higher the elevation lesser the ground water potential and vice versa (Hammouri et al. 2012), for the present study elevation data having 90 meter spatial resolution has been created from the SRTM image. The study area's elevation ranges between 295 meters to 1237 meters from the mean sea level, these values have been classified equally into four classes (Fig.9).

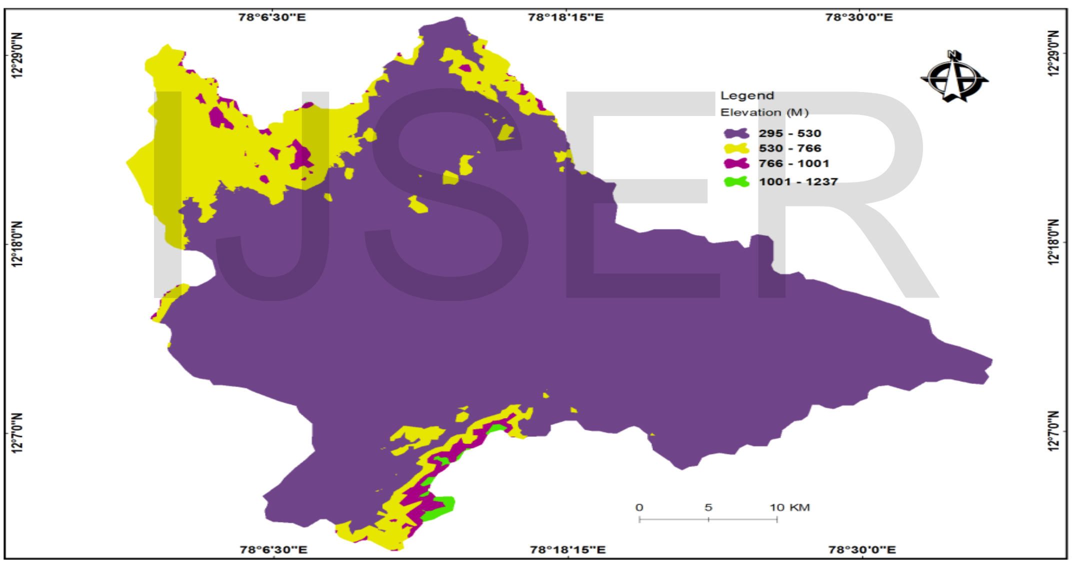

Figure 9 Elevation of the study area

3.2 Multi criteria decision analysis using GIs techniques

AHP is used to demarcate the potential groundwater zones and this technique was proposed by Saaty (1990). In this study, the AHP pair-wise matrix was developed by input values of scale weights of themes and their features based on relative influence on groundwater occurrence and expert opinion (Table 1&2). Thereafter, a pair-wise comparison matrix was constructed using the Saaty's analytical hierarchy process (Saaty, 1980) to calculate normalized weights for individual themes and their features. The AHP method allows assessing the geometric mean (Eq. 1), followed by allotting a normalized weight (Eq. 2) to various themes for finalizing the decision process. The normalized weights were assigned to various thematic layers which include lithology, geomorphology, lineament density, slope, landuse/land cover, soil, drainage density and elevation provides certain clue for the groundwater potential. The pair-wise comparison for the eight layers were given based on the comparison between the layers and their relative importance towards groundwater prospects and an 8×8 matrix was formed. Based on the comparison matrix the following steps were carried out to calculate the normalized weight.

In step 1 each thematic layer of the column were divided by their corresponding sum of the row to form the relative weight matrix. In step 2 the geometric mean was obtained by averaging across the rows and normalized weight was obtained by dividing each geometric mean thematic map with sum of geometric mean is shown in Table 2.

Table.1 Weights assigned to the thematic layers

Theme	weight
Lineament Density	7.5
Lithology	7
Landuse/Land Cover	6.5
Slope	5.5
Drainage Density	6
Geomorphology	8
Soil	5
Elevation	4.5

Table 2 AHP–pair wise matrix analysis of thematic layer's scale weight for geometric mean

Parameters	LD	LI	LU-LC	SL	DD	GEOM	SO	EL	Total value	Geometric Mean
LD	7.5/7.5	7.5/7	7.5/6.5	7.5/5.5	7.5/6	7.5/8	7.5/5	7.5/4.5	9.94	1.24
LI	7/7.5	7/7	7/6.5	7/5.5	7/6	7/8	7/5	7/4.5	9.27	1.16
LU-LC	6.5/7.5	6.5/7	6.5/6.5	6.5/5.5	6.5/6	6.5/8	6.5/5	6.5/4.5	8.61	1.08
SL	5.5/7.5	5.5/7	5.5/6.5	5.5/5.5	5.5/6	5.5/8	5.5/5	5.5/4.5	7.29	0.91
DD	6/7.5	6/7	6/6.5	6/5.5	6/6	6/8	6/5	6/4.5	7.95	0.99
GEOM	8/7.5	8/7	8/6.5	8/5.5	8/6	8/8	8/5	8/4.5	10.6	1.33
SO	5/7.5	5/7	5/6.5	5/5.5	5/6	5/8	5/5	5/4.5	6.62	0.83
EL	4.5/7.5	4.5/7	4.5/6.5	4.5/5.5	4.5/6	4.5/8	4.5/5	4.5/4.5	5.96	0.75

LD = Lineament Density; **LI** = Lithology; **LU-LC** = Landuse / land cover; **SL** = Slope; **DD** = Drainage Density; **GEOM** = Geomorphology; **SO** = Soil; **EL** = Elevation

Table 3.3 Assignment of weight for the feature classes of individual parameter and normalized weight calculation

Name of the parameter	Feature class	Assigned weight (AW)	Geometric mean (G)	Normalized weight (N=AW/G)
Lineament density	Low (0-39.25)	3	1.24	2.42
	Moderate (39.25-78.5)	5		4.03
	High (78.5-117.75)	7		5.64
	Very High (117.75-157)	8		6.45
Drainage density	Low (0-97.61)	7	0.99	7.07
	Moderate (97.61-195.21)	5		5.05
	High (195.21-292.82)	3		3.03
	Very High (292.82-390.42)	1		1.01
Slope (in degree)	0-10.72	7	0.91	7.69
	10.72-21.44	5		5.49
	21.44-32.16	3		3.30
	32.16-42.88	1		1.10
Soil	Red gravelly soil	6	0.83	7.23
	Red sandy soil	4		4.82
	Red loamy soil	2		2.41
Landuse / land cover	Crop land	8	1.08	7.41
	Forest plantation	7		6.48
	Tank/Reservoir	6		5.55
	Upland	5		4.63
	Fallow land	5		4.63
	Sandy area	4		3.70
	River	4		3.70
	Land with scrub	3		2.78

	Scrub forest	3		2.78
	Built-up land	2		1.85
	Barren rocky/stony waste	1		0.92
Geology	Granitoid gneiss	6	1.16	5.17
	Hornblende-biotite gneiss	5		4.31
	Epidote-hornblende gneiss	5		4.31
	Ultramafics	4		3.45
	Pink migmatite	4		3.45
	Anorthosite	3		2.59
	Syenite complex	3		2.59
	Charnockite	2		1.72
	Carbonatite	1		0.86
	Pyroxene granulite	1		0.86
Elevation (M)	295-530	4	0.75	5.33
	530-766	3		4.0
	766-1001	2		2.67
	1001-1237	1		1.33

Geomorphology	Buried pediment	9	1.33	6.77
	Shallow buried pediment	8		6.01
	Flood plain	7		5.26
	Tank/Reservoir	6		4.51
	Valley fill	6		4.51
	Structural hill	5		3.76
	River	4		3.01
	Residual hill	3		2.25
	Inselberg	3		2.25
	Denudational hill	2		1.50
	Linear ridge/dyke	1		0.75

3.2.1 Geometric Mean

The geometric mean is derived from the total sum of score of a specific parameter known as total scale weight divided by total number of parameter; this is expressed as:

$$\text{Geometric Mean} = \frac{\text{Total Scale Weight}}{\text{Total number of parameter}} \quad (1)$$

3.2.2 Normalized Weight

The normalized weight was derived from the assigned weight of a parameter feature class divided by the corresponding geometric mean. The formula is represented as:

$$\text{Normalized weight} = \frac{\text{Assigned weight of a parameter feature class}}{\text{Geometric Mean}} \quad (2)$$

4. Results and Discussion

4.1 Groundwater Potential Zones

On the basis of normalized weights for individual themes and their corresponding categories, all the eight thematic layers are integrated (Fig.10) in the GIS environment. The normalized weighted map is an indicator of potential groundwater zone that was classified into three classes as high, moderate and poor potential zone. The class with maximum weight is considered as high suitable zone and least weighted class is poor or unsuitable zone for groundwater.

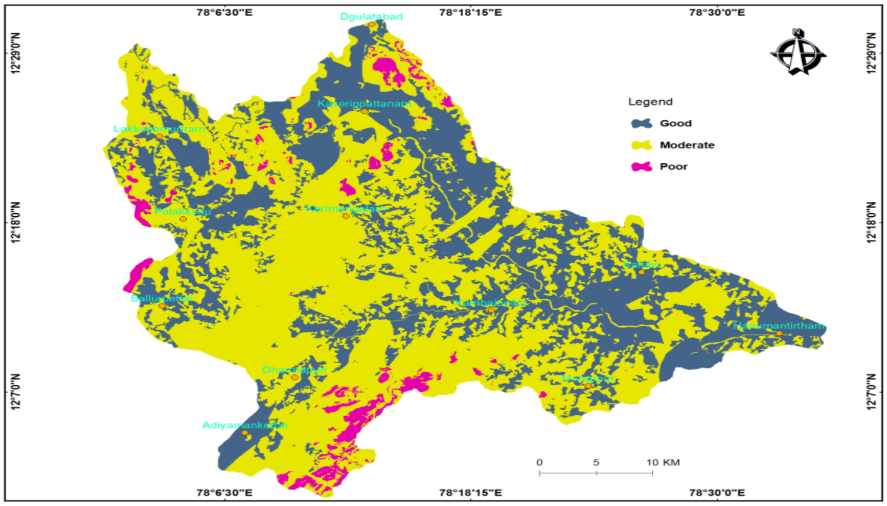

Figure 10 Groundwater potential zones in the study area

4.2 Validation of groundwater potential map

The groundwater potential zone map delineated in the present study was verified using the available well yield data of 39 pumping wells with average potential yield value of ≥44 m^3/h. Mean discharge of the existing pumping wells in individual groundwater potential zones was computed and compared. In addition, cumulative frequencies of the wells falling in individual groundwater potential zones were plotted against well yields.

5. Conclusion

The application of integrated geospatial technology and AHP has proven to be a better tool for the identification of potential groundwater zones in Pulampatti watershed. The present study demarcates the groundwater potential zones by integration of the groundwater influencing factors. Each factor was assigned appropriate weight based on expert knowledge and finally groundwater potential map of the study area was produced. The results indicated that good, moderate and poor potential zones occupying an area of 629.79km^2 (37.20%), 58.33km^2 (3.44%) and 1005.02km^2(59.36%). The study area that buried pediment, low slope angle (0-10°), crop land, very high lineament density (117.75-157) and granitoid gneiss have high infiltration ability which is helps to development of the high potential zone. The validations of groundwater potential map with well yield data, the accuracy of the verified model is 72%, which gives satisfactory result. The findings of this study can be used to watershed development programme and proper sustainable management of groundwater resources.

Acknowledgments

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