Delineation of Groundwater Potential Zone in Sengipatti for Thanjavur District using Analytical Hierarchy Process

G Siva, N Nasir and R Selvakumar*

School of Civil Engineering, SASTRA University, Thanjavur – 613 401. India.

*Email:selvakumar@civil.sastra.edu

Abstract. Purpose of the ground water is very important to in our world. The condition of the ground water level and occurrence is differing from geological nature of earth. The present study, delineate the ground water potential zone in the hard rock terrain of Sengipatti and surrounding area using Remote sensing, Geographical Information System (GIS) and Multi Criteria Decision Making (MCDM) technique. The Analytical Hierarchy Process (AHP) technique is use to determined the weights of the different themes. Thus thematic layers drainage, geomorphology, land use/land cover, slope, lithology are prepare using Geological Survey of India Toposheets and IRS-IC satellite image. The weights are applied to the thematic layers after linear combination of the all layers. Finally delineate the possible ground water potential zone in the study area. Thus prospective zone are classify the three categories high, moderate, low. It has been total study area of the sengipatti region 32.28% of the area is high ground water potential zone and 34.1% area was moderate ground water potential zone and 33.63% area is low ground water potential zone.

1. Introduction

Water, one of the panchaboothas is vital for sustaining lives. Earlier water was abundant and was used judiciously. But as time progressed the increased population and its associated agricultural and industrial expansion impose demand on limited resources[1]. Thus the increased usage leads to overexploitation of various sources of water and thereby creates a condition of water scarcity. Due to scarcity and pollution of surface water resource, people moved on to exploit the ground water resource [2]. Scientist and technocrats adopted many methods to identify the hidden resource. That too in crystalline terrain, targeting the resource is still enigmatic because apart from primary porosity, various parameters play a vital role in controlling accumulation and movement of groundwater. Amongst the surface electrical resistivity has yielded better results in targeting the groundwater resource[3]. This method is a bit tedious because of its extensive field work. To eliminate the field work, indirect methods were developed. Amongst satellite image based interpretation proven an effective tool. In recent years, owing to its multispectral and multi-temporal characteristics, high resolution satellite images are gaining attention in exploring the groundwater resources especially its potential in precisely identifying various ground features are serving as an indirect indicators in targeting the ground water [4-6]. Likewise the geographic information system (GIS) has proven as an effective tool in delineating groundwater prospect zones by integrating and analysing thematic layers [7-9].

The present study discuss on the identification of groundwater potential zones in and around Sengipatti area, Thanjavur district (Figure.1) using the advanced technology of remote sensing and Analytical Hierarchy Process (AHP). The occurrence, rate of infiltration and storage potential of groundwater is governed by multiple parameters like lithology, geomorphology, slope, drainage density and so on. Hence each terrain parameters have to be systematically assessed based on their importance over the occurrence of groundwater. Further in the study area, no previous studies were conducted to find out the groundwater potential areas and also the relationship between groundwater potential and surface and sub-surface units. For the same, using remote sensing and collateral data, various thematic layers were prepared on both the surface and subsurface parameters. Owing to its complexity, a Multi Criteria Decision Analysis (MCDA) method is applied to target the groundwater. In general, a knowledge based weights were assigned to individual thematic layers and ranks to individual features in each theme [10]. Then by multiplying them, scores of each feature were derivedand based on their derived scores, the groundwater potentiality zones was demarcated. In the above basic method weights and ranks to factors governing the problem are simply assigned based on the expert's knowledge and further the connections between the factors are not considered. But in reality they are highly interdependent with each other. Recently there have been advancements in MCDA leading to various methods[11]. Hence a method called Analytic Hierarchy Process (AHP) was developed. In this method a hierarchy of all the factors is considered. AHP is suitable for taking complex decisions which involve the comparison of parameters that are difficult to quantify[11].AHP is a combination of Mathematics and Psychology. The parameters which we have used for the identification of ground water prospects zone are drainage, geomorphology, land use/land cover, Slope and lithology (Description of rock units).Thenusing ANP, the parameters mentioned above are given weightage in accordance with the other parameters as far their importance in influencing the groundwater is concerned [10]. Later weights were derived in terms of numerical numbers indicating their influence of groundwater over the other features. Using ArcGIS 10.2 software, derived values are assigned to the above themes and finally integrated and classified into different classes of groundwater potential zones.

2. Study area

Sengipatti is a mid-sized village located in the district of Thanjavur in the state of Tamil Nadu in India. The geographical position of the Sengipattiis 10° 43' north Latitude and 78° 57' east Longitude.Sengipatti has a total population of 4,271 peoples. There are about 1,029 houses in Sengipatti village.It is located in midway between Thanjavur and Tiruchirapalli districts along the National Highway. Agriculture is the prime activity however in recent times has more small scale industries. Hence the need the water is heaping day by day.

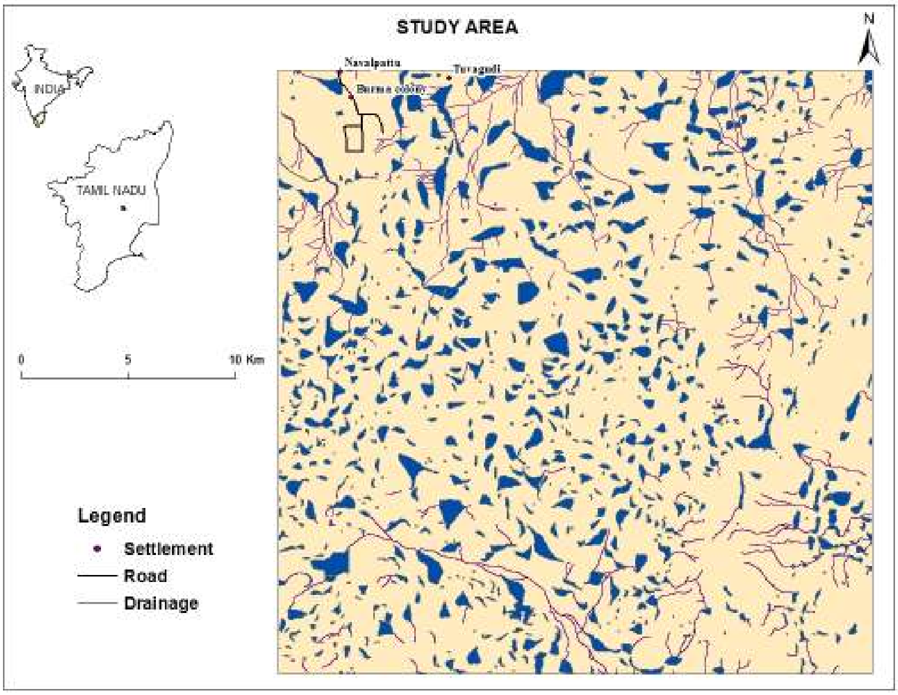

Figure 1. . Study Area.

3. Methodology

In the present study Geocoded satellite data of 20th June 2000 (IRS 1C LISS-III) and Survey of India Toposheet 58J/14 were used. For analysis, Analytic Hierarchy Process (AHP) method is adopted. The parameters which we have used for the identification of ground water prospects zone are drainage, geomorphology, land use/land cover, slope and lithology (description of rock units). The weightage is provided to various parameters by manual process and it is qualitative. It is converted into a quantitative number by creating a table indicating the inter dependency between various parameters. To check whether the assigned weightage is appropriate or not, a ratio known as consistency ratio (C.R) is calculated. This C.R value will be less than 0.1 if the assumed weights are appropriate. Each parameter is further divided into criteria and the individual sub criteria weights are obtained and they are multiplied with the main parameters weightage. Finally, the derived weights are assigned to all the parameters in each thematic layer and subsequently converted into raster datasets. Then using raster addition tool, they were integrated and cumulative factor scores of each pixel was calculated. Consequently, the derived scores were categorized into three and thereby the final groundwater prospect map showing (i) High potential (ii) Moderate potential and (iii) Low potential zone was prepared.

3.1.Surface Parameters

3.1.1 Geomorphology

Geomorphology is the term which mainly deals with the physical shape of the earth and the processes associated with it. There are many factors that play a role in geomorphology. Some among them includes Weathering and erosion, Action of wind, Gravity action etc. (Water Resources- Garald G Parker) Geomorphological characteristics of an area affect its response to a considerable extent. Integrating geomorphological background with hydrological characteristics of an area provides a simple way to understand the groundwater behavior. The parameter geomorphology is further categorized into 6 sub criterions and they are Shallow flood plain, Pediplain moderate, Pediplain shallow, Upland, Pediment Inselberg complex and Residual / Structural hill. The perusal of the geomorphological map shows that the Pediplaincovers majority of the area occupying the central and the south west portion of the study area. While the Shallow flood plains in the south central portion and the uplands in the central and south east parts Sengipatti Village. Structural Hills were observed in the extreme south west portion of the locality (Figure 2).

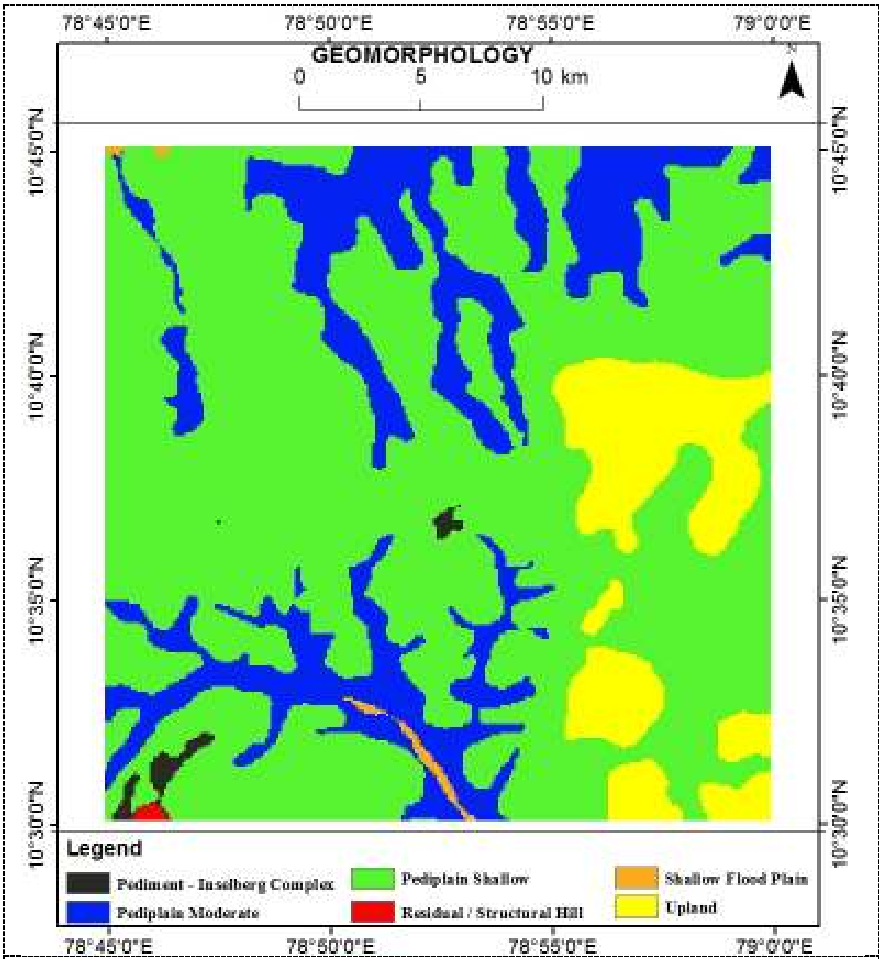

Figure 2. Map showing Geomorphology of the study area

3.1.2 Slope

Slope of an area refers to the natural gradient observed in that locality, which is one of the important parameters as far ground water prospect is concerned. If the slope is too steep then the water runs off quickly and does not infiltrate the ground easily. If the slope is too low then the water stagnates and the condition is suitable for penetration easily and hence ground water improves. We have four sub categories under the parameter slope. They are 0-1%, 1-3%, 3-5% and above 5%. In analyzing the map of the study area taken, the following observations are obtained. Slope of 0-1% is visualized in the central northern part, extreme south eastern part and single central part of the Sengipatti village. The slope percentage 1-3 % is observed in most of the places of the village and it covers the central part and other extremities of the locality. Slightly higher slope percentage of 3-5% is spotted in the central spot, extreme south west and south eastern part of the village. Higher slope percentage exists only in few spots of the village like extreme edge of the map (5-10 %) and other one in western edge with a value of 10-15 % (Figure 3).

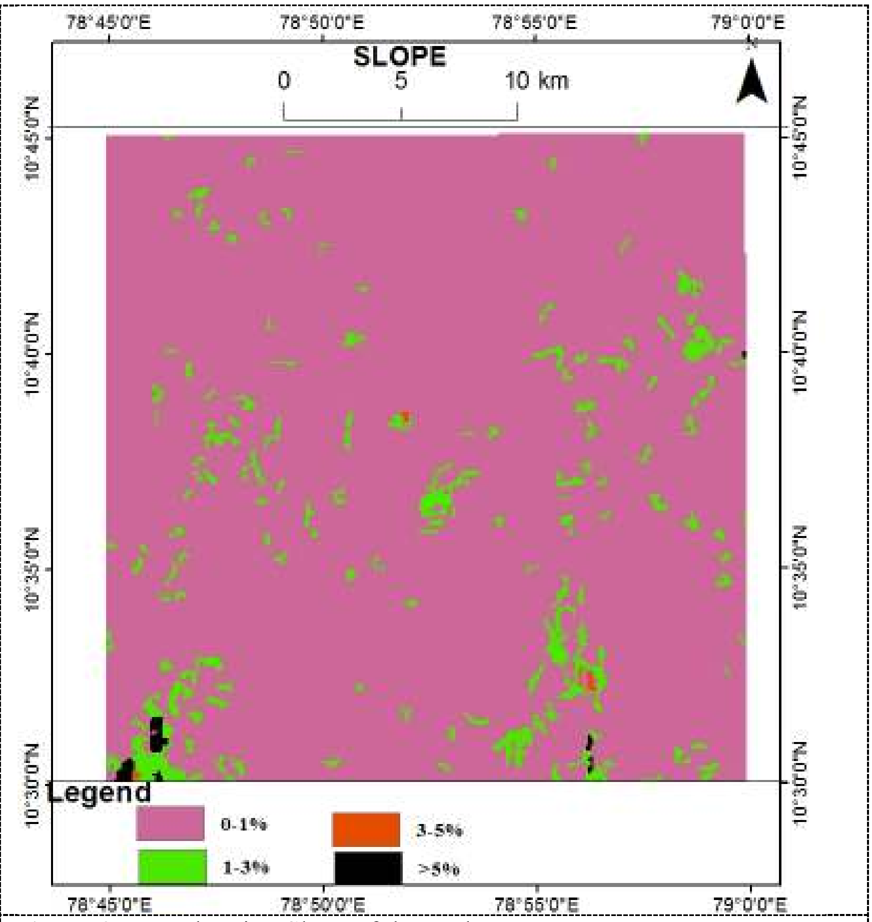

Figure 3. Map showing Slope of the study area

3.1.3 Land Use and Land Cover

Land use/ land cover describes the surface of the earth cover. The land cover is the natural layer which includes features like water bodies, forest and so on while land use is the modified natural environment comprising parameters like crop lands, fallow lands, plantations, built-up lands and so on. These parameters either directly or indirectly influence the groundwater. Agriculture influences ground water by the demand for crop needs. Due to wasteland there is depletion of groundwater in many areas. In forest areas a rise in water table is expected. A rapid deterioration of groundwater might occur if the land is built-up with answered sanitation or poultry farms. The study area consists of agricultural lands, wastelands, built-up and forest lands. The study area is almost covered by agricultural land in all directions. Waste land is found as scattered in the northwest, southeast and central parts of the study while, few built-up lands are witnessed in the northern and southern regions. The forest regions are predominantly found in the eastern and western parts and seldom present in the middle and eastern parts of the study (Figure.4).

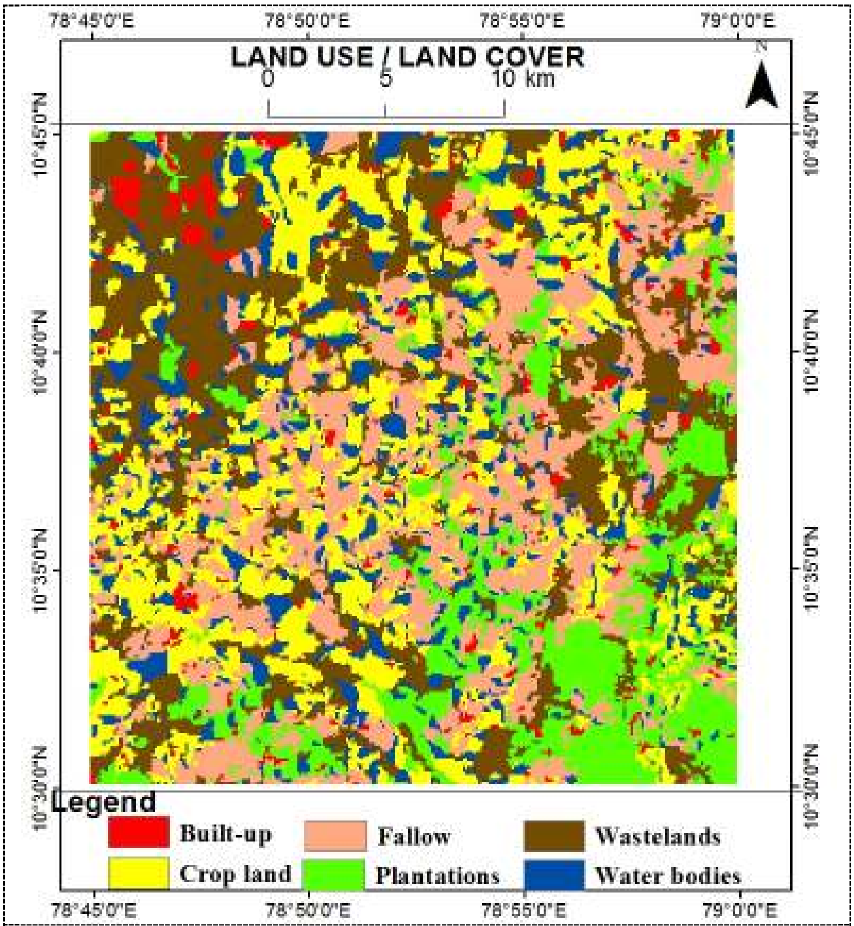

Figure 4. Map showing Land use and Land Cover of the study area.

3.1.4 Drainage

Drainage is the movement of water in terms of and drainage system is the pattern formed by the drainage in an area which includes streams, rivers and lakes thus forming an important part in ground water analysis. Drainage and its pattern depend on number of factors like slope, lithology, soil, land use/land cover and so on. Larger areas of drainage tanks are found in the northern half of the study area.In the study area small sized tanks are found scattered over the entire area. The south eastern part has scarcely distributed tanks. The south western half of the study area has large as well as small sized tanks (Figure.5)

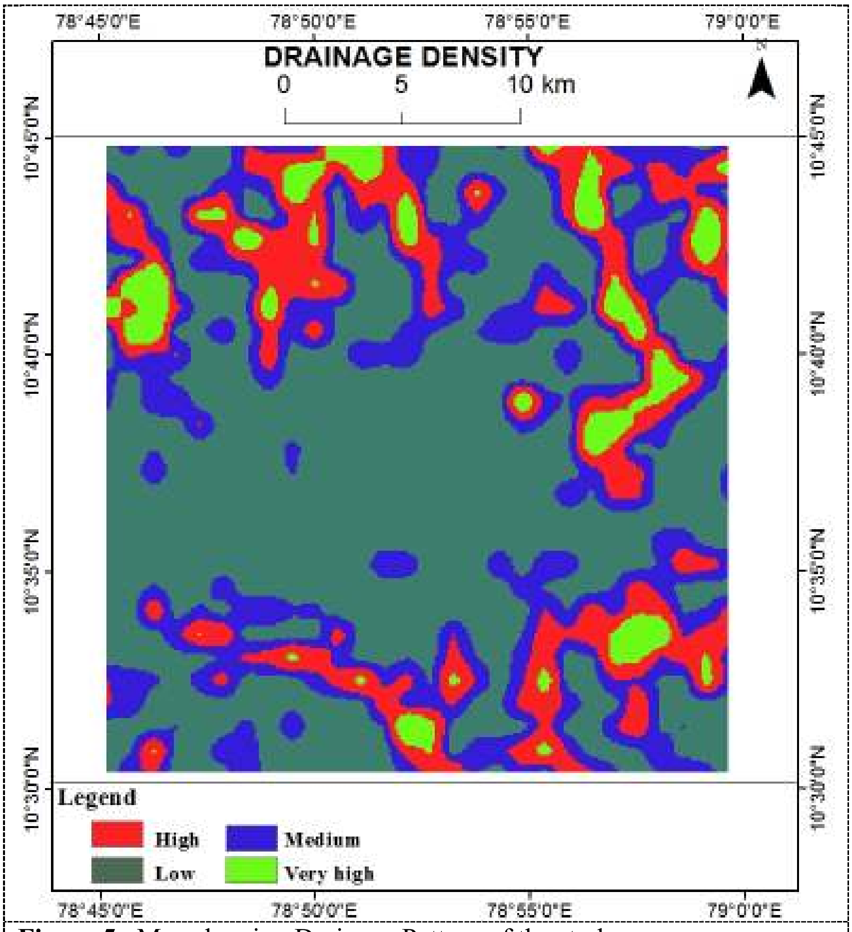

Figure 5. Map showing Drainage Pattern of the study area

3.1.5 Lithology

The lithology describes the physical characteristics of a rock type. There are fivelithological units in the study area viz: clay, Granite/ Quartzite, Laterite, Quartzo-felspathic Gneiss, Hornblende biotite Gneiss. Around 70 percent of the study area is covered with hornblende-biotite Gneiss. Quartzo-felspathic and laterite covers 5 percent each. Quartzite and granite is distributed sporadically over the study area(Figure.6**).**

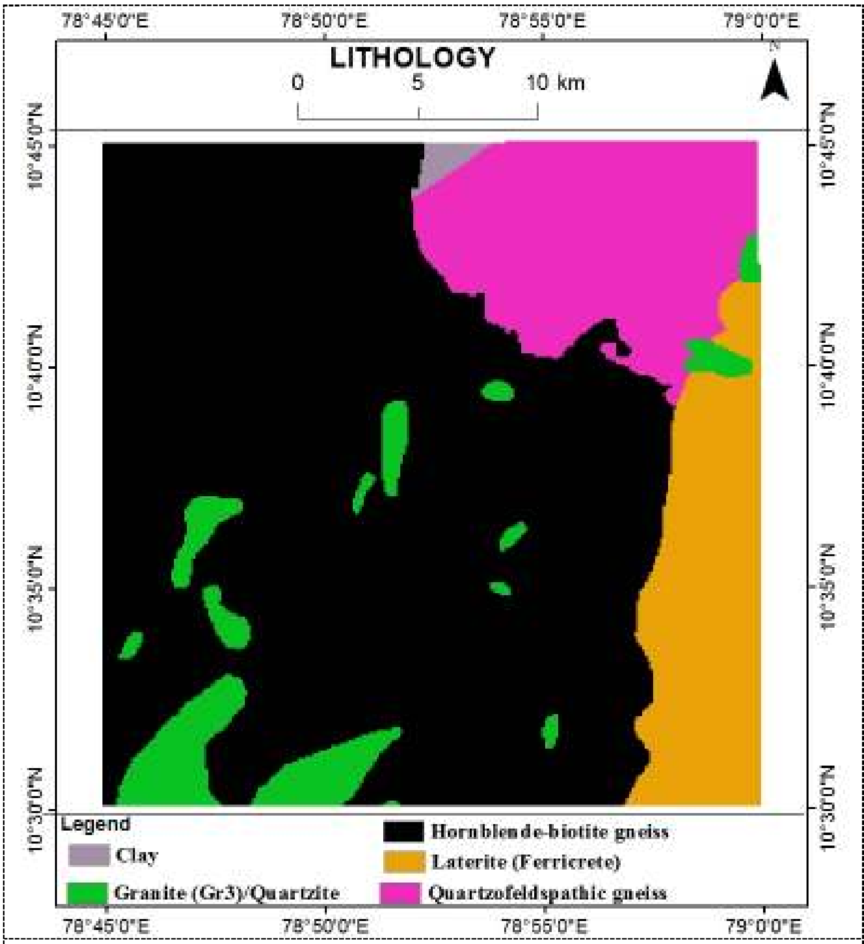

Figure 6. Map showing Lithology of the study area

4. Analytic Hierarchy Process

Analytic hierarchy process is a structured method used for analyzing and organizing complex decisions using the principle of psychology and mathematics. It was developed by Thomas L.Saaty in 1970's. Rather than giving the correct solution to the issue at hand it comes out with the best solution based on the clients need. Hierarchy process deals with step wise operations to give out a solution. It works on the principle of Multi Criteria Decision Making (MCDM) and is useful in analyzing the real world problems which involves multiple criteria. In this process, information is fragmented into packets of alternatives and criteria. This information is further synthesized to derive the relative ranking of alternatives. A final weight obtained gives the best outcome.

4.1 Assigning Weights

The process of assuming weights are done qualitatively as already stated. The weights are given manually and it is verified with the help of certain terms. The terms include Final Weightage for each parameter, Consistency Index, Random Consistency Index and Consistency ratio.

The above criteria are assumed with weights in accord to our study area. The Slope Gradient was observed to be almost constant throughout our study area thus resulting with the weightage of 1. Lithology is nothing but the rock units prevailing in the study area and it seemed to be varying in parts of the study area. Drainage and Land use almost go on the same line, resulting with equal weightage to them. Geomorphology is given with maximum weightage. The above results are tabulated by obtaining the final weightage from each of the parameter with respect to their sub criteria (Table 1)

Table 1. Criteria Weights

	Slope	Lithology	Drainage	Land use	Geomor phology	product	5th root	Weights
Slope	1.000	0.200	0.143	0.143	0.111	0.0004	0.214	0.0275
Lithology	5.000	1.000	0.330	0.200	0.143	0.0471	0.542	0.0697
Drainage	7.000	3.000	1.000	0.330	0.200	1.386	1.067	0.1370
Land use	7.000	5.000	3.000	1.000	0.330	34.65	2.032	0.2608
Geomorphology	9.000	7.000	5.000	3.000	1.000	945	3.936	0.5051

4.2 Slope Weights

0-1% slope is a very low gradient unit and hence the water will not flow under the action of gravity thereby increasing the chances of water penetrating into the underlying layers. Thus when the slope increases the probability that ground water exists gradually decreases. Higher Slopes permits easy flow of water and reduces the water existing in that region. The weightage above are also allocated on the same principle (Table 2).

Table 2. Weights derived for slope sub criteria.

	>5%	3-5%	1-3%	0-1%	Product	4th Root	Weight
>5%	1.000	0.333	0.200	0.143	0.009	0.312	0.0550
3-5%	3.000	1.000	0.333	0.200	0.2	0.668	0.1177
1-3%	5.000	3.000	1.000	0.333	5	1.495	0.2633
0-1%	7.000	5.000	3.000	1.000	105	3.201	0.5638

4.3 Lithology Weights

Clay layers absorb the water within its particles just like hygroscopic sponge and hence the level of groundwater below is fairly reduced. Granite Is a part of the bed rock above the groundwater level. Unlike limestone and chalk that easily get weathered or dissolved, the former withstands a large amount of water not paving its way for penetration. Laterite is formed by intensive weathering, having porous and permeable layers. They enable the function of acquifers also and hence increase the ground water level (Table 3)

Table 3. Weights derived for Lithology sub criteria

	Clay	Granite/ Quartzite	Laterite	QF gneiss	HblBioti te gneiss	Product	5th root	Weight
Clay	1.000	1.000	0.333	0.200	0.143	0.009	0.394	0.0537
Granite /Quartzite	1.000	1.000	0.333	0.200	0.143	0.009	0.394	0.0537
Laterite	3.000	3.000	1.000	0.333	0.200	0.6	0.902	0.1230
QF gneiss	5.000	5.000	3.000	1.000	0.333	25	1.903	0.2594
Hbl.Biotite gneiss	7.000	7.000	5.000	3.000	1.000	735	3.743	0.5100

4.4 Drainage Density Weights

Drainage density showsthe closeness in spacing of steams within a given square grid area. The runoff will be more if density is high while infiltration will be more if density is low. For the same, grid map with 250 x 250m grid size is overlaid over the drainage map and therefrom total length of the drainage in each grid was calculated. Subsequently, contours were generated using SURFER Software and categorized into four as very high, high, moderate and low density areas.Accordingly weights were assigned with Very High density (1485 – 3845 m/sq.km) are given 1, High density (775-1485 m/sq.km) is given 3, Medium density (275- 775m/sq.km) is given 5, and Low density (0-275 m/sq.km) is given 7 (Table 4).

Table 4. Weights derived for Drainage Density sub criteria

	Very High	High	Medium	Low	Product	4th Root	Weight
Very High	1.000	0.333	0.200	0.143	0.009	0.312	0.0550
High	3.000	1.000	0.333	0.200	0.2	0.668	0.1177
Medium	5.000	3.000	1.000	0.333	5	1.495	0.2633
Low	7.000	5.000	3.000	1.000	105	3.201	0.5638

4.5. Land Use / Land Cover Weights

Built up lands are those in which structures are raised and commercial activities take place, so in these lands there is a less possibility that ground water exists leading to the least weightage. Waste lands are almost the same but only with a difference that it is not usable for both agriculture and constructional purposes. Plantation is provided with comparatively higher weightage as there exists few plants which comes out of moisture prevailing in the ground. Fallow lands are used for agricultural purposes in certain period of time so weightage given is the same as plantation and its 3. Crop Lands are those which are completely utilized for agriculture and without water agriculture doesn’t exists, so its given with a weightage of 7. Finally Water Bodies are sure of having water in the underlying depths and thus given with the highest weightage of 9 (Table 5).

Table 5. Weights derived for Land use / Land Cover sub criteria

	Built up land	Waste land	Planta Tion	Fallow land	Crop land	Water bodies	Product	6th Root	Weight
Built up land	1.00	1.00	0.333	0.333	0.143	0.111	0.001	0.347	0.0361
Waste land	1.00	1.00	0.333	0.333	0.143	0.111	0.001	0.347	0.0361
Plantation	3.00	3.00	1.000	1.000	0.200	0.143	0.257	0.797	0.0828
Fallow land	3.00	3.00	1.000	1.000	0.333	0.200	0.6	0.918	0.0953
Crop land	7.00	7.00	5.000	3.000	1.000	0.200	147	2.297	0.2386
Water bodies	9.00	9.00	7.000	5.000	5.000	1.000	14175	4.919	0.5109

4.6 Geomorphology Weights

Shallow Flood plain can be defined as the area where the water exists at shallow depths above the ground level. So in these areas Ground water will always be in charged state. Pediplain surfaces are categorized into two sub divisions as moderate and shallow. Uplands are the areas of topographically unstable terrain, with high peaks and valleys. In simple terms, elevated mountainous plateau. As these are elevated, due to the inclination the water flows down from these areas into low lying areas. Pediment Inselbergs are isolated hill that stands above well-developed plains and its height varies according to different terrains. This category is the one in which ground water is in deficit as it is an isolated huge rock. Hills are the structure that extends above the surrounding terrain. Some amount of water underlies beneath the hills and mountains, but they are not easily accessible and can’t be directly used for potable purposes. Accordingly the weightage is provided considering all the above stated reasons (Table 6).

Table 6. Weights derived for Geomorphology sub criteria

	Residual/ Structural Hill	Pediment Inselberg complex	Up land	Pediplain shallow	Pediplain moderate	Shallw flood plain	Product	6th Root	Weight

Residual/ Structural hill	1.00	1.00	0.5	0.333	0.143	0.111	0.002	0.371	0.0389
Pediment Inselberg complex	1.00	1.00	0.0	0.333	0.200	0.143	0.004	0.410	0.0429
Upland	2.00	2.00	1.0	0.500	0.200	0.143	0.057	0.620	0.0650
Pediplain shallow	3.00	3.00	2.0	1.000	0.333	0.143	0.857	0.974	0.1021
Pediplain moderate	7.00	5.00	5.0	3.000	1.000	0.200	105	2.172	0.2276
Shallow flood plain	9.00	7.00	7.0	7.000	5.000	1.000	15435	4.989	0.5230

5. Results and Discussion

In the present study, using satellite imagegeomorphological and Landuse/Landcover parameters were precisely mapped. Geomorphologically, the area is as represented by alluvial plain, pediplain, and Upland. While the land use/land cover is represented by crop land, land with scrub, land without scrub, water bodies and buildup lands.On caring out the above study it can be concluded that remote sensing, GIS and AHP, when used together is a very effective technique for mapping. Using satellitesand conventional data various thematic maps were generated on base, geology, geomorphology and Land use/Land cover. All the above various thematic maps have been digitized, GIS data base have been creating using Arc GIS 10.2 software. The GIS tools provides a variety of scenario's to be generated and studied before actual finalizing of plans for implementation. The ranks obtained for all the main parameters and their sub-criteria were given to the respective thematic layers and converted into raster format using ArcGIS software. Using raster calculator, thematic layers were added. Finally the derived groundwater potential map evaluated by the weighted linear combination of these weights is shown in Figure.7.

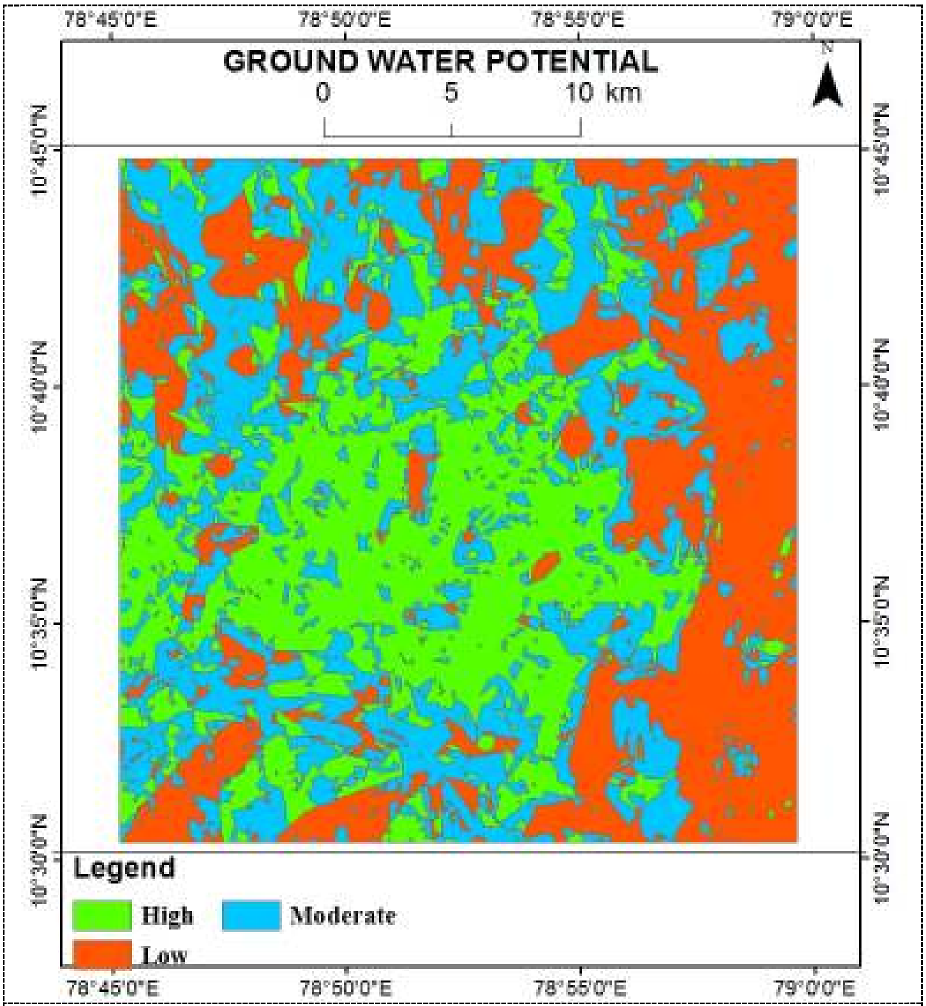

Figure 7. Map showing Groundwater Prospects of the study area.

Results indicated that only32.28% of the area is high ground water potential zone and 34.1% area was moderate ground water potential zone and 33.63% area is low ground water potential zone. Thus the above study demonstrates the potential remote sensing and GIS along with AHP technique in identifying the groundwater potential zone especially in hard rock terrain.

6. Conclusion

The present study details the potential of remote Sensing, GIS and AHP for precisely demarcating the groundwater potential zone, Using remote sensing and collateral data, thematic mapping was done and consequently converted into vector database using GIS. Weights were derived for each parameter in each thematic layers using AHP technique and finally by overlay analysis, the groundwater potential zone was demarcated. In Sengipatti area, three groundwater potential zones have been delineated. The results conclude that the Sengipatti are in Thanjavur district is a water potential zone. The perusal of Groundwater potential map indicates that most of the area falls under moderate to high potential category. Hence it is suggested that if the resources are properly utilized, the growth of industrial, commercial and agricultural sectors can be achieved.

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