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# Delineating groundwater potential zones in Thurinjapuram watershed using geospatial techniques

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**Abstract**

The search for new groundwater resource is essential to sustained economic development in arid environment. The purpose of this study was to investigate new water sources using remote sensing and GIS methods. The thematic layers considered in this study are Lithology, Geomorphology, Drainage, Soil, Lineament, Land use and surface water body, which were prepared using the IRS-P6 LISS-III satellite imagery and conventional data. In addition, soil and drainage maps were digitized from published maps. The thematic layers were finally integrated using ArcGIS V 9.2 software to yield a groundwater potential zone map of the study area. Thus, three different groundwater potential zones were identified, namely 'good', 'moderate' and 'poor'. This GIS based output result was validated using water level depth data collected from Institute of Water studies, PWD. Finally, it is concluded that the RS and GIS techniques are very efficient and useful for the identification of groundwater potential zones.

**Keywords**: Groundwater, GIS, Remote Sensing, Thurinjapuram.

## Introduction

Geospatial technology is a rapid and cost-effective tool in producing valuable data on geology, geomorphology, lineaments slope, etc. that helps in deciphering groundwater potential zone. A systematic integration of these data with follow-up of hydrogeological investigation provides rapid and cost-effective delineation of groundwater potential zones. Although it has been possible to integrate these data visually and delineate groundwater potential zones, however, it becomes time consuming, difficult, and introduces manual error.

In recent years, digital technique is used to integrate various data to delineate not only groundwater potential zone but also solve other problems related to groundwater. These various data are prepared in the form of a thematic map using geographical information system (GIS) software tool. These thematic maps are then integrated using "Spatial Analyst" tool. The "Spatial Analyst" tool with mathematical and Boolean operators is then used to develop a model depending on the objective of problem at hand, such as delineation of groundwater potential zones. In recent years, many workers such as Chatterjee & Bhattacharya (1995), Teeuw (1995), Shahid & Nath (1999), Goyal *et al*. (1999), and Saraf & Choudhary (1998) have used the approach of remote sensing and GIS for groundwater exploration and identification of artificial recharge sites. Jaiswal *et al*. (2003) have used the GIS technique for generation of groundwater prospect zones towards rural development. Krishnamurthy *et al*. (1996), Murthy (2000), Obi *et al*. (2000), and Pratap *et al*. (2000) have used GIS to delineate groundwater potential zone. Srinivasa & Jugran (2003) have applied GIS for processing and interpretation of groundwater quality data. GIS has also been considered for multicriteria analysis in resource evaluation. Jacob *et al*. (1999), El-kadi *et al*. (1994), Shahid *et al*. (2000), Boutt *et al*. (2001) have carried out groundwater modeling through the use of GIS. Mohammed *et al*. (2003) have carried out hydrogeomorphological mapping using remote sensing techniques for water resource management around palaeochannels. GIS has been applied to groundwater potential modeling (Rokade *et al*., 2007; Nagarajan & Sujit Singh, 2009).

Integrated remote sensing and GIS can provide the appropriate platform for convergent analysis of diverse data sets for decision making in groundwater resource mapping and planning. This work aims to develop and apply integrated methods combining the information obtained by analyzing multi-source remotely sensed data in a GIS environment for better understanding the groundwater resource of the Thurinjapuram watershed in Thiruvannamalai district, Tamilnadu.

## Aim and objectives

The overall aim of this study is to contribute towards systematic groundwater studies utilizing remote sensing, field studies, Digital Elevation Models (DEM) and Geographic Information Systems (GIS) in the assessment of groundwater resources. The specific objectives of the study are: a). To prepare thematic maps of the area such as Lithology, Lineament Geomorphology, Land use/Land cover and soils from remotely sensed data and other data sources, b). To identify and delineate groundwater potential zones through integration of various thematic maps with GIS techniques, c). Groundwater potential zone map validated with IWS water level depth data.

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## Study area

The Thurinjapuram watershed covers geographical area of 151.38 sq. km and is located in between $12^{o}$12’58” and $12^{o}$ 21’11” North latitudes and $78^{o}$59’45” and $79^{o}$ 9’28” East longitudes. It is mainly situated in Thiruvannamalai district of Tamilnadu, India. It is mainly located in Thurinjapuram block (in India, a block is a group of villages, an administrative sub-division of a taluk) and partially falls into two other blocks (Chengam and Thiruvannamalai) (Fig.1). Thurinjalar is one of the major tributaries of Ponnaiyar Major River originating from Kavuttimalai reserve forest in Chengam Taluk of Tiruvannamalai district. It flows in south-southeast direction of the basin crossing Thurinjapuram, Kilpennathur and Tiruvannamalai blocks and confluences with Ponnaiyar river near Thirukkoilur after flowing a distance of about 44 kms. The drainage characteristics are very good. Bedrock is peninsular gneiss of Archean age. The Thurinjapuram area can be classified as ‘‘hard rock terrain’’. The predominant soil types in this river basin are Entisols, Inceptisols, Vertisol and Alfisols. The soil in this minor basin is observed to have good infiltration characteristics. Hence groundwater recharge is possible in this area. The area receives an average annual rainfall of about 806 mm.

*Fig. 1. Base map of the study*

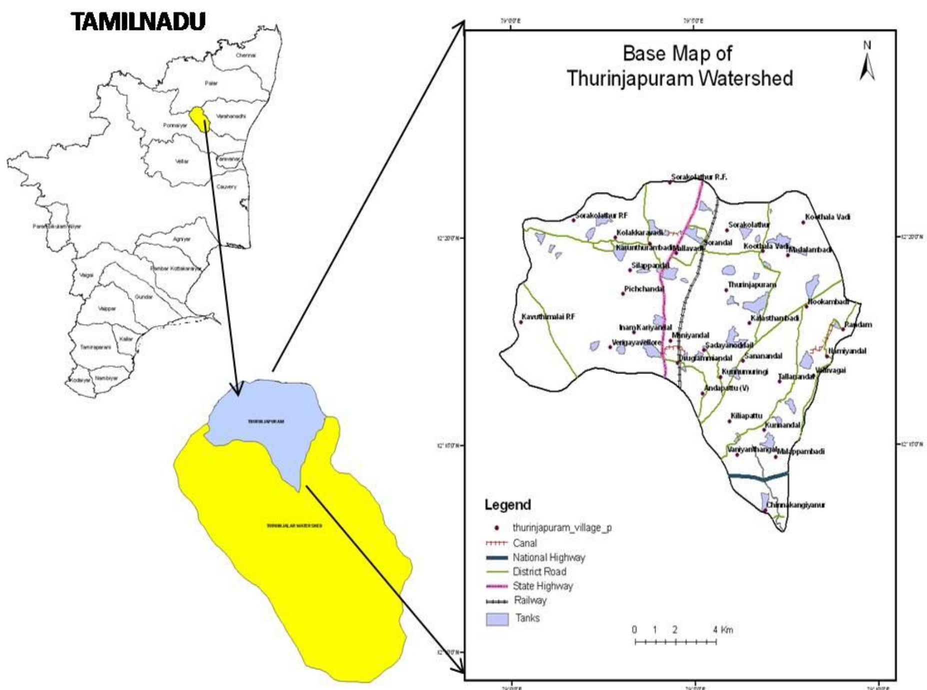
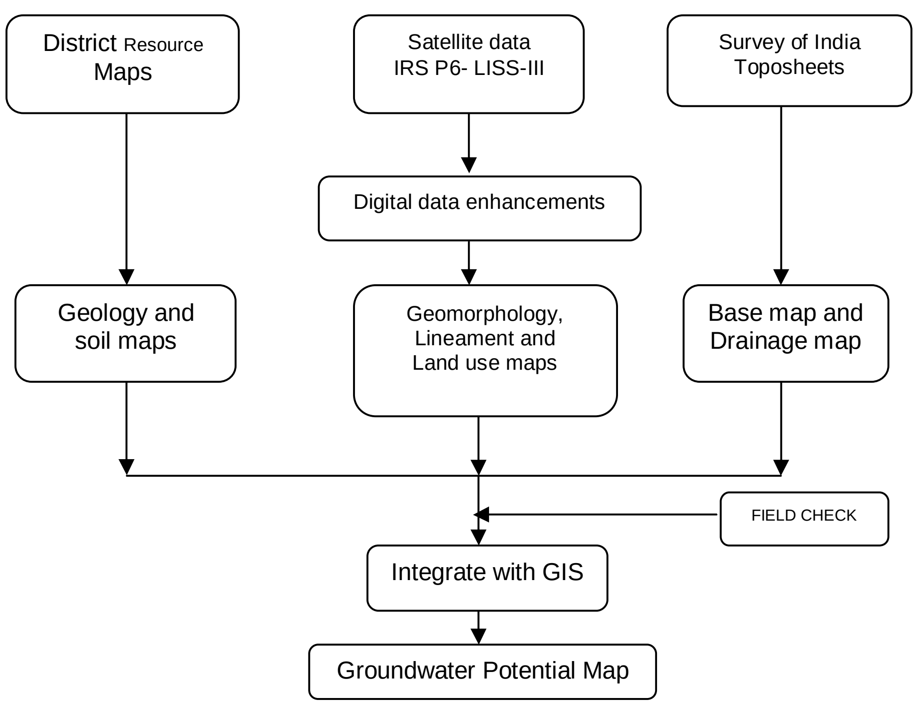



*Fig. 2. Flow chart showing data and methods employed for the study.*




## Data used and methodology

The Indian Remote sensing Satellite (IRS) P6, linear image self-scanning (LISS) III of geocoded false color composites (FCC), generated from the bands 2, 3, and 4 on a 1:50,000 scale, was used for the present study. The Survey of India toposheet maps 57P3,57P4 and 57L15 on a scale of 1:50,000 equal to the corresponding imagery were used for the preparation of thematic maps. The imagery was visually interpreted to delineate geomorphologic units and land use/land cover with the help of standard characteristic image interpretation elements like tone, texture, shape, size, pattern, and association.

The methodology employed is summarized in the flow chart in Fig.2. It involves digital image processing using ERDAS 8.7 software and visual interpretation of IRS P6-LISS-III data for the extraction of lithology, drainage, lineament, geomorphology, land use / land cover and soils as well as field studies. All data were integrated in a Geographic Information System (GIS) using Arc GIS 9.2 software and analyzed to assess the groundwater controlling features. Finally groundwater potential maps were prepared based on the GIS analysis.

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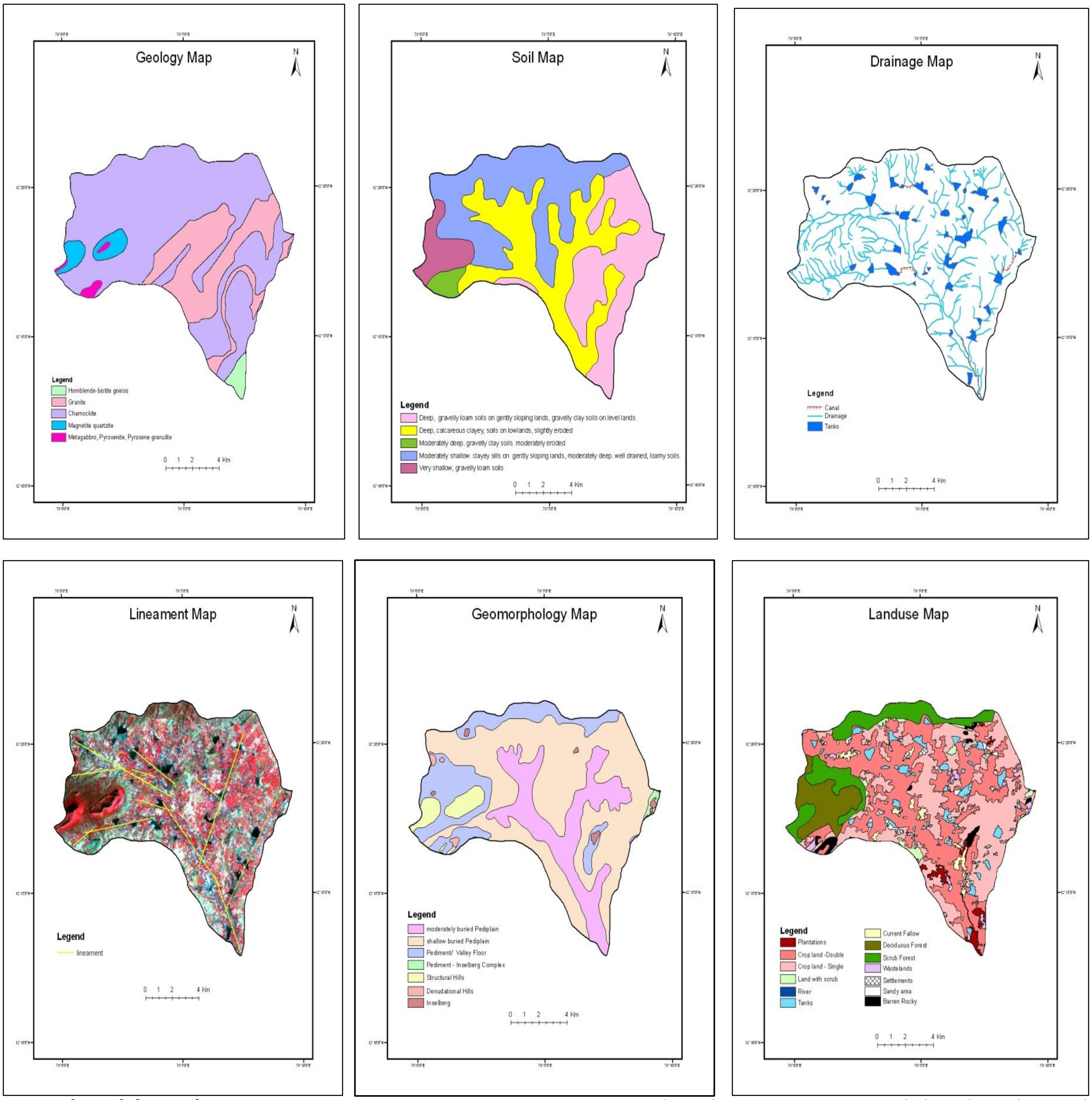
*Fig. 3. Thematic Maps of Thurinjapuram watershed*




## Preparation of thematic maps

*Geology and soils*

An understanding of the local geology and hydrogeology was developed based on existing maps and available borehole records. The solid geology is predominantly Archean complex dominated by charnockite and granite. Extensive data on geology, available from the Geological Survey of India in the form of district resource map have been used as basic tools to prepare the wastershed geology map. The Archean groups of rocks are represented by the charnockite group, granite, magnetite quartzite, Hornblende-biotite gneiss, metagabbro and pyroxenite. The charnockite group comprises of charnockite, pyroxene-granulite, ultra mafic rocks such as pyroxenites and magnetite quartzites. The soils are deep loamy to clay, gravely in plain areas (Fig.3); Sandy loam to clay loam/silty clay loam in plains, clay to gravelly loam soils, gravelly loam to calcareous loam in low lands and loamy to clayey sills, calcareous in hills.

*Table 1. Description of Landforms and groundwater occurrence*

| Geomorphic Unit | Characteristics | Hydrogeology | Groundwater potential |
|---|---|---|---|
| Moderately buried pediplain | It is shallow depressed low relief area with good drainage net works. | Moderate infiltration to good, recharge by hydrological feature, Storage complemented by secondary features. | Good |
| Shallow buried pediplain | Intermediate zone between pediments and deep pediments. Weathering thickness is appreciable | Moderate infiltration, recharge is influenced by hydrological features. | Moderate |
| Pediment valley floor | It forms the Low lying valley in the vicinity of hills | Runoff zone | Poor |
| Pediment- Inselberg complex | Isolated, very steep conical hill presented in the pediment zone. | Runoff zone | Poor |
| Structural hills | Composed of composite ridges and valleys traversed by structural features. | Runoff zone, little infiltration along secondary fractures. | Poor |
| Denudational hill | Small hills or heaps of angular boulders raising abruptly from surrounding | Runoff zone | Poor |
| Inselberg | Isolated, very steep conical hill | Runoff zone | Poor |

*Drainage and Lineament*

The drainage of the area is typical of arid and semiarid areas. It comprises of small depressions and seasonal streams. The drainage of the area is dominated by deeply incised, sand filled, seasonal streams flowing from west to east. These alluvial sands are a locally important source of water during the dry season when water can be found within a few meters of the surface. The regional topography was determined from a Digital Elevation Model and 1:50,000 topographical maps. The study area comprises of hills on the one hand and pediplains on the other, forming irregular and diverse nature of topography. In general the lineament can be defined as along linear or curvilinear feature which formed by tectonism. The lineaments were also interpreted from the satellite imagery, on the basis of the morphological expression and anomalies and structural trend lines break in slopes, long and linear fracture valleys, soil tone linearity's etc. Lineaments have mostly the azimuth directions of NW to SE along the drainage patterns.

*Geomorphology*

Geomorphological investigations include the delineation and mapping of various landform and drainage characteristics that could have a direct control on the occurrence and flow of groundwater. In the study area geomorphological landforms act as synthesis with related components like soil, lithology, structures, and other related hydrological information available in this watershed. Based on the interpretation of the IRS P6-LISS-III satellite image and SOI Toposheet, delineated the different major Hydro-geomorphological units (Table 1) and the process like tectonic and denudational action that have been developed, modified and shaped the rugged terrain into geomorphological units Fig.3. The occurrence of groundwater, based on the Geomorphological units and its characteristics are listed in Table1 (Ref: PWD, Tamilnadu Report).

*Table 2. Rank and weightage of different parameters for groundwater potential zones*

| Criteria | Classes | Rank | Weights (%) |
|---|---|---|---|
| Geomorphology | buried pediments (Moderate), Flood plain, | 1 | 30 |
| | Buried Pediplain (shallow) | 2 | |
| | Inselberg, Pediment complex, hills | 3 | |
| Landuse | Agricultural plantation, cropland - double | 1 | 30 |
| | Crop land - Single, Scrub land, Current fallow | 2 | |
| | Scrub forest, Deciduous forest, Waste land, Barren rocky | 3 | |
| Hydrological soil | A | 1 | 20 |
| | B | 2 | |
| | C | 3 | |
| Lineament | Present (vegetation) | 1 | 10 |
| | Not present (without vegetation) | 3 | |
| Drainage | First order | 3 | 10 |
| | Second order | 2 | |
| | Third order | 1 | |

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*Land use / land cover*

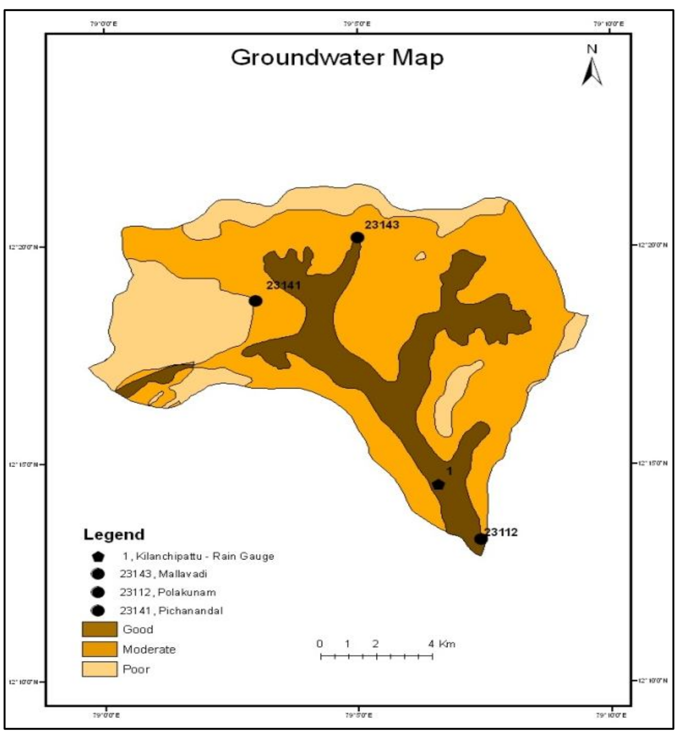
The land use map is depicted in Fig.3. There are twelve types of land use pattern identified in the entire study area namely Agricultural plantations, Single season Crop Land, Double Season Crop Land, Current Fallow or Harvested land, Settlements, Land with Scrub, Wasteland, Sandy areas, Barren Rocky Outcrops, Deciduous forest, Scrub Forest and water bodies respectively. Agricultural, Forest and Water bodies are the predominant land use types in the study area.

The middle part to south east part of the study area has very good vegetation is there compared to other parts. Agricultural plantations and Crop area are restricted along the drainage channels and river bank. The remaining areas are both deciduous, scrub forest and barren lands.

**Integration of remote sensing and GIS modeling for groundwater potential zone mapping**

The groundwater potential zones were obtained by overlaying all the thematic maps in terms of weighted overlay methods using the spatial analysis tool in ArcGIS 9.2. During the weighted overlay analysis, the ranking has been given for each individual parameter of each thematic map and the weightage were assigned according to the influence of the different parameters and was presented in Table 2. These weightage have been taken considering the works carried out by researchers such as Srinivasa & Jugran (2003), Krishnamurthy *et al.* (1996) Saraf & Choudhary (1998).

*Fig. 4. Groundwater potential zone map of the Study area*




All the thematic maps were converted into grid (raster format) and superimposed by weighted overlay method (rank and weightage wise thematic maps and integrated with one another through GIS (Arc / Info grid environment). As per this analysis, the total weights of the final integrated grids were derived as sum of the weights assigned to the different layers based on suitability (Environment System Research Institute Inc.'s ArcView GIS Software, 1997).

The full potential of remote sensing and GIS can be utilized when an integrated approach is adopted. Integration of the two technologies has proven to be an efficient tool in groundwater studies (Krishnamurthy *et al.,* 1996). In models derived through integration of various thematic maps using a GIS approach, several parameters are commonly involved to assess groundwater potential in the study area Fig.4. The modeling involves delineation of zones of varying groundwater potential based on integration of four thematic maps in a raster based GIS. The five parameters considered are: Soil, Geomorphology, Land use/ Land Cover, Lineament and Drainage. Every class in the thematic layers was placed into one of the following categories viz. (i) Good (iii) Moderate (iv) Poor, depending on their level of groundwater potential. Considering their behavior with respect to groundwater control, the different classes were given suitable values, according to their importance relative to other classes in the same thematic layer.

The spatial distribution of the various zones of groundwater potential obtained from the model generally shows regional patterns related to lithology, soils, drainage, geomorphology, Lineament and Land use patterns. The *good* zonal categories are along major lineaments and drainage channels with and without structural control, highlighting the importance of lineaments, geomorphological and soil units for groundwater investigations. Areas with *moderate* groundwater potential are attributed to combinations of lithology and landform. The *poor* categories of groundwater potential are distributed mainly along hills, ridges and pediments and to some extent along lineaments in the *low* to *poor* slope classes.

**Model validation and Results**

The validation of the model developed was checked against the Groundwater Level depth data which reflects the actual groundwater potential. A comparison of this study between the water level depth data and groundwater potential zones prepared by the model was made to check the validity of the proposed model. The Groundwater Level Depth data collected from the Institute of Water studies, PWD for Thiruvannamalai district at village level (Table 3). The co-ordinates were collected using GPS in all the selected wells and incorporated in

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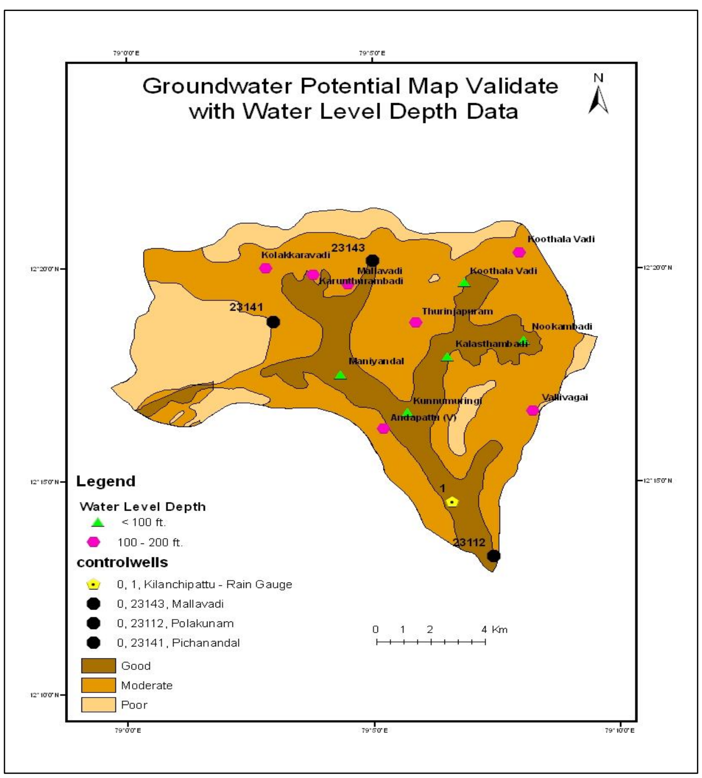
*Table.3 Actual Water Level Depth data for validation of the model*

| Village Name | Groundwater potential zones achieved by the model | Actual Water Level Depth(ft) data from IWS |
|---|---|---|
| Kalasthambadi | Good | 60 |
| Koothala Vadi | Good | 70 |
| Kunnumuringi | Good | 80 |
| Maniyandal | Good | 75 |
| Nookambadi | Good | 78 |
| Andapattu (V) | Moderate | 100 |
| Karunthurambadi | Moderate | 110 |
| Kolakkaravadi | Moderate | 180 |
| Koothala Vadi | Moderate | 170 |
| Mallavadi | Moderate | 120 |
| Thurinjapuram | Moderate | 180 |
| Vallivagai | Moderate | 175 |

village wise details in groundwater potential zone map as depicted in Fig.4 and 5.

The three zone wise wells were identified for the groundwater level depth in each zone (normally < 100 ft in good zones, 100 - 200 ft in moderate zones and >200 ft in poor zones). Good and moderate zones were validated with available water level depth data but the poor zone of the study area was not validated because of the non-availability of data (hilly regions). The results showed that both sets of data complemented each other.

*Fig. 5. Groundwater Map Validate with Water Level Depth*




## Conclusion

The occurrence of groundwater in the study area is controlled by rock type, lineaments and landforms as revealed from GIS analyses and field investigations. Use of Remote Sensing and GIS technology is very useful for the preparation of groundwater prospective areas mapping & management plan on a scientific basis. The overall results demonstrate that the use of remote sensing and GIS provide potentially powerful tools to study groundwater resources and design a suitable exploration plan. This gives more realistic groundwater potential map of an area which may be used for any groundwater development and management programme.

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