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# Groundwater resource exploration in Salem district, Tamil Nadu using GIS and remote sensing

G Maheswaran[1], A Geetha Selvarani[2,*] and K Elangovan[3]

[1]*VSA School of Management, NH-47, Main Road, Uthamasolapuram, Salem 636 010, Tamil Nadu, India.*
[2]*Department of Civil Engineering, K.S.R. College of Engineering, Tiruchencode 637 215, Tamil Nadu, India.*
[3]*Department of Civil Engineering, PSG College of Technology, Coimbatore 641 004, Tamil Nadu, India.*
[*]*Corresponding author. e-mail: geethacivil1201@gmail.com*

Since last decade, the value per barrel of potable groundwater has outpaced the value of a barrel of oil in many areas of the world. Hence, proper assessment of groundwater potential and management practices are the needs of the day. Establishing relationship between remote sensing data and hydrologic phenomenon can maximize the efficiency of water resources development projects. Present study focuses on groundwater potential assessment in Salem district, Tamil Nadu to investigate groundwater resource potential. At the same, all thematic layers important from ground water occurrence and movement point of view were digitized and integrated in the GIS environment. The weights of different parameters/themes were computed using weighed index overlay analysis (WIOA), analytic hierarchy process (AHP) and fuzzy logic technique. Through this integrated GIS analysis, groundwater prospect map of the study area was prepared qualitatively. Field verification at observation wells was used to verify identified potential zones and depth of water measured at observation wells. Generated map from weighed overlay using AHP performed very well in predicting the groundwater surface and hence this methodology proves to be a promising tool for future.

## 1. Introduction

India has been the second largest populated country in the world. To satisfy the growing needs for food in the country, agriculture activity has been increased considerably. Foreign policies of the government have made many multinational companies to invest in industrial sectors in India which have increased the number of industries. Overall development in various fields such as agriculture, industry and urbanization has led to an increase in demand for water particularly in India. Depletion of water levels in aquifers and decline in design yield of wells due to excessive pumping in the absence of adequate knowledge on groundwater availability are becoming a major concern across the globe (Babikar *et al.* (2005) in central Japan; Kendy *et al.* (2003) in north China; Konikow and Kendy (2005); Pandey *et al.* (2010) in Kathmandu Valley; Reddy (2005) in Andra Pradesh; Saha *et al.* (2007) in Bihar; Shah *et al.* (2000) in Colombo, Wada *et al.* (2010, 2012), Lapworth *et al.* (2015) in northwest India; Krishan *et al.* (2015) in northern Punjab; Krishan *et al.* (2014) in Punjab) (Krishanmurthy and Srinivas 1995; Jaiswal *et al.* 2003; Sener *et al.* 2005; Yoshihide *et al.* 2012; Pandey *et al.* 2013; Nampak *et al.* 2014). All the above factors have increased the demand for water in India which would be a crucial problem in the near future. This has led to the overexploitation of groundwater in many parts of our country (Prasad *et al.* 2007). Hence, there is a need for

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proper planning, development and management of water (Rakesh Kumar *et al.* 2005). Therefore, it is imperative to investigate the suitable areas for groundwater extraction to increase the freshwater availability and control the water scarcity. Several conservative methods such as geological, hydrogeological and geophysical techniques were employed to delineate the groundwater potential zones. However, recently, with the use of remote sensing and GIS technologies, mapping of groundwater potential zones has become easier and less expensive compared to conventional methods. Satellite data provide quick and useful baseline information about various factors controlling directly or indirectly the occurrence and movement of groundwater such as geomorphology, soil, land slope, land use/land cover, drainage patterns and lineaments. In addition, geographical information system (GIS) provides an excellent framework for efficiently handling large and complex spatial data for natural resources management (Machiwal *et al.* 2011). Several studies were carried out in the past two decades for identifying the groundwater potential zones using GIS and remote sensing data. The methodology proposed in the literature, Krishanmurthy and Srinivas (1995) in Karnataka; Saraf and Choudhury (1998) in Kandi region of Jammu district, Rao and Jugran (2003) in Chittoor area of Andhra Pradesh; Girish Gopinath and Seralathan (2004) in Muvattupuzha river basin, Kerala; Sikdar *et al.* (2004) and Basudeo Rai *et al.* (2005) in Nambuir district, Kanyakumari; Amin Shaban *et al.* (2006) in Lebanon; Solomon and Quiel (2006) in Eritrea; Ganapuram *et al.* (2009) in Musi basin; Suja Rose and Krishnan (2009) in Nambiyour basin, Kanyakumari; Chowdhury *et al.* (2010) in Manipur district, West Bengal, Upper Langat basin; Machiwal *et al.* (2010) in Mamundiyar basin; Dar *et al.* (2010) and Manap *et al.* (2011) in Malaysia; Khodaei and Nassery (2011) in Urmich Northwest of Iran; Abdalla (2012) in Central Eastern desert, Egypt; Gumma and Pavelic (2013) in Saharan Africa; Sharma *et al.* (2014) in Punjab; Lapworth *et al.* (2014) in northwestern India; MacDonald *et al.* (2014) in Indo-Gangetic basin; Preeja *et al.* (2011) in Tropical River Basin, Kerala; Arkoprovo Biswas (2012) in Ganjam district, Orissa; Selvam *et al.* (2014) in Tuticorin, Tamil Nadu; Domingos Pinto *et al.* (2015) in Comoro watershed, Timor Leste; Shashank Shekhar and Arvind Chandra Pandey (2014) in Palamu district, Jharkhand; Ramu and Vinay (2014) in Mysore taluk, Karnataka; Soumen Dey (2014) in Puruliya district, West Bengal; Rajvir Singh *et al.* (2014) in Mewat district, Haryana; Abhay *et al.* (2011) in Chandrapur and Gadchiroli districts of Maharashtra), to demarcate groundwater potential zone of an area, in which several selected thematic maps from different sources such as remote sensing data, geophysical data and conventional data are integrated in the GIS environment to generate groundwater potential. So, for the study area, exploration of groundwater by Boolean overlay, weighed index overlay analysis and fuzzy logic model (Lohani *et al.* 2014; Lohani and Krishan 2015a, b) were used to identify groundwater potential zones. In all, the three methods were compared and validated with the borewell yield data.

## 2. Study area

Salem district lies in the western part of Tamil Nadu, located between 11°15′–12°00′N latitudes and 77°35′–78°50′E longitudes. The total geographical area is about 5207 $km^2$ out of which the Stanley reservoir covers an area of about 164.5 $km^2$. The study is bounded by the districts Dharmapuri in the north, Namakkal in the south, Erode in the west and South Arcot in the east directions. The district has a maximum and minimum temperature of 40°C and 13°C. The rivers Cauvery, Vashista Nadhi, Swedha Nadhi, Sarabhanga Nadhi and Thirumanimuthar flow in the district.

Salem district is well known for its mineral deposits, Stanley reservoir and for mango fruit. Mineral deposits like magnesite, bauxite, limestone, quartzite, iron ore and granite are available in this district. Stanley reservoir which is also called as Mettur dam is the main source of water supply in this district. Water from the river Cauvery is stored in Stanley reservoir and it is supplied to many districts which is the main source of water for irrigation in many districts of Tamil Nadu. Yercaud, a hill station, which is a tourism spot is also a landmark for this district. Industries like sago, textile and silver ornaments are in this district. The population of this district according to 2011 census was 34,82,056. The districts comprise of 20 administrative blocks which is shown in figure 1.

Salem district is underlain entirely by Archaean crystalline formations with recent alluvial and colluvial deposits of limited areal extents along the courses of major rivers and foothills respectively. Weathered and fractured crystalline rocks and the recent colluvial deposits constitute the important aquifer systems in the district. Colluvial deposits represent the porous formations in the district. The thickness of these aquifers ranges from a few meters to as much as 25 m. Granite gneiss, charnockite, granites and other associates represent the hard consolidated crystalline rocks. Ground water occurs under phreatic conditions in the weathered mantle and under semi-confined conditions in the fractured zones. These rocks are devoid of primary porosity but are rendered porous and permeable with the development of secondary openings by fracturing and their interconnection. The thickness of weathered zone in the district ranges from <1 to more than 25 m. Dug wells have traditionally

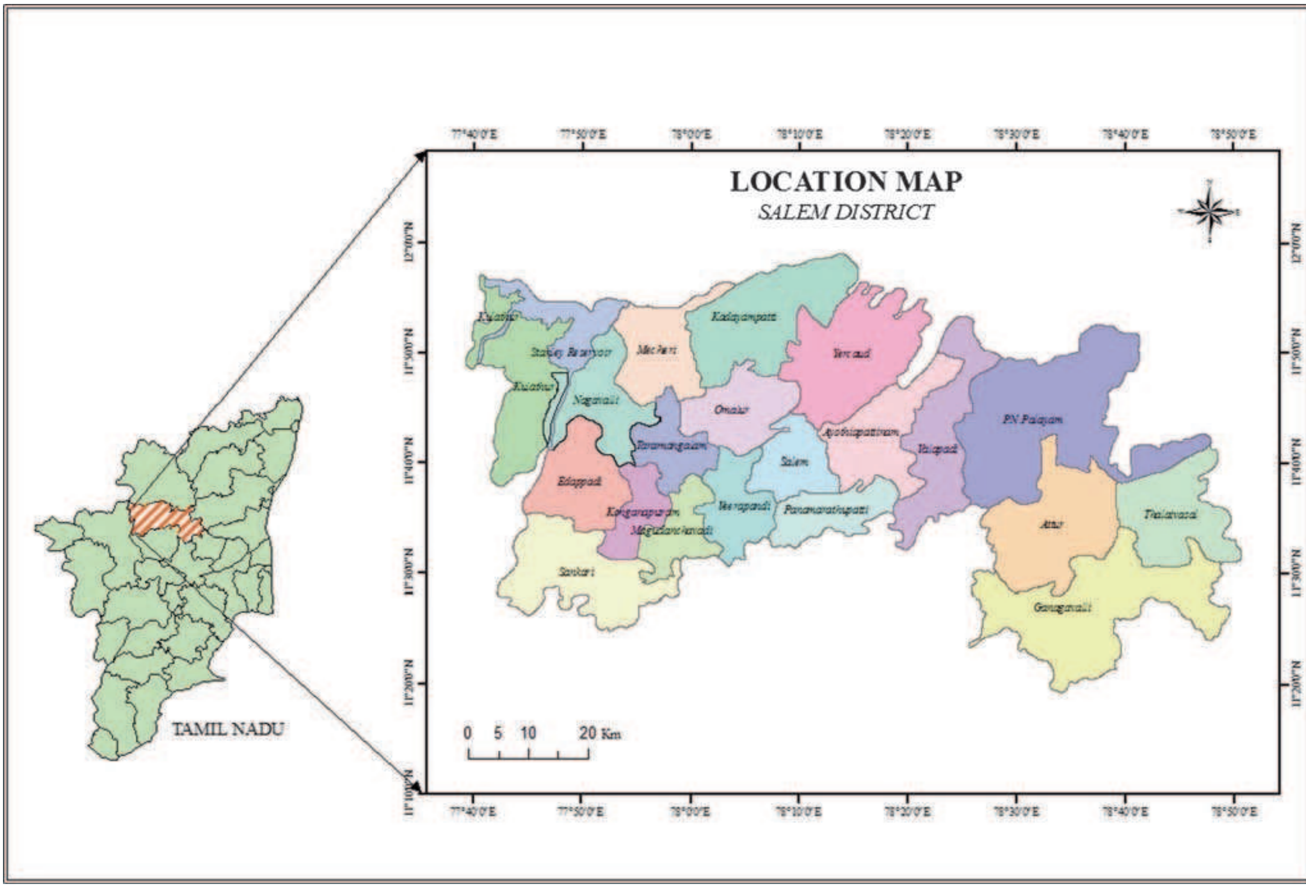


Figure 1. Location map and administrative blocks of the study area.

been the most common ground water abstraction structures used for irrigation in the district. The yields of the open wells are low in the hill areas about 500 lpm for a drawdown of 2 m for 4 hr pumping, whereas the open wells in the plains vary from 200 to 1000 lpm. In recent years, the declining water levels and reduction in yields of wells are being observed due to increased extraction of ground water by a large number of bore wells for irrigation purposes. The depth to water level in the district varied between 0.10 and 11.46 m bgl during pre-monsoon and varied between 0.10 and 17.15 m bgl during post-monsoon (Subburaj 2008).

## 3. Methodology

From the Satellite Imagery (IRS LISS–III) the lineament map, geomorphology map and land use land cover map were prepared. Lithology map of the study area is prepared by using Geological Survey of India district resource map. Soil map of the study area is prepared from SOI Tamil Nadu soil map. Based on the character, the features in different thematic layers were assigned with different weight age values according to the potential for groundwater. After the layers were integrated using GIS and the area can be classified as high, moderate and low groundwater potential zones.

Table 1. *Measurement scale of AHP.*

| Intensity of relative importance | Definition |
|---|---|
| 1 | Equal importance |
| 2 | Weak or slight |
| 3 | Moderate importance |
| 4 | Moderate plus |
| 5 | Strong importance |
| 6 | Strong plus |
| 7 | Very strong |
| 8 | Very very strong |
| 9 | Extreme importance |

### 3.1 *Analytical hierarchy process*

The analytical hierarchy process (AHP) is a theory of measurement through pairwise comparison and relies on the judgement of experts to derive priority scales. The comparison was made on a scale of numbers 1–9 which indicates how many times a layer is important than the other (Saaty 2008). Table 1 represents the scaling used in AHP. If the matrix formed is equal to $a_{ij}$, $a_{ij} = w_i/w_j$, where $w$

is the weight of the parameters and $i, j = 1, \ldots, n$, has positive entries everywhere and satisfies the reciprocal property $a_{ij} = 1/a_{ij}$. Any matrix with this property is called a reciprocal matrix (Saaty 1990).

A pairwise comparison matrix was made for the thematic layers (geology, geomorphology, soil and land use/land cover) and its parameters based on the scale are shown in table 1. Based on the pairwise comparison matrix, the relative weight matrix and normalized principal eigen vector was calculated to determine the influence percentage of thematic layers and the rank for its parameters.

### 3.1.1 *Pairwise comparison – thematic layers*

The pairwise comparison for the seven layers were given based on the comparison between the layers and their relative importance towards groundwater prospects and a 7×7 matrix was formed. In the comparison matrix shown in table 2, L1 represents geology, L2 – geomorphology, L3 – soil, L4 – land use and land cover, L5 – lineament density, L6 – drainage density and L7 – slope.

Based on the comparison matrix, the following steps were carried out to calculate the normalized principal eigen vector. In step 1, the values of $j$ (column) were summed. In step 2, each element of the column were divided by their corresponding sum of the column to form the relative weight matrix which is shown in table 3.

Table 2. *Pairwise comparison matrix – thematic layers.*

| Thematic layers | L1 | L2 | L3 | L4 | L5 | L6 | L7 |
|---|---|---|---|---|---|---|---|
| L1 | 1.00 | 1/2 | 1/2 | 2.00 | 2.00 | 3.00 | 1/2 |
| L2 | 2.00 | 1.00 | 2.00 | 3.00 | 2.00 | 3.00 | 2.00 |
| L3 | 2.00 | 1/2 | 1.00 | 3.00 | 2.00 | 4.00 | 1.00 |
| L4 | 1/2 | 1/3 | 1/3 | 1.00 | 1.00 | 2.00 | 1/2 |
| L5 | 1/2 | 1/2 | 1/2 | 1.00 | 1.00 | 2.00 | 1/3 |
| L6 | 1/3 | 1/3 | 1/4 | 1/2 | 1/2 | 1.00 | 1/2 |
| L7 | 2.00 | 1/2 | 1.00 | 2.00 | 3.00 | 2.00 | 1.00 |
| Total | 8.33 | 3.67 | 5.58 | 12.50 | 11.50 | 17.00 | 5.83 |

Table 3. *Relative weight matrix – thematic layers.*

| Thematic layers | L1 | L2 | L3 | L4 | L5 | L6 | L7 |
|---|---|---|---|---|---|---|---|
| L1 | 0.12 | 0.14 | 0.09 | 0.16 | 0.17 | 0.18 | 0.09 |
| L2 | 0.24 | 0.27 | 0.36 | 0.24 | 0.17 | 0.18 | 0.34 |
| L3 | 0.24 | 0.14 | 0.18 | 0.24 | 0.17 | 0.24 | 0.17 |
| L4 | 0.06 | 0.09 | 0.06 | 0.08 | 0.09 | 0.12 | 0.09 |
| L5 | 0.06 | 0.14 | 0.09 | 0.08 | 0.09 | 0.12 | 0.06 |
| L6 | 0.04 | 0.09 | 0.04 | 0.04 | 0.04 | 0.06 | 0.09 |
| L7 | 0.24 | 0.14 | 0.18 | 0.16 | 0.26 | 0.12 | 0.17 |
| Total | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |

In step 3, the normalized principal eigen vector is obtained by averaging across the rows and it is shown in table 4. Based on the normalized principal eigen vector, the influence percentage for each thematic layer is shown in table 5.

The rule of thumb to check the consistency of the comparison is that a consistency ratio (CR) ≤0.1 indicates an acceptable reciprocal matrix and a ratio over 0.1 indicates that the matrix should be revised (Sani Yahaya *et al.* 2010). The consistency ratio is calculated as mentioned below:

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI}, \tag{1}$$

where CI is the consistency index and RI is the random consistency index.

$$\mathrm{CI} = \lambda_{\max} - n/n - 1, \tag{2}$$

where $\lambda_{\max}$ is the principal eigen value and $n$ is the number of comparisons.

The random consistency index for calculating CR is shown in table 6.

The consistency check for the thematic layers is $\lambda_{\max} = 7.27$, $n = 7$, RI = 1.32, CI = 0.034 and CR is 0.026, which is less than the threshold value of 0.1, which in turn indicates a high level of consistency.

### 3.1.2 *Pairwise comparison – parameters*

In the same procedure prescribed for calculating the influence percentage of thematic layers, the relative ranks of the parameters geology, geomorphology, soil and land use/land cover is calculated. The pairwise comparison for the each parameter

Table 4. *Normalized principal eigen vector – thematic layers.*

| Thematic layers | Normalized principal eigen vector |
|---|---|
| L1 | 0.13 |
| L2 | 0.26 |
| L3 | 0.20 |
| L4 | 0.08 |
| L5 | 0.09 |
| L6 | 0.06 |
| L7 | 0.18 |

Table 5. *Influence percentage for thematic layers.*

| Sl. no. | Thematic layers | Influence percentage |
|---|---|---|
| 1 | Geology | 13 |
| 2 | Geomorphology | 26 |
| 3 | Soil | 20 |
| 4 | Land use and land cover | 08 |
| 5 | Lineament density | 09 |
| 6 | Drainage density | 06 |
| 7 | Slope | 18 |

Table 6. *Random indices for matrices of various sizes.*

| Matrix size | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 |

of the four thematic layers (geology, geomorphology, soil and land use/land cover) was given based on the comparison between parameters and their relative importance towards groundwater prospects. A 10×10 matrix is also formed for geology and land use/land cover and 6×6 matrix is also formed for geomorphology and soil.

### 3.2 *Overlay analysis*

The prepared thematic maps were overlaid to identify the groundwater potential zones using three methods, viz., Boolean overlay analysis, weighed index overlay analysis (WIOA) and fuzzy logic model.

#### 3.2.1 *Boolean overlay*

In Boolean overlay, rank for each parameter of the thematic layer is based on binary logic in which 1 is true and 0 is false. Based on this, all the seven thematic maps were converted into binary maps in which the areas with low groundwater potential are given the value of zero and the areas with possibility of good groundwater potential are given the value of one. These maps are overlaid using Boolean operation where the input maps can be integrated using logical operators such as AND, OR, XOR and NOT (Carter Bonham 1991). The different steps involved in identifying the groundwater potential zones using Boolean operations are shown in figure 9.

In this research, all the thematic layers are combined using logical operators OR (union) and AND (intersection). This analysis results in a binary map which indicates whether groundwater is available or not available.

#### 3.2.2 *Weighed index overlay analysis*

WIOA is a simple and straight forward method for combined analysis of multiclass maps. The efficacy of this method lies in that the human judgement can be incorporated in the analysis. A weight represents the relative importance of a parameter *vis-à-vis* the objective. WIOA method takes into consideration the relative importance of the parameters and the classes belonging to each parameter. There is no standard scale for a simple weighed overlay method. For this purpose, criteria for the analysis should be defined and each parameter should be assigned importance (Saraf and Choudhury 1998).

Each parameter in the thematic map of geology, geomorphology, soil and land use/land cover was assigned ranks from 1 to 5 (low, moderate, moderate to good, good and excellent) based on values obtained from analytical hierarchy process. The parameters of the thematic maps lineament density, drainage density and slope, land use/land cover, soil, geology and geomorphology were made into five classes and the rank was assigned based on their influence towards groundwater which is shown in table 7.

#### 3.2.3 *Fuzzy logic model*

Fuzzy logic model is an attractive one because it is straight forward to understand and implement. It can be used with the data from any measurement scale and weighing of evidence is controlled entirely by the expert. The fuzzy logic model allows for more flexible combination of weighed maps and could be readily implemented with a GIS modelling language (Biswajeet *et al.* 2009). In a fuzzy map, the associated value for each pixel (fuzzy membership value), represents both the relative importance of the thematic layers and the relative values corresponding to different parameters on the map area. In fuzzy set theory, membership can take any value between 0 and 1 reflecting the degree of certainty with respect to some attribute of interest (Tangestani 2003).

In fuzzy logic model, there are some fuzzy operators such as fuzzy AND, fuzzy OR, fuzzy algebraic product, fuzzy algebraic sum and fuzzy gama. These operators are used on the factor maps which was developed based on the influence of the thematic maps and the rank of the parameters in each thematic.

Except for water resources, in other cases, the operator of sum and gamma are used. The fuzzy AND is equivalent to Boolean AND and fuzzy OR is like Boolean OR (Biswajeet *et al.* 2009; Lohani and Krishan 2015a, b). The fuzzy algebraic product operator would be an appropriate combination operator for identifying suitable sites for artificial recharge, because at each location the combined fuzzy membership values tend to be very small in this operator, due to the effect of multiplying several numbers less than one (Saravi *et al.* 2006). So, in this research for identifying groundwater potential zones, the fuzzy algebraic product was used. The fuzzy algebraic product is defined as:

$$\mu_{\text{combination}} = \prod_{i=1}^{n} \mu_i, \tag{3}$$

where $\mu_i$ is the fuzzy membership function for the $i$th map.

3.2.4 *Factors of thematic layers and its parameters*

Based on the analytical hierarchy process, the influence percentage for thematic layers and the rank for the parameters which was considered for WIOA, fuzzy logic model and the rank considered in Boolean overlay for different parameters of the seven thematic maps are shown in table 7.

The groundwater potential zones were delineated in the study area considering seven thematic maps geomorphology, geology, soil, land use/land cover, lineament density, drainage density and slope. Boolean overlay, WIOA and fuzzy logic model were used for integrating the thematic maps to identify groundwater potential zones. Structural hills, reserved forest area and Stanley reservoir were restricted in the analysis.

Of the above three methods (Boolean logic, weighed index overlay analysis and fuzzy logic model), the Boolean logic results only with a binary map shows whether groundwater is present or not present in a particular location. Weighed index overlay analysis is a straight-forward method. But fuzzy logic model is a flexible method, since a variety of data integration methods can be used in this model.

## 4. Result and discussion

### 4.1 *Thematic map*

#### 4.1.1 *Soil*

Thematic layer map of soil type reveals that the study area is having nine categories. They are red *in-situ*, red colluvial, black soil, brown soil, mixed soil and soil association which are shown in figure 2. Major portion of the district is covered by red *in-situ* soil. Red colluvial, black soil, brown soil and soil association are covered over small areas of the district. Red soil was developed on the crystalline rocks like gneissic and granite. It was formed due to the disintegration of metamorphic and igneous rocks. Presence of iron gives red colour and it is rich in iron and aluminium. Red colluvial and red *in-situ* are the types of red soil.

Red *in-situ* was formed due to the residual soil present in the place. The rate of permeability is moderate to high. It is widespread in all the blocks. Red colluvial soil was formed by the transported soils from other places by gravity. The rate of permeability is low and it is found in Nangavalli, Omalur, Veerapandi, Kadayampatti, Yercaud, Ayothiapattinam and Valapadi blocks. Black soil is highly sticky and slightly plastic under wet condition. Its permeability is very low. It is mainly composed of clay, clay loam and sandy soil. It is found in Magudanchavadi, Salem, Omalur, Ayothiapattinam, Pedhanaickenpalayam, Thalaivasal and Gangavalli blocks. Brown soil has a high rate of permeability. It is found in Mecheri, Veerapandi, Taramangalam, Omalur, Panamarathupatty and Ayothiapattinam blocks.

#### 4.1.2 *Geology*

Geology is a science which deals with the different types of rocks that exist on the surface and subsurface of the earth. Groundwater occurrence in a particular area depends on the porosity and permeability of the rocks. So, the geology map was important for the present study since the occurrence of groundwater was controlled more by the geological formations. The different geological units of this district are gneiss, charnockite, leptinite, amphibolites, dunite and magnesite, alluvium, calcareous gneiss and limestone, ultra basic with magnetite and amphibole gneiss which are shown in figure 3.

The major portion of the study area is covered by gneissic rocks and it is spread in the blocks of Mecheri, Nangavalli, Edappadi, Sankari, Magudanchavadi, Taramangalam, Omalur, Veerapandi, Gangavalli, Thalaivasal, Attur, Pedanaickenpalayam and Valapaddi. In these types of rocks, conspicuous foliation trends are seen. Next to gneissic rocks the study area is highly covered by charnockite. These types of rocks are found in Mettur, Salem, Panamaruthupatty, Yercaud and Gangavalli blocks. Calcareous gneiss and crystalline limestone are seen in some parts of Sankari, Edappady and Nangavalli blocks. It is classified as metamorphic rocks. Groundwater potential would be high in these areas if solution cavities are present. Alluvium consists of coarse-grained materials which has high groundwater potential. It is seen along some parts of Thirumanimuthar and Sarabangha river basin. In addition, ultrabasic with magnesite is found in patches in Mettur and Mecheri blocks. Iron is found in these types of rocks and magnesite rich layers are alternating with quartzite rich layers. Leptinite is seen in Attur and Veerapadi blocks. Ultrabasic with magnetite is an igneous rock. Silica content is $<4\%$. It occurs in addition with magnetite and is seen in patches in Valapadi and Attur blocks. Amphibolite is less dominant in the study area. The rocks are highly weathered. It is a metamorphic rock and is seen only in Valapadi block. Dolerite found in the study area is commonly called as black granite which has a good world market. It is mainly seen in Ayothiapattinam block and in patches in Valapadi and Attur blocks. Dunite is an ultramafic igneous rock. Hydrothermal alterations

Table 7. *Influences and weights of thematic layers and its parameters.*

| Thematic map | Parameter | Boolean overlay rank | Influence percentage | WIOA rank | Fuzzy logic rank |
|---|---|---|---|---|---|
| Geology | Leptinite | 1 | | 4 | 0.80 |
| | Gneiss | 1 | | 4 | 0.80 |
| | Amphibolite | 0 | | 1 | 0.20 |
| | Charnockite | 1 | | 3 | 0.60 |
| | Alluvium | 1 | | 5 | 0.99 |
| | Calcareous gneiss and limestone | 0 | 13 | 1 | 0.20 |
| | Amphibole gneiss | 0 | | 1 | 0.20 |
| | Dunite and magnesite | 1 | | 4 | 0.80 |
| | Dolerite | 0 | | 1 | 0.20 |
| | Trap shoten gneiss | 0 | | 1 | 0.20 |
| Geomorphology | Hill plateau | 0 | | 1 | 0.20 |
| | Composite slope | 0 | | 1 | 0.20 |
| | Bazada zone | 1 | | 5 | 0.99 |
| | Pediment | 0 | 26 | 1 | 0.20 |
| | Shallow pediment | 0 | | 1 | 0.20 |
| | Buried pediment | 1 | | 4 | 0.80 |
| | Structural hill | NA | | NA | NA |
| Soil | Red *in-situ* | 1 | | 4 | 0.80 |
| | Red colluvial | 1 | | 5 | 0.99 |
| | Black soil | 0 | | 1 | 0.20 |
| | Brown soil | 0 | 20 | 1 | 0.20 |
| | Mixed soil | 0 | | 1 | 0.20 |
| | Soil association | 0 | | 1 | 0.20 |
| | Reserved forest | NA | | NA | NA |
| Land use/land cover | Water bodies | 1 | | 5 | 0.99 |
| | Mining area | 0 | | 1 | 0.20 |
| | Built up land | 1 | | 2 | 0.40 |
| | Dense forest | NA | | NA | NA |
| | Open forest | NA | | NA | NA |
| | Crop land | 1 | | 4 | 0.80 |
| | Scrub forest | 1 | 8 | 2 | 0.40 |
| | Gully land | 1 | | 4 | 0.80 |
| | Land with scrub | 0 | | 1 | 0.20 |
| | Land without scrub | 1 | | 2 | 0.40 |
| | Fallow land | 1 | | 4 | 0.80 |
| | Stony waste | 0 | | 1 | 0.20 |
| Lineament density (km/km$^2$) | 0–0.500 | 0 | | 1 | 0.20 |
| | 0.500–1.000 | 1 | | 2 | 0.40 |
| | 1.000–1.500 | 1 | 9 | 3 | 0.60 |
| | 1.500–2.000 | 1 | | 4 | 0.80 |
| | 2.000–2.600 | 1 | | 5 | 0.99 |
| Drainage density (km/km$^2$) | 0–0.600 | 1 | | 5 | 0.99 |
| | 0.600–1.200 | 1 | | 4 | 0.80 |
| | 1.200–1.800 | 1 | 6 | 3 | 0.60 |
| | 1.800–2.400 | 1 | | 2 | 0.40 |
| | 2.400–3.000 | 0 | | 1 | 0.20 |
| Slope | 45° –87° | 0 | | 1 | 0.20 |
| | 15° –45° | 1 | | 2 | 0.40 |
| | 3° –15° | 1 | 18 | 3 | 0.60 |
| | 1° –3° | 1 | | 4 | 0.80 |
| | 0° –1° | 1 | | 5 | 0.99 |

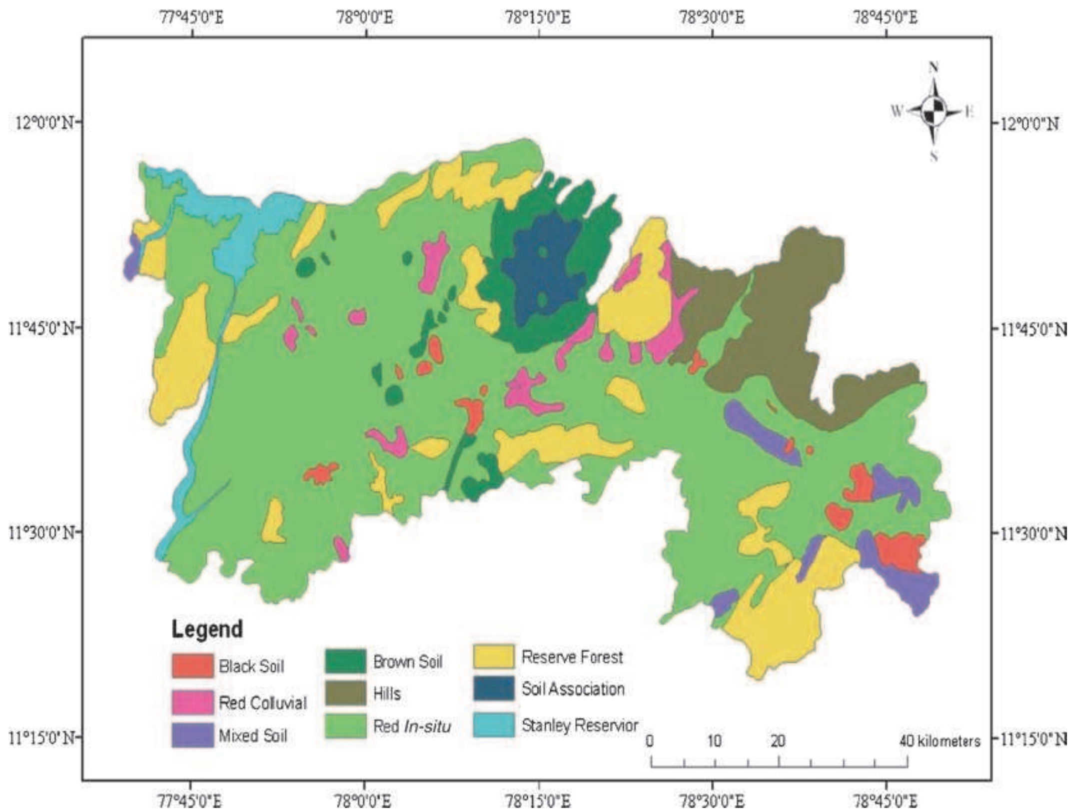


Figure 2. Soil map of the study area.

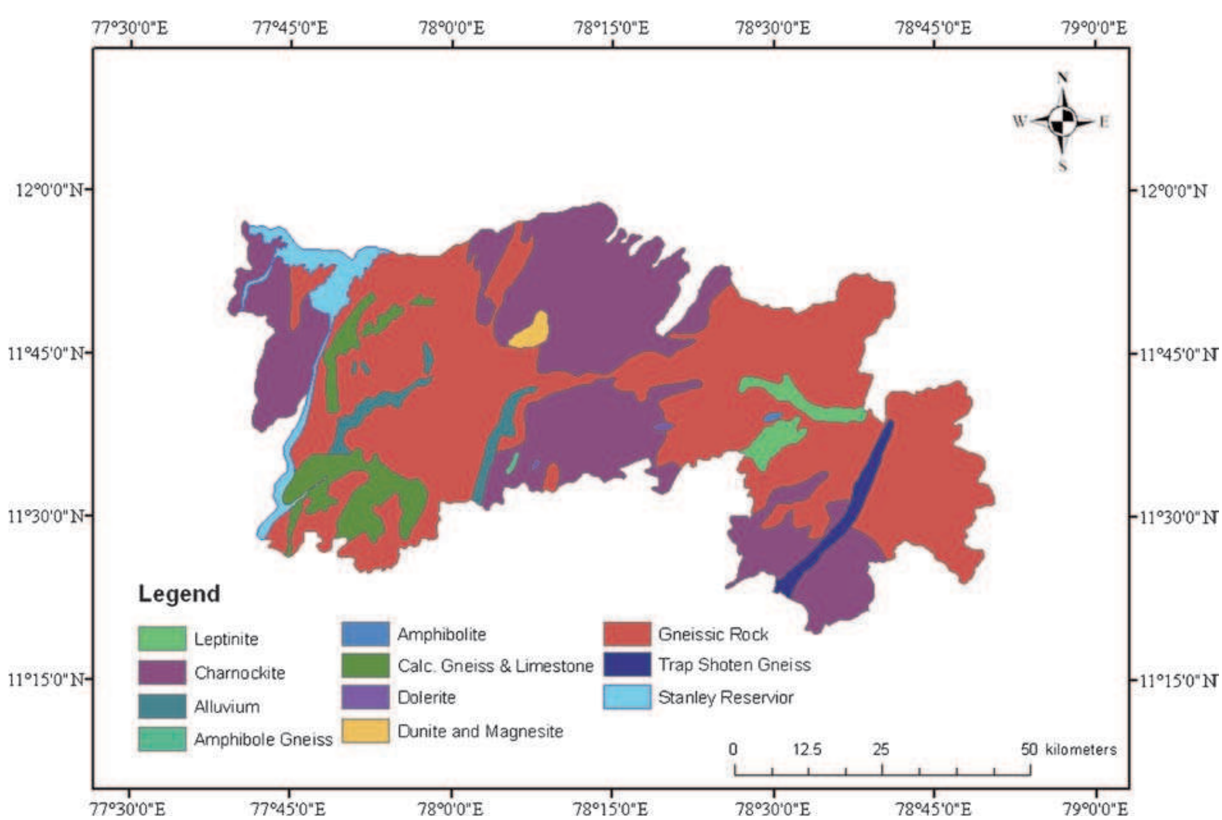


Figure 3. Geology map of the study area.

of dunite have produced magnesite veins within dunite. It is seen only at the foothills of Shevaroys. Trap shoten gneiss is basically charnockite trending northeast and southwest directions and deformed to give trap like appearance. This rock forms the part of Gangavalli shear zone.

#### 4.1.3 *Geomorphology*

Geomorphology indicates the landform in that particular area. The relief, slope, depth of weathered material, types of the weathered material and the overall assemblage of different landforms play an important role in defining the groundwater regime more particularly in hard rock areas and as well in unconsolidated formations (Karanth 1987). The study area is blessed with many hills, viz., Shevaroys on north side, Kalrayan hills on northeastern side, Pachamalai hills on southwest and Palamalaij hills on western side. The different landforms include structural hill, hill plateau, composite slope, bazada zone, pediment, shallow pediment and buried pediment which are shown in figure 4. The entire district is mainly consists of shallow pediment, buried pediment and pediment. Boundary of the district is mainly covered by structural hills. Along the north and northeastern directions, the district is covered by composite slopes and bazada zone.

Shallow pediment is also a type of pediment which was covered by soil of less thickness. Run off is more in this area, so groundwater recharge is less. This geomorphic unit covers most of the western part of the study area and some portion of central and western parts. Buried pediment is more weathered when compared to shallow pediment. Infiltration was good in these areas. These units are seen in some pockets of eastern and western parts of the study area. Pediment is normally seen at the foot of the hills which was of gentle slope. Weathered rocks are seen in this area. It is seen in Mettur, Sankari, Salem, Yercaud, Ayothiapattinam, Valapadi, Gangavalli and Thalaivasal blocks. Bazada is formed by the accumulation of disintegrated rock fragments from a hill slope which allows more infiltration of groundwater. It is found at the bottom of the Kalrayan hills and in Ayothiapattinam, Valapadi and Pedhanaickenpalayam blocks. Composite slope is formed by the weathered debris from structural hills forming a mount. The slope in this landform is high. So, this landform has less groundwater potential. This type of geomorphic units is seen adjacent to the structural hills. Hill plateau is a tableland over the structural hills. It is mainly seen in Yercaud and Pedhanaickenpalayam blocks. Structural hills are the land forms where the run off is very high. So the groundwater potential would be less in these units. Shevaroys, Pachamalai, Palamalai and

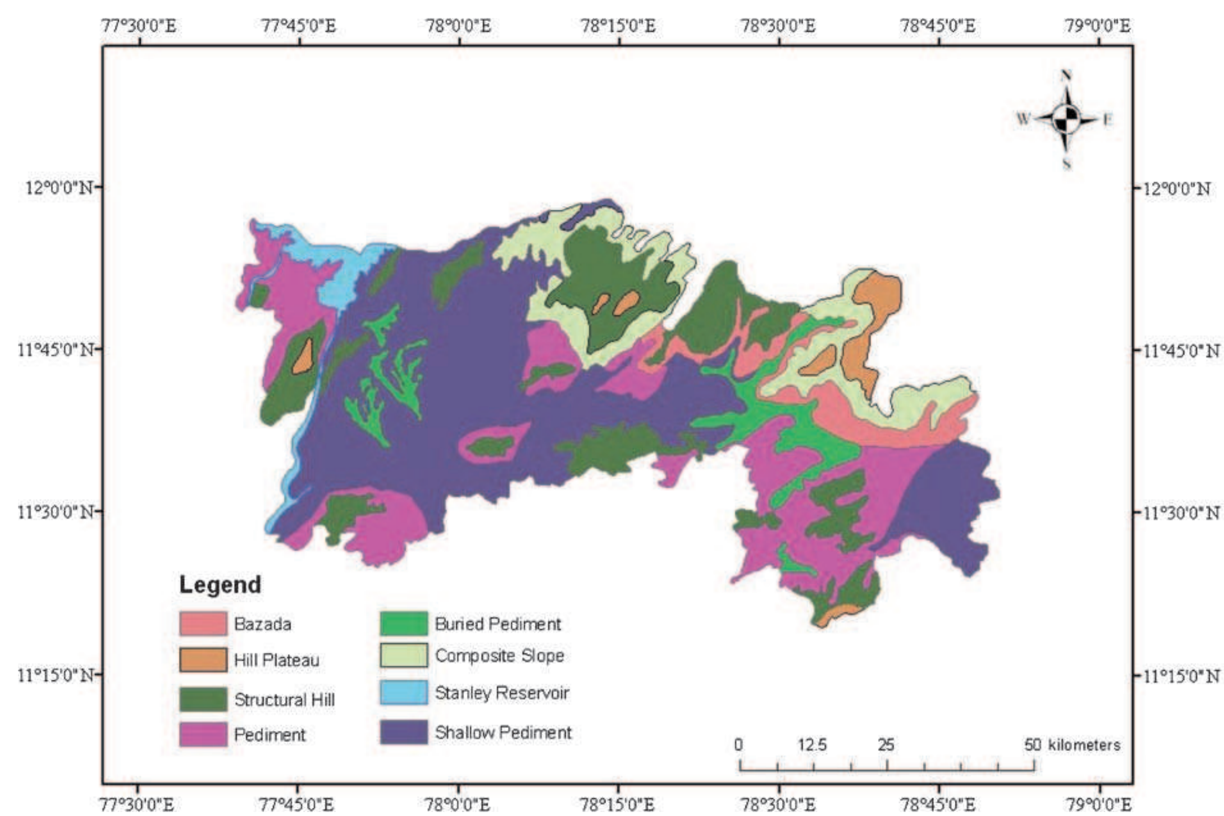


Figure 4. Geomorphology map of the study area.

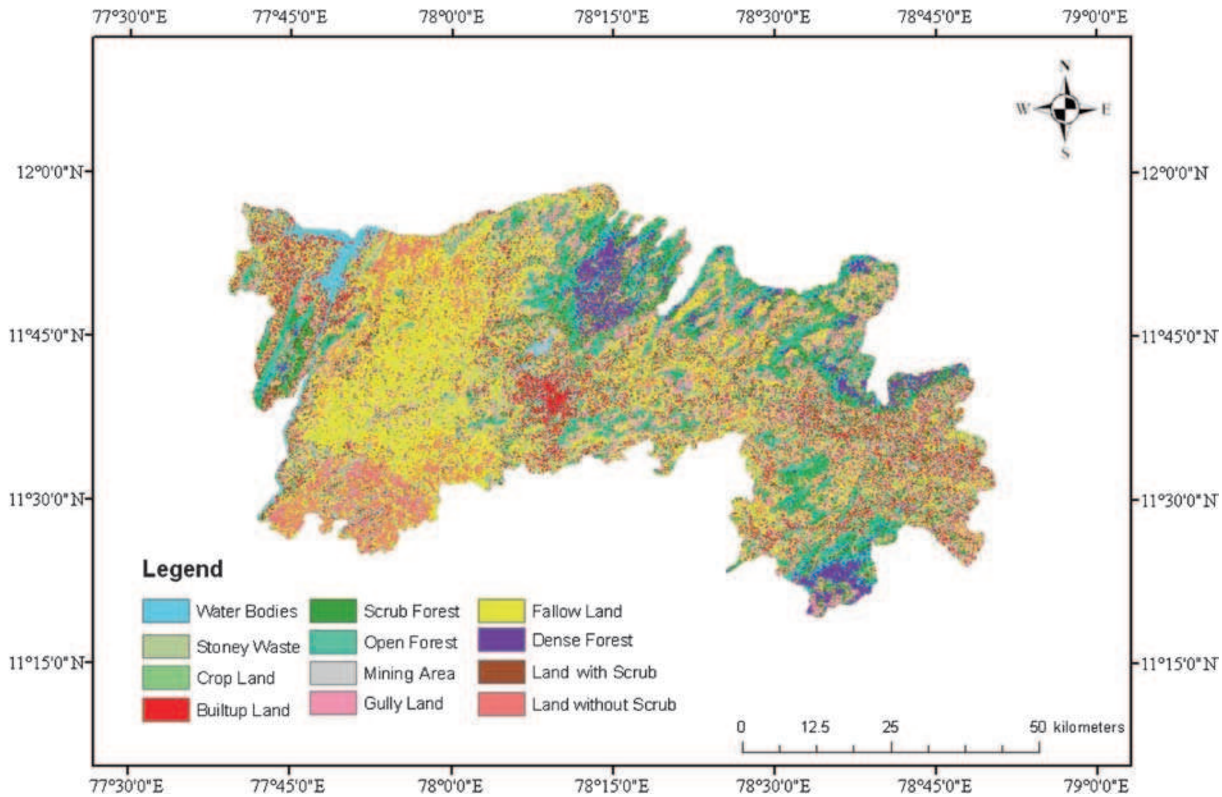


Figure 5. Land use pattern of the study area.

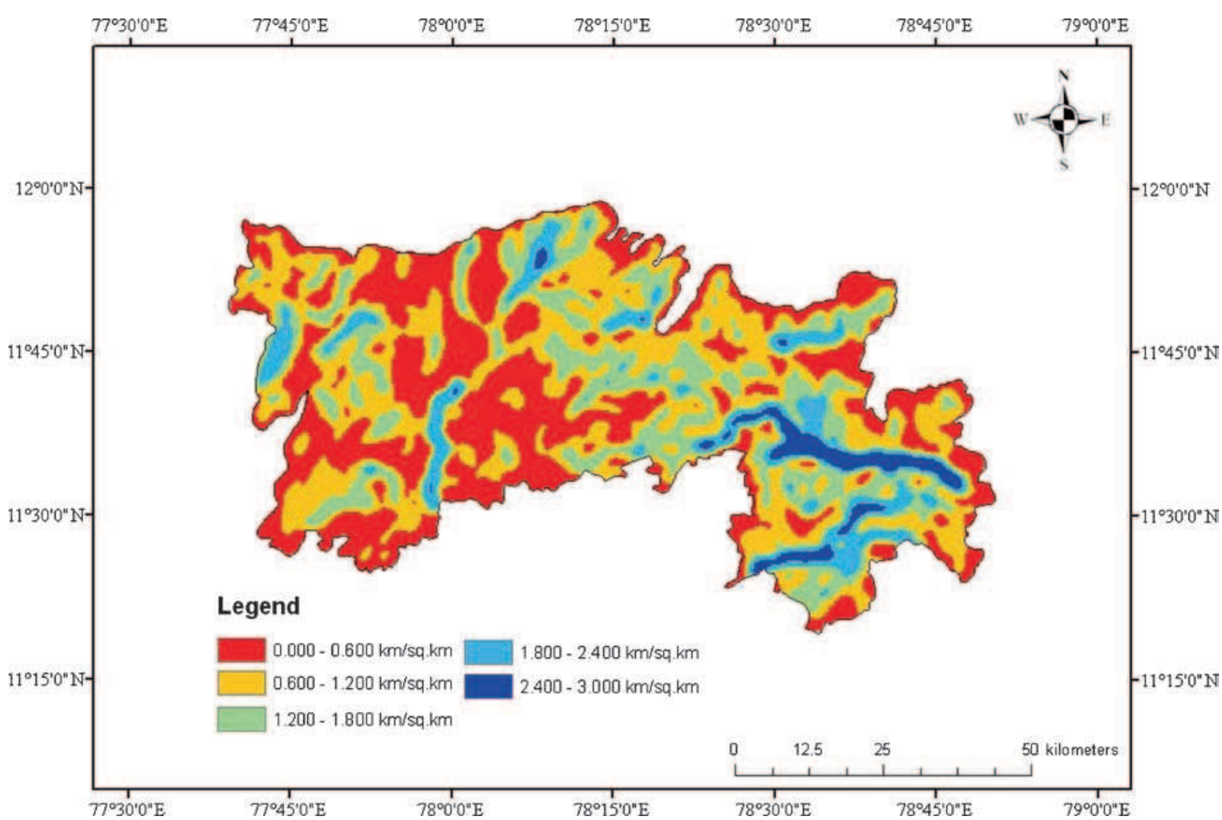


Figure 6. Drainage density map of the study area.

Kalrayan hills are the important hills found in the study area.

#### 4.1.4 *Land use/land cover*

Land use/land cover plays an important role in the occurrence and development of groundwater. The land use of the study area is classified into 12 classes: Built-up land, water bodies, crop land, fallow land, scrub forest, dense forest, open forest, gully land, land with scrub, land without scrub, mining area and stony waste (figure 5). Approximately, 22.48% of the total area is covered by forest land and 22.88% of the area is under cultivation as agriculture land. Settlements represent 4.63 and 4.53% area is covered by the water bodies. The remaining (45.48%) represents gully land, land with scrub, land without scrub, mining area and stony waste. Classification of land use for weighed analysis was decided based on the land-use type, area coverage and properties to infiltrate water, and their characteristics to hold water on the ground surface.

#### 4.1.5 *Drainage density*

Drainage density indicates closeness of spacing of channels as well as nature of surface material (Prasad *et al.* 2007). It was the measure of total length of the stream segment of all orders per unit area. It was affected by factors which control the characteristic length of the stream-like resistance to weathering, permeability of rock formation, climate, vegetation, etc. (Rajiv Chopra *et al.* 2005). The drainage density indicates the relative run off of an area. Places where the density is high, runoff would be more and of less drainage density, run off would be less. In the study area, the density ranges from 0 to 3 km/km$^2$ which is shown in figure 6.

The drainage density map reveals that the drainage density is more in the eastern part of the district and less in the western part which indicates that the rate of infiltration in the western part of the district will be more when compared with the eastern part of the district. So the places where the run off is less, recharge will be good and the groundwater potential in that places will also be good. Drainage density was less in the major portions of Mecheri, Taramangalam, Edappady, Konganapuram, Sankari, Veerapandi, Salem, Omalur blocks and along the periphery of the district. The drainage density was relatively high in a strip of area crossing Thalaivasal, Attur, Valapadi, Gangavalli blocks and a small area in Kadayampatti block.

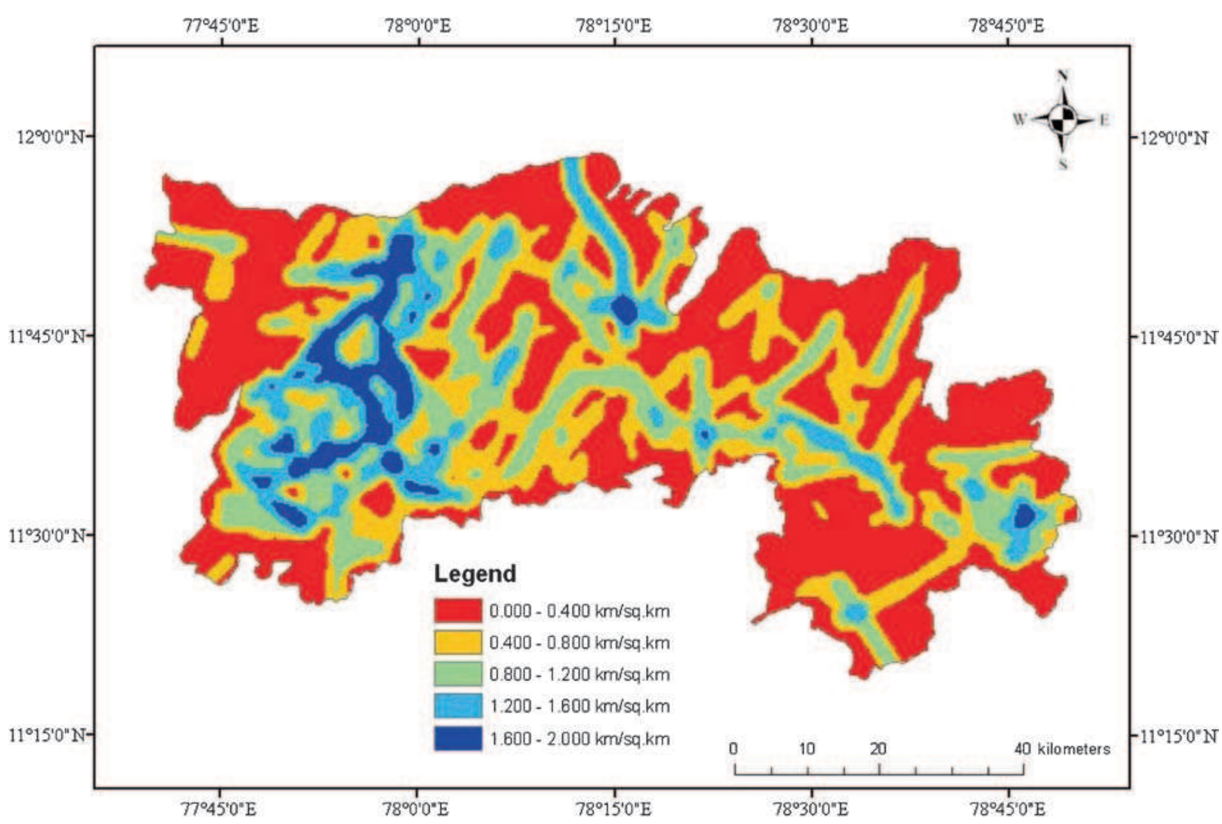


Figure 7. Lineament density map of the study area.

#### 4.1.6 *Lineament density*

The lineament density indicates the relative infiltration capacity of an area. Places where the density is high, infiltration would be more and of less lineament density, infiltration would be less. In the study area, the density, ranges from 0 to 2 km/km$^2$ which is shown in figure 7. The study area based on the lineament density was classified into five categories, viz., 0–0.4, 0.41–0.8, 0.81–1.2, 1.21–1.6 and 1.61–2.0 km/km$^2$. The lineament density was relatively high in west, northwest and southwest parts of the study area when compared with other areas and it was less in the east, northeast, southeast directions and around the periphery of the district. Lineament density was more in Mecheri, Nangavalli, Edappadi, Magudanchavadi and small areas in Sankari, Yercaud and Thalaivasal blocks.

#### 4.1.7 *Slope*

Slope of an area is an indicator of the infiltration rate. The places where the slope is more, the contact period of water with surface is less and the infiltration rate will be less. In places where the

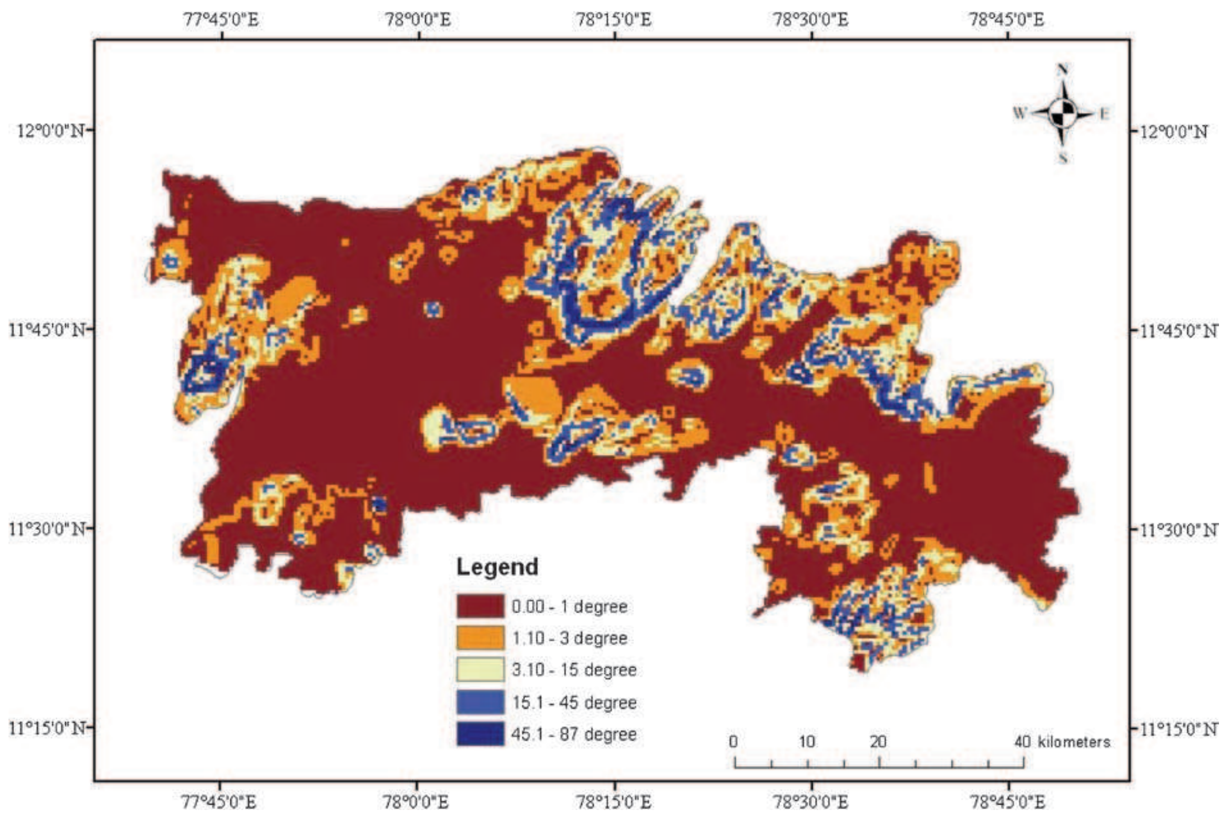


Figure 8. Slope map of the study area.

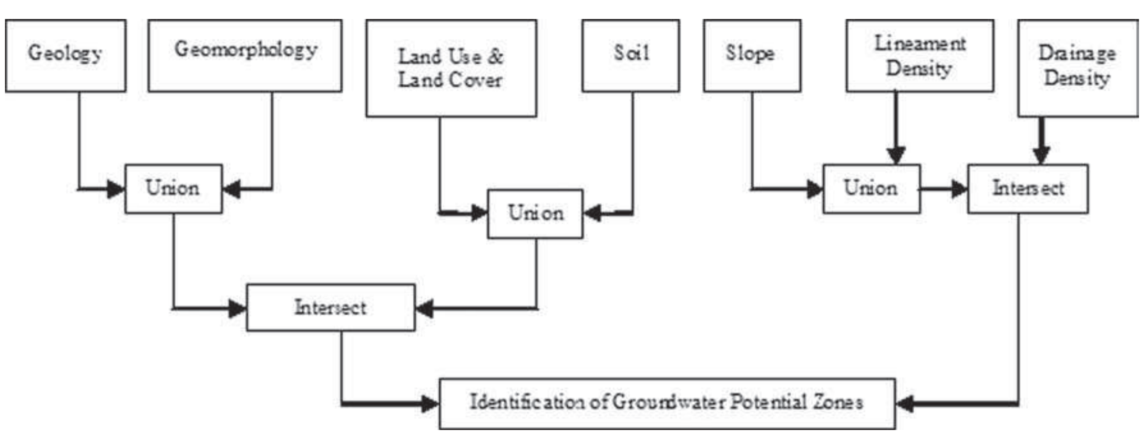


Figure 9. Steps in Boolean overlay analysis.

slope is relatively less, the contact of water with the surface will be high and the infiltration rate will be high which results in good groundwater potential.

The study area was classified into five categories (figure 8): nearly level (0–1°), gentle slope (1.1°–3°), high slope (3.1°–15°) and the other two classes represent the hills (15.1°–45° and 45.1°–87°). The slope map of the study area reveals that the slope was high in the hilly terrain which was situated in the north, northeastern, southeastern and western parts of the study area. Major portion of the district falls under nearly level category (0–1°).

### 4.2 *Groundwater potential zones of the study area using Boolean overlay analysis*

The Boolean overlay analysis results with a binary map is shown in figure 9. The binary map reveals places with and without groundwater presence.

Boolean overlay analysis (figure 10) reveals that groundwater is present in all the geomorphic units except major portions of shallow pediment and composite slope. Considering geological units, the groundwater is present in all units except in calcareous gneiss and limestone, trap shoten gneiss and in major portions of dolerite rocks. Considering soil, the groundwater is present in all the types except in major portions of brown soil and some portions of red *in-situ* soil. Considering slope, the groundwater is present in all the categories except some portions which were categorized as moderate to good, good and excellent which is mainly seen in Sankari block. Considering lineament density and drainage density, the groundwater present in the areas were categorized as less.

### 4.3 *Groundwater potential zones of the study area using WIOA*

WIOA results with a groundwater potential map is shown in figure 11. The WIOA groundwater potential map reveals that groundwater potential is found under good category (occupies 5% of the study area) in the few patches of the north, northwestern and western sides of the study area. The suitable soil (red *in-situ* and red colluvial), geomorphological (bazada and buried pediment) which is present in the portion of the study area, provides favourable condition for good groundwater recharge. The predominant portion of the study area covers moderate to good (occupies 87% of the study area)

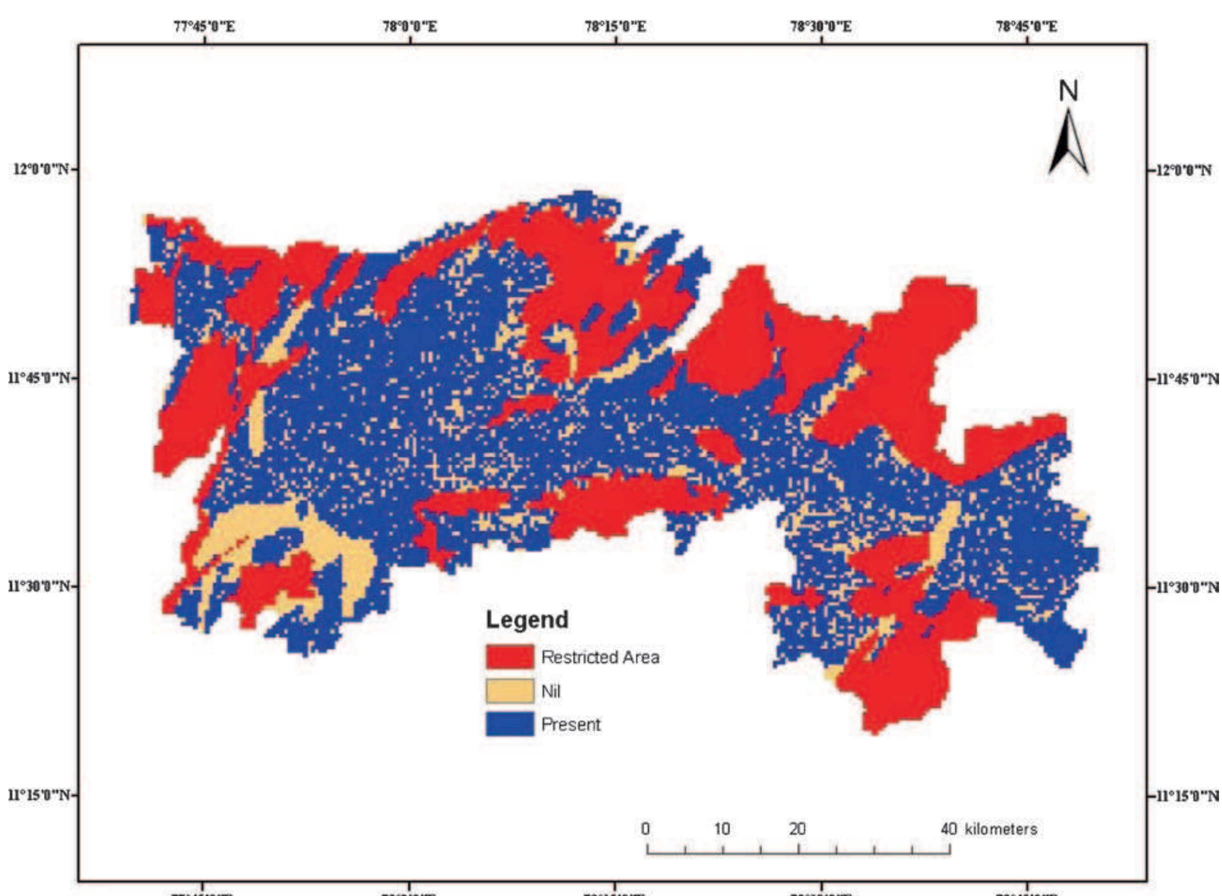


Figure 10. Groundwater potential zones of the study area (Boolean overlay analysis).

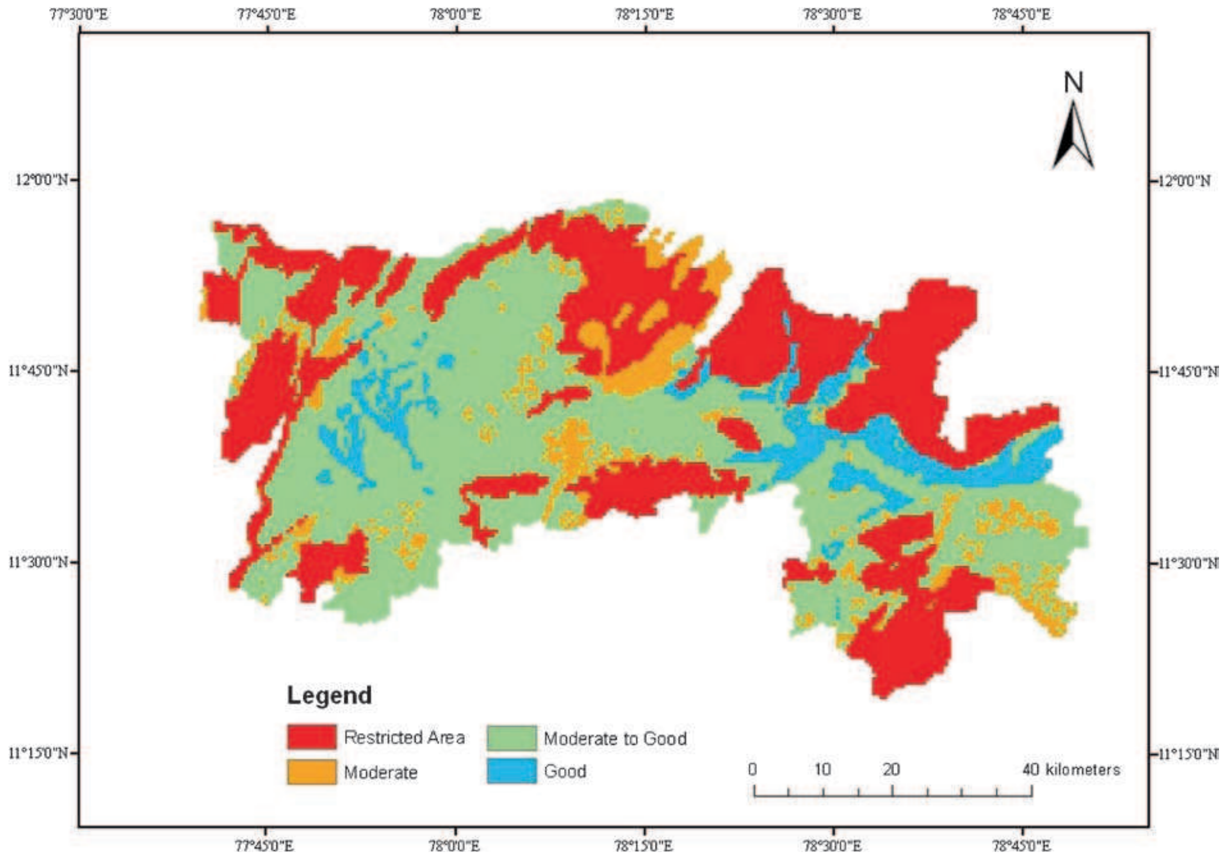


Figure 11. Groundwater potential zones of the study area (WIOA).

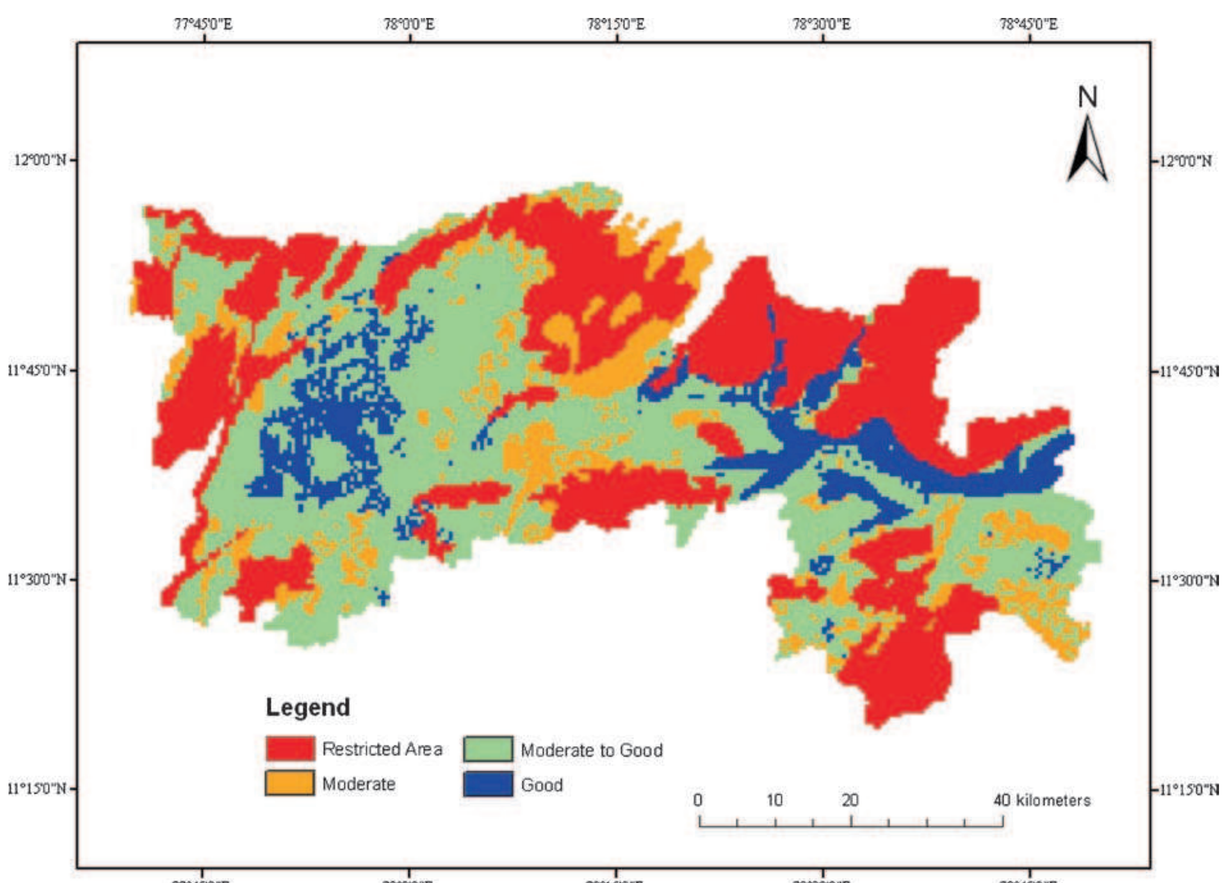


Figure 12. Groundwater potential zones of the study area (fuzzy logic model).

Table 8. *Validation of the identified groundwater potential zones.*

| | | Identified groundwater potential | | | Pumpimg | |
|---|---|---|---|---|---|---|
| Sl. no. | Village name | Boolean overlay | Weighed index overlay analysis | Fuzzy logic model | rate (GPM) | Evaluation |
| 1 | Vaikundam | Nil | Moderate | Moderate | Poor | + |
| 2 | Reddiyur | Present | M to G | M to G | 2.19 | + |
| 3 | Ammapalayam | Present | M to G | M to G | 2.19 | + |
| 4 | Thumbipadi | Present | M to G | M to G | 6.05 | + |
| 5 | Vanavasi | Present | M to G | M to G | 6.05 | + |
| 6 | Uthankattuvalsu | Present | M to G | M to G | 6.05 | + |
| 7 | A. Kumarapalayam | Present | M to G | M to G | 6.05 | + |
| 8 | Gangavalli | Present | M to G | M to G | 6.05 | + |
| 9 | Kumarasamipatti | Present | M to G | M to G | 6.05 | + |
| 10 | Korimedu | Present | M to G | M to G | 8.05 | + |
| 11 | Semmankudal | Present | M to G | M to G | 8.89 | + |
| 12 | Naduvalur | Present | M to G | M to G | 9 | + |
| 13 | M. Kalipatti | Present | M to G | M to G | 10 | + |
| 14 | Karippatti | Present | M to G | M to G | 10 | – |
| 15 | Anuppur | Present | M to G | M to G | 10 | + |
| 16 | Thalaivasal | Present | M to G | M to G | 10 | + |
| 17 | Ulipuram | Present | M to G | M to G | 12 | + |
| 18 | Pakkaliyur | Present | M to G | M to G | 12.4 | + |
| 19 | Kattiyanur | Present | M to G | M to G | 12.4 | + |
| 20 | Kudumalai | Present | M to G | M to G | 12.4 | + |
| 21 | Pottaneri | Present | M to G | M to G | 12.4 | + |
| 22 | Edanganasalai | Present | M to G | M to G | 12.4 | + |
| 23 | Akkamapettai | Present | M to G | M to G | 12.5 | + |
| 24 | Modikadu | Present | M to G | M to G | 16.7 | + |
| 25 | Chandrapillaivalasu | Present | M to G | M to G | 16.7 | + |
| 26 | Veeranam | Present | M to G | M to G | 16.7 | + |
| 27 | Veerapandi | Present | M to G | M to G | 21.7 | + |
| 28 | T. Pudupalayam | Present | M to G | M to G | 21.7 | + |
| 29 | Chinna Agraharam | Present | M to G | M to G | 21.7 | + |
| 30 | Seernganur | Present | M to G | M to G | 23 | + |
| 31 | Muthampatti | Present | Good | Good | 27.5 | + |
| 32 | Irupali | Present | Good | Good | 27.5 | – |
| 33 | Magudanchavadi | Present | M to G | Good | 27.5 | – |
| 34 | Vavvalthoppu | Present | Good | Good | 27.5 | + |
| 35 | Seshenchavadi | Present | Good | Good | 34.2 | + |
| 36 | Kuppampatti | Present | M to G | Good | 34.2 | – |
| 37 | Kalleripatti | Present | Good | Good | 35 | + |
| 38 | Pethanaickenpalayam | Present | Good | Good | 41.8 | + |
| 39 | Anupoor | Present | Good | Good | 41.8 | + |
| 40 | Vilvanur | Present | Good | Good | 50 | + |
| 41 | Uthankarai | Present | Good | Good | 56 | + |
| 42 | Veergoundanur | Present | Good | Good | 70.2 | + |
| 43 | Chinnappampatti | Present | Good | Good | 82 | + |

M to G – Moderate to good.

due to the presence of geomorphology (shallow pediment, pediment and buried pediment), soil (red *in-situ*) and with moderate lineament and drainage density. The groundwater potential is found under the moderate category (occupies 8% of the study area) in few patches of sides of the study area due to the presence of soil (brown soil, red *in-situ* and black soil) geomorphology (composite slope, pediment and shallow pediment) and geological features (charnockite, calcareous gneiss and limestone).

### 4.4 *Groundwater potential zones of the study area using fuzzy logic model*

The fuzzy logic model results with a groundwater potential map is shown in figure 12. The fuzzy logic model groundwater potential map reveals that good groundwater potential zones were identified in the following.

Based on figure 12, groundwater potential is found under good category (occupies 6.12% of the study area) in few patches of the northwestern side and western side of the study area. The suitable soil (red *in-situ* and red colluvial), geomorphological (buried pediment and bazada) which are present in the portion of the study area, provides favourable condition for good groundwater recharge. The predominant portion of the study area covers moderate (occupies 83.52% of the study area) due to the presence of geomorphology (pediments and shallow pediment), soil (brown soil, red *in-situ* soil and black soil) and with moderate lineament and drainage density. The groundwater potential is found under the moderate to good category (occupies 10.36% of the study area) in few patches of sides of the study area due to the presence of soil (red *in-situ* and mixed soil), geomorphology (shallow pediment, few batches of buried pediment, pediment) and geological features (gneissic, dunite and magnesite).

### 4.5 *Comparison between the identified groundwater potential zones by different methods*

The identified groundwater potential zones in all the four methods were compared and the comparison reveals that the good groundwater potential zones were identified at the foothills of Pedhanaickenpalayam and Valapadi blocks, north of Attur block and major portions of Nangavalli block. Moderate to good groundwater potential zones were spread in almost all the blocks. Moderate groundwater potential zones were identified in Sankari, Yercaud, and in few patches in Salem and Omalur blocks.

#### 4.5.1 *Validation of the identified groundwater potential zones by different methods*

The identified groundwater potential zones by the four methods were compared with the pumping test data of 43 locations in the study area. The pumping rate of the locations and their corresponding groundwater potential zones identified in four methods were shown in table 8. The yield of borewells in the 43 locations ranged from 2.19 to 82 Gpm. For validation yield in the range ≥25 Gpm is taken as good, range between 2 and 25 Gpm is taken as moderate to good and range <2 Gpm is taken as moderate groundwater potential locations.

The locations with poor yield show that no groundwater is present in Boolean overlay analysis, moderate category in WIOA and fuzzy logic model. Moderate to good groundwater potential locations show that water is present in Boolean overlay, moderate to good category in WIOA and fuzzy logic model, good groundwater potential locations show that water is present in Boolean overlay and good category in WIOA and fuzzy logic model. The groundwater potential status (pumping rate) of each location was compared with the four output maps, each correct evaluation was identified by '+' and the incorrect evaluation was identified as '−' which is shown in table 8. Out of 43 locations, four locations Karippati, Irupalli, Magudanchavadi and Kuppampatti show incorrect evaluation. Overall accuracy level of the analysis is 90.7% which is a high level of accuracy for a regional study.

## 5. Conclusion

Groundwater occurrence in the study area is controlled by various ground features such as geological structures, geomorphic features and their hydraulic characters may also serve as indicators for the presence of groundwater. Remote sensing and Geographical Information System (GIS) techniques and numerous databases can be integrated together and evaluation of the groundwater potential zones of an area. The weights of different parameters/themes were computed using weighed index overlay analysis (WIOA), analytic hierarchy process (AHP) and fuzzy logic technique. Through this integrated GIS analysis, groundwater prospect map of the study area was prepared qualitatively. Field verification at observation wells was used to verify identified potential zones and depth of water measured at observation wells. Generated map from weighed overlay using AHP performed very well in predicting the groundwater surface and hence, this methodology proves to be a promising tool for future.

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