

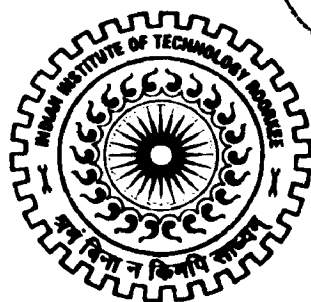
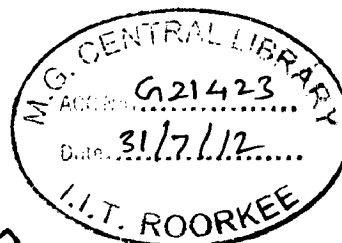
# HYDROGEOLOGICAL INVESTIGATION IN SALEM DISTRICT

## A DISSERTATION

*Submitted in partial fulfillment of the  
requirements for the award of the degree*  
of  
**MASTER OF TECHNOLOGY**  
in  
**GEOPHYSICAL TECHNOLOGY**

By

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JUNE, 2012**

## CANDIDATE'S DECLARATION

I hereby declare that the work which is presented in this dissertation entitled **“Hydrogeological Investigation in Salem District”** in partial fulfillment of the requirement for the award of degree of Master of Technology in **“Geophysical Technology”** with the specialization in Exploration Geophysics submitted in Department of Earth Sciences, IIT Roorkee, Roorkee, is an authentic record of my own work carried out during the period from July 2011 to June 2012 under the supervision of Prof. Sri Niwas, Department of Earth Sciences, IIT Roorkee, Roorkee.

The matter embodied in this thesis has not been submitted by me for award of any other degree.

Date: 12-06-2012

Place: Roorkee

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**Yogandre Singh**

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This is certified that the above statement made by the candidate is correct to the best of my knowledge.

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## CERTIFICATE

I, **Yogandre Singh**, hereby solemnly declare that the dissertation entitled “**Hydrogeological Investigation in Salem District**” being submitted by me towards partial fulfillment of the requirements for the award of “**Master of Technology in Geophysical Technology**”. Degree is a record of my own work and that I have not copied the work of any other person(s) including published literature and material from any web site.

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Place: Roorkee

Date: 12-06-2012

## ACKNOWLEDGEMENT

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I feel short of word to express my feeling toward my parents for their love and moral support, which has been a constant source of inspiration for me.

Date: 12-06-2012

Place: Roorkee

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## ABSTRACT

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Prof. Sri Niwas and Singhal (1981, 1985) theoretically derived two equations using ohm's law of current flow and Darcy's law for porous medium, e.g. the aquifer, which relates the transverse unit resistances and longitudinal conductance of aquifer with the transmissivity of aquifer. Hydraulic conductivity is inversely correlated with resistivity for resistive basement case. In case of conducting basement, hydraulic conductivity is directly proportional to the resistivity.

The study area, 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. The major part of the district is covered by red insitu and red Colluvial soils. The district is a part of Cauvery and Ponnaiar river basins and Sarabanga, Tirumanimuttar, Vasista and Suveda are the important watersheds/sub basins.

Major water bearing formations are Colluvial deposits and weathered & fractured granite, Charnockite & granite gneiss. In major parts of district, water conductivity is more than 1000 micromho/cm. Aquifer water is saline in nature. The depth of ground water vary between (0-20) m, whereas the thickness of aquifer (1- 25) in major part of the district. Different contour map has been drawn to delineate hydraulic parameters and porosity of porous medium. The north-west part of the district shows significant well groundwater conditions than other parts of the district.

# CONTENTS

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CERTIFICATE	
CANDIDATE'S DECLARATION	
ACKNOWLEDGEMENT	
ABSTRACT	i
CONTENTS	ii
LIST OF FIGURES	iv
LIST OF TABLES	vi
CHAPTER 1 INTRODUCTION	1
1.1 General	1
1.2 Objective	2
1.3 Work Plan	2
CHAPTER 2 STUDY AREA	3
2.1 Introduction	3
2.1.1 Map of the study area	3
2.2 Geomorphology	4
2.3 Soil Types	4
2.4 Basin and Sub-basins	5
2.5 Drainage	5
CHAPTER 3 METHODOLOGY	6
3.1 Electrical Resistivity Method	6
3.2 Theoretical Development	8
3.3 Theoretical Equations	9
3.3.1 Relationship between Transmissivity and Longitudinal Conductance	12
3.3.2 Relation between the Transmissivity and the Hydraulic Conductivity	13

3.3.4 The relationship between Porosity and Resistivity	13
CHAPTER 4 CORRELATION STUDIES FROM THE FIELD DATA	14
4.1 Estimation of Hydraulic Conductivity from Aquifer Resistivity	14
4.2 Correlation between Transmissivity and Hydraulic Parameters	15
4.3. Estimation of Porosity of Aquifer from Water Resistivity	15
CHAPTER 5 HYDROGEOLOGICAL ENVIRONMENT IN SALEM DISTRICT	27
5.1 Hydrogeology	27
5.2 Aquifer Parameters	28
5.3 Ground Water Quality	28
CHAPTER 6 INTERPRETATION OF CONTOUR MAPS	29
CHAPTER 7 CONCLUSIONS	38
REFERENCES	39

## LIST OF FIGURES

---

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Figure No.	Particulars	Page No.
Fig. 1	Map of Study Area, Salem district, Tamil Nadu, India.	3
Fig. 2	Basic configuration in electrical resistivity surveys.	7
Fig. 3	A prism of unit cross section of the aquifer material of a 3-layer aquifer model.	11
Fig. 4	The location of the resistivity data points.	20
Fig. 5	The location of the transmissivity data points.	21
Fig. 6	Types of Aquifers.	22
Fig. 7	Estimation of aquifer resistivity and thickness of aquifer by plotting a graph between resistivity with increasing depth.	23
Fig. 8	Plot of Aquifer resistivity with respect to hydraulic conductivity, Salem district.	24
Fig. 9	Correlation between aquifer resistivity and hydraulic conductivity after applying moving average.	24
Fig. 10	Correlation between transmissivity and longitudinal unit conductance.	25
Fig. 11	Correlation between transmissivity and transverse unit resistance.	25
Fig. 12	Correlation between porosity and formation factor.	26
Fig. 13	Drainage pattern (artificial recharge sources) in Salem district.	31
Fig. 14	Depth to water level (in meter below ground level).	31
Fig. 15	Contour map of aquifer resistivity (ohm-m).	32
Fig. 16	Contour map of aquifer thickness (meter).	32
Fig. 17	Contour map of Transmissivity ( $m^2/day$ ) data.	33

Fig. 18	Contour map of hydraulic conductivity (m/day).	33
Fig. 19	Contour map of (resistivity*hydraulic conductivity).	34
Fig. 20	Contour map of (hydraulic conductivity/resistivity).	34
Fig. 21	Contour map of longitudinal unit conductance.	35
Fig. 22	Contour map of transverse unit resistance.	35
Fig. 23	Contour map of aquifer water conductivity (micromho/cm).	36
Fig. 24	Contour map of aquifer resistivity (ohm-m).	36
Fig. 25	Contour map porosity (in percentage).	37

## List of Tables

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	Page No.
Table 1 Estimation of aquifer resistivity and hydraulic conductivity from given transmissivity and VES resistivity data.	16
Table 2 Locations of transmissivity data points, Salem district.	17
Table 3 Estimation of hydraulic parameters from aquifer resistivity and aquifer thickness.	18
Table 4 Estimation of porosity and water resistivity from water conductivity data.	19

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**INTRODUCTION****1.1 General**

The monitoring of water quality is one of the important tools for sustainable development and provides important information for water management. Groundwater quality is based upon the physical and chemical soluble parameters due to weathering from source rocks and anthropogenic activities. In general, the quality of groundwater depends on the composition of recharge water, the interaction between the water and the soil, the soil–gas, the rock with which it comes into contact in the unsaturated zone, and the residence time and reactions that take place within the aquifer. Thus, the principal processes that influence the quality of water in an aquifer are physical, geochemical and biochemical.

Sri Niwas and Singhal (1981, 1985) developed two theoretical equations, for estimating transmissivity using transverse resistance and longitudinal conductance derived from surface geoelectrical measurement. However, the physical bases for choosing either of the two equations are not explained. Furthermore, it is essential that hydraulic conductivity is a priori known at least at one point in an area before using one of the equations (Niwas, S., Tezkan, B., Israil, M., 2011). The flow rate of groundwater and electrical current mainly depend on the hydraulic and electrical conductivities of the formation, respectively. The hydraulic and electric conductivities of an aquifer depend on several factors; such as pore-size distribution, grain size distribution, void ratio, roughness of mineral particles, fluid salinity or mineralization, degree of weathering, fissure density and interconnectivity, and water saturation, etc. But in case of hard rock such as in granite, the rock porosity saturated with water is the dominant factor among all affecting the hydraulic and electrical conductivities (Chandra, S., Ahmed, S., Ram, A., 2008). If the hydraulic potential gradient exists (naturally), groundwater moves its own towards low potential site. The movement of groundwater generates self-potential current (electro-kinetic or streaming potential; Lowrie, 1997). Either in the cases of Darcy's law for groundwater flow or Ohm's law for current flow, processes are controlled by a common factor, i.e. aquifer porosity saturated with water. Conceptually electrical resistivity method deals with the conservation of charge, i.e. Ohm's law likewise hydrodynamics deals with the conservation of mass, i.e. Darcy's law.

## **1.2 Objectives**

This dissertation is aimed at following objectives:

1. To locate the resistivity and transmissivity data points on the map of the study area.
2. To find the depth and resistivity of the aquifer at each well position.
3. To find the degree of correlation between the hydraulic conductivity and resistivity of the aquifer.
4. To find the degree of correlation between the transmissivity and hydraulic parameters (transverse unit resistance, longitudinal unit conductance).
5. To study the geology of the Salem district.
6. To draw the contour map of aquifer resistivity, depth, hydraulic conductivity and hydrological parameters of the study area and analysis of these contour maps to get information about the hydrogeological environment.
7. To investigate the hydrogeological environment of the Salem district from the given VES data and hydrological parameters.
8. To find the porosity, formation factor, and water resistivity from water conductivity.
9. To interpret the contour maps to delineate hydrogeological information in Salem district.

## **1.3 Work Plan**

First chapter is the introduction to the dissertation work. The second chapter would introduce to the study area and drainage and soil type of the study area. The third chapter introduces the methodology and relations between hydraulic conductivity and resistivity, hydraulic parameters and transmissivity and theoretical concept to flow of ground water in hard rocks. In the fourth chapter, the interpretation of correlation between hydraulic equations and calculation of hydraulic parameters has been discussed in detail. Fifth chapter provided the information of geology, aquifer parameters and porosity estimation of the study area. In the sixth chapter, analysis and interpretation of contour maps discussed which helped in delineating hydrogeological environment in Salem district.

## STUDY AREA

### 2.1 Introduction

The study area, Salem District, lies between latitudes 11°19' and 11°57' and longitudes 77°38' and 78°51'. The area occupies about 5207 sq.km with a mean altitude of 1,300 m.a.s.l. Salem district is having administrative divisions of 9 taluks, 20 blocks, 376 Panchayats and 631 Revenue villages. The climate of the study area is semi-arid, with annual precipitation ranging from 504.6 – 920.8 mm. The mean annual temperature varies between 20 and 35° C.

The Salem district, located in semi-arid southeast India, is an important industrial and agricultural center. In recent years rapid development has created an increase in demand for groundwater.

#### 2.1.1 Map of the Study Area

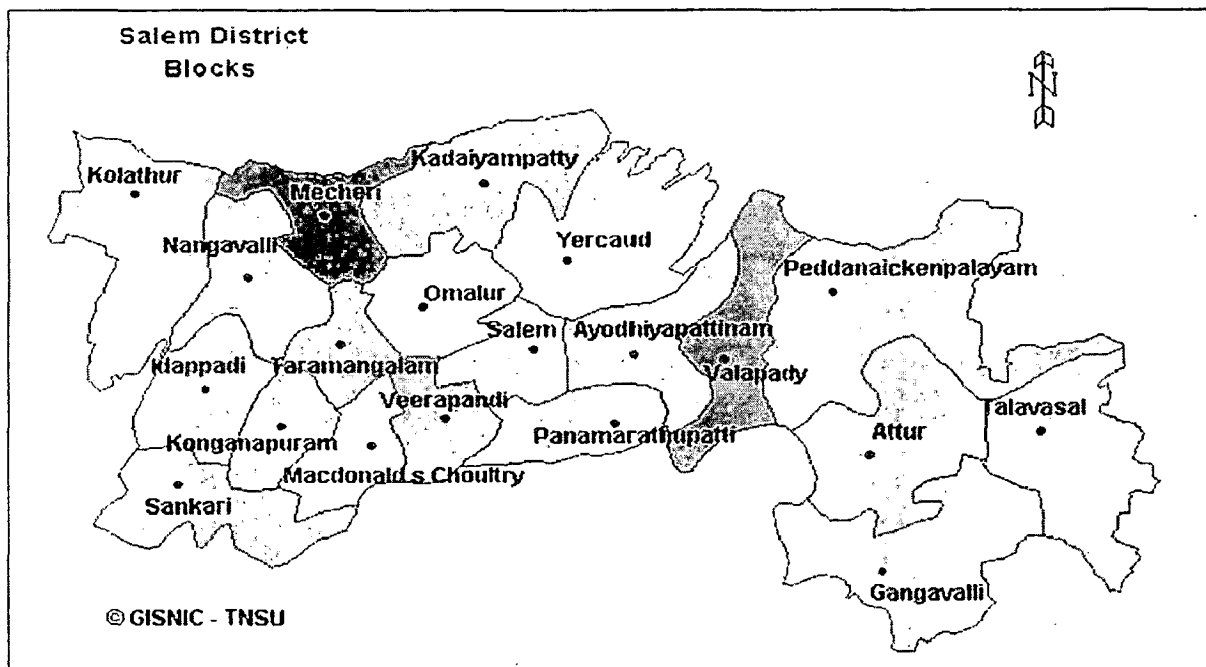


Figure 1: Map of Study Area, Salem district, Tamil Nadu, India.

(Source: <http://tnmaps.tn.nic.in/district.php>)

## 2.2 Geomorphology

Salem district forms part of the upland plateau region of Tamil Nadu with many hill ranges, hillocks and undulating terrain with a gentle slope towards east. The prominent geomorphic units identified in the district through interpretation of Satellite imagery are:

- (1) Plateau,
- (2) Structural hills,
- (3) Bazada zone,
- (4) Valley fills,
- (5) Pediments,
- (6) Shallow Pediments and
- (7) Buried Pediments.

A number of hill ranges are located in the northern and northeastern parts of the district, whereas the southern, western and eastern parts of the district are gently undulating and dotted with a few isolated hillocks. The important hill ranges in the district are:

- (1) Yercaud hills,
- (2) Kanjamalai hills,
- (3) Godumalai hills,
- (4) Pachamalai hills,
- (5) Jaragamalai hills,
- (6) Nagaramalai hills
- (7) Shervaroyan hills
- (8) Eastern Ghats,
- (9) Sankagirimalai hills and
- (10) Poolamalai hill

## 2.3 Soils

The soils can be broadly classified into six major soils types which are as follows:

- (1) Red insitu,
- (2) Red Colluvial Soil,
- (3) Black Soil,
- (4) Brown Soil,
- (5) Alluvial and
- (6) Mixed Soil.

Major part of the District is covered by Red insitu and Red Colluvial soils. Block soils are mostly seen in Salem, Attur, Omalur and Sankari taluks. Brown Soil occupies major portion of Yercaud and parts of Salem and Omallur taluks and the Alluvial Soil is seen along the river courses in Omalur and Sankari taluks. Mixed soil is occurring only in Attur taluk.

## **2.4 Basins and sub-basins**

The district is a part of Cauvery and Ponnaiar river basins and Sarabanga, Tirumanimuttar, Vasista and Suveda are the important watersheds/sub basins. Cauvery River, which is perennial in nature, flows along the western and southern boundaries of the district.

## **2.5 Drainage**

Salem district is drained by tributaries of Cauvery and Vellar rivers. Cauvery River, which is perennial in nature, flows along the western and southern boundaries of the district. Sarabanga and Tirumanimuttar are important tributaries of Cauvery River and originate in the Shevroy hills. The Swetha and Vasishta rivers are tributaries of Vellar River. The Swetha River originates in the Kollimalai and flows eastwards and joins the Vellar River. The Vasishta River originates in the chitteri hills and flows southwards and joins the Vellar River. In general, the district is characterized by dentritic drainage. The drainage pattern has been shown in figure (13), chapter 4.

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**METHODOLOGY****3.1 Electrical Resistivity Methods**

Electrical techniques, especially the resistivity surveys, are the most popular of geophysical methods for groundwater surveys because they often give a strong response to subsurface conditions and are relatively cost-effective (Ernstson and Kirsch 2006a).

Resistivity is defined as the resistance to electric current offered by a unit volume of rock and is a characteristic property of the medium in that state. It is based on the fact that electrical resistivity of a geological formation is dependent upon the material as well as the bulk porosity, degree of saturation and type of fluid. Since electrical resistivity of common minerals is very high, the electrical current flows through the pore fluid (water). The electrical resistivity of water-saturated clay-free material is given by the Archie's Law (Reference Book: Gupta, R.P., Singhal, B.B.S., 1999, Applied Hydrogeology of Fractured Rocks, Page 76):

$$\rho_{aquifer} = \rho_{water} * F$$

Where  $F$  is the formation factor and  $\rho_{aquifer}$  and  $\rho_{water}$  are the specific resistivity of aquifer and pore water respectively. The formation factor  $F$  depends upon porosity, pore shape, cementation etc. The Archie's Law is not valid if grains are conducting (e.g. clay-rich matrix) or if pore water is highly resistive. The electrical resistivity of a dry formation is much higher than that of the same formation when it is saturated with water.

Resistivity of the ground is measured by injecting current into the ground and measuring resulting potential difference at the surface across selected electrode positions. The data on current flow and potential drop are converted into resistivity values. In case of an inhomogeneous earth, the measured resistivity is influenced in varying proportions by material from a wide depth range in the region covered by the electrodes and therefore, the field resistivity values are apparent rather than true.

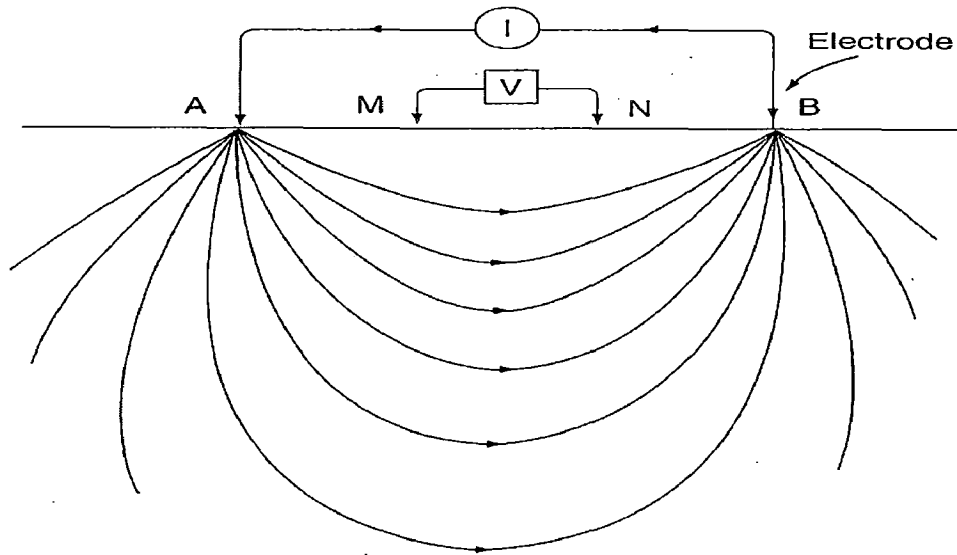


Figure 2: Basic configuration in electrical resistivity surveys. *A* and *B* are current electrodes; *M* and *N* are potential electrodes

(Book: Gupta R.P., Singhal B.B.S., 1999, Applied Hydrogeology of Fractured Rocks, Page 76)

The arrangement of the four electrodes on the ground (two current and two potential) is referred to as the electrode 'array' or configuration. Most commonly used electrode configurations are Wenner and Schlumberger types. In Wenner array, the four electrodes are placed collinearly and are equally spaced. In Schlumberger array, the electrodes are collinear but the distance between the two inner potential electrodes is very small in comparison to the distance between the two outer current electrodes. The apparent resistivity is calculated as:

$$\rho_a = 2\pi aR \quad (\text{For Wenner array}) \quad \dots (4.1a)$$

$$\rho_a = \pi(L^2/2l)R \quad (\text{For Schlumberger array}) \quad \dots (4.1b)$$

(Source: Gupta R.P., Singhal B.B.S., 1999, Applied Hydrogeology of Fractured Rocks, Page 76)

The depth of investigation of a resistivity survey is directly proportional to the electrode separation, and increases with increasing electrode spacing. Vertical Electrical Sounding (VES) is applied to near horizontal layered medium, e.g. sedimentary terrain or weathered zones over hard rocks. It is used to determine variations in electrical resistivity with depth. In VES (also

loosely called electrical drilling), the distances between electrodes are increased so that the electric current penetrates to deeper and deeper

### **3.2 Theoretical Development** (Chandra, S., Ahmed, S., Ram, A., 2008)

The flow rate of groundwater and electrical current mainly depend on the hydraulic and electrical conductivities of the formation, respectively. The hydraulic and electric conductivities of an aquifer depend on several factors; such as pore-size distribution, grain size distribution, void ratio, roughness of mineral particles, fluid salinity or mineralization, degree of weathering, fissure density and interconnectivity, and water saturation, etc. But in case of hard rock such as in granite, the rock porosity saturated with water is the dominant factor among all affecting the hydraulic and electrical conductivities. The current flow in the subsurface is basically formed by two phenomena: electronic and electrolytic conductions (Keller and Frischknecht, 1966). Electronic conduction (i.e. the current flow through the free electrons present in the minerals consisting the rock) in the granite is insignificant due to high resistivity of the minerals and as a result the water in the fissures is the main factor controlling the current flow (i.e. electrolytic conduction). Thus the electrolytic conduction is the dominant phenomenon. Since ions flow through some of the same paths as water, the electrical resistivity and hydraulic conductivity of aquifer are expected to be affected by similar variables. Fluid (i.e. groundwater) and electric currents flow from higher potential to lower potential sites and their flow rates depend upon hydraulic and electric potential gradients, respectively. The potential gradients occurrence could be natural as well as imposed while carrying out tests, for example hydraulic potential gradient is imposed while carrying out a pumping test and similarly electric potential gradient is imposed while carrying out a geoelectrical investigation. If the hydraulic potential gradient exists (naturally), groundwater moves its own towards low potential site. The movement of groundwater generates self-potential current (electro-kinetic or streaming potential; Lowrie, 1997). While doing the pumping test groundwater flows more or less horizontally towards the pumping well from the surrounding region (Marechal et al., 2004). Similarly, the current flows more or less horizontally in the aquifer from source towards sink current electrodes while performing the vertical electrical sounding using Schlumberger configuration. This is quite applicable in the case of hard rock, where aquifer horizon is at quite deeper level and requires

enough inter-current electrode spacing (for Schlumberger configuration) to investigate it. Moreover the top layer is often dried scapolite having high resistivity and bottom layer is unfissured basement characterized by high resistivity too. Thus current flow lines in the aquifer (i.e. fissured layer saturated with water) get channelized and flow horizontally. Thus, groundwater and current flows take place in the same media (i.e. aquifer) and in the same direction. This shows analogy between the two physical properties.

Either in the cases of Darcy's law for groundwater flow or Ohm's law for current flow, processes are controlled by a common factor, i.e. aquifer porosity saturated with water. Conceptually electrical resistivity method deals with the conservation of charge, i.e. Ohm's law likewise hydrodynamics deals with the conservation of mass, i.e. Darcy's law.

### 3.3 Theoretical Equations (Niwas, S., Tezkan, B., Israil, M., 2011)

Prof. Sri Niwas and Singhal (1981, 1985) theoretically derived two equations using ohm's law of current flow and Darcy's law for fluid flow in a medium as

$$T_h = \alpha R; K_h = \alpha \rho \quad \dots (3.3.1)$$

$$T_h = \beta C; K_h = \beta / \rho \quad \dots (3.3.2)$$

Where  $T_h$  is the transmissivity,  $K_h$  is the hydraulic conductivity,  $\rho$  is the electrical resistivity,  $R$  is the transverse unit resistance,  $C$  is the longitudinal unit conductance of the aquifer and  $\alpha$  and  $\beta$  are constants of proportionality. In case of variation, the statistical average or mean value may be obtained and that may be used for estimating  $T_h$  from computed value of  $R$  in an area.

In a geological sequence where resistivity,  $\rho(z)$ , or electrical conductivity,  $\sigma(z)$  is a continuous function of depth  $z$ , one can consider the integrals (Maillet, 1947)

$$R(z) = \int_0^z \rho(z) dz \approx \sum_i \rho_i d_i = R_i \quad \dots (3.3.3)$$

Termed as transverse unit resistance and

$$C(z) = \int_0^z \sigma(z) dz \approx \sum_i \sigma_i d_i = C_i \quad \dots (3.3.4)$$

Termed as longitudinal unit conductance. Both R and C are written for homogeneous aquifer of average resistivity and average thickness d. while dealing with direct current prospecting Maillet (1947) observed that if one considers a geological column built on a square unit, R is the resistance to the line of current perpendicular to the strata and, C is the conductance offered to the lines of current parallel to it.

Eq. 1 is derived by considering a vertical flow of the electric current indicating a direct correlation between hydraulic conductivity and electrical resistivity, whereas Eq. 2 is derived by considering a lateral flow of the current showing an inverse correlation. If it is proved that the electrical response depends entirely on R of the aquifer layer, then the current flow direction can be taken in a vertical direction, whereas it can be taken in a horizontal direction if electrical response depends entirely on C of the aquifer layer.

The theoretical equation for interpretation of apparent resistivity data over an N-layered earth in Schlumberger configuration can be written as (Koefoed 1979),

$$\rho_{as} = s^2 \int_0^x d\lambda [T(\rho_i, d_i; \lambda)] J_1(\lambda s) \lambda, i = 1, 2, \dots, N \quad \dots (3.3.5)$$

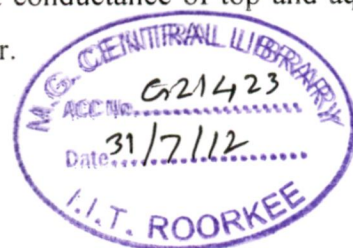
Where  $\rho_i$  and  $d_i$  are respectively resistivity and thickness of  $i^{\text{th}}$  layer,  $J_1(\lambda s)$  is the Bessel function of first order and first kind,  $\lambda$  is the integration variable and  $s$  is the half current electrode separation. The function within the large bracket is the resistivity transforms function,  $T(\lambda)$ .

In the case of multi-aquifer sequence, the N-layered earth can be represented as a 3-layer general aquifer model (GAM) by combining the intermediate aquifer layers (from  $i=2$  to  $N-1$ ) as a single pseudo-isotropic layer of resistivity  $\rho$  and thickness  $d$  and lump parameters R and C through Eqs. (3) and (4).

For this 3-layer GAM (having resistivity  $\rho_1, \rho_2, \rho_3$  and thickness  $d_1, d$ ),

$$\rho_{as} = s^2 \int_0^\infty \frac{[\rho_3 + \lambda(R_1 + R)]}{1 + \lambda\rho_3(C_1 + C)} J_1(\lambda s) \lambda d\lambda \quad \dots (3.3.5A)$$

Where  $R_1 (= \rho_1 d_1)$  and  $R (= \rho d)$  are the transverse unit resistances of the top and aquifer layer respectively,  $C_1 (= d_1 / \rho_1)$  and  $C (= d / \rho)$  are the longitudinal unit conductance of top and aquifer layers respectively, and  $\rho_3$  is the resistivity of the basement layer.



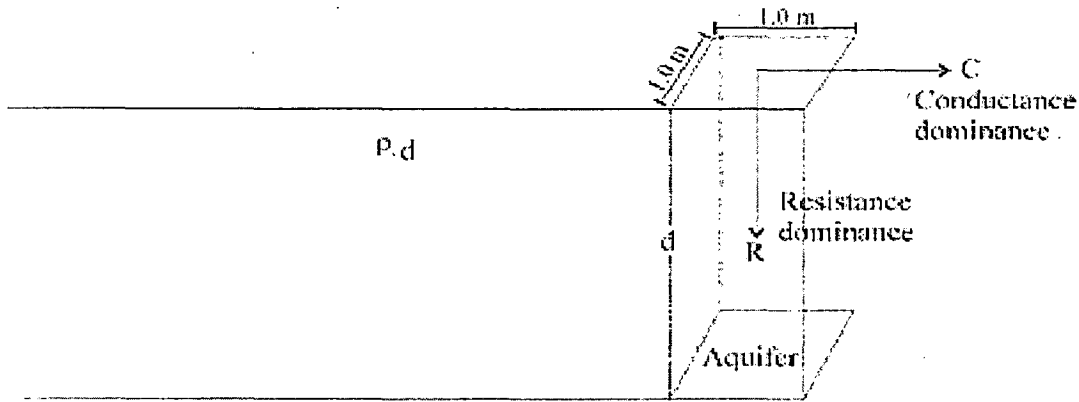


Figure 3: A prism of unit cross section of the aquifer material of a 3-layer aquifer model

(Source: Niwas, S., Tezkan, B., Israil, M., 2011)

In extreme cases (e.g.,  $\rho_3 = 0$  and  $\rho_3 = \infty$ ) for basement layers,

$$\rho_{as} = s^2 \int_0^{\infty} [\lambda(R_1 + R)] J_1(\lambda s) d\lambda \quad \dots (3.3.6)$$

And

$$\rho_{as} = s^2 \int_0^{\infty} \frac{1}{\lambda(C_1 + C)} J_1(\lambda s) d\lambda \quad \dots (3.3.7)$$

Integrating with Mailliet's (1947) definition of R and C, it is obvious that in the case of Eq. 6, the electric current is in the vertical direction as the apparent resistivity is only dependent on R. In the case of Eq. 7, the current is in the horizontal direction as the apparent resistivity is solely dependent on C.

Considering a prism of the unit cross section of the 3-layer aquifer model (Fig. 1), if in aquifer layer R is dominant, one can write Ohm's law [ $\rho = R(A/L)$ ,  $A = 1$ ,  $L = d$ ] and Darcy's law [ $K_h = T_h \left(\frac{L}{A}\right)$ ,  $A = 1$ ,  $L = d$ ] for isotropic, electrical resistivity and hydraulic conductivity,

$$\left\{ \begin{array}{c} \rho \\ K_h \end{array} \right\} = \left\{ \begin{array}{c} R \frac{1}{d} \\ T_h \frac{1}{d} \end{array} \right\} \quad \dots (3.3.8)$$

And if C is domain one can write ohm's law [ $\sigma = C (L/A)$ ,  $L = 1$ ,  $A = d$ ] and Darcy's law [ $K_h = T_h \left(\frac{L}{A}\right)$ ,  $L = 1$ ,  $A = d$ ] in the aquifer layer as

$$\left\{ \begin{array}{c} \sigma \\ K_h \end{array} \right\} = \left\{ \begin{array}{c} C \frac{1}{d} \\ T_h \frac{1}{d} \end{array} \right\} \quad \dots (3.3.9)$$

These developments are based on the fact that water in aquifer flow is dominantly in the horizontal direction, whereas electric current flows dominantly in the vertical as well as the horizontal direction, depending on the electrical nature of the impermeable basement layer.

Eliminating  $\{1/d\}$  from above Equations (8) and (9),

$$T_h = \frac{K}{\rho} R \text{ Or } T_h = \alpha R$$

And

$$T_h = K \rho C \text{ Or } T_h = \beta C$$

This ensures that Eqs. (1) And (6) correspond to a conducting basement case and Eqs. (2) And (7) to a resistive basement case.

### 3.3.1 Relationship between Transmissivity and Longitudinal Conductance

Transmissivity of an aquifer expresses the ability of the aquifer material to transmit water. To estimate the aquifer transmissivity value for the study area, the procedure was based on an analytical relationship between transmissivity of aquifer and longitudinal conductance established by Prof. Sri Niwas and Singhal (1981) as (Niwas, S., Singhal, D.C., 1981),

$$T_r = K \sigma R = \frac{K S}{\sigma} \quad \dots (3.3.1a)$$

Where,

$T_r$  = Transmissivity,

K = Hydraulic conductivity,

$\sigma$  = Electrical conductivity,

R = Transverse resistance of aquifer

### 3.3.2 Relation between the Transmissivity and Hydraulic Conductivity

The transmissivity (T) of aquifer is related to the field hydraulic conductivity (K) by the equation,

$$T = Kb \quad \dots (3.3.2a)$$

$$K = T b^{-1}$$

According to Prof. Sri Niwas and Singhal (1981) in a porous medium,

$$T_c = KR\rho^{-1}$$

$$T_c = KR\rho^{-1} = KS\rho \quad \dots (3.3.2b)$$

Where,

$T_c$  = Calculated transmissivity from VES

R = Total transverse resistance

S = Total longitudinal conductance

$\rho$  = Resistivity of the saturated layers

### 3.3.3 The relationship between Porosity and Resistivity

In clean, porous aquifers, the formation resistivity ( $R_0$ ) is proportional to that of the interstitial water ( $R_w$ ):

$$\text{Rock Resistivity} = F * \text{Water Resistivity} \quad \dots (3.3.3a)$$

$$F = a / (\text{porosity})^m \quad \dots (3.3.3b)$$

Where F is the formation resistivity factor, a is the cementation factor, and m is the saturation exponent.

This is the Archie's formula.

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**CORRELATION STUDIES FROM THE FIELD DATA**

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The above theory as discussed in chapter 3 has been applied to examine with the field data collected from hard rock (granite, Charnockite and granite gneiss) terrain from Salem district, Tamil Nadu (Table 1 and Table 2). Vertical electrical soundings were carried out using Schlumberger configuration with up to 100 m current electrode spacing. Data were processed and interpreted for obtaining aquifer parameters like aquifer resistivity, aquifer thickness, longitudinal conductance, transverse resistance, etc. VES with considerable electrode spacing yield regional aquifer parameters and VES results were taken for correlation studies. The transmissivity value is known at 35 locations and varies between 0.66-158.36 (Table 2). The resistivity values of five layer geoelectrical sections are known at 60 locations in Salem district which are obtained by performing VES survey (Maheswaran, G., 2010). The locations of resistivity and Transmissivity data points have been shown in figure (4) and (5). The latitudes and longitude of resistivity, transmissivity and water conductivity points has been searched with the help of internet (<http://www.latitudeandlongitude.com>).

**4.1 Estimation of Hydraulic Conductivity from Aquifer Resistivity**

The field data belongs to hard rock (granite, Charnockite and granite gneiss) aquifer. At each location, Aquifer resistivity and thickness of the aquifer are obtained by plotting resistivity versus depth graphs (Figure 7). The aquifer resistivity and thickness are utilized to obtain hydraulic parameters (longitudinal unit conductance, transverse unit resistance) as provided in table (4). From transmissivity and thickness of aquifer, hydraulic conductivity is obtained by using equation (3.3.2a) (Table 1). Mathematical relation shows a negative correlation between hydraulic conductivity and aquifer resistivity (equation 3.3.2 in chapter 3). The aquifer resistivity and hydraulic conductivity of corresponding locations (34 data points) have been plotted on logarithmic scale. The plotted data points have shown a well correlation (Figure 8). On applying moving average, the correlation coefficient ( $R^2$ ) obtained between these two parameters is 0.841 (Figure 9). The correlation coefficient has been calculated for 34 data

points falling in the Granite, Gneiss, and Charnockite (Table 1). The given values have shown a negative correlation between hydraulic conductivity and aquifer resistivity (Figure 9).

#### **4.2 Correlation between Transmissivity and Hydraulic Parameters**

Mathematical relation shows a positive correlation between transmissivity and longitudinal conductance as shown in equation (3.3.2) and between transmissivity and transverse resistance as shown in equation (3.3.1). The correlation coefficient ( $R^2$ ) between transmissivity and conductance is 0.772 (Fig. 10). Also the correlation coefficient between transmissivity and resistance is 0.816 (Figure 11). Figures (10) and (11) have shown a linear correlation transmissivity and hydraulic parameters.

#### **4.3. Estimation of Porosity of Aquifer from Water Resistivity**

The water conductivity data points have been known at 47 location of Salem district, Tamil Nadu (Table 4). The values of water conductivity vary between 711-16500 micromho/cm. In most of part of the Salem district, water conductivity values are more than 1000 micromho/cm. The values of formation factor have been evaluated from known data of aquifer resistivity and water resistivity (equation 3.3.3a). Porosity is inversely correlated with the formation factor and aquifer resistivity as shown in equation (3.3.3b). The porosity and formation factor data has been plotted in figure (12).

**Table 1**

Estimation of aquifer resistivity and hydraulic conductivity from given transmissivity and VES resistivity data:

Aquifer Resistivity and Hydraulic Conductivity:						
Resistivity Loc.	Latitude	Longitude	Resistivity	Aquifer	Transmissivity	Hydraulic
			Aquifer	Thickness		Conductivity
			(ohm-m)	(m)	(m <sup>2</sup> /day)	(m/day)
Mettur	11.78	77.79	44.3	25.7	29.5	1.147859922
Mecheri	11.84	77.94	87.9	9.96	3.32	0.333333333
Vanavasi	11.75	77.87	49.7	0.5	158.36	316.72
Arurpatti	11.68	77.95	22.7	0.93	158.36	170.2795699
Kumarapalayam	11.43	77.7	63.6	15.9	7.45	0.468553459
Thirumalai	11.37	77.88	52.32	5.91	7.45	1.260575296
Sankari	11.45	77.88	38.7	3.17	7.45	2.350157729
kottaiyanur	11.45	77.91	103	3	1.74	0.58
Mavellipalayam	11.48	77.9	62.8	21.2	1.74	0.082075472
Attaiyampatti	11.53	78.05	36.1	6.22	13.14	2.112540193
Biroj	11.57	78.07	50.3	7.82	15.93	2.037084399
Mallur	11.53	78.13	42.2	62	7.45	0.12016129
S.K. nagar	11.62	78.14	34.6	11	20.62	1.874545455
Arisipalayam	11.65	78.14	42.41	0.91	20.62	22.65934066
Hasthampatti	11.67	78.15	83.97	10.02	16.66	1.662674651
A.T.C. Nagar	11.68	78.15	71.8	9.52	16.66	1.75
Karuppur	11.72	78.08	63.5	8	1.88	0.235
Omalur	11.73	78.04	69.7	9.98	1.88	0.188376754
Thathiampatti	11.77	78.05	102	5.91	1.88	0.318104907
Thinapptty	11.83	78.08	61.6	18.22	3.32	0.182217344
Karadiyur	11.86	78.2	68.1	2.7	3.32	1.22962963
Kanavaipudur	11.92	78.17	76.4	3.6	3.32	0.922222222
Kettunaicken	11.93	78.21	35.4	10.1	3.32	0.328712871
Maramangalam	11.82	78.32	102.3	2.73	3.56	1.304029304
Kolathukombai	11.73	78.36	34.1	2.42	3.56	1.47107438
Pallatadanur	11.71	78.37	25.9	1.2	35.98	29.98333333
Muthampatti	11.65	78.38	55.2	8.34	35.98	4.314148681
Pudupalayam	11.48	78.19	34.41	4.29	4.05	0.944055944
Attur	11.58	78.6	38.44	12.29	4.41	0.358828316
Manjini	11.55	78.62	39.3	4.51	4.41	0.977827051
Thammampatti	11.43	78.48	41	6.35	3.28	0.516535433
Gangavalli	11.48	78.65	55.9	6.25	0.91	0.1456
Veeraganur	11.47	78.73	68.3	17	1.64	0.096470588
Thalavivasal	11.58	78.73	36.7	3.7	2.6	0.702702703

**Table 2**

Locations of Transmissivity data points, Salem District:

Locations of Transmissivity data points, Salem District:			
Trasmissivity	Latitude	Longitude	Transmissivity
Locations			(m <sup>2</sup> /day)
Naduvalur	11.52	78.66	0.91
Periyeri	11.56	78.79	2.6
Kadayampatti	11.87	78.09	3.32
Gajjalnaickenpatti	11.59	78.16	20.62
Kumarasamipatti	11.66	78.15	0.66
Ammapalayam	11.56	78.14	7.45
T. Pudupalayam	11.65	78.39	4.05
Kalleripatti	11.67	78.45	35.98
Idappadi	11.58	77.83	2.95
Edaganasalai	11.62	77.99	13.14
Kannankurichi	11.7	78.18	24.18
Ammamet	11.65	78.19	2.09
Valasaiyur	11.7	78.25	31.14
Veeranam	11.68	78.21	2.82
Veeragoundanur	11.64	78.49	2.01
Kuppampatti	11.7	77.87	158.36
Kumarapalayam	11.44	77.71	7.45
Akkampettai	11.65	78.18	16.66
Anuppur	11.72	78.32	3.56
Karungalur	11.83	77.74	29.5
Ellampilai	11.6	78.01	15.93
Veeraganur	11.47	78.73	1.64
kadampatti	11.67	77.96	3.43
Yowethopur(Ethapur)	11.66	78.47	4.41
chinnapampatti	11.64	77.95	36.45
Muthampatti	11.65	78.38	13.75
Chinnaagraharam	11.57	78.05	1.74
PN Palayam	11.64	78.49	7.72
GCE	11.71	78.08	1.88
A. kumarapalayam	11.57	78.56	3.28

**Table 3**

Estimation of hydraulic parameters (Transverse unit Resistance, Longitudinal unit Conductance) from aquifer resistivity and aquifer thickness:

Aquifer Resistivity (ohm-m)	Aquifer Thickness (m)	Transverse unit Resistance	Longitudinal unit Conductance
41	6.35	260.35	0.154878049
68.3	17	1161.1	0.248901903
69.7	9.98	695.606	0.143185079
102	5.91	602.82	0.057941176
49.7	0.5	24.85	0.010060362
42.41	0.91	38.5931	0.021457203
42.2	62	2616.4	1.469194313
34.41	4.29	147.6189	0.12467306
44.3	25.7	1138.51	0.58013544
89.8	2.52	226.296	0.028062361
86	17.4	1496.4	0.202325581
34.6	11	380.6	0.317919075
38.44	12.29	472.4276	0.319719043
39.3	4.51	177.243	0.11475827
55.9	6.25	349.375	0.111806798
21.02	3.29	69.1558	0.156517602
71.8	9.52	683.536	0.132590529
63.5	8	508	0.125984252
38.7	3.17	122.679	0.081912145
55.2	8.34	460.368	0.151086957
52.32	5.91	309.2112	0.112958716
76.4	3.6	275.04	0.047120419
83.97	10.02	841.3794	0.119328332
36.1	6.22	224.542	0.172299169
114	1.47	167.58	0.012894737
25.9	1.2	31.08	0.046332046
36.7	3.7	135.79	0.100817439
25.9	5.4	139.86	0.208494208
35.4	10.1	357.54	0.285310734
68.1	2.7	183.87	0.039647577
34.1	2.42	82.522	0.070967742
61.6	18.22	1122.352	0.295779221
103	3	309	0.029126214
63.6	15.9	1011.24	0.25
102.3	2.73	279.279	0.026686217
50.3	7.82	393.346	0.155467197
24.61	9.62	236.7482	0.390898009
62.8	21.2	1331.36	0.337579618
22.7	0.93	21.111	0.040969163
19.8	26.66	527.868	1.346464646
20.9	2.94	61.446	0.140669856

**Table 4**

Estimation of porosity and water resistivity from water conductivity data:

Resistivity Location	Latitude	Longitude	Resistivity	Water	Water	Formation	Porosity
				Conductivity	Resistivity	Factor	
			(ohm-m)	Micro-mho/cm	(ohm-m)		(%)
Thammampatti	11.43	78.48	41	2150	4.65116279	8.815	33.68
Veeraganur	11.47	78.73	68.3	1836	5.44662309	12.53988	28.23
Omalar	11.73	78.04	69.7	16500	0.60606061	115.005	9.32
Thathiampatti	11.77	78.05	102	1907	5.24383849	19.4514	22.67
Vanavasi	11.75	77.87	49.7	1857	5.38502962	9.22929	32.91
Arisipalayam	11.65	78.14	42.41	1414	7.07213579	5.996774	40.83
Mallur	11.53	78.13	42.2	2510	3.98406375	10.5922	30.72
Pudupalayam	11.48	78.19	34.41	2510	3.98406375	8.63691	34.02
Mettur	11.78	77.79	44.3	711	14.0646976	3.14973	56.34
Mecheri	11.84	77.94	89.8	2170	4.60829493	19.4866	22.65
Mecheri	11.83	77.93	86	2170	4.60829493	18.662	23.14
S.K. Nagar	11.62	78.14	34.6	1504	6.64893617	5.20384	43.83
Attur	11.58	78.6	38.44	1312	7.62195122	5.043328	44.52
Manjini	11.55	78.62	39.3	1000	10	3.93	50.44
Gangavalli	11.48	78.65	55.9	1695	5.89970501	9.47505	32.48
Valapadi	11.65	78.39	21.02	1152	8.68055556	2.421504	64.26
A.T.C. Nagar	11.68	78.15	71.8	1050	9.52380952	7.539	36.42
Karuppur	11.72	78.08	63.5	16500	0.60606061	104.775	9.76
Sankari	11.45	77.88	38.7	2150	4.65116279	8.3205	34.66
Muthampatti	11.65	78.38	55.2	1152	8.68055556	6.35904	39.65
Thirumalai	11.37	77.88	52.32	2150	4.65116279	11.2488	29.81
Kanavaipudur	11.92	78.17	76.4	736	13.5869565	5.62304	42.17
Hasthampatti	11.67	78.15	83.97	1050	9.52380952	8.81685	33.67
Attaiyampatti	11.53	78.05	36.1	2190	4.56621005	7.9059	35.56
Konamaduvu	11.58	78.23	114	4575	2.18579235	52.155	13.84
Pallatadanur	11.71	78.37	25.9	1152	8.68055556	2.98368	57.89
Thalaivasal	11.58	78.73	36.7	1188	8.41750842	4.35996	47.89
Oddapatti	11.62	78.49	25.9	2450	4.08163265	6.3455	39.69
Kettunaicken	11.93	78.21	35.4	736	13.5869565	2.60544	61.95
Karadiyur	11.86	78.2	68.1	1486	6.7294751	10.11966	31.43
Kolathukombai	11.73	78.36	34.1	1607	6.22277536	5.47987	42.71
Thinapptty	11.83	78.08	61.6	2230	4.48430493	13.7368	26.98
kottaiyanur	11.45	77.91	103	2150	4.65116279	22.145	21.25
Kumarapalayam	11.43	77.7	63.6	2150	4.65116279	13.674	27.04
Maramangalam	11.82	78.32	102.3	1125	8.88888889	11.50875	29.47
Biroj	11.57	78.07	50.3	2190	4.56621005	11.0157	30.12
Pettampatty	11.53	78.06	24.61	2190	4.56621005	5.38959	43.07
Mavellipalyam	11.48	77.9	62.8	1491	6.70690812	9.36348	32.67
Arurpatti	11.68	77.95	22.7	1628	6.14250614	3.69556	52.01
Morur	11.42	77.87	19.8	2150	4.65116279	4.257	48.46



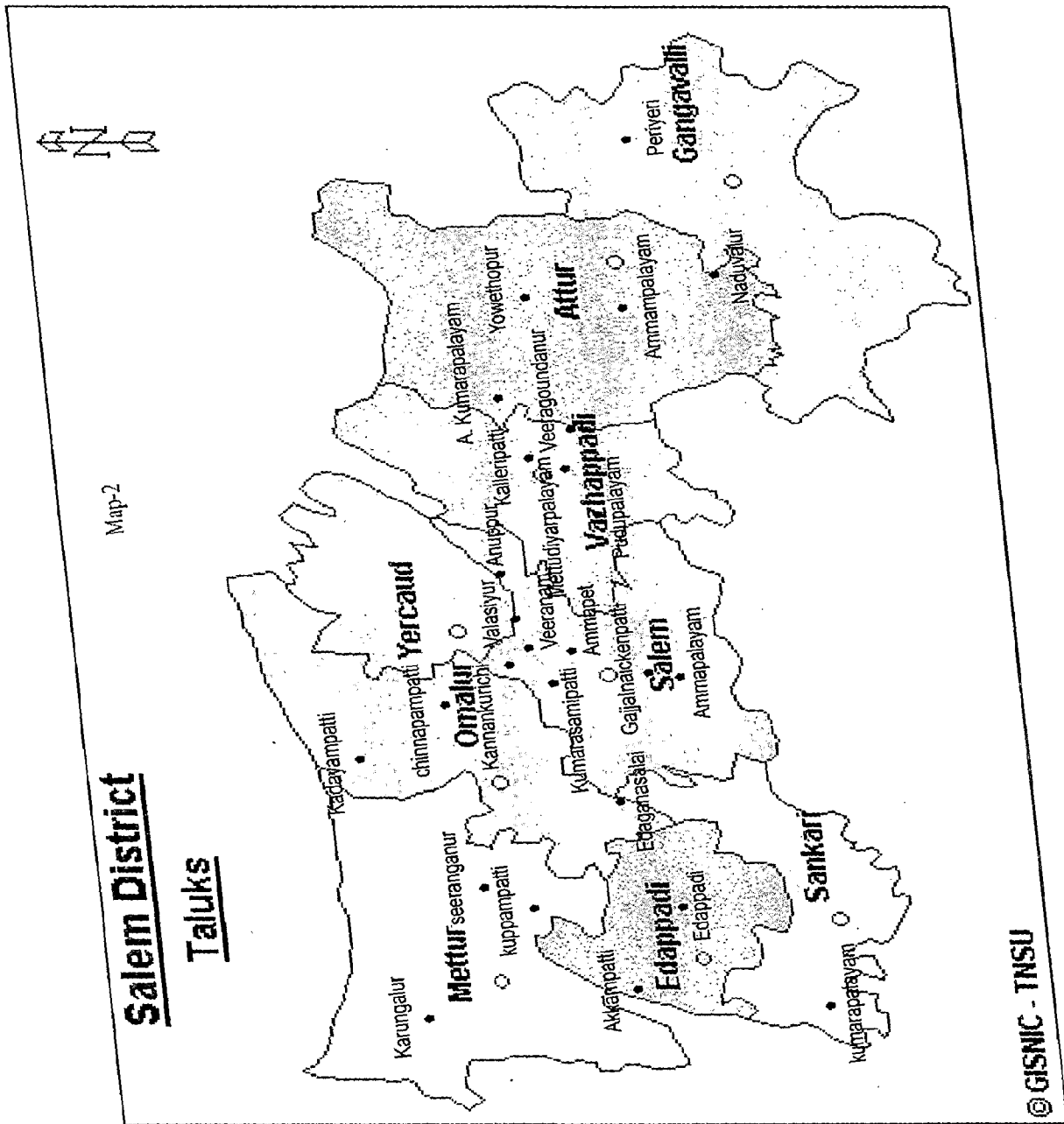
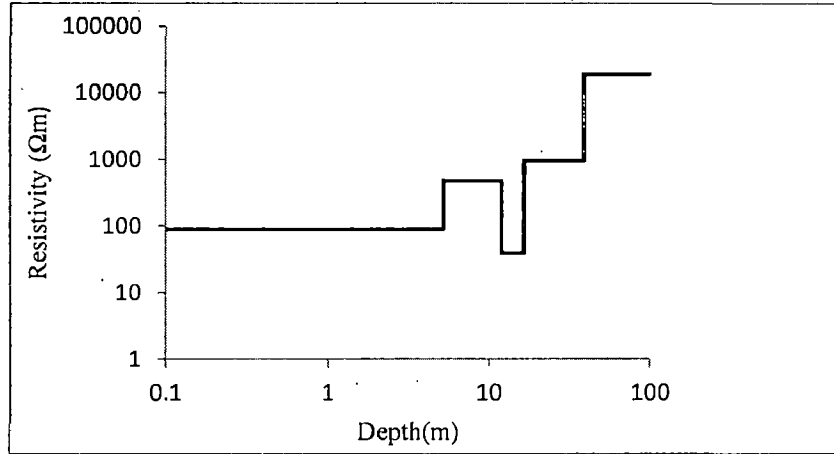


Figure 5: The location of the transmissivity data points.



Location 1-Manjini

Depth(m)	Res.(Ωm)
0.1	89
5.2	89
5.2	483
12	483
12	39.3
16.52	39.3
16.52	956
39.01	956
39.01	19000
100	19000



Transverse unit Resistance (R) = resistivity\*thickness = 39.3\*4.51 = 177.243  
 Longitudinal unit Conductance (C) = d/ρ = 0.0056

Figure 7: Estimation of aquifer resistivity and thickness of aquifer by plotting a graph between resistivity with increasing depth. Here aquifer lies at a depth of 12m and aquifer resistivity is 39.3. The thickness of aquifer body is 4.51.

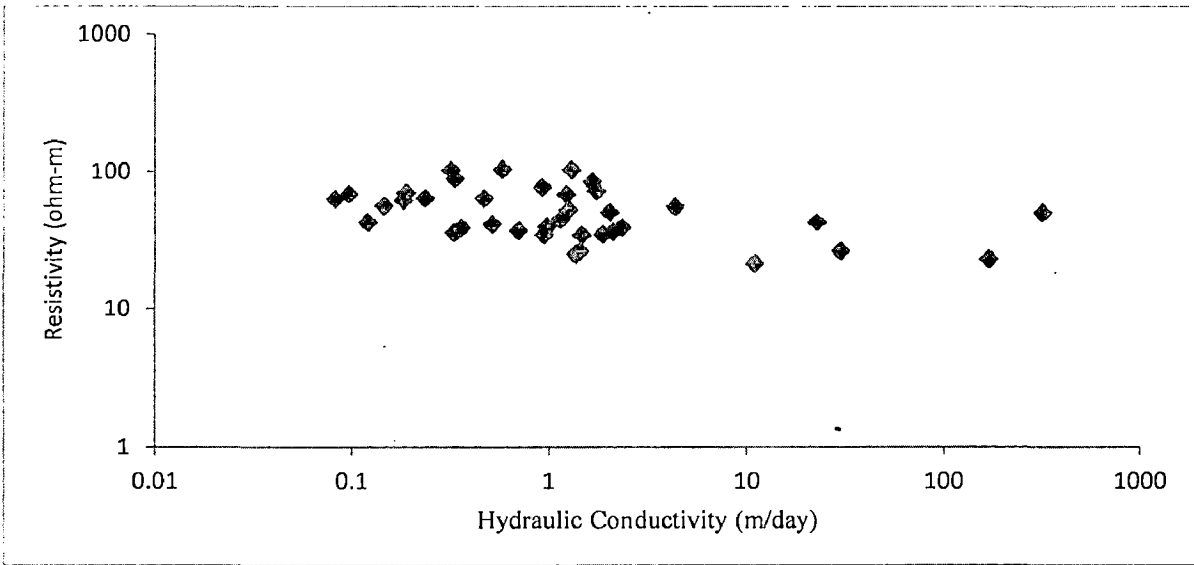


Figure 8: Plot of Aquifer resistivity with respect to hydraulic conductivity, Salem district.

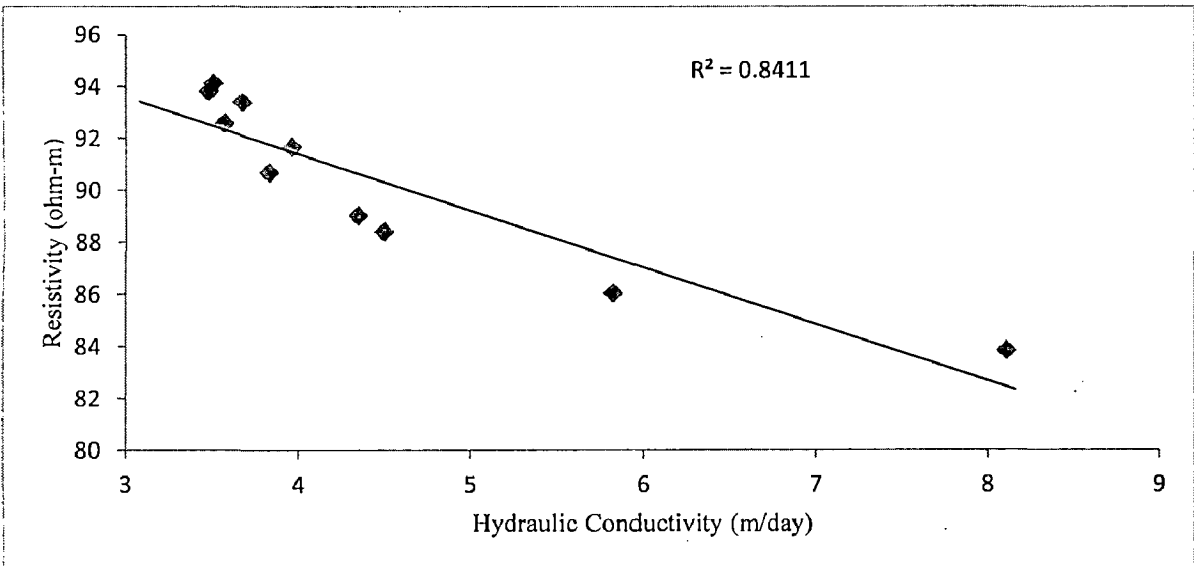


Figure 9: Correlation between aquifer resistivity and hydraulic conductivity after applying moving average. Correlation coefficient ( $R^2$ ) is 0.8411.

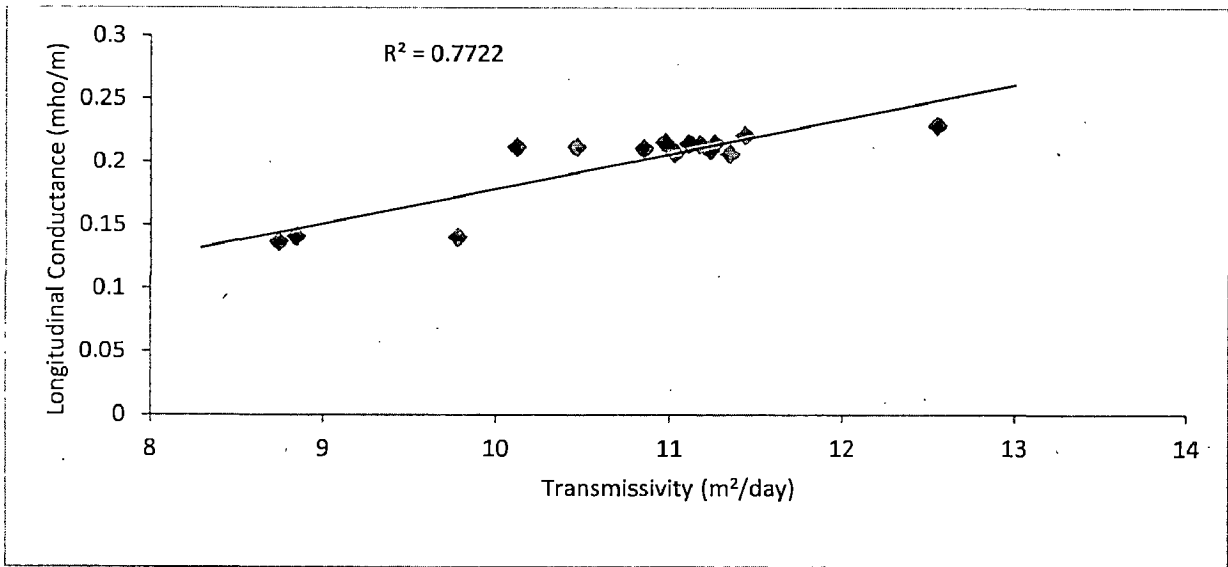


Figure 10: Correlation between transmissivity and longitudinal conductance. Correlation coefficient ( $R^2$ ) is 0.7722.

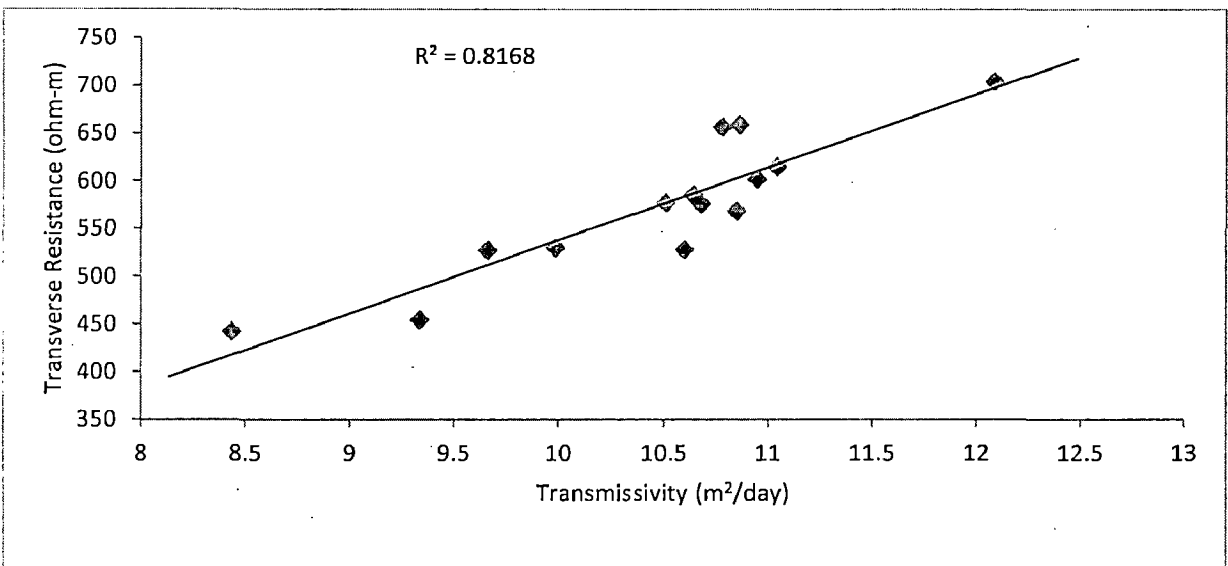


Figure 11: Correlation between transmissivity and transverse resistance. Correlation coefficient ( $R^2$ ) is 0.8168.

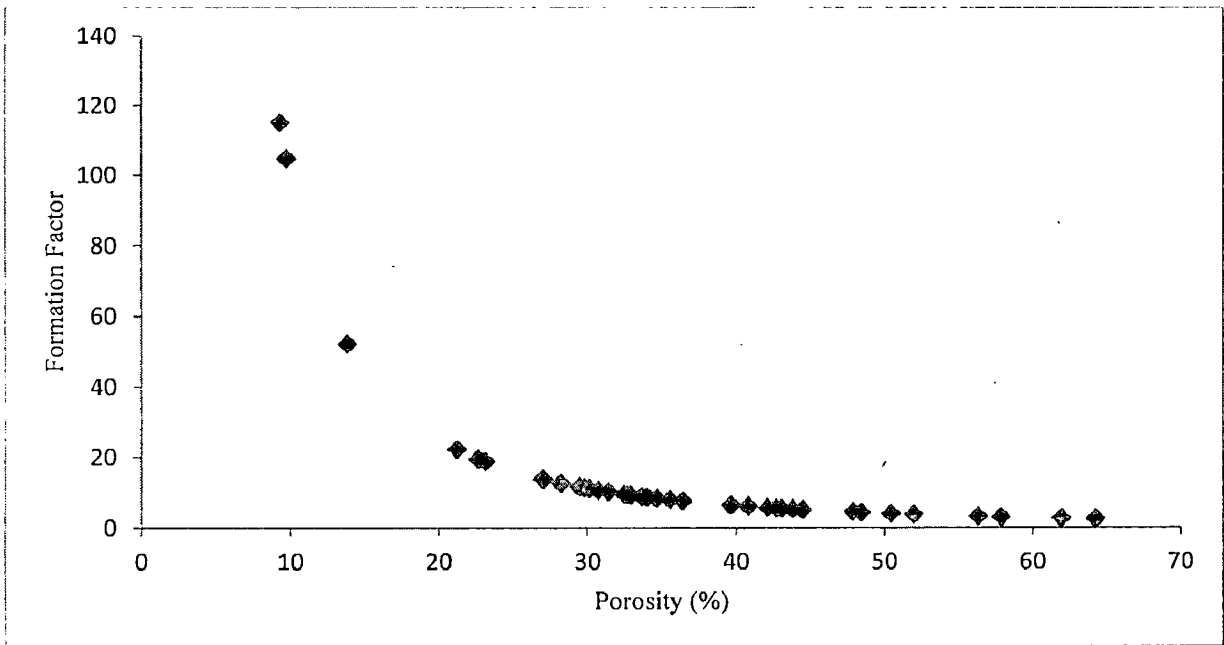


Figure 12: Correlation between porosity and formation factor.

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**HYDROGEOLOGICAL ENVIRONMENT IN SALEM DISTRICT****5.1 Hydrogeology**

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. These deposits comprise boulders, cobbles, gravels, sands and silts and are seen in the foothills of all the major hill ranges. The thickness of these aquifers ranges from a few meters to as much as 25 m. Ground water occurs under phreatic conditions and is developed by means of dug wells. They are important from ground water development point of view in the hilly terrain.

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 <1m to more than 25 m.

The depth to water level in the district varied between 0.10 – 11.46 m bgl during pre-monsoon depth to water level (May 2006) and varied between 0.10 – 17.15 m bgl during post monsoon depth to water level (Jan 2007). The seasonal fluctuation shows a rise in water level, which ranges from 0.20 to 3.25 m bgl. The piezometric head varied between 3.00 to 18.00 m bgl (May 2006) during pre-monsoon and 2.02 to 19.62 m bgl during post monsoon (Subburaj, A., Dec. 2008).

## 5.2 Aquifer Parameters

Aquifers are large body of permeable material where ground water is present in the saturated zone in other words it simply refers to rock or soil mass which not only contains water, but from which can be readily abstracted in significant quantities. Good aquifers are those with high permeability such as poorly cemented sands, gravel and sand stone or highly fractured rocks. Aquifers are underground storage reservoir, which are typically characterized by high porosity and permeability values. Different types of aquifers are shown in the Figure (6) (chapter 5).

The electrical resistivity values and thickness of top five layers are given at 65 locations in Salem district, Tamil Nadu. The calculations of aquifer parameters (aquifer resistivity, aquifer thickness, transmissivity, hydraulic conductivity, resistance, conductance, aquifer porosity and water resistivity) have been summarized in table (1), (2), (3) & (4) in chapter (4).

## 5.3 Ground Water Quality

Ground water in phreatic aquifers in Salem district is in general colorless, odorless and slightly alkaline in nature. In major part of the district the electrical conductivity is above 1000  $\mu\text{S}/\text{cm}$ , except in Yercaud, P.Goundanpalayam & Salem. For the drinkable water, the water conductivity is 1000  $\mu\text{S}/\text{cm}$  (<http://www.geo-hydrology.com/>). The water of the district is mostly saline in nature and data vary between 711-16500  $\mu\text{S}/\text{cm}$  (Elangovan, K., Maheswaran, G., 2010).

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**INTERPRETATION OF CONTOUR MAPS**

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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. At 60 locations, five layer geoelectrical section has been obtained (top soil, weathered zone, semi weathered zone, fracture zone, and bed rock). Second and third layer constitute the aquifer system which represents the weathered zone, semi weathered zone and fractured zone respectively.

Aquifers are large body of permeable material where ground water is present in the saturated zone. Good aquifers are those with high permeability such as poorly cemented sands, gravel and sand stone or highly fractured rocks. Aquifers are underground storage reservoir, which are typically characterized by high porosity and permeability values. The aquifer body has porosity value 25-60 (%) in major part of the district (Figure 25). Porosity has been characterized by the quantity of water, existing in rocks. If aquifer thickness (Figure 16) and porosity (Figure 25) contour map have been compared, the result shows that the volume of ground water is high around Salem city, western part and southern-eastern part of the district.

Ground water in phreatic aquifers in Salem district is in general colorless, odorless and slightly alkaline in nature. The value of aquifer water conductivity is greater than 1000 micromho/cm in major part of the study area (Figure 23). So the water is saline in nature. Hence the aquifer water resistivity is smaller than the water resistivity of fresh water (Figure 24). Transmissivity of an aquifer expresses the ability of the aquifer material to transmit water. It is the volume of water flowing through a cross-section of the aquifer. From the contour map of transmissivity (Figure 17), its value lies in between 1-158 m<sup>2</sup>/day. The north-west part of the district has sufficiently large transmissivity values.

Hydraulic conductivity and aquifer depth are fundamental properties describing subsurface hydrology. Hydraulic conductivity is linked not only to the volume of the available water, but

also to the size of the pores. Figure 14 has shown that the depths to water level vary from 0-20 m but in major part of the district, it is 1-12 m (Figure 14). Aquifer resistivity varies from 25-110 ohm-m (Figure 15). Figure (18) has shown the variation of hydraulic conductivity data between (0.01-316) m/day. The aquifer whose resistivity is in between 40-100 ohm-m, are very good aquifers from electrical resistivity survey point of view. With the help of figure (19) and (20), the values of constant parameters ( $\alpha$ ,  $\beta$ ) in equations (3.3.1) and (3.3.2) would be evaluated at different locations in the study area of Salem district.

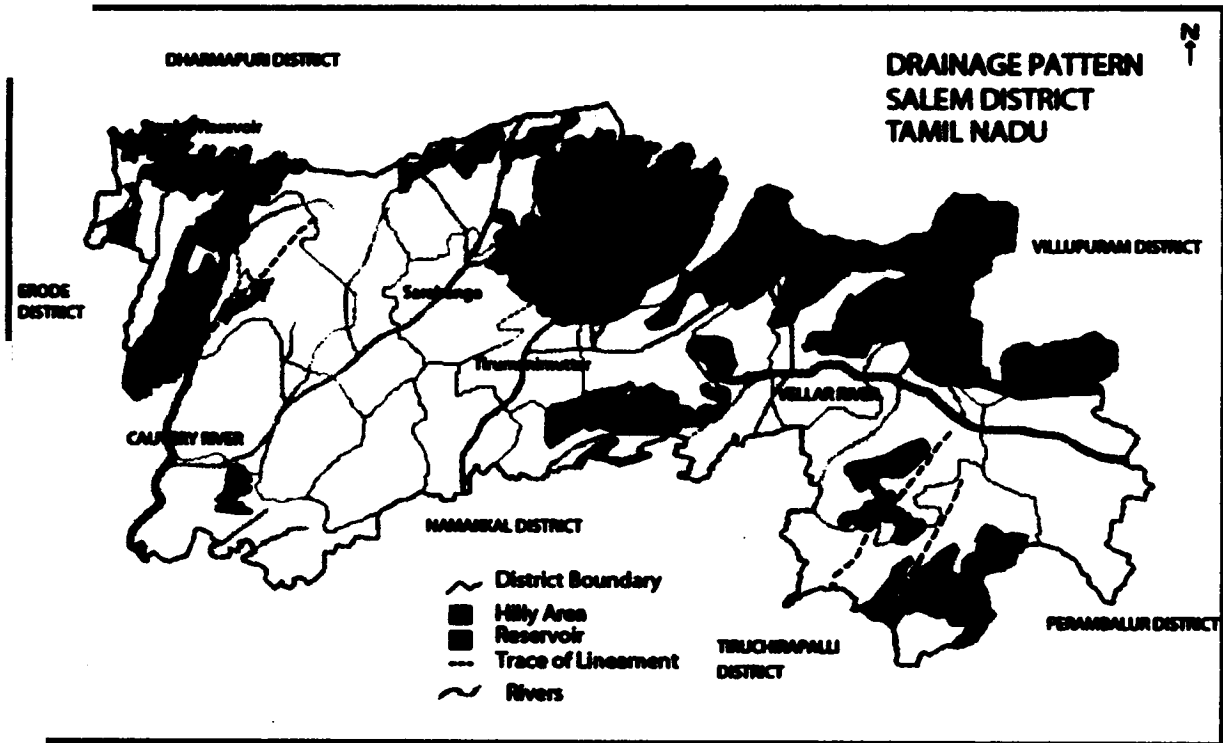


Figure 13: Drainage pattern (artificial recharge sources) in Salem district.

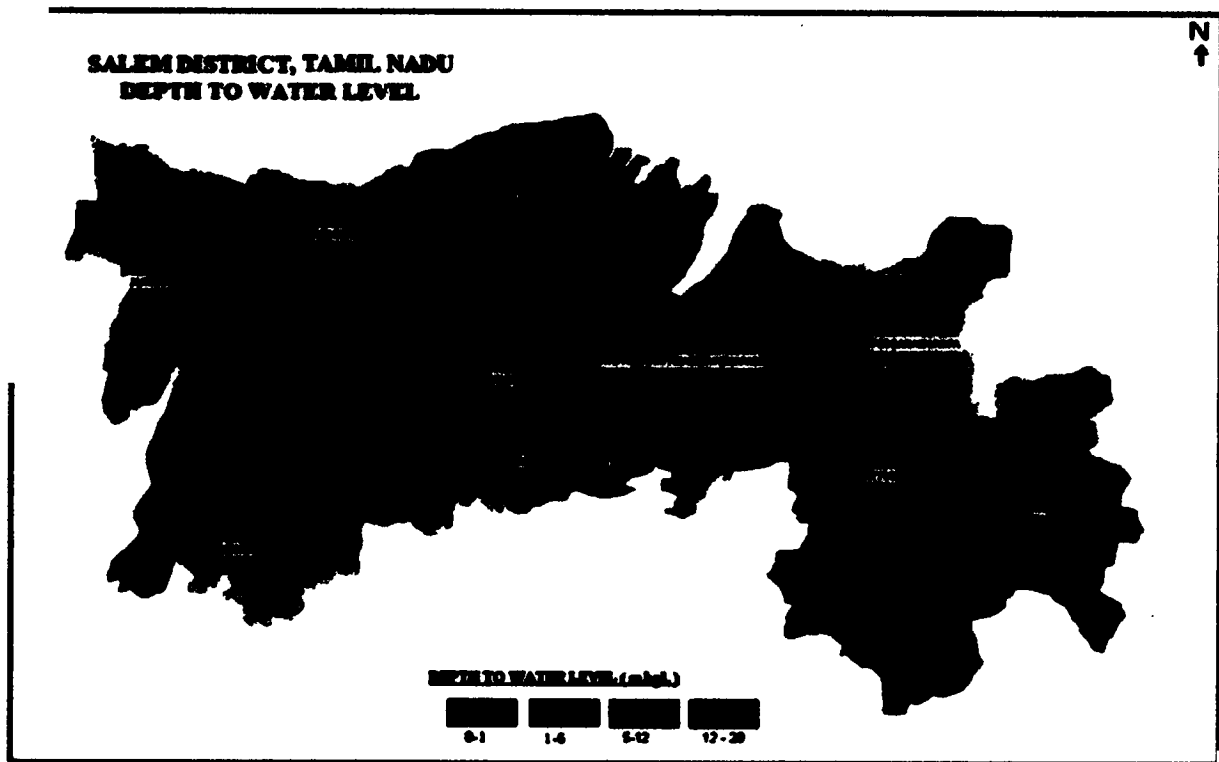


Figure 14: Depth to water level (in meter below ground level).

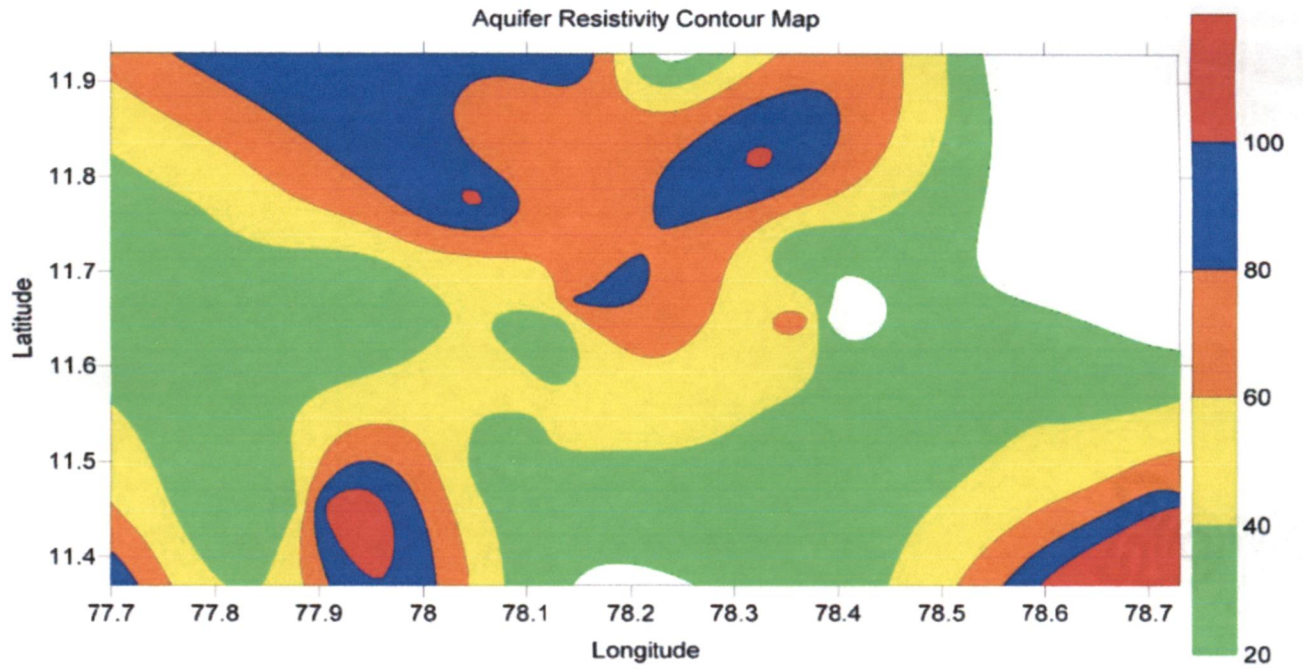


Figure 15: Contour map of aquifer resistivity (ohm-m).

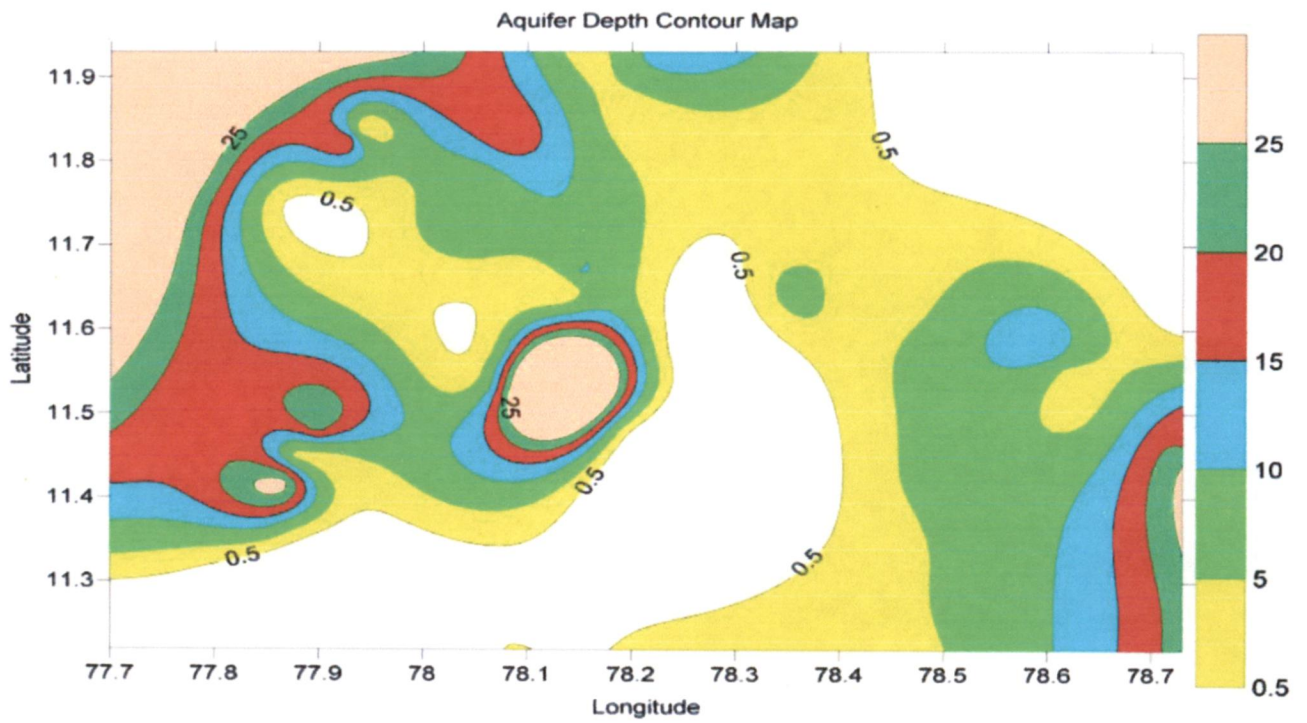


Figure 16: Contour map of aquifer thickness (meter).

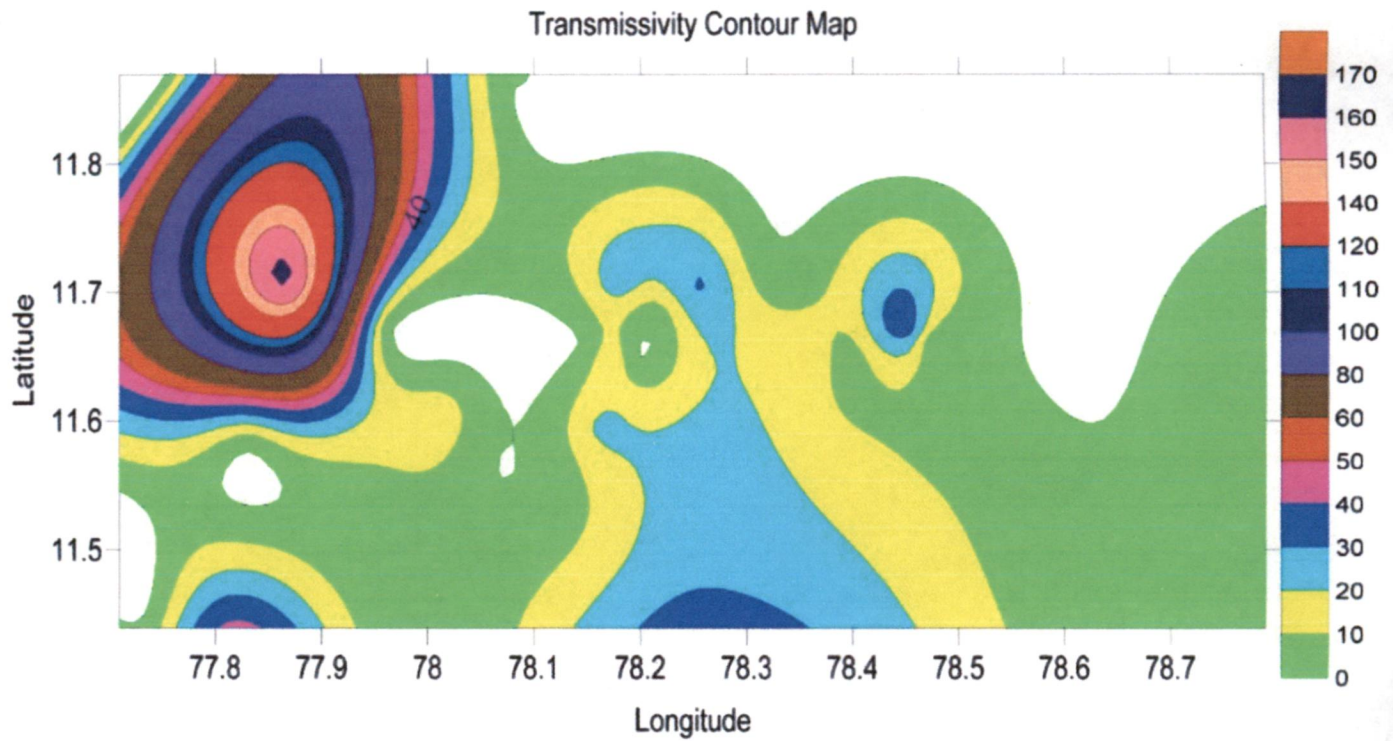


Figure 17: Contour map of Transmissivity ( $m^2/day$ ) data.

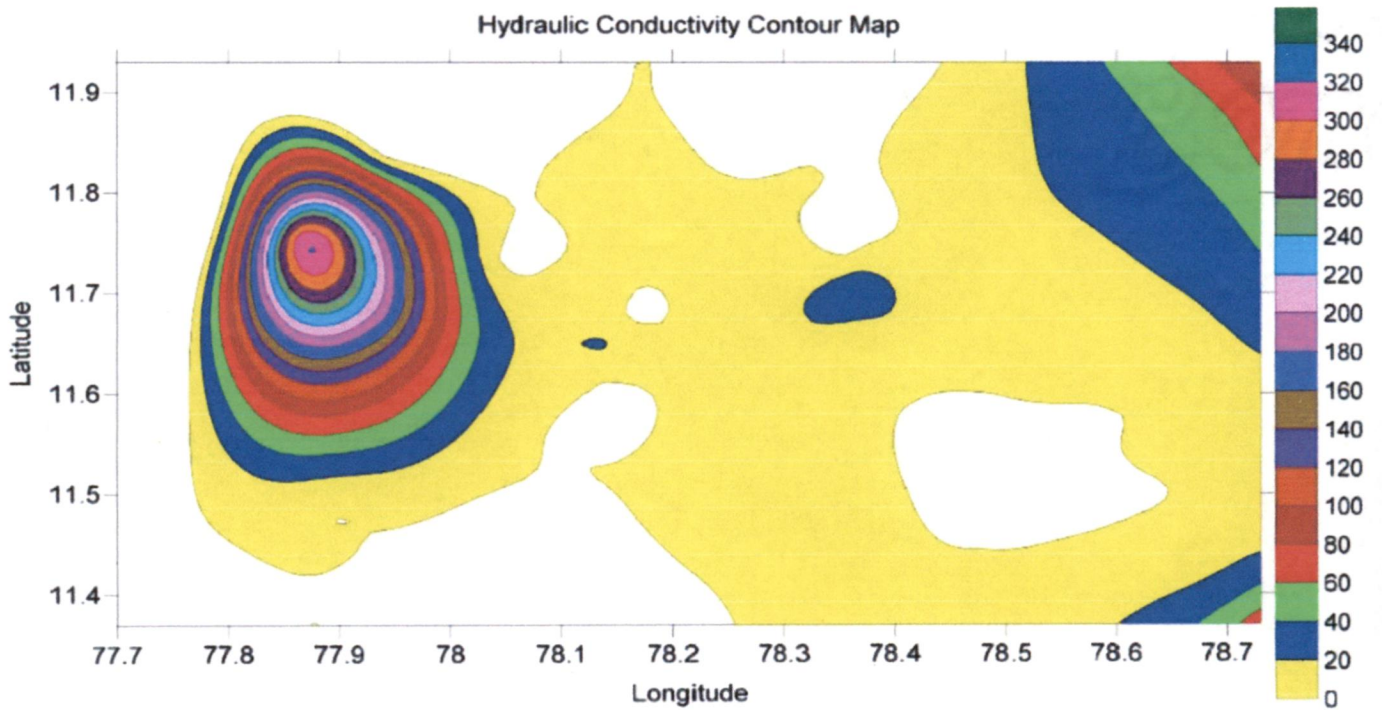


Figure 18: Contour map of hydraulic conductivity ( $m/day$ ).

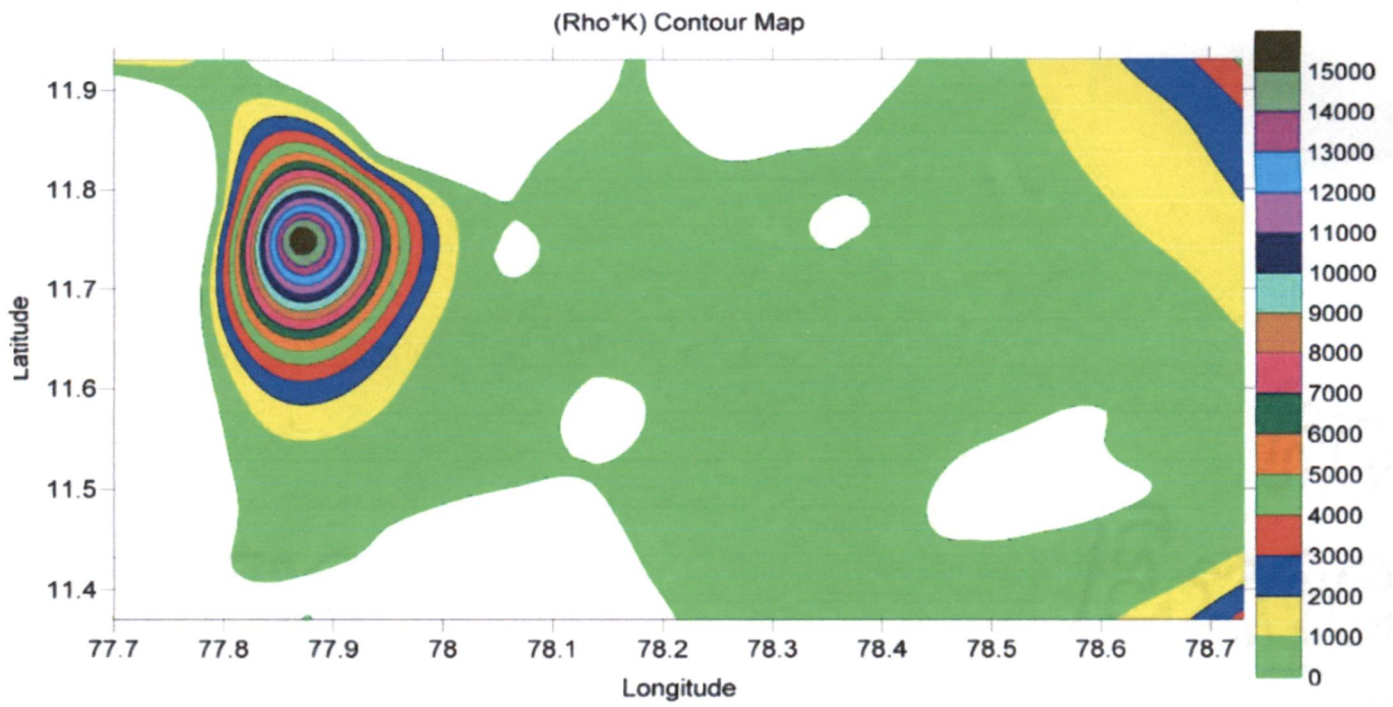


Figure 19: Contour map of (resistivity\*hydraulic conductivity). The scale is in  $\text{ohm}\cdot\text{m}^2/\text{day}$ .

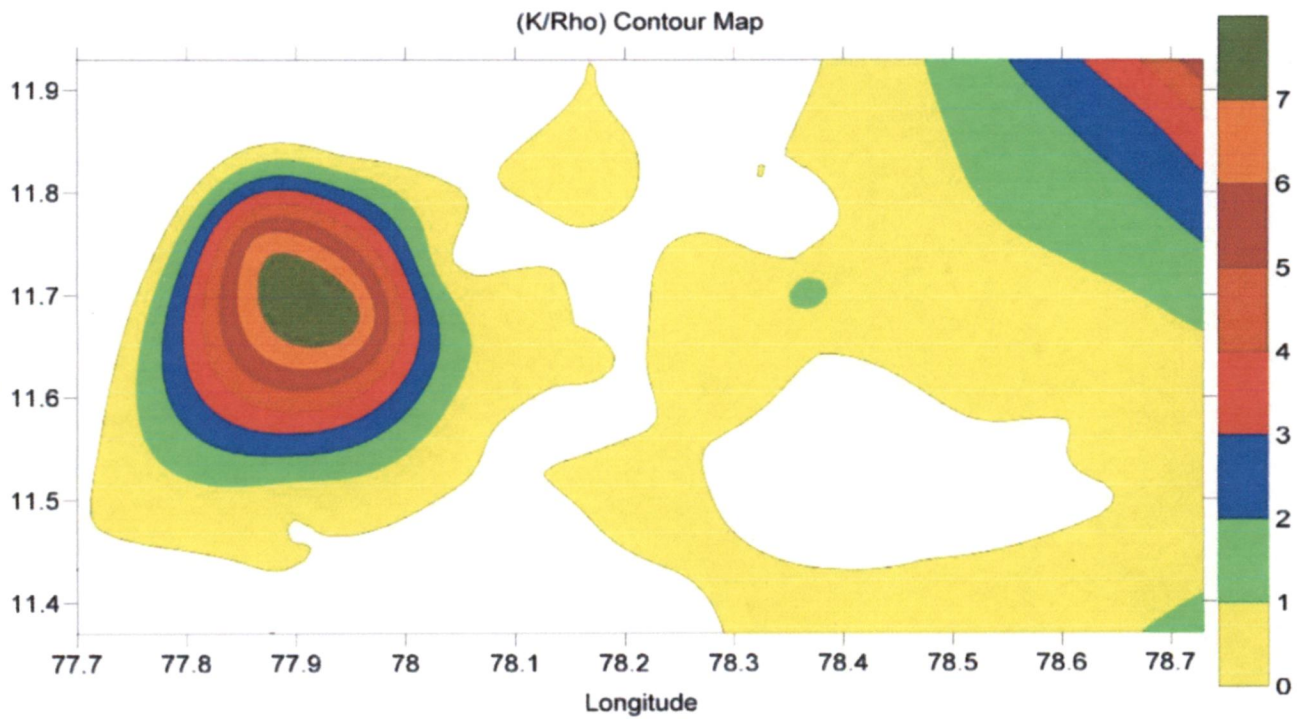


Figure 20: Contour map of (hydraulic conductivity/resistivity). The scale is in  $\text{ohm}^{-1}\text{day}^{-1}$ .

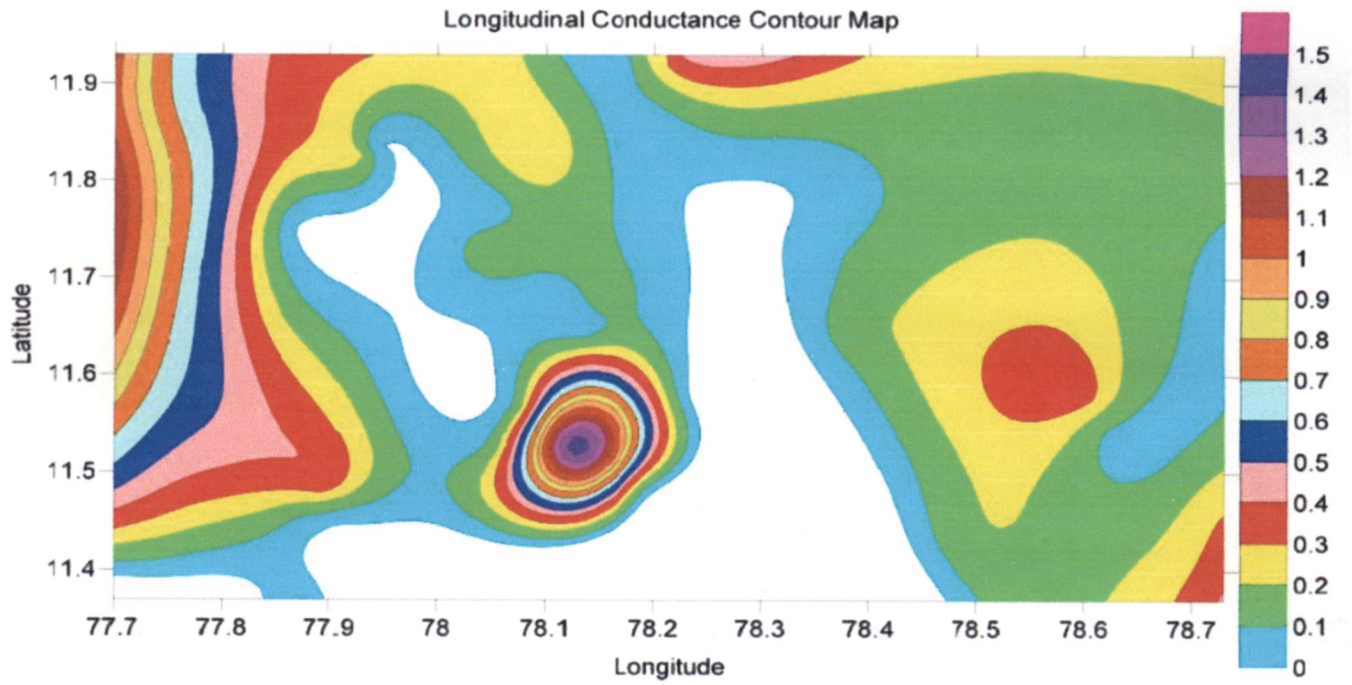


Figure 21: Contour map of longitudinal unit conductance ( $\text{ohm}^{-1}$ ).

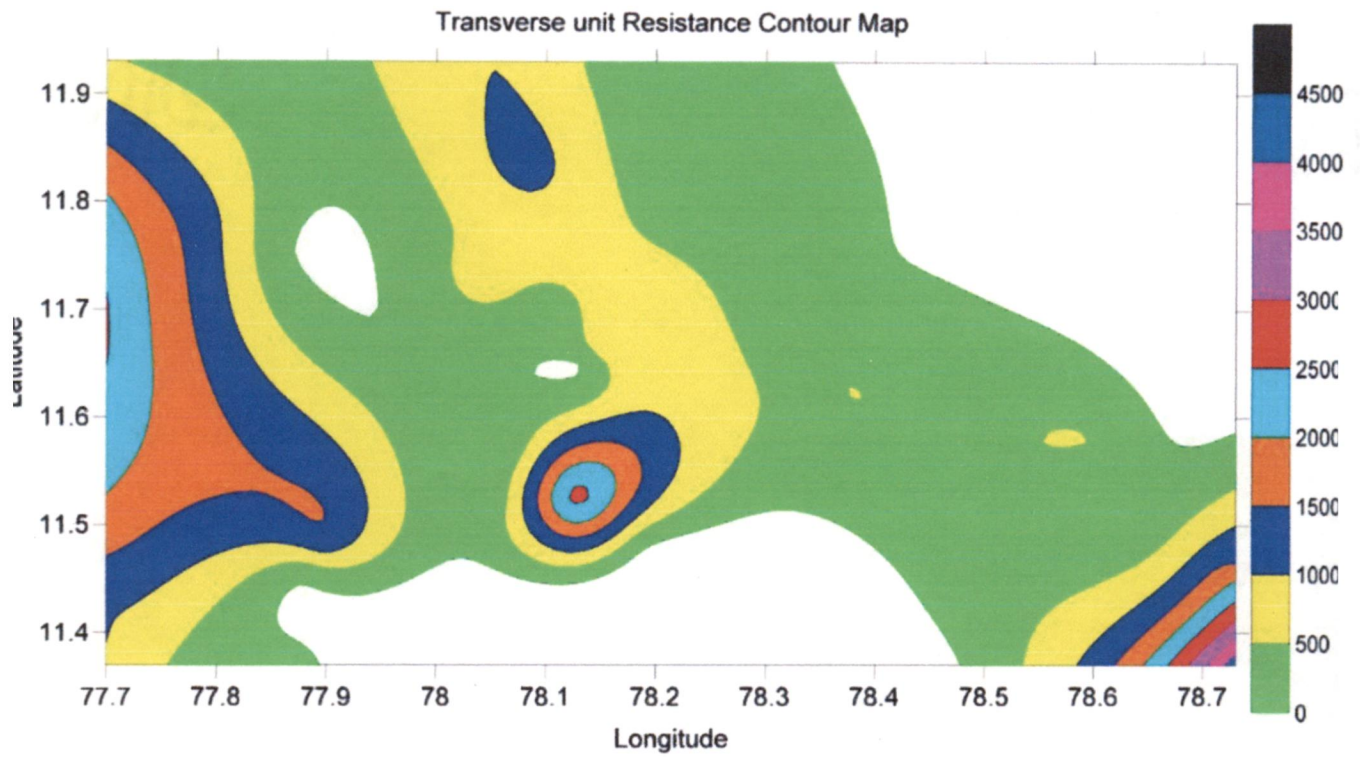


Figure 22: Contour map of transverse unit resistance ( $\text{ohm}$ ).

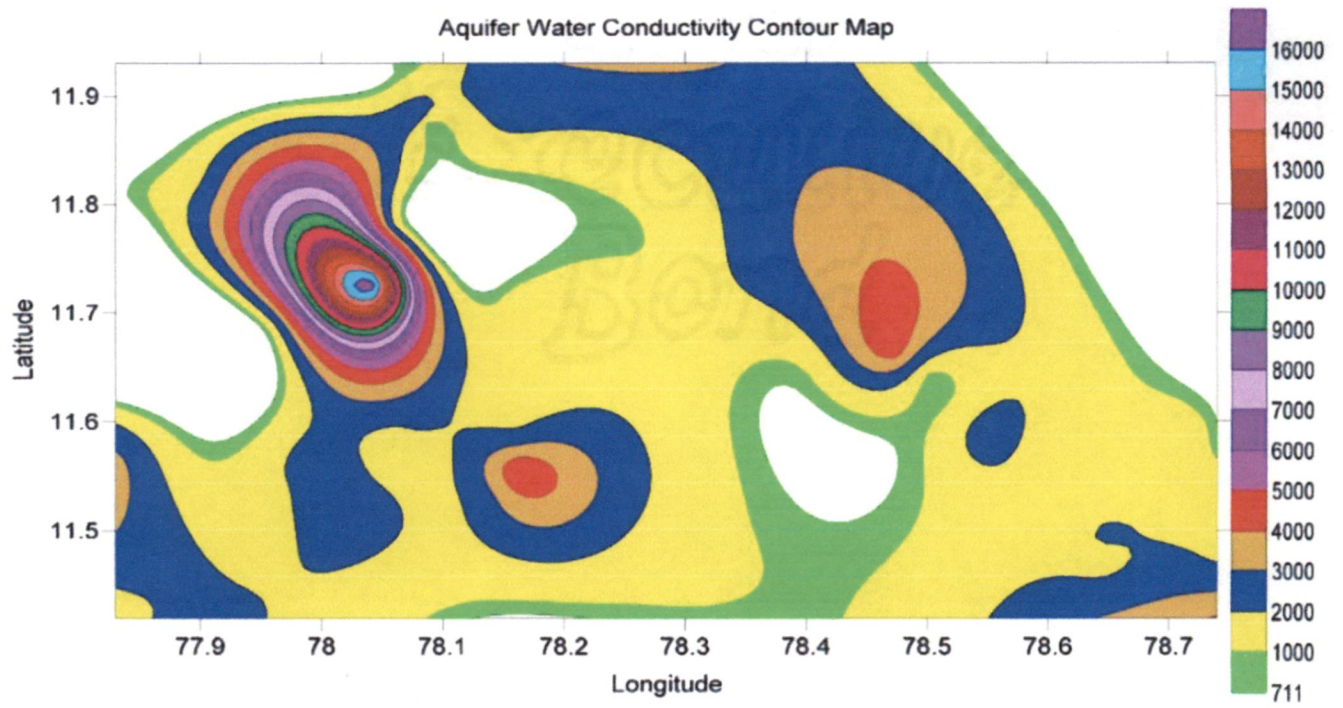


Figure 23: Contour map of aquifer water conductivity (micromho/cm).

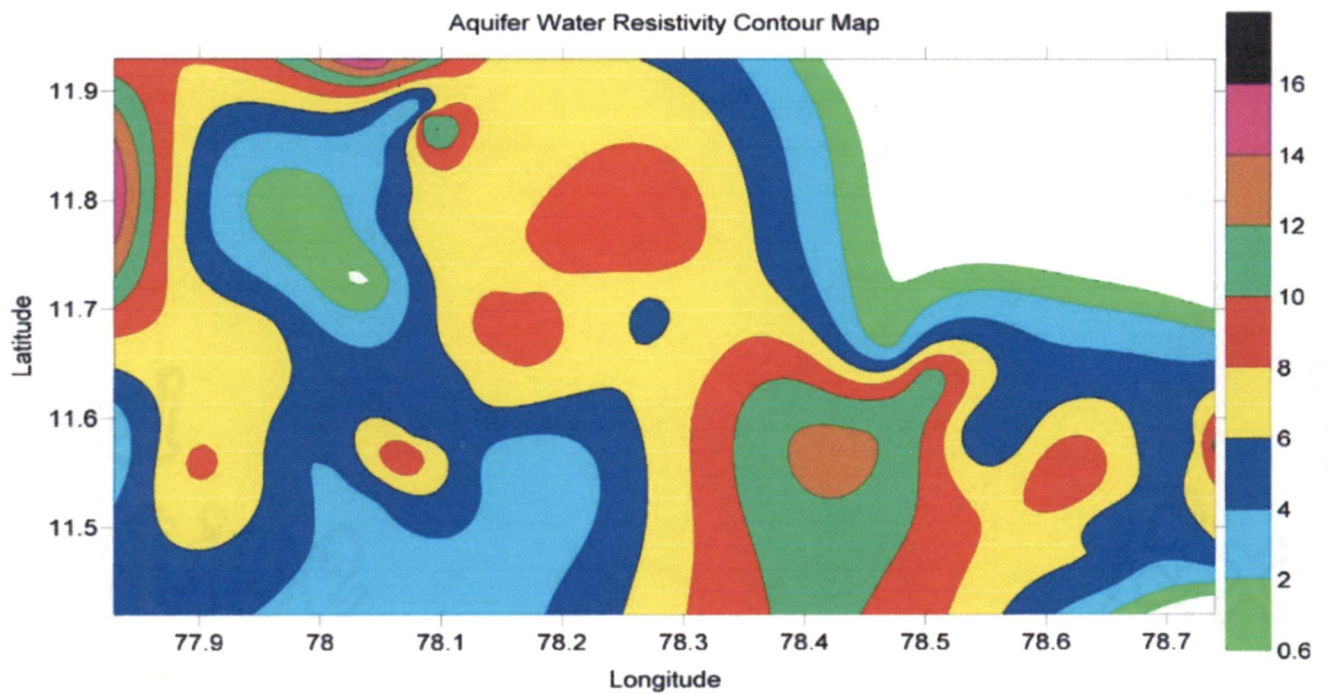


Figure 24: Contour map of aquifer water resistivity (ohm-m).

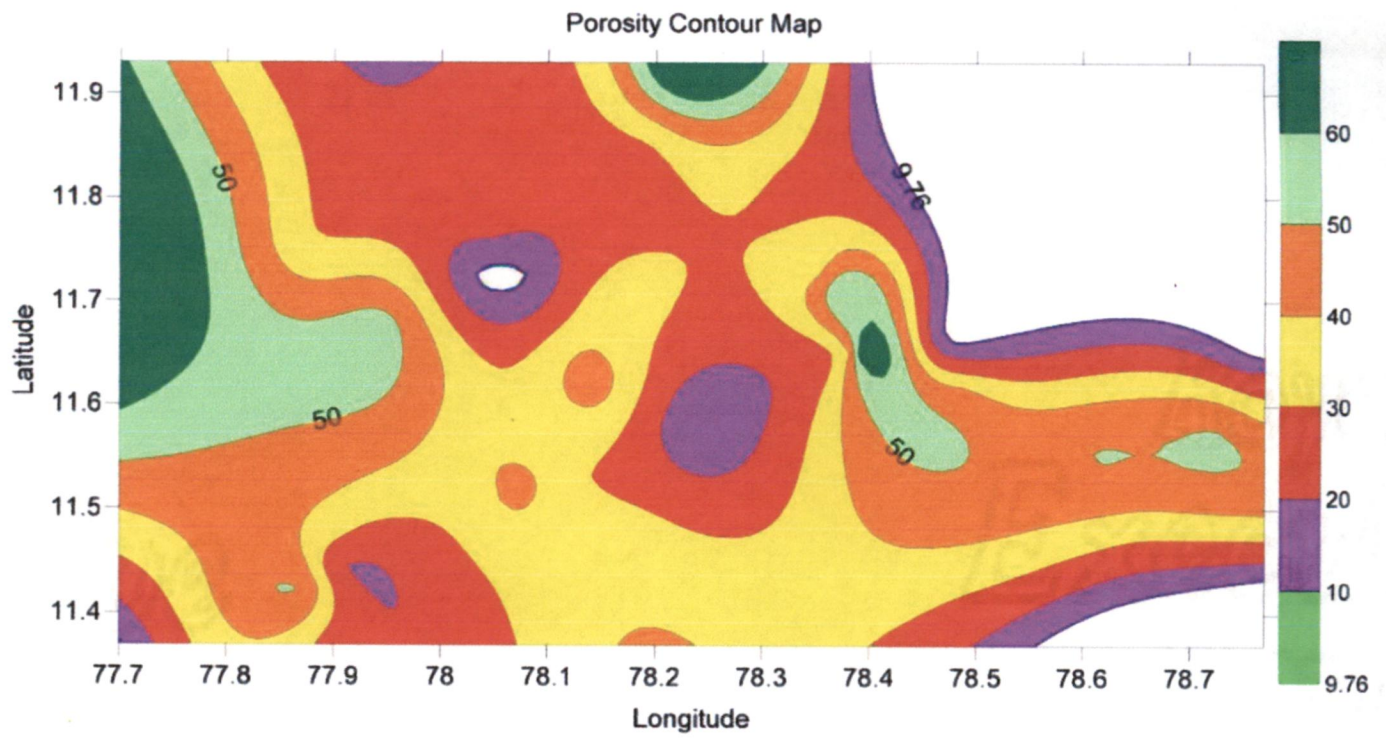


Figure 25: Contour map porosity (in percentage).

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**CONCLUSIONS**

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In this work, the electrical resistivity survey data used to delineate groundwater potential in Salem district. The above studies have shown a useful relationship between hydraulic parameters and geoelectrical properties in hard rock aquifers. A mathematical formulation has been developed between hydraulic conductivity and aquifer resistivity, and between transmissivity and longitudinal conductance. The developed methodologies have been validated with field data from hard rock consolidated aquifer at Salem district (India). On the basis of this dissertation work, following conclusions has been concluded as:

1. Based on the developed formula, hydraulic conductivity has been calculated and inverse correlation has been achieved between aquifer resistivity and hydraulic conductivity. Estimated hydraulic conductivity and resistivity are found very close to each other with a strong correlation factor ( $R^2 = 0.8411$ ) at hard rock consolidated aquifer in Salem district, India.
2. Linear correlation coefficient has been obtained between transmissivity and hydraulic parameters. The correlation coefficient between transmissivity and longitudinal conductance is 0.7722 and between transmissivity and transverse resistance is 0.8168.
3. Porosity and formation factor have shown an inverse correlation. Most of the porosity values lie in between (25-60). Hence the hard rocks of the area are saturated by a good amount of water in pores or fractures.
4. The thicknesses of aquifer body vary between 0-25 m. The depth to water level varies between 1-12 m below ground level in most part of the district. The thickness of aquifer is greater than 10 m around western, central and south-eastern part of the district.
5. The hydraulic conductivity varies form 1-316 m<sup>2</sup>/day. In the western part of the district, the hydraulic conductivity has higher values than other part of the district.

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