JOURNAL OF
ENVIRONMENTAL HYDROLOGY

The Electronic Journal of the International Association for Environmental Hydrology
On the World Wide Web at http://www.hydroweb.com

VOLUME 9 2001

GEOPHYSICAL STUDIES TO DETERMINE HYDRAULIC CHARACTERISTICS OF AN ALLUVIAL AQUIFER

M. Senthil Kumar
D. Gnanasundar
L. Elango

Centre for Geoscience and Engineering
Anna University
Chennai, India

The vertical electrical sounding (VES) data obtained from 70 locations in the unconsolidated sandy formation south of Chennai was interpreted, and layer parameters such as true resistivity and thickness were determined. Formation factor was calculated from the resistivity data. Three empirical relationships were established: they are (i) the relationship between hydraulic conductivity and formation factor, (ii) hydraulic conductivity and modified aquifer resistivity, and (iii) transmissivity and transverse resistance. The aquifer parameters of this alluvial aquifer have been estimated with a reasonable accuracy using the relations between hydraulic properties and electrical resistivity parameters. This study implies that geoelectrical techniques offer an alternate approach for estimating the hydraulic characteristics of alluvial aquifers.

INTRODUCTION

Geophysical techniques in combination with geological and hydrological methods are known to provide valuable information in man's quest for groundwater. Estimation of aquifer characteristics is always very important in groundwater resource studies.

The common method for determining aquifer characteristics is by pumping tests to determine hydraulic conductivity, transmissivity and storativity . Sometimes, due to logistic and other problems, it is impossible to carry out long duration pump tests which are necessary for the best estimation of hydraulic characteristics of an aquifer. However, surface geoelectrical measurements often can be used to calculate aquifer parameters.

Since the late 1960's, surface resistivity measurements have been used to determine aquifer properties such as specific yield, hydraulic conductivity, and transmissivity. Ungemach et al. (1969) correlated transmissivities determined from the results of six pumping tests in the Rhine aquifer with transverse resistance. Kelly (1977) and Kosinski and Kelly (1981) correlated saturated thickness resistivities obtained from pumping tests in southern Rhode Island, USA. Mazac and Landa (1979) analyzed data from Czechoslovakia and concluded that relations between aquifer transmissivities and either transverse resistance or longitudinal conductance are possible for both direct and inverse material-level correlation between resistivity and hydraulic conductivity. Sri Niwas and Singhal (1985) concluded that relations between transverse resistance and transmissivity are more meaningful in alluvial aquifers than relations between longitudinal conductance and transmissivity. Frohlich and Kelly (1985) and Huntley (1986) generally confirmed the wider applicability of direct relations between apparent formation factor and hydraulic conductivity for granular aquifers and transverse resistance and hydraulic transmissivity in glacial aquifers. The objective of this study is to bring out the relationship between hydraulic properties and resistivity related parameters of the Thiruvanmiyur-Muttukadu alluvial aquifer located south of Chennai city (Figure 1), and to estimate the aquifer characteristics i.e., hydraulic conductivity and transmissivity from electrical resistivity data.

STUDY AREA

The area of study is a coastal tract, which lies 10 km south of Chennai City. It extends from Thiruvanmiyur to Muttukadu (Figure 1). The study area covers 60 km^2, extending 20 km in length and 3 km in width, and it is surrounded by salt water on three sides. It is bounded by the Adyar river in the North, by the Muttukadu estuary in the south, and the Bay of Bengal in the east. The Buckingham canal forms the western boundary of the area. The area has a humid and subtropical climate.

The maximum temperature is about 40°C and a minimum temperature of 20°C with an annual rainfall of about 1000 to 1500 mm. The study area contains layers of silt, clay and fine to coarse-grained sand. The basement rock is a coarse massive charnockite. Groundwater is reported to occur in silica sand with intervening layers of black clay. The water level ranges from 3 to 7 m below ground surface. The aquifer thickness ranges from 10 to 20 m.

METHODOLOGY

Geoelectrical methods are the most popular techniques among the geophysical methods for both regional and detailed groundwater explorations because of their wide range of applicability and low cost. The ability to conduct current is an important physical property of rock and rock-

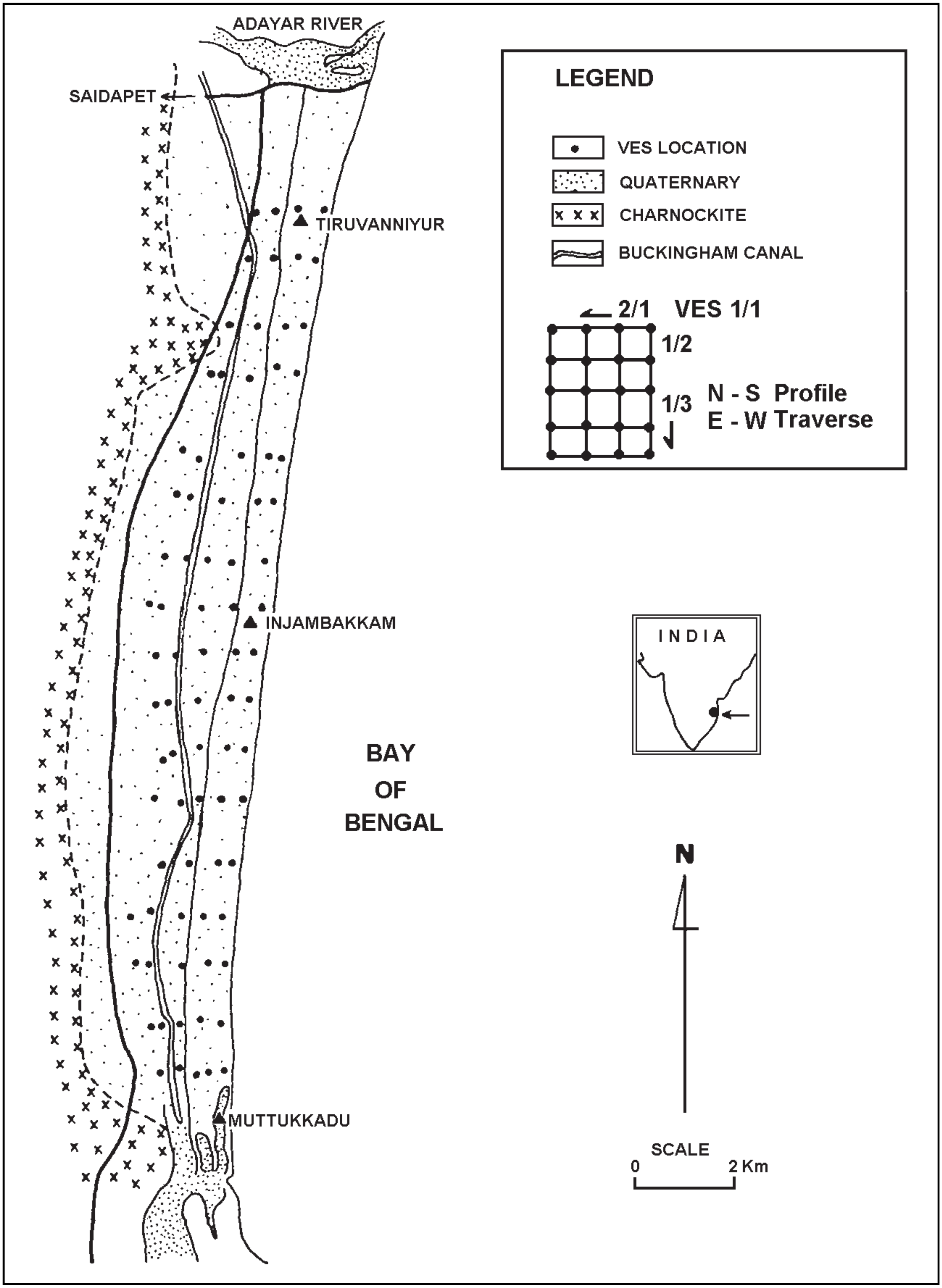

Figure 1. Map of the study area.

forming minerals, and it is put to use in this prospecting method.

A detailed electrical resistivity survey by the vertical electrical sounding (VES) method in the Schlumberger configuration was carried out in the area and reported by Gnanasundar and Elango, 1999. The survey was conducted in a rectangular grid pattern consisting of 17 traverses (N-S) and 5 profiles (E-W). The maximum electrode half spacing (AB/2) ranged from 24-33 m, the majority of the sounding used a AB/2 of 27 m. The distance between the 2 adjacent traverses was approximately 1000 m, and between two profiles was approximately 250 m. Seventy VES location data points were interpreted using a curve matching technique, and layer thickness and layer resistivity were determined. The true resistivities of various layers are calculated by correlating the apparent resistivity r_a (x-axis) and electrode spacing AB/2 (y-axis) in a log-log graph. These field curves were overlapped and matched with the auxiliary point curves (APC), and the type curves were determined. These curves were interpreted with two, three, four and five-layer master curves. From these curves, the resistivity of layers and their thickness were calculated. Water level from open wells near the VES location points was collected to determine the earth resistivity. The electrical conductivity (EC) was also measured in the field.

TRANSVERSE AND LONGITUDINAL RESISTIVITY

In the case of transverse resistivity, the current flow is considered to be perpendicular to the layers. The transverse resistivity (ρt) is calculated from the true resistivity values. (Singhal et al., 1998).

$$\rho t = \frac{\Sigma hi * \rho i}{\Sigma hi}$$

where hi is the thickness of layers and ρi is the resistivity of layers.

In case of longitudinal resistivity, the current flow is parallel to the layers. Longitudinal resistivity (ρL) is given by:

$$\rho L = \frac{\Sigma hi}{\Sigma hi / \rho i}$$

The formation factor (F) is calculated by dividing earth resistivity to water resistivity for a clay free formation.

$$F = \rho o / \rho w$$

where F is the formation factor, ρo is earth resistivity or the resistivity of the brine saturated formation, and ρw is the water resistivity or the resistivity of the brine.

Three types of relations have been established. They are: (i) the relation between hydraulic conductivity and formation factor, (ii) the relation between hydraulic conductivity and modified aquifer resistivity and (iii) the relation between transmissivity and transverse resistance.

RESULTS AND DISCUSSION

The study area contained a maximum of 5 layers and a minimum of 2 layers. Iso-resistivity maps were prepared to study the variation in the resistivity of various layers. The contour pattern obtained is almost parallel to the coast (N-S). Water level and electrical conductivity of the 26 wells of the study area were collected to determine the formation factor. Three empirical relations were established.

Relation between hydraulic conductivity and formation factor

Log-log relation can establish an empirical relationship between hydraulic conductivity and formation factor as

$$K = A * FF^{m}$$

where K is the hydraulic conductivity, FF is the formation factor, and A and M are empirically derived constants. This relation is restricted to unconsolidated sediments where the aquifer is anisotropic due to the layering of fine to coarse sediments; each layer is assumed isotropic. From the relationship the hydraulic conductivity (K) of the study area was determined for the contrasting values of formation factor as shown in Figure 2. The hydraulic conductivity and formation factor data are shown in Table 1.

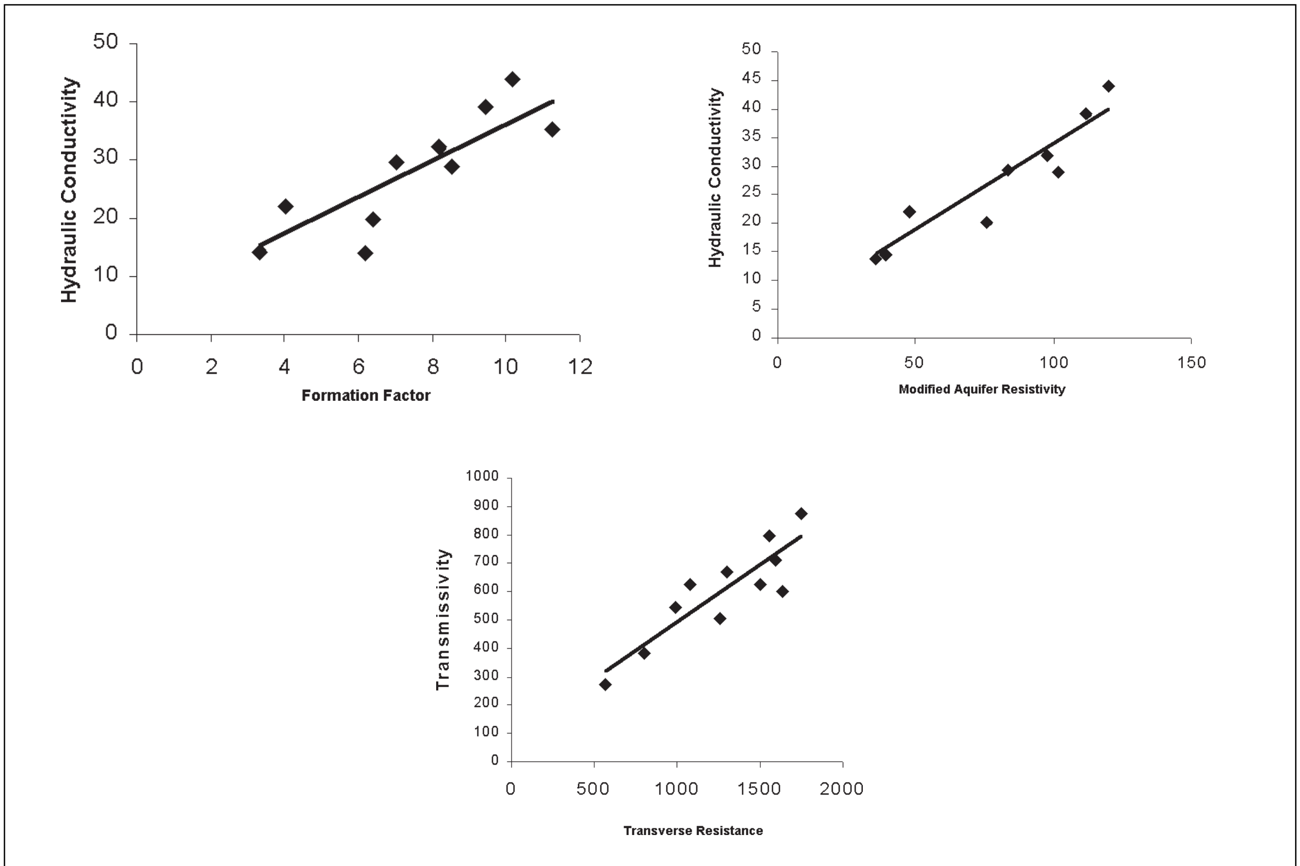

Figure 2. Relations between hydraulic conductivity and formation factor, hydraulic conductivity and modified aquifer resistivity, and transmissivity and transverse resistance.

Relation between hydraulic conductivity and modified aquifer resistivity

Modified aquifer resistivity is the aquifer resistivity modified according to Singhal and Sriniwas (1983) to include the changes in the aquifer material and tortuosity of the interconnected pores. The modification factor is the ratio of average aquifer water resistivity and aquifer water resistivity

$$\rho' = (\rho * \overline{\rho w} / \rho w)$$

where ρ' is the aquifer resistivity, $\overline{\rho w}$ is the average water resistivity and ρw is the water resistivity.

Table 1. Showing the Hydraulic Conductivity Determined from Formation Factor

S. No	Ves No	Formation Factor	Hydraulic Conductivity	S. No	Ves No	Formation Factor	Hydraulic Conductivity
1	1\1	3.182	22	22	3\2	3.47	26
2	1\2	8.888	52	23	3\3	3.747	26
3	1\5	4.125	28	24	3\4	4	28
4	1\10	4.48	30	25	3\9	14.35	73
5	1\11	4.3072	29	26	3\13	3.38	25
6	1\12	5.538	35	27	3\14	6.645	42
7	1\13	7.996	48	28	3\16	5.37	35
8	1\14	4.26	29	29	3\17	5.797	37
9	1\15	9.262	54	30	4\2	5.12	33
10	2\1	3.49	25	31	4\4	13.33	72
11	2\2	4.001	27	32	4\5	4.5	30
12	2\3	10.1575	60	33	4\7	4.21	28
13	2\4	3.17	22	34	4\11	4.05	27
14	2\6	4.1062	28	35	4\12	6.29	40
15	2\7	3.078	22	36	5\5	3.94	26
16	2\9	4.23	28	37	5\6	3.12	23
17	2\13	14.46	74	38	5\8	3.7	26
18	2\14	4.122	28	39	5\9	2.98	21
19	2\15	3.42	26	40	5\10	4.7	31
20	2\17	5.68	36	41	5\16	3.4	24
21	3\1	8.104	48	42	5\17	3.07	22

The empirical relation between hydraulic conductivity and modified aquifer resistivity is shown in Figure 2. A straight line was fitted using regression. The equation obtained was $K=a\rho'$ where K is the hydraulic conductivity and ρ' is the modified aquifer resistivity. Figure 3 shows the hydraulic conductivity contours of the study area.

Relation between transmissivity and transverse resistance

Transmissivity was computed from the relation of

$$T=\alpha R$$

where $\alpha=k\sigma$, T is the transmissivity, k is the hydraulic conductivity, σ is the electrical conductivity, and R is the transverse resistance. Transmissivity is also calculated using the modification factor as

$$T=\left(k\sigma'\right)R'$$

where $\sigma'=\sigma*\rho w/\rho w$ and $R'=R*\overline{\rho w}/\rho w$. Here $\overline{\rho w}$ is the average aquifer resistivity, ρw is the aquifer resistivity. The relation between transmissivity and transverse resistance is plotted in a log-log relation (see Figure 2). The hydraulic parameters such as transmissivity and hydraulic conductivity are then determined. The hydraulic conductivity map of the study area is shown in Figure 3. The various parameters with respect to electrical sounding and pumping tests of the study area are given in Table 2.

Table 2. Results of Electrical Sounding Pumping Test for the Study Area

Evaluated parameters	Thiruvanmiyur	Pallavakkam	Navalur	Sholinganallur	Pettai	Neelangarai	Akkarai	Injambakkam	Uthandi	Uthandi	Muttukadu
Aquifer parameters (b) in mts	18	20	12	12	12	20	22	22	22	19	17
Transmissivity (T) in m^2/day	710	872	387.7	624.5	602.4	673.9	1101	507	1141	545	628
Hydraulic Conductivity (K) in m/day	39	44	32	52	50	34	50	23	52	29	37
Water resistivity ρw in Ωm	7.2	9.4	7.8	5.6	1.5	5.1	21.7	10.9	3.2	13.2	7.8
Formation Factor (FF)	9.43	10.16	8.205	7.053	8	4.05	3.01	3.34	4.03	8.58	6.41
Modified Aquifer resistivity ρ' in Ωm	112.1	120.17	97.28	83.74	95.04	48.23	35.83	39.18	47.85	101.97	76
Modified Aquifer conductivity δ' in Ωm	0.00892	0.00832	0.01027	0.01194	0.0105	0.0207	0.0279	0.0251	0.0208	0.0098	0.01815
Product k * δ in mho/day	0.3478	0.3661	0.3286	0.6208	0.526	0.7038	1.395	0.5773	1.0816	0.284	0.486
Transverse resistivity ρt	1592.5	1746.16	1257.95	1497.04	1636.6	1301.36	568.8	576.34	1563	618.1	493.19
Longitudinal resistivity ρl	1359.03	1300.14	1076.45	591.95	1240.9	106.81	363.23	208.63	1820.8	216.1	30.41
Electrical anisotrophy λ	1.082	1.158	1.08	1.59	1.14	3.49	1.25	1.66	0.926	1.69	4.02
Modified transverse resistance R'	2629.9	2208.8	1912.8	3173.72	12967	3032.1	311.7	628.2	5798.8	556.2	749.6

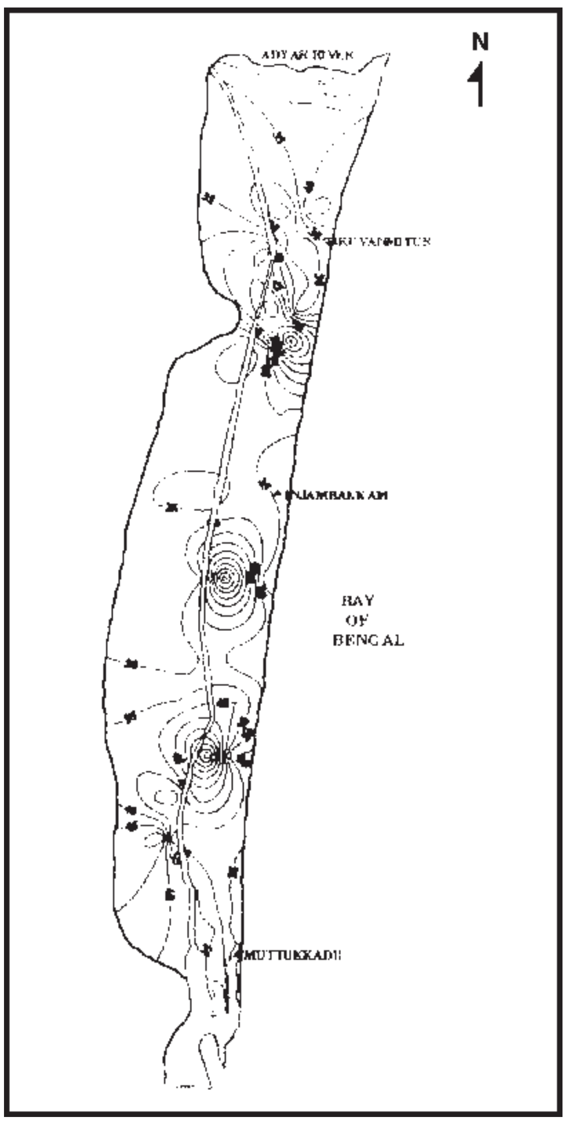

Figure 5. Hydraulic conductivity of the study area

CONCLUSION

Using the relations developed in this study, the hydraulic conductivity of the study area was found to range from 21 to 74 m/day. The transmissivity was found to range from 390 to 1100 m2/day. This study shows that geoelectrical methods can be used, not only for qualitative measurements, but also for quantitative estimates of aquifer properties. This method reduces additional expenditures for pumping tests and offers an alternate approach for estimating the hydraulic characteristic of an alluvial aquifer.

REFERENCES

Frohlich,R and Kelly,W.E.(1985). The relation between transmissivity and transverse resistance in a complicated aquifer of glacial outwash deposits. Jour. of Hydrology v.79 pp.215-219.

Gnanasundar, D. and L. Elango; Groundwater quality assessment of a coastal aquifer using geoelectrical techniques, Journal of Environmental Hydrology, Vol. 7, Paper 2, January 1999.

Heigold, P.C., R.H. Gilkeson, K. Cartwright, K. and P.C. Reed; (1979). Aquifer transmissivity from surficial electrical methods. Ground Water, 17(4); 338-345.

Huntley, D.(1986). Relation between permeability and electrical resistivity in granular aquifer. Ground Water v.24 pp.466-475.

Kelly.W.E.; (1977). Geoelectrical sounding for estimating aquifer hydraulic conductivity. Ground Water 15(6): 420-424.

Kelly, W.E. and P.F. Reiter; (1985). Influence of anisotropy on relations between electrical and hydraulic properties of aquifers. Jour. of Hydrology, V.79, pp. 311-321.

Kosinski, W.K. and W.E. Kelly; (1981). Geoelectrical sounding for predicting aquifer properties. Ground Water 19(2), pp. 163-171.

Mazac, O. and I. Landa; (1979). On determination of hydraulic conductivity and transmissivity of granular aquifers by vertical electrical sounding. Jour. Geol. Sci., (16), pp. 123-139. (In Czech).

Mazac, O., W.E. Kelly and L. Landa; (1985). Hydrogeophysical model for relation between electrical and hydraulic properties of aquifer. Jour. of Hydrology, V.79, pp. 1-19.

Singhal.D.C., Sriniwas, S. M. and Adam, E.M. (1998) -Estimation of hydraulic characteristics of an alluvial aquifer from resistivity data. Jour.Geological Survey of India V-51 pp. 461-470.

Sriniwas, S.M. and D.C. Singhal; (1985). Aquifer transmissivity of porous media from resistivity data. Jour. of Hydrology, V-82, pp. 143-153.

Ungemach, P., F. Mostaghimi and A. Duprat; (1969). Emphasis in determination of transmissivity coefficient and application in nappe alluvial aquifer Rhine. Bult. Int. Assoc. Sci. Hydrol. XIV (3): 169-190.

M.Senthil Kumar
Centre for Geoscience and Engineering
Anna University
Chennai
600025 India

Email:msent50@yahoo.com