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 13 2005

ESTIMATION OF HYDRAULIC PARAMETERS FROM SURFACE GEOPHYSICAL METHODS, KALIAPANI ULTRAMAFIC COMPLEX, ORISSA, INDIA

Ratnakar Dhakate
V.S. Singh
National Geophysical Research Institute
Hyderabad, India

A knowledge of aquifer parameters is essential for the assessment and management of groundwater resources. Conventionally, these parameters are estimated through pumping tests carried out on bore wells. Few bore wells may be available and carrying out pumping tests at a number of sites may be costly and time consuming. The application of surface geophysical methods in combination with pumping tests at a few sites provides a cost-effective and efficient alternative to estimate aquifer parameters. A surface geophysical method is used to obtain geophysical characteristics of aquifer parameters that are estimated through the pumping tests. A correlation is established between these parameters, which is subsequently used to estimate aquifer parameters from surface geophysical measurements at other sites where pumping has not been carried out. In this way, the entire investigation area can be covered to characterize an aquifer system. This study has been carried out in the Sukhinda valley, where the aquifer characteristics are required for the management of groundwater in the region.

INTRODUCTION

In recent years there has been a growing awareness in the field of groundwater management of the need to accurately assess groundwater resources. To accomplish this, it is essential to have knowledge of aquifer parameters such as hydraulic conductivity. The hydraulic conductivity is commonly estimated through pumping tests carried out on bore wells. However, in many circumstances the availability of bore wells at sufficient points may be lacking. Furthermore, drilling new bore wells and carrying out pumping test at each site may be time consuming and costly.

The Sukhinda chromite mining area is an example of an area where aquifer parameters are required for the assessment and management of groundwater resources. The impact of open cast mining on the groundwater regime needs to be studied in detail. Also, the leaching of chromium and its movement in the groundwater is of particular importance. In order to carry out these studies, a knowledge of aquifer parameters and their variation in the area becomes vital.

Surface geophysical methods have been used to delineate aquifer zones in the area, and the geophysical character of the aquifer zone has been estimated at various points. Since there are only a few bore wells available in the study area, these are utilized to carry out pumping tests and thus to estimate aquifer hydraulic parameters at these sites. Correlation coefficients were then established between geophysical parameters and aquifer hydraulic parameters. These correlations were utilized to estimate aquifer parameters at other places in the study area, where bore wells were not available. This method has proven to be cost effective and has rapidly characterized the aquifer system in the study area.

The objective of this study is to find the relationship between aquifer properties and surface resistivity parameters in the ultramafic complex at Kaliapani, Sukhinda Valley, Orissa, and to estimate hydraulic conductivity and transmissivity from the interpreted surface electrical resistivity parameters. The result will be used for further study of groundwater regime in the area and improving the quality of groundwater models. For this study only the aquifer resistivity and thickness is used for estimation of aquifer properties.

STUDY AREA

The study area lies between latitude 21° 1’ to 21° 4’ N and longitude 85° 45’ to 85° 48’ E and is a part of the famous Sukhinda Valley, Jajpur district, Orissa. It is shown in Figure 1. The drainage in the area is towards the NW and the entire area is drained by two streams which finally join the Damsal Nala flowing NE-SW. The Mahagiri Hill Ranges lie to the south, reaching an elevation of 300 m above mean sea level. Most of the area exhibits an even topography.

HYDROGEOLOGY

The chromite deposits form a part of the famous chromite bearing ultramafic complex of the Sukhinda valley. These ultramafics are highly metamorphosed and are Pre-Cambrian in age. The ultramafics appear to have been intruded into the quartzites and this layered laccolithic complex is composed of alternate bands of chromite, dunite, peridotite and orthopyroxenite, repeated in a rhythmic fashion. The ultramafics are extensively lateritized and limonitized. Numerous chert bands are also found within the ultramafics, which are often completely weathered to a mass of talc-limonite. The geology of the study area is shown in Figure 2. The stratigraphy of the areas is

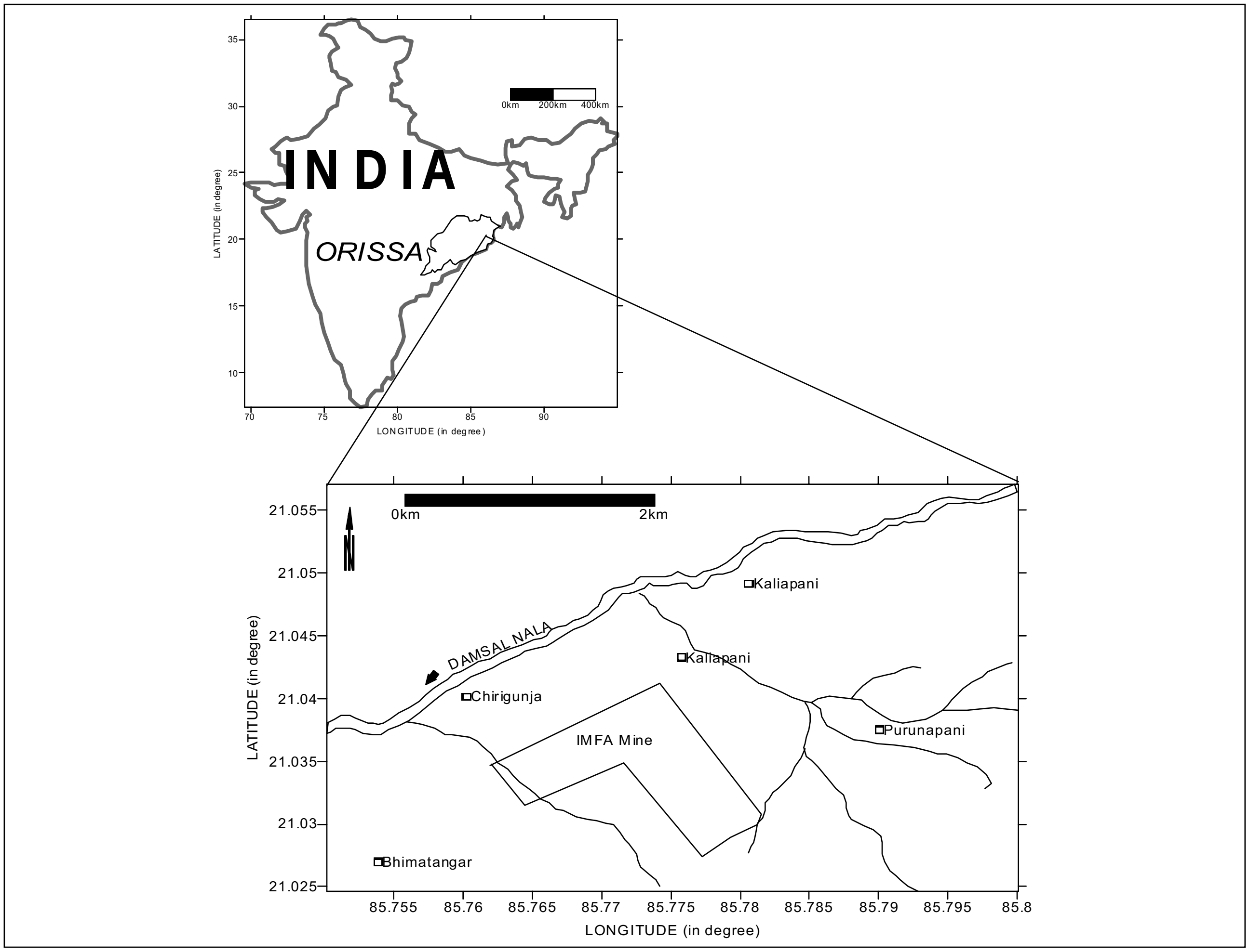

Figure 1. Location map of the study area.

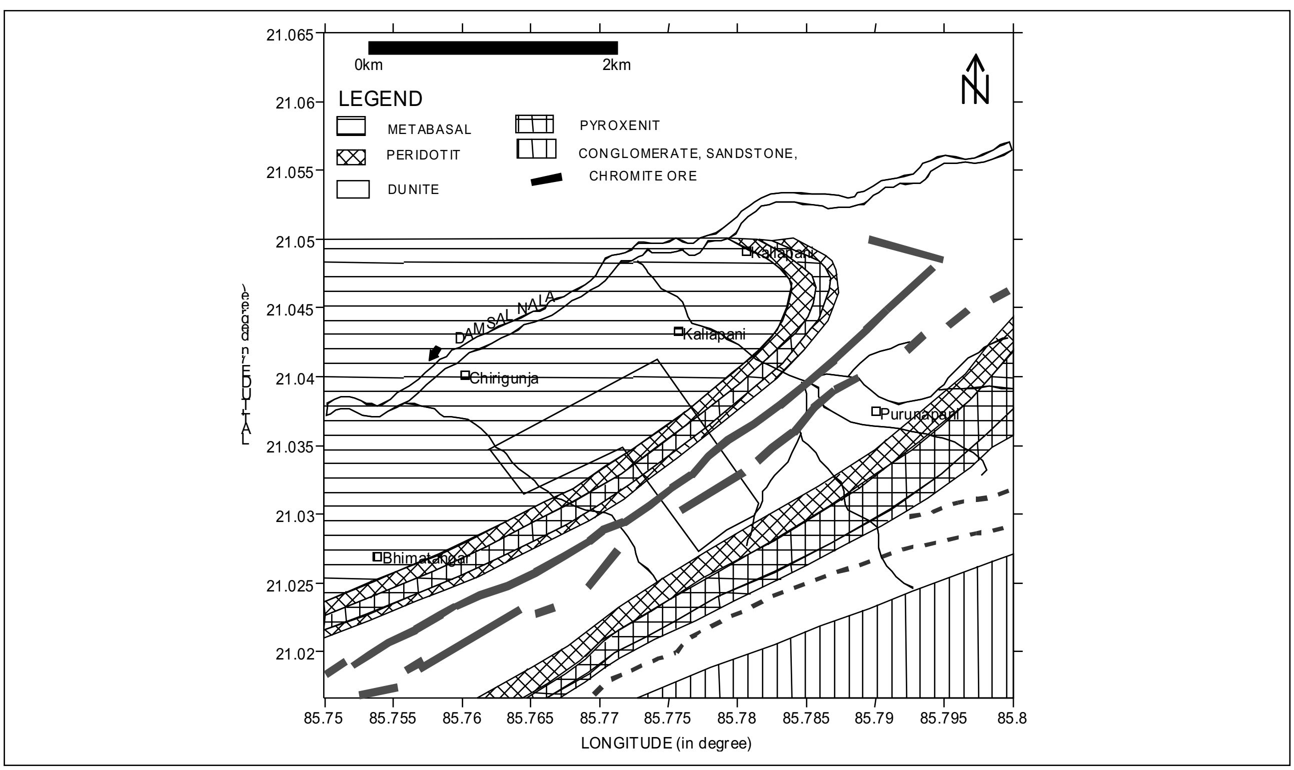

Figure 2. Geological map of the study area.

as follows:

Recent to Pleistocene			Soil, Alluvium laterite
---------------------------------------	Unconformity	---------------------------------------	
		Dolerite	
		Granite	
Precambrian	Ultramafic	Gabbro-diorite	
		Pyroxenite	
		Dunite	
		Peridotite with Chrome ore	
	Meta-sediments and	Gritty-quartzite	
	Meta-volcanics	Meta-volcanics	
---------------------------------------	Base not seen	---------------------------------------	

The weathered lateritized-limonite mantle, ultramafics, orthopyroxenite as well as the underlying semi-weathered and fractured country rocks are the source of groundwater in the area. The groundwater generally occurs under phreatic conditions and occasionally under semi-confined to confined conditions in the deeper aquifers.

GEOELECTRICAL INVESTIGATION

The most popular method used for groundwater exploration is Vertical Electrical Sounding (VES). To determine the aquifer geometry and groundwater quality, 27 VES with a maximum half current electrode separation of 100 m have been carried out. A complete inventory of 22 bore and dug wells was carried out in an area around Kaliapani, Sukhinda Valley, Orissa. The results are shown in Table 1. Some of the VES are carried out near the bore well or in very close proximity to it. Schlumberger configurations were used to for the geoelectrical soundings. The geophysical data were interpreted using an inverse model to determine the layers and their geoelectrical parameters. The location of these soundings and the inventoried wells used for correlation are shown in Figure 3, and the interpreted sounding curves for four VES are shown in Figure 4. In the

Table 1. Wells in the Sukinda Mines Study Area

Sl. No.	Location	Total Depth	Static Water Level (m)	Electrical Conductivity (μmhos/cm)
1.	Chirgunia	47.0	11.0	150
2.	Bhimtangar	45.0	6.80	290
3.	Bhimtangar	7.62	3.85	100
4.	Kalrangi	10.66	3.75	150
5.	Kaliapani	73.15	13.30	490
6.	Chinguripal	92.96	14.25	110
7.	Gurujanga	53.34	20.70	50
8.	Tisco market	76.20	11.0	360
9.	Kaliapani Near Temple	76.20	7.75	260
10.	Puranapani	25.0	3.20	400
11.	Kaliapani Near School	60.96	6.75	250

LOCATIONS OF WELL INVENTORY WELLS IN SUKINDA MINES AREA

Table. 1 (Cont.) Wells in the Sukinda Mines Study Area

12.	Chirgunia	50.0	13.15	150
13.	Kaliapani IMFA Campus	56.5	6.10	200
14.	Kaliapano IMFA Campus	54.86	7.95	200
15.	Kulipasi	25.0	3.08	130
16.	Kaliapani Near Temple	30.0	3.25	150
17.	Kaliapani Near Hanuman Temple	36.57	5.77	240
18.	Kaliapani Near majdoor Union Office	24.38	2.30	200
19.	Kaliapani Opp. IMFA dump site	30.0	7.45	100
20.	Kaliapani	12.40	6.22	210
21.	Kaliapani Near Matarani Temple	45.72	11.79	160
22.	Tata Mines Near Gupta Huting	30.0	6.37	200

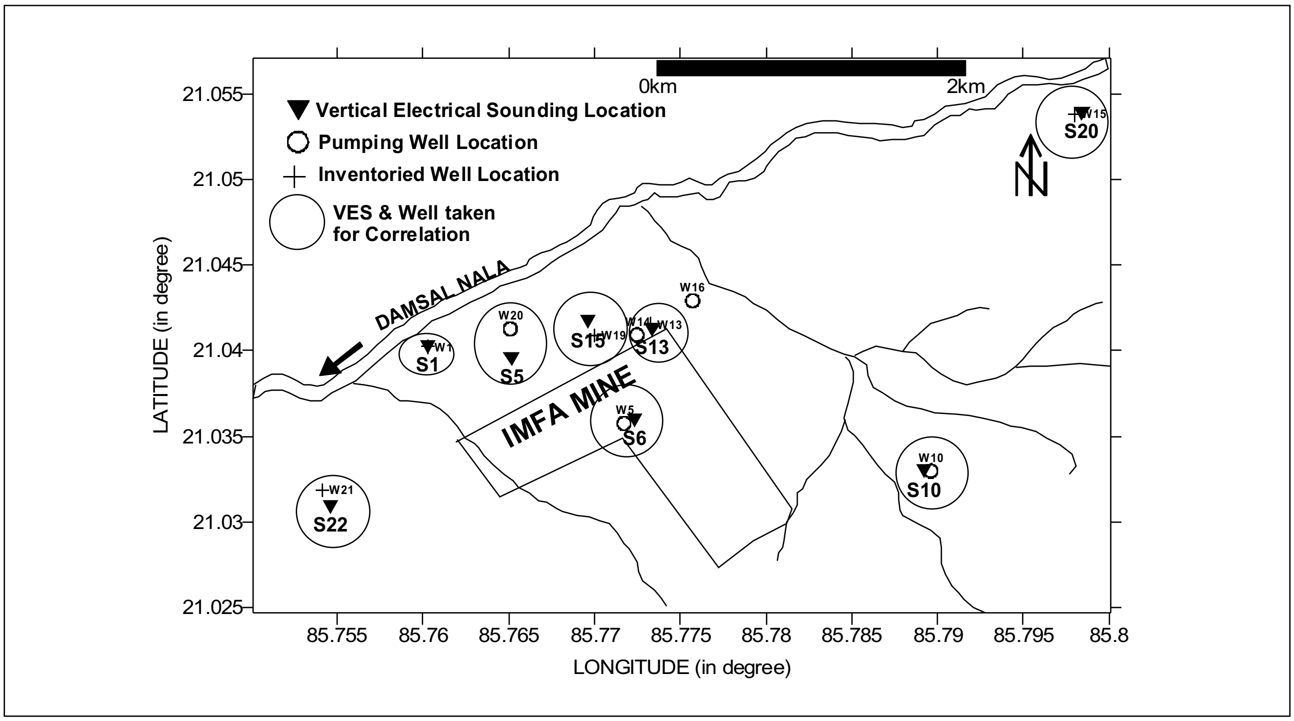

Figure 3. Location of pumping wells

cases of VES S1 and S13, were the aquifer layer is the last layer, the actual depth of the bore wells were taken into consideration for calculating the layer thickness.

In the study area, the VES results show four to five subsurface layers obtained after conventional curve matching and applying the inversion iteration method. The interpreted results of these sounding curves are shown in Table 2. The resistivities of different subsurface layers in the study area encountered during investigation are interpreted as follows:

Clay	< 10 ohm-m
Sandy clay/Clayey sand/	
Clay and Kankar (Aquifer)	10 – 25 ohm-m
Weathered Dunite/Peridotite/	
Metabasalt/Pyroxenite (Aquifer)	> 25 – 160 ohm-m
Hard and massive bed rock	> 160 ohm-m

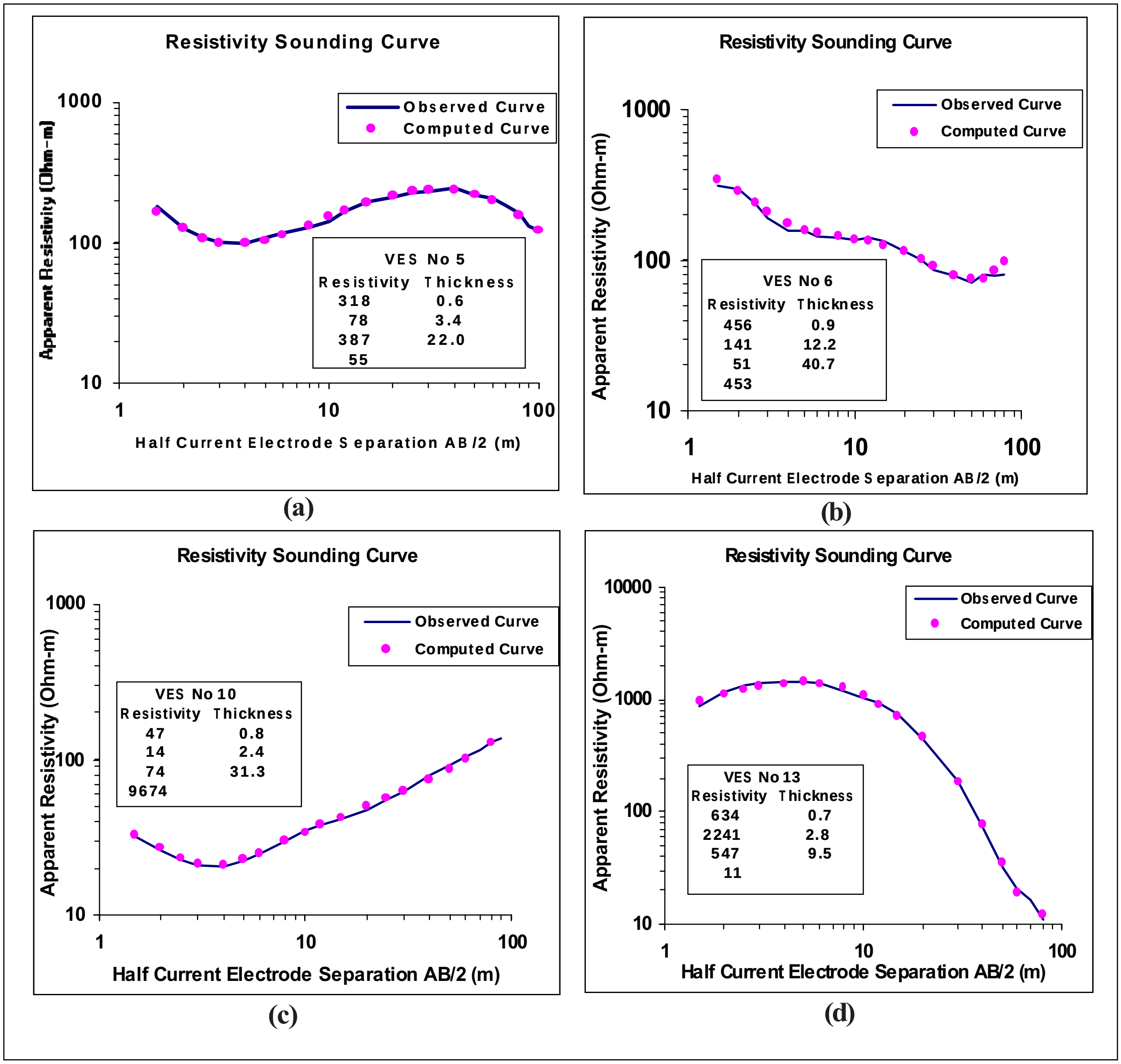

Figure 4. VES curves near the borewell/dugwell.

PUMPING TESTS

The most common in-situ test is the pumping test performed on wells, which involves the measurement of the rise and fall of water level with respect to time. The change in water level with time is then interpreted to arrive at aquifer parameters. The availability of an existing well makes the pumping test cost-effective.

In the study area, five wells were selected for pumping tests. The tests were performed using submersible pumps and observations in the same well. The pumping test data (both pumping and recovery) have been interpreted considering the field conditions to evaluate aquifer parameters. The location of these pumping wells is shown in Figure 3 and a summary of the tests is shown in Table 3.

CORRELATION OF GEOPHYSICAL AND AQUIFER PARAMETERS

Over the last few decades surface resistivity methods have been commonly used to obtain

Table 2. Details of Vertical Electrical Resistivity Sounding (VES) Layer Parameters

Sl. No.	Location	Layer Resistivity 'ρ' in ohm-m.					Layer Thickness 'h' in meters			
		ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4
1.	Chirgunia	214	1486	129	569	81	2.1	2.3	3.4	4.4
2.	Kaliapani (Near	562	2529	133	96	---	1.5	4.0	25.9	---
3.	Bhimtangar	320	1812	206	25	---	1.0	7.0	4.0	---
4.	Kalrangi	374	197	144	47	---	3.6	6.2	22.6	---
5.	Kaliapani	318	78	387	55	---	0.6	3.4	22.0	---
6	Sukinda Mines									
7.	Chinguripal Mine	561	190	2614	301	---	0.7	1.6	11.6	---
8.	Gurjanga (Near A									----
9.	TISCO Old	93	2226	156	51	---	0.8	5.0	21.9	---
10.	Puranapani	47	14	74	9674	---	0.8	2.4	31.3	---
11.	IMFA Magazine									
12.	IFMA Mine	567	398	6344	62	5009	1.3	2.5	15.0	14.
13.	IMFA Office	634	2241	547	11	---	0.7	2.8	9.5	---
14.	Kaliapani (Near A									
15.	Kaliapani	407	1610	40	---	---	1.5	10.5	---	---
16.	Kaliapani (OMC)	16	6.0	38	9920	---	0.9	4.3	30.4	---
17.	Ostia	544	286	2303	537	204	0.8	1.0	10.6	31.
18.	Puranapani	181	114	12	10060	---	1.0	6.1	20.1	---
19.	Kaliapani	10	155	649	205	---	1.5	10.2	32.6	---
20.	Kaliapani (Near	364	113	42	9998	---	1.8	28.5	42.1	---
21.	Kaliapani (Near	336	652	126	240	---	0.8	1.8	20.2	---
22.	Kaliapani (Near									
23.	Mahagiri Mines	130	314	9.0	10434	---	1.0	1.8	11.1	---
24.	Mahagiri mines	32	11	60	23	1021	1.0	14.1	11.8	11.
25.	ISPAT Magazine	265	27.0	119	---	---	0.6	5.0	---	---
26	ISPAT Magazine	15	13.0	65	9996	---	1.6	1.4	58.0	---
27.	JINDAL Mine	343	115	468	52	---	0.7	1.4	4.9	---

aquifer properties including hydraulic conductivity and transmissivity. Ungemach et al. (1969) correlated transmissivities with transverse resistance. Worthington (1975) showed an inverse relation between formation factor and intergranular permeability. Kelly (1977) and Kosonski and Kelly (1981) correlated aquifer resistivities and hydraulic conductivity obtained from pumping test results in Rhode Island, USA. Heigold et al. (1979) found an inverse relationship between aquifer resistivity and hydraulic conductivity in Central Illinois, USA. Sri Niwas and Singhal (1981) in their analysis of the data presented by Kelly (1977) concluded the relations between transverse resistance and transmissivity are more meaningful in alluvial aquifers than relations

Table 3. Summary of Pumping Tests

Sl. No.	Well No.	Pumping period (min)	Drawdown (m)	Recovery time (min)	Discharge (m^3 /d)	Transmissivity (m^2 /d)	Storativity
1	5	60	1.998	471	6.2-8.9	4	0.007
2	10	100	0.616	70	25.27	80	0.0001
3	14	100	3.195	119	27.87	16	0.00004
4	16	60	0.646	70	19.8-35.2	60	0.04
5	20*	90	0.86	1158	37.78	0.25	0.0005

* dug well

between longitudinal conductance and transmissivity. Sri Niwas and Singhal (1985) gave case studies for alluvial aquifers in varying geological environments of northern India by establishing relations to these parameters. Frohlich and Kelly (1985) and Huntley (1986) confirmed the applicability of relations between apparent formation factor and hydraulic conductivity for granular aquifers and transverse resistance and hydraulic conductivity in glacial aquifers in different parts of the USA. Shakeel et al. (1988) used the method of cokriging to estimate the transmissivity from measurements of specific capacity and electrical transverse resistance. In recent years, Hubbard et al. (2000) stated that hydraulic conductivity over a wide range of scales is helpful for numerical modeling to understand the hydraulic nature of the aquifer and to predict contaminant transport. de Lima and Sri Niwas (2000) have estimated these parameters for shaly sandstone aquifers by using IP-resistivity measurements and they conclude that the field and calculated values are in agreement.

Dar-Zarrouk Parameters

The Dar-Zarrouk parameters Longitudinal Unit Conductance (S) and Transverse Unit Resistance (T_R) are calculated for interpreted sounding layer parameters after taking into account only aquifer resistivities and its thicknesses.

$$S = h/\rho \qquad \text{and} \qquad T_R = \rho * h \tag{1}$$

where h is the thickness of the aquifer (m) and ρ is the resistivity of the aquifer (ohm-m).

Formation Factor

The value of formation factor (FF) is calculated using the aquifer resistivity (ρ) estimated from VES and water resistivity of the formation (ρ_w) measured during the field investigation using the well known Archie's law (Archie, 1942).

$$FF = \rho/\rho_w \tag{2}$$

where ρ_w = resistivity of water.

The water resistivity is calculated by using the equation

$$\rho_w = 10{,}000/\text{electrical conductivity of water}$$

In order to determine the aquifer properties of the area, five pumping tests of short duration were carried out. These sites are shown in Figure 3. From these tests, sites are selected where VES are carried out. The hydraulic conductivity was estimated using the well-known equation.

$$T = K\,h \tag{3}$$

where T = transmissivity K = hydraulic conductivity and h = aquifer thickness

Using the calculated hydraulic conductivity (K) and formation factor (FF) a relationship was established

$$K = \mathrm{A}\, FF^{\mathrm{m}} \tag{4}$$

where A= 0.2809 and m = 0.3924 are empirically derived constants. Using this equation the K values for remaining points where calculated and plotted against FF, shown in Figure 5. This Figure shows a linear relationship $K = 0.069\ FF + 0.1989$ with $R^2 = 0.9172$ and correlation coefficient

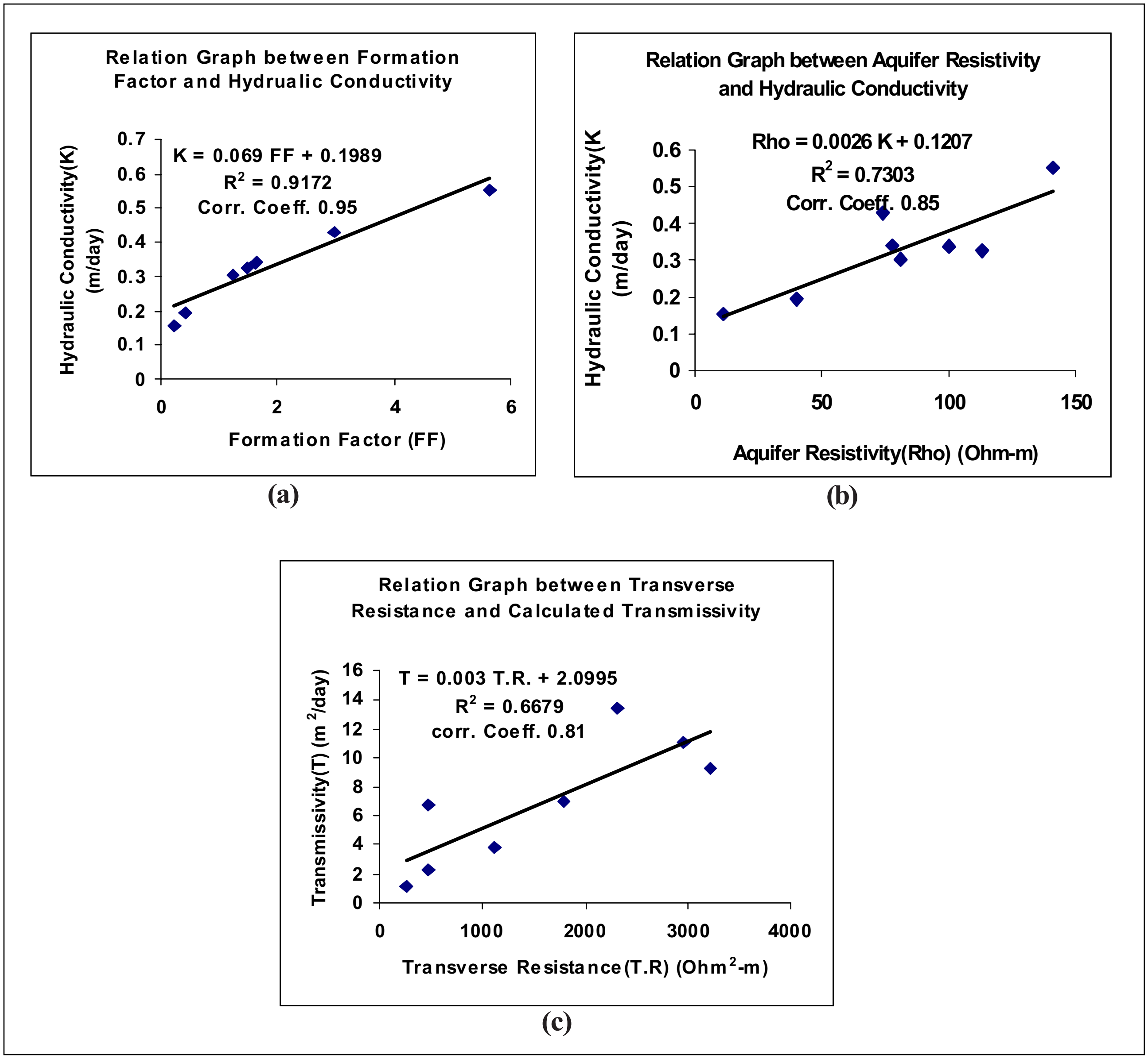

Figure 5. Showing VES curves near the borewell/dugwell.

(a): Relation between Formation Factor and Hydraulic Conductivity

(b): Relation between Aquifer Resistivity and Hydraulic Conductivity

(c): Relation between Transverse Resistance and Transmissivity

Table 4. Parameters Calculated from VES

	Aquifer Resistivity (Ohm-m)	Aquifer Thickness (m)	Electrical Conductivity (μmhos/cm)	Resistivity of water (Ohm-m)	Formation Factor (FF)	Longitudinal Unit Conductance (mhos)	Transverse Resistance (Ohm^2-m)	Aquifer Conductivity (mhos)
S1/W1	128	32.6	150	66.66	1.92	0.254	4173	0.0078
S6/W5	141	12.7	400	25	5.64	0.090	1791	0.0070
S13/W13	31	43.46	280	35.71	0.86	1.401	1347	0.0322
S13/W14	31	43.46	200	50	0.62	1.401	1347	0.0322
S15/W19	65	11.8	100	100	0.65	0.181	767	0.0153
S20/W15	113	23.2	130	76.92	1.46	0.205	2622	0.0088
S5/W20	74	4	210	47.61	1.55	0.054	296	0.0135
S10/W10	74	31.3	200	50	5.64	0.422	2316	0.0135
S22/W21	100	11.2	160	62.50	2.96	0.112	1120	0.0100

0.95. The calculated K values are shown in Table 4.

Relation between aquifer resistivity and Hydraulic Conductivity

The relation obtained between modified aquifer resistivity and hydraulic conductivity is shown in Figure 5. The fit has $R^2 = 0.7303$ and correlation coefficient 0.85.

$$\rho = 0.0026\,K + 0.1207 \tag{5}$$

where K is the hydraulic conductivity and ρ is the aquifer resistivity.

Relation between Transverse Resistance and Transmissivity

The transmissivity of the study area is calculated using the equation

$$T = K\ T_R\ S \tag{6}$$

where S is the longitudinal unit conductance and T_R is the transverse resistance. The relation between transmissivity and transverse resistance is shown in Figure 5. The fit has $R^2 = 0.6679$ and correlation coefficient 0.81**.**

$$T = 0.003\ T_R + 2.0995 \tag{7}$$

The calculated values of hydraulic conductivity and transmissivity along with other parameters are shown in Table 5.

Table 5. Calculated Transmissivity from Vertical Electrical Sounding (VES)

	Modified Longitudinal Unit Conductance (mhos)	Modified Transverse Resistance (Ohm^2-m)	Modified Aquifer Conductivit y (mhos)	Modified Aquifer Resistivity (Ohm-m)	Calculated Hydraulic Conductivity (m/day)	Calculated Transmissivity (m^2/day)	Observed Transmissivity (m^2/day)
S1/W1	0.2970	4868	0.0091	109.7	0.3616	11.79	
S6/W5	0.0394	783	0.0031	322.3	0.5520	7.01	4.0
S13/W13	0.8761	842	0.0201	49.6	0.2648	11.51	
S13/W14	1.2265	1179	0.0282	35.4	0.2321	10.08	16.0
S15/W19	0.3176	1342	0.0269	37.1	0.2364	2.79	
S20/W15	0.2763	3529	0.0119	83.9	0.3256	7.55	
S5/W20	0.0450	247	0.0112	88.8	0.3328	1.33	0.25
S10/W10	0.3700	2026	0.0118	84.5	0.5520	17.27	80.0
S22/W21	0.1224	1225	0.0109	91.4	0.4286	4.80	

CONCLUSIONS

Based on the results, VES is not only used for groundwater exploration or delineation of aquifer geometry, but it can also be used to estimate other hydraulic parameters like hydraulic conductivity and transmissivity. VES can be used not only for qualitative estimation, but also for quantitative estimates of aquifer parameters, which reduces the additional expenditures of carrying out pumping tests and offers an alternate approach for estimating the hydraulic properties. The transmissivity in metabasaltic formations shows a wide range due to different degrees of weathering and metamorphism at different depths. Based on these calculated values of hydraulic conductivity, a map has been prepared which is very useful for further studies of the groundwater regime in the area. The map can also be used to derive input parameters for contaminant migration modeling and to improve the quality of model. The calculated aquifer parameters are well within the range of observed aquifer parameters.

ACKNOWLEDGMENT

Authors are thankful to Dr. V.P. Dimri, Director, NGRI for his permission to publish this paper. Also, thanks are due to Mr. P.T. Varghese for preparation of this manuscript.

REFERENCES

Archie, G.E. 1942. The electrical resistivity log as an aid in determining some reservoir characteristics. Amer. Inst. Min. Met. Eng., Tech. Pub. 1422, Petroleum Technology, 8 p.

de Lima, O.A.L., and S. Niwas. 2000. Estimation of hydraulic parameters of shaly sandstone aquifers from geological measurements. Journal of Hydrology, vol.235, p. 12-26.

Frohlich, R., and W.E. Kelly. 1985. The relation between transmissivity and transverse resistance in a complicated aquifer of glacial outwash deposits. Journal of Hydrology, vol.79, p. 215-219.

Heigold, P.C., R.H. Gilkson, K. Cartwright, and P.C. Reed.1979. Aquifer transmissivity from surficial electrical methods. Groundwater, vol.17, p. 338-345.

Huntley, D. 1986. Relation between permeability and electrical resistivity in a granular aquifer. Groundwater, vol 24, p. 466-475.

Jupp, D.L.B., and K. Vozoff. 1975. Stable iterative methods for inversion of geophysical data: Geophysics. J. RAS, 4 (Implemented by T. Harinarayana on VA 11/750 at NGRI).

Kelly, W.E. 1977. Geoelectric sounding for estimating hydraulic conductivity. Groundwater, vol.15, p. 420-425.

Kosinki, W.K., and W.E. Kelly. 1981. Geoelectric soundings for predicting aquifer properties. Groundwater, vol.19, p.163-171.

Niwas, S., and D.C. Singhal. 1981. Estimation of aquifer transmissivity from Dar-Zarrouk parameters in porous media. Journal of Hydrology, vol.50, p. 393-399.

Niwas, S., and D.C. Singhal. 1985. Aquifer transmissivity of porous media from resistivity data. Journal of Hydrology, vol.82, p. 143-153.

Orellana, E., and H.M. Mooney. 1966. Master tables and curves for vertical electrical soundings over layered structures: Madrid Interciencia, 150 p, 66 tables.

Shakeel, A., G. De Marsily, and T. Alain. 1988. Combined use of hydraulic and electrical properties of an aquifer in a geo statistical estimation of transmissivity. Groundwater, vol.26(1), p. 78-86.

Singh, V.S., B.A., Prakash, R. Dhakate, V. Krishnan, and S.C. Jain. 2003. Estimation of aquifer parameters in chromite mine area, Kaliapani (Jajpur Dist), Orissa, India, NGRI Tech Rept. No. NGRI-2003-GW-368, p. 1-20.

Susan, H.S., and Y. Rubin. 2002. Hydrogeological parameter estimation using geophysical data: A review of selected techniques. Journal of Contaminant Hydrology, vol.45, p. 3-34.

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

ADDRESS FOR CORRESPONDENCE
Ratnakar Dhakate
Groundwater Division
National Geophysical Research Institute
Uppal Road
Hyderabad 500 007 (A.P.)
India

E-mail: dhakate_ratnakar@yahoo.com