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ESTIMATION OF HYDRAULIC PARAMETERS FROM SURFACE GEOPHYSICAL METHODS

Vijay A[1] Hari Prasath R[2],Prakash K[3]

Asst.Professor, Department of Civil engineering Panimalar Engineering College Chennai, India [1].
Student scholar Department of Civil engineering Panimalar Engineering College Chennai, India [2]
Student scholar Department of Civil engineering Panimalar Engineering College Chennai, India [3]

ABSTRACT: *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..*

Keywords- aquifier, groundwater, geophysical method

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

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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 as follows:

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 and the interpreted sounding curves for four VES.

Table 1. Wells in the Sukinda Mines Study Area

Sl. N	Location	Total Depth	Static Water Level (m)	Electrical Conductivit
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
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	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

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

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.

CORRELATION OF GEOPHYSICAL AND AQUIFER PARAMETERS

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

	Location	Layer Resistivity ‘r’ in ohm-m.					Layer Thickness ‘h’ in meters			
		r_1	r_2	r_3	r_4	r_5	h_1	h_2	h_3	h_4
1.	Chirgunia	214	148	129	569	81	2.1	2.3	3.4	4.
2.	Kaliapani (Near	562	252	133	96	---	1.5	4.0	25.9	--
3.	Bhimtangar	320	181	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	561	190	261	301	---	0.7	1.6	11.6	--
8.	Gurjanga (Near									--
9.	TISCO Old	93	222	156	51	---	0.8	5.0	21.9	--
1	Puranapani	47	14	74	967	---	0.8	2.4	31.3	--
1	IMFA Magazine									
1	IFMA Mine	567	398	634	62	500	1.3	2.5	15.0	1
1	IMFA Office	634	224	547	11	---	0.7	2.8	9.5	--
1	Kaliapani (Near									
1	Kaliapani	407	161	40	---	---	1.5	10.5	---	--
1	Kaliapani	16	6.0	38	992	---	0.9	4.3	30.4	--
1	Ostia	544	286	230	537	204	0.8	1.0	10.6	3
1	Puranapani	181	114	12	100	---	1.0	6.1	20.1	--
1	Kaliapani	10	155	649	205	---	1.5	10.2	32.6	--
2	Kaliapani (Near	364	113	42	999	---	1.8	28.5	42.1	--
2	Kaliapani (Near	336	652	126	240	---	0.8	1.8	20.2	--
2	Kaliapani (Near									
2	Mahagiri Mines	130	314	9.0	104	---	1.0	1.8	11.1	--
2	Mahagiri mines	32	11	60	23	102	1.0	14.1	11.8	1
2	ISPAT	265	27.0	119	---	---	0.6	5.0	---	--
2	ISPAT	15	13.0	65	999	---	1.6	1.4	58.0	--
2	JINDAL Mine	343	115	468	52	---	0.7	1.4	4.9	--

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

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

Sl. No.	W No	Pumpi g	Drawdow (m)	Recovery time (min)	Discharge (m^3/d)	Transmissivit (m^2/d)	Storativit
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

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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/〉 and T_R = 〉 * h

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

Formation Factor:

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

FF =□□/□w

where□□w = resistivity 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.

$$T = Kh$$

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

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

$$K = A\,FF^m$$

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 againstFF, shown in Figure 5. This Figure shows a linear relationship K = 0.069 FF+ 0.1989 with R^2 = 0.9172 and correlation coefficient

CONCLUSION AND FUTUREWORK:

Based on the results, VES is not only used for groundwater exploration or delineation of aquifergeometry, 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.

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BIOGRAPHY:

a) Prakash K, Final year in Civil Engineering, Panimalar Engineering College
b) Hari Prasath R, Final year in Civil Engineering, Panimalar Engineering College