IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

APPLICATION OF RESISTIVITY METHOD TO CONFIRM AQUIFER CONDITIONS NEAR RECHARGE STRUCTURES IN DIFFERENT GEOLOGICAL SETUP

[1]Shripad P Tohare,[2]Ketki A Jadhav

[1]Junior Geologist,[2]Assistant Geologist

[1]Groundwater Surveys and Development Agency,

Amravati, State- Maharashtra, India.

ABSTRACT

In recent years there has been considerable advancement in the scientific methods of groundwater investigations. Ground water is regarded more like a mineral resource and therefore prospecting for it involves use of geological and geophysical methods. Hence for locating and identifying presence of water bearing formations, applications of geophysical methods is widely recognized. The vertical electrical sounding with Schlumberger array as a low cost technique and veritable tool in groundwater exploration is more suitable for hydrological survey. This method is regularly used to solve wide variety of groundwater problems.

INTRODUCTION

Although various geophysical techniques are currently being applied to explore and assess water resources, the direct-current (DC) electrical resistivity method still proves the most powerful and cost-effective technique in groundwater studies (Jupp and Vozoff 1975; Koefoed 1979; Rubin and Hubbard 2005). This is due to the close relationship between the electrical conductivity and some hydrogeological properties of the aquifer.

Number of researchers successfully used the electrical resistivity methods for groundwater prospecting in various terrains (Zohdy et al. 1974; Stewart et al., 1986; Prakash et al. 1993; Ballukraya, 2001; Ayolabi, 2005; Rai et al. 2005, Idornigie et al. 2006; Shrivastava and Bhattacharya 2006; Das et al. 2007) and clearly bring out the relationship between electrical and hydraulic properties of the aquifer. Application of the geoelectrical method has led researchers to develop surface resistivity techniques for making quantitative estimates of the water transmitting properties of aquifers (Griffith 1976; Louis et al. 2004). The investigation of the spatial distribution of aquifer properties from geophysical measurements has received great interest over the past two decades (e.g. Allen et al. 1997; Lesmes and Friedman 2005; Singh 2005; Shevnin et al. 2006; Ekwe et al. 2006; Soupios et al. 2007). Rock resistivity depends on number of factors such as the amount of water present in fracture, weathering, porosity, fracturing and the degree of saturation (Yusuf et al. 2011).

In some recent study geophysical approach has been used for artificial recharge of groundwater (Sundararajan et al., 2007, Sable et al., 2009, Arabi et al., 2010, Raimi et al., 2010; Raimi et al., 2011), for determination of zones with high potential (Nejad, 2009, Ahilan and Kumar, 2011; George et al., 2011; Joshua et al., 2011), determination of boundary between saline and fresh water zones (Sikandar et al., 2010; Hodlur et al., 2010; Adeoti et al., 2010), delineation groundwater contamination (Enikanselu, 2008, Ugwu and Nwosu, 2009, Abdullahi et al., 2011), groundwater exploration in hard rock (Yadav and Singh,2007, Armada et al.,2009, Nejad et al., 2011; Nwankwo, 2011; K'orowe et al., 2011;), determination of aquifer parameters (Singh K.P., 2005; Ekwe et al., 2006 , Soupios et al., 2007; Massoud et al., 2010; Tizro et al., 2010 and others) .

LOCATION OF STUDY AREA

Two types of recharge structures i.e. percolation tanks and kolhapur type weirs were selected from Basalt and Alluvium area in Amravati District, Maharashtra to evaluate their efficiencies in the aquifer conditions in different geophysical conditions. Amravati District is one of the eleven districts of Vidarbha region of Maharashtra. It is situated in the northern part of the State and lies between north latitudes 20°3 2' and 21°46' and east longitudes 76°37' and 78°27'. The total area of the district is 12210 sq. km. and falls in Survey of India degree sheets 55 G, 55 H, 55 K and 55 L. The district is bounded on the north by Madhya Pradesh State, on the east by Nagpur and Wardha districts, and on the south and south west by Yavatmal, Akola and Buldhana districts. Badnera and Amravati are nearest railway stations located at distance 20 km and 5 km respectively. Artificial recharge structures with their locations in Amravati district selected for present study are given in Table No.1.1 and Fig. No.1.1.

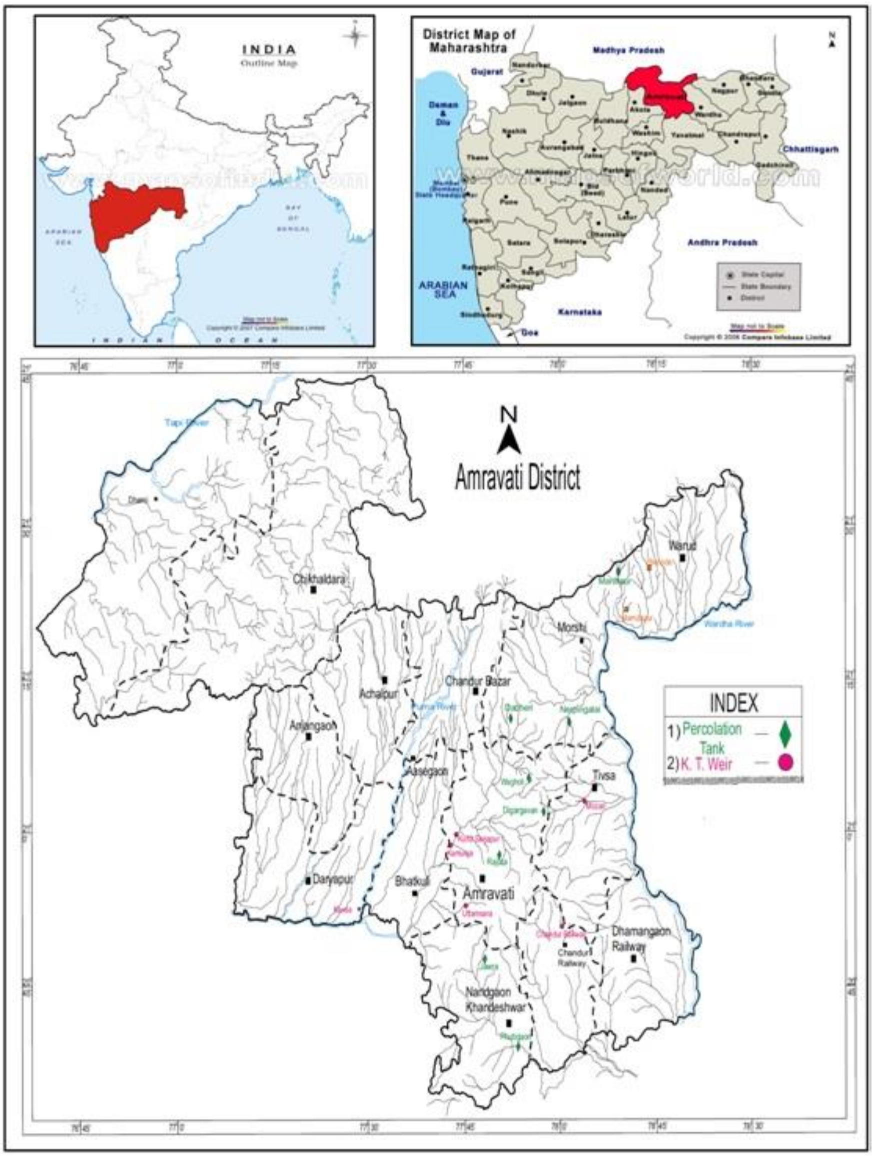


Fig.1. Location map of studay area

Table No. 1.1

Selected Artificial Recharge Structures

Sr. No.	Name of Structure	Location and Toposheet No.	Latitude - Longitude	Lithology
		Percolation Tank		
1	Rajura	Amravati, 55H/13	N21^{0}55'30''to21^{0}58' and E77^{0}48'to77^{0}50'	Deccan Trap
2	Nerpingalai	Morshi, 55G/16, 55K/4	N21^{0}10'30"to21^{0}12'30"and E77^{0}59'to78^{0}1'30''	Deccan Trap
3	Wagholi	Amravati, 55G/16	N21^{0}3'to21^{0}6'and E77^{0}52'15''to77^{0}55'	Deccan Trap
4	Digargavan	Amravati, 55G/16	N21^{0}2'to21^{0}4'15''and E77^{0}54'to77^{0}56'30''	Deccan Trap
5	Jawra	Nandgaon Khandeshwar, 55H/13	N20^{0}45'to20^{0}48'and E77^{0}45'to77^{0}48'	Deccan Trap
6	Phubgaon	Nandgaon Khandeshwar, 55H/14	N20^{0}37'to20^{0}40'and E77^{0}51'to77^{0}54'	Deccan Trap
7	Manikpur	Warud,55K/3	N21^{0}27'30''to21^0 29'30'' and E78^{0}08'to78^{0}09'30''	Deccan Trap
8	Dabheri	Chandur Bazar, 55G/16	N21^{0}12'to21^{0}14 and E77^{0}49'to77^{0}51'	Alluvium
		Kolhapuri type Weir		
9	Mozari	Tiosa, 55 K/4, 55 G/16	N21^{0}2'30''to21^{0}4'and E77^{0}59'to78^{0}1'30''	Deccan Trap
10	Chandur railway	Chandur Railway, 55H/13	N20^{0}48'to20^{0}50'and E77^{0}57'to77^{0}59'30''	Deccan Trap
11	Kavsa	Bhatkuli,55 H/9	N20^{0}51'to20^{0}53'30"and E77^{0}27'30"to77^0 30'	Deccan Trap
12	Uttamsara	Amravati, 55H/9	N20^{0}50'to20^{0}52'30'' andE77^{0}39'to77^{0}41'30"	Alluvium
13	Kund Sarjapur	Amravati, 55H/9	N20^{0}55'30''to20^{0}58' andE77^{0}39'30'' to77^{0}42'	Alluvium
14	Kamunja	Amravati, 55H/9	N20^{0}57'to21^{0}and E77^{0}40' to77^{0}43'	Alluvium

METHODOLOGY

In the present study an attempt has been made to confirm aquifer conditions near percolation tank and kolhapuri type weirs. The soundings were taken for upstream side and downstream side of recharge structure . The quantity and disposition of ground water depends on the geological characteristics of the host rock formation. The search for ground water is faced with lots of uncertainties; to minimize or avoid failures altogether, it is pertinent that the right exploration techniques are utilized in the delineation of subsurface water-bearing formations (Coker et al., 2009).The Schlumberger electrode configuration method used to delineate the groundwater potential aquifers (Coker, 2012).

ELECTRICAL RESISTIVITY METHOD

There are many geophysical methods which make use of physical properties of earth's materials. Amongst all the physical properties, it is the electrical resistivity that changes significantly from the barren to the water bearing rocks and hence electrical resistivity method is used as one of the most effective geophysical methods for groundwater investigation. In the present study an attempt has been made to investigate the efficiency of artificial recharge structure by using electrical resistivity method.

Electrical resistivity method makes use of the fact that different rocks have different electrical resistivities. By passing the current into the ground through two current electrodes and measuring potential difference at the potential electrodes on the ground, it is possible to obtain information about subsurface material through which the current is passing. With this the nature of the subsurface rocks and the depth at which the changes take place can usually be inferred. In homogeneous ground medium the deviations in the pattern of potential differences are used to provide information on the form and electrical properties of subsurface heterogeneities (Kearey and Brooks, 1988). In hydrogeological work, identification of aquifer zones, their depth from the surface, lateral extent and thickness, vertical properties of subsurface is possible by the resistivity method (Vaidya et al, 2002).

The electrical resistivity method can be best employed to estimate the thickness of overburden and also the thickness of weathered/fractured zones with reasonable accuracy. Though both Wenner and Schlumberger electrode configuration methods are popularly employed, the Schlumberger electrode configuration method is more suited to the study area, ensuring better results. The method has practical, operational and interpretational advantages over other methods such as the Wenner method of electrode arrangement (Zohdy et al., 1974).

Vertical Electrical Sounding (VES)

In this approach, the center of the configuration is kept fixed and the measurements are made by successively increasing electrode spacing. The apparent resistivity values obtained with increasing values of electrode separations are used to estimate the thicknesses and resistivities of the subsurface formations (Fig. No. 2).

Principle

The electrical resistivity is a physical property of a substance. It is defined as 'the resistance offered by a unit cube of a substance to the flow of electric current, when voltage is applied across the opposite faces'. The resistivity is expressed in ohm-m, and is given by Ohm's law, as:

$$\rho = RA/ L$$

Where,

ρ= Resistivity

R= Resistance offered by the unit cube of a substance of length 'L' and cross sectional area 'A'

The apparent resistivity depends on the electrode configuration and geometry of aquifer (Zohdy et al., 1974).

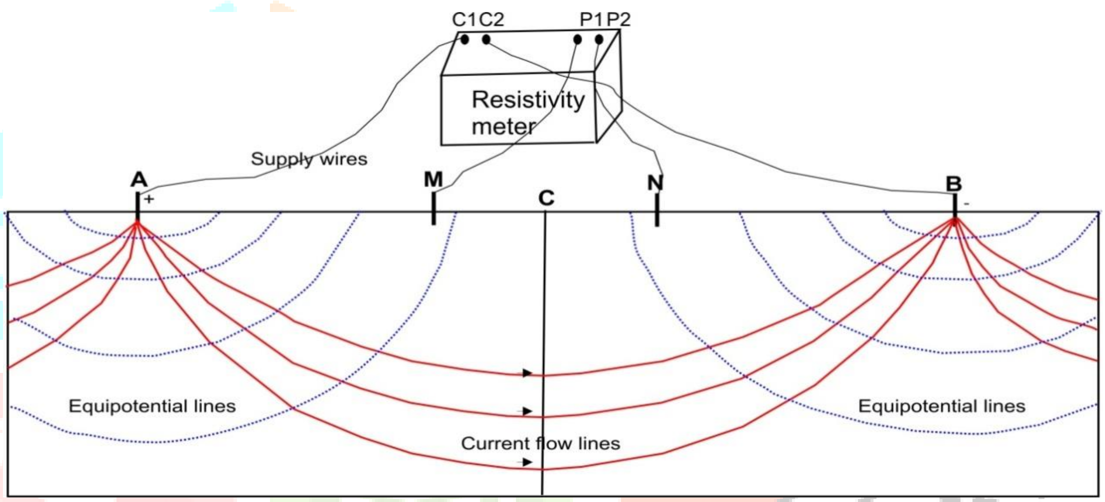


Fig.2

Schematic electrical circuit diagram for earth-measurements

Many configurations have been developed to conduct the electrical resistivity surveys, such as, Wenner (1915), Schlumberger (1920), Dipole-dipole (Al'pin, 1950), Pole-dipole (Yadav, 1988; Yadav et al., 1997). Of these, the Wenner and Schlumberger configurations are the most common. The Schlumberger system has certain practical, operational and interpretational advantages over Wenner method (Bhimasankaram et al., 1969; Zohdy et al., 1974).

In Schlumberger array, all four electrodes are placed in a line disposed symmetrically with respect to central point 'C'. The distance between the current electrodes (AB) is maintained equal to or more than five times the distance between potential electrodes (MN) (Fig.No.3) i.e. $AB/2 \geq 5\ MN/2$. The resistivity of rock formation is calculated on the basis of apparent resistivity values. The apparent resistivity values are obtain if the ground is inhomogeneous and the electrode spacing is varied or the spacing remains fixed while the whole array is moved then the ratio will in general change. This results in different value of resistivity for each measurement. This measured value is known as apparent resistivity. Apparent resistivity for the rock formation can be determined by using Schlumberger equation.

$$\text{Apparent Resistivity} = K \times V/ I$$

Where, $K = \text{constant} = \dfrac{\pi/4\ (AB/2)^2 - (MN/2)^2}{MN}$

Where, AB = Distance between two current electrodes

MN = Distance between two potential electrodes

Whereas, actual resistivity values are determined from apparent resistivity which are computed from measurement of current and potential difference between pairs of electrodes placed in the ground surface. The change of resistivity at a great depth has only a slight effect on the apparent resistivity compared to those at shallow depth.

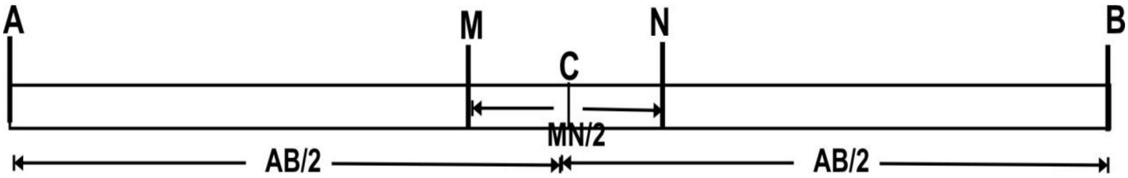


Fig.3

Electrode configuration of Schlumberger array

Thirty eight vertical electrical soundings (VES) using Schlumberger electrode configuration were conducted in the study area having a maximum current electrode spacing of 35 meters. The resistivity meter ANVIC CRM-500 was used for this survey work. At each location total three VES were taken on downstream (DS) and upstream (US) side so that the correlation can be made in terms of thickness, depth, and water bearing and transmitting capacity of the aquifers. The VES data curve was visually interpreted using curve matching technique of Orellana and Mooney (1966) and latter by computer aided software program of Zohdy (1965, 1974, 1989) and IPI_2win (Bobachev, 2003). While interpreting the sounding curve information from observation wells was incorporated. In an attempt to keep the earth model as simple as possible it was interpreted with four layer earth model. The average apparent resistivity's and true resistivities were determined and layered model developed for each artificial recharge structure. The values of resistance and apparent resistivity observed at different structures are presented in the Table No. 1 and 2 while their interpreted graphs presented in Fig.No.4 A and 4 B.

Eleven types of curve are obtained in percolation tanks, 'HA' type, 'HK' type, 'KHK' type, 'HKH' type, 'AK' type, 'KH' type, 'QQ' type, 'AHK' type, 'AKH' type, 'KHA' type, 'AAK' type, . In Kolhapuri type weirs eleven types of curves are obtained 'HA' type, 'HK' type, 'KHK' type, 'HKH' type, 'AK' type, 'KH' type, 'AKH' type, 'HKQ' type, 'H' type, 'QH' type, 'QHA' type.

The data was interpreted separately for Kolhapuri type weirs and percolations tanks. The first layer thickness for Kolhapuri type weirs varied from 0.14 m to 5.14m while for percolation tanks it varied from 0.13 to 1.53m with resistivity range of 2.15 to 36.9 for Kolhapuri type weirs and 6.22 to 102 for percolation tanks. In general high resistivity range was noted to percolation tanks as compared to Kolhapuri type weirs the second and third layer resistivity and thickness also show similar trend. This indicated that low resistivity first and second layer are more favorable for Kolhapuri type weirs as compared to percolation tanks. The detail analysis of resistivity interpreted with location and structure wise have been presented and analyzed in this chapter.

Table No.1

Interpreted Vertical Electrical sounding data in terms of Resistivity Models for Percolation tanks

S. N.	VES No.	Curve type	Resistivity in Ohm-m					Thickness in m.				Depth in m			
			ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	d_1	d_2	d_3	d_4
1	Wagholi US	QQ Type	28.3	19.1	5.09	2084	--	0.398	2.97	3.12	--	0.398	3.37	6.49	--
2	Wagholi US	HA Type	9.59	5.29	11.37	2504	--	0.72	2.24	7.36	--	0.72	2.96	10.31	--
3	Wagholi DS	HA Type	35.9	6.53	6.76	280	--	0.6	2.67	4.29	--	0.6	3.27	7.56	--
4	Rajura DS	AK type	40.95	81.27	132.3	18.67	--	1.53	1.29	4.21	--	1.53	2.82	7.03	--
5	Rajura US	KHK Type	46.5	74.9	43.2	1055	59.8	0.6	0.79	1.85	4.29	0.6	1.39	3.24	7.53
6	Rajura US	HK Type	57.6	13.6	3522	9.8	--	0.635	0.879	3.65	--	0.635	1.51	5.16	--
7	Jawara US	KHA Type	23.79	50.9	42.07	44.68	89.8	0.6	0.79	1.85	4.29	0.6	1.39	3.24	7.53
8	Jawara US	HKH Type	35.7	18.9	228	29.8	262	0.6	0.79	1.85	4.29	0.6	1.39	3.24	7.53
9	Jawara DS	KH Type	6.22	70.1	5.45	341	--	0.6	2.67	4.29	--	0.6	3.27	7.56	--
10	Digargavhan US	AK Type	14.4	18.9	1993	1.71	--	0.72	0.61	1.99	--	0.72	1.33	3.32	--
11	Digargavhan DS	AHK Type	51.5	29.2	16.6	1303	29.5	0.52	0.76	1.57	2.67	0.52	1.28	2.85	5.52
12	Digargavhan US	AKH Type	9.6	12.4	47	8.18	69.5	0.6	0.79	1.85	4.29	0.6	1.39	3.24	7.53
13	Dabheri US	KH-Type	24.6	2768	23.3	1075	--	1.16	1.78	6.8	--	1.16	2.94	9.74	--
14	Dabheri DS	HK-Type	30.2	12.5	1208	2.5	--	0.708	0.856	4.93	--	0.708	1.56	6.49	--
15	Dabheri US	AK-Type	29.1	90.3	2086	18.1	--	1.53	2.37	6.72	--	1.53	3.9	6.72	--
16	Nerpinglai US	HK-Ty	94.6	50.4	317	4.75	--	0.468	2.52	19.7	--	0.468	2.99	22.7	--
17	Nerpinglai DS	KHK-Type	102	194	73.4	787	10.1	1.4	1.85	4.29	9.97	1.4	3.25	7.54	17.5
18	Nerpinglai US	KH-Type	33.6	499	47.8	501	--	1.48	1.56	3.74	--	1.48	3.04	6.78	--

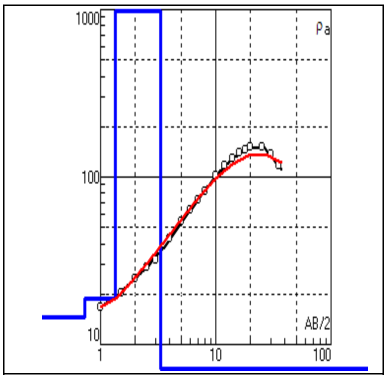
19	Phubgaon DS	HA-Type	9.09	1.55	19.4	1999	--	0.451	0.753	8.09	--	0.451	1.2	9.29	--
20	Phubgaon US	AAK-Type	35.8	64	285	662	251	0.136	3.41	3.61	8.08	0.136	3.55	7.16	15.2
21	Phubgaon US	KHK-Type	42.14	61.58	30.37	201.2	61.28	0.6	0.7944	1.846	4.29	0.6	1.394	3.24	7.53

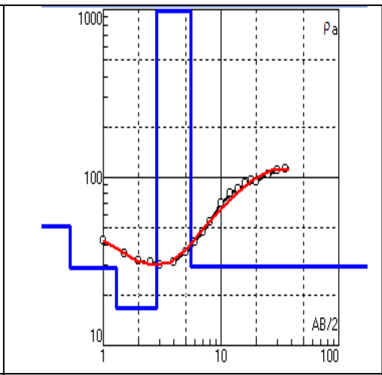
Table No. 2

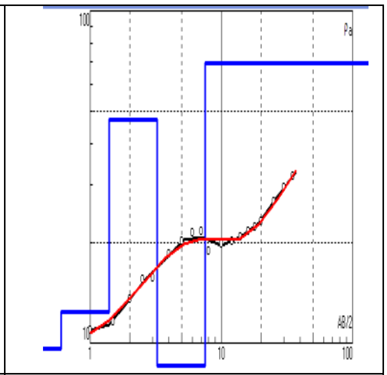
Interpreted Vertical Electrical sounding data in terms of Resistivity Models for Kolhapur type weirs

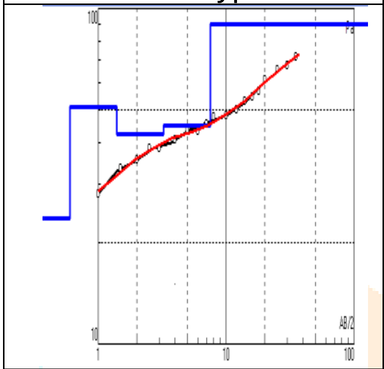
S. N.	VES No.	Curve type	Resistivity in Ohm-m					Thickness in m.				Depth in m			
			ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	d_1	d_2	d_3	d_4
1	Chandur Railway DS	HK-Type	16.9	5.96	1486	54.1	--	0.60	0.65	2.62	--	0.60	1.25	3.87	--
2	Chandur Railway US	HKQ-Type	13	7.09	64.9	21.1	0.45	0.55	0.76	1.89	17.7	0.55	1.32	3.21	20.9
3	Chandur Railway US	HKQ-Type	13.1	7.08	64.2	21.2	0.23	0.56	0.76	1.91	17.9	0.56	1.32	3.23	21.1
4	Kavasa DS	KHK-Type	9.03	30	1.41	6140	43.7	0.89	0.03	1.65	21.1	0.89	0.92	2.57	23.7
5	Kavasa US	HKH-Type	19.3	2.21	11.7	2	917	0.37	0.14	4.63	6.51	0.37	0.51	5.14	11.7
6	Kavasa US	AK-Type	6.08	20	303	1.21	--	5.14	0.61	5.86	--	5.14	5.75	11.6	--
7	Mojhri US	H-Type	15.6	8.97	93.04	--	--	1.19	9.33	--	--	1.19	10.52	--	--
8	Mojhri US	QH-type	36.9	12.5	2.33	46.2	--	0.52	3.35	4.05	--	0.52	3.87	7.92	--
9	Mojhri DS	KH-Type	8.58	16.78	4.13	93.82	--	1.19	1.88	4.16	--	1.19	3.07	7.23	--
10	Uttamsara US	HKH-Type	10.3	3.68	60.6	6.23	49.7	0.59	0.66	1.47	3.18	0.59	1.26	2.73	5.91
11	Uttamsara DS	AKH-Type	4.37	7.03	16.7	3.3	2634	0.15	1.84	1.42	3.31	0.15	1.99	3.41	6.72
12	Uttamsara US	HA-Type	2.15	0.56	88.8	1783	--	0.32	1.17	1.75	--	0.32	1.49	3.24	--
13	DS Kamunja	HKH-Type	59.2	16.5	100	0.67	202	1.19	0.89	2.87	3.24	1.19	2.08	4.95	8.19
14	Kamunja US	HKH-Type	11.8	9.93	34.5	4.88	4872	1.19	0.45	1.82	4.04	1.19	1.64	3.46	7.5
15	Kund DS	KHK-Type	16.7	98.7	1.63	11	0.08	0.25	0.73	1.87	10.2	0.25	0.98	2.85	13.1
16	Kamunja DS	KH-	6.62	13.3	3.93	8.08	--	0.51	0.19	6.28	--	0.51	0.7	6.98	--

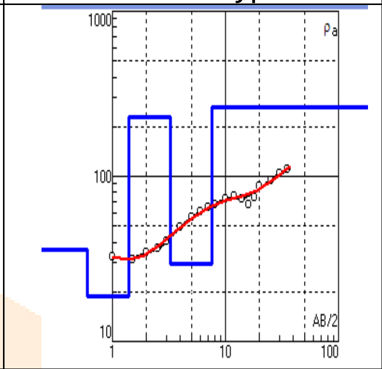
		Type													
16	Kund US	KH-Type	6.62	13.3	3.93	8.08	--	0.51	0.19	6.28	--	0.51	0.7	6.98	--
17	Kund DS	QHA-Type	6.3	3.58	0.998	3.22	518	0.85	0.56	0.89	12.5	0.85	1.41	2.3	14.8
16	Kund US	KH-Type	6.62	13.3	3.93	8.08	--	0.51	0.19	6.28	--	0.51	0.7	6.98	--

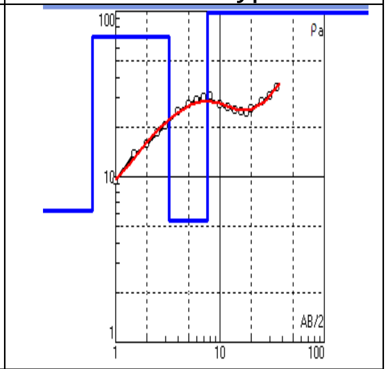

Digargavan US
AK-Type

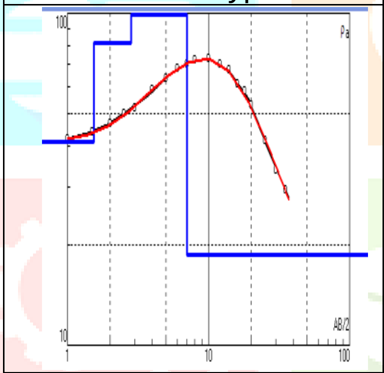

Digargavan US
AHK-Type

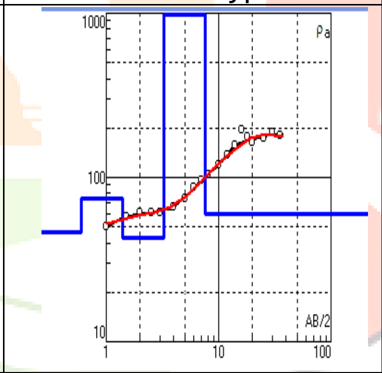

Digargavan DS
AHK-Type

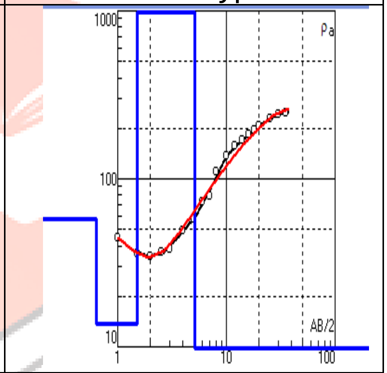

Jawra US
KHA-Type

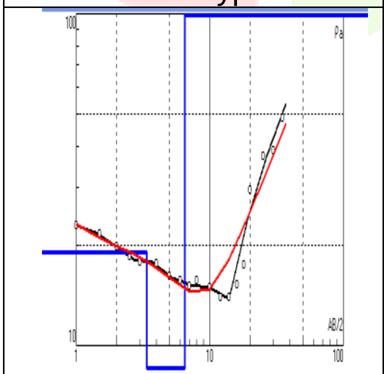

Jawra US
HKH-Type

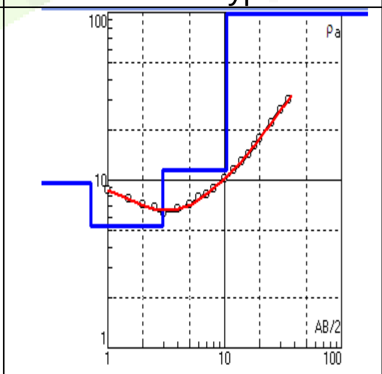

Jawra DS
KH-Type


Rajura DS
AK-Type


Rajura US
KHK-Type


Rajura US
HK-Type


Wagholi US
QQ-Type


Wagholi US
HA-Type

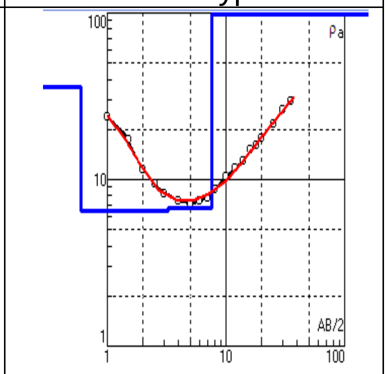

Wagholi DS
HA-Type

Fig. No. 1.3-A
Typical resistivity model curve of percolation tanks

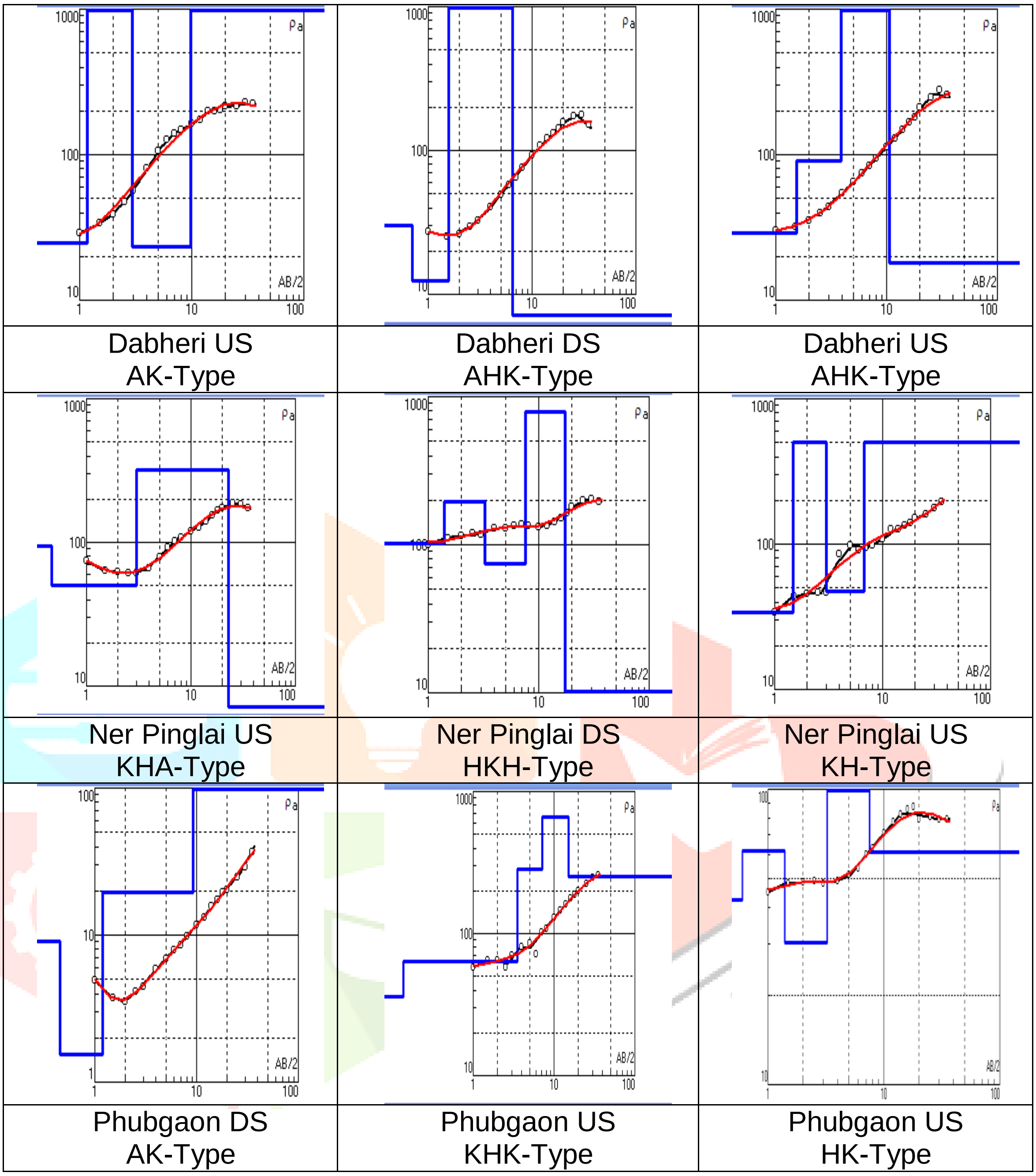


Fig. No. 1.3-B
Typical resistivity model curve of percolation tanks

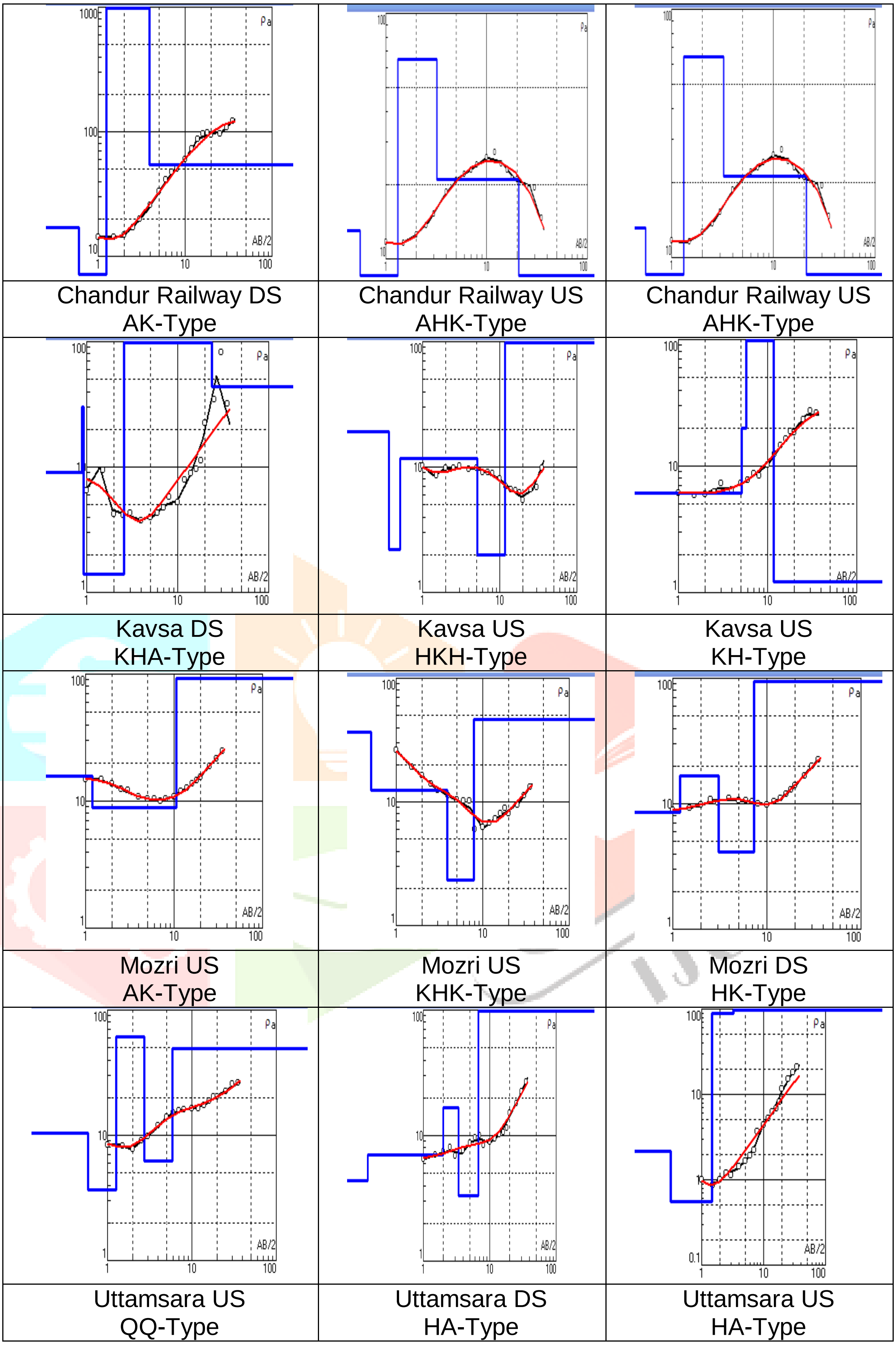


Fig. No. 1.4-A

Typical resistivity model curve of Kolhapur type weirs

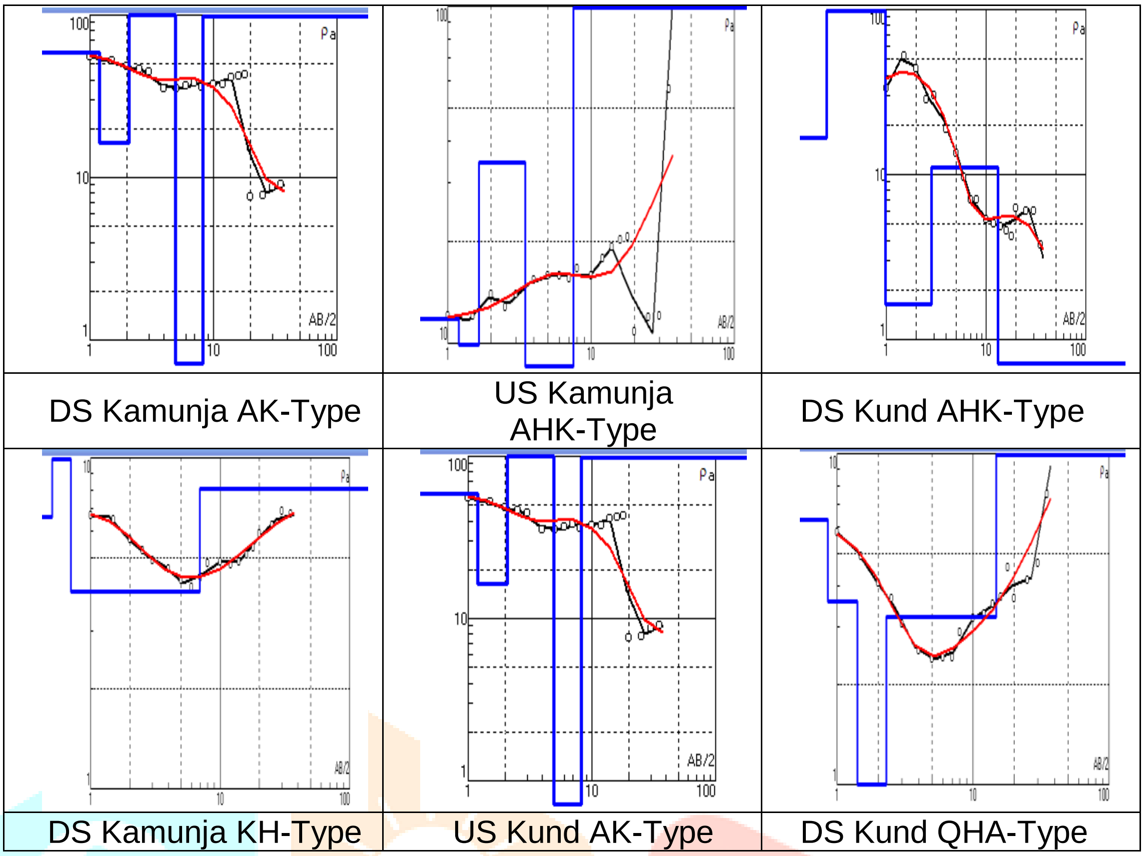


Fig. No. 1.4-B
Typical resistivity model curve of Kolhapur type weirs

RESULT AND DISSCUSSION

Replenishment of groundwater by artificial recharge of aquifers in the arid and semi-arid regions of India is essential as the intensity of normal rainfalls is grossly inadequate to produce any moisture surplus under normal infiltration conditions. The varied hydrogeologic conditions may prevent rapid infiltration into groundwater reservoir. Realizing this many artificial recharge projects have been undertaken up by central and state groundwater department, in an attempt to recharge the depleted aquifers by spending huge amounts. To make the expenditure viable and have the sustainable development, it is essential that the sites and structures should be planned on sound scientific basis.

Geophysical investigation can be interpreted appropriately, using the available geological information for defining the characteristics of sites for artificial recharge structures. It is inferred that though qualitative, the resistivity variations obtained from the resistivity sections provide a quick assessment regarding the geological setting and the aquifer conditions and also can pinpoint the ground water bearing formation. Hence, integrated study can provide useful information on sustainability of artificial recharge structures.

REFERENCES

[1]Abdullahi, N. K., Osazuwa, I. B. and Sule, P.O., (2011). Application of integrated geophysical technique in the investigation of groundwater contamination: A case study of Municipal solid waste leachate. Ozean J. Applied Sci., 4, pp. 7-25.
[2]Adeoti, L., Alile, O.M. and Uchegbulam, O., (2010). Geophysical Investigation of Saline Water Intrusion into Freshwater Aquifers: A Case Study of Oniru, Lagos State. Sci. Res. Essays, 5, pp. 248-259.
[3]Ahilan, J. and Kumar, G.R.S., (2011). Identification of Aquifer Zones by VES Method: A Case Study from Mangalore Block, Tamil Nadu, S. India. Arch. Applied Sci. Res., 3, pp. 414-421.
[4]Arabi, S. A., Raimi, J. and Dewu, B. B. M., (2010). A Geoelectric Survey for Determination of Suitable Sites for Construction of Tube-wells for the proposed Damari Irrigation Scheme in the North-Central Basement Complex, Nigeria. Online Journal of Earth Science, 4(3-4) 2010, pp. 106-110.
[5]Allukraya PN (2001) Hydrogeophysical investigations in Namagiripettai area, Namakakkal District, Tamil Nadu.Jour.Geol.Soc.of India 58: 239- 249
[6]Bhimasankaram, V.L.S., Murali, S. and Tharkar, A.G., (1969). A comparative study of the Wenner and Schlumberger configurations in the Electrical resistivity method of prospecting. Bull. Nat. Geophys. Res. Inst. 7(4), pp. 159-166.
[7]Bobachev, A., (2003). Resistivity sounding interpretation. IPI2win: Version 3.0a 07.01.2003. Moscow state University.

[8]Coker, J. O., Makinde, V., Olowofela, J.A., (2009). Geophysical Investigation of Groundwater Potentials of Oke-Badan Estate, Ibadan, Southwestern, Nigeria. Proceedings of 3rd International Conference on Science and National Development University of Agric. Abeokuta, pp. 119.

[9]Coker J.O., (2012). Vertical Electrical Sounding (VES) Methods to Delineate Potential Groundwater Aquifers In Akobo Area, Ibadan, South-Western, Nigeria Journal of Geology And Mining Research Vol. 4(2), pp. 35-42.

[10]Griffith, D.H., (1976). Application of electrical resistivity measurements for the determination of porosity and permeability in sandstones. Geoexploration 14(3-4), pp. 207-213.

[11]Hodlur, G.K., Dhakatea,R., Sirisha, T. and Panaskar, D.B., (2010). Resolution of freshwater and saline water aquifer by composite geophysical data analysis methods.Hydrol. Sci. Jour., 55, pp. 414-434

[12]Idornigie, A. L., Olorunfemi M.O. and Omitogun A. A., (2006). Integration of remotely sensed and geophysical data sets in engineering site characterization in basement complex area of southwestern Nigeria. Jour. Applied Sciences Research 2 (9), pp. 541-552.

[13]Keckler, D., (1997). Surfer for Windows, Version 6, User's Guide. Golden Software, Inc.

[14]K'Orowe, M. O., Nyadawa, V., Singh, S. and Ratnakar D., (2011). Hydrogeophysical Parameter Estimation for Aquifer Characterisation in Hard Rock Environments: A case study from Jangaon Subwatershed, india. Jour. Oceanogr. Mar. Sci. 2, pp. 50-62.

[15]Koefoed, O., (1979). Geo-sounding principles, Resistivity sounding measurements" Elsevier, Amsterdam, pp. 300.

[16]Lesmes, D. P., Friedman, S. P., (2005). Relationships between the electrical and hydrogeological properties of rocks and soils, Chap. 4. In: Rubin Y, Hubbard SS (eds) Hydrogeophysics. Springer, Dordrecht, pp. 87-128.

[17]Louis, I., Karantonis, G., Voulgaris, N. and Louis, F., (2004). Geophysical methods in the determination of aquifer parameters: the case of Mornos river delta, Greece. Res. Jour. Chem. Environ. 18(4), pp. 41-49.

[18]Massoud, U., Fernando, S., Khalil, M.A., Taha, A., and Abbas. M.A., (2010). Estimation of aquifer hydraulic parameter from surface geophysical measurements: a case study of the upper Cretaceous aquifer, central Sinai Egypt. Hydrol. Jour. 18, pp. 699-710.

[19]Naraypethkar, A.B., (1991). Geohydrological and Geophysical studies for groundwater in the Adila basin of the Deccan trap Region, Maharashtra, Ph.D. Thesis, Shivaji Univ. Kolhapur, Maharashtra, pp. 170.

[20]Nejad, H. T., (2009). Geoelectric Investigation of the Aquifer Characteristics and Groundwater Potential in Behbahan Azad University Farm, Khuzestan Province, Iran. Applied Sci., 9, pp. 3691-3698.

[21]Nejad, H.T., Mumipour M., Kaboli R. and Najib O.A., (2011). Vertical Electrical Sounding (VES) Resistivity Survey Technique to Explore Groundwater in an Arid Region, Southeast Iran. Journal of Applied Sciences 11(23), pp. 3765-3774.

[22]Nwankwo, L. I., (2011). 2D Resistivity Survey for Groundwater Exploration in a Hard Rock terrain: A Case Study of MAGDAS Observatory, UNILORIN, Nigeria. Asian Jour. Earth Sci. 4, pp. 46-53.

[23]Orellana, F. and Mooney, H.M., (1966). Master tables and Curves for vertical electrical sounding over layered structures. Pub. Inter science, Madrid, pp. 150- 66.

[24]Raimi, J., Sule, P. and Dewu, B.B.M., (2010) A Geoelectric Survey for Groundwater: A Case Study in the North Central Basement Complex, Nigeria. Research and Opinion, 2 (12), pp. 158-165.

[25]Raimi, J., Abdulkarim, M. S., Hamidu, I. and Arabi, A. S., (2011). Application of Schlumberger Vertical Electrical Sounding For Determination Of Suitable Sites For Construction of Boreholes For Irrigation Scheme Within A Basement Complex International Journal of Multidisciplinary Sciences And Engineering, Vol. 2, No. 6, pp. 81-84.

[26]Roy, A. and Apparao, A., (1971). Depth of investigation in direct current methods. Geophysics, 36, pp. 943-959.

[27]Sabale, S. M., Ghodake, V. R. and Narayanpethkar, A. B., (2009). Electrical Resistivity Distribution Studies for artificial recharge of groundwater in the Dhubdhubi Basin, Solapur District, Maharashtra, India. Jour. Ind. Geophys. Union Vol.13, No.4, pp. 201-207.

[28]Sikandar, P., Bakhsh, A. and Ali, T., (2010). Vertical Electrical Sounding (VES) Resistivity Survey Technique to Explore Low Salinity groundwater for Tubewell Installation in Chaj Doab. J. Agric. Res. 48, pp. 547-566.

[29]Singh, B. S., Stephen, J., Srinivasa, Y., Singh, U.K. and Singh, K. P. (2002). An integrated geophysical approach for groundwater prospecting case study from Tamil Nadu. Jour. Geol. Soc. Ind., Vol. 59, pp. 147-158.

[30]Stewart, M. and Bretnall, R., (1986). 'Interpretation of VLF Resistivity Data for Groundwater Contamination Surveys', *Proceedings of NWWA Conference on Surface and Borehole Geophysical Methods*, pp. 71–75.

[31]Wenner, F., (1915). A method of measuring earth resistivity. U. S. Bur. Standards, Sci. paper, Vol.258, pp. 469-478.

[32]Yadav, G.S., (1988). Pole-dipole resistivity sounding techniques for shallow investigation in hard rock areas. Jour. Pure and Applied Geophysics, 127(1), pp. 63-71.

[33]Yadav, G.S., Singh, P.N. and Shrivastava, K. M., (1997). Fast method of resistivity sounding for shallow groundwater investigations. Jour. Applied Geophysics, 36, pp. 45-52.

[34]Yadav, G. S. and Singh, S. K., (2007). Integrated resistivity surveys for delineation of fractures for groundwater exploration in hard rock areas. J. Appl. Geophys. 62, pp. 301-312.

[35]Yusuf, S.N., Joseph M.V., Alkali S. C. and Kuku A.Y., (2011). Determination of Porus Zones Using Vertical Electrical Sounding Data from Basement Rocks of Hussara, Askira UBA, North-eastern Nigeria. Ozean J. Applied Sci. 420, pp. 183-189.

[36]Zhdanov, S. M. and Keller, G. V., (1994). The geoelectrical methods in geophysical exploration. Elsevier, Amsterdam, The Netherlands, pp. 83.

[37]Zohdy, A.A.R., (1965). The auxiliary point method of electrical sounding interpretation and its relationship to the Dar Zarrouk parameters. Geophysics, Vol. 30, pp. 644- 660.

[38]Zohdy, A.A.R., Eaton, G.P., and Mabey, D.R., (1974). Application of surface geophysics to Ground Water Investigations. Techniques of water resources investigation U S Geological Survey, pp.116.

[39]Zohdy, A.A.R., (1989). A new method for automatic interpretation of Schlumbergers and Wenner Sounding Curve. Geophysics , Vol. 54 No. 2, pp. 245-253.