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1D resistivity sounding geophysical survey by using Schlumberger electrode configuration method for groundwater explorations in catchment area of Anjani and Jhiri river, Northern Maharashtra (India)

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Abstract: The present paper focuses on groundwater exploration using scientific methods. The area decide for the study, Anjani and Jhiri river basin, which comes under hard rock terrain from Maharashtra province, India. In this regards to conduct the hydrogeological and hydrogeophysical survey to understand the groundwater condition in the area. The aquifer geometry in the study area has been interpreted by carrying out 1D resistivity sounding using the conventional four electrode resistivity meter. The resistivity measurements obtained in sounding have been interpreted by curve matching technique to calculate the layer parameters (resistivity and thickness) and subsequently to reconstruct the depth sections of the profiles. Based on the range of resistivity values, the weathered and fractured zones are interpreted. The contacts between certain saturated and dry formation zones having different resistivity values can be identified from the resistivity section.

Keywords: Geophysical survey, 1D resistivity sounding, VES cross section, groundwater explorations, Anjani and Jhiri River, Maharashtra, India

Introduction

In arid and semi-arid regions, irrigation is the lifeline of agriculture and has assumed greater importance with induction of modern technology, particularly after the introduction of high yielding varieties of seeds, chemical fertilizers, pesticides, insecticides, etc. With the advent of green revolution, the groundwater use in agriculture has increased by a greater proportion as compared to surface water. As a result, water levels have declined significantly in some regions of the India (CGWB, 2009). The lowering of groundwater levels has resulted in reduction in individual well yield, growth in well population, failure of bore holes' drying up of dug wells and increase in power consumption (Imtiyaz and Rao, 2008).

Thus, the issue of availability and sustainability of safe groundwater is of great importance and calls for a scientific action plan to ensure water security in the region. Groundwater is often developed without proper understanding of its occurrence in time and space and is, therefore, endangered by over-exploitation and contamination. For that reason, groundwater management is the key to conflict the emerging problem of water security. Knowledge of water table depth is a crucial element in many hydrological investigations, including agricultural salinity management, landfill characterization, chemical seepage movement, and water supply studies (Buchanan and Triantafilis, 2009).

There are several difficulties for development of groundwater resources in hard rock areas as broad and unpredictable variation of critical parameters (i.e. fractures, joints, porosity, etc), characterize the groundwater regime. Spatial variations of these characteristic parameters are recognized to, among other causes, to tectonic set-up and the degree of weathering of near surface rocks (Barker et al. 2001). These processes induce directly or indirectly secondary porosity in the hard rock's to a variable

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extent. As a result, the groundwater potential also varies significantly from place to place sometimes within a few meters and even within the same geological formations. Indian context the situation becomes all the more unstable due to negligible primary porosity and low permeability of host rocks restrict groundwater storage as well as movement, and also low rainfall, high evaporation and surface run-off limit recharge to the groundwater systems (Rangarajan and Athavale, 2000). Any change in rainfall patterns poses a serious threat to agriculture, and its impact on the country's economy and food security. Agriculture is adversely affected not only by an increase or decrease in the overall amount of rainfall, but also by shifts in the timing of the rainfall.

The fertility of farmland as well as the stability of land resources depends upon the activities of the summer monsoon. Thus the economy of the farmers is closely attached to the good monsoon rain between June to September and it acts as a lifeline to the agricultural society. However basaltic areas, in particular, have shown that a systematic surface exploration succeeds in locating sites where high yielding wells may be drilled. Groundwater is a valuable natural source for several essential purposes such as public, industries and agricultural water supply. The demand of this natural resource is increasing in many folds due to irregularity in the monsoon pattern and human activities. Due to natural and man-made activities the water level also is declining, particularly, in arid and semi arid regions. To understand the subsurface lithology and delineate the groundwater potential zones the vertical electrical sounding (VES) survey has been proven useful and cost-effectiveness. The Schlumberger array is found to be more suitable and common in groundwater investigations (Zhody, 1969). Besides, the technique has been utilized successfully to solve groundwater problems by many researchers (Karanth 1991; Janardhana et al. 1996; Balasubramanian et al. 1985). Water resources development in hard rock terrain in many parts of Kerala State poses a key issue in the management policy (Mohamed et al. 2010). Studies relating to groundwater exploration have suggested that much interest and clearly indicates its relevance and importance in day to day life.

The electrical resistivity method is most widely accepted and used in groundwater exploration. Electric currents are being passed into the ground through electrodes and resistivity of rock formations is measured. Electrical resistivity methods assumed considerable importance in the field of groundwater exploration because of its low cost, easy operation and its capacity to identify between fresh and saline water zones and are therefore widely employed throughout the world (Pal and Majumdar 2001; Majumdar and Pal 2005; Narayanpethkar et al. 2006). The resistivity methods can be employed successfully to estimate the thickness and electrical nature of the formation which provides useful information regarding the groundwater potentialities (Griffith and King 1965; Balakrishna, 1980; Griffith and Turnbull 1985). As a part of ground survey, geoelectrical resistivity studies have wide applications in hydrogeological and related field investigations. The resistivities of different formations/layers can be identified by plotting the data by inverse slope method (Ballukraya, 1997). Geophysical surveys are comparatively quick, cheap and a non-destructive method to gain subsurface information of the Earth. Among the different geophysical techniques, the direct current (DC) resistivity method has emerged as a useful tool in environmental, hydrogeological and engineering applications (Vandam and Meulankamp 1967; Loke and Barker 1996). The DC resistivity is becoming popular as dissimilarity in resistivity of the subsurface is regularly linked to variation in hydraulic properties, such as the presence of fluid, extent of fluid saturation and its quality. The accurateness of DC resistivity method depends on how best the physical properties are interpreted in terms of hydrogeological parameters. The electrical resistivity method gives comparatively reliable results in hydrogeological investigation, where in the nature of the aquifer can be suitably delineated.

It can also help in preparation of contaminated zone maps (Urish 1983; NGRI report 2007; Pujari and Soni, 2009).

Description of the area under study

The present study area is located in Northern Maharashtra, India. The study area is covered under latitude 20^0 45' N to 21^0 08' N and longitude 75^0 09' E to 75^0 27' E and included in the Survey of India topo-sheets No. 46 P/1, 46 P/5 and 46 O/8. Total area of Anjani and Jhiri River basin is an about 1243.65Km^2 out of which Anjani and Jhiri River basin covers an area about 911.71Km^2 and 331.94Km^2 respectively. The study area falls under the semi arid climate zone. The mean maximum temperature ranges from 29.5^{0}C to 48^{0}C in the months of May. The mean minimum temperature ranges from 12^{0}C to 24^{0}C in the month of December - January. The high relative humidity occurs in the rainy season, viz. June to October. The study area receives rainfall during the summer (southwest) monsoon season (SMS), viz. June to September. Monsoons are characterized by phrases such as the onset and advance (June), peak (July and August) and back away (September). The average annual rainfall is about 750mm. As of today's most part of the agricultural land directly depends on the monsoon, therefore the groundwater study are very important for the agricultural point of view. Location map of the area under study has shown in figure 1.

Geological setting

The study area is geologically covered by Deccan trap rocks from the Cretaceous to the lower Eocene age, consisting of amygdaloidal and vesicular basalts (Golekar et al., 2013). Some areas are covered by thick alluvium from the Quaternary age along river channels.

Deccan trap rocks

The different type of basaltic varieties occurs in the study area like amygdaloidal, vesicular, weathered and fractured basalts up to an average depth of 3-5m noticed near Erandol and Dharangaon. The highly weathered basalt exposures were observed in the northern part of investigating the area (Erandol sub district) and NE, SE part of the study area. Massive basalts observed in the northern part of the study area. Zeolitic cavities have also occurred in the northern part of the study area. Southern part of the study area thick covered of the alluvium which parallel band of silt and clay up to 50 - 100meters. Soils are occurred, i.e. BCS (Black Cotton Soil, which is the resultant of the weathering of these rocks, which play a significant role in the geomorhological units. The study area is geologically covered by Deccan trap rocks from the Cretaceous to the lower Eocene age, consisting of amygdaloidal and vesicular basalts. Some areas (downstream catchment of Anjani and Jhiri River) are covered by thick alluvium from the Quaternary age along river channels; these alluvium consisting of parallel bands of silt and clay up to 50 -100meters. The Deccan trap lava sequence is grouped under Sahyadri Group, which is upper Cretaceous to lower Eocene age. The lava assemblages of Sahyadri group consisting of an alternating sequence of Pahoehoe and Aa flow. The Sahyadri group is further subdivided into Ajanta and Upper Ratnagarh formation. Ajanta formation consisting of 11 Aa flows, 5 compound Pahoehoe flows and Megacryst lava flow. Upper Ratnagarh formation consisting of Megacryst lava flow, 5 compound Pahoehoe flows, sparsely to moderately porphyritic and non porphyritic to separately porphyritic. Stratigraphic succession of the area under study is presented in table 1.

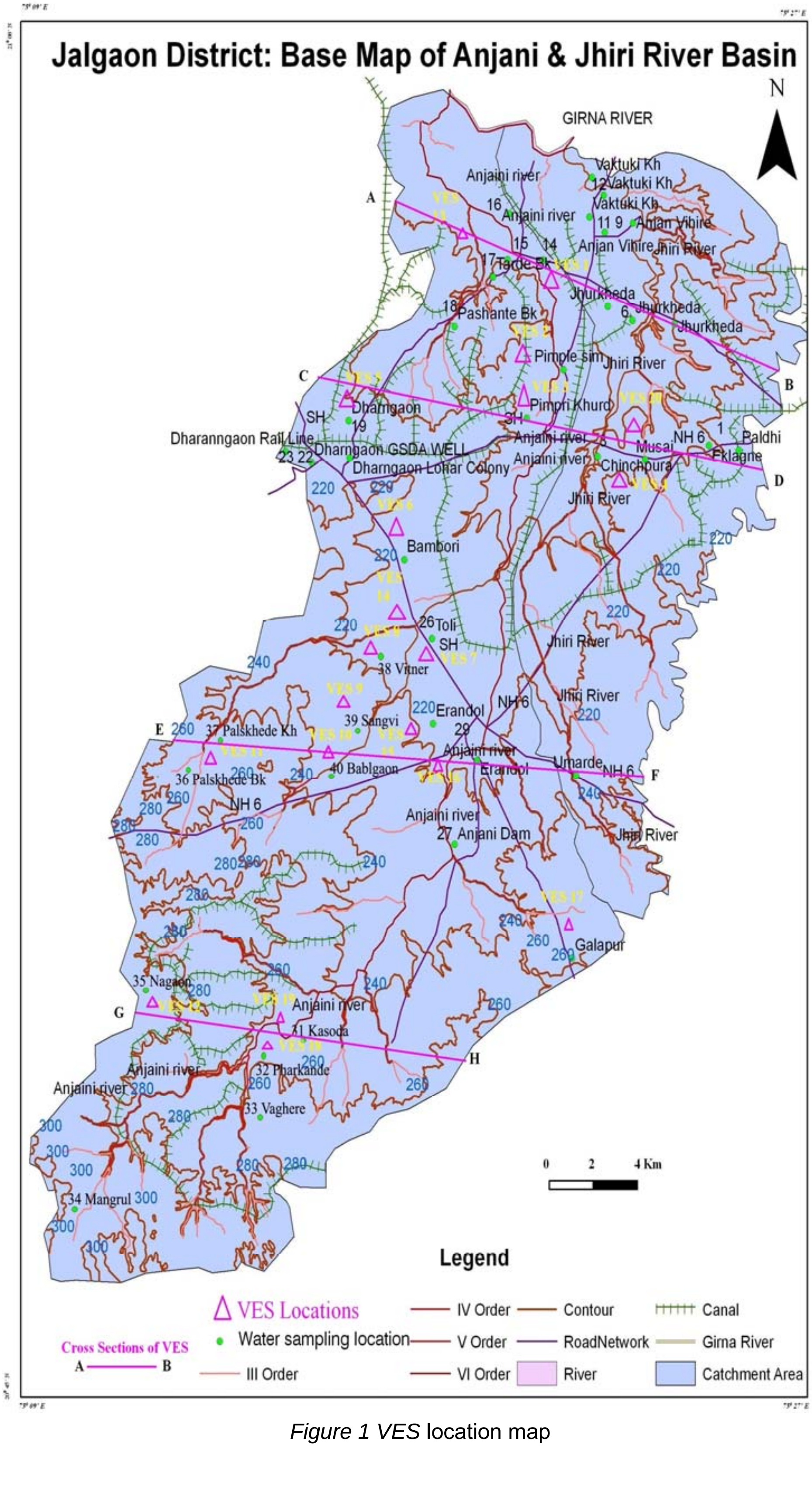


Figure 1 VES location map

Table 1 Stratigraphic succession of area under study area (GSI, 1976)

Age	Super Group	Group	Formation	Flows	Lithological characteristics
			Quaternary	Alluvium	Alluvium
Upper cretaceous to Palaeocene	Deccan Trap	Sahyadri	Ajanta formation	11 Aa flows, 5 compound Pahoehoe flows	Dark massive, fine to medium grained, can be broken into blocks
				Megacryst lava flows	Dark massive, fine to medium grained basalts, prone to weathering effects
			Upper Ratnagarh formation	Megacryst lava flows	Dark massive, fine to medium grained basalts, prone to weathering effects

Alluvium

Alluvial deposits occur along the lower reaches of major river valleys and watercourses. Thickness of alluvium ranges from less than a meter to several tens of meters. Alluvial plains of Girna occur in the north of the study area with a minimum elevation of 163meters above msl. Alluvium consists of unconsolidated to consolidated sand, brownish yellow silt and calcrete (locally known as kankar) along Tapi, Girna, Anjani and Jhiri River. In the study area, however, the alluvium is characterized by unconsolidated clays and silts which are of very limited thickness. These alluvial deposits are observed in many dug wells from the study area.

Methodology

A total 20 vertical electrical soundings have been carried out in the Anjani and Jhiri river basin at selected locations (table 2). The resistivity soundings have been carried out using the Schlumberger electrode configuration with a maximum current electrode separation (AB/2) of 100 m. Vertical Electrical Sounding (VES) data derived from field investigations were interpreted by partial curve matching technique to obtain the initial model parameters. The preliminary interpretation of the VES curves was carried out by the curve matching technique (Orellena and Moony, 1966) in which the field curves are matched with the theoretical master curve. The VES curves plotted using the IPI2WIN Geoscientific Software (Babachev, 2003). The theoretical curve that best fits the actual sounding curve specifies the thickness and resistivity of sub-surface layers of the respective VES station.

Table 2 VES locations from study area

VES ID	Location	Longitude	Latitude	Elevation (masl)	River Basin
1	Jurkheda	75.23 E	21.03 N	180.00	Jhiri
2	Pimri Sim	75.21 E	21.02 N	185.00	Anjani
3	Pimri Khurd	75.21 E	21.03 N	190.00	Anjani
4	Chinchpura	75.22 E	21.01 N	185.00	Jhiri
5	Dharangaon	75.17 E	21.09 N	207.00	Anjani
6	Bambhori	75.17 E	20.59 N	222.00	Anjani
7	Toli	75.19 E	20.56 N	219.00	Anjani
8	Vitner	75.17 E	20.56 N	262.00	Anjani
9	Sangvi	75.17 E	20.54 N	265.00	Anjani
10	Babalgaon	75.16 E	20.53 N	247.00	Anjani
11	Palsakhede Bk	75.14 E	20.55 N	236.00	Anjani
12	Nagaon	75.13 E	20.52 N	282.00	Anjani
13	Tarde Bk	75.19 E	21.03 N	176.00	Anjani
14	Toli	75.20 E	20.56 N	220.00	Anjani
15	Erandol	75.20 E	20.55 N	222.00	Anjani
16	Anjani Dam	75.19 E	20.54 N	235.00	Anjani
17	Galapur	75.22 E	20.49 N	240.00	Anjani
18	Pharkande	75.15 E	20.50 N	262.00	Anjani
19	Kasode	75.18 E	20.52 N	260.00	Anjani
20	Musai	75.23 E	21.00 N	195.00	Jhiri

(masl indicates metres above sea-level)

Results and discussion

Detailed geophysical field results obtained from VES were presented in table 3. Obtained resistivity and thickness of the each layer were presented in table 4. Representative VES curve has depicted in Fig 2.

Curves Types

The resistivity curve types A, Q, H, K and combinations were obtained (Table 5). These curves are interpreted using the curve matching technique using two and three layer master curves (Singh and Tripathi, 2009). The different basic types of curves are:

1. Q Type $\rho 1 > \rho 2 > \rho 3$
2. H Type $\rho 1 > \rho 2 < \rho 3$
3. K Type $\rho 1 < \rho 2 > \rho 3$
4. A Type $\rho 1 < \rho 2 < \rho 3$

A combination of the basic curves can be obtained if the model is obtained for more than 3 layers. Then the combinations possible can be as:

1. HA Type $\rho 1 > \rho 2 < \rho 3 < \rho 4$
2. HK Type $\rho 1 > \rho 2 < \rho 3 > \rho 4$
3. AA Type $\rho 1 < \rho 2 < \rho 3 < \rho 4$
4. AK Type $\rho 1 < \rho 2 < \rho 3 > \rho 4$
5. KH Type $\rho 1 < \rho 2 > \rho 3 < \rho 4$
6. KQ Type $\rho 1 < \rho 2 > \rho 3 > \rho 4$
7. QH Type $\rho 1 > \rho 2 > \rho 3 < \rho 4$
8. QQ Type $\rho 1 > \rho 2 > \rho 3 > \rho 4$

In the study area 5 to 6 layer model is obtained and therefore the curve types are identified accordingly in combinations with the basic types.

The first layer was top soil and weathered basalts consisting of 0.5 m - 1.7m thickness 2.7 – 312 Ω.m resistivity Black cotton soil with highly weathered and fractured basalt except VES 8.

The second layer consisted of 0.5 m thick black cotton soil with highly weathered and fractured basalt having 3.4 – 488 Ω.m resistivity and 0.1 – 9.6m thickness and resistivity more than 80 Ω.m resistivity; Weakly fractured basalts and massive basalts at VES 1, 5, 6, 8, 13,15 16 and 17.

The third layer was a consisted of 0.5 m thick black cotton soil with highly weathered and fractured basalt having 1.5 – 272 Ω.m resistivity and 0.1 - 17.9m thickness and resistivity more than 80 Ω.m resistivity Weakly fractured basalts and massive basalts at VES 1, 6, 9, 14,15 17 and 18.

The fourth layer was composed of 37.4 m thick 80 Ω.m resistivity of black cotton soil with highly weathered and fractured basalt and massive rock having 80- 619 Ω.m.

The fifth layer is made up of fractured and jointed basalts and massive basalts because resistivity having up to 1581 Ω.m resistivity except VES 2, 4, 7, 11, 13, 19 and 20 which comes under either alluvial part or near the foothills.

Interpretation of VES cross sections

The interpreted results of VES cross sections (resistivity and thickness of layers) are correlated with geological features exposed in the vicinity of the sounding stations. Based on field observations, it is suggested to associate 30 - 40 Ω.m zone with the weathered and fractured zone. The cross sections (Fig. 3, 4, 5 and 6) indicate that the depth of weathered and fractured zone varies from place to place. The resistivity cross sections roughly indicate that the weathered and fractured zones constituting the water-saturated zones. These low resistivity zones near Musai (VES 20), Tarde Budruk (VES 13) and Jurkheda (VES 1) roughly match with the actual field observation. It is observed that the low resistivity zones show that close to the thick cover alluvium which is observed in the actual field works. A close look at the resistivity section in the Anjani and Jhiri river basin indicates a very wide zone of weathered to fractured rocks indicated by medium resistivity zone (30 - *50* Ω.m) on Chinchpura (VES 4), Babalgaon (VES 10) and Kasoda (VES 19).

Whereas high resistivity zones shows that close to the massive or hard rock areas which is observed in the actual field works. A close look at the resistivity section in the Anjani and Jhiri river basin indicates a very hard rock's zone indicated by high resistivity zone (>200 Ω.m) at Palskhede (VES 11), Pimri Khurd (VES 3) and Dharangaon (VES 4).

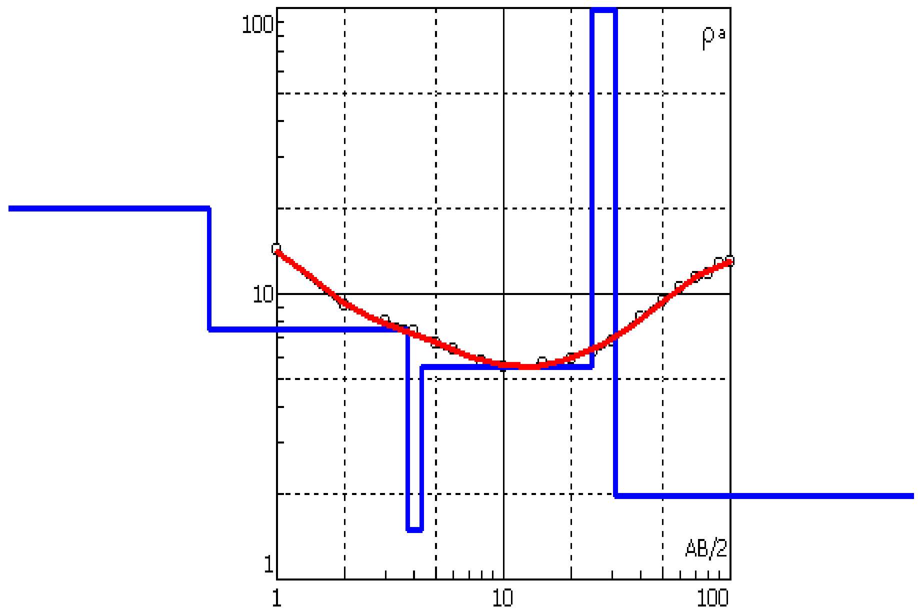
Table 3 Detailed geophysical field results obtained from VES

Location	AB/2	1	2	3	4	5	6	8	10	15	20	25	30	40	50	60	70	80
Jhurkheda	Rho	14.3	9.1	9.1	7.4	7.1	6.4	5.4	5.5	5.7	5.9	6.3	6.8	8.2	7.9	9.1	12.5	16.4
Pimri Sim	Rho	17.4	11.1	11.1	9	8.6	7.9	6.5	6.7	7	7.1	7.6	8.3	10	9.6	11.1	15.3	20
Pimri Khurd	Rho	10	28.6	32	27	20.4	15	20.9	13.2	21	14.6	18.6	22.8	30.4	32.3	37.2	33	48.6
Chinchpura	Rho	16	42.3	70	51.9	18.2	17.4	16.7	12.7	21.3	34.2	44.1	46.5	59.8	70.8	84.1	85.1	79.8
Dharangaon	Rho	137.4	21.2	36.1	52.8	46.5	39.1	49.3	66	60.8	96.6	88.1	92.4	113.5	130.2	135.1	148.4	154.2
Bambhori	Rho	81.2	71.2	74.6	69.4	72.3	74.5	110.9	90	100.3	163.9	242.8	257	355.4	414.7	626	120.3	112.8
Toli	Rho	6.6	8.8	11.7	13.9	13	13.2	16.1	15.5	19.6	22	27.4	28.6	36	45.7	51.4	47	51.5
Vitner	Rho	218.4	136.3	127.2	105.7	98.7	97.8	124.9	108.4	102.3	125.8	114.1	100.3	79.3	85.2	88	100.7	105.7
Sangvi	Rho	12.9	16.4	15.6	19.9	22.5	25.8	29.8	34.4	39.8	41.8	47	47.5	57	58.8	58	57.9	66.5
Babalgaon	Rho	4.7	7.7	9.6	11.6	13.1	12.9	14.6	15.9	18.6	22.6	26.2	23.9	30.1	33.3	38.2	32.8	34.4
Palsakhede Bk	Rho	8.9	14.7	18.2	22.2	25	24.6	27.9	30.3	35.5	43	50.1	45.6	57.5	63.6	72.9	62.6	65.7
Nagaon	Rho	7.7	12.7	15.8	19.2	21.7	21.4	24.2	26.3	30.8	37.3	43.4	39.6	49.9	55.1	63.2	54.3	57
Tarde Bk	Rho	7.7	12	15.3	17	17.5	15	13.7	10.8	18.3	12.5	20	16.3	15.5	16	19.3	20.1	24.2
Toli	Rho	100	83.5	105.4	109.6	130.3	149.4	149.7	196.4	209.1	272.8	279.1	313.1	325.7	353.2	368.2	286.2	292.4
Erandol	Rho	129.4	161.7	188.7	252.6	256.8	239.5	277.7	251.3	252.2	323.5	363.3	243.9	246.4	232.2	231.9	232.2	174.2
Anjani Dam	Rho	43.9	40.4	72.7	53	56.8	70.5	78	76.6	68	93.1	82.3	114.4	154.4	145.4	165.6	164.7	195.6
Galapur	Rho	41.8	69.1	96.4	109.6	116.8	123.3	132.7	144.8	162.7	157.3	169.7	166.8	180.2	199.3	199.9	175.4	180.2
Pharkande	Rho	30.2	36.8	58.9	78.8	60	76.7	79.1	99.6	79.2	123.6	111	106.2	118.4	123	111.1	117.9	127.5
Kasode	Rho	4.8	5.8	7	8.9	10.7	11.9	18	20	30.4	37.7	51	54.1	69	80.1	72	68	64.9
Musai	Rho	5.6	8.7	11.1	12.4	12.7	10.9	9.9	7.9	13.3	9.1	21.8	23.8	33.3	62.3	84.5	79.8	76.2
Maximum		218.4	161.7	188.7	252.6	256.8	239.5	277.7	251.3	252.2	323.5	363.3	313.1	355.4	414.7	626	286.2	292.4
Minimum		4.7	5.8	7	7.4	7.1	6.4	5.4	5.5	5.7	5.9	6.3	6.8	8.2	7.9	9.1	12.5	16.4

Table 4 Table showing the ranges of the resitivity values and thickness for all the layers and curve types

VES point	p 1	p 2	p 3	p 4	p 5	p 6	h 1	h 2	h 3	h 4	h 5	Error %	Curve type	Depth of bedrock (m)
	(Ω.m)	(Ω.m)	(Ω.m)	(Ω.m)	(Ω.m)	(Ω.m)	m	M	m	m	m			
1	19.8	7.5	1.5	5.5	242	2	0.5	3.3	0.6	20	7	1.3	QHA	32.6
2	20.5	9.3	2.9	6.5	233	1.3	0.5	3.1	0.9	19.3	9	1.1	QHA	33.9
3	8.1	309	1.6	255	22.2	4034	0.5	0.3	1.2	2.2	19.8	0.6	HHK	24.6
4	15.6	488	1.9	13237	94.3	8.9	0.5	0.2	1.2	1.2	22.3	1.1	KHK	26.5
5	177	4.1	2728	33.6	1363	14.6	0.5	0.3	0.1	6.4	11.2	2	HKH	20.5
6	89.4	62.8	47.3	1842	3	0.9	0.6	2.3	1.6	5.7	15.2	1.4	QHK	26.7
7	5.8	81.4	4.4	890	7.2	3	1.1	0.7	2.9	5.3	39.2	1.8	KHK	50.9
8	312	108	341	22.7	440	0.8	0.5	9.6	2.6	6.7	11.9	1.2	HKH	32.6
9	12.7	16.4	172	8	61	1515	0.7	2.3	1.9	0.7	72.4	0.4	AKH	78.3
10	2.7	52.1	15.7	57.7	252	1.2	0.5	0.2	8	18.5	5	1.3	KHK	33.4
11	5.1	97.8	30.5	153	259	2.2	0.5	0.2	9.2	24.2	2.4	1.7	KHK	38.2
12	4.6	36.8	23.4	106	479	1.9	0.5	1.6	6.3	26.3	2.3	1.7	KHK	38.6
13	4.7	101	3.2	119	16.9	673	0.6	0.5	2	1.1	72.3	1.8	KHK	78.2
14	151	12.2	179	595	4.2	5	0.5	0.2	5.3	27	35	1.7	HAK	69.7
15	125	93.4	2028	287	97.2	5.4	0.5	0.4	0.1	37.4	61.4	0.6	HKQ	100.4
16	52.6	18.3	327	25.5	3960	230	0.5	0.5	1	4.2	0.8	1.6	HKH	8.5
17	28.3	466	12.4	145	211		0.6	0.9	6.7	5.9		1.3	KHA	15.4
18	32.2	3.4	113	250	36.5	2672	0.5	0.1	17.9	9.5	21.6	1.8	HAK	51.4
19	4.8	28.6	10.8	1121	4.1	0.8	1.7	0.2	1	5.1	17.5	1.7	KHK	27.1
20	4	53.8	2	496	6441	237	0.6	0.7	2.1	4.5	74	1.8	KHA	83.7
Minimum	2.7	3.4	1.5	5.5	3	0.8	0.5	0.1	0.1	0.7	0.8	0.4	-	8.5
Maximum	312	488	2728	13237	6441	4034	1.7	9.6	17.9	37.4	74	2	-	100.4
Average	53.8	102.5	302.3	982.8	711.3	495.2	0.6	1.4	3.6	11.6	26.3	1.4	-	43.6

QHA	2	10
HHK	1	5
KHK	7	35
HKH	3	15
QHK	1	5
AKH	1	5
HAK	2	10
HKQ	1	5
KHA	2	10



N	1	2	3	4	5	6
ρ	19.8	7.49	1.5	5.54	242	1.97
h	0.5	3.25	0.574	20	7	
d	0.5	3.75	4.32	24.3	31.3	
Alt	-0.5	-3.748	-4.322	-24.34	-31.33	

VES 1
Jhurkheda

Figure 2 Interpreted resistivity curve of VES 1

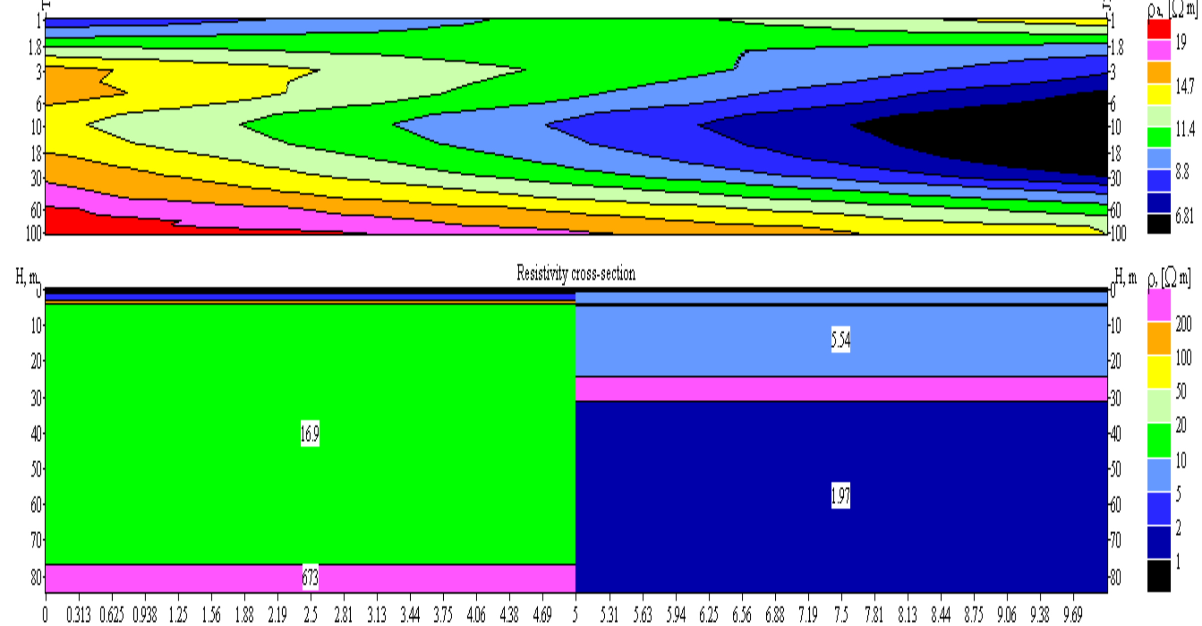


Figure 3 Resistivity depth section on A–B Anjani and Jhiri river basin

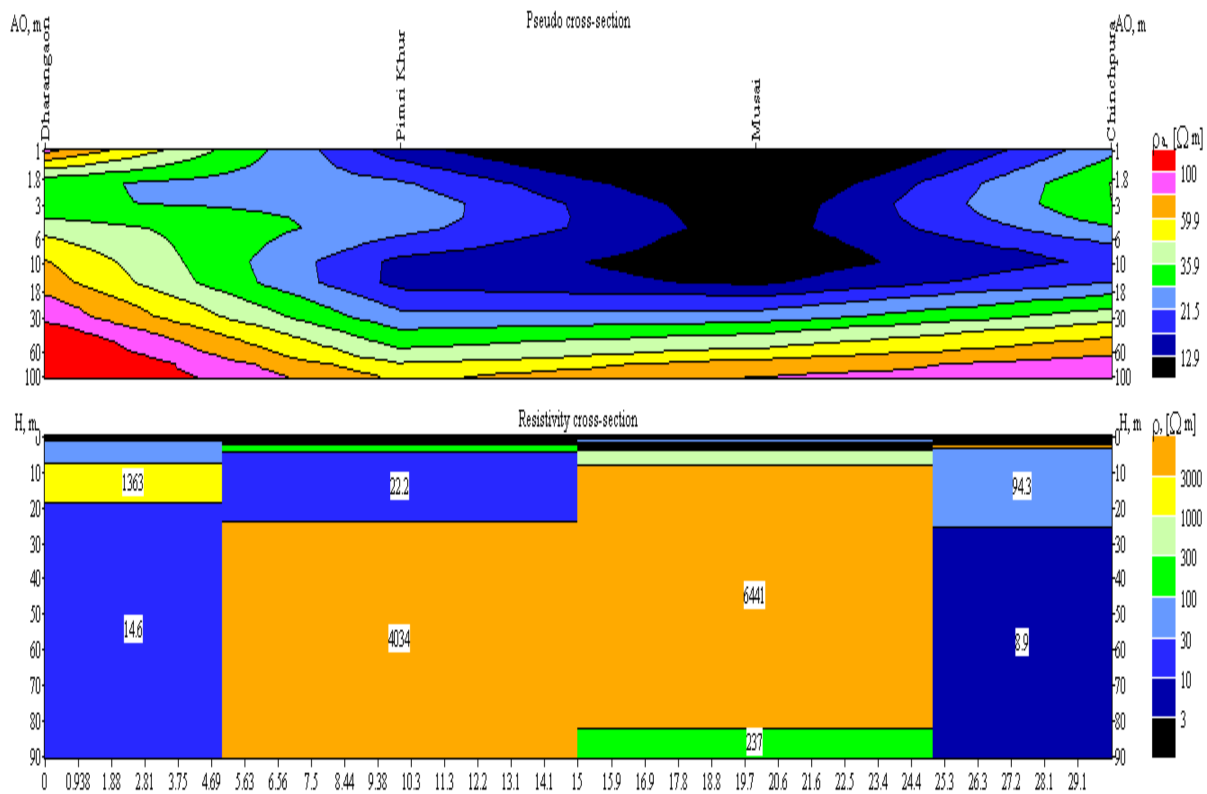


Figure 4 Resistivity depth section on C-D Anjani and Jhiri river basin

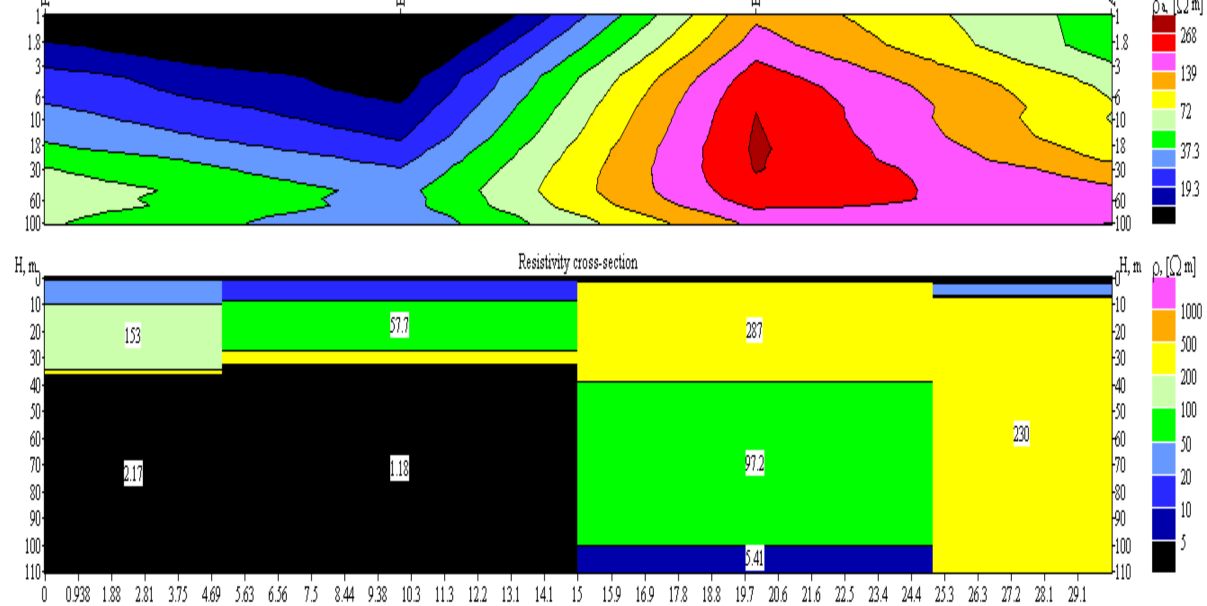


Figure 5 Resistivity depth section on E–F Anjani and Jhiri river basin

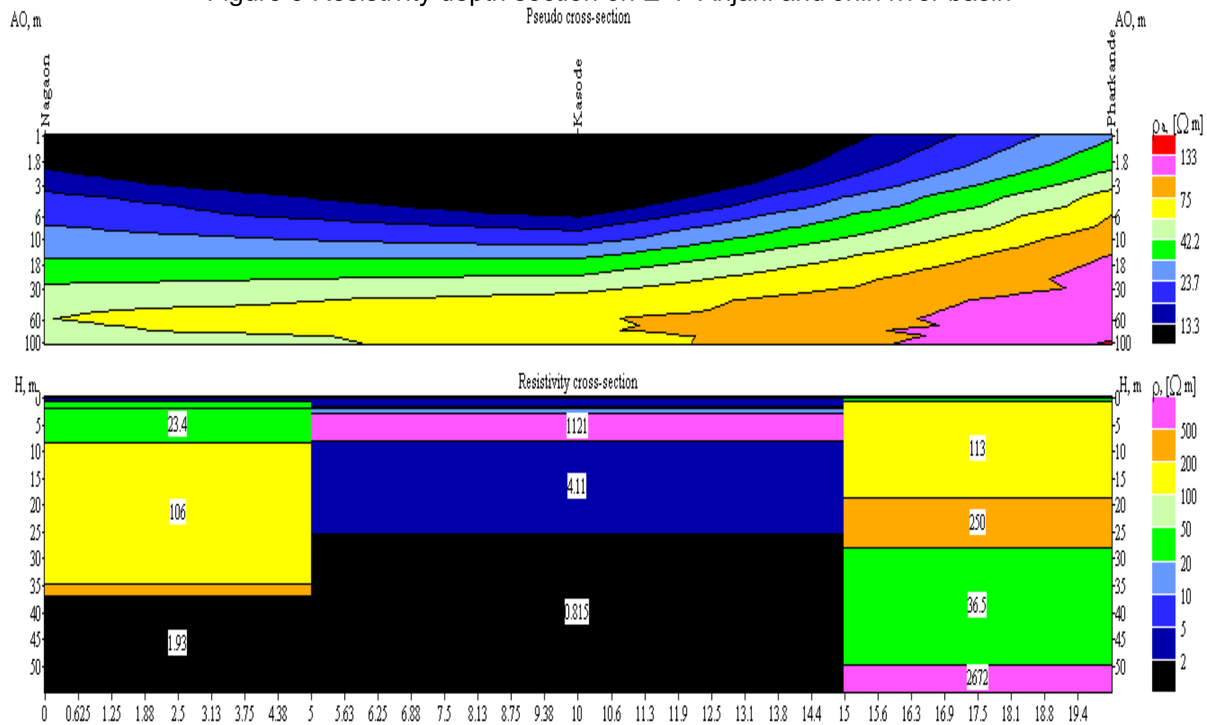


Figure 6 Resistivity depth section on E–F Anjani and Jhiri river basin

Conclusion

The interpreted results of VES cross sections (resistivity and thickness of layers) are correlated with geological features exposed in the vicinity of sounding stations. Based on field observations, it is suggested to associate 30 - 40 Ω.m zone with the weathered and fractured zone. The cross sections look at the resistivity section in the Anjani and Jhiri river basin indicates a very wide zone of weathered to fractured rocks indicated by medium resistivity zone (30 - 50 Ω.m) on Chinchpura (VES 4), Babalgaon (VES 10) and Kasoda (VES 19). Whereas high resistivity zones shows that close to the massive or hard rock areas which is observed in the actual field works. A close look at the resistivity section in the Anjani and Jhiri river basin indicates a very hard rock's zone indicated by high resistivity zone (>200 Ω.m) at Palskhede (VES 11), Pimri Khurd (VES 3) and Dharangaon (VES 4).

General recommendations

i. Southern part of the study area is occupied by Deccan Trap Basalt, where only dug wells are most feasible structures for groundwater development. The sites for bore holes' need to be selected only after proper scientific investigation.
ii. The structures recommended for Basaltic areas are nala bunds, check dams and small weirs. The existing dug wells may also be used for artificial recharge of groundwater provided source water is free of silt and dissolved impurities.
iii. In the Alluvial part of the study area, percolation tanks and recharge wells are suggested.
iv. The study area has 02 urban towns; in these areas recommended the roof water harvesting structure for artificial recharge.
v. Controlling urban expansion in the area under study, which is a recharge area of the shallow and deep aquifers, as it reduce the area of recharge and human activities will pollute the underlying aquifers in the long term.

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References

Balakrishna, S (1980) Hydrogeophysical surveys in India. Presidential address at the Indian association of geohydrologists, NGRI, Hyderabad

Babachev, A. A. (2003) IPI2 Win software, http;//geophys.geol.msu.ru

Balasubramanian, A., Sharma, K.K. and Sastri, J.C.V. (1985) Geoelectrical and Hydrogeochemical Evaluation of Coastal Aquifers of Tambraparni Basin, Tamil Nadu, *Geophys Res. Bulletin*, 23 (4), pp 203-209

Ballukraya, B.N. (1997) Groundwater over exploitation: A case study from Moje- Anepura, Kolar District, Karnataka. *Jour. Geol. Soc. India*, v. 50, pp. 277- 282

Barker, R., Rao, T. V. and Thangarajan, M. (2001) Delineation of contaminant zone through electrical imaging technique, *Current Sci.*, 81, 3, pp 277–283

Buchanan, S. and Triantafilis, J (2009) Mapping water table

CGWB (2009) Ground Water Information, Jalgaon district, Maharashtra 1606/DBR/2009 19 p.

Golekar R B, Baride M V., Patil S N (2013) Human health risk due to trace elements contamination in groundwater from Anjani and Jhiri river catchment of Northern Maharashtra, India *Earth*

Griffith, D. H., and Turnbull, J. (1985) A multi-electrode array for resistivity surveying *First break, 3*, pp 16–20

Geological Survey of India, (1976) Geology of the Jalgaon District, Maharashtra. *Geol. Surv. India*. 125th Ann. Cele pp. 6

Imtiyaz, M. and Rao, D.J.M. (2008) Influence of overexploitation on groundwater ecosystem in hard rock terrain, Proceedings of International Groundwater Conference, March 19-22, Jaipur, India 88

Janardhana Raju, N., Reddy, R.V.K. and Naidu, P.T. (1996) Electrical resistivity surveys for groundwater in the upper Gunjanaru Catchment, Cuddapah District, Andhra Pradesh, *Jour. Geol. Soc. Ind.*, v. 37, pp. 705-716.

Karanth, K. R. (1991) Impact of human activities on hydrogeological environment. *Jour. Geol. Soc. India*, v. 38, pp.195 - 206

Loke, M. H., and Barker, R. D. (1996) Rapid least squares inversion of apparent resistivity pseudo section using quasi-Newton method. *Geophysical Prospecting, 44*, pp 131–152

Majumdar, R. K. and Pal, S.K. (2005) Geoelectric and borehole lithology studies for groundwater investigations in alluvial aquifers of Munger district, Bihar. *Journal Geol Society of India*, 66, pp 463-474

Mohamed Aslam, M.A, Kondoh, A., Mohammed Rafeeque, P. and Manoharan, A.N. (2010) Evaluating groundwater potential of a hard rock aquifer using remote sensing and geophysics. *Journal of Spatial Hydrology*, 10 (1)

Narayanpethkar, A. B. , Vasanthi, A. and Mallick, K. (2006) Electrical resistivity technique for exploration and studies on flow pattern of groundwater in multi-aquifer system in the Basaltic Terrain of Adila Basin, Maharashtra, *Jour. Geol. Soc. India*, v. 35(3), pp. 696-708.

NGRI (2007) Assessment of anthropogenic groundwater contamination in Basaltic terrain, Pithampur, Industrial cluster, Indore and Dhar districts (M.P), NGRI Technical report No.NGRI-2007-Environ-601

Orellena, E. and Mooney, H. M. (1966) Master tables and curves of vertical electrical sounding over layered structures, Interciencia, Madrid, Spain, pp.150-166

Pal, S.K. and Majumdar, R.K. (2001) Determination of groundwater potential zones using Iso-resistivity maps in alluvial areas of Munger district, Bihar, *Ind. J. of Earth Science*-no-1-4,pp-16-26

Pujari, P. R., and Soni, A. K. (2009) Sea water intrusion studies near Kovaya Limestone Mine, Saurashtra coast, India. *Environmental Monitoring and Assessment, 154*, pp 93–109

Rangarajan, R. and Athavale, R. N. (2000) Annual replenishable groundwater potential of India – an estimate based on injected tritium studies, *J. Hydrol.*, 234, pp 38–53.

Singh, V. B. and Tripathi, J. N. (2009) An investigation of groundwater condition using geoelectrical resistivity method: A case study from some parts of Kaushambi district (U.P.), India *Journal of Spatial Hydrology*, v.9 (2).

Urish, D. W. (1983) The practical applications of surface electrical resistivity for detection of groundwater pollution *Groundwater, 21*, pp 144–152

Vandam, J. C., and Meulankamp, J. J. (1967) Some results of geoelectrical resistivity method in groundwater investigations in the Netherlands. *Geophysical Prospecting, 15*, pp 92–115

Zhody, A. A. R. (1969) The use of Schlumberger and equatorial soundings on groundwater investigations near El Paso, Texas *Geophysics, 34*, pp 713–728