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Efficacy of Integrated Geophysical Techniques in Delineating Groundwater Potential Zones in the Deccan Basalt Region of Maharashtra

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ABSTRACT
We developed a methodology to study the depth and aerial extent of aquifers in the Dhotra-Jahangir area of Washim District, Maharashtra to yield better results with more reliability. The area was selected as a model to solve existing groundwater problems due to the droughts of 2013 and 2016 in Maharashtra.
The 2-D interpretation of the data helped to delineate the groundwater horizons, their thickness and orientation for identifying dug-cum-borehole sites. The higher values of real and imaginary component in the VLF-EM profile indicate a low resistive zone which can be attributed to weathered or fractured basalt. The Dug well at the suggested site revealed the static water level at 3.8 m during April 2013. Thus, the integration of resistivity and VLF-EM methods proved to be effective in locating the sources of groundwater with a yield of about 9500 lph which successfully addressed the problem for drinking and cultivation purposes during the entire year.

Key words: Deccan Basalts, Dhotra Maharashtra, Gradient Resistivity Profiling, VLF-EM method, Vertical Electrical Sounding..

INTRODUCTION

The Deccan Lavas are mostly alkali basalts with many irregular flows dipping in different directions (Agashe and Gupte, 1971). They also represent variable morphology, structure and texture depicting thick extensive flows of compact basalt, flows of amygdaloidal basalts and thin irregular flows of vesicular basalts (Karmakar, 1978; Adyalkar and Mani, 1971). The lateral extent of individual flows is of the order of 20 to 160 km (Bean et al., 1986; Choubey, 1973). The Deccan Trap region which comprises of the continental flood basalt with a variety of compositions and many trace elements (Mahoney, 1988) offers a challenge to Earth Scientists to understand the occurrence of groundwater.

The occurrence of groundwater in this region though is not scanty; the source finding becomes challenging as the source is unevenly distributed and controlled by faults, fractures, joints etc., and the weathered layer (Singhal, 1997; Deolankar, 1980; Dhokarikar, 1991; Ghosh et al., 2006; Limaye, 2010). Hence, the areas with extensive agriculture activity faced acute scarcity due to the unscientific source finding.

In Maharashtra, the Groundwater Surveys and Development Agency (GSDA, 1974; 2001; 2008; 2010) under the Water Supply and Sanitation Department is the primary agency involved in solving the drinking water and irrigation problems in rural and urban areas. The initial study in such areas includes study of aerial photos, geo-hydrological data and existing bore well data. Integrated geophysical studies have proved to be effective in delineating the prospective aquifer zones in the Deccan Basalt region (Deshpande and Sen Gupta, 1956; Bose and Ramakrishna, 1978; Nishat Ahmad, 2001; Shettigara and Adams, 1989; Kulkarni et al., 2004).

A rectangular area of length 600 m and width 180 m in Gat No. 29 (Figure 1) was chosen to conduct the geophysical surveys for the present study in the basaltic rock terrain within the Tapi Basin. Hydro-geological study of the area revealed that majority of the region is dry and not suitable for groundwater extraction. The only sources of groundwater in this area are one dug well (6 m deep) and one bore well (120 m deep) which were reported to be dry during all seasons affecting drinking and irrigation requirements.

To address the above issue, detailed geo-hydrological and geophysical surveys comprising Resistivity and VLF-EM surveys were conducted in the study area to suggest new sources for drilling based on the interpreted results. The present study clearly demonstrates the efficacy of integration of different methods in delineating pockets of groundwater potential in the basaltic terrain which could be adopted in similar virgin areas to address the scarcity of water for drinking and irrigation purposes.

STUDY AREA

The Study area, Gat No. 29 (Figure 1) is located due northwest at about 2.5 km distance of Dhotra-Jahangir village settlement (Govtan), Taluka Karanja, District

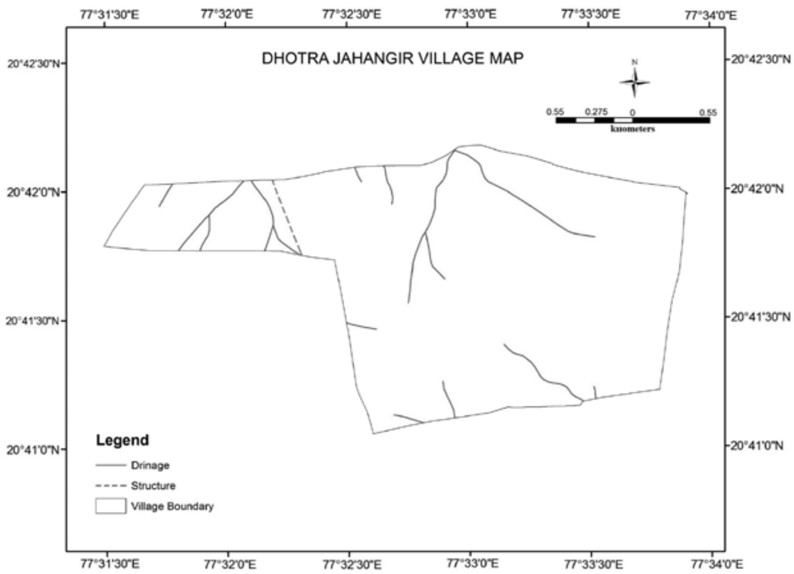

Figure 1. Location, Lineament and Drainage Pattern map of Gat No.29 Dhotra-Jahangir Village, Maharashtra

Washim, Maharashtra, India. The area falls in the SE quadrant of Survey of India Toposheet No 55 H (1:250,000 scale) and the elevation is 336 m above mean sea level (MSL).

The study area falling under the Tapi Basin and designated as Watershed PTU-2 is covered by a normal to undulating topography with a gentle slope towards the southern part of the area. The streams flow from northeast to southwest direction. The drainage pattern is dendritic to sub-dendritic and all streams are seasonal (Figure 1). The area receives a rainfall of about 702 mm. during the southwest monsoon.

Geological and geo-hydrological study

The geo-hydrological surveys comprise of the observations of the well sections of 6 dug wells and 8 bore wells in the area. The Deccan Traps formed due to fissure type volcanic eruption activity during upper cretaceous to lower Eocene periods encompass the entire area under investigation. The delineated aquifers are mostly situated in weathered, vesicular, or fractured basalt underlain by compact basalt. The dug wells with depths ranging from about 6 to 7 m go dry during the summer months starting from March while the bore wells with depths between 60 and 150 m show a reduced yield. Three different layers viz., top soil cover between 1 to 1.5m depth, a middle layer from 1.5 to 5.5 m followed by compact massive basalt were observed from the dug well sections.

Geophysical study

Geo-electrical profiling and sounding were earlier carried out to decipher both lateral and depth variations of resistivity covered by different geological formations (Telford et al., 1976; Yadav and Singh, 2007). The Very Low Frequency (VLF) electromagnetic method (Paterson and Ronka, 1971) has been proved to be a fast and easy tool for locating fractures in hard rock terrain for groundwater exploration (McNeill, J.D., 1991; Sharma, and Baranwal, 2005; Sundararajan et al., 2007).

VLF-EM and Electrical resistivity data were acquired along 9 traverses (Figure 2). The VLF-EM survey was conducted using ABEM-VLF Wadi equipment and the resistivity profiling was conducted with a McOHM Resistivity meter. The real and imaginary components were obtained using the VLF Wadi equipment along the profiles. The McOHM resistivity meter is a digital stacking instrument with the transmitter and receiver completely housed in a case and is controlled by an 8-bit CPU. The maximum output of the transmitter is 400 V peak to peak and 200 mA from an inbuilt battery or external 12V battery through a pressure boosting circuit.

The profile lengths range from 500 to 600 m. The observation interval is 10 m and the profile interval is 20 m. Further, based on the VLF-EM and Gradient Resistivity Profiling (GRP) surveys, which were conducted along nine parallel profiles, Vertical Electrical Resistivity Sounding (VES) were conducted at locations as shown in Figure 2. The results along the profiles 9010W, 9050W and 9090W show the utility of the geophysical surveys in successfully differentiating between the groundwater bearing zones and dry zones.

Analysis of VLF-EM and Electrical Gradient Profiles

The VLF-EM data was interpreted using RAMAG software of ABEM and the current density cross-sections were

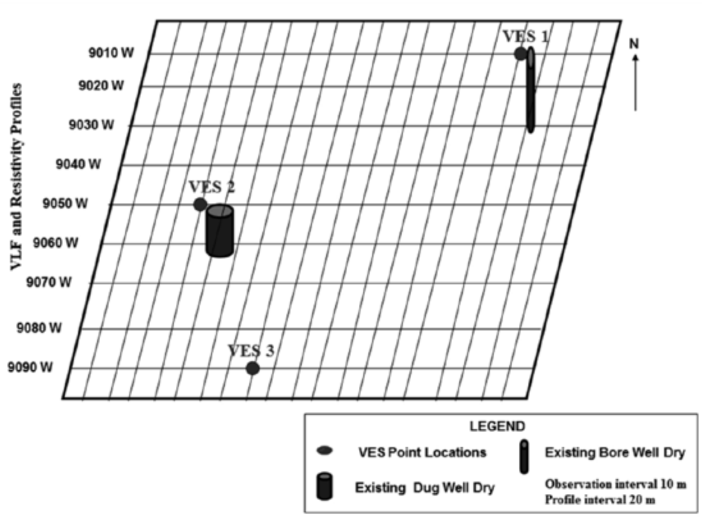

Figure 2. Profile Layout for VLF-EM and Resistivity Profiling surveys (not to scale)

interpreted. The analysis of three profiles that were interpreted for the delineation of the aquifer zones in the area are discussed in this section.

The profile P 9010W is 600 m in length and the existing dry bore well is situated at 440 m along this profile (Figure 2). The VLF-EM in-phase and quadrature components (Figure 3a) clearly demarcate the areas of weathered and fractured basalts depicted by high and low values.

The low values of the in-phase and quadrature components at 60 and 460 m observation points along this profile (Figure 3a) indicate the formation to be moderately weathered as lower current density values correspond to higher resistivity. The current density cross-section (Figure 3b) is computed using Karous and Hjelt filter (Karous and Hjelt, 1983) from the in-phase component (Figure 3a) of the VLF-EM data. The higher current density values at 500 m observation point indicate a low resistive zone which can be attributed to a weathered or fractured basalt and more likely possibility of the presence of an aquifer zone in the area. Conductive zones at 70, 450 and 490 m distances of the profile P 9010W with a dip from northeast to southwest are observed from the pseudo depth section (Figure 3b) and are interpreted as weathered to fractured basalt. These were also observed in well section with a thickness of about 4 to 6 m (GSDA, 2010). The resistivity of weathered to fractured basalt in the area is about 10 to 15 ohm m (GSDA, 2010). The conductive zones observed from 0 to 50 m along profile P 9010W are a part of the weathered to fractured basalt formations discussed earlier. The GRP data along the P 9010W profile (Figure 4) reveals a low resistivity anomaly between 440-450 m and 500-520 m of the profile indicating the formation to be moderately weathered basalt, which coincides with the conductive zones observed in the VLF pseudo depth section at 450 and 490 m. At distances beyond 500 m, the current density concentration (Figure 3b) shows a high value of 10-15%. Also, the negative peak of in-phase does not correspond to a positive peak in the quadrature component or vice-versa, which is considered as a characteristic behaviour for the detection of conductive bodies in the VLF-EM method (Paterson and Ronka, 1971) as is observed at a distance beyond 520 m (Figure 3a) hence not considered for further investigation.

The profile P 9050W (Figure 2) traverses the existing dry dug well at 140 m observation point. A low current density concentration observed between 100 to 140 m along the profile P 9050W (Figure 5b) indicates a high resistivity zone. This phenomenon is also observed from the GRP data (Figure 6). As inferred from VES 2 (Table 2) the resistivity of this formation is approximately 100 ohm m with a thickness of about 10 to 14 m, which is massive basalt and is oriented in a northwest to southeast direction.

The profile P 9090W (Figure 2) traverses along the existing and yielding dug well at 230 m observation point. High current density anomalies are observed at 70 and 230 m along this profile (Figure 7b) indicating weaker zones, which could be weathered, vesicular and/or fractured basalt coinciding with low resistivity zone at this location in GRP data (Figure 8). The GRP data (Figure 8) shows lows at 70, 230, 450 and 500 m. At 70, 450 and 500 m, the VLF data did not indicate higher in-phase or quadrature components (Figure 7a) or high current density anomalies corresponding to that at 230 m (Figure 7b). Also, the quadrature component is clearly marked with an out-of-phase behaviour with respect to the in-phase VLF component (Figure 7a). Hence, for these reasons, a sounding (VES3) was conducted at 230 m distance (Table 2) which revealed a low resistivity layer of about 30 ohm m with a thickness of about 10-15 m implying it to be a weak zone corresponding to weathered, vesicular to

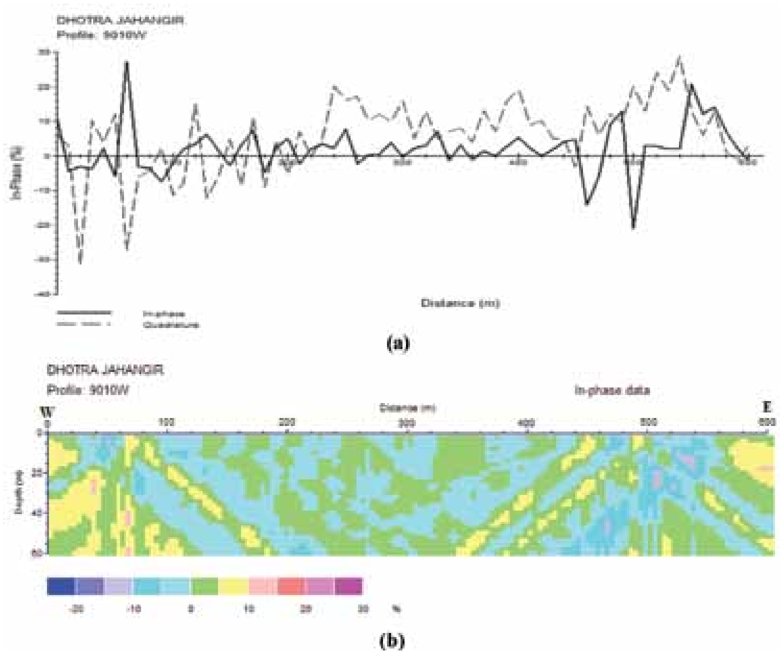

Figure 3. VLF-EM Profile 9010W (a) Real and Imaginary components (b) Pseudo-depth section.

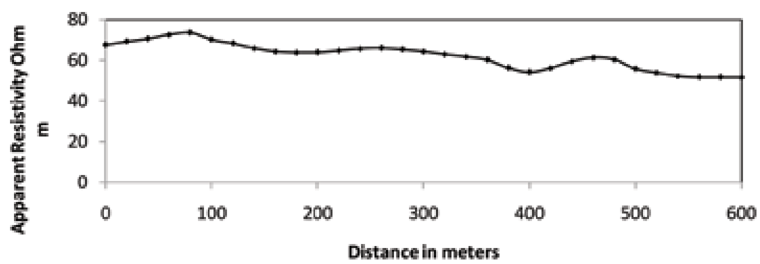

Figure 4. Gradient Resistivity Profile along P 9010W.

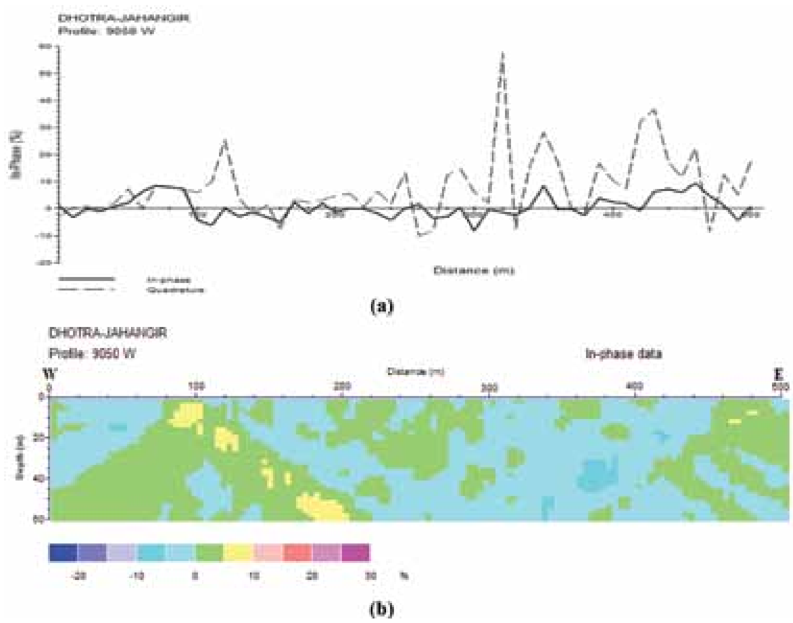

Figure 5. VLF-EM Profile 9050W (a) Real and Imaginary components (b) Pseudo-depth section.

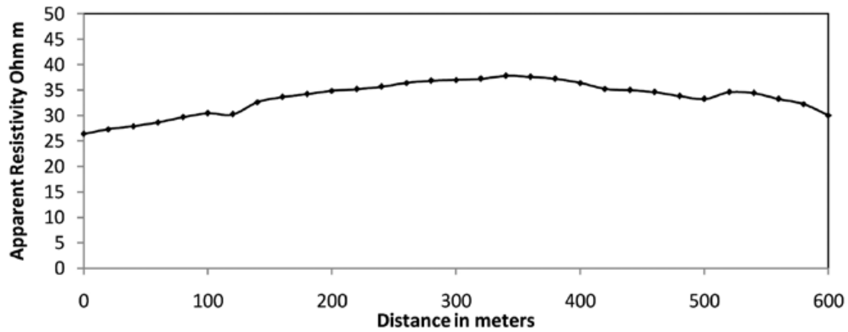

Figure 6. Gradient Resistivity Profile along P 9050W.

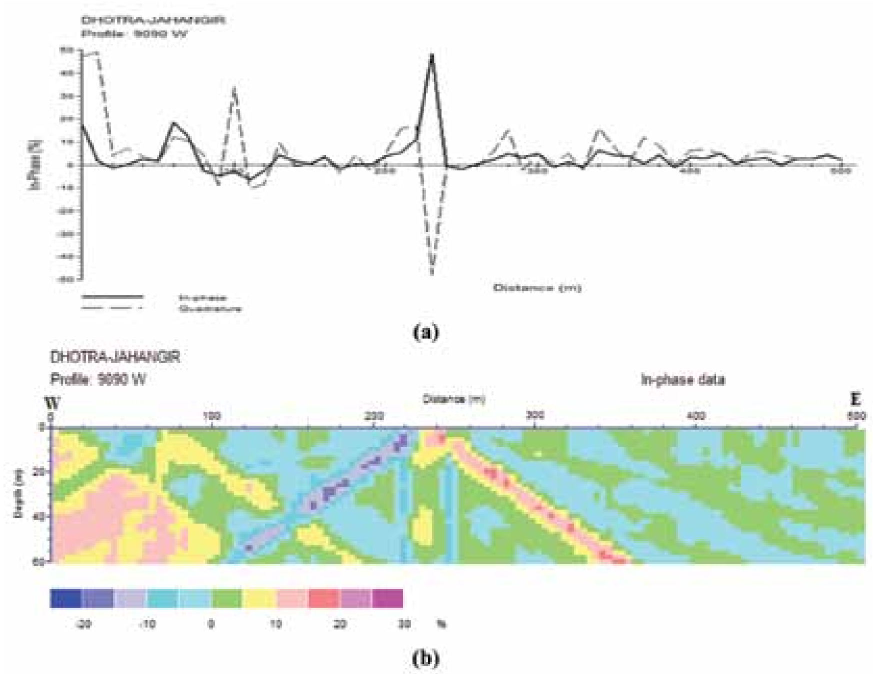

Figure 7. VLF-EM Profile 9090W (a) Real and Imaginary components (b) Pseudo-depth section

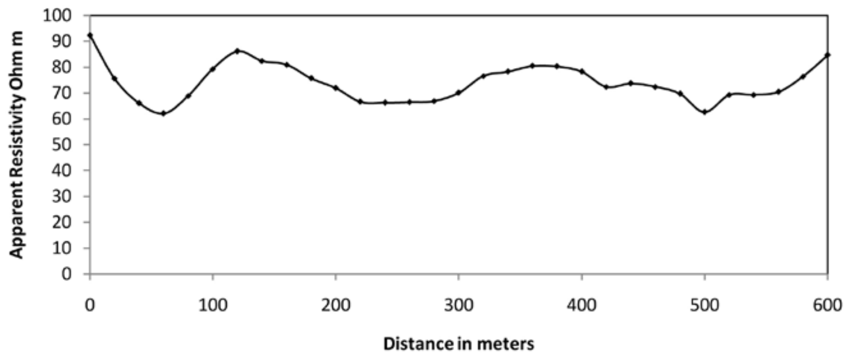

Figure 8. Gradient Resistivity Profile along P 9090W.

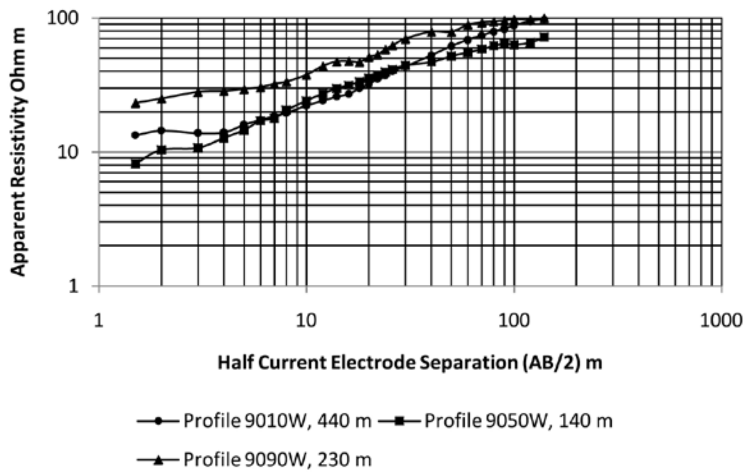

Figure 9. VES on profiles 9010W at 440 m, 9050W at 140 m and 9090W at 230 m observation points.

fractured basalt, oriented from northwest to southeast direction (Figure 7b).

RESULTS AND ANALYSIS

Based on the earlier studies (GSDA, 2010) and comparison of resistivity of different layers with well sections the following resistivity ranges are assumed for different formations.

Figure 9 shows the three Schlumberger Vertical Electrical Resistivity (VES) soundings carried out with maximum current electrode separation of 140 m. VES1, 2 and 3 were carried out on the profile P 9010W at 440 m (near an existing dry bore well), profile P 9050W at 140 m (near an existing dry dug well) and profile 9090W at 230 m observation point respectively (Figure 2). Encouraged by a 53 meter thick low resistive layer of 60 ohm m corresponding to the fractured basalt, a new dug-cum-bore well upto 60 m was suggested at the third location. The interpretation of the VES curves is shown in Table 2.

It can be observed from Table 2 that along VES1 and VES2 the weathered/fractured basalt formations show a resistivity of about 45 ohm m at depths of about 2-10 m, while at VES3 the weathered vesicular basalt of 30-40

Table 1. Resistivity ranges for different formations based on well sections and earlier studies (GSDA, 2010)

Type of Formation	Range of Resistivity
Top soil cover	10-20 ohm m
Weathered basalt	30-45 ohm m
Weathered to Massive basalt	40- 90 ohm m
Compact massive basalt	90-130 ohm m
Fractured basalt	60-90 ohm m
Compact massive basalt	> 130 ohm m

Table 2. Interpreted Results of VES along profiles 9010W, 9050W and 9090W.

Layer No	Interpreted geological formation	VES 1 P 9010W 440 m		VES 2 P 9050W 140 m		VES 3 P 9090W 230 m	
		Resistivity ohm m	Depth m	Resistivity ohm m	Depth m	Resistivity ohm m	Depth m
1	Top soil cover	8	1.2	10	1.5	23	2
2	Weathered Basalt	45	2.5	45	3	32	10
3	Weathered/Massive basalt	96	8.5	96	9	40	14.5
4	Compact massive basalt	145	37	145	21.5	90	23
5	Fractured basalt	73	54.5	93	39	60	53
6	Compact massive basalt	122		122		120	

ohm m was observed between 10 to 25 m depth. This can also be observed at 230 m distance in the VLF-EM pseudo depth section with the weathered basalt corresponding to a current density of 20-25% as dipping towards southeast (Figure 7b). Further, the bore well along near VES1 drilled up to 60 m in a vertical direction went dry as it did not pierce through the length of the aquifer due to its dipping nature. Based on this interpretation, a dug-well upto a depth of 14 m with a 6 m diameter and further a well bore to a depth of 46 m with a 160 mm diameter was recommended to exploit the total aquifer zones corresponding to the deeper horizons to cater to the needs of drinking and irrigation. The static water level during the summer month of April 2014 was observed to be 3.8 m at this location, which was very encouraging. Thus, the integration of VLF-EM and VES surveys has resulted in successful delineation of aquifer zones in the complex hydrogeological trap terrain.

CONCLUSIONS

Groundwater problems associated with the complex geology of the Deccan Basalt region can be resolved by integrating different geophysical approaches. The overlapping ranges of resistivity values of weathered basalt, vesicular basalt and fractured basalt even in closer proximities and their dipping nature in the subsurface lead to confusion in recommending well sites in trap terrain. The VLF-EM method in combination with the resistivity gradient profiling technique can help to resolve this issue and locate the aquifer zones. Never the less identifying of the direction of weathered or fractured zones is vital for groundwater exploitation in such a region. The failure of dug well or bore wells should not be attributed to non-availability of groundwater in the region, but drilling the bore wells in the direction of the weathered and fractured layers is also necessary. This methodology can be successfully applied in similar hard rock basaltic regions to address the existing drought situation to some extent.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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