Journal of Applied Geophysics 171 (2019) 103864

Contents lists available at ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

Vein width measurement of groundwater on Earth's surface using Semiconductor Laser Light and Proton Precession Magnetometer

N.P. Dharmadhikari [a,*], V.V. Muthekar [b], C.S. Mahajan [c], N. Basavaiah [d], A.G. Kharat [b], S.I. Barde [e], A.K. Sharma [f], M.S. Patil [g], M. Laxminarayana [d]

[a] Department of Engineering Physics, Sinhgad Academy of Engineering, Kondhwa, Pune 411048, India
[b] JSPM's RSCOE, Tathawade, Pune 411033, India
[c] Post Graduate Department of Physics, JES College, Jalana 431004, India
[d] Indian Institute of Geomagnetism, New Panvel, Navi Mumbai 410218, India
[e] Department of Electrical Engineering, Sinhgad Academy of Engineering, Kondhwa, Pune 411048, India
[f] School of Physics, Shri Mata Vaishnao Devi University, Katra 182320, India
[g] Department of Physics, Yeshwantrao Chavan College of Art, Commerce and Science, Sillod, Aurangabad 431112, India

ARTICLE INFO

Article history:
Received 23 July 2018
Received in revised form 21 August 2019
Accepted 3 October 2019
Available online 15 October 2019

Keywords:
Dowsing
Groundwater vein
Proton Precession Magnetometer
Semiconductor LASER Light Box
Hard rock terrain
Deccan Trap basalt

ABSTRACT

Near-surface geophysical methods such as Semiconductor LASER Light Box (SCLLB) and Proton Precession Magnetometer (PPM) coupled with Vertical Electrical Soundings (VES) and water dowsing approach are used to measure the vein width of Groundwater (GW) on the Earth's surface at fifteen locations in the Deccan Trap flood basalt area in Pune region, Maharashtra, India. The main objective is to validate old simple water dowsing way of GW detection in hard rock using the established modern science and technology namely VES, PPM and SCLLB techniques. On the basis of deflection of the L-shaped copper rods, the presence of GW with clues on the edges of GW vein is detected using the old traditional dowsing method. The efficacy of dowsing is verified by VES. It is found that apparent resistivity in the range from 48Ωm to 117Ωm over the GW location delineated by the dowser is relatively low, thus confirming the presence of GW in the study area. Variation in the intensity of Earth's Magnetic Field (EMF) measured by PPM is found in the range from 37,788nT to 43,242nT over GW locations. High magnetic intensity values indicated high GW potential in weathered vesicular-amygdaloidal basalt and magnetic field gradient changes enabled to calculate GW vein width. It is suggested that water dowsers might get a dowsing reaction as a result of entering into magnetic field gradient changes caused by GW. Digital barometer records the atmospheric pressure (P) and temperature (T) showing that both P and T are higher than the non-GW location which alters refractive index (RI) of medium over GW locations in the study area. A small change in RI alters the intensity of the semiconductor laser beam (≈234 μA to 1204 μA) indicating the edges of GW vein, thus giving the width of the vein. The results obtained by PPM and SCLLB match with dowsing responses. It is found that GW sources and width of GW vein (≈1 m to 6 m) in Deccan basaltic terrain can be measured quickly and with ease by using SCLLB in comparison to VES and PPM. It is concluded that the application of proposed modern instrumental measurement survey by PPM and SCLLB coupled with the old simple technology of water dowsing demonstrated the potential to generate a subsurface water resource database at the national level, especially in hard rock.

1. Introduction

The effect of location and its geophysical properties on detection of Groundwater (GW) has been known since ancient times. The near-surface geophysical survey is an indirect measurement to map the subsurface features including GW (Basavaiah, 2011; Nazaruddin et al., 2017). On the other hand, direct measurement of the Earth's radiation is also an important stage to characterize the subsurface conditions (Foulkes, 1971; Kristel, 2016). From ancient times, dowsers have used Y-shaped twig, pendulum, L-rods and other similar devices to detect GW vein (Hacker et al., 2008). When the dowser crosses GW vein, there is a reaction in the form of deflection in L-rods, swinging of Y-twig or gyration of a pendulum (Maby and Franklin, 1939; Croome, 1994; Bachler and Living, 2007). Dowsers were deployed to locate wells that could give perennial water since time immemorial. However, the phenomenon of dowsing is debatable and it poses challenges in front of researchers. Several researchers (Foulkes, 1971; Chadwick and Jensen, 1971; Harvalik, 1978; Betz, 1995; Enright, 1995; Jishan, 1995; Saunders, 2003; Carrubba et al., 2007) have presented their views

* Corresponding author.
E-mail address: sejalrohit2007@gmail.com (N.P. Dharmadhikari).

https://doi.org/10.1016/j.jappgeo.2019.103864
0926-9851/

related to accuracy in finding the Earth radiation caused by GW. However, till date dowsing phenomenon could not be accepted because it is a crude technique and does not give any numerical values or a reading (Kristel, 2016).

The study of the Earth's Magnetic Field (EMF) is considered as the earliest geosciences of the first true scientific treatise. When two different geological subsurface rocks are in contact, a conduction discontinuity is created that can weaken or potentiate the magnetic fluctuations (Rikitake and Honkura, 1986; Basavaiah, 2011). Since the beginning of the 19th century, significant changes in the GW exploration methods have been deployed (Bays, 1950; Emenike, 2001; Nazaruddin et al., 2017). The variations in the properties of subsurface furnish the basis for the five main methods of geophysical prospecting, namely electrical, gravitational, magnetic, radioactive and seismic (Page, 1968; Pluhowski, 1972; Zohdy et al., 1974; Kelly, 1977; Todd, 2007; Ling et al., 2016; Xuelong, 2018).

Generally, while conducting any geophysical investigation for exploration of GW, the basic principle of the geophysical method is to send some signals either in the form of electric current, seismic waves or in other forms and get the responses from the subsurface. The interpretation of signal variation results in existence or non-existence of sources such as the location of subsurface structural details, aquifers, spatial contact, petroleum, and mineral deposits. All these modern methods are lengthy, time-consuming and complicated as compared to the old traditional behavior and traits of nature by dowsing to explore GW sources (Dharmadhikari et al., 2011).

For instance, a small variation in atmospheric temperature (T) can cause variation in Refractive Index (RI) of air, which presents significant challenges for laser propagation (Ochs et al., 1969; Wesley, 1976; Andrews and Phillips, 2005). In the present paper, the same principle was used for developing a new GW exploration technique to identify edges of GW vein using Semiconductor LASER Light Box (SCLLB). The atmospheric pressure (P) and T were recorded in the SCLLB on the GW location identified by the dowser. On the same location, the intensity of the total EMF was measured using PPM. In order to authenticate the presence of GW, Vertical Electrical Sounding (VES) was carried out in the study area and the presence of GW was corroborated. The electrical resistivity method is one of the most promising techniques, which is well suited for the applications in the fields of geohydrology, environmental science and engineering (Urish and Frohlich, 1990; Barker and Moore, 1998; Yadav and Singh, 2007; Kumar et al., 2010).

The study of GW availability in the Deccan Trap flood basalt area is presented with a specific focus on the width of the GW vein and discussion of the science behind dowsing method. Also, an effort was made to provide scientific evidence for L-rod dowsing way of GW detection on Earth surface by the well-supported experimental evidence using the most sophisticated instruments, namely PPM and SCLLB. Recording and processing of multidisciplinary data provided complementary information to understand the subsurface with GW availability, especially in hard rock areas.

2. Geomorphological and hydrogeological setting of the study area

The field work was carried out at 15 locations in Pune region, Maharashtra within western Indian peninsula at $18^{0}31'$N Latitude and $73^{0}55'$E Longitude (Fig. 1a) between January–May 2016 and 2017. The study area included residential, non-residential areas and interstate highways situated in the valley of Mula and Mutha rivers on typical rugged Deccan topography (popularly known as Deccan Traps) with elevation difference between the highest and lowest point being 30 m. The mountain and hill ranges in the west, river basins with undulating topography at the center, and in the east highland plateaus with wider river basins mark the physical landscape of the region (Bhakare, 2010). Geomorphologically (Fig. 1b), the entire study region of Pune is mainly formed by two major parts of the Western Ghats and 2000 m thick multiple layers of Deccan basalts formed in the prolonged Deccan volcanic activity initiated in magnetochron 31R between 65 and 71 Ma during Late Cretaceous period (Basavaiah et al., 2018). Hydrogeological map in Fig. 1c shows that the study area is dominated by hard basaltic rocks with discontinuous lineaments and hilly terrain (Gabale, 2016).

The occurrence of GW in limited quantity within hard rock terrains such as Deccan Traps is well known. The type of basalt, its degree of weathering, and the nature and intensity of fracturing, control the occurrence and movement of GW resources in the Deccan basalt (Kulkarni et al., 2000). The main aquifer horizons occur in vesicular, fractured and weathered amygdaloidal basalts (Pawar, 1993). The inter-trap formations, such as red bole, also form aquifer horizons at places. The study area is dominated by zeolites as cavity fillings and veins in the basalt. The natural zeolites are characterized by water molecules in the pores and voids of the structure (Querol et al., 2002). This near-surface geophysical study was planned to understand the physical framework of basalts within which GW resides and moves.

3. Methodology

The methodology that has been utilized for carrying out this work was related to dowsing for GW, which is a qualitative aspect that has been well established since ancient time and has an accuracy of more than 90% (Bird, 1993). L-rod dowsing has been used in the present study to identify the edges of the GW vein. To confirm the GW veins identified by dowsing, VES stations were established at two Girivan locations (S.Nos. 10 and 11 in Table 1). The resistivity measurements were carried out using SSRMPAT computerized DC resistivity meter (Integrated Geo Instruments & Services Pvt. Ltd., Hyderabad, India) with permissible tolerance of ±5% by adopting the Schlumberger electrode configuration (Sharma and Baranwal, 2005; Mahmoudzadeh et al., 2012).

The VES data were processed and interpreted with curve-matching techniques using theoretically calculated master curves (Orellana and Mooney, 1966). To reconstruct the depth sections of the profiles, the measured data were plotted on a log-log graph with the apparent resistivity values on the y-axis and the distance in current electrode spacing (AB/2) on the x-axis for the electrical soundings. The interpretation of resistivity depth curves was done by curve matching technique of small segments of a field curve with an appropriate theoretical curve to calculate the thickness (h) and apparent resisitvity (ρa) of particular layers. The initial Earth models were double checked and reinterpreted using 1D modeling program (IPI2Win of Moscow State University, 2001) to obtain final Earth layered resistivity models (Bernard, 2003; Bureau of Indian Standards, 2007; Gurugnanam et al., 2018).

The newly-developed SCLLB by our group with measurement accuracy up to 1 μA was used on the edges of GW veins identified by the dowser. On observing the changes in the readings of the SCLLB, it was decided to use PPM on the same spots to check the EMF variability in the area. To further understand the effect on LASER light, atmospheric P and T were measured using digital barometer in the SCLLB over GW and non-GW locations. Thus, the qualitative aspect of dowsing was checked by quantitative aspects such as VES, SCLLB, atmospheric P and T and PPM.

4. Experimental procedure

4.1. Dowsing for identification of edges of Groundwater vein

In the study area, the dowsers moved in search position and wherever deflection of copper L-rods occurred, the point was marked. After crossing the identified edge, the L-rods were again brought in search position till they deflected again at the next edge of the GW vein. The dowser stood at the mid-point of the identified edges in search position of the L-rods for confirmation of GW existence. In case the L-rods deflected after some time, it was considered that the dowser is over the GW vein. If no deflection occurred in L-rods, it showed an absence

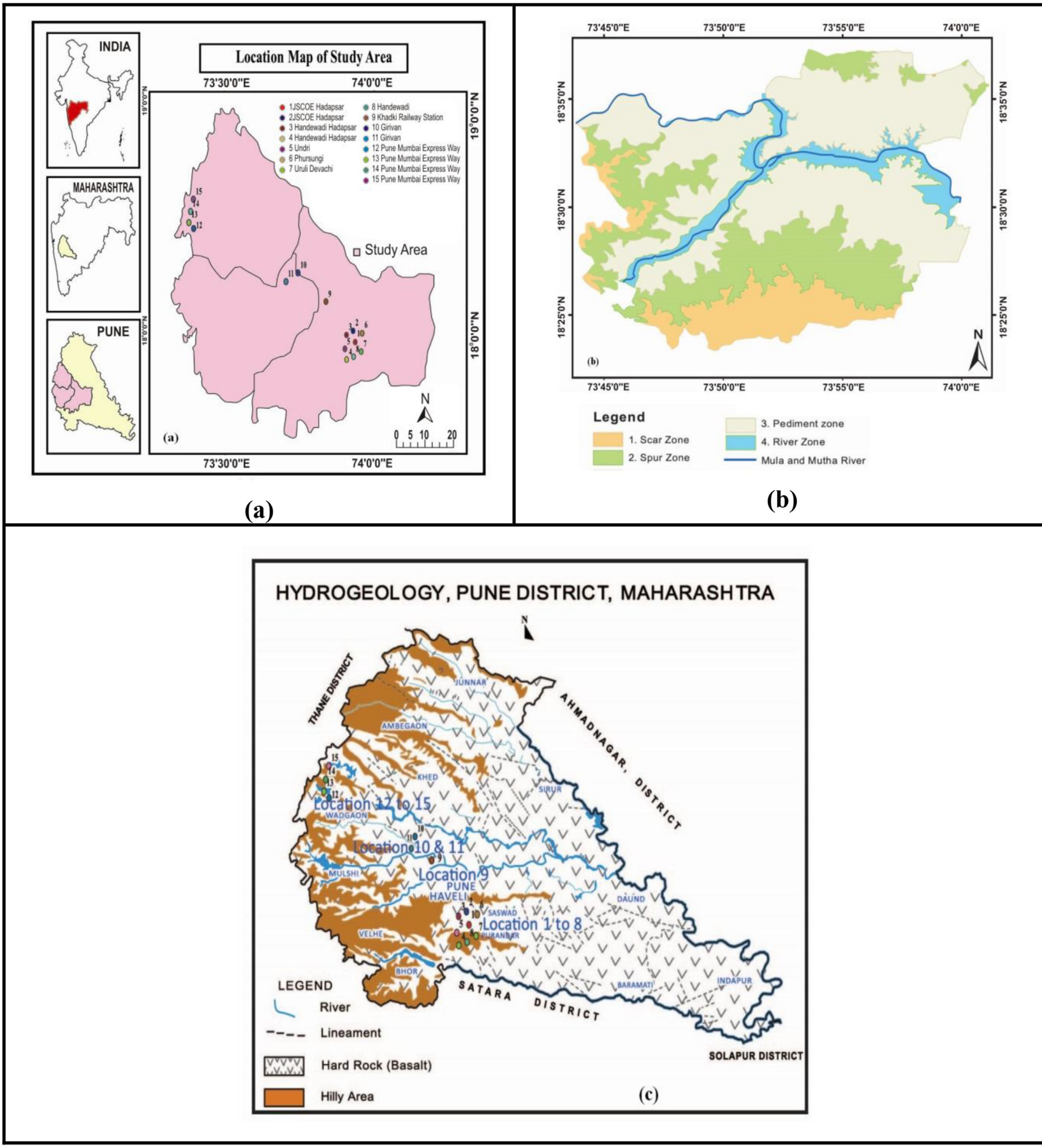


Fig. 1. Study area. (a): Map showing survey localities in Pune region along with inset maps of India, Maharashtra and Pune district, (b): Geomorphology of Pune city (Gabale, 2016), and (c): Hydrogeology of Pune district (Mishra, 2013).

of GW vein below. The dowser then moved criss-cross for establishing a number of edge points in the study area (Fig. 2). All such points were marked on site to form GW vein edges at that location.

4.2. Vertical Electrical Soundings and Semiconductor LASER Light Box

Further, the existence of GW was evaluated and confirmed using well-established VES method finding the GW potential in shallow subsurface zones of the locations identified by the dowser. A grid of 30 m × 30 m was plotted around the location confirmed by VES and dowser in the study area at an interval of 2 m aligned in North-South direction (Fig. 2). SCLLB was used to find the variations in the current (μA) on the same GW vein edges, where dowser had L-rod deflection. Following procedure was adopted for conducting the field test by using SCLLB:

a) Profile lines and grid point locations were made as shown in Fig. 3.
b) All the 15 locations were open plots on which a total of 3840 readings were taken.

Table 1
Observation showing variations in current data by Semiconductor LASER Light Box, Earth magnetic field intensity by PPM and width of Groundwater vein.

Location No.	Location		Current (μA) using Semiconductor LASER Light Box (SCLLB)		Variation in current (μA)	Total intensity of Earth's Magnetic Field (nT) using PPM		Variation in Earth's magnetic field (nT)	Groundwater (GW) Vein Width (m)		
	Latitude	Longitude	Non-GW (A)	GW (B)	A - B	Non-GW (C)	GW (D)	D - C	Dowsing	PPM	SCLLB
1	18°28′19.48″N	73°56′08.05″E	1800	800	1000	35,567	42,190	6623	4.9	5.9	6.0
2	18°28′19.26″N	73°56′10.93″E	1568	1002	566	34,456	38,023	3567	4.2	3.8	4.0
3	18°28′18.41″N	73°55′55.88″E	1347	345	1002	34,567	43,242	8675	1.8	2.3	2.0
4	18°27′14.36″N	73°55′47.77″E	1234	613	621	34,566	38,553	3987	4.8	5.0	4.9
5	18°27′13.36″N	73°55′45.77″E	1789	1204	585	34,578	37,788	3210	1.8	2.5	2.0
6	18°28′58.41″N	73°57′08.01″E	1234	234	1000	34,567	42,131	7564	4.7	4.9	5.0
7	18°37′11.03″N	73°44′47.62″E	1798	878	920	34,213	41,200	6987	1.8	1.8	2.0
8	18°45′49.41″N	73°23′11.81″E	1356	643	713	34,532	38,652	4120	2.7	2.7	3.0
9	18°27′16.08″N	73°57′24.54″E	1345	678	667	34,523	38,509	3986	4.8	4.8	5.0
10	18°33′34.46″N	73°50′38.86″E	1185	795	390	34,512	41,217	6694	4.9	6.0	5.9
11	18°49′10.20″N	74°21′18.21″E	1678	1050	628	34,534	38,479	3945	1.8	2.7	2.0
12	18°28′19.48″N	73°56′08.05″E	1117	388	729	34,678	39,245	4567	3.6	3.9	4.0
13	18°37′11.03″N	73°44′47.62″E	1088	345	743	34,123	39,111	4988	1.8	2.6	2.0
14	18°45′49.43″N	73°23′11.85″E	1233	367	866	35,234	41,217	5983	4.6	4.6	4.8
15	18°27′14.30″N	73°55′47.70″E	1100	401	699	35,324	39,474	4150	3.4	3.4	3.6

c) SCLLB was kept at each grid point to measure the current (Fig. 3). Between the identified edges of the GW vein, readings were taken precisely for GW vein width measurement (Table 1).
d) MSB780X portable standard barometer (5 to 35 V DC) device having pressure range 500 hPa to 1100 hPa (with resolution 0.001 hPa), temperature range -50 °C to +80 °C and relative humidity 0 to 100% was used to record atmospheric P and T in morning and evening sessions inside and outside GW vein edges. The average readings of atmospheric P and T were plotted for each location (see Fig. 7c and d).

4.3. Proton Precession Magnetometer

A total of 3840 field measurements were taken in the morning and evening sessions on the identified grid points and GW edges. An indigenous portable field PPM type 587, designed and assembled by Indian Institute of Geomagnetism, Navi Mumbai, India, was used to measure the total intensity of EMF over the range of 25,000 to 80,000nT with an accuracy of 1nT. The device used in this study consists of sensor and detector. Liquid water acts as a sensor, which is kept at 1 m - 3 m above the surface, representing a good compromise

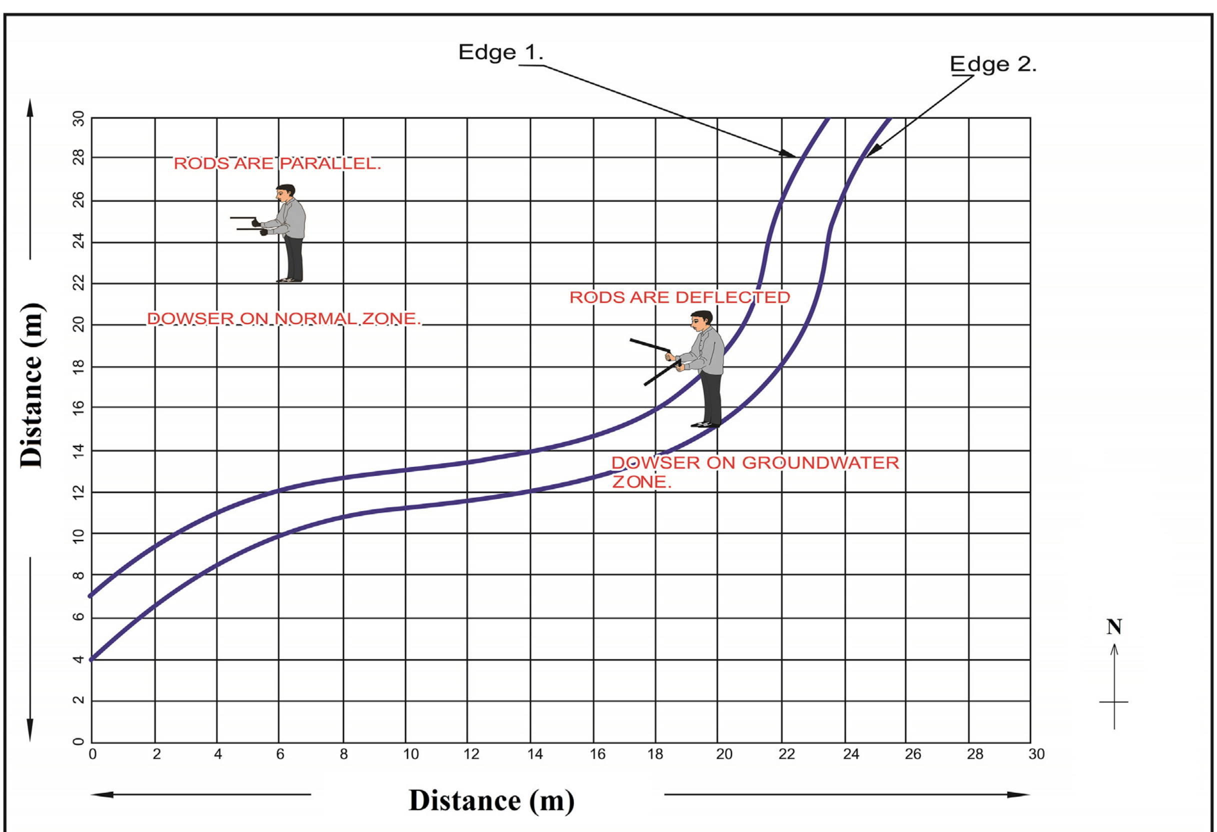


Fig. 2. Dowsing survey for identification of Groundwater vein.

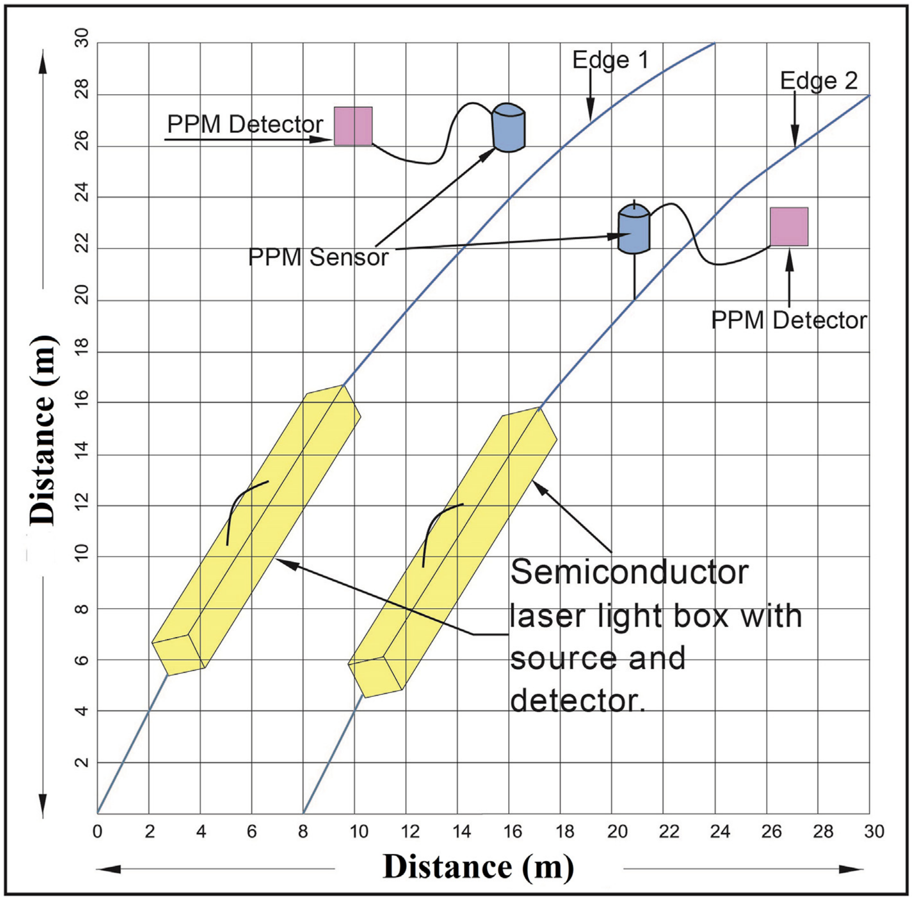


Fig. 3. Geophysical survey working principles of Semiconductor LASER Light Box (SCLLB) and Proton Precession Magnetometer (PPM) for identifying edges of Groundwater vein.

for a 2 m grid (Weymouth and Huggins, 1985). This vertical offset minimizes the effect of ground noise due to local magnetic mineral accumulations because the magnetic signal diminishes with increasing sensor height (Burger, 1992).

As the study area is mostly lying in and around Pune region, it was ensured that the magnetic observations are free from extraneous magnetic disturbances such as cars, fences, metal poles, AC power lines, buried metal pipes, or buildings with metal beams or metal doors that can easily overwhelm the magnitude of a local magnetic anomaly. The detector and sensor were connected by 5 m long two-core shielded wire. The sensor has to be mounted along the North-South direction (Fig. 3). The detector has a manual button and was used to take the reading. The proton in the water has a magnetic moment along the magnetic axis due to its spin. When the sensor is placed in the external magnetic field, torque was exerted due to magnetic movement along the spin axis.

In sum, the magnitude of the total intensity of EMF was measured using PPM at the same locations where dowser and SCLLB had predicated GW existence by following the same procedure as adopted for SCLLB.

5. Results and discussion

Dowsing, VES, PPM and SCLLB techniques were deployed in the study area. Two case studies at Girivan location (Table 1) are discussed below focussing on the interpretation of the geophysical results based on the integration of the various prospecting methods. The results of the comparative study among different techniques showed identical results revealing the detection of GW vein and its width.

5.1. Dowsing

The L-rods of the dowser deflected at the edges of the GW vein. At the Girivan location, dowser measured GW vein width 4.9 m. At 15 locations, the GW vein width was found to be from 1.0 m to 6.0 m. In the same study area, extensive work has been carried out by several researchers (Kharat, 2000; Pimplikar, 2010; Dharmadhikari et al., 2011; Sorate, 2016) to detect GW using L-rods. Kharat (2000) correlated GW existence with the well-being of human body and road accidents, while Pimplikar (2010) analyzed the effect on human aura over GW zones and Dharmadhikari et al. (2011) studied the effect of GW radiation on the human system. In his studies, Sorate (2016) identified that the major cause of road accidents on certain spots in Mumbai-Pune expressway was GW veins.

The research carried out till date and the advances made in the area of dowsing indicate that human body has characteristics of detecting subtle changes in the environment, but are censored because of the knowledge to other prominent areas in order to avoid chaos in the thinking process. Dowsing is a process and it sets up the conditions of the unfolding of awareness. Our nervous system is a biological antenna ~45 km long if each cell in the system is joined. This antenna picks up the subtlest signals from the environment (Ross and Wright, 1990).

One school of thought is that the dowser can program this antenna (human body) to detect GW vein edges. Dowsing devices, such as L-rods, can be programmed by the dowser to deflect when walking over the edges of the GW vein. There is a possibility that copper L-rods are deflecting at specific locations because of dowser entering the magnetic field gradient changes due to GW. The second school of thought is that piezoelectric potentials are developed in the human body while walking. The surface voltage in the body ranges from

10 mV to150mV (Charman, 1996). It was found that while entering in the GW zone, the surface voltage in the body increases from 150 mV to 250 mV (Dharmadhikari et al., 2011). These surface voltages in the body are transferred to the conducting material such as the L-rods or Y-twig held in the palms of the dowser in search position (Fig. 4a). On stepping on the edge of the GW vein, the charges produced due to the movement of GW on the Earth surface are encountered by the charged rods in the hands of the dowser, causing deflection of L-rods (Fig. 4b).

However, dowsing phenomenon involves tuning the sensitivity of human to the Earth radiations due to GW, which the human body generally neglects as these are very subtle. However, training the human body to detect these radiations is possible. It is observed that throughout the world, Dowsing Societies have trained many people and they have had consistent results (Robert, 2018). Although considerable research has been done on dowsing, its status remains uncertain. Therefore, there is a need to gain a better understanding of the process of evaluating its status in geophysical realms. This paper attempts to clarify this problem. It is noteworthy that in-depth studies in dowsing have opened new vistas for further exploration and identification of GW veins in Deccan Trap basalts.

5.2. VES analysis

Results from Fig. 5 suggest the resistivity models whose estimated apparent resistivity best fit the measurements of the VES field curves. The resistivity values of VES data collected from two Girivan sites revealed that the area is characterized by mostly three to four distinct geoelectric layers (Fig. 5). The lithological formations in this study area include the basaltic lava flows consisted of vesicular, amygdaloidal and compact basalts (Kulkarni et al., 2005). The GW resource potential is controlled by the degree of weathering, geomorphological and geological features, such as the size and distribution of vesicles, and the frequency and interconnection of joints and fractures (Kulkarni et al., 2000). Groundwater in the region mainly exists in shallow semi-weathered basalts and under subsurface semi-confined conditions in the zones of vesicular, fissured and fractured amygdaloidal basalts (Kulkarni et al., 2000; CGWB, Central Ground Water Board, 2013). In general, lithology plays a significant control over weathering of rocks and GW potential.

5.2.1. VES 1 curve

Three layers were identified in VES 1 using interpretation of master curves of HKQ types (Fig. 5a). It is inferred that the average resistivity (Ωm) of the 1st top layer of black cotton soil 1.3 m thick, composed of clay and weathered fragments of basalts is of 180, the 2nd layer is 117 and the 3rd layer is 195 of 32 m thick (Fig. 5a). The area of low apparent resistivity indicates the occurrence of relatively good conductors, while those with high values indicate poor conductors (Prasanna et al., 2008). Low resistivity values (<117Ωm) in the second layer of 6.7 m thickness indicated GW potential in weathered and vesicular amygdaloidal basalts at the 1.3 m to 8.0 m depths, while high resistivities (>180 Ωm) suggested a low GW potential (Fig. 5a).

5.2.2. VES 2 curve

The interpreted VES 2 results revealed four geoelectric layers using HKQA type curves (Fig. 5b). The first layer is the top black cotton soil with resistivities (<125Ωm) and 1.3 m thickness. It is underlain by semi-weathered amygdaloidal basalt layer with resistivity of 81.25Ωm and 1.3 m thickness. Amygdaloidal basalt with red bole in the third layer showed thickness and resistivity 12.5 m and 195Ωm, respectively. The 16 m thick fourth layer of fissured, fractured, and vesicular amygdaloidal basalt has resistivity of 48Ωm (Fig. 5b). The characteristic low resistivity values (high conductivity values) in the second ($\rho_2 = \sim 81\Omega m$) and fourth ($\rho_4 = \sim 48\Omega m$) suggested a high GW potential in the depth range of 1.3 m - 2.6 m and 12.5 m - 22.5 m, while high resistivities (>125Ωm) indicated a low GW potential at VES 2 location (Fig. 5b).

The resistivity results revealed that the low resistivity zones showed weathered basalts, while the high resistivity indicated presence of compact hard rock terrain. The identified four subsurface layers have resistivity values ranging from 48Ωm to 195Ωm. Low resistivity values mean that the subsurface material allow electrical currents to flow through it easily. Low resistivity layers could also be associated with GW aquifers (Telford et al., 1990). When a water zone range is detected, the drop in electrical resistivity value is significant (Fig. 5). From these characteristic observations, the depths of GW at two Girivan locations (Fig. 1) were observed approximately in the range of 1.3 m - 8.0 m (VES 1) and 12.5 m - 22.5 m (VES 2) in the highly weathered and vesicular amygdaloidal basalt. At 15 sites, it is expected that the apparent resistivity might vary in the range between 48Ωm and 117Ωm over the GW location that was earlier identified by the dowser, whereas over

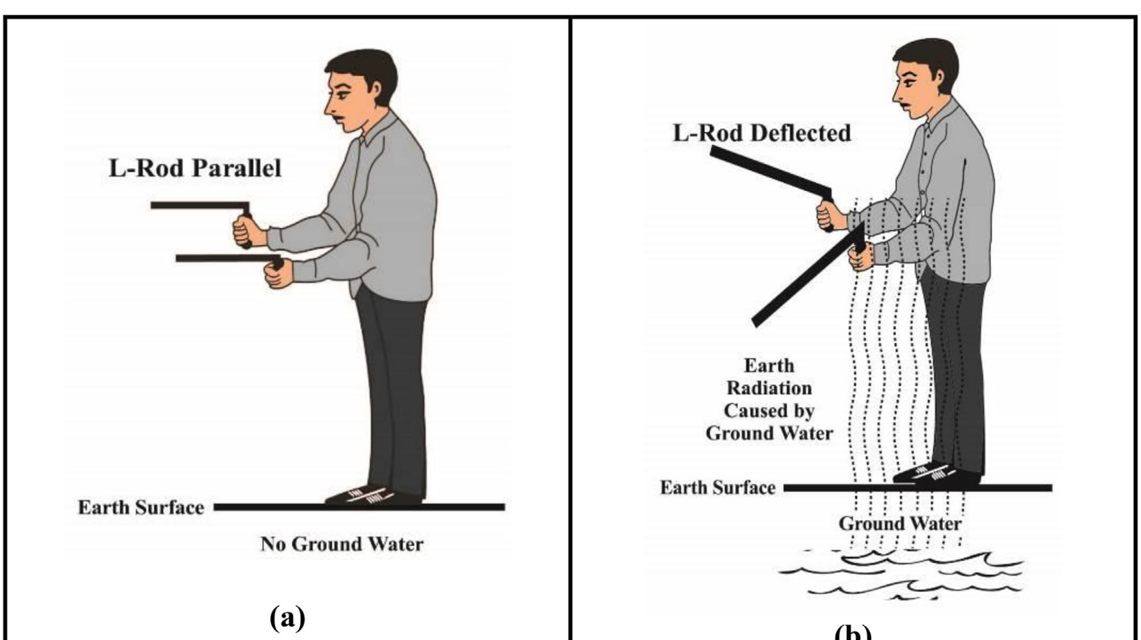
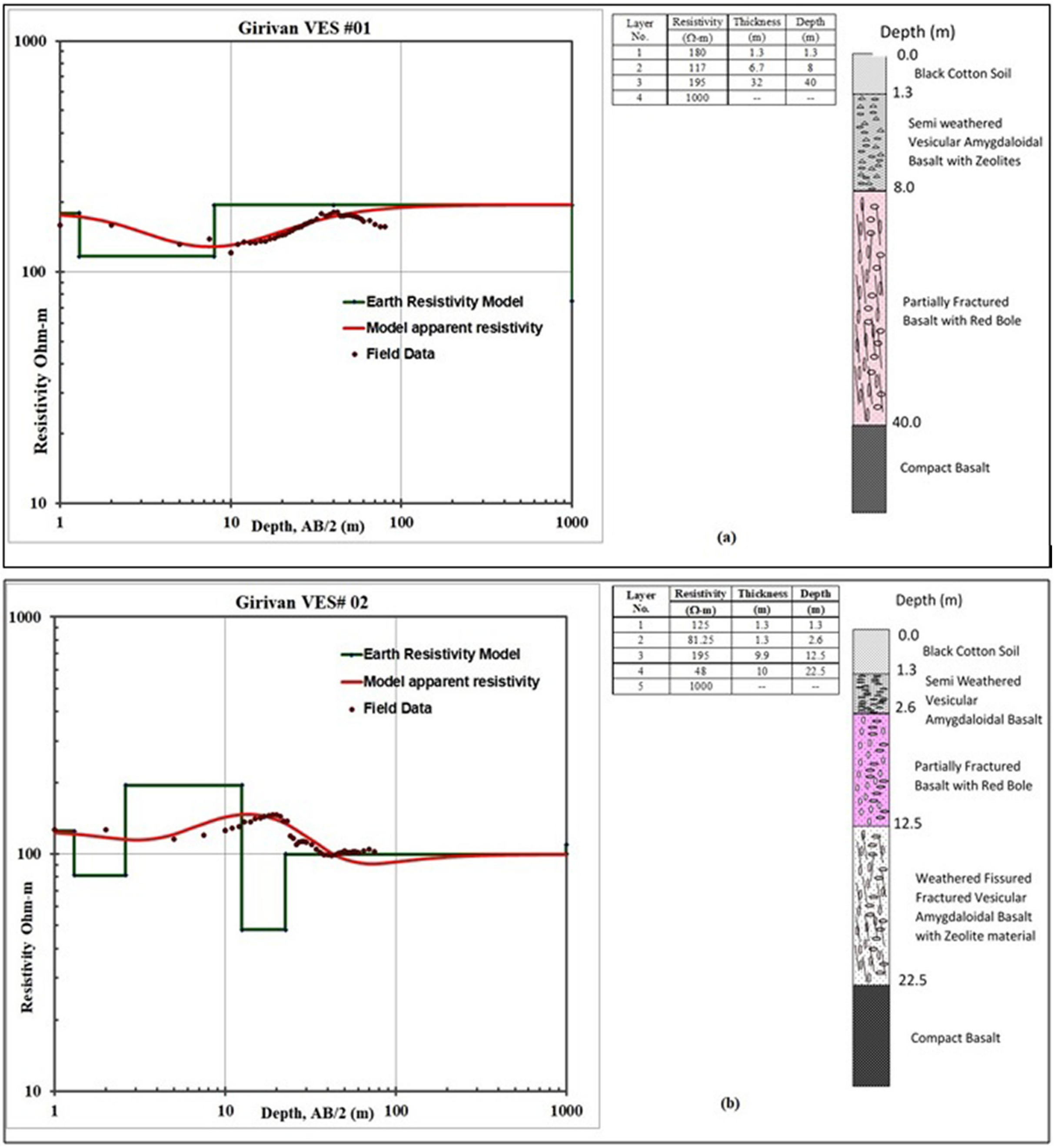


Fig. 4. (a): Search position of L-rods and (b): Deflection of L-rods at the edge of Groundwater vein.



Layer No.	Resistivity (Ω-m)	Thickness (m)	Depth (m)
1	180	1.3	1.3
2	117	6.7	8
3	195	32	40
4	1000	--	--

Layer No.	Resistivity (Ω-m)	Thickness (m)	Depth (m)
1	125	1.3	1.3
2	81.25	1.3	2.6
3	195	9.9	12.5
4	48	10	22.5
5	1000	--	--

Fig. 5. The apparent resistivity curves for the Vertical Electrical Sounding (VES) at two Girivan locations superimposed on the best-fit models of (a): three-layers for VES #1 and (b): four-layers for VES #2. On the right, the figure shows the table summarizing the layer resistivities and thickness with inferred lithostratigraphic section.

the non-GW locations, the values might exceed 117Ωm (Fig. 5). The availability of GW depths as per VES surveys was found to be a minimum of 2.6 m and maximum of 22.5 m on the locations in the study area.

5.3. Proton Precision Magnetometer

The PPM ground magnetic survey measuring the intensity of the total EMF was performed to estimate subsurface occurrence of GW veins within the Deccan Trap sequence at Girivan location (Fig. 1). Fig. 6a shows the contour map of the total EMF intensity over the same location, where GW vein was identified previously using dowsing (Fig. 4) and confirmed by measurements of VES (Fig. 5).

At all locations, over the non-GW zone, the total EMF intensity was observed to be in the range of 34,123nT to 35,567nT with an average magnetic intensity of 34,845nT. On the GW location, the variation in the total intensity of EMF was observed in the range of 37,788nT to 43,242nT, mean 40,515nT. The average intensity of EMF (~40,515nT) over GW zone was observed to be higher than the magnetic field intensity (~34,845nT) over the non-GW zone.

Generally, weathered and fractured hard rock saturated with GW depletes magnetic intensity. However, high magnetic intensity values suggested GW, whereas low magnetic intensity suggested non-GW (Fig. 6a). Several possibilities of the results about changes in magnetic intensity are discussed. Weathering, fracturing and vesicular state of basaltic rocks all have important effects on the magnetization of crustal rocks (Basavaiah, 2011). Rock magnetic properties indicated that Low-Temperature Oxidation (LTO) process, governed by weathering and water saturation of soils, is found to be quite common in titanomagnetites from Deccan Trap basalts (Basavaiah and Khadkikar,

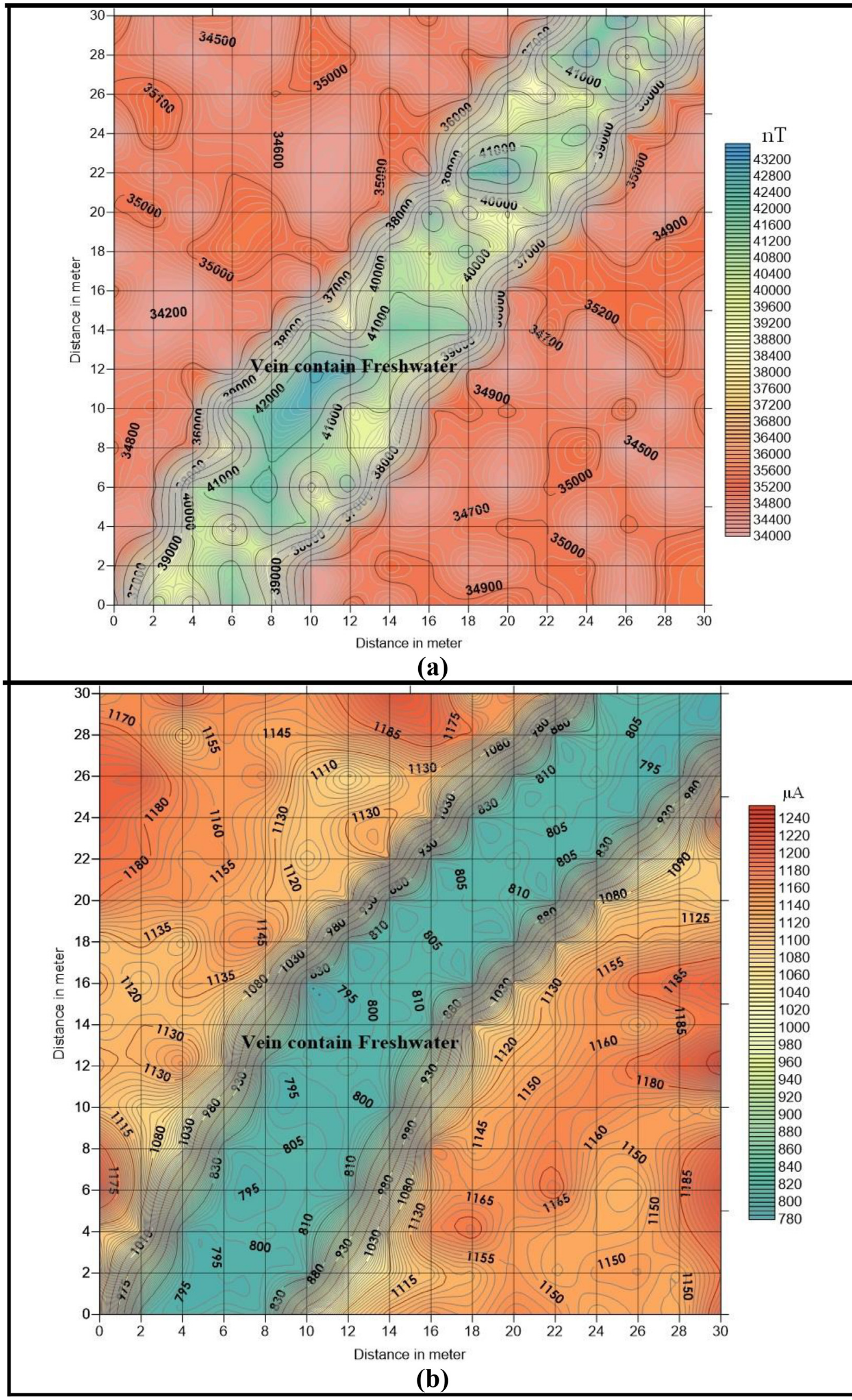


Fig. 6. Contour maps superimposed on measured grid at Girivan location. (a): The intensity of the total Earth Magnetic Field (nT) data obtained from PPM survey and (b): Current (µA) data from readings of Semiconductor LASER Light Box, which is designed and developed by our team for the present study.

2004; Basavaiah, 2011; Basavaiah et al., 2015; Xuelong, 2018; Basavaiah et al., 2019). Newly produced magnetite during LTO process of titanomagnetite might be responsible for high magnetic intensity values in GW zone and could be a causative source for the low resistivity and a high GW potential (Fig. 5). Under the magnetization of the EMF, the newly formed magnetic mineral (magnetite) can produce a magnetic field, which influence the in situ magnetic field distribution causing high magnetic intensity. In contrast, the LTO of titanomagnetites to magnetite is not significant in less weathered or unaltered non-GW zones explaining the fall in magnetic intensity values and high resistivity values (Fig. 5). Therefore, it is interpreted that high magnetic intensity contoured in the GW veins represented the effects of weathering by LTO (Fig. 6a).

PPM was moved in the same manner as the dowser walks over the terrain. At the point of increase in a magnetic field, the edge was marked and further moved to the point where magnetic field decreased, and the second edge of GW vein was marked (Fig. 7b). These coincided with the findings of the GW vein edges by the dowser.

5.4. Semiconductor LASER Light Box

The SCLLB at the identified zone of GW vein showed a sharp decrease in current readings in comparison with non-GW location (Fig. 7a). The drop in a variation of current readings was in the range from 1800 to 566 μA over investigated 15 GW locations. Fig. 6b indicates the contour map of current obtained from SCLLB readings (μA) at Girivan location. At the same location, the existence of GW vein was specified previously by dowsing and VES.

As the number of air molecules varies, the RI changes. It is given by the equation,

$$C = \frac{P}{K\,T} \tag{1}$$

where, C = No. of air molecules per unit volume, P/T = Atmospheric P (hPa) and T (Kelvin) and K = Boltzmann constant.

$$n = 1 + \left(\frac{77.6P}{T}\left[1 + \frac{0.00753}{\lambda^2}\right]X10^{-6}\right) \tag{2}$$

where n = RI and λ = Wavelength (nm) (Valley, 1965).

It was observed that atmospheric P and T were higher over GW zone in comparison with non-GW zone (Fig. 7c–d). This resulted into decreased RI and number of air molecules inside the SCLLB, indicating a rarer medium and inducing refraction of LASER beam in the SCLLB which caused decrease in current readings (Fig. 8a and b). In the study area, the GW vein width was observed in the range of 1.0 m to 6.0 m by using SCLLB.

The above discussions revealed that various GW investigation techniques, viz. dowsing, VES, PPM and SCLLB method are capable of

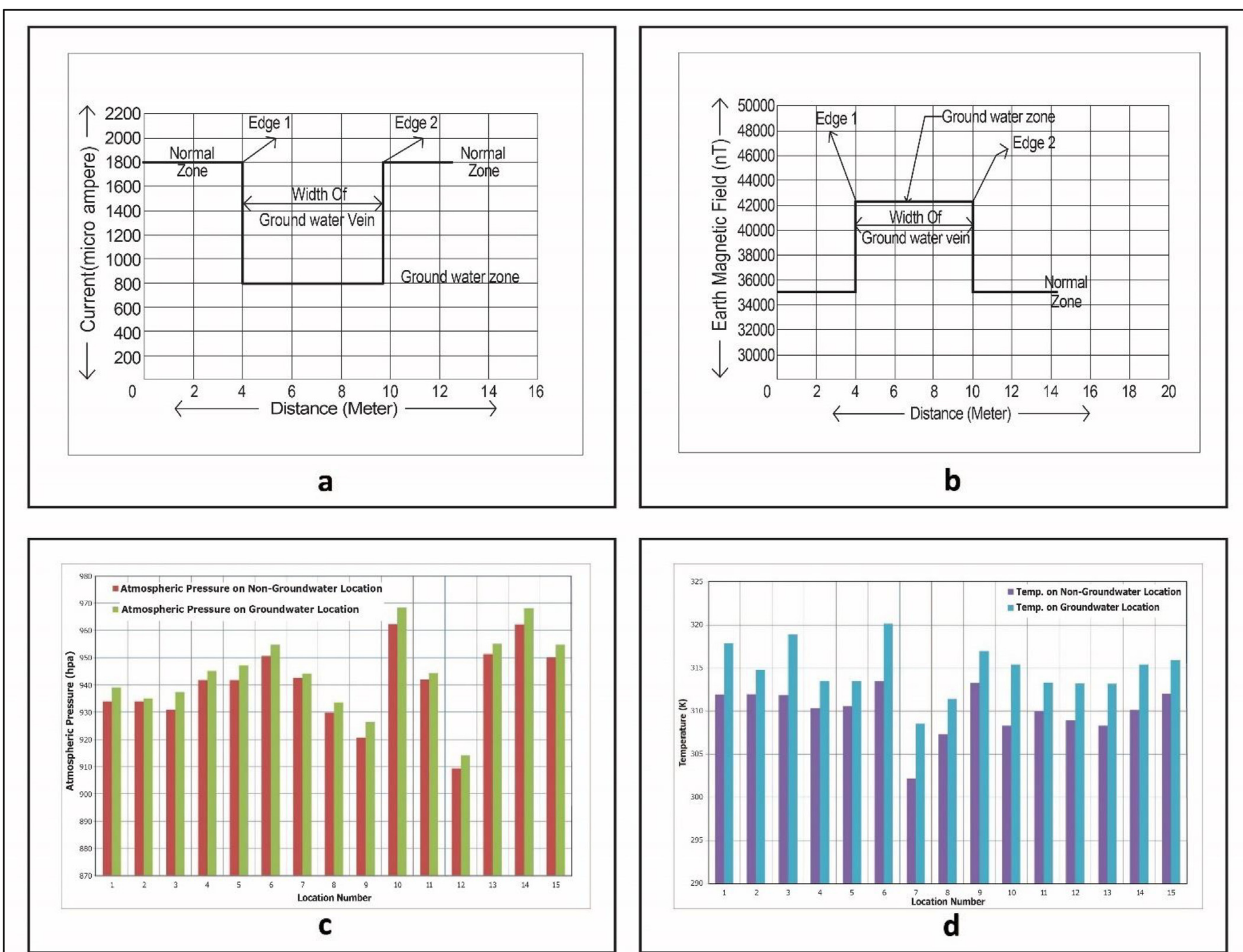


Fig. 7. Calculation of width of Groundwater Vein from: (a): Current data (μA) using SCLLB, (b): Intensity of the total Earth Magnetic Field (nT) data using PPM and (c-d): Monitoring of atmospheric pressure (hPa) and temperature (K) with respect to location.

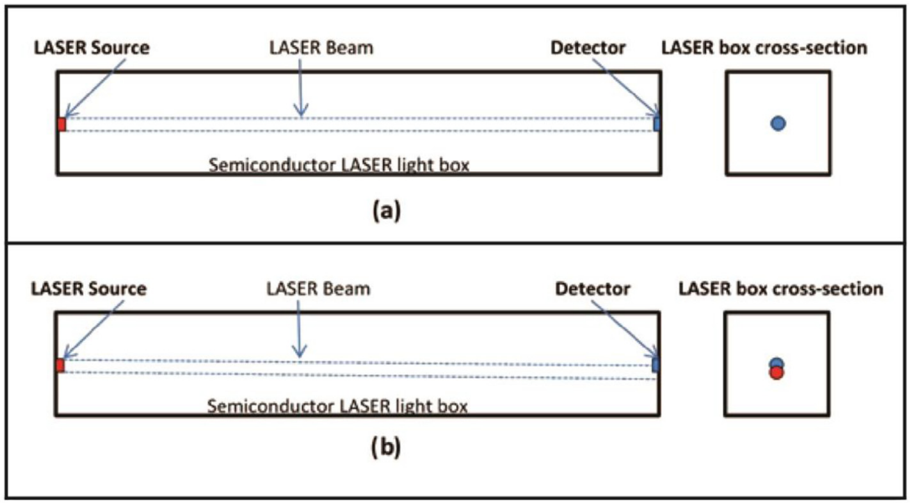


Fig. 8. Sketch showing the propagation of LASER light beam through media. (a): Non-Groundwater and (b): Groundwater (refraction).

successful exploration of GW at the site. Analysis of GW extracted at all the locations identified by all mentioned techniques showing physical, chemical and microbiological properties are within permissible limits and it is concluded that extracted water is drinkable. Each method has certain conditions under which it gives satisfactory results. Conduction of VES and PPM at the site requires large test setup, manpower and specialized skill for result interpretation.

As aforementioned, although VES and PPM are proven techniques for identification of GW resources, such techniques have not yet been fully utilized for GW exploration under conditions of congested building arrangement, dry soil zones at large depth, and electric facilities at the ground surface near test setup. However, the utility of SCLLB is highlighted in circumventing the limitations associated with modern instrumental surveys for exploration of GW in Deccan Trap flood basalt terrain.

6. Conclusions

The assessment of GW zones is limited in hard rock areas of Deccan volcanic region, as of the present study area. This necessitated the application of modern geophysical methods to delineate and identify the subsurface GW potential zones by using combined VES, PPM and SCLLB surveys that provided data for the reliable GW exploration in hard rocks.

Dowsing has been deployed since time immemorial to locate hidden treasure like GW, coal, minerals and heavy metals before quantifiable scientific gadgets came into existence. However, earlier it was considered that only those who have divine powers were able to practice dowsing. The recent understanding of the human body showed that it has the capacity to detect GW resources. As dowser walks over GW region L-rods deflected showing that a certain percentage of Earth radiations interacted with electrophysiological nature of the human body.

The VES method was applied to describe lithologic units as a function of depth depending on their electrical resistivity contrast. It is concluded that VES data provided a good indication for water-bearing weathered vesicular-amygdaloidal basalts, thus indirectly confirming the GW existence at all studied locations. For example, low resistivity readings in the range between 48Ωm and 117Ωm of the study area suggested a high GW potential, while high resistivity values (>125 Ωm) suggested a low GW potential. The present paper emphasized that radiations coming from GW location are of electromagnetic nature and there was a change in atmospheric P and T over the GW veins. The human body has the ability to detect these subtle changes over GW veins.

For more comprehensive results, the newly-developed SCLLB provided a quantifiable result to identify the edges of GW vein. In this study, the validation of SCLLB was done with the help of PPM by identifying GW-bearing vein edges of the study area with high magnetic intensity values in the range from 37,788nT to 43,242nT with the average intensity 40,515nT. It is suggested that water dowsers might get a dowsing reaction when entering into the geomagnetic field gradient changes caused by GW. A maiden attempt was made to identify air medium as rarer on GW zone than on non-GW zone and thus the refraction of the LASER light in the SCLLB occurred over GW vein giving quantifiable change in current (≈234 μA to 1204 μA).

It is shown that a combination of the archaic method of dowsing using L-rods and SCLLB provided the GW vein width (≈1 m to 6 m) in the study area. It may be inferred that over GW vein location, exposure of Earth radiations is more in case wider GW vein width. This integrated geophysical study demonstrated that the GW veins and their width can be measured advantageously by using SCLLB in comparison to VES and PPM in Deccan basaltic terrain. The right mix of technology and traditional wisdom developed in the present study would help to generate reliable subsurface GW resource database, especially in the Deccan Trap flood basalt region.

Acknowledgements

The authors are thankful to Dept. of Physics, Shivaji University for making available PPM and H.P. Gaikwad and Onkar B. Gurav for help in installation and observations of PPM and V.J. Jacob for discussion on ground magnetic survey. Also, authors are thankful to Board of College and University Development (BCUD), Savitribai Phule Pune University for providing financial support for research work.

References

Andrews, L.C., Phillips, R.L., 2005. Laser Beam Propagation through Random Media. SPIE Optical Engineering Press.
Bachler, K., Living, J.M., 2007. Earth Radiation. Word Asters Ltd. (ISBN 978-4357-0246-2).
Barker, R., Moore, J., 1998. The application of time-lapse electrical tomography in groundwater studies. Lead. Edge 17 (10), 1454–1458.
Basavaiah, N., 2011. Geomagnetism: Solid Earth and Upper Atmosphere Perspectives. Springer Science & Business Media.
Basavaiah, N., Khadkikar, A.S., 2004. Environmental magnetism and palaeomonsoon. J. Ind. Geophys. Uni. 8, 1–77.
Basavaiah, N., Mahesh Babu, J.L.V., Gawali, P.B., Naga Kumar, K.Ch.V., Demudu, G., Prizomwala, S.P., Hanamgond, P.T., Nageswara Rao, K., 2015. Late Quaternary environmental and sea level changes from Kolleru Lake, SE India: Inferences from mineral magnetic, geochemical and textural analyses. Quat. Int. 371, 197–208.
Basavaiah, N., Satyanarayana, K.V.V., Deenadayalan, K., Prasad, J.N., 2018. Does Deccan volcanic sequence contain more reversals than the three-Chron N-R-N flow

magnetostratigraphy? – a palaeomagnetic evidence from the dyke swarm near Mumbai. Geophys. J. Int. 213, 1503–1523.
Basavaiah, N., Deenadayalan, K., Mahesh Babu, J.L.V., Kanu, M.O., Naga Kumar, K.C., Demudu, G., Nageswara Rao, K., Mallikarjunarao, N., 2019. Last 3,000 years of geomagnetic field intensity from India: New reference palaeointensity data from two east coast archaeological sites and archaeomagnetic dating insights. J. Archaeol. Sci. Rep. 27, 101943. https://doi.org/10.1016/j.jasrep.2019.101943.
Bays, C.A., 1950. Prospecting for groundwater-geophysical methods. J. Am. Water Works Assoc. 42, 947–956.
Bernard, J., 2003. Short Note on the Depth of Investigation of Electrical Methods. IRIS Instruments http://www.iris-instruments.com/Pdf_file/Resistivity_Imaging/methods_depth_investigation.pdf.
Betz, H.D., 1995. Unconventional water detection: field test of the dowsing technique in dry zones: part 1. J. Sci. Explor. 9, 159–189.
Bhakare, P., 2010. Spatio-temporal Changes in Population Structure of Pune Division of Maharashtra. Ph.D. Thesis. Shivaji University, Kolhapur.
Bird, C., 1993. Divining Hand. Shiffer Publishing, USA.
Bureau of Indian Standards (BIS), 2007. Geological Exploration by Geophysical Method (Electrical Resistivity) - Code of Practice. BIS 15736, Manak Bhavan, New Delhi, India.
Burger, H.R., 1992. Exploration Geophysics of the Shallow Subsurface. Englewood Cliffs, Prentice Hall.
Carrubba, S., Frilot II, C., Chesson Jr., A.L., Marino, A.A., 2007. Evidence of a nonlinear human magnetic sense. Neuroscience 144 (1), 356–367.
CGWB, Central Ground Water Board, 2013. Ground water information of Pune district, Maharashtra. Technical Report. Ministry of Water Resources, Govt. of India, Central Region, Nagpur.
Chadwick, D.G., Jensen, L., 1971. The detection of magnetic fields caused by groundwater. Reports Paper 568. Res. Lab, Utah Water https://digitalcommons.usu.edu/water_rep/568.
Charman, R.A., 1996. Electrical properties of Cells and Tissues. In: Kitchen, S., Bazin, S. (Eds.), Clayton's Electrotherapy. WB Saunders Co. Ltd, London.
Croome, D.J., 1994. The effect of geopathic stress on building occupants. Renew. Energy 5 (5), 993–996.
Dharmadhikari, N.P., Mesharam, D.C., Kulkarni, S.D., Kharat, A.G., Pimplikar, S.S., 2011. Effect of geopathic stress on human body voltage and skin resistance. J. Eng. Technol. Res. 3 (8), 255–263.
Emenike, E.A., 2001. Geophysical exploration for groundwater in the sedimentary environment: a case study. Global J. Pure Appl. Sci. 7 (1), 97–102.
Enright, J.T., 1995. Water dowsing: the Scheunen experiments. Naturwissenschaften 82 (8), 360–369.
Foulkes, R.A., 1971. Dowsing experiments. Nature 229, 163–168.
Gabale, S.M., 2016. Impact of urbanization on the geomorphic environment of Pune and surrounding. Ph.D. Thesis, Dept. Geography. Tilak Maharashtra Vidyapeeth. Pune, India lib.unipune.ac.in.
Gurugnanam, B., Suresh, M., Manokaran, K., Vasudevan, S., Kumaravel, S., 2018. IPI2Win Software usage for the interpretation of sub-surface water in Sirukattur Village, Cuddalore District, Tamilnadu (India). J. Ultra Scientist Phy. Sci. 21 (1), 29–36.
Hacker, G.W., Eder, A., Augner, C., Pauser, G., 2008. Geopathic Stress Zones and their Influence on the Human Organism. Proceedings of the congress on Earth's Fields and Their Influence on Human Beings, Druskininkai, Lithuania, pp. 8–17.
Harvalik, Z.V., 1978. Anatomical localization of human detection of weak electromagnetic radiation: experiments with dowsers. Physiol. Chem. Phys. 10 (6), 525–534.
Jishan, H., 1995. Geoelectromagnetic Fields and their Frontiers of Study. Bull. National Sci. Found. China 2, 14.
Kelly, W.E., 1977. Geoelectric sounding for estimating aquifer hydraulic conductivity. Groundwater 15 (6), 420–425.
Kharat, A.G., 2000. Empirical and theoretical investigation on built environment. Ph.D. Thesis. SP Pune University lib.unipune.ac.in.
Kristel, K., 2016. Dowsing as a link between natural and supernatural. Folkloristic reflections on water veins, Earth Radiation and Dowsing Practice. Ph.D. Thesis. University of Tartu.
Kulkarni, H., Deolankar, S.B., Lalwani, A., Joseph, B., Pawar, S., 2000. Hydrogeological framework of the Deccan basalt groundwater systems, west-central India. Hydrogeol. J. 8, 368–378. https://doi.org/10.1007/s100400000079.
Kulkarni, H., Badarayani, H., Phadnis, V., Robb, R., 2005. Detailed case study of Kolwan valley, Mulshi taluka, Pune district, Maharashtra. AGRAR Project, Final Case Study www.bgs.ac.uk/hydrogeology/agrar.
Kumar, D., Rao, V.A., Nagaiah, E., Raju, P.K., Mallesh, D., Ahmeduddin, M., Ahmed, S., 2010. Integrated geophysical study to decipher potential groundwater and zeolite-bearing zones in Deccan Traps. Curr. Sci. 98 (6), 803–814.
Ling, C., Xu, Q., Zhang, Q., Ran, J., Lv, H., 2016. Application of electrical resistivity tomography for investigating the internal structure of a translational landslide and characterizing its groundwater circulation (Kualiangzi landslide, Southwest China). J. Appl. Geophys. 131, 154–162.
Maby, J.C., Franklin, T.B., 1939. The Physics of the Divining Rod. George Bell and Sons Ltd., London.
Mahmoudzadeh, M.R., Francés, A.P., Lubczynski, M., Lambot, S., 2012. Using ground-penetrating radar to investigate the water table depth in weathered granites-Sardon case study, Spain. J. Appl. Geophys. 79, 17–26.
Mishra, S.S., 2013. Groundwater Information of Pune District, Maharashtra. Report. Central Ground Water Board, Govt. of India, Nagpur, India.
Moscow State University, 2001. IPI2Win, Ver. 2.1 User's Guide.
Nazaruddin, D.A., Amiruzan, Z.S., Hussin, H., Jafar, M.T.M., 2017. Integrated geological and multi-electrode resistivity surveys for groundwater investigation in Kampung Rahmat village and its vicinity, Jeli district, Kelantan, Malaysia. J. Appl. Geophys. 138, 23–32.
Ochs, G.R., Bergman, R.R., Snyder, J.R., 1969. Laser-beam scintillation over horizontal paths from 5.5 to 145 km. JOSA 59 (2), 231–234.
Orellana, E., Mooney, H., 1966. Master Tables and Curves for Vertical Electrical Sounding over Layered Structures. Interciencia, Madrid.
Page, L.M., 1968. Use of the electrical resistivity method for investigating geologic and hydrologic conditions in Santa Clara County, California. Groundwater 6 (5), 31–40.
Pawar, N.J., 1993. Geochemistry of carbonate precipitation from groundwater in basaltic aquifers: an equilibrium thermodynamic approach. J. Geol. Soc. India 41, 119–131.
Pimplikar, S.S., 2010. Empirical and theoretical investigations of accidents on expressways and national highways. Ph.D. Thesis. SP Pune University lib.unipune.ac.in.
Pluhowski, E.J., 1972. Hydrologic interpretations based on infrared imagery of Long Island, New York. Geol. Survey Water-supply Paper 2009-B. United States Government Office, Washington.
Prasanna, M.V., Chidambaram, S., Pethaperumal, S., Srinivasamoorthy, K., John Peter, A., Anandhan, P., Vasanthavigar, M., 2008. Integrated geophysical and chemical study in the lower subbasin of Gadila River, Tamilnadu, India. Environ. Geosci. 15 (4), 145–152.
Querol, X., Moreno, N., Umana, J.C., Alastuey, A., Hernandez, E., Lopez-Soler, A., Plana, F., 2002. Synthesis of zeolites from coal fly ash: an overview. Int. J. Coal Geol. 50 (1–4), 413–423.
Rikitake, T., Honkura, Y., 1986. Solid Earth Geomagnetism. Scientific Publishing, Tokyo, pp. 296–325.
Robert, E., 2018. The Silent Killer below Hunting and Healing Geopathic Stress. Three Mile Point Publishing, USA, pp. 1594–1866.
Ross, T.E., Wright, R.D., 1990. The Diving Mind. Destiny Books, USA.
Saunders, T., 2003. Health hazards and electromagnetic fields. Complement. Ther. Nurs. Midwifery 9 (4), 191–197.
Sharma, S.P., Baranwal, V.C., 2005. Delineation of groundwater-bearing fracture zones in a hard rock area integrating very low frequency electromagnetic and resistivity data. J. Appl. Geophys. 57 (2), 155–166.
Sorate, R.R., 2016. Empirical and theoretical investigations for attenuation of geopathic stress on expressways and national highways. Ph.D. Thesis. SP Pune University lib.unipune.ac.in.
Telford, W.M., Geldart, L.P., Sheriff, R.E., 1990. Applied Geophysics. Cambridge University Press.
Todd, D.K., 2007. Groundwater Hydrology. John Wiley and Sons, India.
Urish, D.W., Frohlich, R.K., 1990. Surface electrical resistivity in coastal groundwater exploration. Geoexplor. 26, 267–289.
Valley, S.L., 1965. Handbook of Geophysics and Space Environments. Air Force Cambridge Res. Lab., Bedford, Mass.
Wesley, M.L., 1976. The combined effect of temperature and humidity fluctuations on refractive index. Am. Meteor. Soc. J. 15, 43–49.
Weymouth, J.W., Huggins, R., 1985. Geophysical surveying of archaeological sites. In: Rapp, G., Gifford, J.A. (Eds.), Archaeological Geology. Yale University Press, New Haven, pp. 191–235.
Xuelong, Li, 2018. Study on characteristics of coal rock electromagnetic radiation (EMR) and the main influencing factors. J. Appl. Geophys. 148, 216–225.
Yadav, G.S., Singh, S.K., 2007. Integrated resistivity surveys for delineation of fractures for ground water exploration in hard rock area. J. Appl. Geophys. 62 (3), 301–312.
Zohdy, A.A.R., Eaton, G.P., Mabey, D.R., 1974. Application of surface geophysics to groundwater investigations. Techniques of Water-Resources Investigations. U.S. Geol. Surv. Book 2, U.S. Dept. of Interior (Chapter D1).