International Journal of Scientific Engineering and Science
Volume 3, Issue 3, pp. 68-75, 2019. ISSN (Online): 2456-7361

Sustainable Groundwater Resources for Environmental Management in Watershed Areas– A Case Study

G. Nagamallesh*[1], Ram Raj Mathur
[1]Groundwater Surveys and Development Agency, Nagpur, Maharashtra, India
[1]Centre of Exploration Geophysics, Osmania University, Hyderabad, India
*Corresponding Author: mallesh.gampala@gmail.com

Abstract— *The Deccan Volcanic Basalt Province (DVB) has been facing acute shortage of groundwater for drinking and irrigation purposes. The distribution of the aquifers in this region is limited due to the porosity of the Deccan Basalts also due to the increasing population groundwater in shallow aquifers are overexploited. Infiltration is less due to the insufficient seasonal rainfall and hence there is a continuous decline of the groundwater in the area. The environment management has suffered a great loss due to the unethical practices adopted by the community to overexploit the groundwater situation in this region. The impact of equal groundwater sharing has developed inconsistency in the eco-system management of the area the need of the hour is sustainable governance for groundwater resources.*

Geophysical exploration tools for groundwater to develop and monitor a watershed have proved to be promising and solutions for sustainable groundwater management have also been developed. As a case study to solve such problems in the DVB the TE41 mini watershed No.4/4 of Tapi Basin, Dharangaon Taluka, Jalgaon, District, Maharashtra State was chosen. The Very Low Frequency Electromagnetic (VLF-EM) method that has proved to as a successful, fast, and simple tool to map shallow aquifers in hard rock terrain was used for this purpose. The study area is occupied by the basaltic flows of Deccan Trap of Sahyadri group of cretaceous to Eocene age. The area consists of compound flow of vesicular basalts with exclusive weathering and joints. The paper presents a simple and effective method using the 2-D interpretation of the VLF-EM data to delineate fracture zones in the area and in locating the groundwater sources that successfully helped in providing a sustainable development socially, economically and in environmental to protect and enhance this valuable resource for future generations.

Key words— *Deccan Volcanic Province, VLF-EM method, Eco-system management, DharangaonTaluk.*

I. INTRODUCTION

Most of the fresh water resources that occur on the surface of the earth come from groundwater. Groundwater occurs in pores, fractures, joints in subsurface rocks. The infiltration occurs during precipitation through the soil and into the underlying rocks where it is trapped and stored. Depending on the geological nature of the rocks groundwater occurs in aquifers that are the permeable rocks in the subsurface. The geological processes like sedimentation and volcanism can behave as aquifers due to the porous nature of such rocks.

The Very Low Frequency Electromagnetic (VLF- EM) method is an active source electromagnetic technique for rapidly mapping shallow subsurface conductivity variations. VLF instrumentation is portable as it utilizes distant Naval broadcasting transmissions as an electromagnetic source(Jutzeler et al., 2011) in the frequency band of 15–30 kHz and is suitable for delineation of vertical and dipping conductors (Sharma et al., 2010). VLF-EM method is popular in geophysical investigations worldwide especially for groundwater exploration, as it is economical, effective, and efficient for locating potential groundwater zones (Adepelumi et al., 2006).

The anomaly observed in any geophysical survey is usually associated with the deviation of the measured signal from the normal level, and this deviation is a result of the response of the subsurface geological objects of interest. The measured signal can be processed for locating the geological structures which are causing the anomaly and then quantitatively interpreted in terms of depths, width, dip, physical properties etc. There are many well-known methods for processing and interpretation of geophysical data (Nabighian, 1972; Sundararajan and Ramabrahmam, 1997). In VLF-EM surveys, both the in-phase and quadrature components are measured to delineate the anomaly. Fraser Filter (Fraser, 1969) and Karous and Hjelt Filter (Karous and Hjelt, 1983) were used to delineate the groundwater potential zones in the area.

II. STUDY AREA

The watershed TE41 mini watershed No.4/4 of Tapi basin, Dharangaon Taluka, Jalgaon District, Maharashtra State was chosen as the study area. This area was chosen to enhance the groundwater availability from shallow aquifers for a sustainable and ecological development in the area using the VLF-EM geophysical technique. This paper demonstrates the efficacy of the implemented technique that could be adapted to other regions of similar areas to solve socio-economic and ecological problems.

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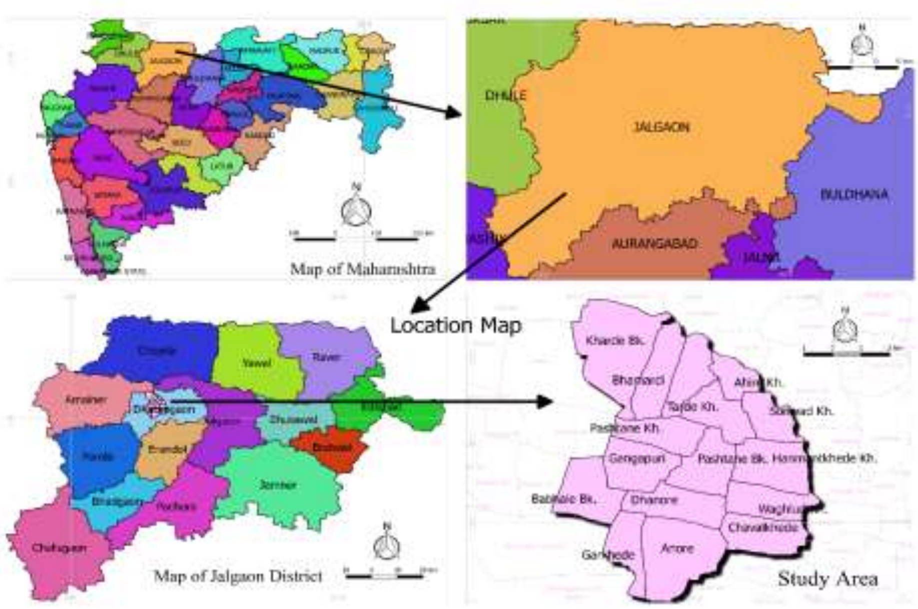

Fig. 1. Location Map of the Study Area

III. Geology and Groundwater Potential of the Area

The Deccan Volcanic Province (DVP) is an extensive lava eruption and formation in Peninsular India. It covers parts of Maharashtra, Gujrat, Karnataka and Telangana States (Krishnan 1982). The major rock type in this area is the Basaltic rock with vesicles created during the consolidation of lava flows due the evaporation of hot gases. These vesicles are sometimes filled with amygdaloidal basalts that can hinder the storage of groundwater. Hence, because of the decrease of porosity in the Deccan Basalt rocks groundwater occurrence in aquifers become scanty and results in shortage (Singhal, 1997; Deolankar, 1980; Dhokarikar, 1991; Ghosh et al., 2006; Limaye, 2010). The aquifer management is of great concern in these areas due to poor governance and lack of knowledge of hydrogeological behavior of rocks resulting in environmental and economic complexities.

Earlier Geophysical studies have proved to be effective in delineating the porosity of the Deccan Basalts by detecting the fracture zones (Deshpande and Sen Gupta, 1956; Bose and Ramakrishna, 1978; Nishat Ahmad, 2001; Shettigara and Adams, 1989; Kulkarni et al., 2004). The Very Low Frequency Electromagnetic Method (VLF-EM) has proved to delineate minor groundwater potential zones in the Deccan Basalts that could address and solve the scarcity of water for drinking and irrigation purposes (Ram Raj Mathur and Rao, 2018).

The study area falls under Survey of India Topo sheet No.46 O/8 and watershed No.TE41 mini watershed No.4/4 of Tapi Basin, Dharangaon Taluka, Jalgaon District, Maharashtra State between north latitudes 21^{0} 00′ to 21^{0} 60′ and east longitudes 75^{0} 15′ to 75^{0} 22′.

The area consists of 16 villages, viz., Kharde(Kh), Bhamardi, Ukkalwadi, Ahire(Kh), Tarde (Kh), Sonwad(Kh), Pasthane(Kh), Pasthane(Bk), Gangapuri, Hanmantkhede(Kh), Babhale(Bk), Dhanore, Waghlud(Kh), Gurkhede, Anore and Chavalkhede. The alkali basaltic rocks (Figure 1) of Upper Cretaceous to Lower Eocene age form the major part of the area (Agashe and Gupte, 1971). There are many irregular flows that have been structurally disturbed representing variable morphology, texture and thickness of the flows.

The soils of Jalgaon District are classified as dark black, medium black, Loamy and sandy and forest soils. The dark black soils are observed in northern part of Amalner, Erandol/Dharangaon, Jalgaon, Bhusaval and Edilabad Talukas. Medium black soils occur over large areas in the district in the central region of the Tapi Valley and southern hills. In Tapi Valley alluvial basin, soils are black alluvial clay occurring in the southern parts of Yaval, Raver, Chopda, Jalgaon, Bhusaval, Chalisgaon, Amalner, and Bhadgaon Talukas. Loamy soils are observed in the southern part of Amalner, Erandol, Jalgaon and Bhusaval Talukas. Sandy soils are observed on the foothills of Satpura ranges and near southern hillocks. Forest soils are dark brown and occur on slopes mainly in the Satpura ranges.

The drainage pattern of an area can reveal the topography, structure and tectonics of the area that are important to assess the infiltration rates due to precipitation and study the changes in the groundwater table. The adequate availability of surface water improves irrigation in the area that helps stabilize the economic growth of the area. The main source of drainage in the area is the Tapi River (Figure 2). Black soil or Recur soil forms this part of the area near the Tapi River and the surface is covered with alluvial soil on both sides of the Tapi River till Bhusawal Village. The hills surrounding the Tapi River are covered with dark basalts. The exposed basaltic rocks on the hills form large rounded boulders due to the weathering in the Deccan Trap region. The soil produced by erosion and weathering is dark brown to red or black that is rich in plant nutrients and favorable for cotton farming.

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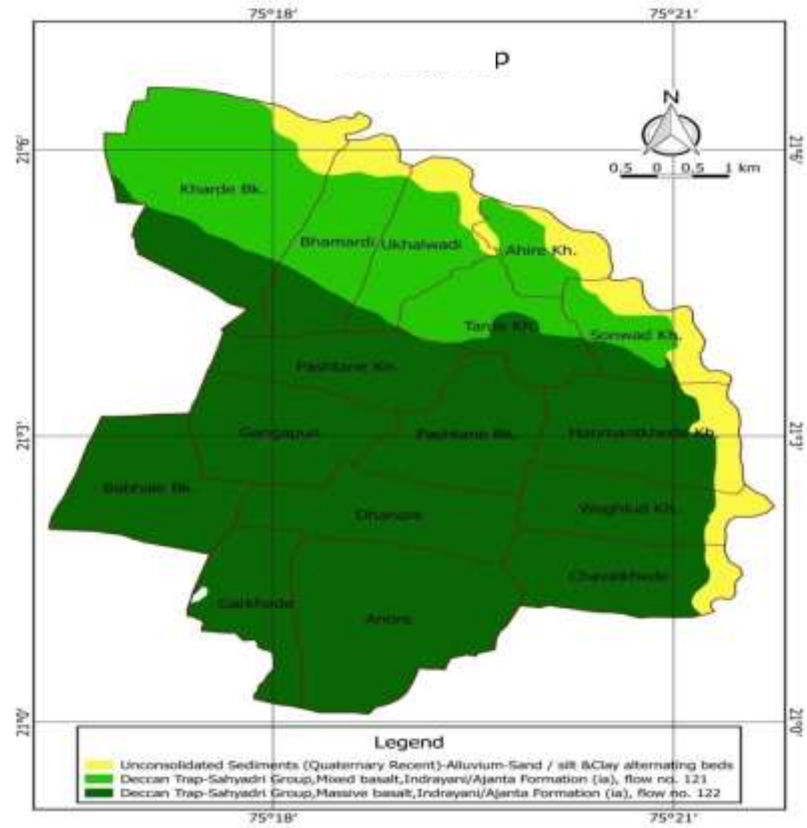

Fig. 2. Geology of Dharangaon Taluka, Jalgaon District, Maharashtra State

From Figure 2 it can be observed that all the streams of district drain into the main river systems, viz., Tapi, Girna, Bori, Waghur, Anjani, Panzara that flow in the north, south and west boundaries of the district. Tapi River flows from east to west for about 130 km in the northern side of the district and covers an area of about 70,000 sq. km. The Anjani River flows from north to west and forms a major discharge zone in the area. The Hatnoor Dam Project on the Tapi River has helped banana farming in Rawer, Yawal, Chopda Talukas on its right bank. On the right bank of Tapi River, Bhokar, Suki, Mora, Harki, Manki and Gule are the main tributaries and Purna, Bhogwati, Vaguer, Girna and Bori on the left bank that are near the Sat pura Hills.

Ground water in Deccan Trap Basalt occurs mostly in the upper weathered and fractured parts at shallow depths of 20-25 m in unconfined aquifers. Groundwater occurs in deeper fractured basaltic rocks with higher porosity in semi-confined conditions. The yield of dugwells in the shallow aquifers range between 21 and 337 m^3/day and those in the unconfined aquifers at depths of 60 to 150 m in bore wells range between 1.8 to 52 m^3/day.

The northern part of the district is underlain by Alluvium soil along the Tapi River consisting of the younger alluvium to a depth ranging between 70 to 80 m underlain by older alluvium extending to a depth of about 450 m. The younger alluvium consists of 2 to 5 layers of granular zones of sand and gravel ranging in thickness from 2 to 20 m a potential source for groundwater. At deeper levels the alluvium is mostly clayey and hence devoid of sufficient groundwater.

The groundwater in the alluvium occurs in semi-confined and confined conditions with yield varying from in winter from 120 to 200m^3/day and 100 to 180m^3/day in summer.

IV. Geophysical Surveys

The Very Low Frequency Electromagnetic (VLF-EM) Method (Paterson and Ronka, 1971) has been found to be a fast and simple geophysical exploration method for locating fractures in hard rock terrain for locating shallow aquifers (McNeill, J.D., 1991; Sharma, and Baranwal, 2005; Sundararajan, et al., 2007).Different thumb rules for interpretation of VLF-EM data (Paterson and Ronka, 1971) were suggested to compute the depth to the top of a conductor and from physical modeling (Kaikkonen, 1979)and laboratory and large-scale modeling.

The VLF-EM survey in the present study area was conducted using ABEM, Sweden VLF-EM Wadi equipment. The simple portable belt strap microprocessor equipment measures the In-phase and quadrature components of the VLF-EM field. The VLF-EM data was processed using the RAMAG ABEM Software using pseudo-depth sections(Karous and Hjelt, 1983) from the In-phase data.

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International Journal of Scientific Engineering and Science
Volume 3, Issue 3, pp. 68-75, 2019. ISSN (Online): 2456-7361

The VLF-EM data in the Dharangaon Taluka, Jalgaon District (Figure 1) was acquired along 26 traverses in the east-west direction with traverse spacing of 500 m and observation interval of 50 m with minimum length of the profile being 750 m and the maximum length being 8.9 km (Figure 3).

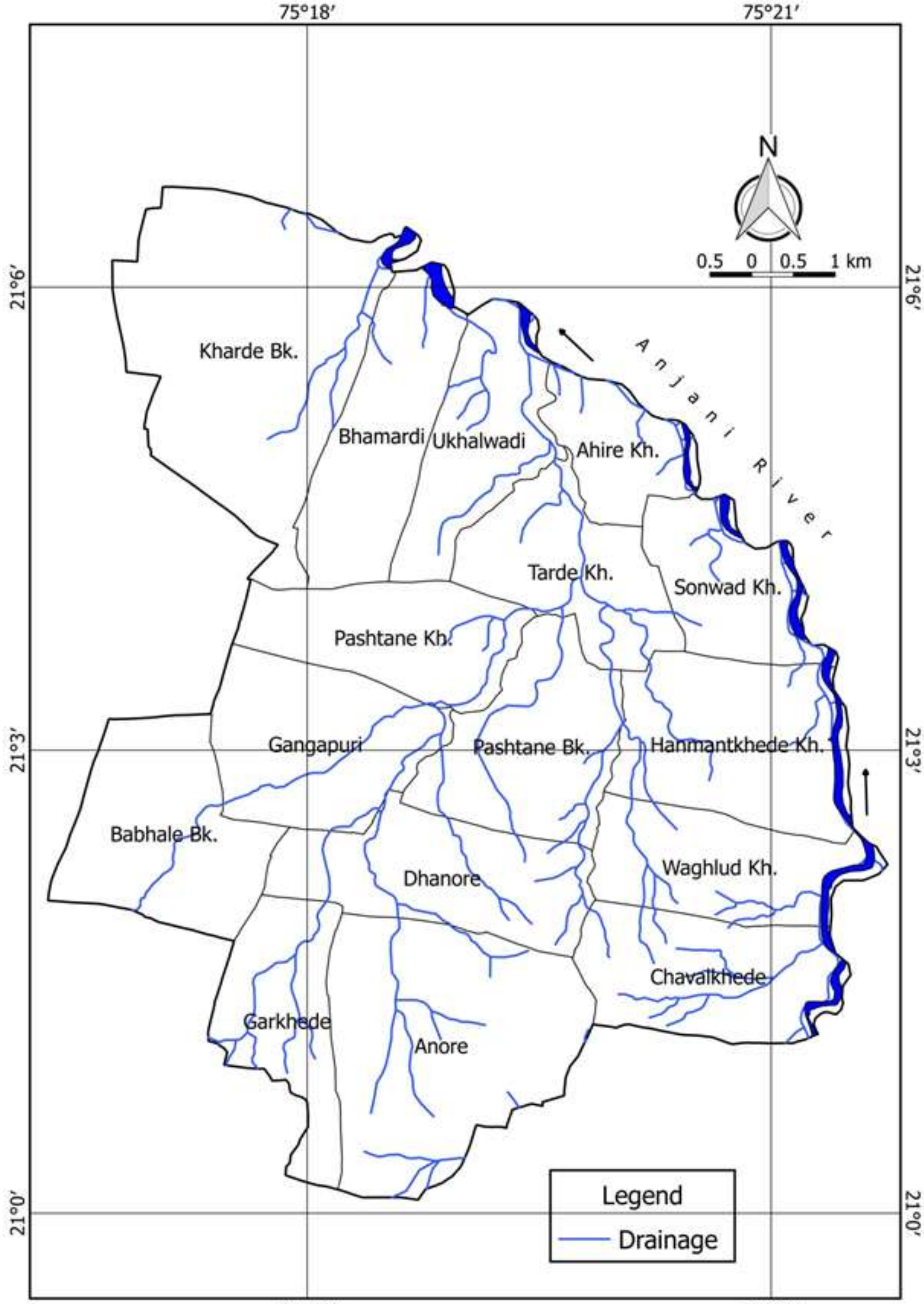

Fig. 3. Major Drainage sources of Dharangaon Taluka, Jalgaon District, Maharashtra State

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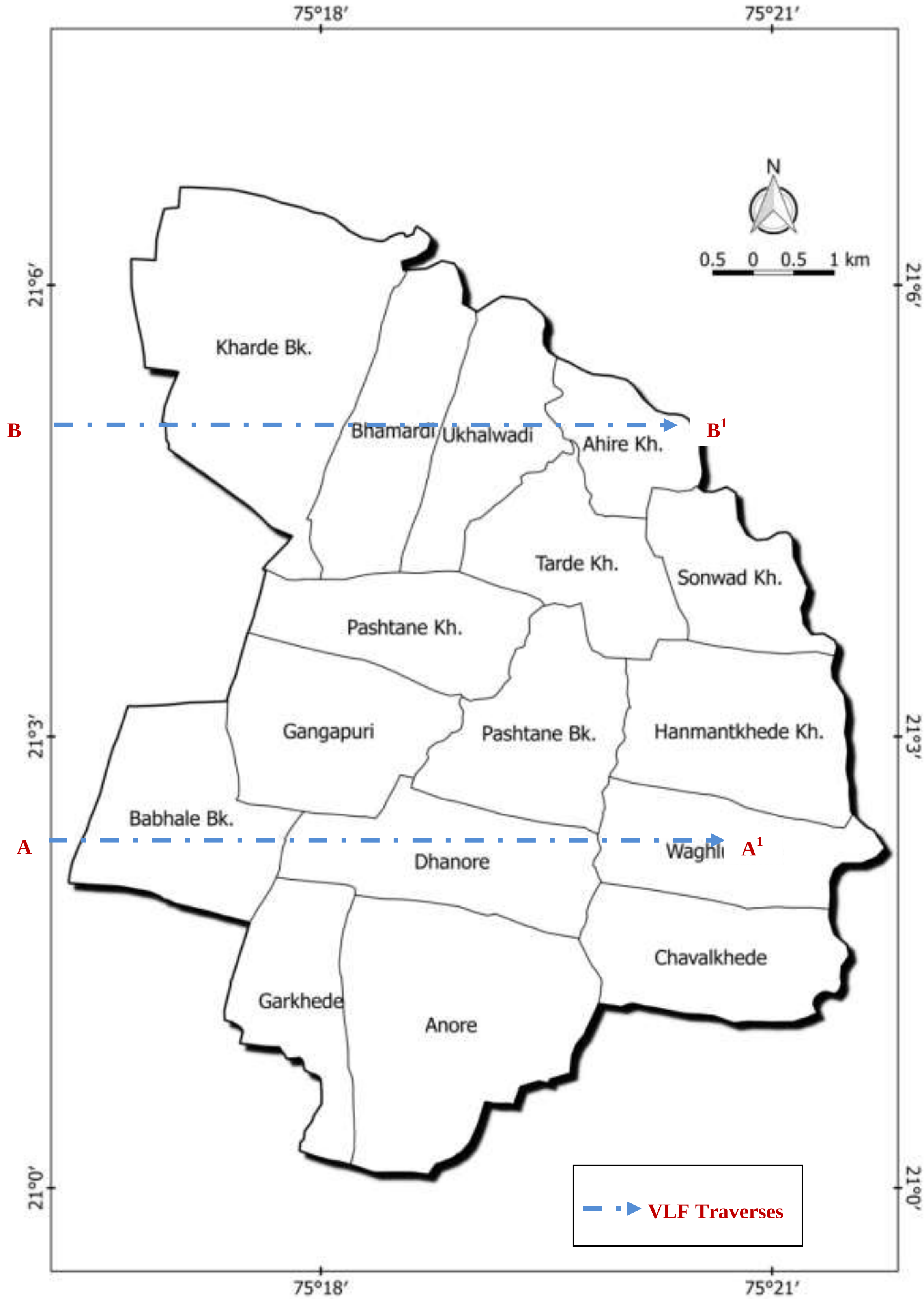

Fig. 4. VLF EM Traverses in Dharangaon Taluka, Jalgaon District, Maharashtra State

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V. Results and Discussion

The current density concentration of the In-phase VLF-EM data was computed using the Karous and Hjelt filter (Karous and Hjelt, 1983) using RAMAG software along the 2 traverses (Figure 4) in the study area. The interpreted VLF-EM data along two traverses A-A[1] and B-B[1] were interpreted to delineate the potential groundwater zones in the area.

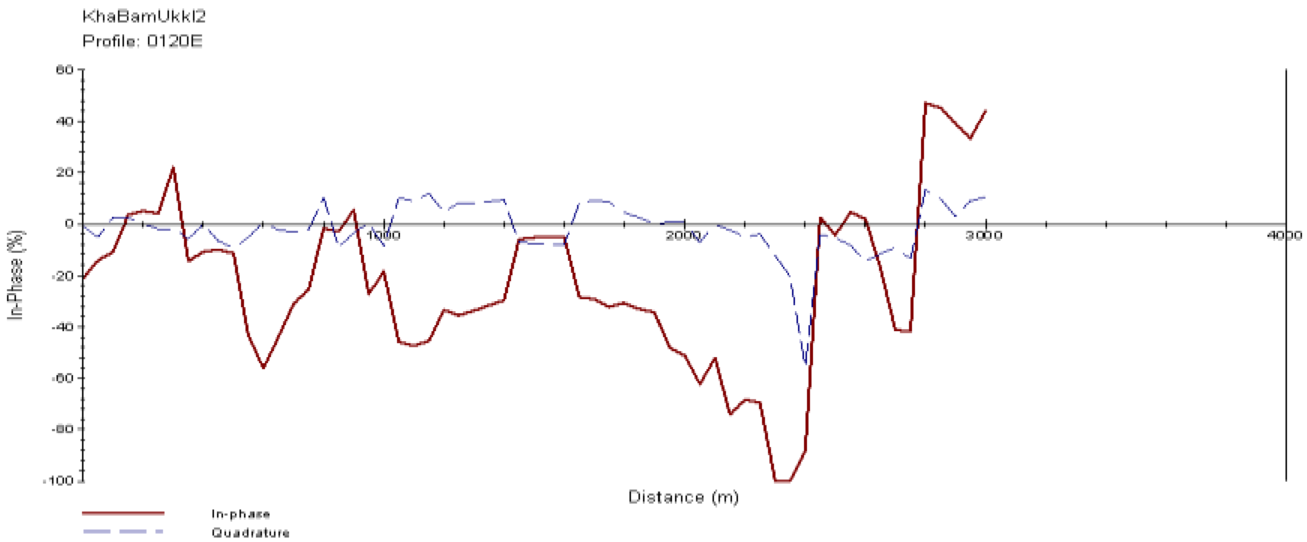
The succession of the various formations obtained from the well sections and comparison from previous studies (GSDA, 2010) is shown in Table 1.

TABLE 1. Resistivity and thickness ranges for different formations based on well cross sections studies

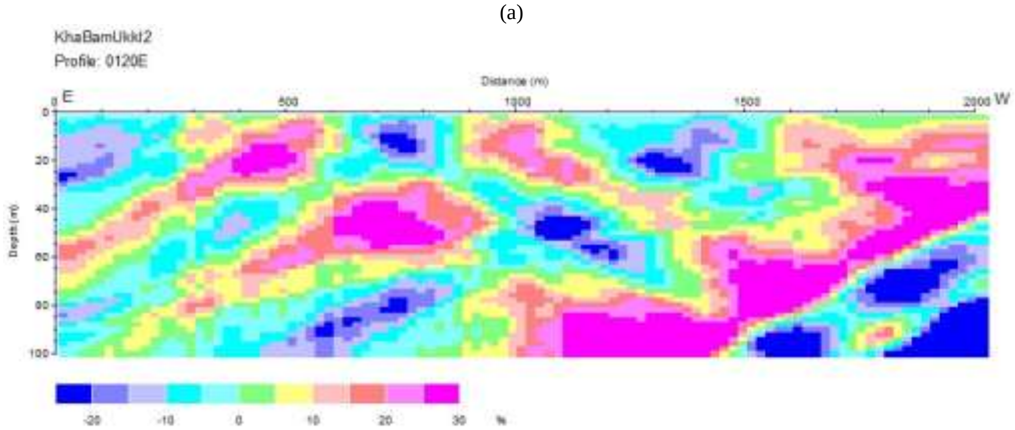
Type of Formation	**Range of Resistivity**
Weathered basalt	5-10 ohm m
Weathered vesicular basalt	25- 30 ohm m
Fractured basalt	50-70 ohm m
Compact massive basalt	> 100 ohm m

Profile: A-A[1]

The traverse 0120E (Profile A-A[1]) is 3km in length with 61 observations and passes through the villages Kharde (Kh), Bhamardi and Ukkalwadi in the study area. The In-phase and quadrature plot (Figure 5a) show positive peaks between 200-600 m (5-20%), 800-1400 m (5-30%) and 1500-2000 m (70-80%) depicting probable conductive zones at a depth extending to 60, 100 and 100 m from the surface. The conductive zones are oriented in NW-NE, NE-SE and NE-SE directions respectively as observed from the current density pseudo depth section (Figure 5 a and b).



(a)



(b)

Fig. 5. VLF-EM Profile (A-A[1]) (a) In-phase and quadrature components, (b) Pseudo-depth section

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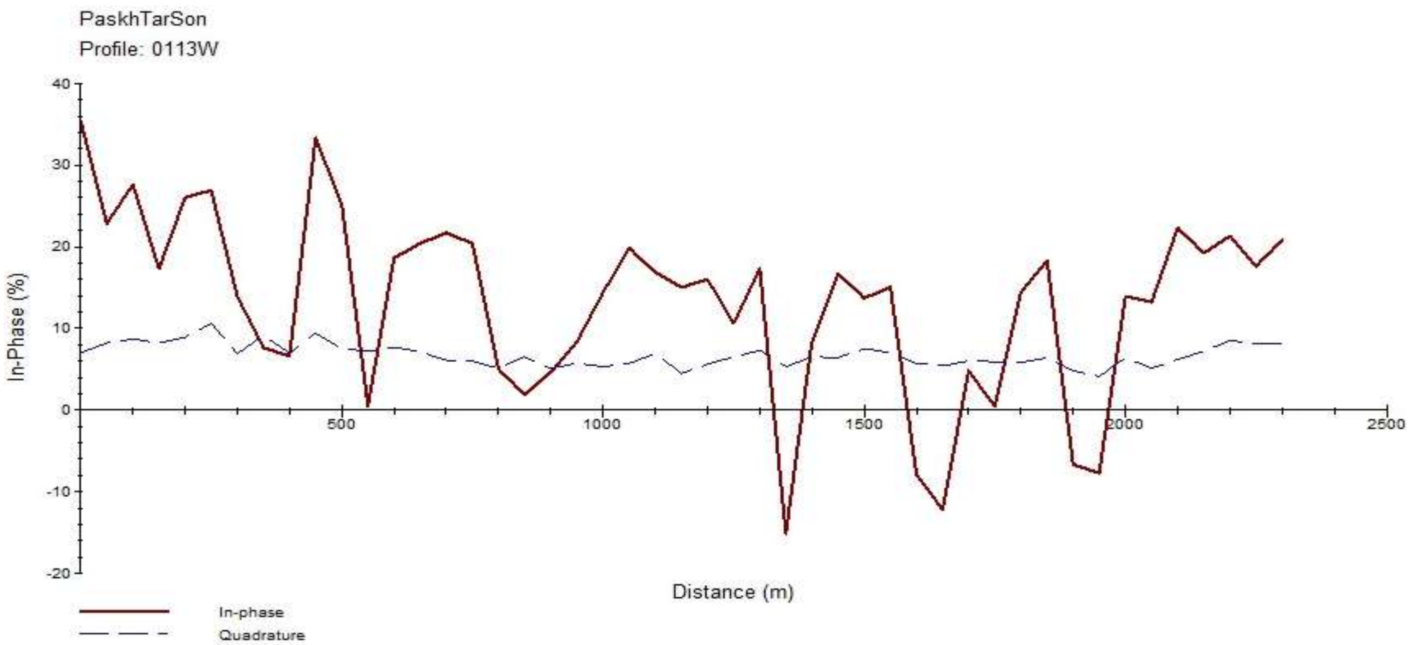
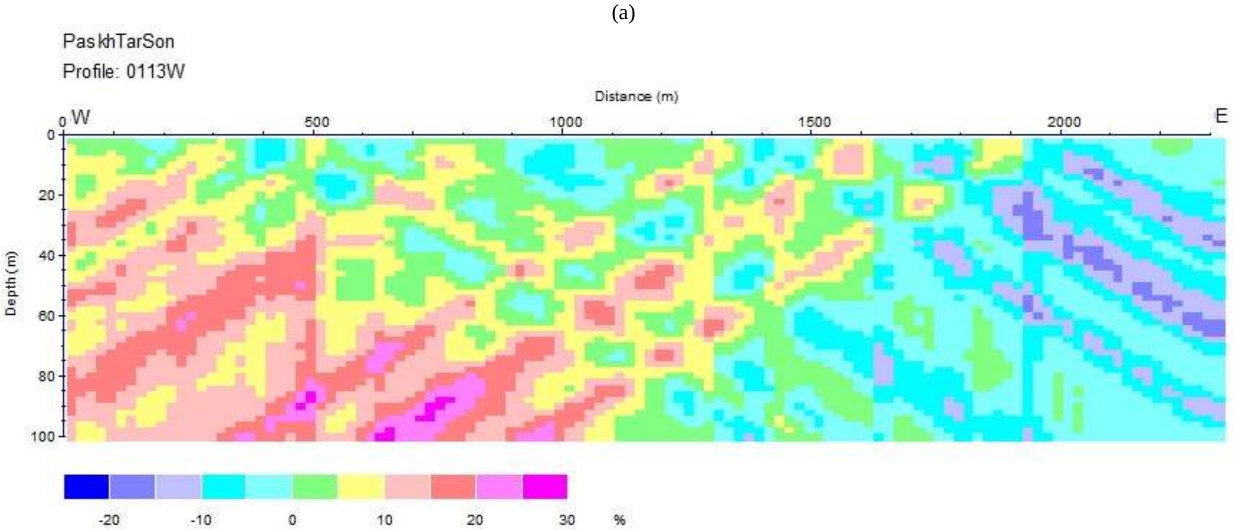
International Journal of Scientific Engineering and Science
Volume 3, Issue 3, pp. 68-75, 2019. ISSN (Online): 2456-7361

Profile: B-B[1]

The traverse VLF 0113 W (Profile B-B[1]) is 2.3km in length with 47 observations and passes through Pasthane(Kh), Tarde(Kh) and Sonwad villages. The In-phase and quadrature plot (Figure 6a) show positive peaks between 0-500 m (10-30%), 700-1100 m (5-30%) and 1400-2100 m (60-80%) depicting probable conductive zones at a depth extending to 65, 80 and 100 m from the surface. The conductive zones are oriented in NW-NE, NE-SE and NE-SE directions respectively as observed from the current density pseudo depth section (Figure 6 a and b).



(a)



(b)

Fig. 6. VLF-EM Profile (B-B[1]) (a) In-phase and quadrature components, (b) Pseudo-depth section

VI. CONCLUSION

Based on the analysis of VLF-EM data and comparison of earlier studies the ranges of resistivity in the study area have been shown in Table 1. The complex geology of the Deccan Basalt region could be deciphered for groundwater exploration in the area based on the VLF-EM depth section that helped located the fracture zones classified in three groups as low, moderate and high based on percentage of current density and peaks of Fraser filtering curves. The two VLF-EM traverses (Figure 3) show high anomaly and indicate the presence of fracture zones, which are more favorable for the occurrence of groundwater. Spatial variability of In-phase filtering data is more prominent at the location of fracture zones that is supported by the succession of strata observed in the surrounding bore and dug wells.

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Volume 3, Issue 3, pp. 68-75, 2019. ISSN (Online): 2456-7361

Based on the VLF-EM cross sections highly weathered basalts and fractured basalts indicate high conductivity zones, vesicular basalts indicates moderate conductivity zones, compact massive basalts indicates low conductivity zones. The high conductive zones in the present watershed area are in the villages Kharde(Kh), Bhamardi, Ukkalwadi, Ahire(Kh), Tarde(Kh), Sonwad(Kh), Pasthane(Kh), Pasthane(Bk), Gangapuri, Hanmantkhede(Kh), Babhale (Bk), Dhanore, Anore, Waghlud(Kh), Gurkhede and Chavalkhede. These villages are having highly fractured zones most suitable for dugwells that areat shallow depths and bore wells for deeper depths.

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