Utilization of Very Low Frequency (VLF) Technique in Surveying of Groundwater: a Case Study- Shadnagar-Papireddyguda, A.P., India

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Abstract

Groundwater is one of the precious water resources, especially in the areas suffering from scarcity of surface water resources during lean periods. Consequently various surveying techniques are developed. Very Low Frequency (VLF) surveying is one of the promising techniques in prospecting of groundwater. Studied area is located in Shadnagar district, A.P., India. The area mainly occupied by granite and gneisses intruded by dolerite dykes of Archean age and covered by thin soils layers. The groundwater occurs in such terrains as isolated pockets in fracture zones. To overcome the probability of getting failed bore well, and to identify the ground water potential zone, VLF surveying has been used as in-situ prospecting technique. Surveying using VLF ABEM Wadi instrument, at 7 profiles in E-W direction are carried out. The VLF profile data obtained from surveyed locations are analyzed by RAMAG, IXVLF and KHFFilt software packages, using Karous-Hjelt and Fraser linear filtering. The analysis of the collected data shows various percentages of current density ranging from 5 to 30%. With many In-phase Fraser filtering anomaly peaks. The result of the study, indicate the occurrence of groundwater in two main fracture zones at varying depths. Also the results indicate that, low yield of groundwater, because the area is located on the boundary of a major watershed with low recharging of groundwater.

Keywords: VLF survey, Hard rocks, Groundwater, Linear filtering

INTRODUCTION

Groundwater represents an important part of water resources especially in areas which are suffering from scarcity of surface water resources during lean periods, like India.

Study area is located near to latitude 17° 1’N and longitude 78° 16’E in Shadnagar district, A.P., India (Fig. 1). The area mainly occupied by granite and gneisses intruded by dolerite dykes of Archean age and covered by thin soils layers.

The availability of water in many areas is really critical during summer and lean periods, so much so that it is difficult even to provide water for drinking to the population. In a large number of areas bore wells become dry in the summer months and in quite few areas the water table is not stable. There is also the problem of locating a ground water source in many habitations.

The situation is compounded, by inadequate recharge of ground water aquifers. Sustainability of aquifers has become a major cause of concern of ground water. In the deeper horizons ground water occurs in fractures zones under semiconfined conditions. In the present investigation VLF survey were carried out at 7 East-West parallel profiles for locating the fractured zones favorable for ground water occurrence. The Very Low Frequency (VLF) survey method is a quick reconnaissance mapping tool for near surface structures (Oskooi and Pedrson, 2005).
VLF-EM method is an active source electromagnetic technique for rapidly mapping shallow subsurface conductivity variations. VLF instrumentation is highly portable because it utilizes distant very low frequency radio transmissions as an electromagnetic source (Jutzeler, et al., 2011). Very low-frequency electromagnetic method works in the frequency band of 5–30 kHz and is suitable for delineation of vertical and dipping conductors (Sharma, et al., 2010). VLF methods become increasingly popular in pre-drilling geophysical investigations worldwide because it has been found that the use of these methods is rapid, inexpensive and helps in increasing the chances, effectiveness and efficiency of site selection (Adepelumi, et al., 2006). VLF is an Electromagnetic technique that use Very Low Frequency, VLF Electromagnetic Waves between 15 and 30 kHz are transmitted by radio military transmitting stations emits a very powerful electromagnetic waves between 300 to1000 kilowatts located all over the globe. Transmission signals emitted in horizontal circular electromagnetic field called primary field (ABEM, 1991). The Eddy current induced by VLF magnetic field produce a secondary magnetic field when intersect perpendicularly with inclined low resistivity subsurface structure and have the same frequency as primary but in different phase and always charged in opposition to the charges in primary field (Milsom, 2003). Most VLF instruments compare vertical with horizontal magnetic fields, either directly or by measuring tilt angle (Milsom, 2003; Peter, et al., 2003) . The generation of secondary field is related with the conductivity, which is inversely related to the resistivity of the geological body (Chambel, et al., 2006). VLF- Surveying methods are divided in two categories on the basis of the measured parameters. The first one is called VLF-Z or VLF-EM which take in to a count only components of the elliptically polarized magnetic field. This method also called tilt mode. In the second category the horizontal magnetic and horizontal electric components of the VLF field is measured (Bernard and Valla, 1991; Oskooi and Pederson 2005).

To get anomaly from any inclined structures, it must have dimensions more than 50 meters in length, depth about 10 meters and thickness 1 meter or more, and VLF transmitter location must lie in the direction of the body's strike (ABEM 1991).

Hongtao et al., (2006) said that the detection depth of VLF - survey depends largely upon the overall ground conductivity, but it is commonly over 30 -50 meters. Any two steeply dipping conductors close to each other produce a resultant anomaly similar to the sum of the anomaly that would have been produced by each body singly (Milsom, 2003). VLF data are insufficient to resolve a complex structure details, but well suited to getting an over view of the lateral extent of the conductors and to some extent of their depth distribution (Oskooi and Pederson, 2005). Sharma and Baranwall (2005) conclude that the anomaly obtained in VLF measurement is an indication of the presence of conductive but may or may not suitable to discriminate between
deep and shallow sources. When the quadrature response shows a positive inflection, it may indicate a relatively weak conductor in nonconductive ground (Jeng et al., 2004)

Abdullahi and Osazuwa (2011) are mentioned that, the Fraser-filtered data (in-phase) which have high positive peak response; indicate anomalous body of large dimension and steeply dipping source, whereas the broader shape of the VLF anomaly indicates greater depth.

Farther, higher values of relative current density in pseudo section correspond to conductive subsurface structure. A high positive Fraser peak with high positive current density at the crossover point indicates the presence of conductive zone e.g. a possible fracture location (Sundararajan, et al., 2007; Abdullahi, and Osazuwa, 2011).

In the presence of conductor, the total VLF field is elliptically polarized and can be used to discriminate between the poor and good conductor, because the tilt angle and ellipticity have the same polarity for a poor conductor, but the ellipticity changes both in polarity and shape for a good conductor (Kaikkone, 1979; Ogilvy and Lee, 1991). The in phase (real) part of VLF WADI data show that the positive bulge appear just before the subsurface structure and negative bulge after it along the profile (ABEM, 1991). The tilt angle variations follow a response across the anomaly and thus the crossover point coincidence with the center of the anomaly (Peter, et al., 2002). The pseudo section of current density resulted from filtered data at different depths can be used to estimate roughly the depth of single anomaly body (Milsom, 2003).

Method of VLF surveying and data filtering

This study attempts to reveal the occurrence of groundwater using VLF- WADI instrument developed by ABEM Corporation. This instrument record the ratio of the strength of vertical and horizontal magnetic fields at the ground surface (Hz/Hx) and also measure the real and imaginary parts (ABEM, 1991).

Data are collected from selected area in Shadnagar-Papireddyguda at 7 parallel profiles in E-W directions with point distance of 10 meters based on the major trend of structural features in the area.

For analysis of VLF data, characteristics of cross sectional depth wise of a single profile, RAMAG and KHFfilt software using Karous and Hjelt (1983) and Fraser (1969) filtering are used. For multiple parallel traverses interpretation, IXVLF-Interpex software is used to calculate Karous and Hjelt (1983) and Fraser (1969) linear filtering to present fracture zones based on horizontal In-phase data anomalies.

Linear filters are working on real and imaginary parts of magnetic field such as Karous-Hjelt filter and other work on tilt angle as Fraser filter. Real and imaginary responses can be calculated from tilt angle and ellipticity of polarization ellipse. Tilt angle (θ) is the inclination of the major axis of polarization ellipse and ellipticity (ε) is the ratio of the minor to the major axis of the ellipse as shown in the following equations.

\[
\tan(2\theta) = \pm \frac{2(H_z/H_x)\cos\Delta\phi}{1 - (H_z/H_x)^2}
\]

Where \(H_z\) and \(H_x\) are the amplitude of the phase difference, \(\Delta\phi = \phi_z - \phi_x\) and in which \(\phi_z\) is the phase of \(H_z\) and \(\phi_x\) is the phase of \(H_x\) and \(H_i = |H_z|e^{i\Delta\phi}\sin\theta + H_x\cos\theta|\) (Kaikkonen and Sharma, 1998).

From the ellipticity and tilt angle the real and imaginary responses for the conductor can be calculated from the equations:

\[
\text{Re}a{l}(H_z/H_o) = 100.\tan\theta
\]
Rea(%) = 100.θ(θ - in Radian)
Imaginary(H_2/H_0) = 100.e

After Ogilvy and Lee (1991); Karous and Hjelt (1983).

The linear filtering of karous and Hjelt (1977) work on current density using a numerical algorithm to smoothening the collected VLF data by taking the averages of neighboring values, \( H_i \) and \( I_a \) a symmetrical filter is obtained as follows:

\[
\frac{\Delta z}{2\pi} I_a(0) = -0.102.H_{-3} + 0.059.H_{-2} - 0.561.H_{-1} + 0.561.H_1 - 0.059.H_2 + 0.102.H_3
\]

Where; \( I(0) = \frac{1}{2} [I(\Delta x/2) + I(-\Delta x/2)] \)

\( H_{-3}, H_{-2},...,H_{+3} \) are the measured data at consequence stations, \( (\Delta x) \) is the distance between measured points (Karous and Hjelt, 1983). The polarity of the filter need to be reversed in case of K-H filter to conform the plotting conversion that assume the plotting drop from positive to negative values as the operator crosses over a line conductor (Ogilvy and Lee, 1991).

Linear filter of Fraser (1969) work on tilt angle values and used to improve the resolution of anomalies by applying the following equation:

\[
F(2,3) = (m_3 + m_4) - (m_1 + m_2)
\]

\( m_1, m_2, m_3 \) and \( m_4 \) are the tilt angles at consecutive stations and \( F \) represent a midway tilt angle between the four stations (Fraser, 1969).

RESULTS AND DISCUSSION

VLF surveying data are analyzed for exploitation the groundwater, using RAMAG, IXVLF-Interpex and KHFfilt software. Many graphs for unfiltered and filtered data and current density pseudo sections for each profile are prepared (figs. 2, 3, 4 and 5). The pseudo sections of current density, location of anomaly and approximate depth of anomaly at each profile are extracted from graphs to be used in estimation of occurrence of groundwater in the study area.

It is observed, that there are several anomalies with various intensities of current density, ranged approximately from shallow to deeper depths. Considering the produced current density pseudo-depth sections and In-phase and quadrature data profiles, more than one fractured zones are recognized to be favorable for occurrence of groundwater in study area.

Low anomalies are recognized along the profiles Nos. 0005N, 0041N, 0121N (Fig. 2), Characterized by less than 10% of current density on K-H filtering current pseudo section, while shows small and narrow anomaly peaks on in-phase Fraser filtering graphs (Fig. 3), indicating narrow fracture zones and low favorable for occurrence of groundwater.

Another group of moderate anomalies with current density between 10% and 20% are appears at profiles Nos. 0001N, 0021N, 0041N, 0101N, and 0121N (Fig. 2), and moderate peaks of anomalies on Fraser filtering (Fig. 3), this group is related to fracture zones with moderate favorability for occurrence of groundwater.

The third group of anomalies is recognized on profiles Nos. 0005N, 0021N, 0081N, with current densities more than 20%. The same group is shows high peak of anomalies on Fraser filtering Curves (Fig. 3), indicating relatively large fracture zones and more favorable for locating the bore well. The anomaly which appears on profile no. 0021N is a pseudo high anomaly, resulted from problem in power supply getting during surveying process.
The last group of anomalies is characterized by low percentage of current density and low anomalies with a broad peak on Fraser filtering curves, indicating deeper fracture zones. In the most of Karous-Hjelt filtering curves (Fig. 2), the quadrature curves show positive inflection in area of massive rock or dry fracture zones.

To take an idea about horizontal extend of fracture zones, spatial variability of anomalies are interpolated using In-phase VLF reading for both magnetic field of Karous-Hjelt filtering (Fig. 4) and of tilt angles of Fraser filtering (Fig. 5). The interpolated maps are used to discriminate the anomalies of fracture zones which are most favorable for the occurrence of groundwater in the study area. The results of the study was verified with the field data, which shows that, The failed bore well is drilled in the area of massive hard rocks with low anomalies of VLF data.

Fig 2: In-phase, Quadrature plots and current density pseudo-sections of Karous–Hjelt filtering (Processed by RAMAG software).
Fig 3: In-phase Fraser filtering and Karous–Hjelt current density pseudo-sections (Processed by KHFfilt-program).
Fig. 4: Profiles and spatial variability of magnetic field of Karous-Hjelt linear filtering.
CONCLUSIONS
The analysis of VLF data indicate that the fracture zones occurs at three groups of anomalies i.e. low, moderate and high based on percentage of current density and peaks of Fraser filtering curves. Out of 7 profiles, only two profiles shows high anomaly and indicate the presence of fracture zones, which are more favorable for the occurrence of groundwater.

The study shows the important of VLF surveying for pre-drilling of bore well in study area, and proved that, the failed bore well, unfortunately was located at low fractured zone. Spatial variability of In-phase filtering data is more clarified the location of fracture zones, and assisted in selection of bore well location.

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