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Identification of Groundwater Prospective Zones Using Geoelectrical and Electromagnetic Surveys

Sajeena, S., Abdul Hakkim, V. M., and Kurien, E. K.
Kelappaji College of Agricultural Engineering and Technology, Tavanur P.O. Malappuram, Kerala

I. INTRODUCTION

Groundwater resources play a major role in ensuring livelihood security across the world. Utilization of groundwater reservoir as a viable source for meeting drinking and domestic water needs is safer and economical than surface water, as groundwater is available everywhere and is generally uncontaminated. As a result groundwater investigation has assumed top priority in recent years. Groundwater is usually held within porous soils or rock materials. People all around the world face serious water shortage because of the over exploitation of groundwater for domestic, industrial and agricultural purposes. It is estimated that (2003) around seven billion people out of the projected 9.3 billion in the entire world will face water shortage and out of these, 40% will face acute water crisis. The annual replenishable groundwater resources in India is estimated as 432 BCM out of which 398 BCM is available for utilization leaving aside 34 BCM for natural discharge. Groundwater contributes 60% of the total irrigated area of the country and plays a significant role in irrigation development. Presently the overall stage of groundwater development is 58%, however there exists a significant regional variation in its development.

In many parts of the world, groundwater is the only source of water to meet domestic, industrial or agricultural demand (Komatina, 1994). Electrical geophysical methods have been applied in groundwater exploration for decades (Chapellier et al., 1991). The methods used were electromagnetic and electrical resistivity (namely vertical electrical sounding). Geophysical methods are used to obtain more accurate information about subsurface conditions, such as type and depth of materials (consolidated or unconsolidated), depth of weathered or fractured zone, depth to groundwater, depth to bedrock and salt content of groundwater (Bouwer, 1978)).

II. GEOPHYSICAL METHODS OF GROUND WATER INVESTIGATIONS

The role of geophysical methods in groundwater exploration is vital. The aim is to understand the hidden subsurface hydro-geological conditions adequately and accurately. The basis of any geophysical method is measuring a contrast between physical properties of the target and the environs. The better the contrast or anomaly, the better the geophysical response and hence the identification. So, the efficacy of any geophysical technique lies in its ability to sense and resolve the hidden subsurface hydro-geological heterogeneities or variation. Hence for groundwater exploration, a judicious application or integration of techniques is most essential for success in exploration, technologically as well as economically (Rosli et. *al.*, 2012).

Electrical Resistivity method has the widest adoption among the various geophysical methods of groundwater investigation. (Olorunfemi, 1999; Ariyo, 2007; and Afolayan et al., 2004). This is due to the fact that the field operation is easy, the equipment is portable, less filled pressure is required, it has greater depth of penetration and it is accessible to modern computers. The Electrical Resistivity method has helped in the identification and better understanding of aquifer dimensions (Stephen and Gabriel O., 2009).

In geophysical investigations for water exploration, depth to bedrock determinations, sand and gravel exploration etc, the Electrical Resistivity Meter (ERM) method can be used to obtain quickly and economically the details about the location, depth and resistivity of subsurface formations. Emenike (2001) tested the groundwater potential and a correlation of the curves with the lithologic log from a nearby borehole and suggested that the major lithologic units penetrated by the sounding curves were laterite clay sandstone and clay. The sandstone unit, which was the aquiferous zone, had a resistivity range between 500 ohm-m and 960 ohm-m and thickness in excess of 200 m.

ERM uses an artificial source of energy, rather than the natural fields of force, such as in gravity surveying, hence the source detector separation can be altered to achieve the optimum separation, which effectively controls the depth of measurement. The water exploration survey with the help of ERM is low cost, easy for operation, speedy and accurate. Liu (2004) used ERM method for imaging changes of moisture content in the vadose zone. The ability of the integrative approach was tested by directly estimating moisture distributions in three-dimensional, heterogeneous vadose zones. This survey can also be used for geotechnical and environmental purposes. ERM is generally employed for groundwater studies, such as quality, quantity, mapping fresh water lenses, investigation of salt water intrusion and determination of the extent of contaminants.

2.1 Vertical Electrical Sounding (VES)

The Vertical Electrical Sounding (VES) method is a depth sounding galvanic method and has proved very useful in ground water studies due to simplicity and reliability of the method. The electrical resistivity of rock is a property which depends on lithology and fluid contents. For example, the resistivity of coarse- grained, well consolidated sandstone saturated with fresh water for example is higher than that of unconsolidated silt of the same porosity, saturated with the same water. Similarly, the resistivities of identical porous rock samples vary according to the salinity of the saturated water. The instrumentation of this method is simple, field logistics are easy and straight forward while the analysis of data is less tedious and economical (Zhody *et al*., 1974; Ekine and Osobonye, 1996; Ako and Olorunfemi, 1989). With this method, depth and thickness of various subsurface layers and their water yielding capabilities can be inferred. These measurements have been used to solve ground water and its related problems; notably in determining suitable site for drilling of boreholes and in studying ground water contamination. This can also be used for the estimation of dynamic and static groundwater reserves (Paliwal and Khilnani, 2001).

2.2 2-D Electrical Resistivity Tomography

2-D Electrical Resistivity Tomography (ERT) has been extensively used for many years for groundwater exploration. The technique is employed together with drilling for determination of resistivity value of alluvium and the effect of groundwater. 2-D Electrical Resistivity Tomography (ERT) is now mainly carried out with a multi-electrode resistivity meter system (Figure 1). Such surveys use a number (usually 25 to 100) of electrodes laid out in a straight line with a constant spacing. A computer-controlled system is then used to automatically select the active electrodes for each measure (Griffith and Barker, 1993).

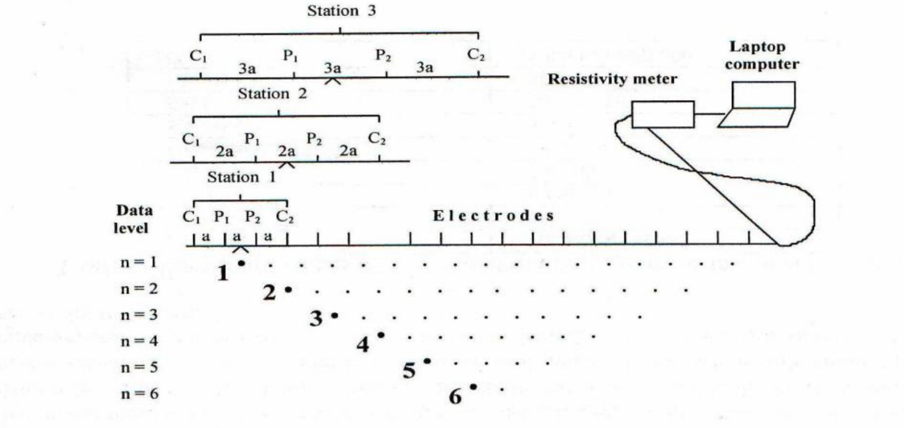

Fig. 1. The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudosection

The resistivity method basically measures the resistivity distribution of the subsurface materials. Table 1 and 2 shows the resistivity value of some typical rocks, soil materials and water (Keller and Frischknecht 1996). Igneous and metamorphic rocks typically have high resistivity values. The resistivity of these rocks is mainly dependent on the degree of fracturing. Since the water table is generally shallow, the fractures are commonly filled with ground water. The greater the fracturing, the lower is the resistivity value of the rock. As an example, the resistivity of granite varies from 5000 Ωm in wet condition to 10,000 Ωm when it is dry. When these rocks are saturated with ground water, the resistivity values are low to moderate, from a few Ωm to a less than a hundred Ωm. Soils above the water table are drier and have a higher resistivity value of several hundred to several thousand Ωm, while soils below the water table generally have resistivity values of less than 100 Ωm. Also clay has a significantly lower resistivity than sand (Rosli *et. al.*, 2012). The study was conducted in areas which have a geology record of thick alluvium. The result show that groundwater will lower the resistivity value and silt also will bring down the resistivity value lower then groundwater effect. Groundwater reservoirs are found in saturated sand, saturated sandy clay and saturated silt, clay and sand.

Table 1. Resistivity values of common rocks and soil materials in survey area

Material	**Resistivity (Ωm)**
Alluvium	10 to 800
Sand	60 to 1000
Clay	1 to 100
Groundwater (fresh)	10 to 100
Sandstone	8 – 4 x10^3
Shale	20 -2 x10^3
Limestone	50 – 4 x 10^3
Granite	5000 to 1,000,000

(Keller and Frischknecht 1996)

Table 2.]= Resistivity values of some types of water

Types of water	**Resistivity (Ωm)**
Precipitation	30-1000
Surface water, in areas of igneous rock	30-500
Surface water, in area of sedimentary rock	10-100
Ground water, in areas of igneous rock	30-150
Ground water, in area of sedimentary rock	>1
Sea water	= 0.2
Drinking water (max. salt content 0.25%)	>1.8
Water for irrigation and stock watering (max. salt content 0.25%)	>0.65

(Keller and Frischknecht 1996)

2.3 Direct Current (DC) resistivity method

Direct Current (DC) resistivity method is used to determine the electrical resistivity structure of the subsurface. Resistivity is defined as a measure of the opposition to the flow of electric current in a material. The resistivity of a soil or rock is dependent on several factors that include amount of interconnected pore water, porosity, amount of total dissolved solid such as salts and mineral composition (clays) (Rosli *et. al.*,2012). From various electrical methods, the Direct Current (DC) resistivity method for conducting a vertical electrical sounding (i.e. Schlumberger sounding) is effectively used for groundwater studies due to the simplicity of the technique, easy interpretation and rugged nature of the associated instrumentation. The technique is widely used in soft and hard rock areas (e.g. Van Overmeeren, 1989; Urish and Frohlich, 1990; Ebraheem et al., 1997). However, groundwater investigations in hard rock areas are often more difficult as tube-wells must be located exactly to be successful. Tube-wells drilled without proper geophysical and hydro-geological study often fail to yield groundwater. In hard rock areas, groundwater is found in the cracks and fractures of the local rock. Groundwater yield depends on the size of fractures and their interconnectivity. Use of Schlumberger sounding is well known for determining the resistivity variation with depth. However, it is very difficult to perform resistivity soundings everywhere without prior information.

2.4 Electrical resistivity method using a terrameter SAS 4000

SAS stands for Signal Averaging Systems, a method whereby consecutive readings are taken automatically and the results are averaged continuously. The Terrameter SAS/4000 can operate in different modes (resistivity, self potential & induced polarization). A useful facility of the SAS/4000 is its ability to measure in four channels simultaneously. This implies that well resistivity and induced potential measurements as voltage measurements can be performed up to four times faster. Resistivity measurements with ERM are one of the simplest methods to be used in geophysics. By putting two electrodes into the ground and inducing an electric current through the ground, a potential field is created. Two additional electrodes are used to measure the potential at some location. Increasingly deeper measurements are achieved by using a bigger separation between the current electrodes. Moving the current electrode and having the potential electrode fixed is named the “Schlumberger” method (Fig. 2).

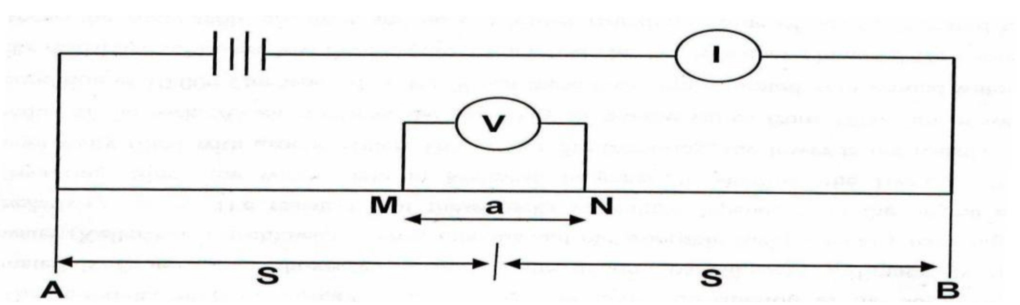

Fig. 2. Geometric arrangement of the Schlumberger array configuration

For this setup, a direct current is introduced into the ground through two current electrodes A and B. The potential electrodes M and N are inserted in the ground between the outer current electrodes A and B, to measure the potential difference. By measuring the current (I) between the two current electrodes A and B and the associated potential difference (V) between the potential electrodes M and N, the apparent resistivity (ρa) is computed by the Eq1 as given below:

$$\rho_a = K\,(V/I) \qquad \text{---------------------} \quad (1)$$

Where,

K is the geometric factor of the electrode arrangement in case of Schlumberger electrode configuration, which is given by Eq 2:

$$K = \frac{\pi (AB/2)^2 - (MN/2)^2}{MN} \qquad \text{-----------} \ (2)$$

By repeating the Schlumberger measurements with the entire setup moved one step to the side, vertical electrical soundings (VES) are performed continuously and the resistivities along a profile are measured.

2.5 VLF electromagnetic method

The VLF (Very Low Frequency) method has been applied successfully to map the resistivity contrast at boundaries of fractured zones having a high degree of connectivity (Parasnis, 1973). Further, the VLF method yields a higher depth of penetration in hard rock areas because of their high resistivity (McNeill et al., 1991). Therefore, a combined study of VLF and DC resistivity has potential to be successful (Benson et al., 1997, Bernard and Valla, 1991). VLF data are also useful in determining the appropriate strike direction to perform resistivity soundings (i.e. parallel to strike), again improving the likelihood of success. The radio signals transmitted from worldwide transmitters, used for navigation purposes in the frequency range of 5-30 kHz are used as a source for the primary field in a VLF survey. Such type of transmitting source makes VLF instrument very light and portable, and can be useful to survey a large area quite quickly. VLF magnetic field measurement makes use of E-polarization in which a transmitter is selected in the direction of strike and measuring profiles are taken perpendicular to the strike direction. Generally, the horizontal and vertical components of magnetic fields are measured and real and imaginary anomalies are computed using the expression given by Smith and Ward (1974)

$$\tan 2\alpha = \pm \frac{2(H_z - H_x)\cos\Delta\Phi}{1-(H_z - H_x)^2}$$

And

$$e = \frac{H_z H_x \sin\Delta\Phi}{H_1^2}$$

Where α is dip angle, *e* is ellipticity, *Hz* and *Hx* are the amplitudes, the phase difference $\Delta\Phi = \Phi_z - \Phi_x$, in which Φ_z is the phase of H_z and Φ_x is the phase of H_x, and $H_1 = Hx\, e^{i\Delta\Phi} \sin\alpha + Hz \cos\alpha$.

The tangent of the tilt angle is a good approximation of the ratio of the real component of the vertical secondary magnetic field to the horizontal primary magnetic field. The ellipticity is a good approximation of the ratio of the quadrature component of the vertical secondary magnetic field to the horizontal primary field (Paterson and Ronka, 1971). These quantities are called the real (= tan a × 100 %) and imaginary (= *e* × 100 %) anomalies, respectively and they are normally expressed as percentage.

VLF data were collected using an ABEM-WADI instrument. Since the strike of the formation was approximately in the E-W direction, a transmitter in this direction with a frequency of 19.8 kHz was used.

III. CONCLUSION

ERM solves the problems of groundwater exploration in the alluvium formation aquifer by serving as an inexpensive and useful method. The Electrical Resistivity Method helps in the identification and better understanding of aquifer dimensions. It has been concluded from this study that electrical resistivity methods are suited for estimating thickness of weathered mantle and mapping of bedrock topography and fractured zones. It is therefore suggested that geophysical methods, especially the electrical resistivity method, along with geological methods should form an integral part of groundwater exploration programs in solving complex geohydrological problems associated with ground water occurrence and resource development. Some uses of this method in groundwater are: determination of depth, thickness and boundary of an aquifer, determination of interface saline water and fresh water porosity of aquifer, hydraulic conductivity of aquifer, transmissivity of aquifer, specific yield of aquifer, contamination of groundwater (Choudhury *et al*., 2001). Contamination usually reduces the electrical resistivity of pure water due to increase of the ion concentration (Frohlich & Urish, 2002). However, when resistivity methods are used, limitations can be expected if ground in homogeneties and anisotropy are present (Matias, 2002). However, the use of geophysics for both groundwater resource mapping and for water quality evaluations has increased drastically during last 10 years in large part due to the rapid advances in microprocessors and associated numerical modelling solutions.

The Vertical Electrical Sounding (VES) methods have proved to be very reliable for ground water studies and therefore the method can effectively be used for shallow and deep underground water geophysical resistivity investigation.

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