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Application of Geoelectric Method for Groundwater Exploration from Surface (A Literature Study)

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Abstract. Groundwater utilization as a source of fresh water supply for various purposes in discharge area shows an ever to increasing trend, while land use of recharges also changes as development progresses. To meet its needs, many people rely on land-based exploration and exploitation. Groundwater is one of nature's most valuable and inseparable resources for life on earth. Groundwater exploration requires appropriate and efficient techniques. One commonly used method is the electrical resistivity method since, it is efficient and economical to determine groundwater. Vertical Electrical Sounding (VES) Method measurement of rock resistivity from the surface to determine the subsurface rock layer [1]. Geoelectric resistivity is one of the variables which is the physical properties of the rock layers below the surface. Rock resistivity data can be used to develop a model of subsurface and stratigraphic structures in terms of electrical properties. Geoelectric resistivity depends on lithology, air content, porosity, and pore ions concentration [2]. Geoelectric method is divided into two parts: Mapping resistivity method as a resistivity method that aims to study horizontal variations of horizontal layer resistivity types and Resistivity sounding method or, the drilling resistivity method that studies the variety of rock resistivity beneath the surface of the earth vertically. Data processing of geoelectric measurement results can be done by standard curve method, 2-Dimensional method (Schlumberger and Wenner), 3-Dimensional Method (Configuration of dipole-dipole, Lee Partition Configuration, Rectangle Line Source, 3 Point Gradient System). Therefore, ambiguity in interpretation can occur and become indispensable for calibrating the geoelectric measurement data with available borehole data to establish the resistivity range of various lithology units. Resistivity data can be used to identify and describe subsurface features such as the presence and type of aquifers, contaminated groundwater, and sediment size distribution [3, 4, 5].

INTRODUCTION

Groundwater is water that fills water saturated pathways, including springs that surface naturally. Groundwater is a vital source of water, especially in areas with no drains, streams and rain, and provides an indication of groundwater to the potential for community formation to the extent permitted by their validity in terms of quality and quantity. The geoelectric resistivity method is considered to be the most suitable and efficient method for groundwater exploration. It is based on the concept of subsurface determination, which can yield useful information on the structure, composition and water content of the soil. Geoelectric can also be used to determine the aquifer depth, stratigraphy and water quality of the aquifer [6]. It is one of the geophysical methods that study the nature of electrical current in the earth and to know the change of resistance of rock layers beneath the soil surface by passing a DC current (direct current) that has high voltage into the ground. This method is more effective for superficial exploration, such as determination of depth of bedrock, water reservoir search, and also for geothermal exploration. One of the physical properties of rock is its capacity carrying an electric current or commonly referred to as a type of resistance [7]. This capacity is used by humans to distinguish the type of rock without having to make physical contact or drilling that takes a long time and high cost, yet the accuracy level of data is reliable because the pumping test can provide important information on transmissivity and storativity of groundwater aquifers [8].

There are several geoelectric measurement methods for groundwater investigation. Based on the configuration of potential electrodes and current electrodes, there are several types of resistivity methods, such as Schlumberger Method, Wenner Method, and Dipole Sounding Method. Of the several methods, the Schlumberger method is often used particularly for ground water investigation in alluvial and hard rock fields. However, previous researches have shown that in wide open spaces along the lines, coverage time, this method requires high labor and cost. The suggested method is a convenient and economical operation for rapid and shallow groundwater investigations in the populated of hard rocky areas. In fact, many groundwater investigations are needed in densely populated areas. Therefore, there is a need for appropriate techniques that are cost effective and require no large open space and extensive labor.

Geoelectric exploration does not only obtain the type of rock layers, but can also be interpreted as a potential groundwater such as the depth of the aquifer and its distribution below the surface. In addition, groundwater movement can also be investigated based on the type of rock layers illustrated by the geoelectric measurements. The movement of atmospheric water and surface water is relatively easier to visualize, but it is not easy for groundwater movement. Eslamian (2014) investigated groundwater movement with hydrogeochemical modeling. Geoelectric can also show the relationship between hydraulic parameters and geoelectric properties of granite aquifer with a mathematical formulation such as hydraulic conductivity value, transmissivity, and storativity [9]. The purpose of the geoelectric survey is to determine the subsurface resistivity by measuring the surface of the earth. Resistivity is related to minerals, fluid content and degree of water saturation in rocks.

GEOELECTRIC BASIC PRINCIPLES

Geoelectric is a tool for measuring the electrical resistance of rocks below the surface that is detected from above ground level. This tool can also be used to study the freshwater lens in coast aquifer. Investigation of the type of resistance can be carried out over long distances and long periods, from unsaturated layers to saturated seawater and freshwater zones. Large resistivity values often leading to quite complex interpretations, for example, are extreme resistivity values in freshwater saturated zones, which are hardly recognized by pressure [10]. Another problem of nonuniqueness arises in the correlation of the resistivity layer with the hydraulic parameters.

The working principle of geoelectric is to inject electrical current into the earth. The electrode consists of two current electrodes (C1 and C2, see figure 1) that deliver the electric current, and two potential electrodes reading the potential difference value after the current through the rocks (P1 and P2). The four electrodes are plugged into the ground at a certain distance. The longer the distance of the current electrode will cause the flow of electric current can penetrate deeper rock layers. With the flow of electric current, it will cause electrical voltage in the ground. Electrical voltage occurring at the ground surface is measured using a multimeter connected via 2 voltage electrode P1 and P2, which is shorter than the distance of C1-C2 electrode. When the position of the electrode distance of the current is changed to be greater than the electric voltage, potential electrode also changes according to the information of the type of rock that participates in the injection of electric currents at a greater depth. See Fig. 1.

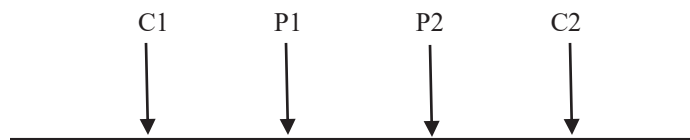


Figure 1. Simple Electrodes Array In Conventional Geoelectric Survey [11]

- C1 = Current Electrode 1
- C2 = Current Electrode 2
- P1 = Potential Electrode 1
- P2 = Potential Electrode 2

Resistivity can be done by configuration of Wenner, Schlumberger and dipole-dipole. However, the system of these four electrodes can be made effective for only three electrodes by keeping one of the far current electrodes from the rest of the electrode that it will have a negligible effect on the potential measurement. Hoel (1954) described a pole-dipole electrode system resembling the Schlumberger array, except that it uses only one current electrode. Eve and Keys (1956) and Coggon (1973) used three electrodes system, but only for profiling by keeping

all three lines. The application of pole-dipole resistivity techniques for detecting cavity solutions under the highway was delivered by Smith (1986). A similar configuration has been proposed for resistivity where the position of the potential electrode is fixed and only one current electrode is used as the electrode moves along the line [12].

Measurements for resistivity surveys are made by the streaming current into the ground through two electrodes type (potential electrode and current electrode), and measuring the resulting voltage difference across two potential electrodes. In its most basic form, the resistivity meter has a current source and voltage measurement circuit connected by cable to a minimum of four electrodes. The basic data obtained from the resistivity survey is the position of the current and potential electrode, current (I) injected into the ground and the resulting voltage difference (ΔV) between the potential electrode (Figure 1). Current and voltage measurements are then converted into a type resistance (ρa) of clear values using the following formula

$$\rho a = k \frac{\Delta V}{I} \quad (1)$$

where k is a geometric factor that depends on the configuration of current and potential electrodes [13]. Equation (1) is the simplest form and assumes that the earth is homogeneous for any combination of current measurements. Different settings of current and potential electrodes (or arrays) have been designed for years. The most commonly used arrays are shown in Fig. 2, accompanied by related geometric factors.

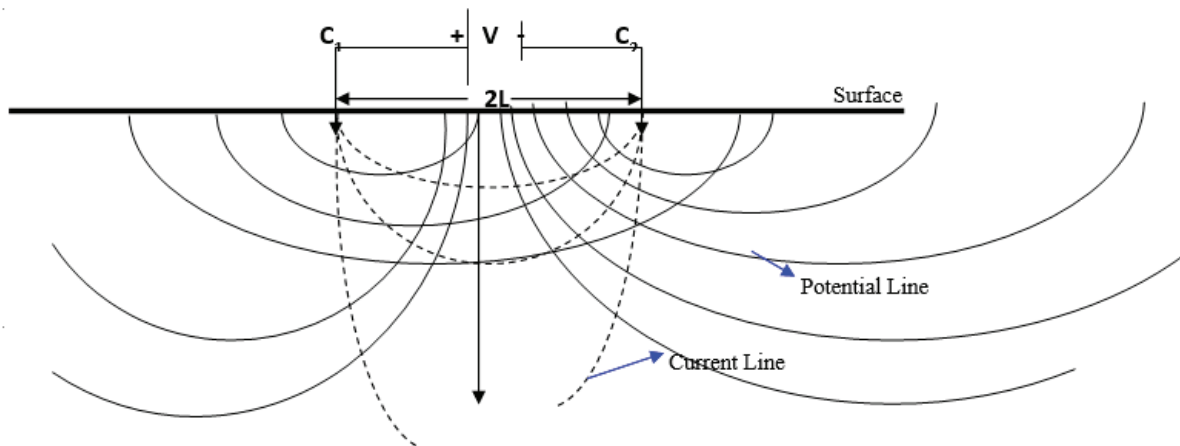


Figure 2. The Gradient Array [13]

Argued that electrical gradients can produce water flow from high to low voltage when electric current is flowing into the ground [14]. When an electric current is poured into the ground, it will produce a resistance value. The resistance equation is:

$$R = \frac{A \Delta V}{L I} \quad (2)$$

Where:

- A = Area of current flow (m^2)
- L = The flow length (m)
- ΔV = Voltage Difference / Voltage (V)
- I = Current (A)
- R = Resistivity (ohm-meter)

Vertical Electrical Sounding (VES) is commonly used in electrical resistivity surveys to determine the vertical variation between the earth's bottom of the electrical resistance and the potential field generated by the current. This technique involves the electric current induced into the ground through two implanted electrodes and measures the potential difference between the two other electrodes, referred to as the potential electrode. The current electricity used is the direct current provided by the dry cell. Therefore, the analysis and interpretation of geoelectric data is on the basis of resistivity value. The resistivity is calculated from the measurement of induced currents and the potential difference is referred to as "apparent resistivity". This measurement is based on the assumption that the soil is

uniform. However, in reality, the Earth's resistivity is determined by homogeneous lithology and geological structure. Therefore, the graph of the apparent resistivity to the current electrode distance is used to determine the vertical variation in the resistance formation. Interpretation of this graph provides true resistivity and depth of sand, which is also used to ensure the presence of aquifers or groundwater in the area. Parameters known to influence the estimation of groundwater resources include aquifer thickness and size and interconnection rates of pore space in aquifer materials.

Similar systems for soil surveys have also been developed. Some systems use cylindrical steel electrodes based on in-line geometry arrays, while others use spiked wheels to achieve continuous galvanic contact with the ground. The combined capacitive systems are used in areas with highly resistive surface materials (e.g. dry or frozen soil) or paved surfaces. This instrument uses an oscillating, electric dipole to produce a current flow in the ground and a second similar dipole to measure the distribution potential produced at ground level [15].

ELECTRODE CONFIGURATION

Goelectric method consists of several configurations, for example four pieces of electrodes located in a straight line. Each configuration has its own calculation method to know the value of thickness and resistance of rock types beneath the surface. The Schlumberger configuration method (fig. 3b) is a favorite method that is widely used to determine the characteristics of subsurface rock layers with relatively inexpensive survey costs. [16] conducted a study to determine the accumulation of groundwater in the west of Suez Bay with seventeen vertical power estimating points from the Schlumberger configuration, which was measured by $AB/2$ starting at 1,5 m up to 1500 m in the southern part of the study area. Quantitative interpretation results of goelectric data show that the subsurface consists of six goelectric units with different results. It discovered freshwater aquifers, fresh water, clay layers, and limestone layers, based on resistivity values of goelectric measurements.

Generally, the rock layers do not have the perfect homogeneous properties, as required by goelectric measurements. The position of rock layers located close to the ground surface will greatly affect the voltage measurement results and this will make the goelectric data to deviate from the true value and affect the homogeneity of rock layers are other rock fragments that are inserted in the layers, the uniformity factors of weathering the rock, material contained, local water logging, piping of metal materials that can carry electrical current, the wire fence connected to the ground and so on [17].

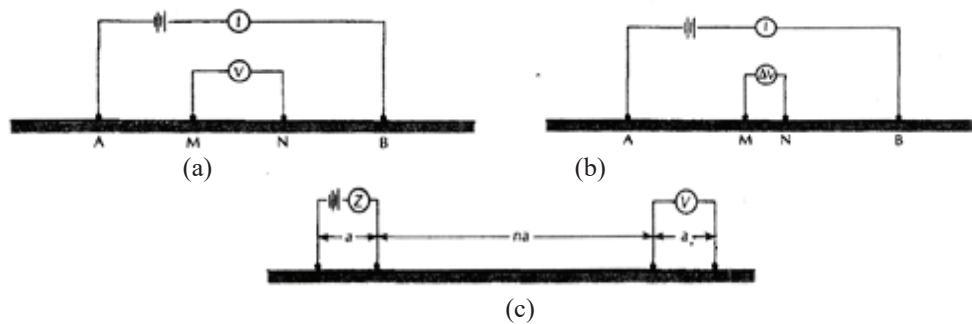


Figure 3. Electrode Configuration of Goelectric (a) Wenner Configuration, (b) Schlumberger Configuration, (c) Dipole-Dipole Configuration [17]

If ; C: The positive current electrode
D: The negative current electrode
M and N: Potential / voltage electrode
Then, the Resistivity formula becomes:

$$R = \left(\frac{2\pi}{\frac{1}{CM} - \frac{1}{DM} - \frac{1}{CN} - \frac{1}{DN}} \right) \frac{\Delta V}{I} \quad (3)$$

Resistivity Formula for Wenner Configuration is:

$$R = 2\pi a \frac{\Delta V}{I} \quad (4)$$

Resistivity Formula for Schlumberger Configuration is:

$$R = \pi \frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \frac{\Delta V}{I} \quad (5)$$

Resistivity Formula for Dipole-Dipole Configuration is:

$$R = n(n+1)(n+2)a \frac{\Delta V}{I} \quad (6)$$

Conventional electrode configurations used for such surveys include Wenner, Schlumberger, dipole–dipole, pole, pole–dipole and pole–pole arrays. The choice of a given array relied largely on the objective of lateral are effective depth of investigation, horizontal data coverage [11].

The advantages and disadvantages of different arrays have been discussed in various papers; such as in Dahlin and Zhou (2004), Saydam and Duckworth (1978), Szalai and Szarka (2008) and Zhou et al. (2002). The compatibility of arrays depends on many factors, such as the sensitivity to attractive targets, signal-to-noise ratio, depth of inquiry, lateral data coverage and more recent efficiencies using it in multichannel systems. Meanwhile, multiple gradient arrays are designed for use in multi-channel systems [18].

GEOELECTRIC SURVEY METHOD

The procedure of resistivity measuring performed varies depending on the geometry of its geological object [19]. Several methods of measurement of type resistance are 1D measurement (Vertical Electrical Sounding / VES), 2D (Horizontal Profiling), and 3D (Mapping of formation resistance).

1-D Resistivity Method

This method is called Vertical Electrical Sounding (VES), which is used to measure the distribution of vertically resistivity value below the surface of the sounding point. This method is better used for layers of rock or horizontal precipitate [19]. The result of measurement of VES method is resistivity value and thickness of rock layer. The interpretation model consists of a series of 1-D horizontal layers, and this method has been widely used to investigate soils for the management of various resources, such as minerals, petroleum, and groundwater resources. Initially quantitative interpretation of geoelectric data is done by using sounding standard curve. The sounding curves were subsequently replaced by computer inversion techniques with the advent of linear filter methods [20, 13].

2-D Resistivity Method

This method is also called the horizontal profiling method used to determine the distribution of apparent resistivity horizontally per depth. Measurement of 2D method is a combination of sounding and profiling measurements, which investigate geological objects by changing resistivity horizontally so that it will get the resistivity information in the vertical and horizontal direction simultaneously. The resistivity meter used in the survey typically has four electrodes connected via four separate cables, a multi-electrode system that has 25 or more electrodes connected to the resistivity meter via a multi-core cable [11]. According to [19], the 2-dimensional measurement data provides a subsurface view into several squares that have resistivity value according to the measurement results. The model used for inversion consists of cell unit which size depends on the distance of the installed electrode that is set manually. For groundwater exploration, the 2D type of measurement method is preferred than the 1D method. The main limitation of the 2-D survey method is the assumption that the geological structure does not change in the perpendicular direction to the survey line. This is a reasonable assumption when the survey line can be placed perpendicular to the strike structure.

3-D Resistivity Method

Surveys and interpretations of the 3-D resistivity model should provide the most accurate results in compared to the 1D and 2D methods. Nevertheless this method is most widely used in mineral exploration surveys with higher costs for equipment and labor. Although this method has not reached the same level of use of the 2-D survey, it is already widely used in complex areas to environmental and engineering problems [21].

4-D Resistivity Method

In a 4-D survey, resistivity changes in space and time are measured. Measurements are repeated at different times using the same survey line in a 2-D or 3-D survey. This survey is used for dams monitoring [22], landslide areas [23], methane gas in landfills [24], and water movements in the aquifer [25, 26]. A number of techniques have been proposed for inversion of time-lapse data, including independent inversion [25], using data ratios from initial data and then data sets, using differences in apparent resistivity values [27], simultaneous inversion, and combine the temporary data and models into quadratic-regularization methods [18].

DISCUSSION

Electrical resistivity methods are applied to solve the hydrological problem of regional scale water resource exploration for local scale to estimate hydraulic conductivity. Initially, hydrological-based electrical resistance issues are focused on the location of the source for exploitation by vertical one-dimensional electric sounding. Hydraulic parameter estimation has better result by combining pump test with resistivity information from VES to formulate regression model at measurement location. This methodology is still used and developed rapidly to detect aquifer depths [28], transmissive of rocks and soils, determination of the geometry of aquifers, geologic structures, and hydro stratigraphic sequences. Research on the depth of bedrock from the use of resistivity helps to determine geometry. For example, [29] examined the case of topsoil over the limestone karst system. Holcombe and Jiracek (1984) and Al-Khafaji and Al-Dabbagh (2016) also examined the topography of bedrock. Loke (2013) and Cassiani (2006) explored the aquifer through a detailed analysis of the subsurface structural components. The mapping of hydro stratigraphy, which uses resistivity to determine unit is important for hydrogeological analysis, is effectively performed [30, 31].

Some researchers have studied the relationship between the electrical and hydrological parameters of the aquifer. [32] measured the formation factor and intrinsic permeability of some graded sand samples and found that grain size increased, while the respective formation factor and intrinsic permeability also increased. [33] developed a link between aquifer permeability and porosity. Various researchers have attempted to establish empirical and semi-empirical relationships between various aquifer parameters and geoelectric parameters. [34] formed an empirical relationship between aquifer resistivity and hydraulic conductivity aquifer and a semi-empirical relationship between the aquifer forming factor and the hydraulic conductivity to integrate the flow of water with the geophysical model. [35] provided a coherent definition for each type of hydro geophysical analysis. Measurements of electrical resistance, or geophysical measurements sensitive to hydrogeological variables, have the ability to provide information with much higher spatial resolution than hydrological measurement methods only.

Electrical resistance is the relationship between the potential value and the electric current regulated by Ohm's law. The potential at any point on the surface or inside the medium can be calculated if the resistivity distribution is known. For the 1-D model, the problem is generally solved by using the linear filter method [36]. For 2-D and 3-D models, analytical methods are used for simple structures such as cylinders or spheres in a homogeneous medium [37, 38]. Boundaries and elements of method analysis [39, 40], can also be used for more general structures but are usually limited to subsurface models in relatively small numbers. For limited field data modeling using volume methods [41], and finite-element methods [42] are more commonly used. The purpose of the resistivity method is to calculate the subsurface electrical resistivity which quantity is unknown.

The quality of geoelectric data depends on the measured data, the resulting resistivity images, errors from various sources including those introduced by measurement devices, electrode polarization, and other indefinite external effects [43]. Electrode positions are usually specified for surveying and geoelectric monitoring. However, for difficult soil conditions such as steep or heavily vegetated areas, it can be difficult to accurately position the electrodes. In addition to unstable soil monitoring of the land sliding, electrode position may shift resulting in systematic data errors that cannot be reduced through reciprocal error filtering. Approaches to reduce the impact of

this effect include geometry selection of various measurements that are less sensitive to positioning errors [44], and in the case of moving electrodes, to estimate the position of the electrode using the inversion position. For very long 2-D survey lines, and for 3-D grid imaging, it can be impractical to carry out measurements in a single deployment because long cable lengths are required. As a result, very long 2D lines are often surveyed using overlapping parts, and a 3-D survey on the surface is done with a single line gradually migrating across the surface to construct a set of measurements consisting of data from multiple lines [45].

CONCLUSION

Based on the analytical and interpretative input of representations from various studies by some experts, it can be concluded that geoelectric are a fairly effective and reliable geophysical tool to detect the presence of groundwater, lithology and rock stratigraphy in the earth. Longitudinal conductance calculations and transversal resistance are reliable indicators for aquifer used for groundwater extraction and they produce contour maps showing an area for groundwater exploration and drilling locations. The results of measurement and interpretation of geoelectric data will be better if combined with well bore data and geological map of research area. The most common method used to measure the earth's resistivity through soil is the use of four electrodes. AC current is driven through a pair of electrodes and the potential is measured with a second pair of electrodes. Such surface resistivity methods have been efficiently used for groundwater exploration for many years. Earth resistivity is related to geological parameters from subsurface including rock and soil type, porosity, and degree of saturation. From the magnitude of the current it is possible to calculate the distribution potential and current flow path if the soil is homogeneous. The conditions of anomalies or inhomogeneities in the soil, such as better electricity or worse layers, are inferred from the fact that they deflect currents and distort normal potentials [46].

Geoelectric surveys cannot provide pollution-based answers: natural (over wash) or industrial (shipbuilding activities). The high amount of absorbed organic compounds, though, indicates that at least some of the pollutions may come from activities such as paint stripping and handling of hazardous materials. Geoelectric data can also indicate lateral geometry errors. The resistivity survey method is one of the oldest and most commonly used geophysical exploration methods [47]. It is widely used in environmental and engineering, hydrology [48], archeology [49] and mineral exploration [50]. This survey has been used for image structures from millimeter scales to kilometers. In addition to ground level surveys, it is also used throughout drill holes [15] and in water areas [18] due to the first commercial use of the early 1920s resistivity method and to the end 1980s, had been used primarily as a one-dimensional survey (1-D) mapping method. However, even in fairly complex areas, the 1-D approach is not accurate. Over the past 25 years, there has been a revolutionary overhaul with the usual two-dimensional resistivity (2-D) method. The three-dimensional (3-D) survey is used in areas with complex geology, while a four-dimensional (4-D) survey has not been widely used.

The electrical resistivity of the stone depends on its composition, degree of saturation, porosity and connectivity of the pores. Compact and dry rocks can be characterized by resistivity of up to 10,000 Ohm m. The electrical resistivity value is cracked / altered and not consolidated stones, depending on saturation, lowering very low values. The electric resistivity survey is very efficient for identifying, mapping and monitoring groundwater from surfaces for plain areas. The electrical resistivity method is evident to be a valuable tool complementing the hydrogeological methods for direct subsurface exploration, such as isotope geochemistry and subsurface modeling methods, which are the basis for the characterization of aquifers. Geoelectric surveys have the advantage of data acquisition and sub-surface modeling that can be done only with simple, compact equipment with reliable data accuracy, short time, and low cost [7].

ACKNOWLEDGEMENT

The authors thank to Kemeristek Dikti and LPDP for scholarship in the completion of doctoral studies at Universitas Indonesia. Gratitude is also expressed to Universitas Muhammadiyah Metro Lampung, Dr. Muh. Sarkowi, Diah Indriana Kusumastuti, Phd., Ahmad Zakaria, Phd., (Lecture at Universitas Lampung), Dr. RR. Dwinanti Martanti (Universitas Indonesia), Dwi Nugroho, S.T., and Mufidah, S.T. (CV. Ratu Rania Consultant).

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