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# Estimation Of Hydraulic Conductivity And Transmissivity Of Quarternary Deposit Aquifer Using Vertical Electrical Sounding in Kertajati Majalengka West Java

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**Abstract:** ***The integration of geophysical data with direct hydrogeological measurements can provide a minimally invasive approach to characterize the subsurface at a variety of resolutions and over many spatial scales. The field of hydrogeophysics has attracted much attention during the last two decades. In this domain, the geophysical data inverted to geophysical models are interpreted in terms of the hydrogeology to serve as a basis for the definition of hydraulic models in the areas of interest. The hydraulic conductivity (K) value measured in a reference borehole has been combined with the electrical conductivity obtained from nearby Vertical Electrical Sounding data in the Kertajati confined aquifer. The resulting relation was interpreted with Dar Zarrouk parameters to infer the transmissivity variations at other vertical electrical sounding locations, where (K) values are unknown. The results indicate that the transmissivity values in the aquifer of interest vary from 553.935 to 14074 m$^2$/day, and K varies from 38.48 to 203.776 m/day throughout the studied area.***

**Keywords:** Geophysics, Hydraulic Conductivity, Transmissivity, Vertical Electrical Sounding

## 1. Introduction

Groundwater and aquifers are characterized by a number of parameters which can be determined by surface geophysical measurements; commonly porosity, transmissivity and conductivity. The occurrence and movement of groundwater depends on subsurface characteristics, such as lithology, texture and structure. Hydraulic conductivity/ permeability $(K)$, Transmissivity $(T)$, and Storativity $(S)$ are all commonly applied hydraulic parameters in the modelling of groundwater flow [5]. Hydraulic conductivity $(K)$ and transmissivity $(T)$are important parameters for assessment of aquifers. They describe the general ability of an aquifer to transmit water over a unit thickness for hydraulic conductivity and over the entire saturated thickness for transmissivity. The conventional method for determining aquifer parameters is a pumping test, which is expensive and yields results appropriate only to a small region of the aquifer. These methods are expensive and time consuming especially when a large set of data is required Because the hydraulic parameters of geologic formations vary over relatively small spatial scales, it is difficult to accurately characterize subsurface aquifer properties using just the information obtained from widely spaced boreholes. A more complete and accurate characterization of the subsurface can be achieved by using an integrated exploration approach in which borehole and geophysical data are jointly interpreted [1]. Surface geophysical methods have been developed as an alternative to field hydrogeological methods. These provide rapid and effective techniques for groundwater exploration and aquifer evaluation [16].

The investigation of the spatial distribution of aquifer properties from geophysical measurements has received great interest over the past two decades [1] [16]. A key step in quantitative hydrogeophysical interpretations is the transformation of the measured geophysical properties into the desired hydrogeological parameters.

Although various geophysical techniques are currently being applied to explore and assess water resources, the direct-current (DC) electrical resistivity method still proves the most powerful and cost-effective technique in groundwater studies [9] [11]. This is due to the closerelationship between the electrical conductivity and some hydrogeological properties of the aquifer. Moreover, subsurface lithological information and the depth to water obtained from the existing boreholes were used to confirm the results of the measured data inversion. Accordingly, this report shows how the geoelectrical parameters can be used for the estimation of transmissivity and hydraulic conductivity variations throughout kertajati research area.

## 2. Regional Geology

Geology of the study area included in the Geological Map of Arjawinangun Quadrangle. It is composed of Lower Quaternary Sedimentary Rocks (Qos) and Aluvium Deposition (Qa). Lower Quaternary Sedimentary Rocks

(Qos) large extend almost throughout the study site and consist of tuffaceous sandstones, sand, silt tuffaceous clays, conglomerates and breccias and tuffaceous contains pumice, as revealed in the Kertajati Village form of conglomerates and Pasiripis Village form of coarse sand. This form of soil weathering residue (residual soils) in the form of yellowish brown clay plastic and swelling.

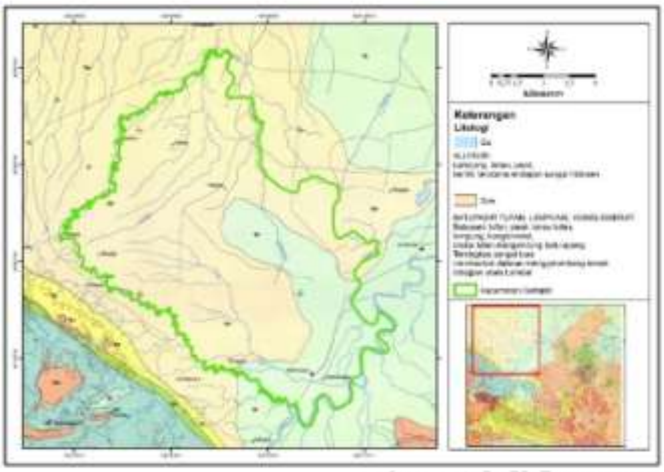


**Figure 1:** Geological map of the study area (modified from Djuri 1995)

Alluvium (Qa) Holocene age are in the southeastern part of the study area, the flood plains of the River Cimanuk deposition results. Alluvium deposits consist of clay, silt and sand (Hasibuan, 2009). According to Hasibuan (2009), rocks are found in the village of Kertajati and in the village of Pasiripis. In the Kertajati Village rocks form a conglomerate with strong weathered condition, so that the gravel fragments apart, whereas in the Pasiripis Village form of layered sandstone medium sized grains with a fragile condition. The residual soil is the result of weathering of Quaternary sedimentary rock (Qos) consisting of: sand, silt, and clay. The soil is transported which is an alluvium deposit.

### Geomorphology

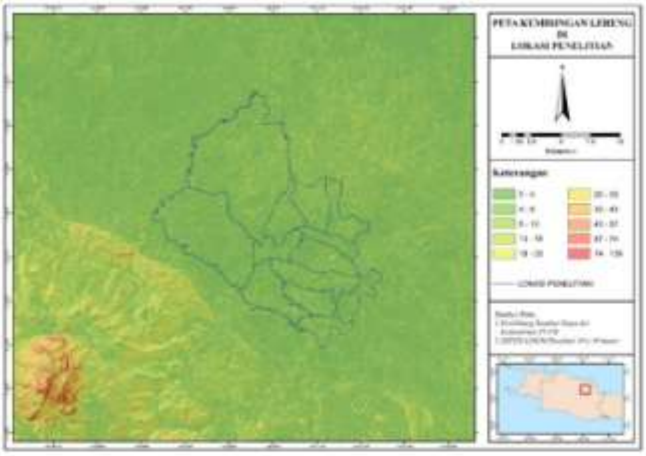


**Figure 2:** Slope map of the study area

The location of the study was a wavy plateau with an altitude of 25 - 37.5 m above sea level (dpl), with a slope of less than 3% to the southeast (Figure 2). The rivers in the study area are seasonal rivers that can be separated into rivers flowing north and south and east to Cimanuk River. Study area are included in the Cimanuk River Basin, Kalicilet, Cibuaya, and PasiranginWhere each basin has an area of 3739 km$^2$, 415 km$^2$, 471 km$^2$, 66 km$^2$. In areas of depression, there are swamps that function as retention used in the dry season. The swamps include Rawa Cicabe and Rawa Telik in Pasiripis Village, Rawa Cimaneuh and Rawa Jawura in Kertajati Village, and several swamps in Sukakerta Village

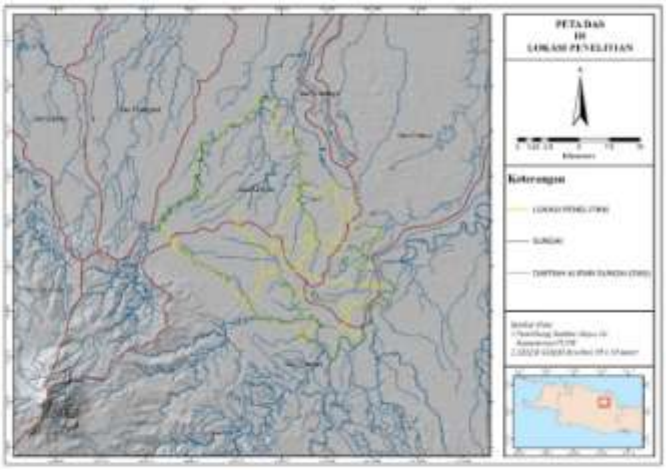


**Figure 3:** Watershed map of the study area

### Hydrogeology

Based on the Report by IWACO-WASECO The Majalengka region shows the dominance of Ciremai volcano in the southeast and has a height up to 3078 m above sea level. The volcano appears on the sediment of Tertiary-aged sea sediments consisting mainly of claystone. The rocks are mainly exposed in the south and west of the district and covered by alluvial / talus deposits in the northern coastal plains. Based on its hydrogeological characteristics, this area can be divided into several zones: Quarter volcanic deposits, Tertiary sediment deposition, Sedimentation of Quaternary Volcano fan, Alluvial deposits, Alluvial river Cimanuk and Cilutung, Cikijing Basin

## 3. Methods

### Methodology and data acquisition

Electrical methods are widely applied in hydrogeophysical investigations [3]. VES sounding measurements have been conducted in the studied area to identify groundwater occurrences [13][17]. The VES data were measured at 12 points arranged in a grid-like pattern, using a GL-4200 resistivity meter. A Schlumberger electrode array was applied with current electrode spacing (AB/2) ranging from 1.5 to 150 m.

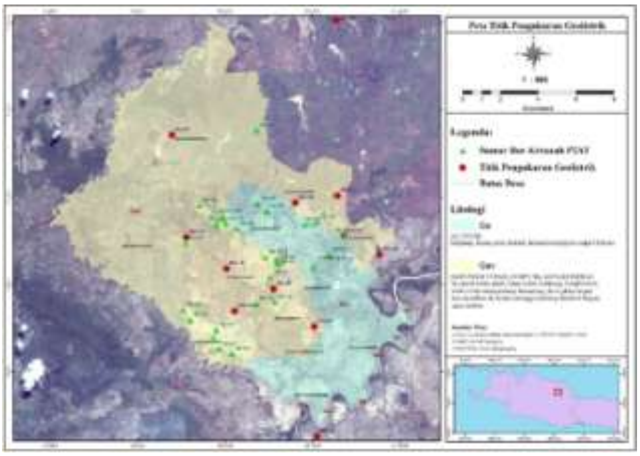
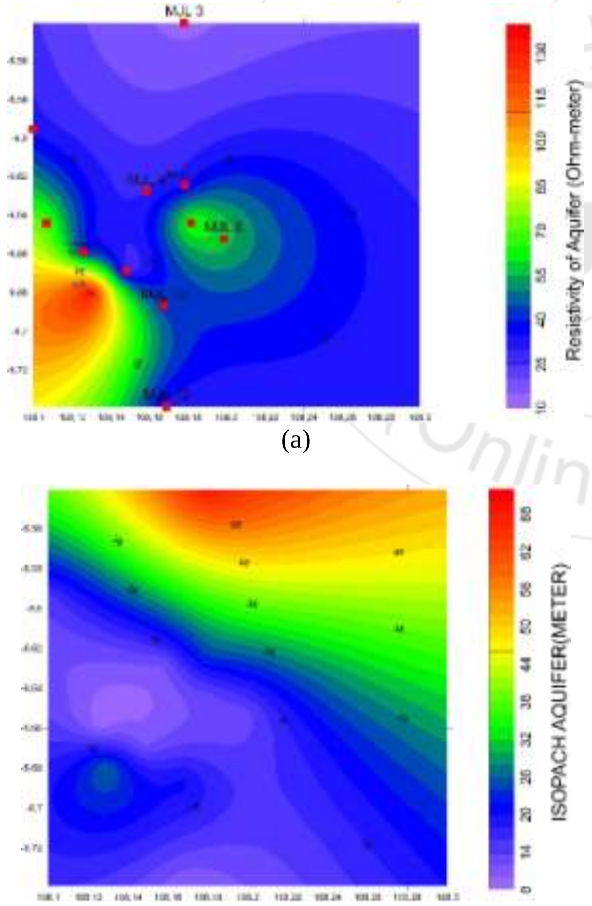


**Figure 4:** VES measurement points (red dots), green triangle Borehole

**Data inversion**

In the present work, the VES inverted in a one-dimensional (1-D) scheme. The VES data were inverted using Russian software [8], where well information was used for building up the initial models. The geophysical studies conducted in this area revealed the following results; the aquifer exhibits relatively low resistivity values ranging from 13.3 to 133 Ohm-m (Fig. 5a), and thickness values ranging from 9.13 to 69 m as shown in Fig. 5b. This aquifer is composed of Sand deposits.



(a)

**(b)**

**Figure 5:** (a) Lateral Distribution of Aquifer Resistivity (b) isopach Aquifer (thickness in meter)

**Transmissivity-Dar Zarrouk approach**

The theory and mathematical expressions used for groundwater investigation by geoelectrical methods are well established [10] [3] [11]. Mathematically, the flow of electrical current in a conducting medium is governed by Ohm's law and groundwater flow in a porous medium is controlled by Darcy's law, where both have similar formulae as follows:

$$J = \sigma E \ (Ohm's\ law)$$

$$Q = K\ I\ A\ (Ohm's\ law)$$

where, $J$ = electric current density, $\sigma$ = electrical conductivity, $E$ = electric field intensity, $Q$ = discharge (volume of water per unit time), $K$ = hydraulic conductivity, $I$ = hydraulic gradient, $A$ = cross-sectional area perpendicular to the direction of flow. The analogy between these two macroscopic phenomena and the relationship between electric and hydraulic parameters are widely accepted [5][4]. Groundwater flow through an aquifer is governed by the bulk parameter, transmissivity (T), which is expressed by:

$$T = K\ h$$

where, $h$ = saturated thickness of the aquifer. Therefore, it is more appropriate to develop a relation between transmissivity and the Dar Zarrouk parameters. The Dar Zarrouk parameters were first introduced by [12] to explain the problem of non-uniqueness in the interpretation of resistivity depth sounding curves. They consist of two variables which can be assigned to each horizontal layer of a simple stratified model; the transverse resistance $T$ and the longitudinal conductan (S).

$$T = hp = h/\sigma \dots \text{ and } \dots S = h/\sigma$$

where, h is the saturated thickness of the layer (in meters) and ρ is the electrical resistivity of the layer in Ohm-meters which is equivalent to 1/conductivity (σ).

[14] have established an ana-lytical relationship between the aquifer transmissivity (T) and both the transverse resistance (T) and the longitudinal conductance (S). Taking into account a prism of aquifer

$$T = (K\sigma)T$$

and, $T = (K\sigma)T$ In areas of similar geologic setting and water quality, the K_σ product (the K to σ relation, either Kmultiplied by or divided by σ) remains fairly constant[14] [15]. Estimation of the appropriate constant (either K σ orK/σ) can be done by combining aquifer pumping test results and surface conductivity measurements at a few points in the aquifer. Then, transmissivity variations over the rest of the aquifer can easily be determined from additional conductivity measurements.

## 4. Result and Discussion

Prior to the investigation of transmissivity variations throughout the aquifer of interest, it was necessary to calculate the appropriate K σ constant. The K_σ product can be expressed in terms of both transverse resistance (T) and longitudinal conductance (S). In this case study, T and S values at all stations could be calculated by means of resistivities and thicknesses obtained from the VES data modeling. Regarding the VES method, the transverse resistance is the dominant parameter for a layer with a K-shaped sounding curve while a layer with an H-type curve [6].

**Table 2** Estimated transmissivity values obtained from the combining of $K/\sigma$ constant with the longitudinal conductances at all stations in the studied area

| ID VES | $h$ | $\rho$ | $S = h/\rho$ | $T = (K/\sigma)\,S$ | $K = (T/h)$ |
|---|---|---|---|---|---|
| MJL 1 | 23.9 | 33.9 | 0.705015 | 1912.636 | 80.02662 |
| MJL 2 | 26.8 | 133 | 0.201504 | 546.6601 | 20.39776 |
| MJL 3 | 69 | 13.3 | 5.18797 | 14074.46 | 203.9776 |
| MJL 4 | 12.41 | 29.8 | 0.416443 | 1129.769 | 91.037 |
| MJL 5 | 13.66 | 66.9 | 0.204185 | 553.9349 | 40.55161 |
| MJL 6 | 13.01 | 57.5 | 0.226261 | 613.8237 | 47.18091 |
| MJL 7 | 12.6 | 70.5 | 0.178723 | 484.8592 | 38.48089 |
| MJL 8 | 9.13 | 41.2 | 0.221602 | 601.1845 | 65.84715 |
| MJL 9 | 11.8 | 26.6 | 0.443609 | 1203.468 | 101.9888 |
| MJL 10 | 20.6 | 41.9 | 0.491647 | 1333.79 | 64.74708 |
| MJL 11 | 14.8 | 33.1 | 0.44713 | 1213.02 | 81.9608 |
| MJL 12 | 9.81 | 32.6 | 0.30092 | 816.3673 | 83.21787 |

Remarks: $\rho$ electrical resistivity (Ohm-m); $h$ saturated thickness (m); $S$ longitudinal conductance; $K$ hydraulic conductivity (m/day); $\sigma$ = electrical conductivity (Siemens/m).

$T$ transmissivity ($m^2$/day)

$K/\sigma$ constant: the $K/\sigma$ constant was calculated by using the $K$ value obtained from the pumping test ($K = 15.6$ m/day) and $\sigma$ obtained from $\rho = 48.35$ Ohm-m $\left(\sigma = \frac{1}{\rho} = \frac{1}{48.35} = 0.0207\right.$ Siemens/m

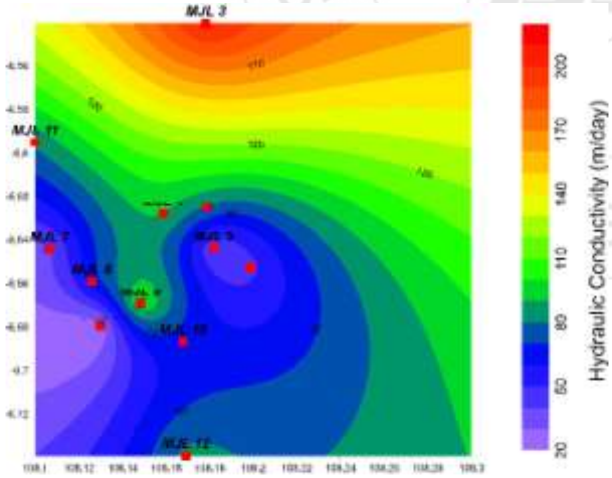


**Figure 7:** Lateral Distribution of Hydraulic conductivity in study area

## 5. Conclusion

The present study is an attempt to demonstrate a quick, simple and relatively inexpensive method for estimating the transmissivity variations throughout aquifer. The results gave a useful first approximation for the transmissivity changes, which will be very useful for further studies of the groundwater regime in the study area. This approximation can be used to site exploratory boreholes or as an initial input to a groundwater flow model.

Application of the Dar Zarrouk parameters for transmissivity estimation is an advantageous approach over resistivity or thickness-dependent estimations. This is based on the fact that both the transmissivity and the Dar Zarrouk parameters are bulk parameters, and do not depend on independent geoelectrical parameters. Since the area is highly fractured, determination of the aquifer geoelectrical properties by a single geophysical method may be a very difficult task. So, themiho integrated interpretation of galvanic and inductive data sets has been conducted to overcome the problems of equivalence and layer suppression encountered in a Ksingle method.

## 6. Acknowledgements

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