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Vertical Electrical Sounding Exploration of Groundwater in Kertajati, Majalengka, West Java, Indonesia

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Abstract - Continuously increasing population and progressive infrastructural development in the region of Kertajati International Airport, Indonesia, emphasize the need to develop a sustainable water supply network. Airport facilities require sufficient water resources, which can be obtained from surface water and groundwater. Groundwater exploration can provide necessary information for assessing water resources. The purpose of this study is to analyze the configuration of aquifers in the studied area. A Schlumberger array was used to carry out twelve vertical electrical soundings (VES) with AB/2 electrode spacing ranging from 1.5 m to 150 m. IPI2win software was used to qualitatively interpret the VES results and it suggested the presence of three distinct lithological units interpreted as clay, alluvial sand, and a Lower Quaternary formation. In general, resistivity values in the studied area can be divided into five resistivity categories: very low resistivity with values ranging from 1 Ωm to 10 Ωm, low resistivity with values ranging from 10 Ωm to 50 Ωm, medium resistivity with values ranging from 50 Ωm to 100 Ωm, high resistivity with values ranging from 100 Ωm to 200 Ωm, and very high resistivity with values > 200 Ωm. The geo-electric interpretation revealed three geo-electric layers: topsoil (1 - 144 Ω m), sand (1 - 298 Ω m), and clay (1 - 82 Ω m). Aquifers in the studied area are lithologically composed of sand. Clay is the dominant lithology in the studied area, so the presence of aquifers in this area is very limited, and thus the supply of groundwater is also limited. The exploitation of groundwater must be limited and controlled to maintain the sustainability of groundwater in the studied area.

Keywords: vertical electrical sounding, aquifer, groundwater, geo-electric layers

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INTRODUCTION

Background

Groundwater is a highly valuable natural resource (Song *et al*., 2012) and an essential geological agent in the transport of mass and energy within the earth (Llamas, 1987), providing a wide variety of ecological and social services (Houben and Weihe, 2010). The advantages of groundwater over other sources of water have been emphasized in literature (Bayewu *et al*., 2018). A high percentage of water users worldwide rely substantially on groundwater (Reilly *et al*., 2008). Demand for this resource has increased significantly throughout the world due to population growth, socio-economic development, technological and climatic changes (Alcamo, 2007). Despite its advantage of easy accessibility, surface water is often polluted by anthropogenic activities, making groundwater a desirable option to satisfy our demand for quality water (Anomohanran, 2015). The continuous increase in population and the progressive infrastructural development in Kertajati area emphasize the need to develop a sustainable water supply network. Airport facilities require sufficient water resources, which surface water and groundwater are often used to fulfill. Groundwater exploration can provide necessary information for assessing water resources. The purpose of this study is to analyze the configuration of aquifers in the area of Kertajati Airport.

Kertajati Airport is the second largest airport in Indonesia, located in the Majalengka Regency, northeastern part of West Java Province, approximately 68 km east of Bandung City.

The urgent need for groundwater has driven the application of appropriate geophysical and hydrogeologic exploration techniques (Anudu *et al*., 2011) to locate areas of high and reliable groundwater potential or to characterize seasonal changes in near-surface aquifers (Webb *et al*., 2011). A geophysical investigation is a powerful tool for exploring subsurface geology and collecting information about subsurface layers and structures (El-Sayed, 2010). Various geophysical techniques or applications have been employed in groundwater exploration in many parts of the world, including magnetic resonance sounding (MRS), remote sensing, geographic information systems, seismic refraction, and electrical resistivity, among others (Kamble *et al*., 2012).

The electrical resistivity method has been extensively used for groundwater aquifers mapping (Massoud *et al*., 2015), investigating aquifer vulnerability (Sørensen *et al*., 2005), and freshwater/saline water studies (Khalil, 2010). The electrical resistivity survey method is one of the oldest geophysical exploration techniques and has been extensively employed in environmental, engineering, hydrological, archaeological, and mineral exploration surveys (Reynolds, 2011). Vertical electrical sounding (VES) has been the most frequently used electrical resistivity tool in groundwater studies, as it can give information about subsurface rocks and structures at depths useful for water exploration (Araffa *et al*., 2015). It is also comparatively less expensive than other methods, and its methodology is simple. The VES technique is based on the fact that the subsurface layer can only transmit current because of the presence of water, since the rock itself is considered an insulator (Anomohanran, 2015). The VES technique is thus widely used to explore groundwater resources (Hafeez *et al*., 2018; Mohamaden *et al*., 2009), and has therefore been chosen to analyze aquifer configurations in this study.

Geological and Hydrogeological Settings

The geology of the studied area is composed of Lower Quaternary sedimentary rocks (Qos) and Holocene alluvium deposits (Qa) (Figure 1). The Lower Quaternary sedimentary rocks extend across almost all of the studied area and consist of tuffaceous sandstone, sand, tuffaceous silt, clay, conglomerate, and tuffaceous breccia containing pumice, which crop out in Kertajati Village in the form of conglomerates, and in Pasiripis Village in the form of coarse sand. The weathering of these rocks produces residual soils which include clays subject to swelling (Hasibuan *et al*., 2009) . Holocene-aged alluvium (Qa) deposits occur in the southeastern part of the studied area, as a result of flood deposition from the Cimanuk River. This alluvium consists of clays, silts, sands, and gravels which has been mainly deposited by Holocene streams (Hasibuan *et al*., 2009). The studied area has a widespread medium aquifer consisting of undifferentiated sandstones and tuffs, with groundwater flowing through the pore spaces in the media (IWACO-WASECO, 1990).

A geoelectrical survey using VES was conducted on November 2015. The electrical resistivity of the studied area was measured using a GL-4100 Earth Resistivity meter. A Schlumberger array was used to carry out 12 VES with AB/2 electrode spacing ranging from 1.5 m to 150 m (Figure 2). These stations are referred to as MJL-01 - MJL-12. The geo-electrical method

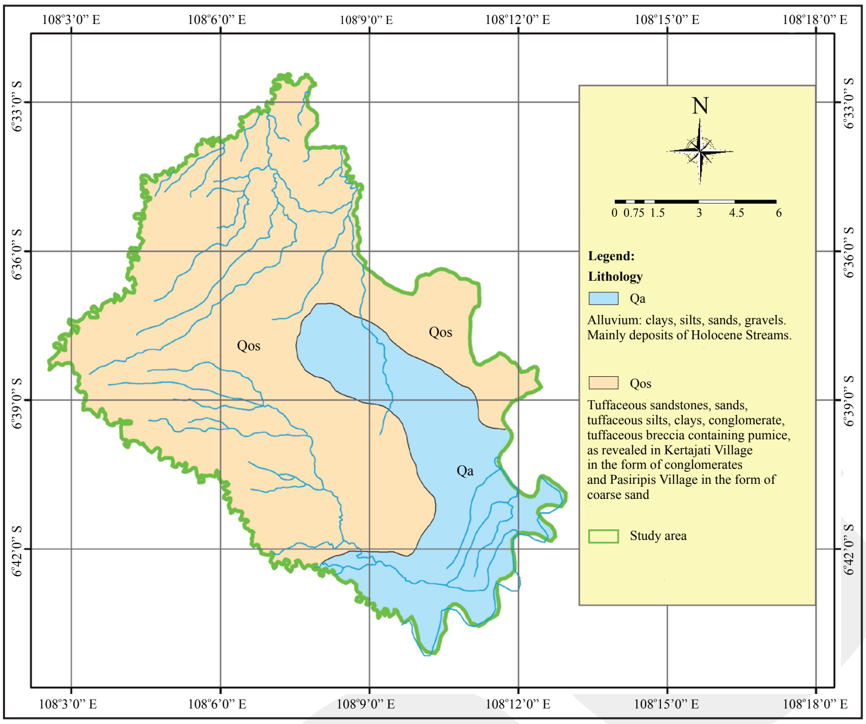


Figure 1. Geological map of the studied area.

was adopted in this study, because it is a useful tool for ascertaining the subsurface geology of an area (Tizro *et al*., 2012). VES data interpretation aims to determine the true resistivities and thicknesses of the successive strata below the different stations, utilizing measured field curves (El-Gawad *et al*., 2018). The apparent resistivity (ρa) values were obtained from the voltage (mV) and current (mA) read from the resistivity meter and its calculated corresponding geometric factor (Zohdy, 1975).

A VES station, MJL-05, was located beside a borehole with known lithologic logs to serve as parametric measurements, which were helpful in interpreting the VES data (El-Gawad *et al*., 2017). The lithology data obtained from well TW-88, which were drilled by the Groundwater Development Project (P2AT), Ministry of Public Works, Republic of Indonesia, were used to calibrate the geo-electrical models obtained from the apparent resistivity curves. Figure 3 shows the correlation between geo-electrical parameters of well TW-88 and the geology obtained from station MJL-05. Figure 3 shows the correlation between geo-electrical parameters measured at VES station MJL-05 and the geological data obtained from well TW-88. The measured vertical electrical soundings were interpreted qualitatively and quantitatively to build a geo-electrical model, which was initiated using all available data about the geologic and hydrogeologic settings. The data were calculated to obtain the apparent resistivity and thickness values, which were again used in the computerized interpretation to obtain the true resistivity and thicknesses of the various layers encountered. The interpretation of geo-electrical resistivity data from the twelve VES curves was conducted by converting the values of AB/2 and ρa into a multilayer model. The quantitative interpretation has been applied to determine the correlation between the geo-electrical parameters obtained from station MJL-05 and geological information from drilled hole TW-88 (Figure 3). The initial models have been constructed using the available geologic data from the existing boreholes. IPI2 win is a programme provided by Moscow State University, Russia, to produce quantitative interpretations of the geo-electrical sounding curves. It is an inverse modeling programme for interpreting resistivity sounding

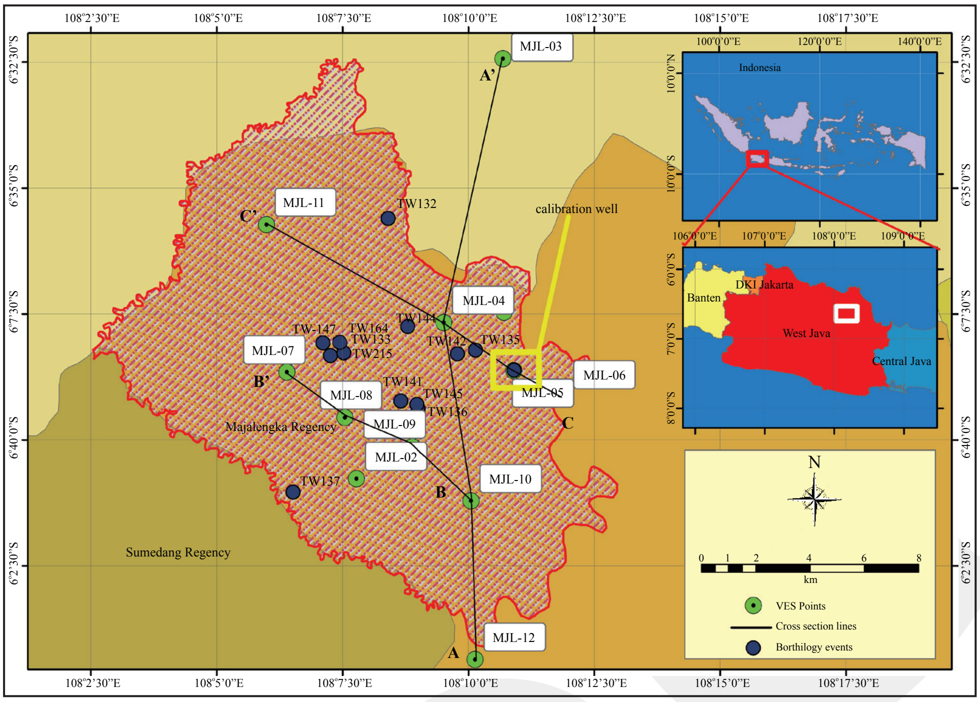
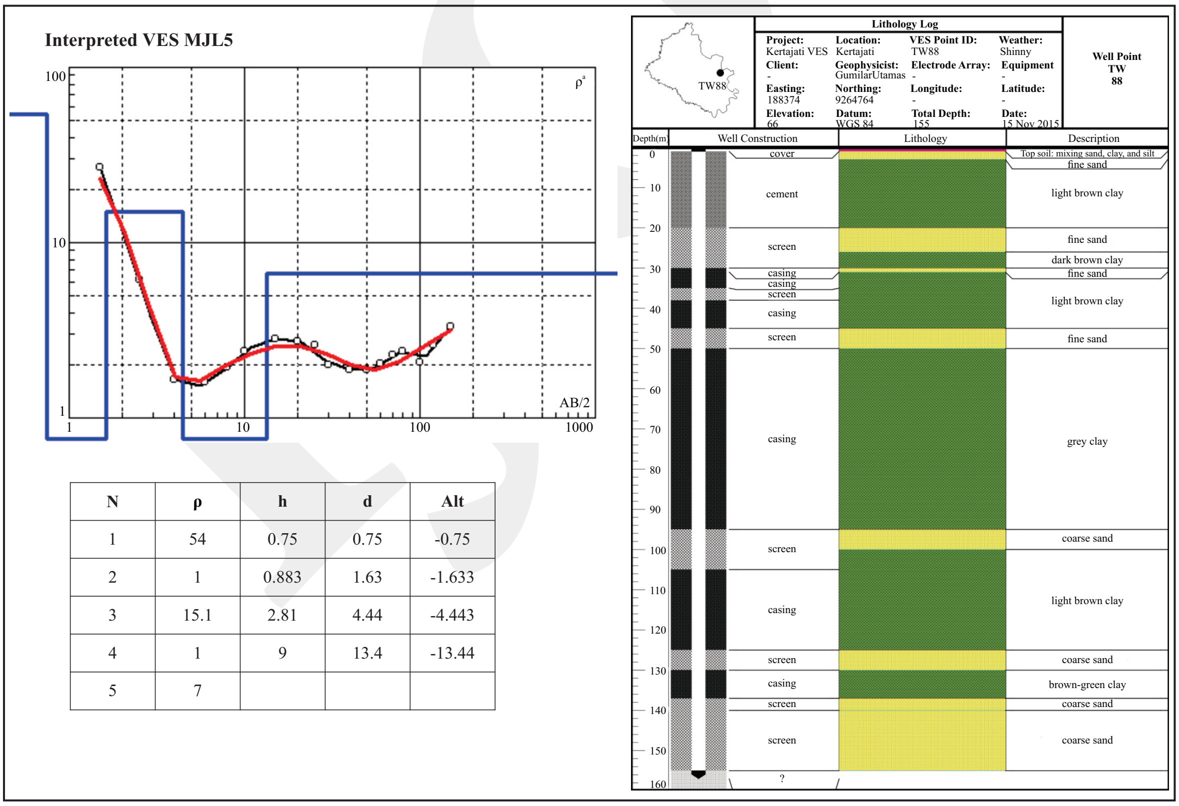


Figure 2. Location map of sampling sites in the studied area.



N	ρ	h	d	Alt
1	54	0.75	0.75	-0.75
2	1	0.883	1.63	-1.633
3	15.1	2.81	4.44	-4.443
4	1	9	13.4	-13.44
5	7			

Figure 3. Corelation between lithological data and the interpreted results of vertical electrical sounding (VES) station MJL5.

data in a layered earth (1-D) model. In order to perform this step, sounding curves were entered as apparent resistivity *versus* spacing (AB/2) for the Schlumberger soundings. The results of geo-electric survey were used to establish the depth of the aquifer layer and to construct a geo-electric section for the studied area. These results were then used to describe the geological framework for the studied area (Tizro *et al.*, 2012; Anomohanran, 2015). The pseudosections and geo-electrical resistivity sections were obtained from the quantitative interpretation of the VES data.

RESULTS

Twelve VES measurements were conducted at locations around the area of West Java International Airport, Kertajati Subregency, Majalengka Regency, West Java Province (Table 1).

Table 1. Vertical Electrical Sounding Point Locations

VES Points	Lon	Lat	Easting	Northing	Z (m)
MJL1	108.1786	-6.62436	188005	9266890	69
MJL2	108.1297	-6.6795	182632	9260756	66
MJL3	108.1781	-6.5405	187904	9276171	40
MJL4	108.1586	-6.62777	185793	9266500	69
MJL5	108.1817	-6.64369	188368	9264752	66
MJL6	108.1987	-6.65247	190249	9263791	68
MJL7	108.1067	-6.64422	180059	9264646	74
MJL8	108.1259	-6.6592	182193	9263000	66
MJL9	108.1483	-6.66887	184677	9261944	66
MJL10	108.1677	-6.68682	186837	9259970	66
MJL11	108.0999	-6.59537	179275	9270048	40
MJL12	108.169	-6.73927	187017	9254166	65

Resistivity values in the studied area can be divided into five resistivity categories: very low resistivity with values ranging from 1 Ωm to 10 Ωm, low resistivity with values varying from 10 Ωm to 50 Ωm, medium resistivity with values ranging from 50 Ωm to 100 Ωm, high resistivity with values between 100 Ωm and 200 Ωm, and very high resistivity categories with values > 200 Ωm. Table 2 shows the details of resistivity and the thickness for each layer as inferred from resistivity inversion using IPI2win software.

The inversion result was interpreted qualitatively and quantitatively using the geological and lithological information from Hasibuan *et al.* (2009) and drill hole section from the Groundwater Development Project (P2AT) by the Ministry of Public Works, Republic of Indonesia, as described in the previous section. The number of units was interpreted as three to seven resistivity layers. These layers have true resistivities ranging between 1 and 298 Ω m, with various thicknesses. The VES interpretation revealed three layers: topsoil (1 - 144 Ω m), sand (1 - 298 Ω m), and clay (1 - 82 Ω m). A detailed description for each station can be seen on Table 3.

Groundwater

At MJL-01, the aquifer layer was interpreted lithologically as a sand layer at a depth range of 5 - 14 m, with an aquifer resistivity value of 31 Ωm. At MJL-02, the aquifer layer was interpreted lithologically as a sand layer at a depth range of 13 - 40 m, with an aquifer resistivity value of 133 Ωm. At MJL-03, the aquifer layer was estimated to lie at a depth range of 2 - 71 m, with an aquifer re-

Table 2. Resistivity and Thickness of Each Layer

VES ID	Resistivity (ρ) Ωm							Thickness (*h*) m						
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	ρ_7	h_1	h_2	h_3	h_4	h_5	h_6	h_7
MJL1	141	14	31	14	34	5	233	1	1	3	9	24	64	48
MJL2	1	5	1	133	-	-	-	3	3	7	27	-	-	-
MJL3	45	8	13	247	-	-	-	1	2	69	79	-	-	-
MJL4	22	82	8	298	1	-	-	3	2	5	12	98	-	-
MJL5	54	1	15	1	7	-	-	1	1	3	9	137	-	-
MJL6	1	13	1	6	-	-	-	1	1	18	130	-	-	-
MJL7	1	4	2	7	-	-	-	1	4	18	127	-	-	-
MJL8	42	9	41	-	-	-	-	1	8	91	-	-	-	-
MJL9	3	19	1	27	1	-	-	1	1	3	12	83	-	-
MJL10	1	8	1	10	1	258	-	1	1	2	8	21	118	-
MJL11	5	1	33	1	-	-	-	1	7	15	128	-	-	-
MJL12	5	42	1	33	2	-	-	1	1	3	10	135	-	-

Table 3. VES Interpretation and Their Inferred Lithologies

VES No.	No of Layers	Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Inferred Lithology
MJL1	Layer 1	141	1	1	Top Soil
	Layer 2	14	1	2	Top Soil
	Layer 3	31	3	5	Sand
	Layer 4	14	9	14	Clay
	Layer 5	34	24	38	Sand
	Layer 6	5	64	102	Clay
	Layer 7	233	48	150	Sand
MJL2	Layer 1	1	3	3	Top Soil
	Layer 2	5	3	6	Clay
	Layer 3	1	7	13	Clay
	Layer 4	133	27	40	Sand
MJL3	Layer 1	45	1	1	Top Soil
	Layer 2	8	2	2	Top Soil
	Layer 3	13	69	71	Clay
	Layer 4	247	79	150	Sand
MJL4	Layer 1	22	3	3	Top Soil
	Layer 2	82	2	5	Clay
	Layer 3	8	5	9	Clay
	Layer 4	298	12	22	Sand
	Layer 5	1	98	120	Clay
MJL5	Layer 1	54	1	1	Top Soil
	Layer 2	1	1	2	Sand
	Layer 3	15	3	4	Clay
	Layer 4	1	9	13	Clay
	Layer 5	7	137	150	Sand
MJL6	Layer 1	1	1	1	Top Soil
	Layer 2	13	1	2	Top Soil
	Layer 3	1	18	20	Clay
	Layer 4	6	130	150	Sand
MJL7	Layer 1	1	1	1	Top Soil
	Layer 2	4	4	5	Clay
	Layer 3	2	18	23	Clay
	Layer 4	7	127	150	Sand
MJL8	Layer 1	42	1	1	Top Soil
	Layer 2	9	8	9	Clay
	Layer 3	41	91	100	Sand
MJL9	Layer 1	3	1	1	Top Soil
	Layer 2	19	1	2	Top Soil
	Layer 3	1	3	5	Clay
	Layer 4	27	12	17	Clay
	Layer 5	1	83	100	Sand
MJL10	Layer 1	1	1	1	Top Soil
	Layer 2	8	1	2	Top Soil
	Layer 3	1	2	4	Clay
	Layer 4	10	8	12	Sand
	Layer 5	1	21	32	Clay
	Layer 6	258	118	150	Sand
MJL11	Layer 1	5	1	1	Top Soil
	Layer 2	1	7	8	Clay
	Layer 3	33	15	23	Sand
	Layer 4	1	128	150	Clay
MJL12	Layer 1	5	1	1	Top Soil
	Layer 2	42	1	2	Top Soil
	Layer 3	1	3	5	Clay
	Layer 4	33	10	15	Sand
	Layer 5	2	135	150	Clay

sistivity value of 247 Ωm. At MJL-04, the aquifer layer was estimated to lie at a depth range of 5 - 9 m, with an aquifer resistivity value of 298 Ωm. At MJL-05, the aquifer layer was estimated to occur at a depth range of 13 - 150 m, with an aquifer resistivity value of 7 Ωm. At MJL-06, the aquifer layer was estimated to exist at a depth range of 2 - 20 m, with an aquifer resistivity value of 6 Ωm. At MJL-07, the aquifer layer was estimated to occur at a depth range of 5 - 23 m, with an aquifer resistivity value of 7 Ωm. At MJL-09, the aquifer layer was estimated to appear at a depth range of 5 - 17 m, with an aquifer resistivity value of 1 Ωm. At MJL-10, the aquifer layer was estimated to lie at a depth range of 4 - 12 m, with an aquifer resistivity value of 258 Ωm. At MJL-11, the aquifer layer was estimated to occur at a depth range of 4 - 12 m, with an aquifer resistivity value of 33

Ω. At MJL-12, the aquifer layer was estimated to exist at a depth range of 5 - 15 m, with an aquifer resistivity value of 33 Ωm. The detailed summary of aquifer resistivity is described in Figure 4.

The values of aquifer resistivity in the studied area are very diverse (Figure 5). This is consistent with previous studies that measured the resistivity values of sand layer aquifers (Maiti *et al.*, 2011; Obiora and Ibuot, 2020; Reynolds, 1997; Telford *et al.*, 1990). Differences in the degree of compaction and also the physical properties of the sand within the aquifer layer can cause very significant differences in the resistivity values of the aquifer in the studied area (Dobrin and Savit, 1988; Kearey and Brooks, 1991; Reynolds, 1997; Telford *et al.*, 1990; Tiab and Donaldson, 2012).

Figure 6a shows a sand layer thickening towards the north. The existence of this continuous layer shows that this layer is part of the hydrogeological system in the studied area. The impermeable zone of the groundwater system in the studied area was dominated by the presence of a clay layer which acts as an aquiclude layer in the studied area. Aquiclude layers may store water easily, but do not transmit the groundwater easily (Fetter, 2001; Freeze and Cherry, 1979; Harter,

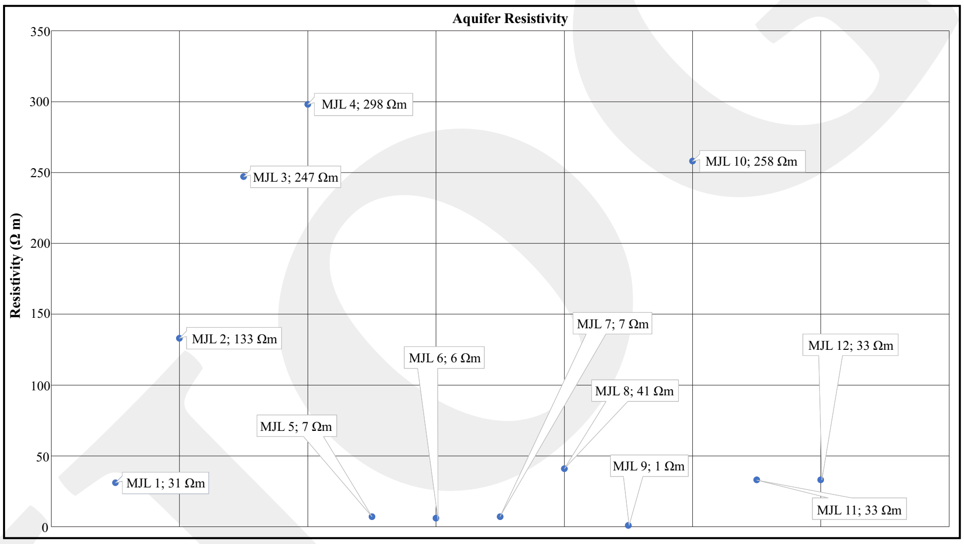


Figure 4. Aquifer resistivity chart of studied area.

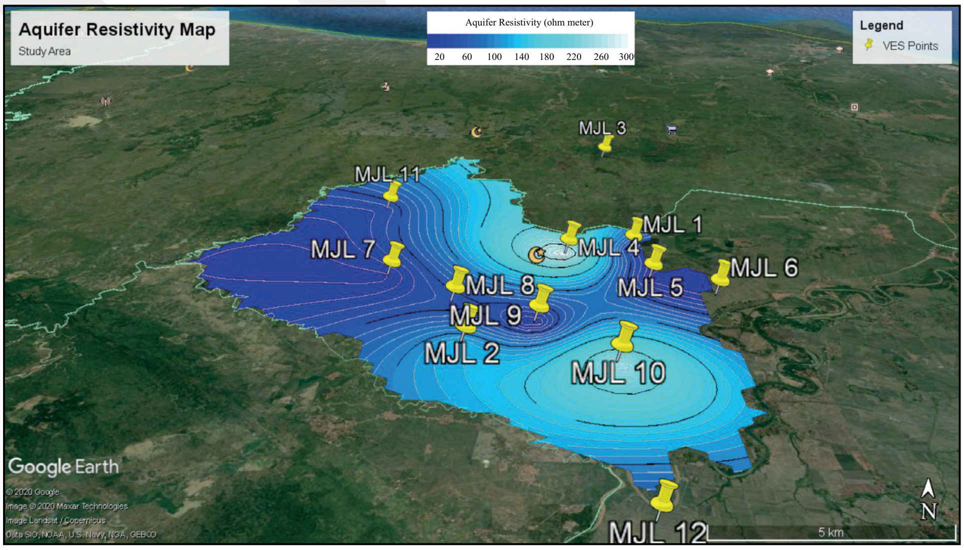


Figure 5. Aquifer resistivity map of studied area.

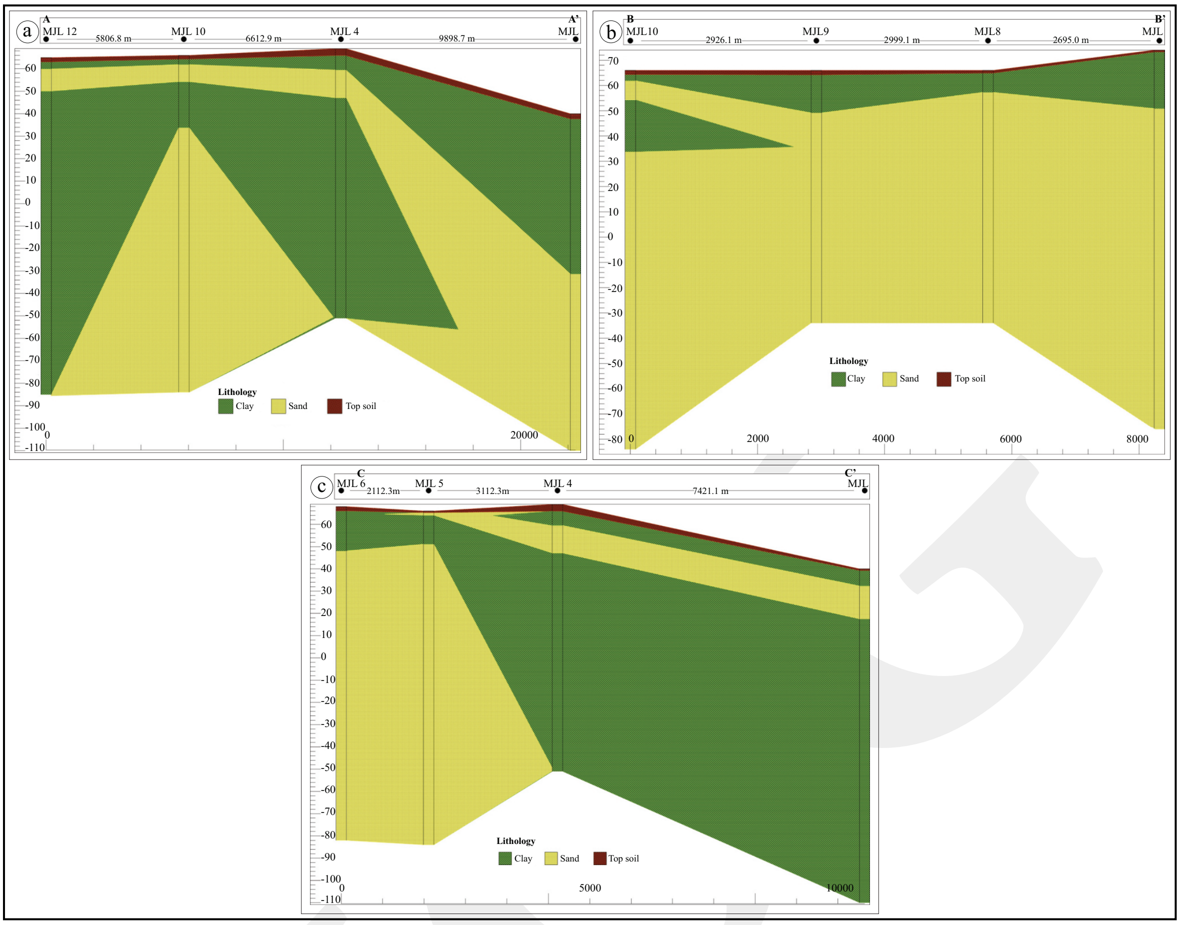


Figure 6. Cross-sections of 12 measured points in the studied area. (a). A - A cross-section; (b). B - B cross-section; (c). C - C cross-section. (Cross-section lines are presented in Figure 2).

2003). The clay layer can be classified as an aquiclude layer (Freeze and Cherry, 1979; Fetter, 2001; Lopez-Gunn *et al*., 2011; Singhal and Gupta, 2010), while the sand layer can both store and transmit groundwater, acting as an aquifer (Freeze and Cherry, 1979; Fetter, 2001; Wal, 2010). The pattern distribution of sand in cross-section 1 tends to follow the elevation of the studied area. A layer of sand that is thick enough to serve as an aquifer is found at the MJL-10 VES station, but nevertheless does not have the potential to be an aquifer, because it is present only locally and noncontinuously. Groundwater may be present in this layer but is not sustainable, because it does not have a continuous water supply. Figure 6b shows a layer of sand that is thick enough to act as an aquifer, with a small lens from the clay layer. In this cross-section, the sand layer functions as an aquifer layer and the clay layer functions as an aquiclude. Figure 6c shows that the sand layer is continuous towards the northwest. The clay layer dominates in almost all cross-sections, and the aquifer potential is found in the sand layer.

Figures 6a and 6b show that the clay layer predominates in all studied areas. Due to the dominance of the clay layer compared to the sand layer, the presence of aquifers in the studied area is very limited. With limited aquifer layers, the groundwater supply in the studied area is also limited (Fetter, 2001; Lopez-Gunn *et al*., 2011; Ramsar, 2006). Figure 6 shows the geometry of the aquifer, which suggests that groundwater cannot be exploited excessively if the sustainability of groundwater in the studied area is not to be maintained. IWACO-WASECO (1990) states that in the studied area, there is an aquifer with medium potential. Resistivity values indicate that clay layers dominate the studied area.

CONCLUSIONS

Twelve VES measurement points were conducted around the area of West Java International Airport, Kertajati Subregency, Majalengka Regency, West Java Province. In general, resistivities in the studied area can be divided into five categories from very low resistivity to very high resistivity. Aquifer resistivities falling into all of these categories are found in the studied area. The aquifer resistivity values for each VES station are 31 Ωm for MJL1, 133 Ωm for MJL2, 247 Ωm for MJL3, 298 Ωm for MJL4, 7 Ωm for MJL5, 6 Ωm for MJL6, 7 Ωm for MJL7, 41 Ωm for MJL8, 1 Ωm for MJL9, 258 Ωm for MJL10, 33 Ωm for MJL11, and 33 Ωm for MJL12. In general, aquifers in the studied area are lithologically composed of sand. The sandy aquifer layer was typically found at relatively shallow depths of less than 20 m, although at a few sites the aquifer extended deeper. The dominance of the clay layer compared to the sand layer means that the presence of aquifers in the studied site is very limited, and that the groundwater supply at the studied site is thus also limited. Groundwater exploitation, therefore, cannot be excessive but must be moderate and controlled to maintain the sustainability of groundwater in the studied area.

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