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Three-Dimensional Resistivity Model for Ground Water Exploration In Volcanic Zone of Tidar Pleteau, Malang, East Java

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ABSTRACT

Geoelectrical resistivity method is popular technique for subsurface mapping of groundwater, mining exploration, and structural geology. For case study in Tidar Plateau which characterized by hard rock of volcanic breccia, lava, tuff, and conglomerate, the groundwater system occurs only by the secondary porosity (faulting, facturing, and weathering). Therefore it becomes difficult task for determine position of good well site in Tidar Plateau. Geoelectrical technique by Schlumberger configuration was choosen to investigated the ground water system in this area. Total 5 Vertical Electrical Sounding (VES) acqusition point (400 m length measurement; spacing 10 m) for data measurement with coverage area about 400 x 400 m^2. For data processing was used IP2Win, Progress3, and RockWork 16. The data processing results showed high accuration with avarage Root Mean Square (RMS) error about 0.3 – 8.3 %. According to resistivity results, the study area has resistivity between 0.3– 2.5x10^4 Ωm. The rocks which have resistivity between 0.3 – 12.52 Ωm interpreted as sandy-clay; 12.52 – 50 Ωm interpreted as wet sandstone (aquifer); 129 – 178 Ωm interpreted as conglomerat; 700 – 1300 Ωm interpreted as tuff, sand, and dry gravel; 2600 – 2.5x10^4 Ωm interpreted as volcanic breccia. This geoelectrical results has succesful finding the fresh water at VES 5 after drilled at depth 100 m at wet sandstone formation. To findout distrubution of aquifer layer, a three-dimensional (3D) resistivity model was developed. The 3D resistivity model shows the aquifer layer image look the dome-like structure and image the fracture regions which becomes the pathway of groundwater system.

Introduction

Water is one of the main necessary for a human life. The water flow to rivers, lakes, underground rivers, and others. As the increasing of human civilization, the necessary of water increasing rapidly, such as for daily needs, agriculture, farming, and industry. This problem occured in Tidar Plateau because the area dominated by the volcanic product such as volcanic breccia, tuff, lava, agglomerate which has low porosity (Fig. 1). The groundwater accumulation in volcanic and metamorphic area occurs from secondary porosity developed from the weatehring, fracturing which contribute in near-surface inhomogenity [1-2]. To study the ground water system in Tidar Plateau, we applied geolectrical method with schlumberger configuration. The geoelectrical resistivity survey is familiar method in geophysics for ground water exploration, ground water pollution at an open dumpsite [3], ground water system in semiarid area [4], ground water aquifer in sedimentary formation [5], ground water investigation in crystallin terrain [6], ground water system in granite gneiss and banded gneiss [7], ground water mapping in crystallin basement [8], and ground water detecting in resistive bedrock [9]. In general, the principle of this method by injecting an electric current to the subsurface and then record the resistivity of subsurface structure [10-11]. While, the geoelctrical resistivity method using Schlumberger configuration was done in a way the space between the potential electrodes are fixed while the space between the current electrodes change gradually [12]. The Schlumberger configuration used to measured the Vertical Electrical Sounding (VES) for determine the resisitivity change the rock resistivity to the depth domain [13]. The rock resistivity from measurement can be used to analysis the geological structure and ground water. The main goal of this study for imaging of subsurface geological structure and the possibility of ground water at a certain depth by using geoelectrical resistivity with Schlumberger configuration. The resistivity analisis based on the different resistivity value for different material. The ground water charactrized by low resisitivity (conductive), while the volcanic breccia, agglomerate, and metamorphic rock have high resistivity value bacause these rock have low porosity which caused this rock have low possibility for water infiltrate to the aquifer layer.

Geological Setting

Figure 1, show the geological setting of study area which dominated by old and young volcanic rock from Mt. Kawi vulcanic eruption which consist of volcanic breccia, lava, agglomerate, tuff, and sand [14].

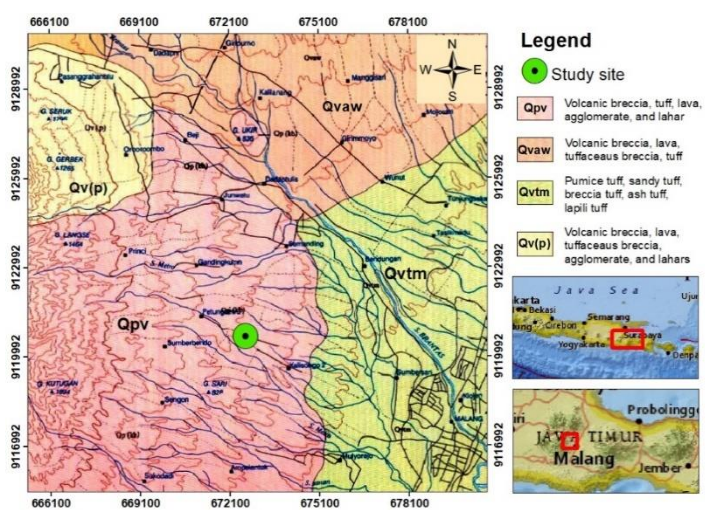

Figure 1. Geological setting of the study area [14]. Green circle indicate the study location in Tidar Plateau, Malang, East Java.

Tidar Plateau dominated by the hard volcanic rock, so pipeline of groundwater is ununiform in all region and the presence of ground water are very deep. There is spring water at depth

15 meters an elevation of 685 m above sea level in the west of the study location. The spring rise from fracturing or faulting of volcanic breccia. The presence of the spring water as reference for the Vertical Electrical Sounding (VES) point measurement.

Methodology

Geoelectrical survey will give an idea about the subsurface resistivity distribution of rock, mineral, soil, grund water system, fault, fold structure, and geochemical element or material. The specific resistivity value of rock or material will be associated with geological anomaly conditions [13,15]. High resistivivty of rock related to low conductivity of rock or material, while low resistivity correlated to high conductivity of rock formation such as ground water system. The subsurface mapping of groundwater in Tidar Plateau was conducted on September 2013 using Geoelectrical Resistivity method with Schlumberger configuration. The study site location at UTM coordinate 49M 672604 E – 672737 E and 9120598 S – 9120797 S an elevation of 715 m above sea level (Fig. 2).

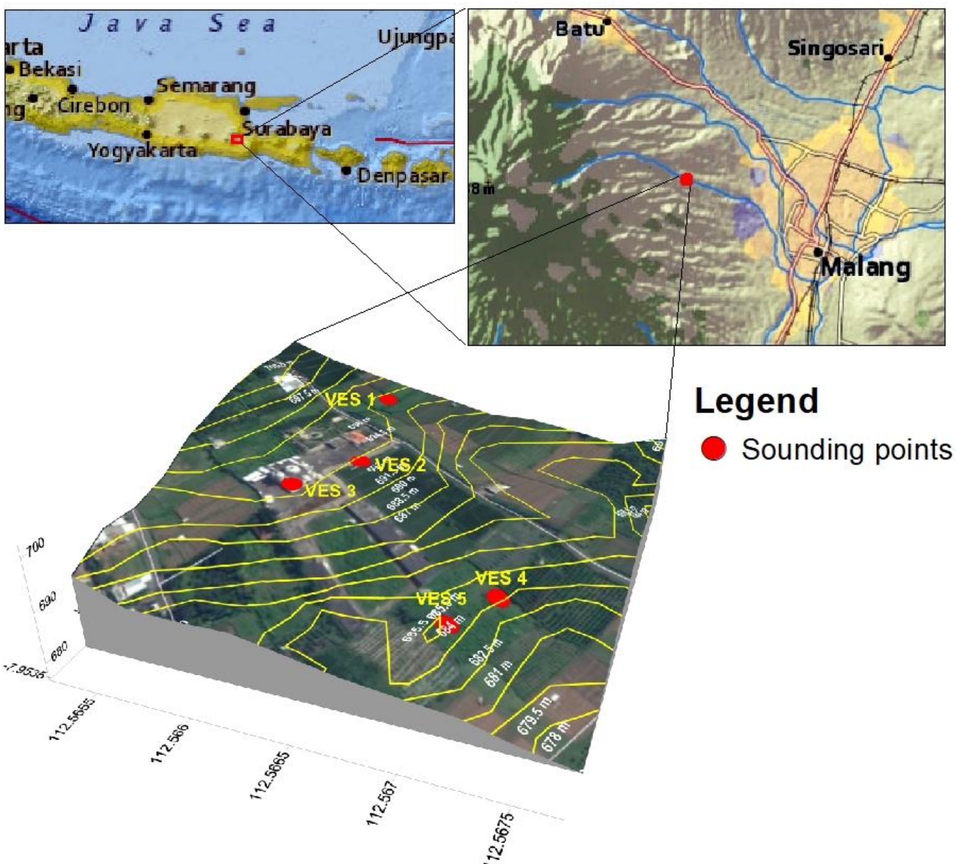

Figure 2. Study area for geoelectrical resistivity measurement in Tidar Palteau. Red circle indicate the Vertical Electrical Sounding (VES) Position. VES 1 (Top: 701 m msl; VES 2 (Top: 697 m msl); VES 3 (Top: 696 m msl); VES 4 (Top: 686 m msl); VES 5 (Top: 686 m msl).

There are 5 VES point and the length of each VES line measurement about 400 m with 10 m inspacing. Data measurement was collected using Resistivity Meter Oyyo McOhm Model 2119D to measure apparent resistivity of rock and processed using Inversion method by Ip2win and Progress3 software to calculate resistivity value with depth (Fig. S1-S5 in Suplementary Data). For Geological analysis of ground water system, the 2-Dimensional (2D) lithology (Fig. 3) and 3-Dimentional (3D) resitivity model (Fig. 4) were developed using

Rockwork 16. The 3D resistivity model shows the geological structure and the size of groundwater system in study area.

Result and Discussion

Geologically, the rock type at the study site dominated by the young volcanic deposits from Kawi volcano, including: volcanic breccia, tuff, lava, agglomerate, sandy tuffs, sandstone, pumice tuff, and lahar. High ground water permeability especially in sandy tuff, sandstone, and vascularity lava flows. While, hydrogeologically the acquifer layer in the study site flow trough the fracture, fault, and porosity of rock formation of ground water system. The 3D resistivity model (Fig. 4c) show the limited productive aquifer layer in study area.

Table 1. Resistivity value and interpretation in each VES site at Tidar Plateau, Malang, East Java [14, 16, 17].

Site	RMS Error	Depth (m)	Thickness (m)	Resistivity (Ω.m)	Lithology
VES 1	1.22 %	0 – 12.62	12.62	1.00 – 62.30	Sandy-clay
		12.62 – 46.39	33.77	139.11 – 129.08	Conglomerate
		46.39 - 93.67	47.28	397.64	Tuff and Gravel
		93.67 - 140	46.33	3458.99	Volcanic breccia
VES 2	8.27 %	0 - 0.4	0.40	0.30 - 6.52	Sandy-clay
		0.40 – 5.12	4.72	922.24 - 1766.19	Tuff, sand, and dry gravel
		5.12 – 33.79	28.67	8763.14 – 6522.90	Volcanic breccia
		33.79 – 53.49	19.70	1587.76	Sand and dry gravel
		53.49 – 92.84	39.35	596.03	Tuff and Gravel
		92.84 - 138	45.16	178.33	Conglomerate
VES 3	3.85%	0 – 1.06	1.06	0.63 -12.55	Sandy-clay
		1.06 – 6.98	5.92	700.86 – 1369.52	Tuff, sand, and dry gravel
		6.98 - 210	203.02	2603.30 – 5177.53	Volcanic breccia
VES 4	2.94%	0 - 0.88	0.88	0.57 - 13.2	Sandy-clay
		0.88 – 7.56	6.68	854.68 – 1109.84	Tuff, sand, and dry gravel
		7.56 – 20.09	12.53	1527.69 – 2900.43	Sand and dry gravel
		20.09 – 126.46	106.37	25358.20 – 22153.93	Volcanic breccia
		126.46 - 185	58.54	3502.52	Volcanic breccia
VES 5	0.81%	0 – 8.83	8.83	0.84 -28.65	Sandy-clay
		8.83 - 107.93	99.10	156.95 – 162.73	Conglomerate
		107.93 - 160	52.07	31.97	Wet sandstone (aquifer)

Based on inversion of the apparent resistivity values, the subsurface interpretation of each sounding point was performed until the depth about 200 meters below the surface, so the rock type (lithology) and its aquifer characteristics and position are known (Table. 1). The rock type alomost similar in each sounding point. Generally, the first layer was identified as soil (top soil), then the second layer are Tuff, Lava, conglomerate, volcanic breccia, and Sandstone Layer as an aquifer layer which is the target of this study.

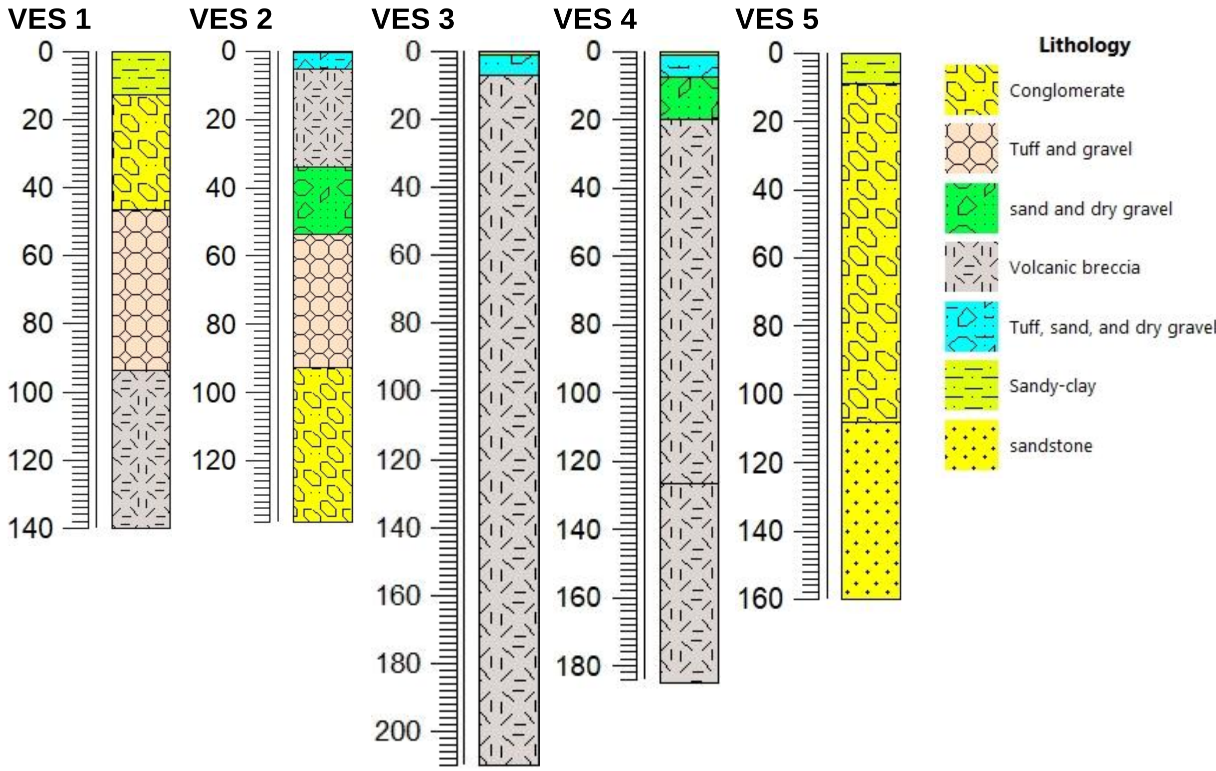

Figure 3. Lithology log analysis in depth scale base on resistivity value and geological information in Tidar Plateau. VES 1-5 coresponding to Vertical Electrical Sounding (VES) Position.

The subsurface interpretation of geoelectrical resistivity data at VES 5 sounding points indicate the presence of aquifer layer on sandstone formation at depth about 107-160 m with resistivity value 31.97 Ω.m and thickness about 52 meter. Whereas in the VES 1, VES 2, VES 3, and VES 4 measurement points there is no aquifer layer. The VES sites characterisize by high resistivity value which indicate low porosity of rock for that the water can't flow and spread to VES 1, VES 2, VES 3, and VES 4.

For geological analysis of ground water system model, the 2-dimensional (2D) and 3-dimensional (3D) resistivity rock structure was developed using Rockwork 16 (Fig. 3 and Fig. 4). Figure 3 and 4 shows the volcanic breccia groups at VES 1, VES 2, VES 3, and VES 4 with varying thickness between 40 – 200 m. The volcanic breccia at VES 1, VES 3, and VES 4 characterisize by phyroclastic breccia resulted from volcanic explotion of Mt. Kawi volcano. While volcanic breccia at VES 2 characterisize by epiclastic volcanic breccia resulted from transportation of loose volcanic material of Kawi volcano by geomorphic or gravity process. Thus VES 2 and VES 5 have different characteristic, at depth below 100 m, VES 2 shows conglomerate sedimentary rock and VES 5 manifest of thick sandstone as aquifer of groundwater with conglomerate as caprock.

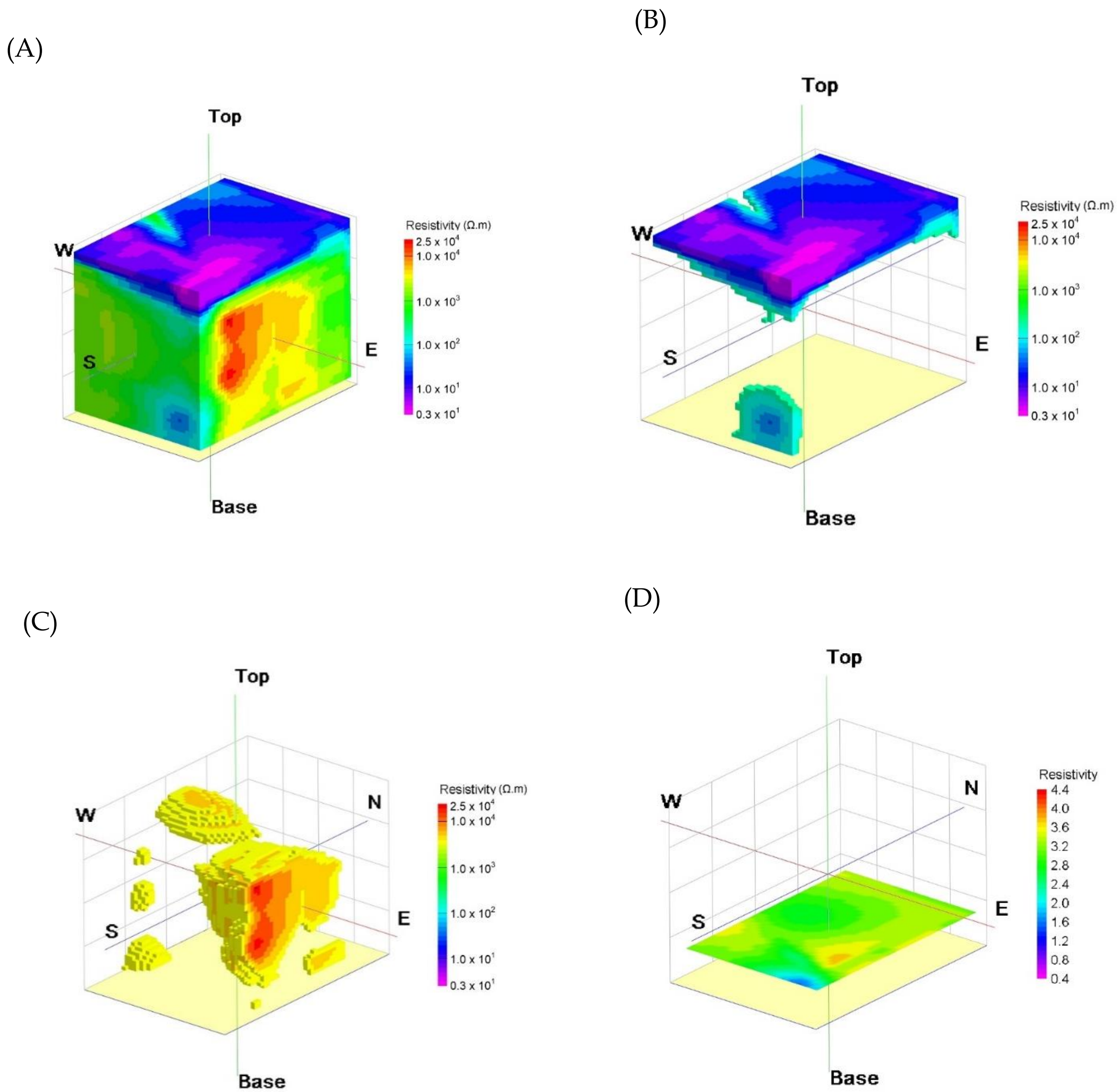

Figure 4. The 3-dimensional resistivity structure calculated from VES 1, VES 2, VES 3, VES 4, and ES 5 in Tidar Plateau.

Figure 4a, show the 3D geoelectrical resistivity model in study area. The surface layer (blue contour) characterized by low resistivity (3-100 Ω.m). This layer dominated by sandy clay which can absorb dan save the meteoric water. The thickness of this layer variety between 0.4 to 12..67 m belowich the surface. The green contour which characterized by medium resistivity (100-1000 Ω.m) identified as dry gravel, tuff, and conglomerate. Low porosity and permeabelity of these rock cause the metoric water can't absorb properly to the aquifer layer. Figure 4b, show the aquifer model at study area (blue conture at depth 107-160 m below the surface). The 3-dimesional (3D) structure of the aquifer indicate the aquifer model look dome-like structure and fracture for pipeline groundwater sistem. The metoric water infiltrate to the aquifer system by flow in the gap between the sandy tuff and vascularity lava flows (yelow contour in Fig. 4c). The slicing aquifer model (blue contour) at depth 100 m indicated the aquifer system localized and influences by meteoric recharge (Fig. 4d).

Conclusion

The geoelectrical resitivity data processing and interpretation by Schlumberger configuration for identified the structure and ground water system in the Tidar Pleteau area shows a sandstone layer potentially as an aquifer with a thickness of 52 meters below the VES 5 measuring point at a depth of 107.93 - 160 meters below sea level with rock resistivity values around 31, 97 Ω.m. Whereas at the measurement points VES 1, VES 2, VES 3, and VES 4 are dominated by tuffs, breccia, and lava volcanic rocks which have low porosity and permeability so that it is not possible to become a subsurface aquifer in the area.

The accumulation water in aquifer layer recharge from local infiltration of metoric water flow in the gap between sandy tuff and vascularity lava volcanic. Additional ground water from Kawi Volcano and water flow via fault and fracture affected by rainwater inflation. So that the water discharge that accumulates in aquifers depends on the rainfall. Water discharge in aquifers will increase when rainfall increases. The most interesting, this research was succesfull finding ground water after the drilling in VES 5 at depth 85 meter.

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