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Shallow Aquifer Identification Using Geo-Electrical Sounding and 2D Mapping at Krawangsari, Pringsewu, Indonesia

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***Abstract*— The need for water for agricultural irrigation sources and the water home industry in the Krawangsari area can be a source of conflict in the future if it is not immediately addressed. Gradual studies are needed to maintain the continuity of groundwater resources and the equal distribution of utilization, one of which is to map groundwater aquifers. This study aims to determine the potential of groundwater resources using geoelectric resistivity methods with vertical electrical sounding (VES) and horizontal profiling techniques (2D mapping). The inversion results of vertical electrical sounding (VES) show variations in depth and thickness of shallow aquifers with groundwater resistivity values in sedimentary rocks ranging from 1 - 100 Ωm and in igneous rocks between 0.5 - 150 Ωm. The results of 2D Resistivity Mapping show that aquifer characteristics in the eastern part of Krawang Hill have a depth of 1-3 m for shallow aquifers with a thickness of aquifers between 15 m and more than 70 m. The depth of the bedrock ranges from 50 - 150 m with a pattern deeper into the west. While for aquifers in the southern part it has a characteristic depth between 2-5 m for shallow aquifers with a thickness of aquifers ranging from 25 - 50 m and the depth of the bedrock between 20 - 70 m. The potential of groundwater aquifers in the agricultural environment is in the western region of Krawang Hill so the development of irrigation wells for agriculture should be carried out in the western part.**

***Keywords*— Aquifer, VES, Resistivity, Krawangsari.**

I. Introduction

Krawangsari is a small area in the Ambarawa sub-district, Pringsewu District, Lampung Province, Indonesia which produces clean water sources for drinking water needs to be known as "Water Krawang" [1], [2], [3]. The water is produced from groundwater wells by several refill water home industries with an average total production capacity reaching 520000 liters/day [2]. The flow of water from the well reaches an average of 2 liters/second.

Around the Krawangsari area are agricultural lands, most of which are semi-productive rainfed rice fields. This land can only be planted during the rainy season by utilizing water sources that come from rain. Overall, the agricultural area reaches 300 ha which is managed by approximately 1300 farmers [4]. They have tried to increase crop production by utilizing the transition period of the rainy season to the dry season. But climate uncertainty has caused the effort to fail and crops failed.

Some farmers have tried to get water sources that come from groundwater. They make shallow wells on agricultural land independently. The well is used to meet water needs during the dry season for horticulture crops. Even so, some drilling sites for groundwater wells have failed, even in areas that have been successful also have decreased water discharge [5]. This condition is a contrast between the production of raw water in Krawangsari and the surrounding agricultural land.

The occurrence of an alliance between the use of groundwater resources in Krawangsari-Ambarawa between domestic raw water, irrigation of agricultural land and refill water-based home industries can be a source of future conflict. Gradual studies are needed to maintain the continuity of groundwater resources and the equal distribution of their use, one of which is to map groundwater aquifers [6].

The geoelectric method is one of the many geophysical methods used for various groundwater exploration including groundwater aquifers mapping [7] - [10]. The geoelectric resistivity method with vertical electrical sounding (VES) and horizontal profiling techniques (2-Dimension or 2D) is the simplest method in groundwater exploration using geophysical surveys [11]. This technique is able to determine the depth and thickness of groundwater aquifer systems based on the electrical properties of rocks [7], [12], [13].

This study focused on mapping shallow groundwater aquifers using geoelectric resistivity methods with vertical electrical sounding (VES) and horizontal profiling techniques (2D mapping). This study aims to determine the potential of groundwater resources that can be used as a source of water for agricultural land around the Krawangsari area. The results of this mapping are expected to be able to determine the exact location of the well and study material to build a groundwater-based agricultural irrigation system.

II. The Material and Method

Geographically, the location of the study (Fig. 1) is at coordinates (x, y) (496170 - 496762, 9402521- 9401909) UTM zone 48S. The data used in this study came from observational data and geological maps and geoelectric measurements directly at the study site.

A. Geological Settings

Geologically, the study area is in a rock formation dominated by volcanic tuff material deposits (Lampung Tuffs Fm.). These Pliocene-Pleistocene rock materials are composed of tuffaceous sandstone, tuffaceous claystone, and pumiceous tuff [14] [15]. This rock is surrounded by Quaternary sediment deposits as a product of sedimentation from the results of rock erosion in higher geomorphological conditions.

Quaternary volcanic rocks are the youngest volcanic rocks found around the research area. This rock is the result of past activities from Mount Betung, Mount Pesawaran (Ratai) and Mount Sulah which is east-southeast to the south. The rock composition is dominated by andesite-basal breccia, lava, and tuff [14].

In the southern part of the study site, there is a Cretaceous (Menanga Fm.) Rock formation in the form of interbreeding between shales, claystones, and sandstones with flint inserts and limestone lenses [14]. Some rock outcrops in the form of marble can also be found around the research area. It cannot be confirmed whether this marble originated from changes in rock from this formation or part of the oldest rock formations in this area.

The oldest rocks that were exposed around the study site were Paleozoic rocks (Gunungkasih Fm) with the main composition of quartzite and partially marble and schist [14]. But the location of the marble outcrops of this formation is far north-northwest.

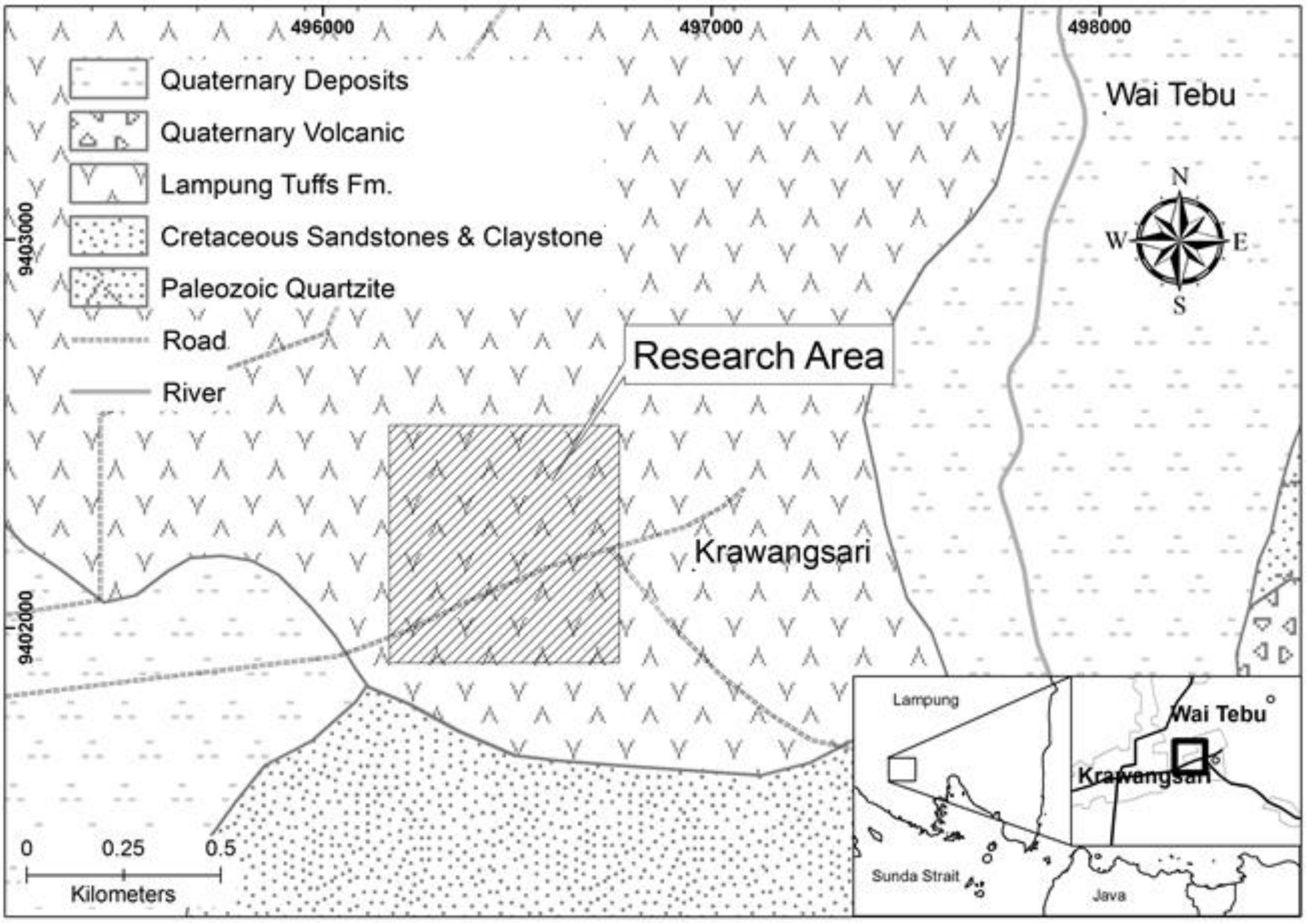

Fig.1 Research areas showing the Krawangsari geology and surrounding areas, the research area is indicated by a box with a striped pattern. There are five rock formations that are Paleozoic to the quartz (modified after [14]).

B. Geoelectrical Resistivity Aquisition

Geoelectric resistivity data acquisition was carried out using Naniura resistivity meter (for VES) and ARES resistivity meter (for 2D mapping) using two acquisition methods, namely vertical electrical sounding (1-Dimension or 1D) and horizontal profiling (2D) methods. The resistivity geoelectric method is a method of measuring the electrical properties of subsurface rocks by injecting an electric current into the earth and measuring the potential magnitude produced.

1) Vertical Electrical Sounding (VES): is a 1D acquisition method with a target of rock resistivity values vertically. VES data acquisition of 18 points scattered randomly in the study area (Fig. 2), was carried out with a Schlumberger configuration and a stretch of the current electrode (AB / 2) ranging from 1.5 m to 225 m. This method is used to measure the resistivity value at the measurement point by optimizing it vertically.

2) Horizontal Profiling (2D Mapping): is a 2D acquisition method with target values of rock resistivity vertically and horizontally. 2D data acquisition is carried out in 4 paths with alpha Wenner electrode configurations (Fig. 2). The maximum length of the electrode stretch is 225 m with the smallest electrode spacing is 5 m. This method is used to complete the distribution of resistivity value data horizontally.

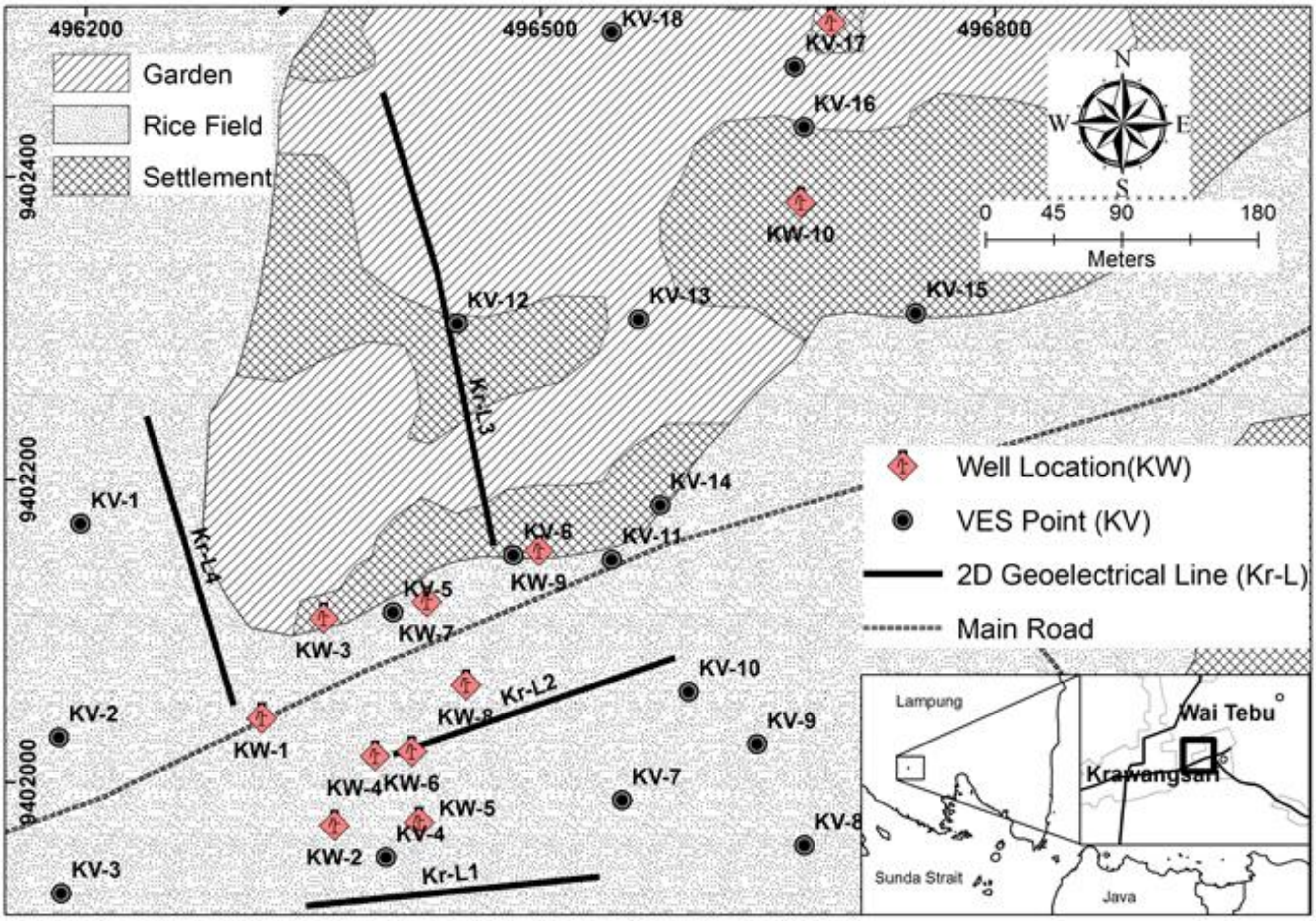

Fig. 2 The point of measurement of vertical electrical sounding (VES) is indicated by a circle with a black dot and a 2D Mapping track marked with a firm black line. The location of groundwater wells is marked with a red symbol.

C. *Data Processing and Inversion*

Data from VES and 2D Mapping measurements are apparent resistivity values. The apparent resistivity value obtained is then inverted using IPI2Win (VES data) and RES2DINV (2D Mapping) software to get the actual resistivity value and resistivity layer model. The depth and thickness of the groundwater aquifer are obtained based on the interpretation of the resistivity layer model.

The least-squares inversion method with smoothness constraints is used to inverse all 2D paths. This method tries to minimize the difference between measured resistivity values and resistivity values calculated [16]. Each inversion is performed with optimal iteration to get the smallest RMS error value.

III. RESULTS AND DISCUSSION

Analysis of field acquisition data using the VES and 2D Mapping methods that have been processed and inverted is able to show the location of the presence of shallow groundwater aquifers.

A. *1D Inversion Analysis*

The 18 point inversion results of vertical electrical sounding (VES) data showed depth and thickness variations of shallow aquifers (Table I). Reference [17] shows groundwater resistivity values in sedimentary rocks ranging from 1 - 100 Ωm and in igneous rocks between 0.5 - 150 Ωm. Modeling using a minimum of 3 layers shows that the average aquifer potential is in layer 2. However, some layers do not show any potential for shallow aquifers.

TABLE I
SUMMARY OF VES MODEL RESISTIVITY VALUES AND THEIR CORRESPONDING THICKNESSES

VES Point	Layer 1		Layer 2		Layer 3		Layer 4	
	Resistivity (Ωm)	Thickness (m)	Resistivity (Ωm)	Thickness (m)	Resistivity (Ωm)	Thickness (m)	Resistivity (Ωm)	Thickness (m)
KV-1	17.8	12.7	2.47	20.3	47000	-	-	-
KV-2	7.01	1.85	53	4.23	5.05	7.69	128	11.4
KV-3	5.95	1.24	6.32	143	20000	-	-	-

KV-4	0.65	1.31	367	2.66	15652	-	-	-
KV-5	8.69	2.14	0.77	1.72	15000	-	-	-
KV-6	14	2.21	40.2	2.23	4.83	3.13	53.3	11.3
KV-7	62.3	4.92	106	27.3	31.4	34.8	569	-
KV-8	24.7	2.14	2.45	6.37	14000	-	-	-
KV-9	191	3.12	1167	15.2	12	32.8	1340	-
KV-10	1.14	1.5	677	4.83	39000	-	-	-
KV-11	4.54	0.42	12.1	2.08	0.56	3.73	19000	-
KV-12	883	1.79	186	1.68	1884	14.8	28.8	-
KV-13	120	1.2	171	19.8	920	14.1	3.05	-
KV-14	108	4.04	5.2	15.6	116	25.5	2820	106
KV-15	108	4.03	5.2	15.3	385	30.5	404	-
KV-16	111	1.22	308	9.84	1463	10.5	1.72	-
KV-17	93.5	0.92	364	5.89	2198	10.8	84.9	-
KV-18	197	0.7	1184	9.12	357	4.21	1710	20.3

The examples of plotted images of pseudo-resistivity curves for 1D layered resistivity modeling (Fig. 3) show potential aquifers at layer 2 and layer 4. This model shows that there is a fairly thick aquifer potential, ie from layer 2 to layer 4. The range of resistivity values of aquifer soil at point KV-6 between 4 - 53 Ωm. the depth of the aquifer ranges from 2 meters to 46 meters with a thickness of aquifers around 44 meters. Nevertheless, VES data has not been able to detect the presence of bedrock. Therefore, it is possible to find a larger aquifer thickness.

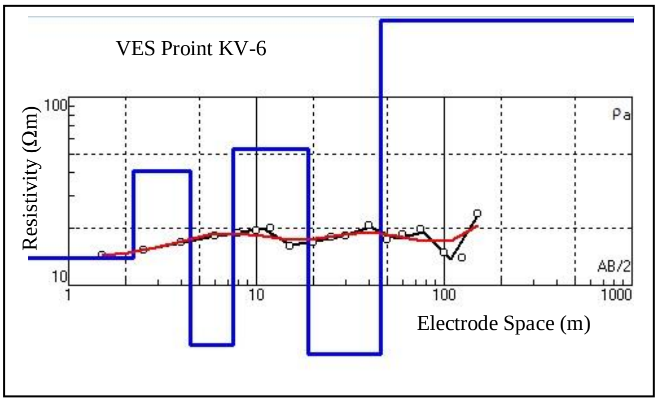

Fig 3. The results of the plot of apparent resistivity curves at the KV-6 point of VES data.

Different conditions are shown by pseudo resistivity plot curves at the KV-18 point (Fig. 4). The measured apparent resistivity values are more than 100 Ωm. The resulting plot curve does not indicate the existence of shallow aquifer potential. The resistivity value of the second layer after the topsoil in the first layer is 1184 Ωm. High resistivity values indicate layers of rock with greater density. The possibility of igneous rocks with low or dry water content, or bedrock close to the surface. However, the trend of resistivity values that continue to decline in line with depth also indicates the presence of depressed aquifer/aquifer potential. To test this, it is necessary to re-measure the long stretch of the electrode (AB / 2).

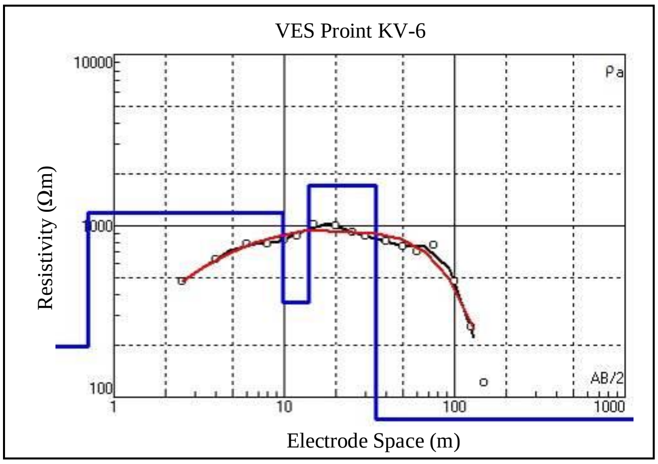

Fig 4. The results of the plot of apparent resistivity curves at the KV-18 point of VES data.

Based on all the measurement data of vertical electrical sounding has been inverted, the value of resistivity zone of shallow groundwater aquifer in the study area ranged between 0.5 - 200 Ωm.

B. 2D Inversion Analysis

The inversion results from 4 2D trajectories of resistivity mapping show a clearer variation in horizontal and vertical resistivity values. The inversion rock resistivity values range from 3 - 25000 Ωm. The pattern of resistivity layers shows a clear pattern related to the position of aquifers and bedrock. By using the same resistivity range with aquifer resistivity in the VES data, the depth and thickness of the shallow aquifer zone can be interpreted.

The inversion results on the paths Kr-L1 and Kr-L2 (Fig. 5) show resistivity patterns which are dominated by bedrock with high resistivity values. This dominance starts at a depth of 12-33 m and is constantly in harmony with depth. While the location of shallow aquifers is right under the topsoil with a thickness of thin aquifers ranging from 5-33 m.

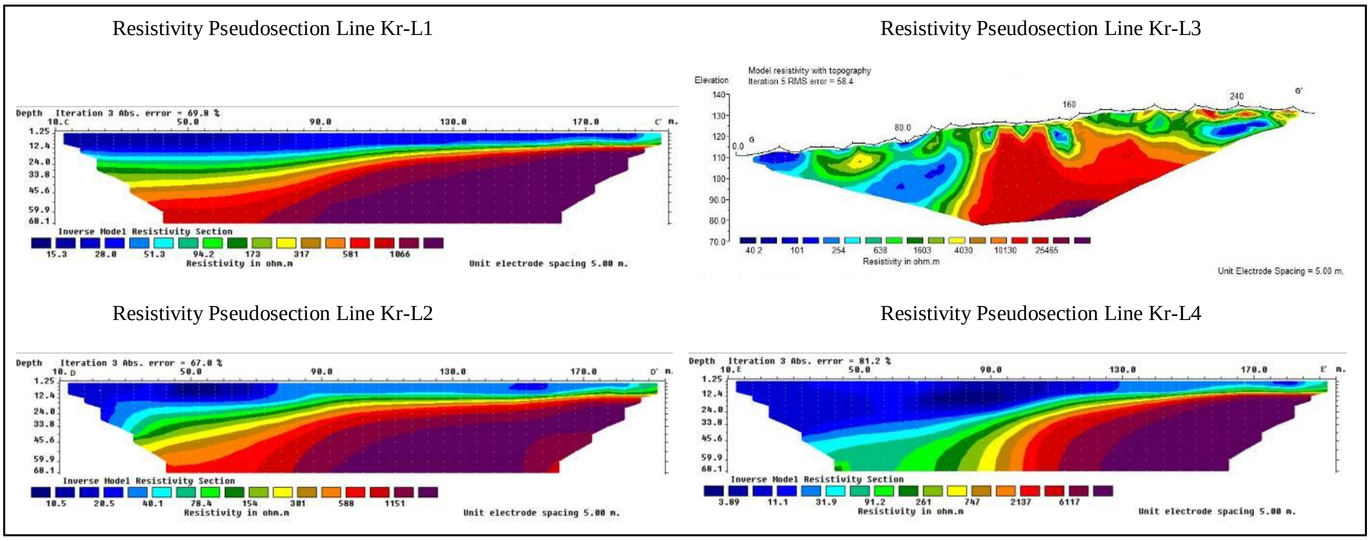

Fig. 5 The results of 2D resistivity inversion on the Kr-L1 and Kr-L2 path (left) show a very thin shallow aquifer pattern under the topsoil. On the Kr-L3 and Kr-L4 path (right) shows the aquifer pattern is quite thick at the beginning of the track. The dominance of the rock response which has a high resistivity value is estimated as bedrock.

The agricultural area in the southern part of the research location is the location of the Kr-L1 and Kr-L2 paths. Shallow aquifer conditions on the track are characterized by resistivity values range between 30-150 Ωm. This aquifer is located between layers of clay on topsoil with resistivity values range between 1-30 Ωm and rock pedestal at high resistivity value is more than 1000 Ωm. The tendency to decrease the bedrock body which is deeper at the beginning of the trajectory can be an indication of the potential for thickening of the groundwater aquifer.

Investigations conducted in several community wells in the rice fields (KW-2, KW-4, KW-5, KW-6, KW-8) showed similar conditions. Some wells managed to get water at a depth of more than 10 m. However, the amount of water that can be pumped from these wells is very limited, especially in the dry season. Even when the investigation is done, the KW-8 wells in dry conditions. This condition is related to the location of a very shallow aquifer, although it has the potential of sufficient aquifer thickness, the shallow position causes very large climatic and seasonal influences on the ability of aquifers to hold water.

Different conditions can be observed in the inversion results of the path resistivity data Kr-L3 and Kr-L4 (Fig. 5). Even though the Kr-L4 path shows a pattern similar to the previous two trajectories, a considerable decrease in the base rock body has increased the thickness of the shallow aquifer zone at the starting point of this path. Aquifer layer is estimated to be in the range of resistivity values 30-150 Ωm. Meanwhile, in the topsoil layer there are clay lenses with a range of resistivity values between 1 - 10 m. This condition is also confirmed by the results of the 1D curve at the point of KV-1 which has a thickness of up to 30 m for the range of resistivity values <100 Ωm.

The potential shallow aquifer zone is also detected by resistivity data on the Kr-L3 path. In the initial area, this path shows a range of resistivity values of 40 - 250 Ωm which is estimated as a potential groundwater aquifer. KW-9 and KW-7 wells in the vicinity of the area are wells that have successfully gotten groundwater, even able to survive during the dry season despite a decrease in discharge. Getting away from the start area track Kr-L3, the higher resistivity values even reached more than 25000 Ωm. This resistivity value is estimated as the response of bedrock composed of igneous rock. The remains of igneous rock form a small hill known by the surrounding community as Bukit Krawang.

C. Aquifer Distribution

The distribution of shallow aquifers is based on the results of the interpretation of aquifer data vertical electrical sounding (VES) and 2D Resistivity Mapping layers showing aquifer patterns in two potential zones (Fig. 6). The first zone is located at the location of the KW-9 well which is a well water source for Krawang. The thickness of aquifers in this zone ranges from 25-50 m even though the area is not large enough. This condition was also strengthened by the adequate production of drinking water from these wells and several experimental wells around it failed due to being outside the potential zone of groundwater aquifers.

The most potential aquifer zone is in the west of the research location with a thickness of aquifers ranging from 15 - 75 m and a fairly large area. But unfortunately, there are no wells that can be used to confirm the potential of aquifers in this region. This was caused by people who were interested in the success of the KW-9 well so they built wells around them even though most of them failed.

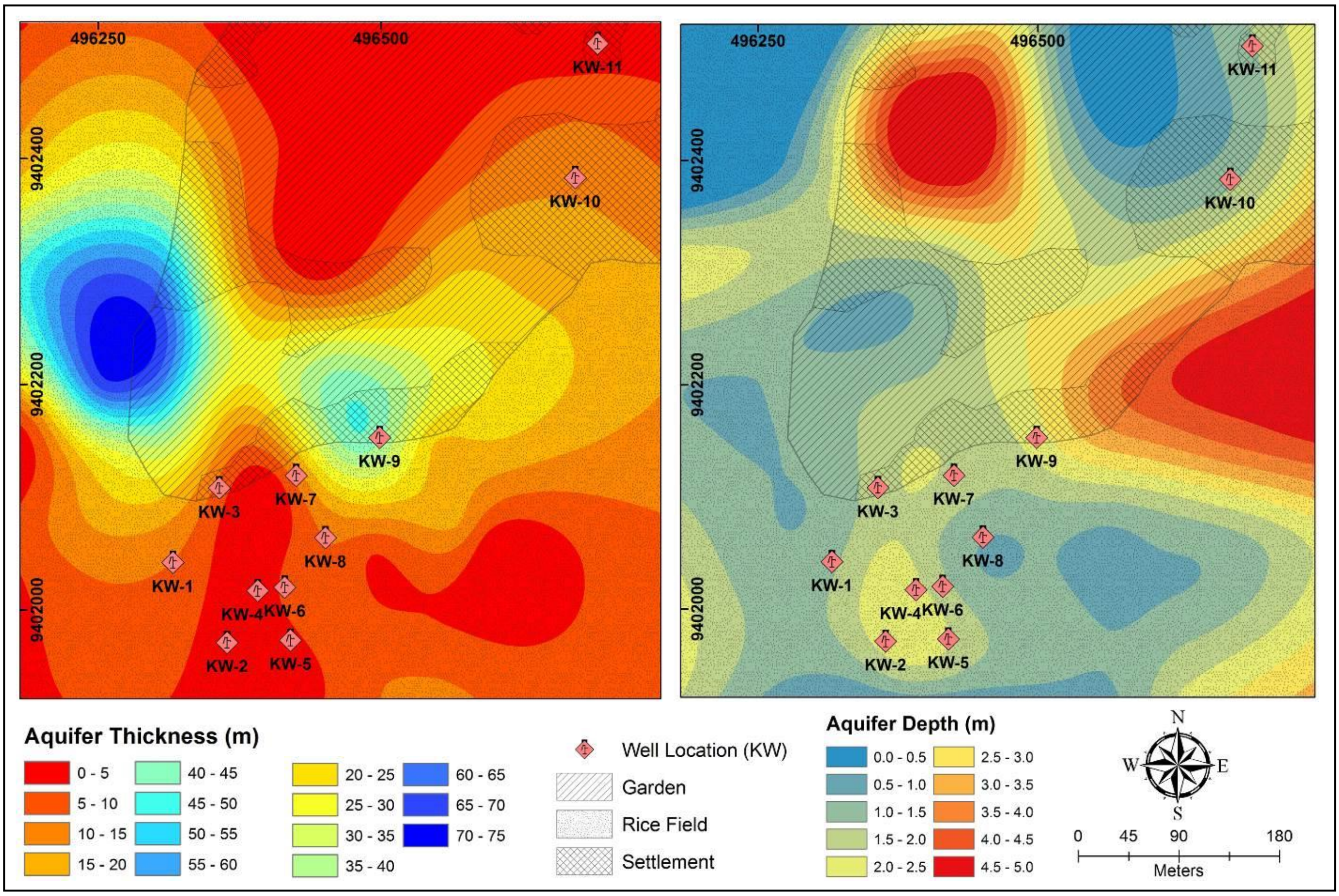

Fig. 6 Potential zone distribution map of shallow groundwater aquifer (VES) and 2D Mapping data interpretation for aquifer (left) and aquifer depth (right) thickness. Red to blue gradations indicate the thickness and depth of aquifers.

Based on the map of shallow aquifer thickness, it appears that the failure of farmers in making wells for agricultural needs is related to the thinness of shallow aquifers in the area. So that most of the wells in the agricultural area are unable to meet irrigation needs, especially in the dry season. Development of wells must begin to be directed to the western part of the research area.

Based on the distribution map of aquifer depth, it can be seen that the wells made by the community follow contours which show shallow aquifers. This shallow aquifer distribution dominates most of the study area, although there are areas that do not have shallow aquifers with red dominance characteristics on the map of the thickness and depth of the aquifer (Fig. 6). If it is related to the geological conditions of the study area which are in tertiary volcanic rock formations, then the possibility of igneous bodies causes thin aquifer conditions.

D. Discussion

The use of geo-electrical sounding and 2D mapping methods can identify shallow aquifers quite well. The results of the identification of potential zones of groundwater aquifers are in the rice fields in the west and center of the research area. The first aquifer zone is in the KW-9 well area which is used as a drinking water production well. The success of the production well is related to its location right in the zone of the groundwater aquifer. This aquifer is interpreted as part of a sub-basin due to the geomorphological formation of the Krawang hill which is thought to be an intrusive body. This interpretation is based on the results of interviews with several communities when they conducted well drilling.

Some wells that managed to get water, during drilling, they found rocks in the form of sandstones mixed with claystone with the size of sand grains from fine to coarse. If it is associated with the geological conditions of the area with the dominance of volcanic tuff rocks on the surface it is certainly not part of the formation that becomes an aquifer. Possible groundwater aquifers in this area are in deeper rock formations, namely cretaceous sandstone and claystone formations. To prove this assumption, drilling data from the drilling result is certainly needed.

Another condition that is also quite interesting to discuss is the area around the well KW-9 which has a fairly good aquifer but only within a radius that is not too large. Some wells in the vicinity do not get the same water as in the KW-9 well. This condition is also reinforced by the results of measurements of 2D resistivity mapping that form aquifer patterns in a small area. Are these aquifer patterns influenced by structures that are likely to form around the area or sub-basin patterns formed by the presence of granite plutons in Bukit Krawang. Both of these are debatable until supporting data can be obtained that can prove it.

IV. Conclusions

The potential of groundwater aquifers in the Krawangsari area is a major magnet in the home water industry in the region. However, this condition is the opposite of the need for agriculture to get water. The condition of agricultural areas that can only be planted during the rainy season causes a decrease in production and income of the community. Therefore, the development of groundwater-based irrigation is expected to overcome the problem of water shortages during the dry season.

The results of this study indicate that the potential of groundwater aquifers in agricultural environments is found in the western region of Bukit Krawang, while in the south it is not. This condition gives a strong indication of why residents' irrigation wells in the southern part of Bukit Krawang failed. Therefore, by utilizing the results of mapping groundwater aquifers, the development of irrigation wells for agriculture should be carried out in the western part.

Based on the results of vertical electrical sounding (VES) and 2D resistivity mapping, aquifer characteristics in the eastern part of Krawang Hill have a depth between 1-3 m for shallow aquifers with a thickness of aquifers between 15 m and more than 70 m. The depth of the bedrock ranges from 50 - 150 m with a pattern deeper into the west. While for aquifers in the southern part it has a characteristic depth between 2-5 m for shallow aquifers with a thickness of aquifers ranging from 25 - 50 m and the depth of the bedrock between 20 - 70 m. With the potential of two separate aquifers, the water requirements for agricultural irrigation during the dry season can be met, while aquifers for drinking water production wells in the south can still be sustainable.

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