



Aquifer Porosity Prediction Base on Resistivity Data and Water Conductivity



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Abstract

The research of aquifer porosity prediction based on resistivity data and water conductivity was conducted. The research was a case of study that conducted at Desa Bugbug, Karangasem Regency in Bali. Resistivity data were taken by geoelectric tools set off. Water conductivity data was obtained by directly measuring the water conductivity of the wells drilled based on geoelectric data. In regard the measurement results was obtained 26.5 ohm.m of resistivity aquifer and the water conductivity was 0.02 s/m so that the aquifer porosity based on the calculation was 39.9%. The implications of this calculation were to obtain data that serves as a soil porosity aquifer, e.g. as the soil porosity at existing wells site, it was enough conducted resistivity measurements on the spot and measure the conductivity of wells water. Thus the process was expected to be more practical.

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1. Introduction

The knowledge of the aquifer porosity or rock coating that contains a water is needed by a civil engineer in designing a building. Therefore, the civil engineer used a way of taking a rock sample then examines it's in the laboratory. In regards this as a way of obtaining a rock sample. There was not all location easy to get it. It is one way to obtain a rock porosity based on resistivity data and water conductivity.

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2. Materials and Methods

2.1 Theoretical Framework

Aquifers can be defined as a coating, formation or formations group saturated a water, its water can be taken and can be refilled. There are geological formation varieties that are able to serve as an aquifer. The geologic formations including alluvial deposits, limestone, volcanic, sandstone and igneous and metamorphose rock (Todd, 1980). Reviewing on rock coating that belongs to aquifer around, the aquifer can be group into two, those are un-confine aquifer and confine aquifer (Redana, 2012). The free aquifer is an aquifer under the groundwater level, therefore its aquifer in a free condition, without any pressing. In respect of free aquifer water fills the pores of the formation to be saturated. A confined aquifer is an aquifer of under pressure from *Aquitard* coating. In confined aquifer, the water level could be higher than the ground level for greater artesian pressure.

Aquifers are formed as a result of the geomorphological processes on the earth's surface. The forces that influences of geomorphology processing is the power of exogenous, endogenous powers and the powers that come from outside of earth (Tjia, 1987). The results of the weathering process, avalanches, volcanoes, erosion and water overhaul as his agent will be deposited to cover the valleys, lower areas or along rivers.

According to Tjia (1987), the volcano effects has enormous power in changing the earth surface morphology. At the time, the volcano erupted a volcanic material that are able to cover the valleys, lower areas or follow the river as far as flowing down. Likewise, the volcanic ash that can reach a wider area. These events are continuously repeated during the volcano erupted. As a result of erupting the material will show a coat in accordance with material types that are deposited. The hardness of sediment material is highly dependent on the temperature and the content of the material deposited. Material deposited materials are not uniform from the large up-sized sand and clay. The thickness is about few centimeters to a few meters. Eruption materials are hard and impenetrable to water (Tjia, 1987). Due to this nature that material is called overburden aquifer. Whereas, non-hard materials and can still be penetrated by water into the aquifer.

Based on the location of materials deposition of making up the aquifer geomorphology results, can be divided into three types (Simpfen, 2015), those are:

- 1) Material that settles along the river flow or trench, the hardest part will be covered coating or coating protection, while the hard coating cannot be penetrated by water aquifer. For this case, the aquifer will be a vein of forms such as rivers or trenches are buried.
- 2) Material that settles in the flat structure area, the hard part becomes the cover coating, whereas the soft one can be penetrated by water will be an aquifer. The hard coating and soft coatings are alternate will form the aquifer in the form of a flat.
- 3) Material that settles in the valley, a hard coating at the bottom next filling by the soft part and the hard part is covered by and last longer covered by the soft part. The composition of such materials will form the aquifer in the form of the basin.

2.2 The concept of porosity

Porosity is the ratio between the pore volume numbers of to the rock total volume, therefore it is able to be written:

$$\eta = (V_p/V_b) \times 100\% \quad (1)$$

Wherein η : porosity in %; V_p : pore volume and V_b : bulk volume (in overall sample volume). The cavities in rocks that are between the grains are called the pore. These pores can be filled with liquid or gas fluid. Reviewing on geology, this pore can be categorized into the primary and secondary pores. The primary pore is a pore formed when the rock is formed, otherwise, the secondary pore is formed by the rock due to geological processes. Referring on the technique, the pore can be seen as a total pore, which is the ratio of pore volume (V_p) with a rock total volume (V_b) although the samples were related or not. There are several factors that influence the amount of rock porosity, the grain shape, grain uniformity or sorting, compaction processes during and after the deposition, cementation degree and rock grouping, fiction and tunnel, and particle packing arrangement.

2.3 The theory of geoelectric method

In order to interpret measurements on earth geoelectric method considered homogeneous isotropic, i.e. each coating has the same resistivity. The basic principle of the method of geoelectric is measuring the potential response towards a potential density due to a current density is injected into the soil through the current density, therefore, the formulation of the theoretical method of geoelectric is based on density potential calculation principle in a certain medium with reference to a source of current density on the earth surface. If the current (I) is injected into the earth that is homogeneous and isotropic via a single electrode, the current density will be spread in all directions inside surfaces of equipotential to the earth in the form of the hemispherical surface as illustrated in Figure 1 (Telford, 1990).

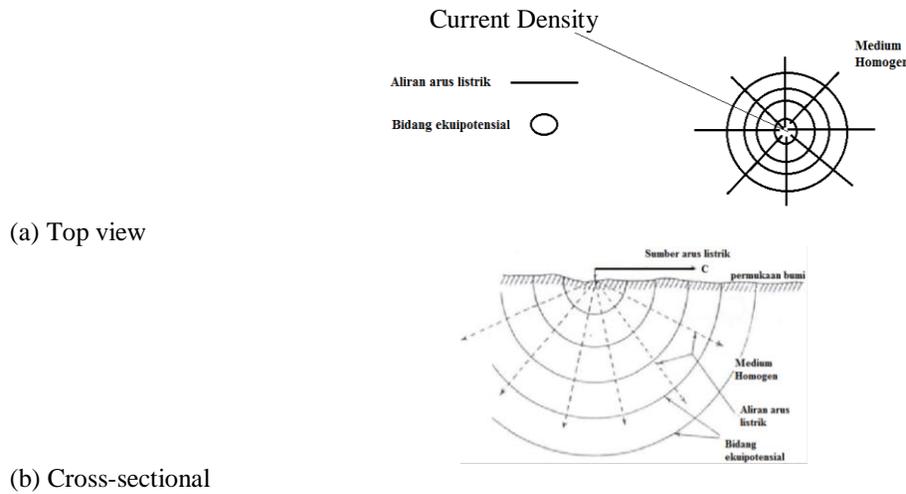


Figure 1. Current density and equipotential field

The value of electrical resistivity is a formation of the subsurface can be determined in accordance with its similarity (Mudiarto, et al., 2013):

$$V(r) = I\rho/(4\pi r) \tag{1}$$

Due to the current-carrying surface is a hemispherical surface that has a spacious $2\pi r^2$, so that

$$V = \left(\frac{I\rho}{2\pi}\right)\frac{1}{r} \text{ or } \rho = \frac{2\pi rV}{I} \tag{2}$$

If there are installed four electrodes such as figure 2, and the spacing between two electrodes the current is not too large, the potential at each point near the surface will be influenced by both current electrodes so that equipotential that generated from these two point sources are more complex than a single current source.

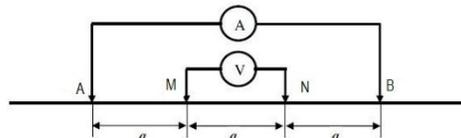


Figure 2. Schematic Flow Electrodes and Electrode Potential (Telford et al., 1990)

If it is drawn the equipotential lines will be obtained seems figure 3. If it is depicted in the cross-sectional shape will be obtained as shown in figure 4. The potential change is a very drastically in the area near the current source, meanwhile, the area between A and B the potential gradient is the small and linear approach. In regards this reason, the best potential measurement is conducted on the area between A and B which have the potential gradient linear. In

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order to determine the potential distinction between two points generated by current density source of A and B, next to the two potential electrodes e.g. M and N are placed near the source as in figure 3.

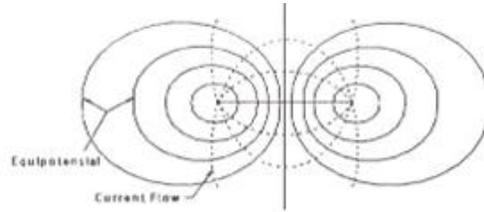


Figure 3. The equipotential outline is seen from above (Telford *et al.*, 1990)

In respecting of the principle of the equipotential field, it will be gotten that potential measurements on the soil surface will yield a value equal to the potential difference in the ground on the same radius for measuring the potential difference between the points M and N of the current source of A and B on the surface. See figure 4. (Telford, 1990, Mudiarto, *et al.*, 2013).

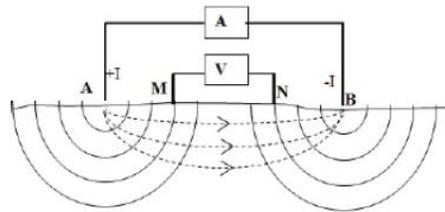


Figure 4. Current electrodes and the potential electrode, and equipotential lines

$$V_M = \frac{\rho I}{2\pi} \left[\frac{1}{AM} - \frac{1}{BM} \right] \quad (3)$$

$$V_N = \frac{\rho I}{2\pi} \left[\frac{1}{AN} - \frac{1}{BN} \right] \quad (4)$$

Then the difference between the potential difference between points M and N are:

$$V = V_M - V_N \\ V = -\frac{\rho I}{2\pi} \left[\left(\frac{1}{AM} - \frac{1}{BM} \right) - \left(\frac{1}{AN} - \frac{1}{BN} \right) \right] \quad (5)$$

Therefore, it will be obtained the similarity of resistivity determining i.e.:

$$\rho = 2\pi \left[\left(\frac{1}{AM} - \frac{1}{BM} \right) - \left(\frac{1}{AN} - \frac{1}{BN} \right) \right]^{-1} \frac{\Delta V}{I} \\ \rho = K \frac{\Delta V}{I} \quad (6)$$

Where in K is a geometric factor, it has a value:

$$K = \frac{2\pi}{\left[\left(\frac{1}{AM} - \frac{1}{MB} \right) - \left(\frac{1}{AN} - \frac{1}{NB} \right) \right]} \quad (7)$$

If the data is taken by the same electrode spacing is equal to $AM = MN = NM = a$, so that $AM = NB = a$ and $MB = AN = 2a$, see figure 2, the equation (7) will be:

$$K = \frac{2\pi}{\left[\left(\frac{1}{AM} - \frac{1}{MB} \right) - \left(\frac{1}{AN} - \frac{1}{NB} \right) \right]}$$

$$K = 2\pi\alpha \quad (8)$$

This configuration is known as the Wenner Configuration, wherein K is a geometric factor. Thus by measuring the distinction potential (V), a current value (I) and the space between the electrodes (a) it will be obtained resistivity (apparent resistivity) at the measurement point.

2.4 Relationship among aquifer porosity, aquifer resistivity, and water conductivity

There are several factors that determine the conductivity overall value of the rock, which is a type of material, the water content is in rocks, rock porosity and chemical properties of water is in the rocks. In referring to the types of rocks, each rock has a different ability to conduct an electricity, so that, the conductivity is different as well. The more water content in the rock, means a greater of conductivity since water serves as a conductor of current density, therefore, the conductivity is greater. The greater of the rock porosity means more pore is in the rocks, the water content will be more and more, which means the conductivity is greater. The whole rock conductivity is also affected by the chemical properties of water, salt water conduct electricity more easily than in fresh water, therefore it has a greater conductivity. This occurs belongs to ions that are able to conduct electricity.

The relationship among aquifer resistivity, aquifer porosity, and water conductivity was investigated and it has been conducted by [Mark & Uri \(2004\)](#). The porosity towards the clay was conducted by [Mark & Uri in Sultan Sultan Araffa Award \(2012\)](#), they were obtained:

$$\eta_w = \eta_b \phi^2 \quad (9)$$

Wherein η_b is a total rock resistivity, η_w is water resistivity, ϕ is rock porosity. However, this equation is merely valid for drilling mud alone. Then, it was stated by [Sen et al., \(1988\) in Sultan Sultan Araffa Award \(2012\)](#) developed the equation becomes:

$$\sigma = \phi^m \{ \sigma_w + A Q_v / (1 + C Q_v / \sigma_w) \} \quad (10)$$

Wherein σ is aquifer conductivity, σ_w is water conductivity, ϕ is aquifer porosity, m A and C are constants. Based on the 140 samples, the research was conducted by [Sen et al., \(1988\) in Sultan Sultan Araffa Award \(2012\)](#), it was found that $m = 2$, $A = 1.93 \times m$ (mho m^{-1}) (1 per mole), $Q_v = 2.04$ and $C Q_v = 0.07$ (mho m^{-1}). According to this equation if one aquifer resistivity is obtained, therefore, the water conductivity water from to aquifer can be measured, then the porosity magnitude of the aquifer in the area of observation can be searched.

2.5 Data Source

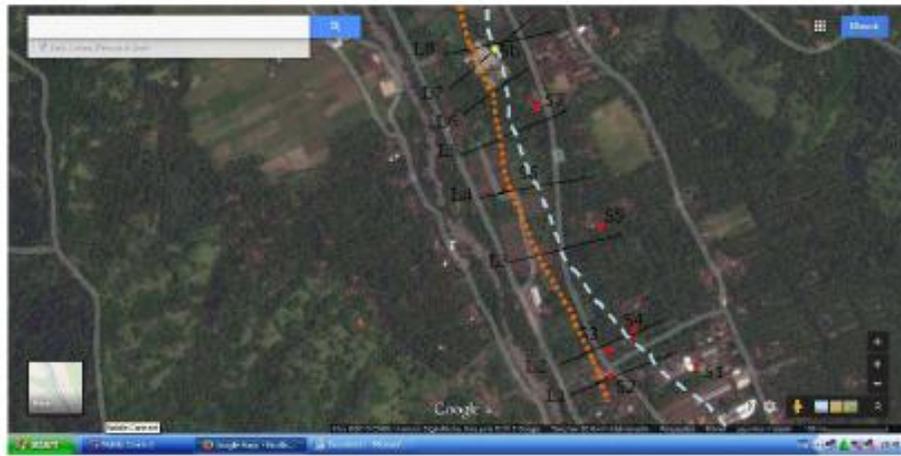
The data were cited in this research taken from two area, those are aquifer conductivity and water conductivity. Aquifer conductivity data was taken using Method *Geolistric*. Then, the apparent resistivity data results Method *Geolistric* was analyzed on the *Res2Divn* program due to obtaining the aquifer conductivity. The data of water conductivity was obtained by taking samples from well water that have been made to be measured their conductivity to higher.

3. Results and Discussions

3.1 Geographical circumstances in the research location

The research area was located in a height of 10-20 m above the sea level of rounding coordinates of 8.500584 115.594636 LS BT. The rock formations around this place consist of the early volcanic rock formation ([Hadiwidjojo, 1971](#)). This study focused on eight wells, there were one bore wells and seven wells. Each wells position, research [Simpen, I. N., Sutama, I. N. S., Redana, I. W., & Zulaikah, S. \(2016\). Aquifer porosity prediction base on resistivity data and water conductivity. International Research Journal of Engineering, IT & Scientific Research, 2\(5\), 7-16.](#)
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location, trajectory measurements by the Geolistic method, it can be seen in Figure 5 below (Simpén, 2015; Simpén, et al., 2015).



S1...S7 Wells; Sb: boreholes; L1...L8: Geolistic measurements section

Figure 5: Research Location

In this study, there were made seven tracks, that are some tracks near wells (S1S7, and Sb). Geolistic data was taken by Geolistic tool set. Furthermore, the data were analyzed by *Res2Divn* program and its result of resistivity contour for each track shows as follows: (Simpén, 2015; Simpén, et al., 2015).

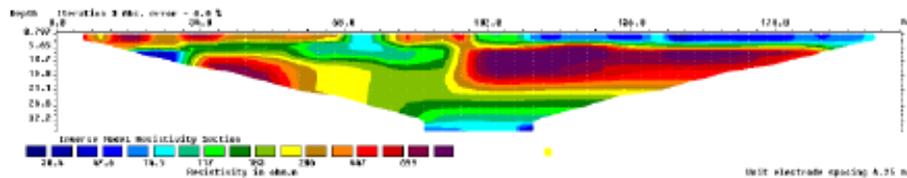


Figure 6. Tracking Resistivity Section 8

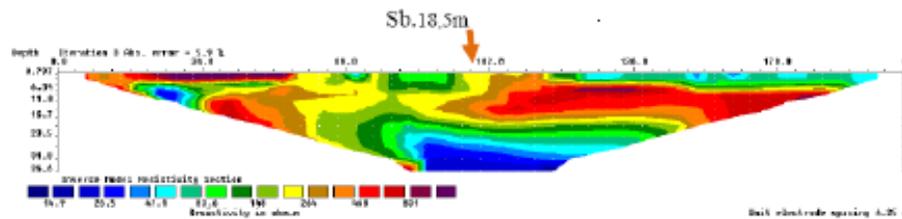


Figure 7. Tracking Resistivity Section 7

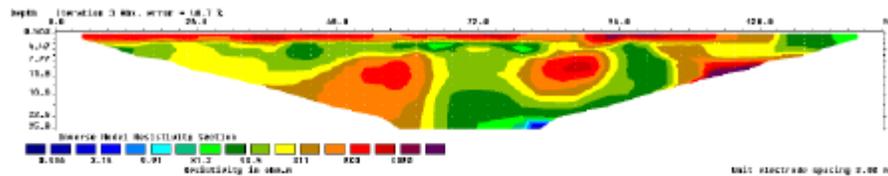


Figure 8. Tracking Resistivity Section 6

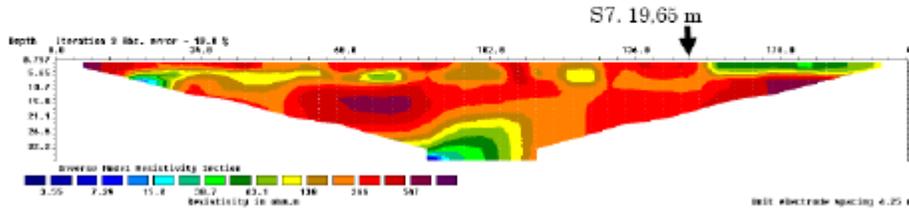


Figure 9. Tracking Resistivity Section 5

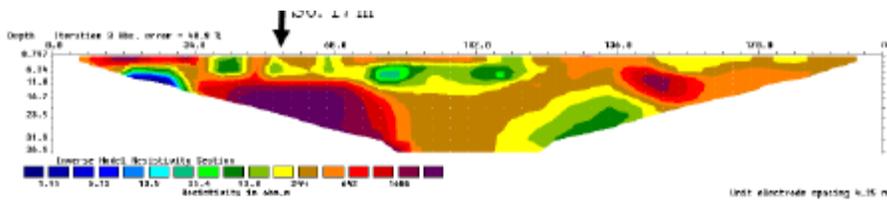


Figure 10. Tracking Resistivity Section 4

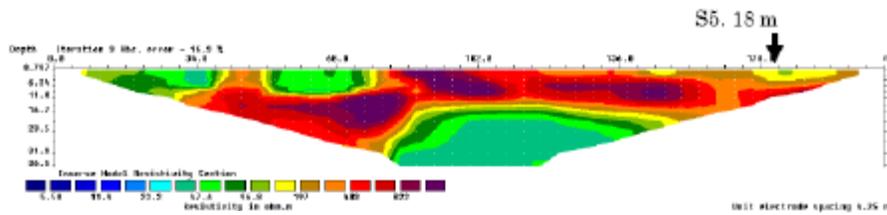


Figure 11. Tracking Resistivity Section 3

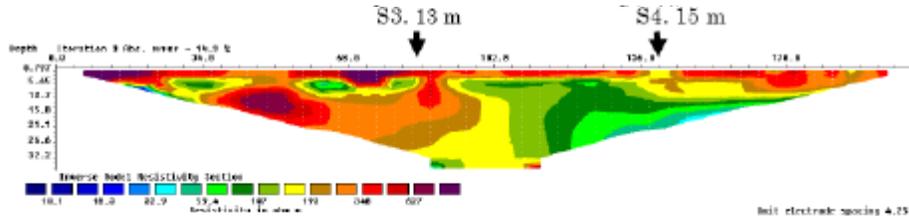


Figure 12. Tracking Resistivity Section 2

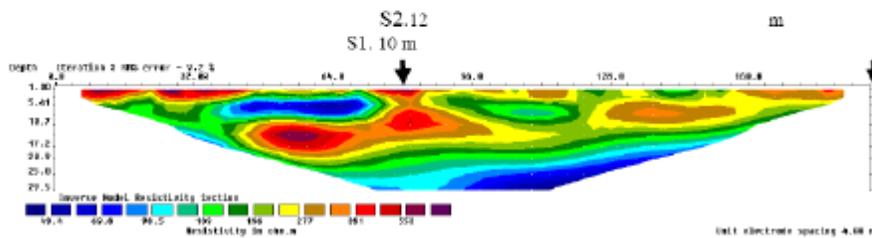


Figure 13. Tracking Resistivity Section 1

Based on data from resistivity and it is analyzed by the RES2DINV program, it is to obtain that prices conductivity aquifer wells. Well, water conductivity data were obtained by taking a sample of 500 ml of wells water for measured conductivity. Magnitude conductivity and conductivity of well water aquifers can be seen in the table, which further

if it calculated porosity aquifer with equation (10) will be obtained as reflected in column 7 in Table 1. As a comparison, in Table 2 are as well presented estimates of porosity of various materials.

Table 1
Calculation of Porosity in Various Aquifer

No.	Well	Depth (m)	Aquifer Type	Aquifer Conductivity (s/m)	Water Conductivity (s/m)	Aquifer Porosities (%)
1	Sb	17,50	Oppressed	0,03250	0,0200	36,90
2	S2	12,00	Irrepressible	0,03544	0,0725	20,07
3	S4	14,00	Irrepressible	0,07250	0,0995	24,55
4	S7	19,65	Irrepressible	0,03235	0,0712	19,34

Table 2
Estimated Porosity Various Materials

No.	Material	Porosity (%)
1	Clay	45
2	Sand	35
3	Gravel	25
4	Gravel and sand	20
5	Sandstone	15
6	Limestone and shale	5
7	Quartzite and granite	1

Source: [Linsley et al., 1989](#)

Porosity Aquifer towards boreholes (Sb) amounted to be 36.90%. Aquifers in the wellbore is a confined aquifer. Based on the data from the results of drilling, in areas such as material gained a sand aquifer rather large. Sand porosity in according to [Linsley et al., \(1989\)](#) is 35%. So that in accordance with the results estimation of existing data.

Wells aquifer porosity S2 is 20.07%. These wells are dug that has a depth of 12 m with the aquifer is irrepressible. Based on data from excavations in the well showed that S2 and its sand aquifers mixed with small gravel. When it is compared with the porosity of the table [Linsley et al., \(1989\)](#), the corresponding costs, therefore, the estimation results corresponding to the data.

Wells aquifer porosity S4 is about 24.55%. These wells are dug well has a depth of 15 m with the aquifer is irrepressible. Based on the results it is obtained that S4 digging wells that its form of sand soil (in Bali called the cider land is), no part of gravels. When it is compared by the porosity of [Linsley et al., \(1989\)](#) table of corresponding value. So that, the prediction results are consistent with existing data.

Wells aquifer porosity S7 is about 19.34%. These wells are dug well that has a depth of 19.65 m to the aquifer is irrepressible. Based on data from excavations at S7 wells showed that its aquifers are small gravel mixed with sand and gravel being. When it is compared with the porosity of [Linsley et al., \(1989\)](#) table of corresponding costs. So that, the estimation results corresponding to the data.

In this study, it is merely four aquifers wells for measured porosity, whereas others such as wells of S1, S3 wells, wells of S5 and S6 wells to be measured yet. For S3 wells encountered obstacles that the well has been permanently concreted so it is difficult to take some water samples. Wells included S1, S5 and S6 are outside cone resistivity cross-section, so that standing by its aquifers data is not available recently.

In timing of observed results, Geolistric data for measurements can be said that in each cross-section there are areas that have a very small resistivity alleged aquifer. These aquifers have a pattern of circles is not flat shape. If the aquifers are connected, will be obtained grooves aquifer as seen in Figure 5. This aquifer founded the groove as well as the blood vessels in the human body ([Simpfen, 2015 and Simpfen, et al., 2015](#)). This aquifer is a confined aquifer. In the study area found two grooves aquifer, see Figure 5 on the red line and the gray line. Sb wells tapping water from aquifers under pressure from the blue line, while the S6 wells tapping water from the confined aquifer with a red line. Among the well, Sb with aquifer wells S6 has a different groove. In other say, it is observed Sb aquifer wells, aquifers allegedly formed by the accumulation of small creeks and rivers by the eruption of Mount Agung

material when Mount Agung erupted, therefore, its aquifers form of grooves such as blood vessels in the human body. Likewise aquifers for S6 wells.

Aquifer wells are S2 and S7 are not pressured aquifer formed by the accumulation of material at the time of eruption of Mount Agung Mount Agung erupted. Between aquifer wells aquifer wells S2 to S7, when considered in the conductivity and porosity its aquifer convergence, as well as its position in the research areas that are equally the result of hoarding material Agung eruption, then its aquifers allegedly have the same bedding. The water content contained in this aquifer is only in the form of rainwater infiltration or infiltration of water in the upper reaches of rice fields and has nothing to do with the aquifer wells Sb so that in the dry season the water subsided (Simpfen, 2015).

S4 has different aquifer wells with aquifer wells S2, S7, and Sb. Aquifer wells received water infiltration of rainwater or from the fields in the upper reaches. In the dry season the water was subsided (Simpfen, 2015), When viewing from the material or porosity, allegedly aquifer wells S4 are not formed due to accumulation of material eruption of Agung Mount, in addition to these regions is higher when compared to well position S2, S7 and Sb, further it is not allow material to Agung eruption in well position S4.

4. Conclusion

Based on the above discussion it can be concluded that the porosity of an aquifer can be estimated based on the data of resistivity and conductivity of water.

Conflict of interest statement and funding sources

The author(s) declared that (s)he/they have no competing interest. The study was financed by.

Statement of authorship

The author(s) have a responsibility for the conception and design of the study. The author(s) have approved the final article.

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