

Identification of the Aquifer in Sungai Raya and Its Surroundings, Bengkayang, West Kalimantan

Identifikasi Akuifer di Sungai Raya dan Sekitarnya, Bengkayang, Kalimantan Barat

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ABSTRAK

In Sungai Raya Village, Bengkayang Regency, West Kalimantan Province, the people are fully depending on groundwater to fulfill their daily clean water needs where the presence of groundwater is influenced by seasons. Based on these facts, it is necessary to conduct a hydrogeological study at this location with the objectives of the study were to identify the aquifer in Sungai Raya, along with its type, depth, and distribution. The methods used in this study were literature studies of geological data and geoelectrical measurement. Based on the literature study, it was known that the study area, from the oldest to the youngest, consists of andesite, granodiorite, diorite, quartz sand deposit, littoral deposit, and alluvial deposit. Based on the geoelectrical measurement, it resulted that most of the subsurface layers recorded by the instrument are alluvial deposit (characterized by their low-resistivity value) which is underlaid by the bodies of igneous rocks, i.e. diorite and andesite (characterized by its high-resistivity value). Based on the comprehensive analysis, there are two aquifers in the study area, namely alluvial deposit and quartz sand deposit. Both of them are unconfined aquifers. The aquifers can be found at the surface to the depth of ± 100 m. It can be inferred that the aquifers relatively deepen to the north and east. The quartz sand deposit is a better aquifer since it has more-uniform sorting and more-open fabric than the alluvial deposit which provides the deposit larger capacity for storing and transmitting groundwater.

Kata kunci: Sungai Raya, groundwater, aquifer, geology, geoelectric

ABSTRACT

Penduduk Desa Sungai Raya, Kabupaten Bengkayang, Provinsi Kalimantan, bergantung sepenuhnya pada air tanah untuk memenuhi kebutuhan air bersih yang ketersediaannya bergantung pada musim. Berdasarkan fakta tersebut, diperlukan kajian hidrogeologi di lokasi tersebut dengan tujuan untuk mengidentifikasi akuifer di Desa Sungai Raya, beserta tipe, kedalaman, dan distribusinya. Metode yang digunakan dalam kajian ini adalah studi literatur data geologi dan pengukuran geolistrik. Berdasarkan studi literatur, diketahui bahwa daerah studi, dari tertua hingga termuda, tersusun atas andesit, granodiorit, diorit, endapan pasir kuarsa, endapan litoral, dan endapan aluvial. Berdasarkan pengukuran geolistrik, diperoleh hasil bahwa sebagian besar lapisan bawah permukaan yang terekam oleh instrumen adalah endapan aluvial (dicirikan oleh nilai resistivitas rendah) yang berada di atas tubuh batuan beku, seperti diorit dan andesit (dicirikan oleh nilai resistivitas tinggi). Berdasarkan analisis terpadu, terdapat dua akuifer di daerah studi, yaitu endapan aluvial dan endapan pasir kuarsa. Keduanya merupakan akuifer tak tertekan. Kedua akuifer tersebut dapat ditemukan di permukaan hingga kedalaman ± 100 m. Diperkirakan keduanya mendalam ke utara dan timur. Endapan pasir kuarsa adalah akuifer yang lebih baik karena memiliki sortasi yang lebih seragam dan kemas yang lebih terbuka daripada endapan aluvial sehingga memiliki kapasitas penyimpanan dan pengaliran yang lebih besar.

Keywords: Sungai Raya, air tanah, akuifer, geologi, geolistrik

INTRODUCTION

Groundwater is an essential resource to all human beings (Ferragina 2009). It fulfills many of

the human necessities, i.e. consumption, housing, industry, irrigation, mining, urban living, etc (Darsono, Legowo, and Darmanto 2017; Fajana

2020; Firdaus, Bakri, and Rauf 2018; Hanifa, Sota, and Siregar 2016; Onawola *et al.* 2021). It is estimated that 70% of the population's clean water needs and 90% of industry's water needs are fulfilled by groundwater.

Until today, groundwater is still a primary solution to fulfill the world's clean water needs (Darsono, Legowo, and Darmanto 2017; Fajana 2020; Firdaus, Bakri, and Rauf 2018; Hanifa, Sota, and Siregar 2016; Onawola *et al.* 2021). It provides an easy and low-cost exploitation process. But, the groundwater is not always abundant throughout the year. In the dry season, the quantity of groundwater decreases.

The same problem happens in Sungai Raya Village, Bengkayang Regency, West Kalimantan Province. In that location, the people are fully depending on groundwater to fulfill their daily clean water needs. They are affected by the reduction of groundwater quantity in the dry season. By these problems, a hydrogeological

study must be carried out in Sungai Raya. The study aims to identify the aquifer (groundwater-bearing rock layer) in Sungai Raya, along with its type, depth, and distribution.

The study is conducted mostly in Sungai Raya and in Karimunting and Sungai Keran. Geographically, the study area is located on the coordinate of 260,000-270,000 meters east and 10,075,000-10,082,500 meters north. The location map of the study area is pictured in Figure 1.

Groundwater is stored in an aquifer (Raymond Jr 1988). An aquifer is a rock that is capable to store and transmit groundwater in a significant amount (Irawan and Puradimaja 2015). The opposite of the aquifer is aquifuge, which can not store and transmit groundwater at all. The rock which can be an aquifer should be porous (to store) and permeable (to transmit). The favorable rocks are sedimentary rocks (especially sandstone) and fractured crystalline rocks (igneous and metamorphic rocks).

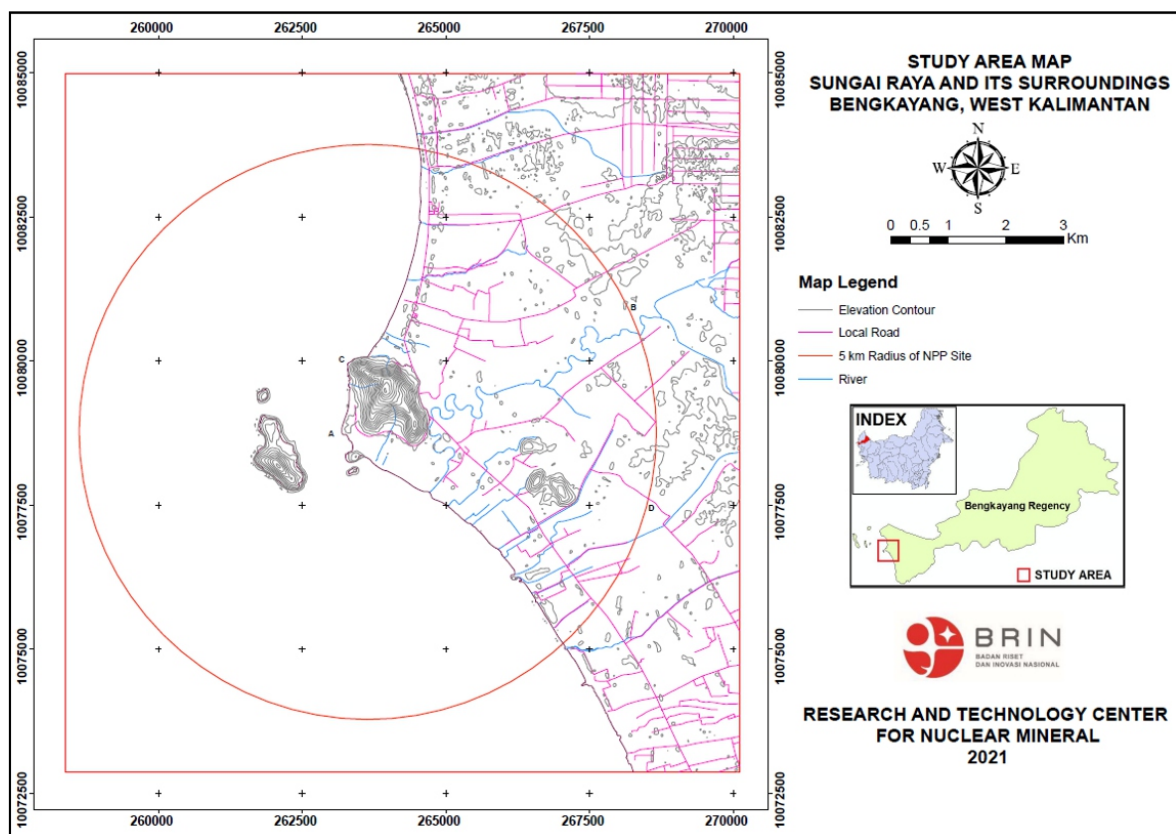


Figure 1. The location map of the study area.

Hydrodynamically, there are three types of the aquifer (Kruseman and de Ridder 2000), namely confined aquifer, unconfined aquifer, and leaked aquifer. Confined aquifer is the aquifer which its top and bottom are limited by impermeable layers. Unconfined aquifer is the aquifer which is limited by impermeable layers on its top or bottom. Leaked aquifer is the confined aquifer which is limited by a semipermeable layer on its top or bottom.

Based on *Peta Geologi Lembar Singkawang* (Figure 2) (Suwarna and Langford 1993), the study area is composed of four rock formations, from the oldest to the youngest, they are Raya Volcanic Rocks (Klr), Sintang Intrusions (Toms), Littoral Deposits (Qc), Alluvial and Swamp Deposits (Qa). Raya Volcanic Rocks (Klr) is Cretaceous-aged; consist of andesite, dacite, and basalt. Sintang Intrusions (Toms) is Oligocene-aged; consist diorite, microdiorite, granodiorite, quartz diorite, quartz gabbro, and

tonalite. Littoral Deposits (Qc) is Quaternary-aged; consist of granules, sands, and muds. Alluvial and Swamp Deposits (Qa) is Quaternary-aged; consist of muds, sands, granules, and plant remains.

There is an indication of structural lineament in the study area (Suntoko and Soetopo 2013; Zulfikar, Kaelani, and Turdjaja 2007). That lineament seems to intersect the volcanic rocks and the intrusions in the NE-SW direction.

Based on the result of geological mapping in the previous study (Muhammad *et al.* 2021), stratigraphically, the study area is composed of six rock units, from the oldest to the youngest, they are andesite, granodiorite, diorite, quartz sand deposit, littoral deposit, alluvial deposit.

Andesite is exposed in the west and central parts of the map. Megascopically, fresh andesite is light gray-colored; massive; compact; aphanitic to porphyro-aphanitic; inequigranular; subhedral; extrusive; composed of quartz, plagioclase,

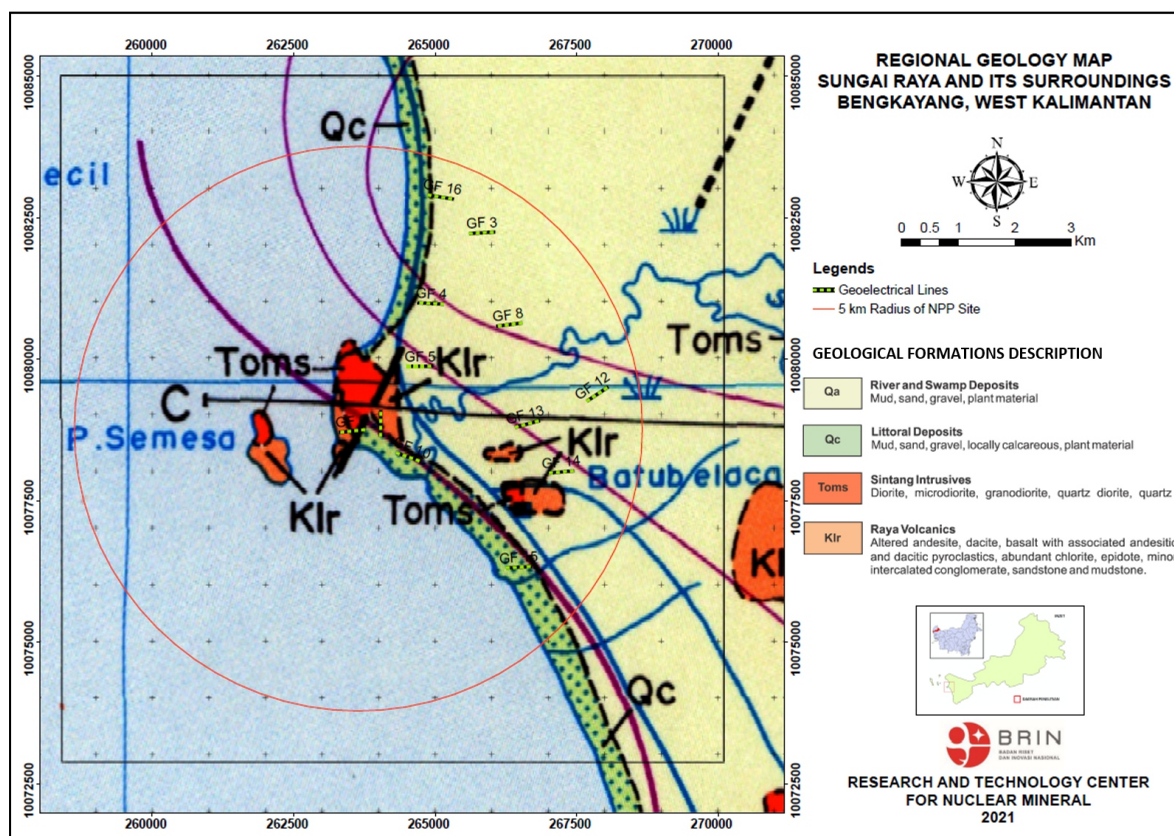


Figure 2. Regional geological map of the study area (modified from (Suwarna and Langford 1993)).

and some mafic minerals. Locally, basalt is found as a xenolith in andesite; dark gray-colored; massive; compact; aphanitic; composed of plagioclase, pyroxene, and aphanitic mafic minerals.

Granodiorite is plutonic rocks that intrude the andesite unit. At outcrop scale, the weathered granodiorite is brownish gray-colored; the fresh one is gray and reddish brown-colored; holocrystalline; porphyritic; massive; equigranular; composed of plagioclase, quartz, K-feldspar, and biotite. Diorite is younger than the andesite unit. At some outcrops, diorite is found as veins in andesite. The weathered diorite is reddish brown-colored; the fresh one is whitish gray-colored; holocrystalline; phaneritic; massive; compact; equigranular; composed of plagioclase, hornblende, pyroxene, and little quartz.

Quartz sand deposit exists in the east part of the study area. Generally, the quartz sand deposit is brownish white-colored; medium sand-grain

sized; well-sorted; medium rounded-grain shaped; unconsolidated; composed of quartz. Littoral deposit covers 7% of the study area in the west part (from south to north). The littoral deposit consists of unconsolidated mud and clay-coarse sand that comes from erosion and coastal sedimentation. Mangrove forests and tidal areas in this location are mostly composed of mud. Alluvial deposit exists on flood plain and swamps that comprise most of the study area. The alluvial deposit consists of clay, sand, and granule-grain-sized unconsolidated materials that come from alluvial erosion. The geological map of the study area is pictured in Figure 3 (Muhammad *et al.* 2021).

The complex of igneous rocks which exposed on the surface consists of andesite, granodiorite, and diorite. The complex forms isolated hills and is subsequently weathered to be soils that fill the slope and valley of the hills. The porosity and permeability of this complex are

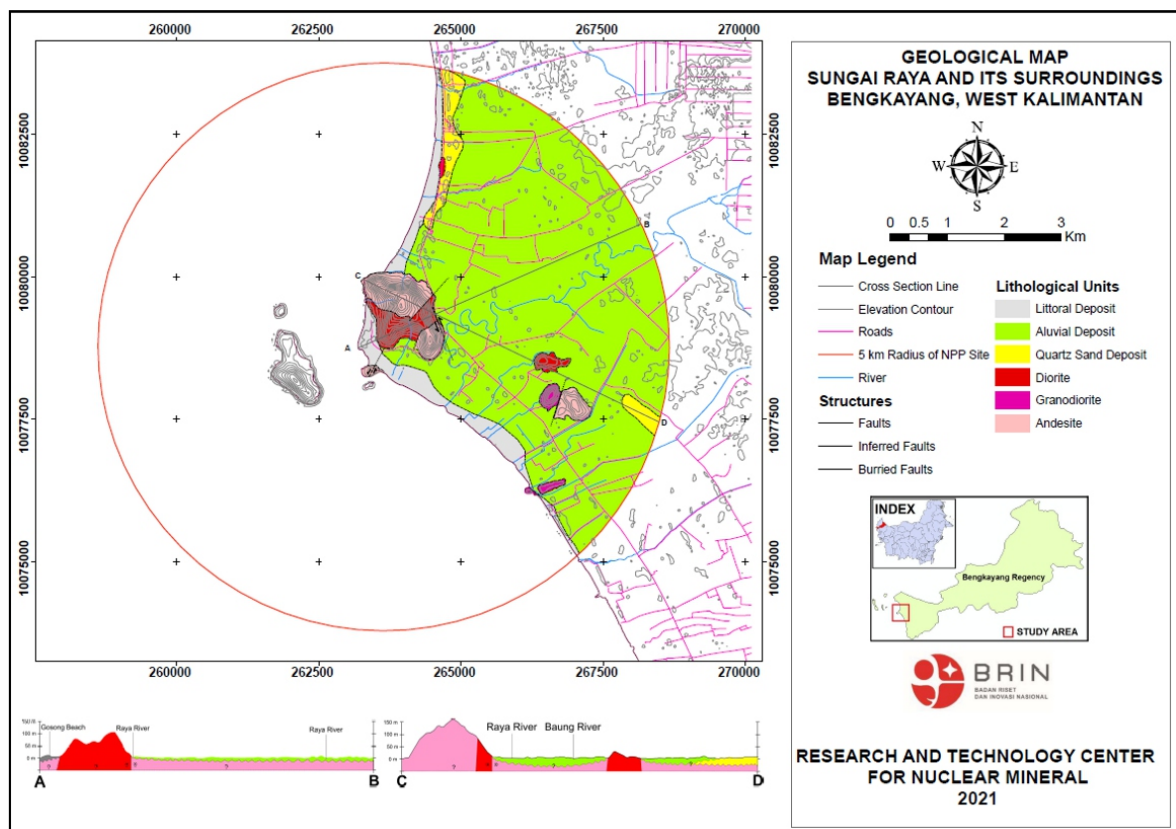


Figure 3. The geological map of the study area (Muhammad *et al.* 2021).

so low. The aquifer that existed in this complex is in the form of fractured rocks. At some places in Sungai Raya Village, it manifests as springs. Generally, the complex is classified as an aquifuge. A limited groundwater supply can be found in the valley or in weathered areas. The supply can increase as the rocks continue to fracture.

The indication of tectonic activity in the study area is recognized from the lineaments and morphology pattern. Based on the joints measured in this location, it can be inferred that the tectonic force is SSW-NNE and NNW-ESE-directed. Some older structures trending N210°E and N340°E are found on the Upper Cretaceous-aged andesite and are already filled by intrusive diorite.

The andesite complex is the oldest rock exposed in the study area. The complex is formed by intermediate-composition volcanic activity. The fracture orientation reflects the sinistral horizontal movement. Locally, the fractures can be found on this complex and are already filled by diorite. In addition to diorite, granodiorite intrusion is also found on an isolated hill in Sungai Keran Village.

After the intrusion occurred, regression of the relative sea level was taking place and formed the quartz sand deposit containing a cross-bedding structure. The deposit sedimented forms non-conformity with the older volcanic or intrusive rocks. Generally, the deposit is brownish white-colored, sand-grain-sized, and uncemented. The existence of groundwater in Karimunting Village is controlled by the deposit. The deposit is a result of the arid climate taken place during the Ice Age, on the wide-open Sunda Shelf. In that condition, savanna vegetation was rare. When the climate changed, flood and sediment production largely and rapidly happened (Thorp *et al.* 1990). In Holocene time, coastal deposits (consists of unconsolidated mud, clay-coarse sand) and alluvial deposits were sedimented. Both deposits sedimented form a disconformity with the older units.

METHODOLOGY

Geoelectrical measurement is one of the geophysical method popularly applied in hydrogeological study (Mazac, Kelly, and Landa 1985). The geoelectrical instruments inject current into the subsurface to measure the resistivity of the materials inside. By using the newer technology of the geoelectrical instrument (*MAE* multichannel geoelectrical instrument with 48 electrodes), the measurement could be more efficient and accurate as well as reach a deeper and wider range. The photograph of the instrument is pictured in Figure 4.



Figure 4. The multichannel geoelectrical instrument *MAE*.

This method is started by arranging the location and direction of the geoelectrical lines. The location of the lines is determined based on the research objective. Meanwhile, the direction of the lines is determined based on the geological condition, especially the orientation of aquifer thickness and the depth of basement rocks. The coordinate of the location is determined by GPS and its elevation is determined by the altimeter. Every line is 470 m long and the spacing of each electrode is 10 m. DC is injected by a 12-volt voltage source to the ground through stainless steel 48 electrodes connected to 4 rolls of multicore cable jumper which has 195-meter length each. The location of the electrodes was recorded by a portable GPS on the tipping point and using elevation difference for the rest of the points.

This method is implemented by measuring the resistivity of rocks/soils. The geoelectrical instrument injects direct current (DC) into the earth and records the potential difference. The current and the potential are the parameters to calculate the resistivity. Every rock type has its resistivity value (Figure 5) (Telford, Geldart,

and Sheriff 1990). By determining its resistivity value, the rock type can be identified.

This method uses two kinds of electrodes: the current electrode (C) and the potential electrode (P). The electrode configuration used in this study is Wenner (Figure 6) (modified from (Binley 2015)) with datum rows (n) of as many as 15. The

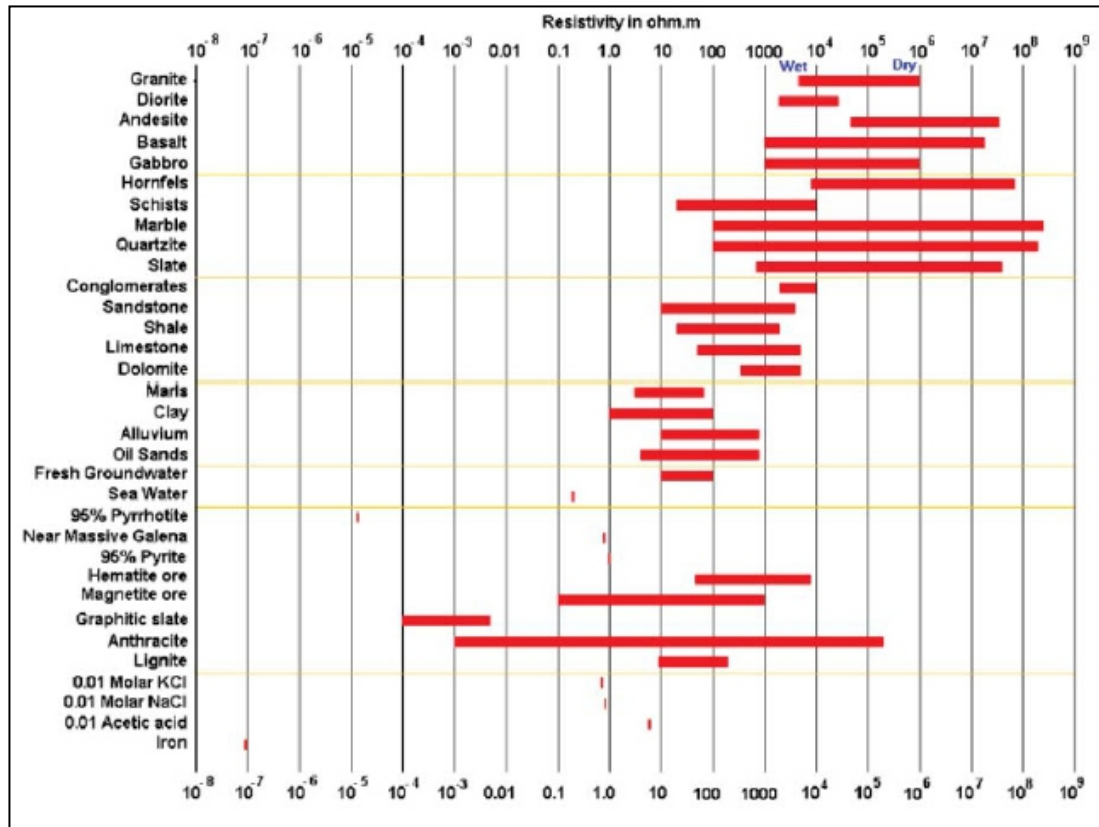


Figure 5. The resistivity values of various rocks, soils, and minerals (Telford, Geldart, and Sheriff 1990).

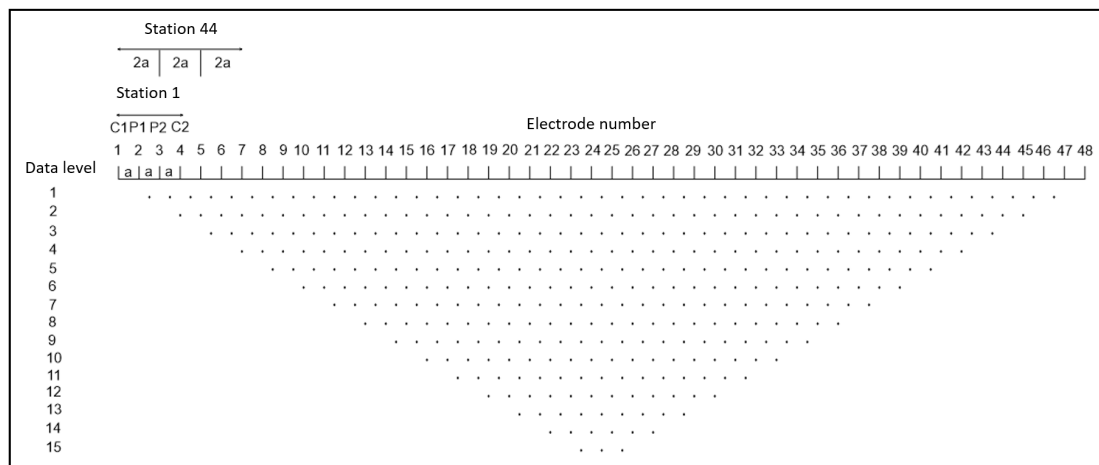


Figure 6. 2D geoelectrical measurement using Wenner configuration (modified from (Binley 2015)).

configuration could get a more deep penetration compared to the other configurations.

The raw data was processed in several steps: input data forming, data reduction/filtering, elevation data input, and inversion modeling. The raw data consists of the location of the electrodes, n datum sequence, apparent resistivity value, and elevation of the electrodes. Those data were formatted in a file with DAT extension which subsequently used as the input data. Data reduction/filtering is a technique to catch the error in data and delete it manually. The filtered input data was then 2D-modeled to result in a true resistivity cross-section using the inversion approach in the software *Res2Dinv*.

RESULTS AND DISCUSSION

The geoelectrical measurement was carried out mostly in Sungai Raya and in Karimunting and Sungai Keran (representing all rock units that exist there). The measurement was executed at

12 lines out of 17 planned lines. Each line has 470 m in length and 10 m electrode spacing. Five lines could not be executed because they all are located on wet rice fields. The location map of the geoelectrical lines is pictured in Figure 7.

The interpretation of the geoelectrical section was made by combining the result of the geological observation and the anomaly contrast. To enhance the certainty in interpretation, a calibration/background check was undertaken by measuring the resistivity of some exposed rock units. The measurement resulted in a value of $<30 \Omega\text{m}$ for alluvial deposits and $>300 \Omega\text{m}$ for igneous rocks.

Anomalies are found on some processed resistivity sections. The anomaly in this study is defined as the resistivity value of $>300 \Omega\text{m}$. Mostly, the anomalies are spotted in the lower part of the sections. Some anomalies are spotted in the upper part of the sections, reflecting the occurrence of igneous rocks on the surface. The resistivity value has a connection to the occurrence of fluids in

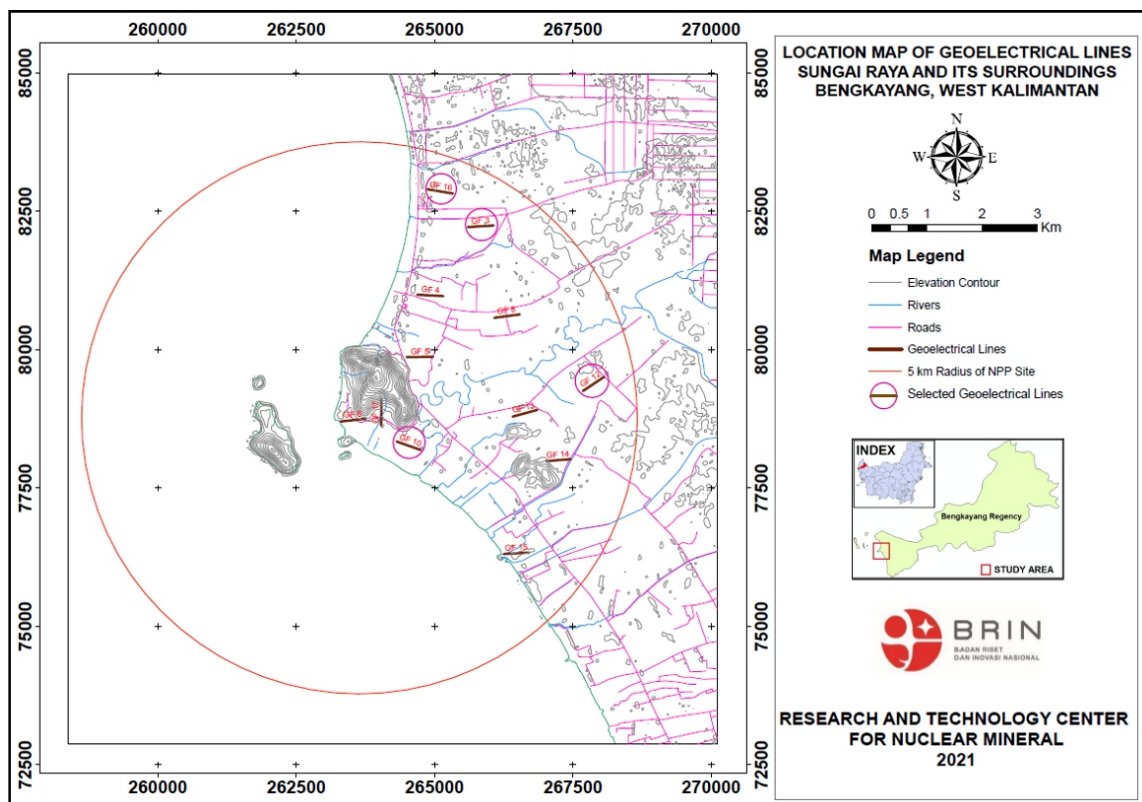


Figure 7. The location map of the geoelectrical lines.

the rocks (Mazac, Kelly, and Landa 1985). The aquifuge, which has no/minor water content, tends to have a higher resistivity value while the aquifer, which has a significant amount of water, tends to have a lower one. In this study, the sections which are going to be discussed are just GF-10, GF-12, GF-03, and GF-16 which are considered to represent the geological conditions of the Bengkayang area and its surroundings.

The geoelectrical measurement at line GF-10 was done on 13 June 2021 on a sunny day. The line is in Sungai Raya, on a coconut plantation to be exact. This location is composed of alluvial and littoral deposits. The condition of the measurement location and the resistivity cross-section of line GF-10 are pictured in Figures 8 and 9.

The anomaly is found at 10-80 m deep. It has a resistivity value of 300-8,000 Ωm . The anomaly is interpreted as a body of volcanic rocks that is intruded by plutonic igneous rocks (as aquifuge). Above the anomaly, there is an elongated

zone that has a resistivity value of $<30 \Omega\text{m}$. It is inferred as a water-saturated alluvial deposit (as aquifer). The alluvial deposit at this location is thinner on the central part and thickens up to $\pm 40 \text{ m}$ on the west and east parts.

The geoelectrical measurement at line GF-12 was conducted on 19 June 2021 on a sunny day. The line is in Sungai Raya Village. Mostly, the line lies on a land-clearing area and a few of it lies in the woods. This location consists of dry clay soil. The condition of the measurement location and the resistivity cross-section of line GF-12 are pictured in Figure 10 and Figure 11.

The anomaly (resistivity value of $>300\text{-}8,000 \Omega\text{m}$) is found in the central part. It is interpreted as diorite which intrudes andesite (as aquifuge). Both of them lie at the depth of 30 m and deepen to east and west up to 60 m. The low resistivity zone ($<30 \Omega\text{m}$) above the anomaly is inferred as a water-saturated alluvial deposit (as aquifer), which is composed of clay-granule grain-sized unconsolidated materials.

The geoelectrical measurement at line GF-03 was carried out on 23 June 2021, on a sunny day. Line GF-03 is located in Karimunting Village. Land use in this location is oil palm plantations on plain morphology which is composed of alluvial deposits. Based on the information from the locals, this location was once a ricefield but since the surface water is brine so it was converted into an oil palm plantation. The condition of the measurement location and the resistivity cross-section of line GF-03 are pictured in Figures 12 and 13.



Figure 8. The location of line GF-10.

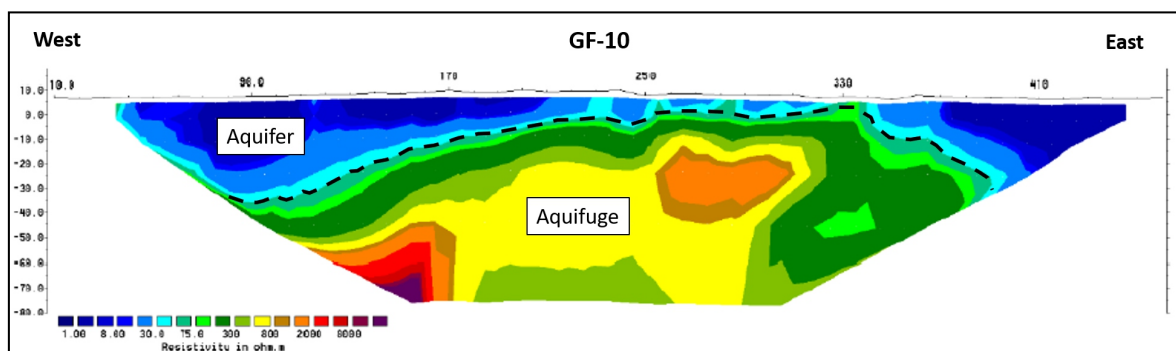


Figure 9. The resistivity cross-section of line GF-10.



Figure 10. The location of line GF-12.

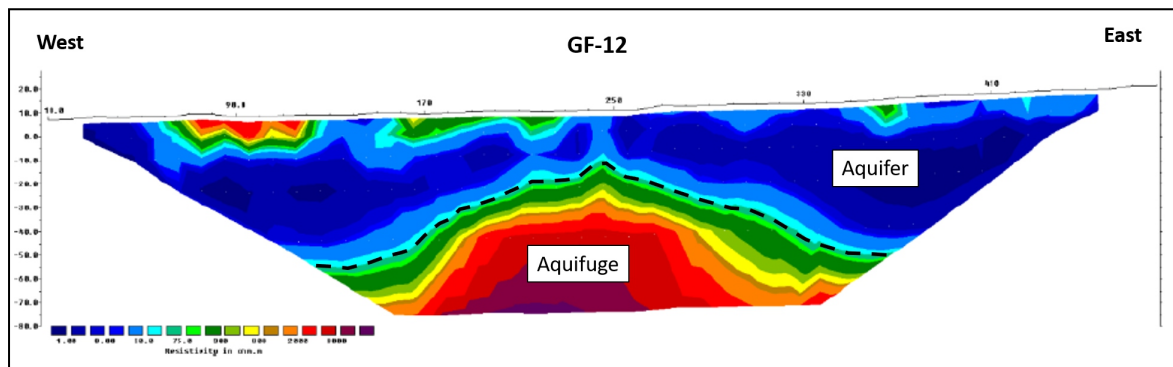


Figure 11. The resistivity cross-section of line GF-12.

There is a high anomaly (300-2,000 Ωm) on the lower eastern part of the section. That contrast pattern is interpreted as a body of volcanic igneous rock (as aquifuge) as the bedrock. The lower resistivity zone (<30 Ωm) around the anomaly is inferred as an alluvial deposit (as aquifer) up to ± 100 m thick.

The geoelectrical measurement at line GF-16 was undertaken on 22 June 2021 on a sunny day. The line is at the border of Sungai Raya Village and Karimunting Village. The land use in this location is palm oil plantation. The west part of the line consists of a quartz sand deposit while the eastern part consists of an alluvial deposit that is used to plant. The condition of the measurement location and the resistivity cross-section of line GF-16 are pictured in Figures 14 and 15.

A resistivity anomaly (300-8,000 Ωm) is spotted on the west part and goes deeper to the east up to the depth of 80 m. The anomaly is interpreted as two different igneous rocks (as aquifuge). The zone which has 300-800 Ωm resistivity is volcanic-type while the higher one (>2,000 Ωm) is plutonic-type. The quartz sand and alluvial deposits (as aquifer) are inferred from the low-resistivity zone (<30 Ωm) which is getting thicker to the east. Both deposits overlie the body of igneous rocks, forming a nonconformity.

Based on the geology of the study area (Muhammad *et al.* 2021), two units that are capable to become aquifers, are alluvial deposit and quartz sand deposit. The textures of the deposits, *i.e.* sorting and fabric make them have good porosity and permeability. Their porosities and permea-



Figure 12. The location of line GF-03.

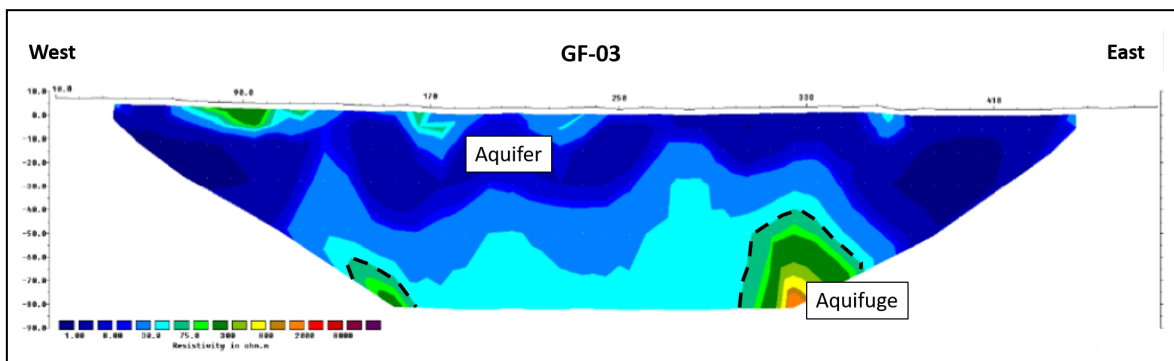


Figure 13. The resistivity cross-section of line GF-03.



Figure 14. The location of line GF-16.

bilities are so favorable to store and transmit groundwater in a significant amount. Quartz sand deposit has a better sorting and more-open

fabric than the alluvial deposit. Hence, quartz sand deposit has a better quality to become an aquifer.

Based on the four geoelectrical cross-sections above, it is known that the aquifers are unconfined. They are not covered by an impermeable layer above Figure 16. It means, no need to remove any overburden layer to exploit them. Both of them can be found at the surface to the depth of ± 100 m (at Karimunting Village, the north part of the study area). In the south part of the study area, the aquifer's thickness is up to ± 50 m. So, to exploit them, it is not necessary to drill a so deep well to get the water. However, the quantity of groundwater in unconfined aquifers is so dependent on the season and is much

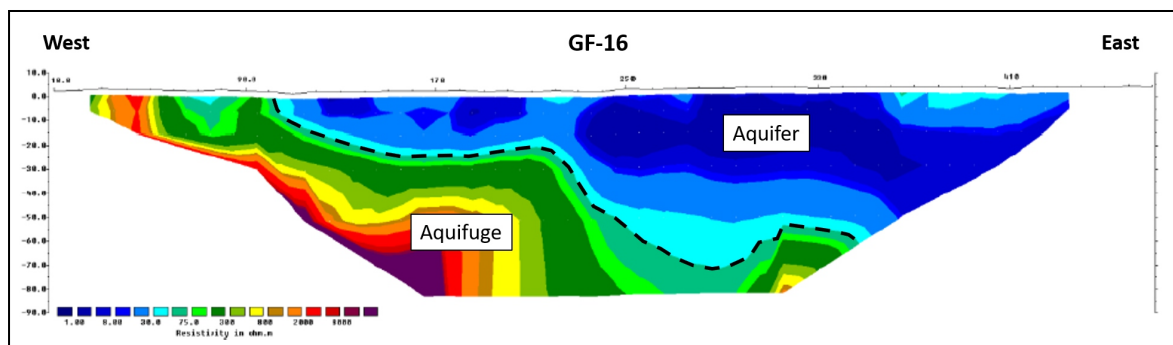


Figure 15. The resistivity cross-section of line GF-16.

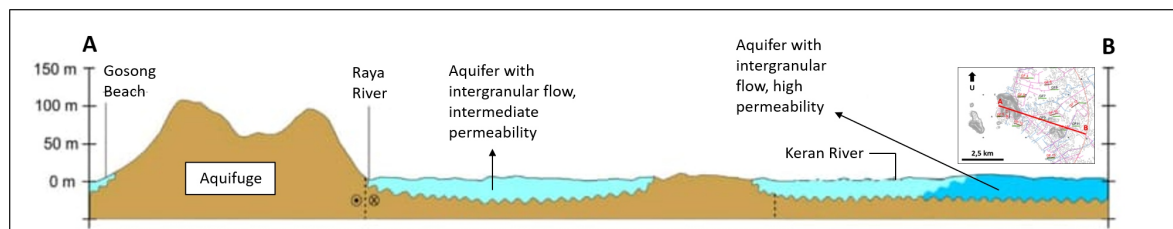


Figure 16. Hydrogeological cross-section of the south part of the study area (modified from (Muhammad *et al.* 2021)).

affected by the extraction since the aquifers do not have piezometric pressure. The aquifers, in this location, are equivalent to the alluvial and quartz sand deposits, so their thickness and distribution are equivalent to the deposits as well. The sections show that the aquifers tend to deepen to the north and east. Hence, the exploitation of the aquifers can be started in the south and west of the study area. The mentioned results conclude that the aquifers in the study area can be exploited on a low-cost budget. Figure 16 shows the hydrogeological cross-section of the south part of the study area (Muhammad *et al.* 2021)).

CONCLUSION

Based on a literature study of geological data and geoelectrical measurement, at least, there are two aquifers in the study area, namely alluvial deposit and a quartz sand deposit. Both of them are unconfined aquifers, meaning they are not covered by an impermeable layer above. The aquifers can be found at the surface to the depth of ± 100 m. The geoelectrical sections show that

the aquifers relatively deepen to the north and east. The quartz sand deposit is a better aquifer since it has better sorting and more-open fabric than the alluvial deposit. Better sorting and more-open fabric mean a larger capacity for storing and transmitting the groundwater.

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REFERENCES

Binley, A. 2015. "Tools and Techniques: Electrical Methods." In *Treatise on Geophysics*, p.233-259.

- Darsono, Darsono, Budi Legowo, and Darmanto Darmanto. 2017. "Identifikasi Potensi Akuifer Tertekan Berdasarkan Data Resistivitas Batuan (Kasus: Kecamatan Sambirejo Kabupaten Sragen)." *Jurnal Fisika dan Aplikasinya* 13 (1), 34h.
- Fajana, Akindeji Opeyemi. 2020. "Groundwater Aquifer Potential Using Electrical Resistivity Method and Porosity Calculation: A Case Study." *NRLAG Journal of Astronomy and Geophysics*, 9 (1), 168-175. <https://doi.org/10.1080/20909977.2020.1728955>.
- Ferragina, E. 2009. "Bridging Divides for Water : The 5th World Water Forum (WWF)." *Global Environment*, 2 (4), p180-186.
- Firdaus, Hasbi Bakri, and Jamal Rauf. 2018. "Penentuan Lapisan Akuifer Berdasarkan Hasil Interpretasi Geolistrik (Tahanan Jenis) Di Desa Nonong, Provinsi Sulawesi Tengah." *Jurnal Geomine*, 6 (2), h.71-79.
- Hanifa, Dinisa, Ibrahim Sota, and Simon Sadok Siregar. 2016. "Penentuan Lapisan Akuifer Air Tanah Dengan Metode Geolistrik Konfigurasi Schlumberger Di Desa Sungai Jati, Kecamatan Matraman, Kabupaten Banjar, Kalimantan Selatan." *Jurnal Fisika FLUX* 13 (1), h.30-39.
- Irawan, D. E., and D. J. Puradimaja. 2015. *Hidrogeologi Umum*. Yogyakarta: Ombak.
- Kruseman, G. P., and N. A. de Ridder. 2000. *Analysis and Evaluation of Pumping Test Data*. Wageningen: International Institute for Land Reclamation and Improvement.
- Mazac, O., W. E. Kelly, and I. Landa. 1985. "A Hydrogeophysical Model for Relations between Electrical and Hydraulic Properties of Aquifers." *Journal of Hydrogeology* 79, p.1-19.
- Muhammad, A. G. et al. 2021. "Karakterisasi Hidrogeologi Daerah Sekitar Tapak PLTN Di Bengkayang, Kalimantan Barat." *Eksplorium*, 42 (2), h.99-110. <http://jurnal.batan.go.id/index.php/eksplorium/article/view/6479>.
- Onawola, Babatunde R, Saminu Olatunji, Oluwatoyin Ologe, and Razak O Jimoh. 2021. "Determination of Aquifer Parameters from Resistivity Data: A Case of University of Ilorin Campus, Northcentral Nigeria." *Tanzania Journal of Science*, 47 (1), p.91-103.
- Raymond Jr, Lyle S. 1988. *What Is Groundwater*. New York: New York State Water Resources Institute.
- Suntoko, Hadi, and Bambang Soetopo. 2013. "KAJIAN ASPEK GEOLOGI DAN POTENSI MINERAL URANIUM DI KALIMANTAN BARAT UNTUK PERSIAPAN PLTN." *Jurnal Pengembangan Energi Nuklir*, 15 (2), h.103-14.
- Suwarna, N., and R.P. Langford. 1993. *Peta Geologi Lembar Singkawang, Kalimantan*. Bandung.
- Telford, W. M., L. P. Geldart, and R. E. Sheriff. 1990. *Applied Geophysics*. 2nd ed. New York: Cambridge University Press.
- Thorpe, M. B., M. F. Thomas, T. Martin, and W. B. Whalley. 1990. "Late Pleistocene Sedimentation and Landform Development in Western Kalimantan (Indonesian Borneo)." *Geologie en Mijnbouw*, 69 (2), p.133-50.
- Zulfikar, S. Kaelani, and D. Turdjaja. 2007. "EKSPLORASI UMUM ENDAPAN BALL CLAY DI KABUPATEN BENGKAYANG, PROVINSI KALIMANTAN BARAT." In *Proceeding Pemaparan Hasil Kegiatan Lapangan Dan Non Lapangan PSG Tahun 2007*, Pusat Sumber Daya Geologi.