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EVALUATION OF AQUIFER POTENTIAL USING 2-D RESISTIVITY AND INDUCED POLARIZATION IN MACHANG, KELANTAN, MALAYSIA

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Abstract: Identifying potential groundwater is essential, especially in the rural areas. However, there is uncertainty in distinguishing groundwater from soil particles when using 2-D resistivity and Induced Polarization (IP) survey. Many researchers faced the problem of determining the exact location or missed the full capacity of the aquifer when drilling in the subsurface layers. Therefore, the purpose of this study is to use the combination of resistivity and IP analysis to determine the potential groundwater in Machang, Kelantan and to differentiate the saturated zones between aquifer and unconsolidated sediments. Four resistivity survey lines, each 200 metre (m) long, with 5 m electrode spacing using the pole-dipole array were set up. From the results of 2-D resistivity and IP survey the possible groundwater area in the subsurface can be indicated by low resistivity values ranging from 10 - 100 Ωm (Ohm-m) and overlapped by low chargeability values ranging from 0 - 1 millisecond (msec). Alluvium, which consists of sandy clay and sand, has resistivity value of 500 - 2000 Ωm and chargeability value of 3 - 10 msec. Fault and fracture in the subsurface may also indicate existence of an aquifer. The result of this study provides beneficial information on groundwater occurrence by differentiating aquifer to unconsolidated sediments.

Keywords: 2-D resistivity, induced polarization, groundwater, aquifer, chargeability.

Abbreviations: Induced Polarization (IP), two dimensional (2-D), millisecond (msec).

Introduction

Low quality water is a major problem these days. Identifying potential groundwater is essential, especially in the rural areas. Groundwater is beneath the ground and is of better quality than water sources above the ground, such as lakes and rivers. One of the main reasons for locating a groundwater resource is when surface water is running low or its quality is very poor. Groundwater is the perfect solution to overcome this problem. One of the effective approaches to detect a groundwater resource is by conducting a geophysical survey. Resistivity method is one of the geophysical survey methodologies that is proven to be able to locate potential groundwater sources (Oseji *et al*., 2005). This method is based on the subsurface composition and layering, interpretation of soil properties, structures and cavities or bodies of different geological surroundings from its physical properties found underground (Dor *et al*., 2011). It is also suitable to determine the thickness, depth, and boundary of an aquifer (Omosuyi *et al*., 2007).

Ahzegbobor *et al*. (2016) stated that integration of 2-D resistivity techniques with Induced Polarization (IP) imaging for groundwater exploration in a sedimentary terrain is the most common geophysical method for hydrological investigations. It is often difficult to distinguish between clay and saturated sandy formations as both are characterised by low resistivity. The lithology of the delineated layers was established by integrating all available information from boreholes, hand-dug wells, known geology and previous studies (Aizebeokhai & Oyeyemi, 2014).

Saad *et al.* (2012) employed 2-D resistivity with drilling for determination of resistivity value of alluvium and the effect of groundwater. The study was conducted in areas which have a geology record of thick alluvium. The results show that groundwater will lower the subsurface resistivity values and silt will also bring down the resistivity value lower than groundwater. Therefore, groundwater reservoirs can be found in saturated sand, saturated sandy clay and saturated silt, clay and sand.

Riwayat *et al.* (2018) stated that 2-D resistivity is the most suitable method in the exploration of groundwater using resistivity and induced polarization. The method is suitable to study and explore various ground resources, such as groundwater, minerals, and hydrocarbons. This method is often involves the interpretation of soil properties, layering, and composition of the subsurface, cavities and structures or bodies generally found underground which has different physical characteristics from their geological surroundings (Dor *et al.,* 2011). Groundwater is defined as water that is located beneath the Earth's surface in soil pore spaces and fractures of rock formations (Muchingami *et al.,* 2012). The problem faced by engineers is to determine the exact location of the groundwater accumulation zone in the subsurface layer. 2-D resistivity method is part of geophysics used as preliminary step in any groundwater exploration. With supporting borehole data and 2-D resistivity inversion obtained, reliable information regarding groundwater can be produced.

However, there is uncertainty in distinguishing between groundwater and soil particles when using resistivity survey. Therefore, the purpose of this study is to use the combination of resistivity and Induced Polarization (IP) analysis to determine the potential groundwater in Machang, Kelantan. The study area is a rural district and it is important to have clean water supply to the rural areas with unsustainable water resources. Groundwater is the best solution for such problem, and one of the advantages is that its sustainable existence when all the surface water has dried out or getting scarcer.

Geoelectrical Method

Resistivity Measurement

The 2-D resistivity method is a survey that measures potential differences produced by current run into the ground. Current is run into the ground by two current electrodes, thus measuring the potential difference at another two potential electrodes (Muztaza *et al*., 2012). The 2-D inversion produced varies depending on the subsurface properties of the study area, due to the difference in resistivity values of different subsurface type.

Induced Polarization Measurement

This survey is conducted to reduce the uncertainty in distinguishing clay soil to groundwater. When an electric current flows through a mass, positive charges stack outside the mass, and as electric current flows out the mass, negative charges will stack out of the mass. Thus, positive charges in the mass are polarized to the negative charges outside the mass, while the negative charges in the mass are polarized to the positive charges outside the mass (Zawawi & Wayayok, 2015). When the electric current is turned off, an induced potential difference (voltage) will be in the mass (Kiberu, 2002). The decay of voltage is measured by the two potential electrodes. Chargeability is obtained by combining the area under-voltage decay curve (Dahlin *et al*., 2002).

Geological Area

The study area is in Kelantan, in the northeast of Peninsular Malaysia. It was formed during the Permian period as shown in Figure 1. The lithology is mainly pelite consisting of quartz-mica schist, quartz-mica-garnet, and garnet-mica schist. Mudstone and shale are also present to be metamorphosed into phyllite and schist. The oldest rock discovered was gneiss.

Study Area

The site is in Machang, Kelantan. The survey lines were conducted in an agriculture area inside a school and a rubber plantation as shown in Figure 2. The length of each of the four lines

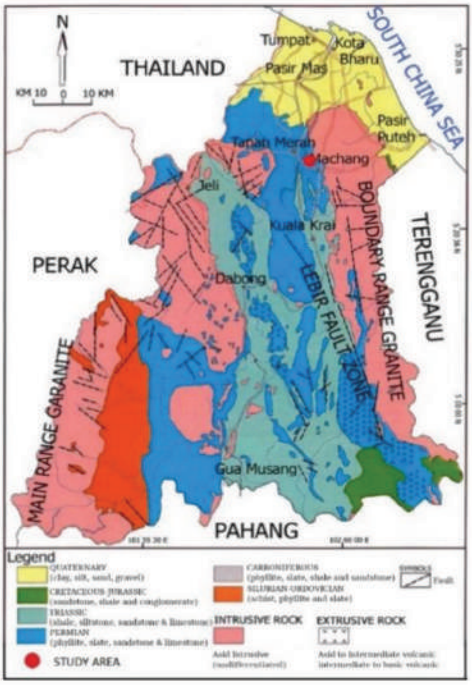

Figure 1: Geological map of Kelantan showing the location of the study area
(Geological map of Peninsular Malaysia, based on 8th edition geological map, 1985)

is 200 m with 5 m electrode spacing and the region is considered to be a plain flat area and the coordinates of the survey lines are shown in Table 1.

Table 1: Coordinates of survey lines at Machang, Kelantan

Line	Latitude	Longitude
1 (0 m)	5.77913º N	102.15644º E
1 (200 m)	5.780614º N	100.88598º E
2 (0 m)	5.78056º N	102.15627º E
2 (200 m)	5.78009º N	102.15802º E
3 (0 m)	5.78102º N	102.15657º E
3 (200 m)	5.78024º N	102.15812º E
4 (0 m)	5.78016º N	102.15605º E
4 (200 m)	5.77976º N	102.15780º E

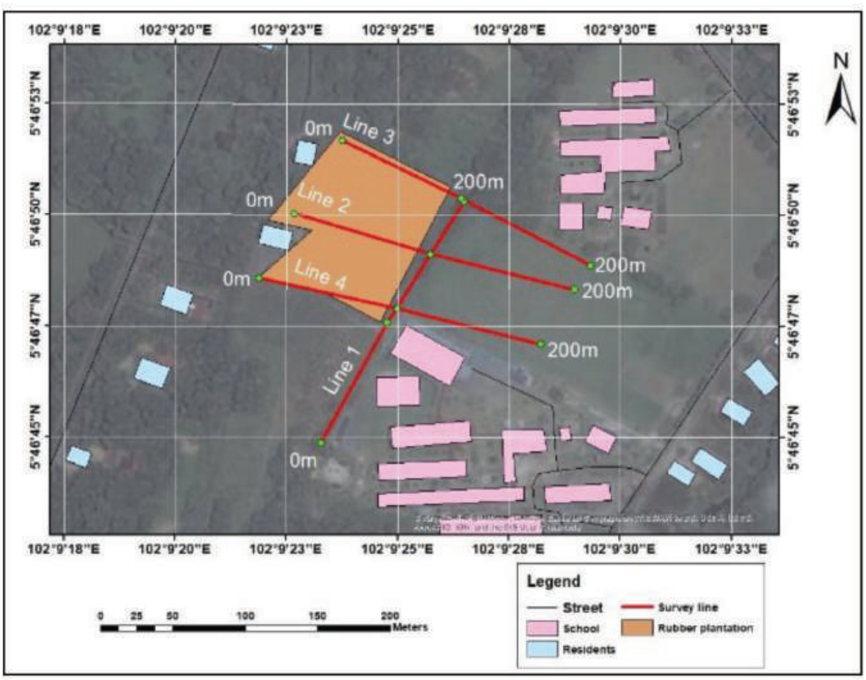

Figure 2: The location of the survey lines and a pumping well at Machang, Kelantan

Methodology

A total of four survey lines with 5 m electrode spacing of 2-D resistivity and induced polarization were carried out by using the ABEM SAS4000 and the Lund electrode selector that functions to select the relevant four active electrodes at a time for each measurement of the survey lines. The pole-dipole array was selected for all the survey lines due to its higher resolution and deeper penetration compared to other arrays. After collecting the data from the field, the raw data were processed to the computer from an ABEM Terrameter using ABEM SAS 4000 Utility software. The format is in ".s4k" file type and to be converted to ".dat" file type. RES2DINV software was used to process and produce the 2-D resistivity inversion model and induced polarization modeling (Loke, 1999). The final data is then transferred to Surfer8 software for gridding, contouring and mapping. The contouring inversion model from this survey will be correlated with the borehole record.

Results and Discussion

Line 1 was arranged in the direction of NNE (North-Northeast) to SSW (South-South west) as shown in Figure 3. The borehole was located 110 m from the first electrode. The resistivity value ranges from 1 to 1000 Ωm (Ohm-m). The resistivity values of the top layer with soil along the line ranges from 0.1 to 10 Ωm (Riwayat *et al*., 2018). The blue colour represents low resistivity values, and the dark purple colour represents high resistivity values. The resistivity values depend on various geological parameters, such as fluid and mineral content, the degree of water saturation and porosity of the rock (Omosuyi *et al.,* 2007). Based on the resistivity

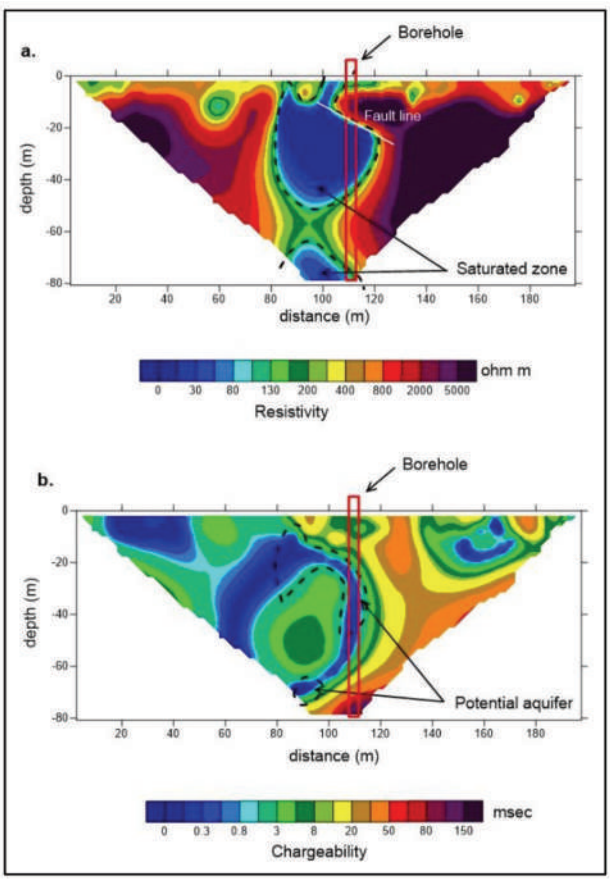

Figure 3: Inversion model of (a) 2-D resistivity and (b) chargeability for line 1

distribution, a fault splits the layer into two by high resistivity that indicates as massive rock and lack of conductivity properties. Low resistivity anomalies, below 100 Ωm are spotted and suspected to be water saturated layer or aquifer zone (Marsan *et al.,* 2017*;* Marwan & Amsir, 2015).

For induced polarization, the chargeability values indicate alluvium, gravel or sandstone. Fine grain such as silt and clay have a major composition of minerals, such as montmorillonite, kaolinite, and vermiculite, that makes the current flows easily, thus producing low resistivity values in contrast to coarse soil, such as gravel and sand (Zainal Abidin *et al.,* 2017). There are two zones showing low chargeability values. The first zone shows the low chargeability at 10 m to 120 m distance from the first electrode up to 75 m depth of penetration. The blue colour indicates groundwater at the chargeability value of 0 to 1 millisecond (msec), the light green colour indicates alluvium at the chargeability value of 1 to 4 msec, and dark green colour indicates gravel at the chargeability value of 3 to 9 msec (Keller & Frischknecht, 1996). The second zone from the distance of 135 m to 177 m at a depth of 38 m shows low chargeability value.

The result of resistivity and chargeability surveys were correlated with the borehole record as shown in Figure 4. Based on the borehole record, topsoil was found from 0 to 6 m. Sandy clay was found from 6 to 10 mand coarse sand at 10 to 14 m. Alluvium, which consists of sandy clay and sand, has resistivity values from 500 to 2000 Ωm (Keller & Frischknecht, 1996) and chargeability values from 3 to 10 msec. At a depth of from 14 to 27 m, mudstone is found, with resistivity values from 0 to 1000 Ωm and chargeability values from 0.3 to 8 msec. At a depth of 27 to 34 m, shale is found with the resistivity values of 0 to 30 Ωm, which differs slightly to what was described by to Keller and Frischknecht, that the resistivity values of shale ranges from 20 to 2000 Ωm. but still overlapped on the low resistivity value scale. However, the measured chargeability for shale from 0 to 0.5 msec, slipped out of the scale in Telford's

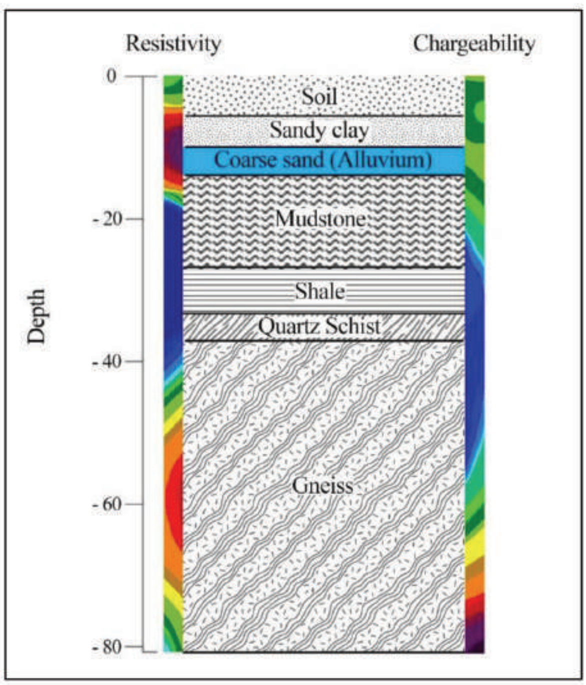

Figure 4: Result of resistivity aligned with the borehole record at line 1

theory, which provides a range of 50 to 100 msec. The depth of 34 to 37 m consists of quartz schist, which shows resistivity values ranging from 0 to 50 Ωm, which slightly different to Keller and Frischknecht's range of 2 to 10,000 Ωm and chargeability value from 0.1 to 0.5 msec. Which is out of range when compared to the Telford theory range of 5 to 20 msec for schist. The quartz minerals in the schist formed quartz schist, with lower values of resistivity and chargeability. Finally, the last layer of the borehole is gneiss, which shows resistivity values from 30 to 2000 Ωm. These values are out of range of Keller and Frischknecht's theory, which is 10,000 to 3×10^6 Ωm and the chargeability value shows 0.3 to 150 msec, but the theory of Telford provides a range from 6 to 30 msec.

Thus, the chargeability value were more precise than resistivity value that showed a wider range. The aquifer zone starts at a depth of 10 to 27 m from the layers of coarse sand to mudstone. At the layer of mudstone, an occurrence of a minor fault explains the low to high resistivity value from 0 to 1000 Ωm and acts as the groundwater flow path through these fractured zones. The summary for resistivity and chargeability values using the theory of Keller and Frischknecht (1996) and Tellford *et al.* (1976) are in Tables 2 and 3.

Table 2: Resistivity value for soil and rocks (Keller & Frischknecht, 1996)

Material	Resistivity (Ωm)
Alluvium	10 - 800
Sand	60 - 1000
Clay	1 - 100
Fresh groundwater	10 - 100
Sandstone	100 - 1000
Shale	20 - 2000
Limestone	50 - 4000
Granite	2000 - 1,000,000
Schist	20 - 10,000
Gneiss	10,000 - 3,000,000

Table 3: Chargeability value (Tellford *et al.,* 1976)

Material	Chargeability (msec)
Groundwater	0 – 1
Alluvium	1 – 4
Gravels	3 – 9
Sandstones	3 – 12
Schist	5 – 20
Gneiss	6 - 30
Granite	10 – 50
Limestone	10 – 20
Shale	50 – 100

Lines 2 and 3 were arranged in NWW (North West-west) to SEE (South wast-East), crossing line 1 at 160 m from the first electrode, as shown in Figures 5 and 6. Due to the same line orientation and the distance of 100 m from each other, both results look almost the same. The line is straightened up to 200 m long; 100 m approximately is on the region of the field and the other half is on the rubber plant plantation. Resistivity value in line 2, starting from low resistivity at the bottom layer with a depth of 80 m to the top layer at a depth of 6 m with high resistivity value. The resistivity values range from 1 Ωm to 5000 Ωm. Based on the result of the resistivity distribution, the layer dominated by high resistivity is coloured in dark purple, indicating the presence of a massive rock at a depth 10 m, which is interpreted as gneiss with resistivity value > 5000 Ωm. The line at the top layer shows high resistivity values between two anomalies on the right and on the left, showing a clear gap of splitting it into two. From lines 2 and 3, the layers on the right are going upwards and could be considered as a normal fault due to its direction toward a foot wall at the bottom and hang wall at the top (Bernhard & Christoph, 2009). The fault line is shown in Figure 5. The centre of the contact is at the centre of the line which is at the distance of 100 m. The blue colour shown in the data at a depth of 40 m is suspected to be a saturated layer or aquifer zone due to its low resistivity values of below 100 Ωm at a depth of 80 m (Amiruzan *et al.,* 2016). Based on the geological analysis, the centre of the line is the point of the groundwater recharge area, which gives the upward shape of the layer from 20 m to 40 m depth of the aquifer zone.

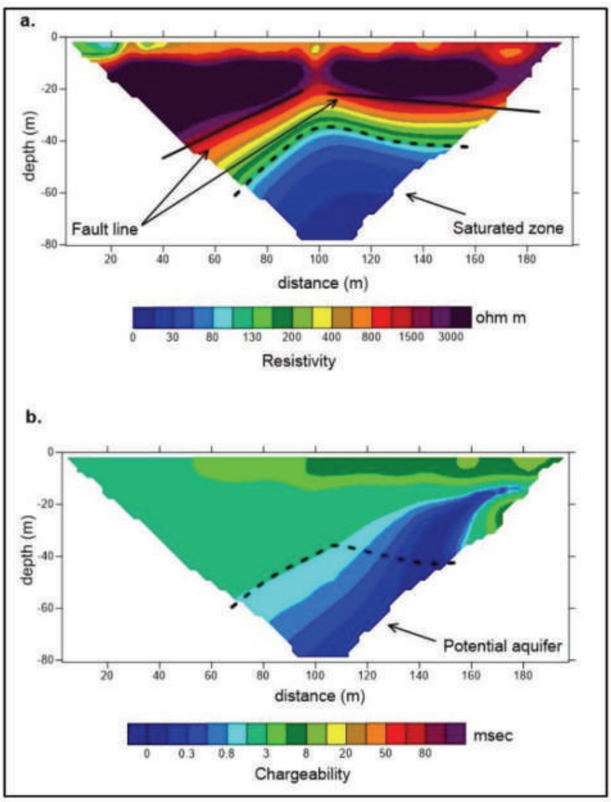

Figure 5: Inversion model of (a) 2-D resistivity and (b) chargeability for line 2

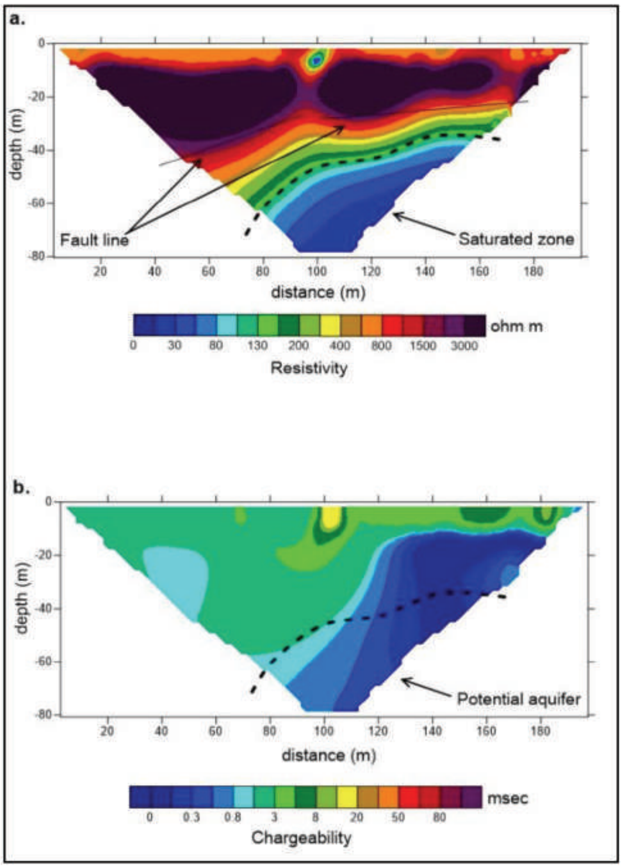

Figure 6: Inversion model of (a) 2-D resistivity and (b) chargeability for line 3

Meanwhile, the induced polarization in the survey lines show positive result for potential alluvium and groundwater. Groundwater will lower the resistivity values and silt will also bring down the resistivity value lower than groundwater. Groundwater reservoirs are found in saturated sand, saturated sandy clay and saturated silt, clay and sand (Saad *et al.,* 2012). The clay can be differentiated from the range of chargeability of 1.5 to 3.5 msec (Santoso *et al*., 2016). The subsurface area that has been coloured in dark and light green at a depth of 0 to 15 m could be classified as sandstone with chargeability from 3 to 9 msec. The pale green colour which starts from 0 to 50 m, at a depth of 60 m could be consider alluvium. Finally, groundwater which is indicated in blue with the occurrence of geo-structural (faulting) is at the low layer with the chargeability from 0.1 to 2 msec (Sowers, 1979). Therefore, the potential groundwater is at the maximum a depth of 40 to 80 m 70 to 150 m from the induced polarization (IP) at the first electrode. The chargeability value for groundwater ranged from 0 to 1 msec and this is the best potential of discovering groundwater.

Line 4 was arranged NWW (North west-West) to SEE (South east-East) and crosses at the centre of line 1, as shown in Figure 7. This line consists of resistivity values from 10 Ωm to 5000 Ωm. Two saturated zones were identified which are indicated by the blue coloured regions with resistivity values of 10 Ωm to 100 Ωm (Ahzegbobor *et al*., 2016; Idris *et al*., 2018) located at a depth of 7 to 80 m. While the smaller scale is located at a distance of 50 m from the first electrode at a depth of 7 to 12 m. The alluvium consists of silt, clay, sand, and gravels and has high porosity and permeability to detect an early stage of groundwater. Resistivity values of saturated sand is 45 - 75 Ωm, and silty sand is 29 - 57 Ωm, whereas area with values of resistivity from 100 Ωm to 500 Ωm may be composed of silt and dry clay (Sowers, 1979).

Four boulders have been spotted which could be interpreted as the presence of gneiss due to its resistivity value of 5000 Ωm. The position of each boulder blocked the direction of water flow to the aquifer zone except at the position measurement of 110 m due to the absence of high resistivity value above it. The best potential to find the aquifer is at the distance of 110 m at a depth of 15 m below the resistivity value of 100 Ωm (Asry *et al.*, 2012). However, when analyzing the induced polarization data, the data showedt a large area of saturated zone with a colour of blue starting from the distance of 40 to 105 m at the subsurface area with a chargeability of 0.1 to 1 msec. The potential aquifer was identified at a depth of 20 mto more than 80 m at the distance of 75 to 150 m. High chargeability can be seen in orange colour with chargeability value of 6 to 30 msec and may indicate gneiss, while yellow colour with changeability value of 5 to 20 msec indicated schist. The higher resistivity values between these two rocks is the key to differentiate a gneiss to a schist with resistivity value > 5000 Ωm.

Unconsolidated sediments and groundwater in the study area can be differentiated using induced polarization method to support the exploration due to its different chargeability values and not depending on resistivity method only. Table 4 shows the summary of the lithology in Machang, Kelantan.

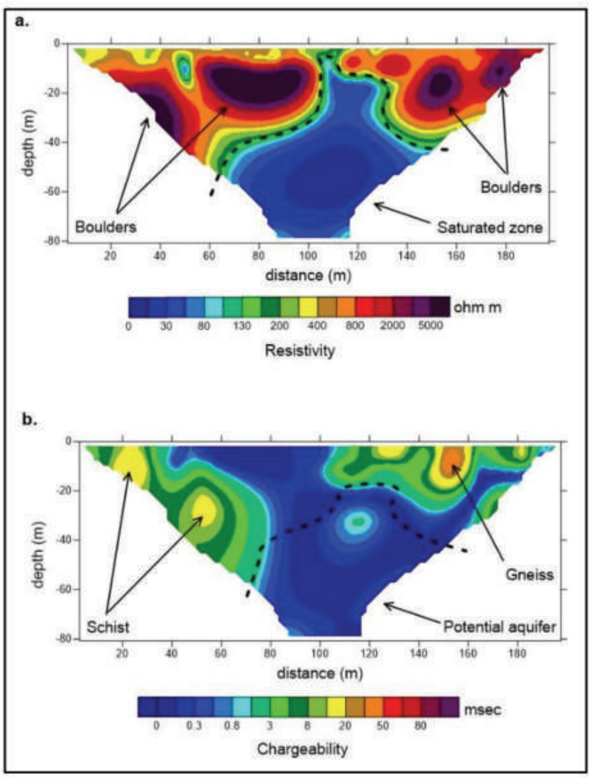

Figure 7: Inversion model of (a) 2-D resistivity and (b) chargeability for line 4

Table 4: Summary of geophysical and geological of area Machang, Kelantan.

Study Area	Geology	Method	Values	Lithology
Machang, Kelantan	This area is consisting of sandstones, shale, schist, and gneiss due to the area is in Paku Schist formation	2-D resistivity	500 - 2000 Ωm	Alluvium
			0 - 100 Ωm	Saturated zone
			10 - 1000 Ωm	Fresh water (aquifer)
			100 - 1000 Ωm	Sandstone
			0 - 1000 Ωm	Mudstone
			20 - 2000 Ωm	Shale
			0- 50 Ωm	Quartz Schist
			30 - 2000 Ωm	Gneiss
		Induced polarization	0 - 8 msec	Groundwater
			3 - 10 msec	Alluvium
			3 - 12 msec	Sandstones
			0.1 - 0.5 msec	Quartz Schists
			0.3 - 150 msec	Gneiss

Conclusion

The resistivity and chargeability results show that the saturated zone in the study area is an aquifer with resistivity value ranged from 10 - 100 Ωm and chargeability values ranged from 0 - 1 msec. From this study, it is observed that groundwater activities come along with the presence of geological structure, such as faulting and fractures in the subsurface layers, which influences the formation of an aquifer because water flow trapped in the layers of those fractured rocks (geostructural). Also, the porosity and permeability of sediments; clay, silt and sand indicate a huge amount of water due to its water-flow when the area is being recharged. From the analysis of induced polarization results, the uncertainty between unconsolidated sediments and groundwater was able to be deduced. Some recommendations for further studies are more borehole wells purposes should be drilled due to its high potential of aquifer in Machang, Kelantan.

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References

Ahzegbobor, P., Aizebeokhai, Kehinde, D., Oyeyemi & Emmanuel, S. J. (2016). Electrical resistivity and induced polarization imaging for groundwater exploration covenant. *SEG International Exposition and 87th Annual Meeting,* 2487-2491.

Aizebeokhai & Oyeyemi. (2014). The use of the multiple-gradient array for geoelectrical resistivity and induced polarization imaging. *Journal of Applied Geophysics*, *111*, 364-376.

Amiruzan, Z. S., Hussin, H., Khan, M. A., & Jafar, M. T. (2016). Integrated geological and multi-electrode resistivity surveys for groundwater investigation in Kampung Rahmat Village and its vicinity, Jeli District, Kelantan, Malaysia. *Journal of Applied Geophysics, 138*.

Asry, Z., Samsudin, A. R., Yaacob, W. Z., & Yaakub, J. (2012). Groundwater investigation using electrical resistivity imaging technique at Sg. Udang, Melaka, Malaysia. *Bulletin ofthe Geological Society of Malaysia, 58*, 55-58.

Bernhard, G., & Christoph, I. (2009). Characteristics of low-angle normal faulting in Serifos, Western Cyclades, Greece. *Trabajos de Geología, Universidad de Oviedo, 29*, 329-331.

Dahlin, T., Leroux, V., & Nissen, J. (2002). Measuring techniques in induced polarisation imaging. *Journal of Applied Geophysics*, *50*(3), 279-298.

Dor, N. (2011). Verification of surface-groundwater connectivity in an irrigation canal using geophysical, water balance and stable isotope approaches. *Water Resources Management, 25*(11), 2837-2853.

Geological map of Peninsular Malaysia, based on 8th edition geological map. (1985). Minerals and Geoscience Department, Malaysia.

Idris, S., Syukri M., Surbakti M. S., Marwan, Muchlis, Rusydy, I., & Aflah, N. (2018). A preliminary study on aquifer identification based on Geo-electrical data in Banda Aceh. *Jurnal Natural, 18*(1), 122-126.

Keller, G. V., & Frischknecht, F. C. (1996). *Electrical methods in geophysical prospecting*. Oxford: Pergamon Press Inc.

Kiberu, J. (2002). *Induced polarization and resistivity measurements on a suite of near surface soil samples and their empirical relationship to selected measured engineering*. International Institute for Geo-Information Science and Earth Observation Enschede, The Netherlands.

Loke, M. H. (1999). *Electrical Imaging Surveys for environmental and engineering studies. A practical guide to 2-D and 3-D surveys.*

Marsan, D., Azimmah, A., Adli, D. P., Muthi'a, J. M., Yuantoro, E., & Fatkhan. (2017). Aquifer characterization using 2D Electrical Resistivity Imaging in Kidangpananjung, Cililin District, West Java. Southeast Asian Conference on Geophysics. *Earth and Environmental Science*, *62*.

Marwan & Amsir, M. A. (2015). The investigation of groundwater using geophysical techniques in Baitussalam Sub-district, Aceh Besar District, Aceh Province, Indonesia. *Electronic Journal of Geotechnical Engineering, 20*(205), 5.

Muchingami I., Hlatywayo D. J., Nel J. M., & Chuma, C. (2012). Electrical resistivity survey for groundwater investigations and shallow subsurface evaluations of the basaltic- greenstone formation of the urban Bulawayo aquifer. *Physics and Chemistry of the Earth, Parts A/B/C*, *50*, 44-51.

Muztaza, N. M., Saad, R., Saidin, M. M., Noordin, M. N. M., & Ismail., N. A. (2012). Imaging subsurface characterization at Bukit Bunuh using 2D Resistivity Method: The effectiveness of Enhancing Horizontal Resolution (EHR) Technique. *Int. J. Environ. Sci. Develop*, *3*(6), 569-573.

Omosuyi, G. O., Adeyemo, A., & Adegoke, A. O. (2007). Investigation of groundwater prospect using electromagnetic and geoelectric sounding at afunbiowo, near Akure, Southwestern Nigeria. *Pacific J. Sci. Technol., 8*, 172-182.

Oseji, J. O, Atakpo, E. A., & Okolie, E. C. (2005). Geoelectric investigation of the aquifer characteristics and groundwater potential in Kwale, Delta State, Nigeria. *J. Applied Sci. Environ. Mgt.*, *9*, 157-160.

Riwayat, A. I., Nazri, M. A., & Abidin, M. H. (2018). Detection of Potential Shallow Aquifer Using Electrical Resistivity Imaging (ERI) at UTHM Campus, Johor Malaysia. *Journal of Physics.*

Tellford, W. M., Geldart, L. P., & Sheriff, R. E. (1976). *Applied geophysics*. Cambridge University.

Saad, R., Noordin, M. N. M., & Mohamad, E. T. (2012). Groundwater Detection in Alluvium Using 2-D Electrical Resistivity Tomography (ERT). *Electronic Journal of Geotechnical Engineering, 17*, *Bund D*, 369-376.

Santoso, D., Laesanpura, A., & Sulistijo, B. (2016). *Influence of Physical Parameters to Time Domain Induced Polarization (TDIP) Response*. American Institute of Physics.

Sowers, G. F. (1979). *Introductory soil mechanics and foundations. Geotechnical Engineering*. (4th ed.). New York: Macmillan Publishing Co., Inc.

Zainal Abidin, M. H., Z. A. M., Raqib A. G. A., Aziman M., Azhar A. T. S., Khaidir A. T. M., Fairus Y. M., Rosli S., Fakhrurrazi I. M., & Izzaty R. A. (2017). Preliminary Groundwater Assessment Method at Quaternary Deposits Area using Electrical Method at Quaternary Deposits Area. *IOP Conference Series: Materials Science and Engineering*, 12042.

Zawawi, M. A., & Wayayok, A. (2015). Detection of fractured aquifer using combination of resistivity and induced polarization analysis. *Jurnal Teknologi, 76*(15), 119-124.