DOI : https://doi.org/10.7186/wg512202502

Investigation of potential groundwater sources using electrical resistivity imaging for industrial facilities in Gebeng, Kuantan, Malaysia: A case study

S. Daud[1], M.F. Ishak[1,*], P.I. Ismi[1], M.F. Zolkepli[2]

[1] Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, Lebuh Persiaran Tun Khalil Yaakob, 26300, Paya Besar, Pahang, Malaysia
[2] Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia
*Corresponding author email address: fakhrurrazi@umpsa.edu.my

Abstract: In dry regions with limited access to surface water, groundwater is an essential source of freshwater supplies. This is especially true in areas where there is limited availability of surface water. Industries such as manufacturing make extensive use of water for various purposes, including cleaning, heating, and cooling, the production of steam, use as a solvent, transportation of substances that have been dispersed into it, and as a component of the manufactured product itself. Because of its large size, the groundwater reserve has the potential to become an additional source of water supply for the country, particularly in industrialized regions. The geophysical approach, which geophysicists dominate, has become one of the most prominent methods researchers use to offer the best technique in mineral or resources exploration. Electrical Resistivity Imaging, more commonly referred as ERI, is one of the geophysical techniques that offers a very intriguing method for determining subsurface profiles across a wider region. The primary purpose of this assessment is to assess a potential groundwater aquifer and determine whether it might be economically viable in industrial development facilities. The method described above is suitable for investigating various subsurface conditions. ERI's groundwater investigation using alternative methods, which enhance standard methods, could provide complete and convincing findings, increase efficiency in costing and timing. The ERI survey was carried out with the assistance of an ABEM LS2 Terrameter, which featured 61 electrodes that were planted along a line 400 meters long Line 1, with an electrode spacing of 5 meters (inner) and 10 meters (outer). When the survey was done on Line 2, the electrode spacing was set at 2.5 meters (inner) and 5 meters (outer). The results of the ERI tests indicate that Lines 1 and 2 are good indicators of groundwater presence. Line 2 was undertaken with a length of 200 meter rather than 400 meters, resulting in less data (shallow depth) being obtained. Furthermore, groundwater would have low resistivity (20 to 200 Ωm). An ERI provided a very significantly by enhances groundwater investigations by providing detailed subsurface information that aids in locating and managing water resources effectively. Its ability to integrate with other data sources, coupled with its cost-effectiveness and efficiency that make it an invaluable tool in hydrogeology and environmental management.

Keywords: Groundwater investigation, potential groundwater, electrical resistivity imaging, 2D resistivity, geophysical survey

INTRODUCTION

Many different types of businesses rely heavily on groundwater, making it an important contributor to both economic expansion and development (Cochrane, 2008). Groundwater resources are utilised in a variety of industrial operations in situations where surface water is scarce in quantity and quality of the water is a significant consideration (Petrick *et al*., 2023). According to Ilahi *et al*. (2021), groundwater can be an alternative facility for rural and urban catering for various industrial, agricultural, and domestic uses through several appropriate methods and processes. Manufacturing, mining, oil and gas extraction, energy generating, engineering, and building are all examples of industries that extract groundwater. At the conclusion of many production processes, products require a substantial volume of water in order to be washed and cleaned. As stated by Saimy & Raji (2015), the majority of countries, including Malaysia, rely on surface water supply, and when it comes to water shortage or disruption of water supply, the natural response is

0126-5539; 2682-7549 / Published by the Geological Society of Malaysia.

to hunt for alternatives from other sources, primarily groundwater (Riwayat *et al.,* 2018; Petrick *et al*., 2023). Compared to those of surface water, the expenses of groundwater capital are significantly lower (Saimy & Raji, 2015). Since groundwater is kept below, it can be relied upon even during times of drought, which is especially helpful for countries with a hot temperature. The water is found below the surface of the earth and in the spaces between the soil particles, which is where the greatest amount of water may be stored since it is protected from evaporation caused by the surrounding high temperatures (Hasan *et al*., 2022). It is well-known as a source of water that may be used by all living creatures as an alternative. Industrialists and researchers are faced with the challenge of determining the precise position of the groundwater zone in the subsurface layer (Riwayat *et al*., 2018). The field of geophysics applies the principles of physics to the investigation of the planet Earth by doing measurements on or very close to the surface of the planet (Suryadi *et al*., 2019). Due to its frequent application in geotechnical and environmental studies and research, the geophysical method is frequently regarded as a comprehensive instrument for underground air exploration and investigation (Riwayat *et al*., 2018). Since the beginning of these types of investigations, geophysics has been an important contributor to the advancement of the equipment used, as well as the research and development of methods that produce better results and expand the field's application scope.

Today, groundwater exploration uses a multidisciplinary methodological approach based on the analysis of large-scale geology and tectonic conditions (Sulaiman *et al*., 2022). Addition as stated by Sulaiman *et al*. (2022), for the spatial exploration of groundwater, geophysical and remote sensing methods play a central role. The use of remote sensing and geographic information systems (GIS) has been used in many states in Malaysia, including Selangor, Kedah, Perlis, and Perak, to conduct groundwater surveys (Petrick *et al*., 2023). Comparison in terms of cost and time for soil drilling works, electrical resistivity imaging method in underground water investigation is more economical in terms of cost and time (Suryadi *et al*., 2019; Lin *et al*., 2020). By dividing the landscape into zones with low and high groundwater potential, a groundwater potential map effectively reduces the number of locations where drilling could take place (Hasanuzzaman *et al*., 2022). Nevertheless, the collecting of data in situ is still extremely important for the validation of interpretations that are based on remotely sensed data (Zaini *et al*., 2019; Ishak *et al*., 2021).

According to Riwayat *et al*. (2018), the subsurface water that exists on this planet is a natural resource that cannot be perceived through the lens of time. In the uppermost layer of the Earth's crust, it can be found in a variety of various rock formations, in a variety of different concentrations, and a variety of different depths (Ishak *et al*., 2022). When there was no obvious water flow along the rivers in the distant past, people dug small trenches in the ground to collect groundwater for the purposes of drinking and supplying their other household requirements. In a similar manner, the people who lived in mountainous regions relied on natural springs as their primary source of drinking water. According to Hao *et al*. (2020), in order to investigate groundwater, one must have a comprehensive understanding of the hydrology and geology of the area in question.

Electrical Resistivity Imaging (ERI) is a component of the geophysical technology that is utilised as an initial phase in the process of any investigation of groundwater (Asry *et al*., 2012). ERI has seen significant use on a yearly basis and has been put to use to determine the thickness of the layered media and map the geological environment of existing aquifers (Ishak *et al*., 2021; Zolkepli *et al*., 2023). In addition, ERI has been utilised in order to map the geological environment (Ishak *et al*., 2022; Daud *et al*., 2024). Because of the ease with which the method may be used, its effectiveness, and the fact that it does not involve any damaging processes while obtaining images of the subsurface, it has shown to be a useful tool for assessing groundwater (Ilahi *et al*., 2021; Petrick *et al*., 2023). As stated by Osinowo & Falufosi (2018), ERI is a geophysical active non-destructive test (NDT) approach that produces two-dimensional (2D) or three-dimensional (3D) images of the subsurface's electrical resistivity distribution. The vast majority of groundwater investigations have used the geoelectrical exploration technique of electrical resistivity tomography (ERT) to link the electrical properties of geologic formations with their fluid content (Alshehri, 2023). This has been done in order to better understand how groundwater flows. The key elements influencing electrical resistivity are formation fluid salinity, saturation, aquifer lithology, and porosity (Al-Garni, 2009). Examination of the groundwater's quality has been accomplished with great success using this method in every region of the world. The electrical resistivity method is typically utilised in order to ascertain the boundaries of aquifers in addition to the depth, kind, and thickness of alluvium. In this particular area of research, ERI conducted in order to measure and map the resistivity of the subsurface resources. It also refers to a survey that passes an electrical current down many distinct pathways and measures the accompanying voltage to show the subsurface's electrical properties (Abidin *et al*., 2011). The ERI is predicated on the interaction that takes place between the ground and the flow of electrical electricity (Abdulrazzaq *et al*., 2020). It is sensitive to differences in the electrical resistivity of the subsoil measured in ohm meters.

In its most fundamental form, the resistivity approach evaluates the distribution of the underlying material in terms of its resistivity. Table 1 lists the resistivity values of a selection of the most prevalent common rocks and soil materials published by Loke (2015). Besides that, listed in the same table also presented the resistivity values of a selection of the most pervasive minerals, soils, and water types (Loke, 2015). In general, igneous and metamorphic materials have high resistivity values. The degree of fracturing has the most significant influence on the resistivity of these materials. Fractures are frequently filled with groundwater in Malaysia due to the relatively low water table depth throughout the country. For instance, the greater the fracturing, the lower the resistivity of granite, which ranges from 5,000 ohm/m when wet to 10,000 ohm/m when dried. When these materials are saturated with groundwater, their resistivity values range from a few to a few hundred ohm/m. Soils above the water table are arid and have a resistivity value that ranges from several hundred to several thousand ohm/m.

In contrast, soils below the water table typically have resistivity values of less than 100 ohm/m. In addition to this, the electrical resistivity of clay is noticeably lower than that of sand. In conclusion, the purpose of this investigation is to evaluate the prospective groundwater aquifer that may be harvested in an economically viable manner by conducting a field investigation utilising ERI.

RESEARCH METHODOLOGY

The study had been carried out includes various parts, the first of which is a desk study regarding the study area involved. The second involves field measurements in the problematic areas, and the last is analysing the data obtained. Due to obtaining preliminary information such as geological sites and topography on a global and local scale, as described in the subtopics in the methodology section of this research, the desk study carried out is to consolidate preliminary information data about the study region through existing reports and maps. After that, field measurement was carried out with electrical resistivity imaging (ERI) support. The original data collected during the field work at the location study was ultimately reviewed and processed by utilizing the RES2DINV program. ERI method is utilized in the process of the groundwater resource assessment that is carried out. Two surveys are engaged with Line 1, which has a length of 400 meters and 61 electrodes that are spaced at intervals of 5 meters for the inner spreads and 10 meters for the outer spreads. Concerning Line 2, the electrode spacing utilized was 2.5 meters for the inner spreads and 5 meters for the outer spreads, respectively. Due to the constraints imposed by the available space in the study area, Line 2 has a total length of only 200 meters, making it shorter than Line 1. An ABEM Terrameter LS is used to get the reading.

Table 1: Resistivity of some common materials (Loke, 2015).

Material	Resistivity (ohm/m)
Granite	$5 \times 10^3 - 10^6$
Basalt	$10^3 - 10^6$
Slate	$6 \times 10^2 - 4 \times 10^7$
Marble	$10^2 - 2.5 \times 10^8$
Quartzite	$10^2 - 2 \times 10^8$
Hematite Ore	$8 – 1 \times 10^4$
Magnetite Ore	$0.1 – 1 \times 10^3$
Sandstone	$8 - 4 \times 10^3$
Shale	$20 - 2 \times 10^3$
Limestone	$50 - 4 \times 10^2$
Clay	1 - 100
Alluvium	10 - 800
Groundwater (Fresh Water)	10 - 100
Sea Water	0.2

Material	Typical Resistivity, Ωm	Usual Limit, Ωm
Sea Water	2	0.1 – 10
Clay	40	8 – 70
Ground Well and Spring Water	50	10 – 150
Clay and Sand Mixtures	100	4 – 300
Shale, Slates, Sandstones	120	10 – 100
Peat, Loam and Mud	150	5 – 250
Lake and Brook Water	250	100 – 400
Sand	2000	200 – 3000
Moraine Gravel	3000	40 – 10 000
Ridge Gravel	15 000	3000 – 30 000
Ice	10 000	10 000 – 100 000

Study area and geological background

The area being surveyed is located in the Gebeng industrial area (Mukim Sungai Karang) at an approximate latitude of 3°59'33.5"N and longitude of 103°24'27.7"E, which is represented in RSO coordinates as 441486 (Northing) and 601572 (Easting). Figure 1 shows that the study area was formed during the Quaternary period (the last period of the Cenozoic Era). Generally, the Kuantan district sits on a large area of underlying sand within the Titiwangsa range. The surface soils around the Gebeng industrial area are alluvial and mainly comprise peat. Marine and continental deposits of variable thickness are underlying the coastal belt between Kemaman, Terengganu and Kuantan, Pahang. Based on the Mineral and Geoscience Department of Malaysia's available boring and seismic data, the coastal deposit becomes deeper from west to east (towards the coast) and southwards towards Pekan, Pahang.

A study has shown that Gebeng and Sungai Karang areas are underlain by alluvium up to a depth of approximately 38 meters (Akreditasi, 2019). The underlying lithology of Mukim Sungai Karang is an arenaceous sedimentary rock, and it is composed of quartz and feldspar minerals as well as sand-cemented sedimentary rocks (Akreditasi, 2019). Sedimentary rocks form throughout time as a result of erosion and weathering, which is enhanced by water and wind transport. The most common sedimentary rocks in this area are sandstone and siltstone. The sandstone and siltstone have fine grain size, orange to brown in colour, well-rounded, and non-angular grain shape. The grain shape properties depict the great distance transportation of sediment from the source before being deposited and forming bedrock. In addition, the grain is mediumly-sorted, indicating that this area was a shallow marine area. Fossils also indicate a shallow marine environment with high depositional energy (McLaren & Bowles, 1985). Towards the Balok region (west and southwest), igneous rocks such as basalt and granite could be observed abundantly at shallow depths. The coastline's shape is seasonal, and monsoons govern it. During the northeast monsoon (November to February), strong waves are prevalent when the winds blow onshore. On the contrary, the winds are weak and offshore during the southwest monsoon (May to August). Published by Environment Impact Assessment (EIA) Malaysia 2015, the northeast monsoon causes high erosion on the beach while the southwest monsoon causes accretion.

Equipment and methodology of surveying

The instruments that are used to determine the resistivity of materials are detailed in Figure 2, which may be found here. In its most basic form, the apparatus can be separated into three primary parts: the source, the inducer, and the record. A dry cell battery was employed to supply the power for the data-collecting process, while a steel electrode served as the current inducer. The ABEM Terrameter LS2 was utilized in order to record the apparent resistivity data. The apparatus needs to be set up appropriately and follow the method of work to reduce the excessive reading mistake after the analysis. In addition, the area to be studied should be devoid of any surface structures to minimize the disruption along the survey line. At the same time, the electrode plant is being installed.

The resistivity method is an electrical geophysical imaging method that is used to assess the apparent distribution of subsurface resistance. This is accomplished by injecting direct current (DC) into the ground through the use of two (2) current electrodes designated as C1 and C2. Two (2) potential electrodes, designated P1 and P2, are used to determine the magnitude of a potential difference. An electrical imaging system is now mainly carried out with a multi-electrode resistivity meter system. Table 2

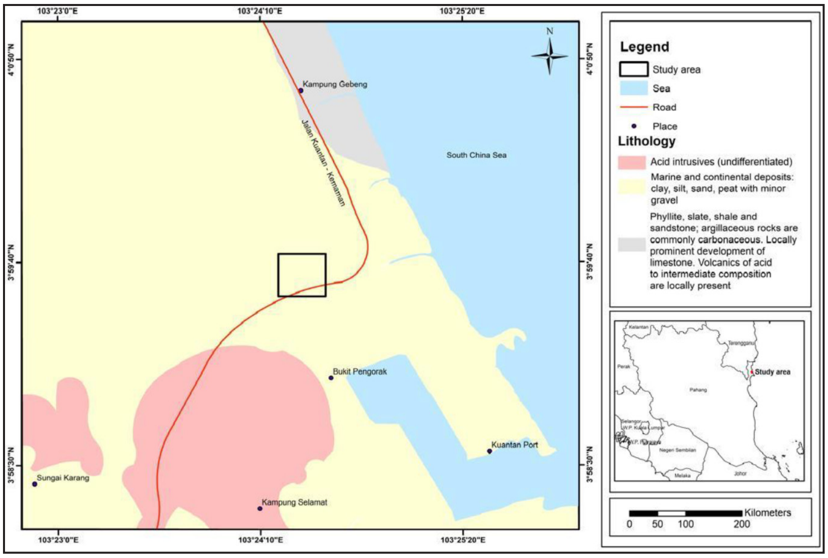

Figure 1: Geological Map of the study area.

Figure 2: Multi-electrode resistivity meter system. Modified from Meterland (2024).

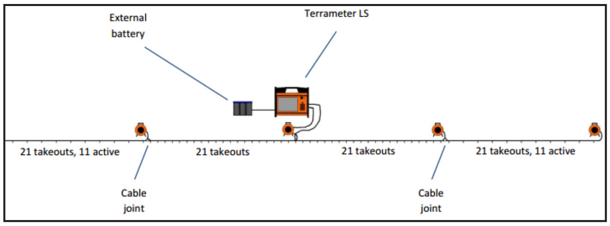

Figure 3: The resistivity cable configuration on field arrangement for Line 1 and Line 2 (Bobachev, 2015).

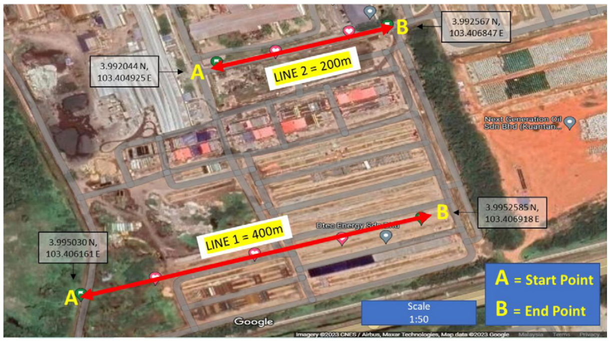

Figure 4: Actual survey line conducted at study area.

and Table 3 show two (2) parts of parameters known as survey lines configuration and receiver parameters that used in this study.

Data acquire and data processing

A total of two (2) resistivity lines have been carried out with different lengths which are 400m for Line 1 and 200m for Line 2 respectively. The resistivity imaging was conducted using the ABEM Terrameter LS2 system. The equipment includes an inducer, source, and record. One of the earliest uses of electrical resistivity is to detect water, distinguish between fresh, brackish, and saline deposits, monitor aquifer decline and recharge, or estimate its extents by scanning a terrain (Suryadi *et al*., 2019; Ilahi *et al*., 2021; Petrick *et al*., 2023). An external battery of 12 volts set up the ABEM Terrameter LS2 source. This surveying works involved 61 steel electrodes combined with 64 transmitters utilized as a current inducer for both survey lines. The resistivity cable configuration on field arrangement is presented in Figure 3 and Figure 4. This equipment creates a record and visualizes the apparent resistivity value, and RES2DINV software was used to finally evaluate, interpret and clarify the raw data acquired from an on-site survey measurement. The data recorded from the exploration work in the field utilizing the Schlumberger protocol method, which is a method that is frequently utilized for work related to exploration (Ishak *et al*., 2022). It produces dense near-surface coverings while producing a measuring pattern that is slightly sparser when the electrode spacing is longer.

Table 2: Total length and electrode spacing of ERI survey line.

Survey Line	Inner Electrode Spacing (m)	Outer Electrode Spacing (m)	Total Length (m)
Line 1	5	10	400
Line 2	2.5	5	200

Table 3: Setting up of the ERI receiver parameters survey line.

Receiver Parameters	Description Setting
Measure Mode	Res
Minimum Number of Stacking	1
Maximum Number of Stacking	2
Error Limit	1.0%
Delay Time	0.4s
Acquired Time	0.6s
Number of IP Windows	8
Record Full Waveform	Yes
Power Line Frequency	60 Hz

RESULTS AND DISCUSSION

Electrical resistivity imaging (ERI)

Figure 5 until Figure 8 below present interpreted two-dimensional (2D) electrical resistivity profiles. The horizontal scale is given in meters for the length of survey lines, and the vertical scale is given in meters for elevation. The results show that the maximum penetration depth for the subsurface imaging is 43m for all surveyed line. The RMS error produced for the 2D resistivity model is lower than 14%. RMS value is used to find the average value of current or instantaneous voltages. It is used when the given variable is positive or negative or the set of given values is random. RMS value can be used to quantify and depict the discrepancy between calculated and observed values. Although the final model should have a low RMS, this does not always mean that it is the most accurate geological model. The resistivity value obtained for this study is ranged from 1 Ωm to 500 Ωm. As seen in the following figures, an overall total of two (2) electrical resistivity lines were planned to travel through the area of interest. According to the Schlumberger methodology, the maximum depths that allow for data coverage in the centre portion of survey lines are between 65 to 90 meters, respectively (Niaz *et al.*, 2021). The resistivity value exhibits a medium range between 0.5 Ωm to 888 Ωm. The low resistivity value of 0.1 Ωm to 10 Ωm presented in the processed ERI profiles are bluish. It is interpreted as alluvium (silty clay), which might consist of salty water (Loke, 2015). The resistivity value range between 10 Ωm to 80 Ωm (greenish and yellowish) is interpreted as alluvium (clayey silt). Resistivity range between 80 Ωm to 500 Ωm, which is presented in orange to reddish in colour interpreted as sand or gravel and may act as groundwater aquifer. The presence of boulders (sandstone clastic rock boulders) and altered rocks are a possibility along this range of resistivity reading. Commonly, the resistivity of 1000 Ωm and above shows the presence of bedrock (igneous, sedimentary, and metamorphic). The topsoil of the survey area consists of various soil types and properties. However, the main soil types observed are clayey silt with mixture of organic matter (humus) and sand at the stream. The variation of soil types such as clayey silt, silty clay and silty sand had contributed to the wide range of resistivity value from 10 Ωm to 888 Ωm. Based on the two (2) resistivity profiles obtained, the overburden soil thickness range between 25 to 40m.

Electrical resistivity for line 1

Figure 5 shows the 2D resistivity model of Line 1 at a depth of 74m from the surface with a RMS of 39.3%. On the other hand, Figure 6 shows the 2D resistivity model of Line 1 at a depth of 43m from the surface with an RMS of 11.2%. The lower the RMS, the more accurate the result. Hence Figure 6 is used for the detailed interpretation of Line 1, while Figure 5 is used for comparison at depth. Based on Figure 6, the topsoil layer could be seen dominated by clayey silt (greenish colour in 2D resistivity model). The profile is dominated by thick alluvial soils with gravel and a minor of sedimentary boulders and altered rocks. Commonly, a resistivity reading of 10 Ωm and below indicates the silt/clay or the presence of saltwater. Freshwater aquifers are commonly found in sand or gravel resistivity range of 10 to 150 Ωm. The resistivity of an aquifer can vary to 500 Ωm. Thus, the orange and reddish area in the 2D resistivity model is marked as sand or gravel (potential aquifer). In contrast, the bluish area is marked as silty clay, stated by Omosuyi *et al.* (2007), that a resistivity range of 20 to 100 Ωm is related to excellent weathering and groundwater potential. In comparison, the 101 to 150 Ωm resistivity is suggestive of medium aquifer condition and potential. Three (3) borehole works are proposed at electrodes 9, 30, and 51 to the depth of 15m, 30m, and 20m from the surface, respectively. Electrode 9 is located at 3.992044 N, 103.404925 E, electrode 30 is located at 3.99236 N, 103.405947 E, while electrode 51 is located at 3.992567 N, 103.406847. The distance of electrodes 9, 30, and 51 from the first electrode location is 80m, 195m, and 300m, respectively.

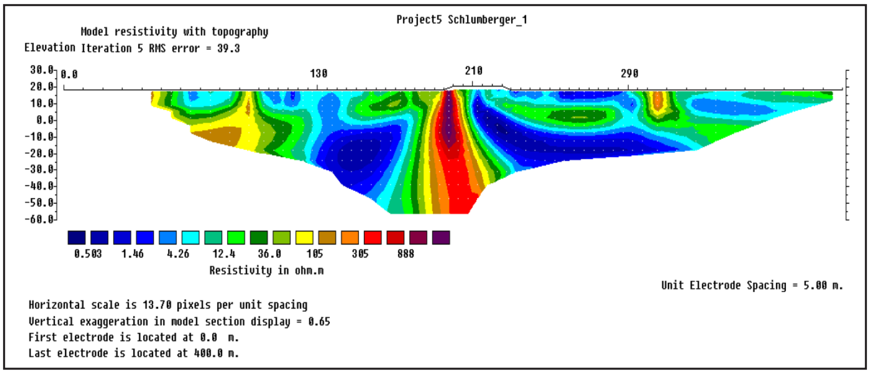

Figure 5: 2D resistivity model of Line 1 (Depth 74m from the surface).

Electrical resistivity for line 2

Figure 7 shows the 2D resistivity model of Line 2 at a depth of 35m from the surface with an RMS of 32.6%, while Figure 8 shows the 2D resistivity model of Line 2 at a depth of 25m from the surface with an RMS of 13.5%. As Figure 7 shows the lowest RMS, it is used to interpret the data for Line 2. The lower resistivity reading, 0.2 to 10 Ωm, indicates the clayey/silty material is present and shown with a bluish to greenish colour in the 2D resistivity model. The orange-reddish area in the 2D resistivity model has a resistivity range of 80 to 200 Ωm, which can be indicated as the sand or gravel, which may act as the water aquifer. Two (2) boreholes are proposed at electrodes 19 and 52 at 20m and 15m depths, respectively. Electrode 19 is at 3.99503 N, 103.406161 E, while electrode 52 is at 3.995285 N, 103.406918 E. For locating water in bedrock, lower resistivity would mean the fractured zone, while higher resistivity indicates the

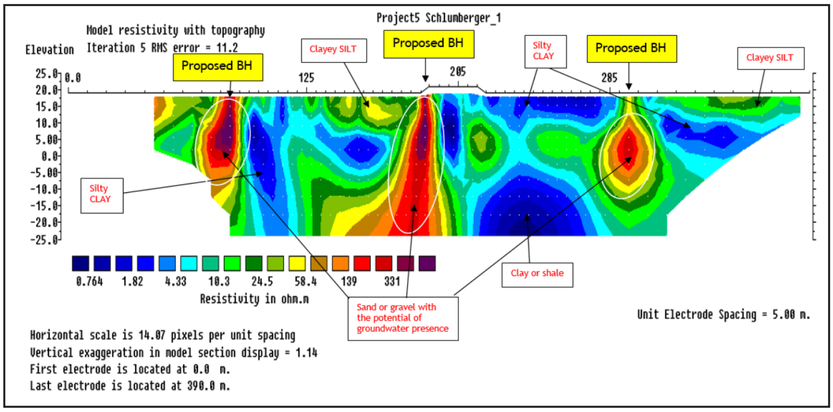

Figure 6: 2D resistivity model of Line 1 (Depth: 43m from the surface).

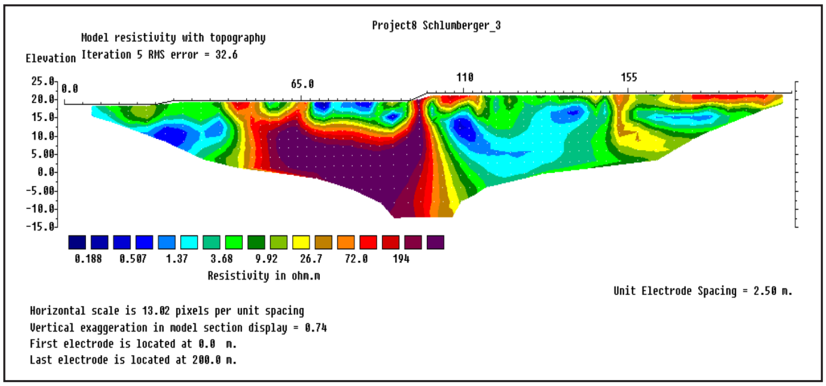

Figure 7: 2D resistivity model of Line 2 (Depth: 35m from the surface).

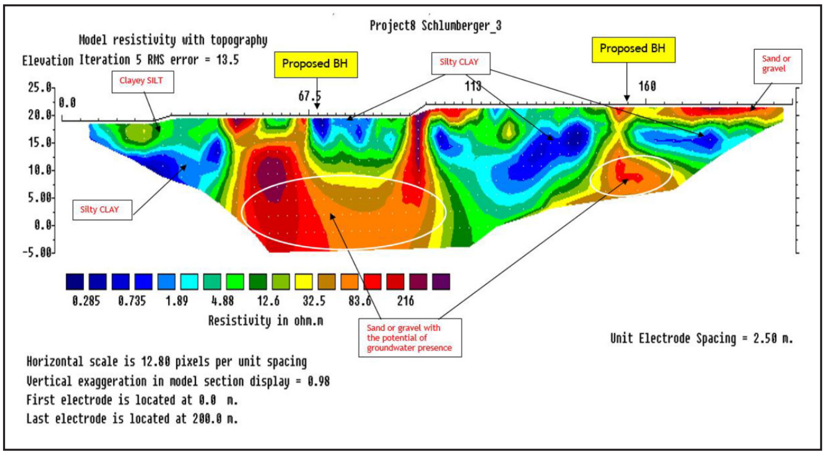

Figure 8: 2D resistivity model of Line 2 (Depth: 25m from the surface).

hard rock. Fractured zone resistivity is lower because the hard rock moisture will collect in the fissures of the fracture zone. Since it contains moisture, it will be more conductive than hard rock, thus having low resistivity. Like in sedimentary areas with thick alluvial, this research study should consider slightly higher resistivity. For example, clay is more conductive (lower resistivity) than sand and gravel. Clay is sticky and wet and not permeable, which means water cannot flow through it; thus it cannot hold water (Agiusa, 2018).

CONCLUSION

Two (2) 2D resistivity imaging profiles of electrical resistivity were acquired in this geophysical survey investigation. According to the findings of the investigation carried out in the Gebeng, Kuantan industrial area, both survey line (Lines 1 and 2) provide good indicators of the presence of groundwater. The length of Line 2 was just 200 meters, in contrast to the length of Line 1, which was 400 meters; as a result, only less data (a shallower depth) was collected. In addition to that, groundwater would have a low resistivity (between 20 and 200 Ωm). The combination of the resistivity reading and the chargeability reading would better interpret the outcome since both readings could be compared and complemented. Because the induced polarization (IP) survey (chargeability) was not carried out as part of this study, the uncertainty rate will be relatively high. Some recommendations for further studies are that more borehole wells should be drilled due to a better understanding of the groundwater in the study area. Since this study is focused on industrial facilities, it can be seen that the ERI method is a non-invasive technique and can reduce the cost of investigation work. In addition, this method can provide high-resolution 2D images of subsurface resistivity, thus enabling detailed mapping of groundwater features such as aquifer boundaries and freshwater interfaces. It also creates a method suitable for various environments where it offers real-time data acquisition and provides flexible depth penetration, making it an invaluable tool for groundwater investigation and natural resource management, and makes ERI an essential tool for ensuring the sustainable management of water resources and monitoring environmental impacts in industrial settings.

ACKNOWLEDGEMENT

The authors would like to thank the Faculty of Civil Engineering Technology (FCET), Universiti Malaysia Pahang Al-Sultan Abdullah (UMPSA) for their contribution and opportunity to complete this work. The authors would also like to thank UMPSA, for the financially supported provision of a Penyelidikan Unggul (RDU243007) grant to conduct this research. The authors also sincerely thank all anonymous peer reviewers for their valuable feedback and constructive comments, which significantly improved the quality of this manuscript.

AUTHORS CONTRIBUTION

SD: Conceptualization, writing-original draft preparation, investigation, methodology and data collection; MFI: Supervision, resources and writing review; PII: Data Collection and Validation; MFZ: Data collection, validation and writing review.

CONFLICT OF INTEREST

The authors affirm that they do not have any known competing financial interests or personal ties that could have looked like they had an influence on the work that is disclosed in this study.

REFERENCES

Abdulrazzaq, Z.T., Agbasi, O.E., Aziz, N.A., & Etuk, S.E., 2020. Identification of potential groundwater locations using geophysical data and fuzzy gamma operator model in Imo, Southeastern Nigeria. Applied Water Science, 10(8), 1–7. https://doi.org/10.1007/s13201-020-01264-6.

Abidin, M.H.Z., Saad, D.R., Ahmad, F., Wijeyesekera, D.C., & Baharuddin, E.M.F.T., 2011. Application of Geophysical Methods in Civil Engineering. International Conference on Engineering & Technology, November 2015, 1–12.

Agiusa, 2018. How to find groundwater using Electrical Resistivity Imaging. © 2023 Advanced Geosciences, Inc. https://www.agiusa.com/blog/how-find-groundwater-using-electrical-resistivity-imaging.

Akreditasi, S., 2019. Environmental Impact Assessment: Proposed Onsite Secure Landfill (Prescribed Prmise) for the Storage of NUF Solids within the Existing LAMP Site located in PT 17212, Gebeng Industrial Estate, Kuantan, Pahang.

Al-Garni, M.A., 2009. Geophysical investigations for groundwater in a complex subsurface terrain, Wadi Fatima, KSA: A case history. Jordan Journal of Civil Engineering, 3(2), 118–136.

Alshehri, F., 2023. Groundwater Potentiality of Wadi Fatimah, Western Saudi Arabia : Geophysical and Remote Sensing Integrated Approach. Water 2023, 15, 1–18.

Asry, Z., Samsudin, A.R., Yaacob, W.Z., & Yaakub, J., 2012. Groundwater investigation using electrical resistivity imaging technique at Sg. Udang, Melaka, Malaysia. Bulletin of the Geological Society of Malaysia, 58, 55–58. https://doi.org/10.7186/bgsm58201209.

Bobachev, A., 2015. Protocols for Terrameter LS, LS2, ABEM (Sweden). x2ipi. https://x2ipi.ru/news/protocols-for-terrameter.

Cochrane, C., 2008. Groundwater Information Sheet - The Impact of Industrial Activity. British Geological Survey, 1–6.

Daud, S., Zolkepli, M.F., Ishak, M.F., & Talib, Z.A., 2024. Suction Variation of a Single Mature Tree on Top of Tropical Residual Soil. International Journal of Integrated Engineering, 16(9), 37–52. https://doi.org/10.30880/ijie.2024.16.09.003.

Hao, Q., Xiao, Y., Chen, K., Zhu, Y., & Li, J., 2020. Comprehensive understanding of groundwater geochemistry and suitability for sustainable drinking purposes in confined aquifers of the Wuyi region, central north China plain. Water (Switzerland), 12(11), 1–25. https://doi.org/10.3390/w12113052.

Hasan, M.F.R., Pradiptiya, A., Setiawan, Y., Agung, P.A.M., Susilo, A., & Sunaryo, 2022. Detection of groundwater sources in Lembor village using geoelectrical resistivity method Schlumberger configuration. IOP Conference Series: Earth and Environmental Science, 1116(1). https://doi.org/10.1088/1755-1315/1116/1/012051.

Hasanuzzaman, M., Mandal, M.H., Hasnine, M., & Shit, P.K., 2022. Groundwater potential mapping using multi-criteria decision, bivariate statistic and machine learning algorithms: evidence from Chota Nagpur Plateau, India. Applied Water Science, 12(4), 1–16. https://doi.org/10.1007/s13201-022-01584-9.

Ilahi, W.F.F., Hassan, N.H.A., Ismail, M.R., Che'ya, N.N., Berahim, Z., Omar, M.H., Zakaria, N.I., & Zawawi, M. A.M., 2021. Potential groundwater exploration in use of 2-d electrical resistivity tomography (Ert) techniques at the Department of Agriculture Kelantan Research and Developmental platform Padang Raja Kelantan. Pertanika Journal of Science and Technology, 29(2), 1219–1228. https://doi.org/10.47836/pjst.29.2.28.

Ishak, M.F., Zolkepli, M.F., Masyhur, E.M.H., Yunus, N.Z.M., Rashid, A.S.A., Hezmi, M.A., Hasbollah, D.Z.A., & Yusoff, A.R., 2022. Interrelationship between borehole lithology and electrical resistivity for geotechnical site investigation. Physics and Chemistry of the Earth, 128(October), 103279. https://doi.org/10.1016/j.pce.2022.103279.

Ishak, M.F., Zolkepli, M.F., Yunus, M.Y.M., Ali, N., Kassim, A., & Zaini, M.S.I., 2021. Verification of tree induced suction with numerical model. Physics and Chemistry of the Earth, 121, 102980. https://doi.org/10.1016/j.pce.2021.102980.

Lin, D.G., Chang, K.C., Ku, C.Y., & Chou, J.C., 2020. Three-dimensional numerical investigation on the efficiency of subsurface drainage for large-scale landslides. Applied Sciences (Switzerland), 10(10), 3346. https://doi.org/10.3390/APP10103346.

Loke, M.H., 2015. Tutorial: 2D and 3D electrical imaging surveys. 14th March, 1–176. http://www.geotomosoft.com/coursenotes.zip.

McLaren, P., & Bowles, D., 1985. The effects of sediment transport on grain-size distributions. Journal of Sedimentary Research, 55(4), 457–470. https://doi.org/10.1306/212F86FC-2B24-11D7-8648000102C1865D.

Meterland, 2024. ABEM Terrameter LS2, the world leading resistivity and IP imaging instrument for geophysical investigations. Meterland. https://www.meterland.ro/en/resistivity-and-ip-meters/1687-abem-terrameter-ls2-the-world-leading-resistivity-and-ip-imaging-instrument-for-geophysical-investigations.html.

Niaz, A., Wan, A.M., Bibi, T., Qureshi, J. A., Rahim, S., Hameed, F., & Shedayi, A.A., 2021. A Comparison Between Schlumberger and Wenner Configurations in Delineating Subsurface Water Bearing Zones: A Case Study of Rawalakot Azad Jammu and Kashmir, Pakistan. International Journal of Economic and Environmental Geology, 12(3), 25–31. https://doi.org/10.46660/ijeeg.vol12.iss3.2021.615.

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(2), 172–182. http://www.akamaiuniversity.us/PJST8_2_172.pdf.

Osinowo, O.O., & Falufosi, M.O., 2018. 3D Electrical Resistivity Imaging (ERI) for subsurface evaluation in pre-engineering construction site investigation. NRIAG Journal of Astronomy and Geophysics, 7(2), 309–317. https://doi.org/10.1016/j.nrjag.2018.07.001.

Petrick, N., Jubidi, M. F. bin, & Ahmad Abir, I., 2023. Groundwater Potential Assessment of Penang Island, Malaysia, Through Integration of Remote Sensing and GIS with Validation by 2D ERT. Natural Resources Research, 32(2), 523–541. https://doi.org/10.1007/s11053-023-10164-w.

Riwayat, A.I., Ahmad Nazri, M.A., & Zainal Abidin, M.H., 2018. Application of Electrical Resistivity Method (ERM) in Groundwater Exploration. Journal of Physics: Conference Series, 995(1). https://doi.org/10.1088/1742-6596/995/1/012094.

Saimy, I.S., & Raji, F., 2015. Applications and sustainability in groundwater abstraction in Malaysia. Jurnal Teknologi, 73(5), 39–45. https://doi.org/10.11113/jt.v73.4318.

Sulaiman, M.S., Khan, M.A., Sulaiman, N., & Udin, W.S., 2022. Groundwater Potential Using Electrical Resistivity Imaging In Batu Melintang, Jeli, Kelantan. IOP Conference Series: Earth and Environmental Science, 1102(1). https://doi.org/10.1088/1755-1315/1102/1/012028.

Sulaiman, N., Ariffin, N.A., Sulaiman, M.S., Sulaiman, N., & Jamil, R.M., 2022. Groundwater exploration using Electrical Resistivity Imaging (ERI) at Kemahang, Tanah Merah, Kelantan. IOP Conference Series: Earth and Environmental Science, 1102(1). https://doi.org/10.1088/1755-1315/1102/1/012027.

Suryadi, A., Batara, & Amir, S.N., 2019. Electrical Resistivity Imaging (ERI) and Induced Polarization (IP) Survey to Solve Water Drought Problem at Alor Gajah, Melaka, Malaysia. IOP Conference Series: Materials Science and Engineering, 532(1). https://doi.org/10.1088/1757-899X/532/1/012025.

Zaini, M.S.I., Ishak, M.F., & Zolkepli, M.F., 2019. Forensic assessment on landfills leachate through electrical resistivity imaging at Simpang Renggam in Johor, Malaysia. IOP Conference Series: Materials Science and Engineering, 669(1), 0–10. https://doi.org/10.1088/1757-899X/669/1/012005.

Zolkepli, M.F., Ishak, M.F., & Daud, S., 2023. The Application of Unmanned Aerial Vehicle (UAV) For Slope Mapping at Gambang Damai Residents, Pahang: A Case Study. International Journal of Integrated Engineering, 15(2), 219–227. https://doi.org/10.30880/IJIE.2023.15.02.021.

Manuscript received 17 September 2024;
Received in revised form 26 December 2024;
Accepted 11 February 2025
Available online 30 August 2025