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GEOPHYSICAL INVESTIGATION OF GROUNDWATER RESOURCES USING ELECTRICAL RESISTIVITY AND INDUCED POLARIZATION METHOD

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ABSTRACT: Identifying potential groundwater is crucial, especially in the area that faced water stress issue. Geophysical surveys are one of the most reliable ways to find a groundwater supply. However, when performing a resistivity survey, there is uncertainty in distinguishing between soil particles and groundwater. Therefore, this study combines the electrical resistivity and induced polarization method to distinguish the saturated zones between an aquifer and unconsolidated sediments and the results were validated with borehole data. The pole-dipole array was used to build up two resistivity survey lines. According to the results of the 2-D resistivity and IP survey, low resistivity values between 10 and 100 m (Ohm-m) and low chargeability values between 0 and 1 millisecond can be used to identify potential groundwater areas in the subsurface (msec). Silty sand and sandy clay make up alluvium, which has a resistivity range of 125 to 255 m and a chargeability range of 7 to 10 msec. The reflection coefficient (Rc) values generally range between 0.41 and 0.70 and suggest a highly fractured formation with respect to the hardrocks. A comparison between the depth to bedrock as predicted by electrical resistivity tomography (ERT) and the borehole logs was in strong agreement with the correlation coefficient value (R^2 = 0.9478). On the other hand, the study revealed a relatively week correlation (R^2 = 0.4351) between the final drilled depth and the borehole yield. The study therefore has demonstrated the efficacy of the ERT and IP technique as a tool in delineating groundwater potential zones for the drilling of boreholes.

Keywords: Groundwater, Geophysical, Resistivity, Imaging and Potential.

1. INTRODUCTION

According to Sustainable Development Goal 6 (UN General Assembly 2015), freshwater is crucial for both national and human health (i.e. ensure availability and sustainable management of water and sanitation for all). A location's distribution of freshwater resources varies greatly throughout time and space. Access to potable water is therefore coupled with obstacles for every alternative source (i.e. surface and groundwater).

Geophysical surveys are one of the most reliable ways to find a groundwater supply. The common approach for the geophysical survey is resistivity method which can identify sources of groundwater potential [1]. This method is based on the composition and layering of the subsurface, interpretation of the soil's physical characteristics, and underground structures, cavities, and bodies from various geological environments [2]. It is also helpful for figuring out an aquifer's boundary, thickness, and depth.

The electrical resistivity method (ERT) has proven to be one of the most efficient and economical geophysical methods that is used for the delineation of potential groundwater zones. A variety of applications for the resistivity approach have been published extensively in the literature [3, 4, 11 - 15]. It provides subsurface information with little or no environmental impact, as well as a comparison of rock layers with different electrical properties [13-14]. Besides groundwater exploration, the electrical resistivity method is applied in mineral exploration and in foundation engineering [10], determining saltwater intrusion [6], environmental pollution [19] and in slide modelling [20]. In Brunei, the electrical resistivity method and induced polarization method has been used successfully to explore groundwater for agricultural area [17]. The results from the electrical resistivity survey revealed the presence of fracture zones or with resistivity values ranging from 1 to 100 Ω m and chargeability values ranging from 0 to 10 ms. In Nigeria, the electrical resistivity technique has been employed together with other methods where the results revealed the second layer comprises of the weathered/fractured basement with depths of 1.5 - 15.8 m and ranges in resistivity values between 1 Ωm and 3000 Ωm. The bedrock which makes the third layer at depths of 10 - 15.8 m has resistivity range of 1000 Ωm to 3500 Ωm. [11]. Similarly, [18] also used a combined method including electromagnetic and induced polarization (IP) techniques to explore for groundwater resources in the Punata, Bolivia. The IP revealed that the geoelectrical methods used in this research (i.e. ERT and normalized chargeability) are useful and powerful techniques for mapping the aquifer systems in the Punata. The combined interpretation of the ERT and IP results indicated the presence of possible aquifer units including the fresh bedrock, fractured and weathered within the subsurface of the study area. However, when performing a resistivity survey, there is uncertainty in distinguishing between soil particles and groundwater. Thus, this study is to investigates the efficacy of the combination method of electrical resistivity and induced polarization technique as a tool to explore groundwater potential zones.

2. RESEARCH SIGNIFICANCE

Very limited studies have focused on the ERT and IP technique as a tool in delineating groundwater potential zones for the drilling of boreholes especially in hard rock and alluvium soil. Past study surveys have found that when drilling in the subsurface layers, many researchers struggled to determine the exact position of the aquifer or missed the aquifer's full capacity. This study thus evaluates the ERT and IP technique for exploring groundwater potential zones in hard rock and alluvium environment. The significance of this study is, with the application of 2D resistivity inversion and supporting borehole data, reliable groundwater information is generated and quantitatively evaluated for figuring out an aquifer's boundary, thickness, and depth.

3. METHODOLOGY

Electrical resistivity imaging (ERI) and induced polarization (IP) surveys are two hydrogeophysical techniques that have been conducted for groundwater exploration in National Defence University of Malaysia (UPNM). Two survey lines were conducted at the proposed area with a length of 400m and 800m. The length of 400m cable was laid with a minimum spacing between electrodes is 5 m and maximum spacing is 10m. Whereas, for 800m cable was laid with a minimum spacing between electrodes is 10 m and maximum spacing is 20m. The newest Terrameter LS2 from ABEM was used for measurement, which included several equipments as shown in Fig. 1 for the electrical resistivity and induced polarization survey. Instruments used such as 4 units of multi-purpose cable, 64 units of the jumper cable, 61 units of stainless-steel electrode, 2 units of cable connector, 1 unit of a 12-volt battery, and 1 unit of remote cable. A 2D multielectrode ERI survey is conducted using 61 units of stainless-steel electrode connected to a multicore cable. The electrodes attached to the cable take-outs are then placed along a survey line into the ground at a specified daily interval [8]. The ABEM Terrameter LS2 is set up to measure resistivity and induced polarization at the same time during data gathering. Next, data processing will be conducted using the RES2DINV software when the data acquisition is finished [5]. The field data were processed using the RES2DINV version 4.5.16 software package to create a 2D electrical resistivity and induced polarization image. By using an inversion method, the resistance measurements of earth materials are converted to apparent resistivity readings. Ground resistivity is affected by several geological factors, including mineral and fluid composition, porosity, and water saturation. Sedimentary rocks are often more porous and have a larger water content than igneous and metamorphic rocks, resulting in lower resistivity values. The resistivity contour value is modified based on geological data that corresponds to the resistivity range with various colours. Finally, correlations between the borehole record and the contouring inversion model from this survey will be made.

Fig. 1 Multi-electrode resistivity system tools

Four locations of borehole drilling results and geophysical surveys have been added in this study to verify the effectiveness of ERT and IP method. The locations are Sek Men Sultan Hishamuddin, Klang, Masjid Al-Hasanah, Bangi, Klinik Kesihatan Cheras and Klinik Beranang. Selection of the most promising site for drilling was made by considering factors such as overburden thickness, bedrock resistivity and the nature of the curve. The reflection coefficients (Rc) for all the drilling points were calculated using Eq. (1) [16].

$$\boldsymbol{R_c} = \frac{\boldsymbol{\rho_n} - \boldsymbol{\rho_{n-1}}}{\boldsymbol{\rho_n} + \boldsymbol{\rho_{n+1}}} \tag{1}$$

where n is the layer resistivity of the nth layer, and n − 1 is the layer resistivity overlying the nth layer.

4. RESULTS AND DISCUSSION

Figure 2 depicts how Line 1 was routed from North-Northeast to South-South west). The borehole was proposed at 270 m from the first electrode. The resistivity values were between 125 and 7400 m. (Ohm-m). According to [9], the resistivity values of the top layer with soil along the line range from 0.1 to 10 m. High resistivity values are represented by the dark purple colour, whereas low resistivity values are represented by the blue colour. The resistivity values are influenced by many geological factors, including mineral content and fluid, water saturation, and rock porosity. Following the resistivity distribution, the groundwater potential zone is located within the distance from 255m to 275 m with a depth from 25 m to 50 m. However, this water potential area is not within the fractured zone to exhibit a higher chance of groundwater in granite formation. The water potential zone in this area is probably associated with a weathered granite environment. Low resistivity anomalies below 100 Wm have been observed and are thought to be an aquifer zone or a water-saturated layer [7 - 8, 11].

Next, integrated with the induced polarization profile, low chargeability values (<7.5ms) give a supportive interpretation of water containing zone for this area. As mentioned before, in the water zone, the low values of chargeability are reflected in a water-saturated zone as water is a poor medium to retain electrical charges. The chargeability values for induced polarisation indicate gravel, sandstone or alluvium. In contrast to coarse soil, such as gravel and sand, fine grain soils like silt and clay have a substantial composition of minerals, such as vermiculite, kaolinite, and montmorillonite, that makes the current flow easily and produces low resistivity values [10]. Two zones have low values for chargeability. The initial zone exhibits low chargeability between 20 and 270 metres from the first electrode and up to a penetration depth of 70 metres. Groundwater is represented by blue at a chargeability value of 0 to 1 milliseconds (msec), alluvium is represented by light green at a chargeability value of 1 to 4 msec, and gravel is represented by dark green at a chargeability value of 3 to 9 msec [16]. Low chargeability is present in the second zone, which extends from a depth of 40 m to a distance of 280 m to 310 m.

Lines 2 were set up in NWW (North West-west) to SEE (South West-East), intersecting line 1 at 300 m from the first electrode. The line is straightened up to 800 m long; roughly 250 m is on the region of very thick shrubs area and from 500 m onwards, is the area with a moderate to steep slope face. Other than that, the area is classified as a flat landform. For survey line 2, water containing zone is less potential than the area of survey line 1. This is because the water-containing zone is mainly located in rock formation which is an indication of low volume than survey line 1. It is located at the distance from 580 m to 590 m with a depth from 20m to 30m only as shown in Figure 3. This survey line was carried out on undulating topography. Hence, the water-containing zone probably

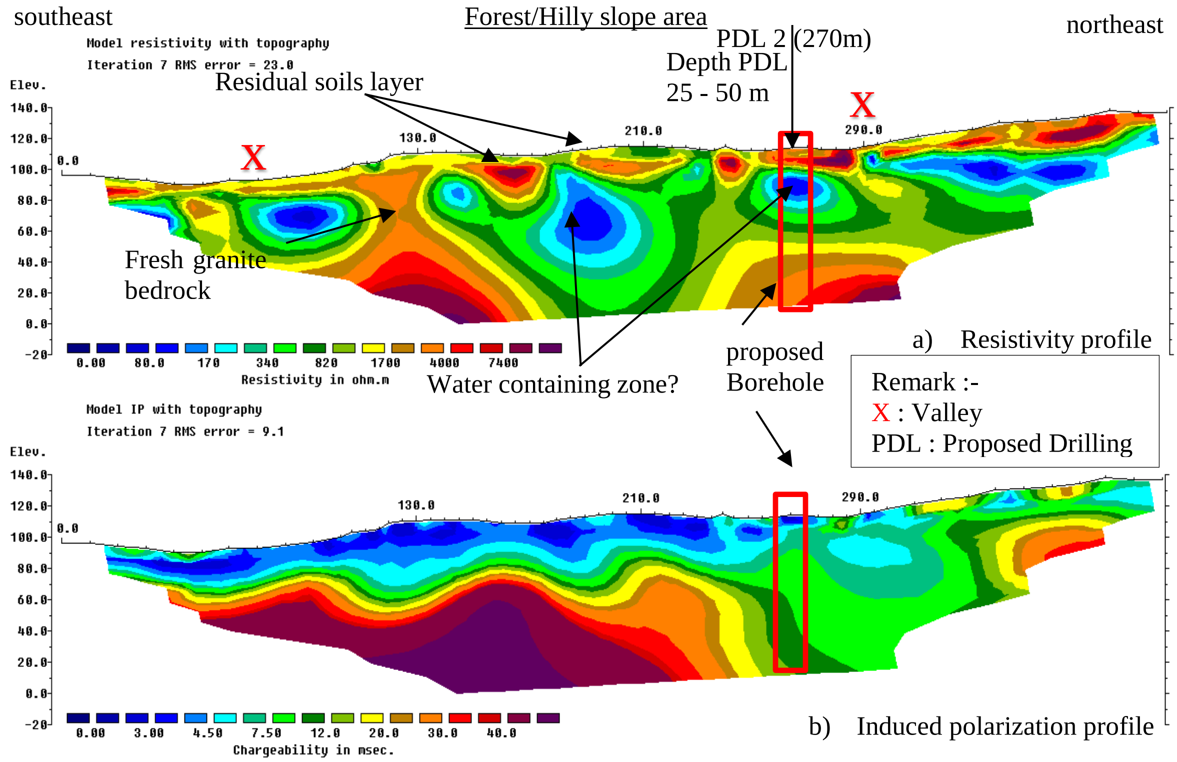


Fig. 2 Inversion model of (a) 2D resistivity and (b) chargeability for line 1

infiltrated from the high topography (south) and accumulated towards the low topography region (north).

The resistivity value in line 2, at the bottom layer, starts of from high resistivity at a depth of 140 m to the top layer with a low resistivity value at a depth of 20 m. The resistivity values vary from 1 Ωm to 9000 Ωm. The layer with the highest concentration of resistivity is coloured dark purple based on the results of the resistivity distribution, indicating the presence of a massive rock at a depth of 140 m, which is interpreted as granite with a resistivity value > 5000 Ωm. At a depth of 120 m, the green and the yellow coloured area is depicted in the data as sandstone. The saturated layer presumed as blue colour in the data at a depth of 20 m until 30 m due to its low resistivity values of below 100 Ωm. This survey line was carried out on undulating topography. Hence, the water-containing zone probably infiltrated from the high topography (south) and accumulated towards the low topography region (north).

The induced polarization in the survey lines, meantime, indicates some potential groundwater and alluvium. Resistivity values will be lowered by the presence of groundwater, and silt will also bring down the resistivity value below groundwater. The subsurface area that has been coloured in dark and light blue at a depth of 0 to 30 m could be classified as the saturated zone with chargeability from 1 to 5 msec [13 - 14]. Therefore, the maximum depth of potential groundwater is at depth of 20 to 30 m with a distance of 580 to 590 m from the induced polarization (IP) at the first electrode. The high probability of finding groundwater was when the chargeability value for the groundwater was between 0 and 4.5 msec. The light green colour at a depth of 60 -100 m could be considered sandstones.

High chargeability can be found in orange colour with a chargeability value of 20 to 30 msec and it can be represented as gneiss, while yellow colour at 16 to 20 msec of chargeability value showed schist. The bigger resistivity values between these rocks are the best approach to distinguish schist to a gneiss with a value of resistivity greater than 5000 Ωm. This is consistent with the results of previous studies conducted within the same geologic environment [13].

Unconsolidated sediments and groundwater in the study area can be distinguished using the induced polarization method to support the exploration due to its different chargeability values and not relying solely on the resistivity method only.

3.1 Correlating drilling and geophysical results

Table 1 gives a quantitative overview of the drilling data and the electrical resistivity tomography (ERT) simulated results from hardrock area which is from borehole data at Sek Men Agama Sultan Hishamuddin, Klang and Masjid Al-Hasanah,

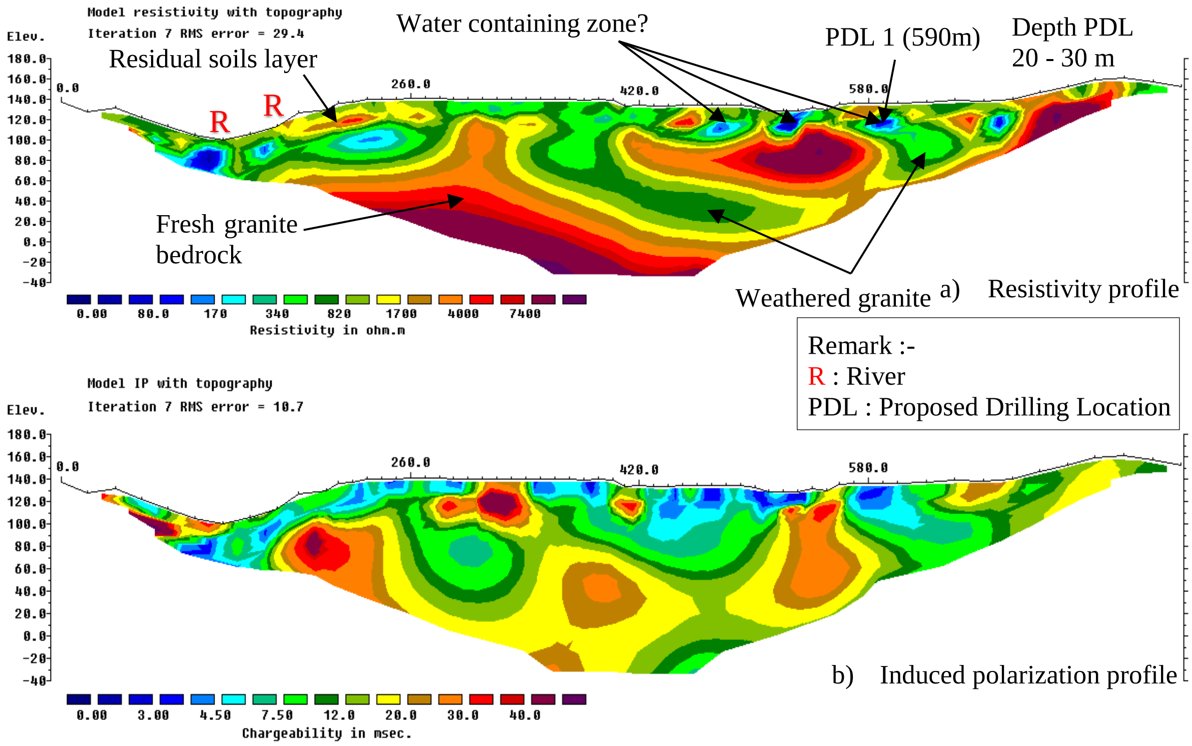


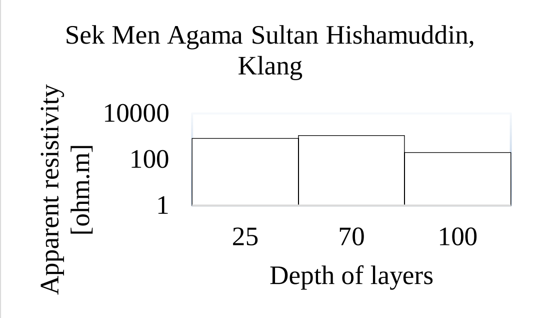
Fig. 3 Inversion model of (a) 2D resistivity and (b) chargeability for line 2

Bangi. According to the ERT data, the underlying bedrock's resistivities are typically low (600 Ωm), indicating a more fractured formation with a greater potential for groundwater storage.

As a result of the water in the pores, reduced bedrock resistivity was anticipated. The lowest bedrock resistivity was measured in Masjid Al-Hasanah in Bangi, and it was in the range of 150 Ωm. The existence of salty water intrusion may be the cause of the low bedrock resistivity. A successful well is often predicted to be developed in the sandstone formation when the resistivity is, between 150 Ωm and 600 Ωm, whereas an unproductive well may result if the bedrock resistivity is over 800 Ωm. The overburden's thickness is another element that affects groundwater development. Only the basement resistivity cannot be utilised to determine a site's groundwater potential, and for that matter, overburden thickness and aquifer reflection coefficient should be used to enhance the selection methods, claim [16]. Low resistivity difference value indicates the presence of a bedrock rock fracture and, as a result, has a larger potential for groundwater infiltration.

The basement resistivity may not provide a clearer picture of the degree of fracture than the aquifer reflection coefficient. Because of this, a healthy aquifer zone is defined as having a reflection coefficient (Rc) of less than 0.8. According to the computed Rc values (see Table 2), regions with lower Rc were assumed to have the most weathered or fractured bedrock, which might facilitate the development of groundwater resources. The sandstone formation is where the lower Rc values (0.8) were found in Sek Men Agama Sultan Hishamuddin, Klang (0.70) and Masjid Al-Hasanah, Bangi (0.41), which point to a fragmented bedrock. These observations suggest a basement that is less stable, with deep fissures. The research area's overburden thickness ranges from 12.5 to 75 m, with SMKA Sultan Hishamuddin, Klang recording the thickest overburden and Masjid Al-Hasanah, Bangi the thinnest. As a result, this shows that secondary porosity, such as fissuring, fracturing, weathering, and permeability, is crucial for groundwater occurrence in the research region.

In order to get more comprehensive interpretation and understanding on the correlation between borehole data and geophysical findings, two more locations (Klinik Cheras and Klinik Beranang) have been added where both of this location were from alluvium environment. Table 2 provides a summary of the drilling results for the four (4) test wells. It includes drilling information like yield, depth to bedrock, static water level, and borehole depth. It was discovered that in several areas, the drilling logs did not match the number of



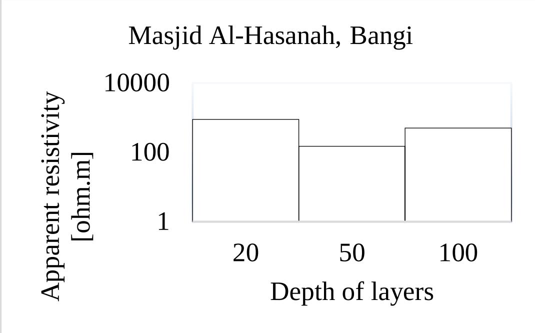


Fig. 4 ERT modelled chart at SMKA Sultan Hishamuddin, Klang and Masjid Al-Hasanah,Bangi.

Table 1 ERT interpretation and their reflection coefficient (Rc)

Location	No. of layers	Res (Ωm)	Thickness (m)	Rc	Geology
SMKA Klang	1	820	25		
	2	1100	75	0.70	Sandstone / Siltstone
	3	200	30		
Masjid Hasanah, Bangi	1	900	20		
	2	150	12.5		Sandstone
	3	500	12.5	0.41	

Table 2. Borehole drilling results

Locations	BHID	Depth of BH (m)	Depth to bedrock (m)	BH yield (l/m)	Static water level (m)	Status of BH	Geology
SMKA Sultan Hishamuddin, Klang	BKTP/BAT/2020/1	100	46	336	1.5	Succesful	Sandstone/ Siltstone
Klinik Cheras	TW2	33	13.5	73	1.8	Succesful	Granite
Klinik Beranang	BHLTP03	93	20	108	7.03	Succesful	Granite
Masjid Al-Hasanah, Bangi	BHLTP05	81	36	265	4.5	Succesful	Sandstone

layers indicated by the electrical resistivity tomography (ERT).

For instance, the ERT analysis at Masjid Al-Hasanah, Bangi. The suppression of thin layers or even thicker layers at greater depths may be causes for this ambiguity (as the resolution decreases). When a low resistive layer is placed between higher conductive layers, and vice versa, this suppression issue arises. As a result, thin layers with low resistivity contrast against the background won't be noticeable [16]. This is demonstrated by the model findings from the Masjid Al-Hasanah in Bangi, where two (2) layers with significantly greater resistivities 900 Ωm and 500 Ωm, respectively are sandwiched between a relatively low resistive layer (150 Ωm). Given the small resistivity contrast in this instance, it is possible that there are other low resistive layers sandwiched between these two (2) layers that could not be detected. As a consequence, the drilling findings revealed four (4) layers, contrary to the ERT's prediction of three (3) at this location (Masjid Al-Hasanah, Bangi). The discrepancies in the layer prediction by the ERT may have been caused by this suppression issue and other unanticipated human mistakes.

On the other hand, around 25% of the layers estimated by the ERT agreed with the borehole logs. This is proven by the outcomes from Klinik Beranang, which both indicated the presence of three (3) layers (see Table 3). To determine the relationship between the ERT predictions on the number of layers, depth to bedrock, and overburden thickness, the ERT and the drilling logs were compared. The details of the relationship between these aforementioned characteristics are shown in Figure 5a–c. It is clear that the anticipated depth to bedrock by the ERT and the borehole logs have a significant connection (r2 = 0.9478). (Fig. 5a). High resistivity difference between the bedrock surface and the loose overburden material, which makes it simple for the ERT to find it in contrast to layers

Table 3. Comparison between driller log and geophysical

Locations	Number of layers		Depth to bedrock (m)	
	ERT	BH drilling	ERT	BH drilling
SMKA Sultan Hishamuddin, Klang	3	4	50	46
Klinik Cheras	4	4	12	13.5
Klinik Beranang	3	4	18	20
Masjid Al-Hasanah, Bangi	3	3	30	36
UPNM	3		60	

with similar or low resistivity changes, is the cause of this strong association. Due to suppression of tiny layers or due to low resolution at depth, there was no significant association between the layers predicted by the ERT and those of the borehole logs. The plot of SWL vs borehole depth (Fig. 5c) once more revealed a poor association ($r^2 = 0.145$), suggesting that the depth of the boreholes may not always influence the static water levels in the research area. When the borehole yield was plotted against the drilling depth (Fig. 5b), a substantial correlation gradient was visible ($r^2 = 0.4351$). The sealing of possible fracture zones during borehole construction may be the cause of the observed loss in yield with respect to depth [21]. It could also imply that the secondary porosity of the rocks in the region represented by fracturing/weathering is distinct, occurs at different depths, and has different water-holding capacities.

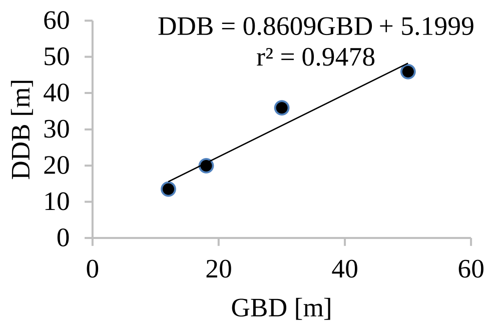


Fig. 5a A plot of drilling depth to bedrock (DDB) against geophysics depth to bedrock **(**GDB**).**

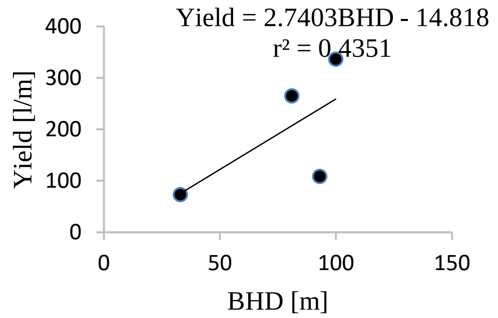


Fig. 5b A plot of borehole yield against borehole depth (BHD).

4.0 CONCLUSIONS

At the site, two (2) profile lines of measurements were conducted at the proposed area within the National Defence University of Malaysia. From the results, water containing zone interpreted approximately about resistivity values below 100 Ωm and chargeability values below 7.5 ms. Integrated with the induced polarization profile, low chargeability values make survey line 1 have

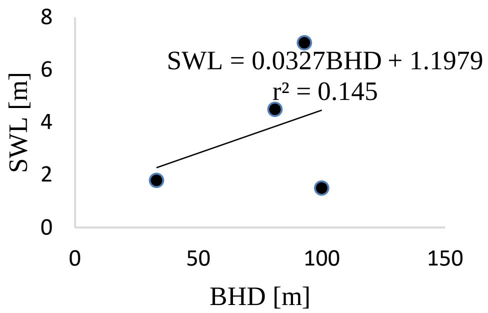


Fig. 5c A plot of static water level (SWL) against borehole depth (BHD)

more potential in terms of the water-containing zone. Thus, survey line 1 gives a higher chance of groundwater containing zone than survey line 2. Also, the porosity and permeability of sediments; clay, silt and sand indicate the presence 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. Validation of the test drilling with the ERT's prediction of the depth to bedrock at four selected locations shows the correlation was in close agreement with the correlation coefficient value (R^2 = 0.9478). The ultimate drilled depth and borehole yield, on the other hand, revealed a poor connection (R^2 = 0.4351) in the research.

Finally, the combined geophysical method findings have demonstrated to be beneficial in defining the groundwater potential zone, identifying prospective drilling locations, and revealing geological features such cracks and/or fissures via which both deep and shallow groundwater can be combined. As a result, this study may be utilized to provide a much more comprehensive knowledge of the types of groundwater potential in the area and how they relate to the regional geology. In a nutshell, with the help of the information this research offers, it is possible to gain a deeper knowledge of the types of groundwater potential in the alluvium and hard rock environment and how they relate to the surrounding geology. Some recommendations for further studies are more borehole wells purposes should be drilled due to a better understanding of the groundwater at the study area.

5. ACKNOWLEDGMENTS

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