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Delineation of Groundwater Potential Zones Using 2-Dimensional Electrical Resistivity Imaging at Universiti Sains Malaysia, Penang, Malaysia

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Abstract

Groundwater exploration is increasing in demand, including use in the domestic, industrial and agricultural sectors. The extracted groundwater is an alternative water supply in these sectors. However, there has also been unsuccessful groundwater exploration due to limited subsurface information. Therefore, geophysical methods were applied to obtain subsurface information to determine and classify the subsurface materials using selected geophysical properties. This research aims to evaluate the delineation of potential groundwater zones using 2D electrical resistivity imaging in Universiti Sains Malaysia, Penang Island, Malaysia. Nine resistivity survey lines are conducted within the research area in USM. The geology of the research area is underlain by igneous rock with a centrally located granitic range running in a north-south direction with low-lying elevations ranging from 5 meters to 20 meters above sea level. The electrical resistivity method measures the resistivity distribution by injecting a small current into the ground through two current and potential electrodes, respectively. The voltage reading is measured between two active potential electrodes alternatively. The instrument used for this research is an automated multi-electrode resistivity meter, ABEM Terrameter SAS 4000 system. Apparent resistivity values undergo an inversion process using RES2DINV software to produce the electrical resistivity topography model. The results show the resistivity values ranging from 1Ùm to 20000Ùm. The subsurface materials are classified into four subsurface materials according to the resistivity values ranges: water-saturated zones, topsoil, weathered bedrock, and fresh bedrock. Several anomalies are interpreted as potential water-saturated zones within the project area and suggested as proposed drilling locations for the groundwater drilling program. The extracted groundwater can act as an alternative source for water supplies in Universiti Sains Malaysia.

Keywords: *Geophysics; 2D electrical resistivity imaging; groundwater exploration; granitic*

1.0 Introduction

A clean water supply is essential for public health, whether used for drinking, domestic use, sanitation, food production, and/or industrial purposes. Penang's water supply is regulated by the Department of Irrigation and Drainage Penang, while the water operator is PerbadananBekalan Air Pulau Pinang (PBAPP). Penang's water supply depends on two dams: Air Itam Dam, TelukBahang Dam, and the Muda River. According to PBAPP, eighty per cent (80%) of the raw water supply for Penang comes from the Muda River. However, the El Nino phenomenon and insufficient rainfall caused a significant decrease in the water level of the Muda River in 2021[1]. Ayer Itam Dam and TelukBahang Dam also show a trend of declining dam capacity due to this phenomenon. Water supply disruption will occur if such phenomena recur and are extended for longer periods because

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the water supply in USM entirely depends on the PBAPP.

According to USM's Financial Report, USM needs around 417 million liters per month (14 MLD) for water consumption on the main campus. This high consumption rate causes the USM to spend approximately RM 1 million yearly to pay water bills tariff. Therefore, this study was conducted to find alternative water sources in USM as an alternative water source. Besides, the reduction of the expenses in water bill payment can help USM operate in optimum operation.

Electrical resistivity methods are most commonly geophysical methods applied for groundwater exploration. The resistivity method can be applied in many stages of research, from the preliminary, reconnaissance, regular or periodic maintenance stages. The electrical resistivity method is chosen because it is sensitive to small changes in the resistivity value of the subsurface materials. The ability to detect small changes in value helps to analyze the type of subsurface material more accurately. It also efficiently covers a wide area of data and is non-destructive to the environment. The resistivity values depend on several factors, such as earth-forming minerals, porosity, quantity and nature of the porosity fluid, and ground temperature[2]. The measured apparent resistivity is measured during data acquisition and undergoes an inversion process to produce the subsurface resistivity tomography. The tomography is interpreted according to the resistivity value ranges of subsurface materials.

2.0 Study area

The study area is Universiti Sains Malaysia's main campus in Gelugor, Penang Island. The central part of Penang Island is a mountainous granitic range running in a north-south direction[3]. Coastal areas of Penang Island are underlain by the Simpang Formation, Gula Formation, and Beruas Formation. The Pleistocene Simpang Formation consists of gravel, sand, clay, and locally silt and peat and has been interpreted as a terrestrial fluvial deposit. The lithology of the Gula Formation consists of silt, clay, sand, gravel, and peat, often containing shell fragments. The Holocene Beruas Formation is a fluvial deposit comprising sand, gravel, clay, silt, and occasional peat[4]. The geological map was generated using ArcGIS software with geological information obtained, as shown in Fig.1.

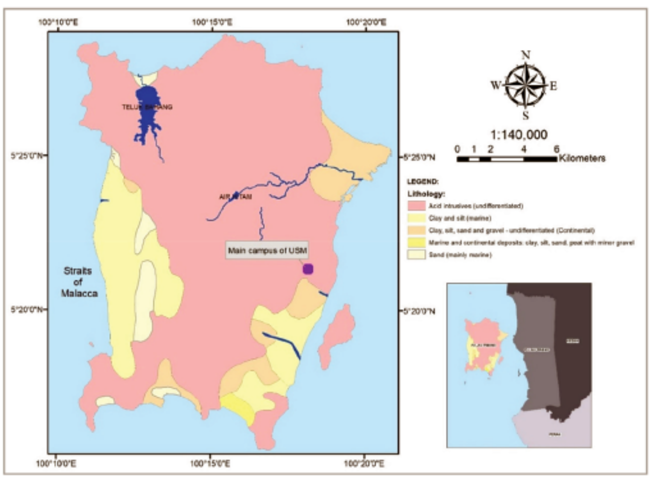

Figure 1: The geological map of Penang Island

The study area is Universiti Sains Malaysia's main campus in Gelugor, Penang. The topography is plain, with elevations ranging from 4 to 11 meters. Nine surveys were conducted within the USM Campus, ranging from 200m to 400m (Fig. 2). Survey line RL01 is laid out behind the animal house (L15), and the starting point of survey line RL03 is laid out at 240m of RL01 extended until behind Indah Kembara student's residence (K10). Survey line RL02 is set up along the tennis court while 75m of survey line RL09 intersects at 200m of RL02. Survey line RL04 is laid out along the TasikAman.

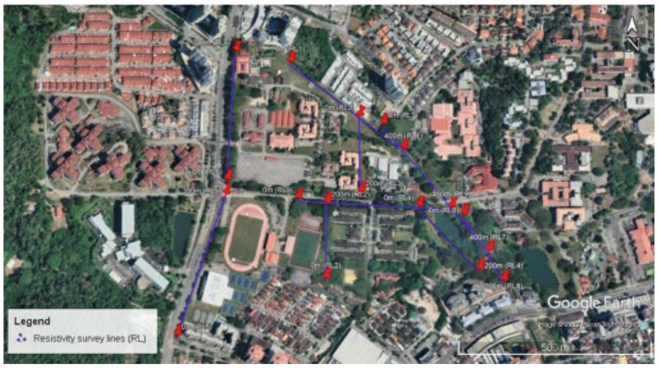

Figure 2: Location of resistivity survey lines within the main campus of Universiti Sains Malaysia (USM)
(Source: Google Earth, February 2021)

Table 1: The electrical resistivity survey lines parameters

No lines	Electrode protocol	The total length of the survey line (m)	Estimation of the depth of data (m)
RL 01	Wenner Schlumberger	400	70
RL 02	Pole dipole	200	70
RL 03	Wenner Schlumberger	200	35
RL 04	Pole dipole	200	70
RL 05	Pole dipole	390	125
RL 06	Pole dipole	340	125
RL 07	Pole dipole	400	125
RL 08	Pole dipole	200	70
RL 09	Pole dipole	400	125

Survey lines RL05 and RL06 were set up along the main road near the Bukit Gambier main entrance. Survey lines RL07 and RL08 are laid out between TasikAman and Tasik Harapan. Table 1 shows the electrical resistivity survey lines parameter for this study.

3.0 Methodology

3.1 Resistivity values

A resistivity survey is relatively sensitive to small changes in resistivity variation, which allow for determining the subsurface materials and geological mapping features such as fractures, faults, and cavities. For groundwater exploration in a granitic environment, fractures and faults increase the possibility of groundwater filling the pore spaces of rocks. The porosity of rocks also influences the degree of water saturation, thus affecting the resistivity values of some types of water, as shown in Table 2[5].

Table 2: The resistivity values of some types of water

Types of water	Resistivity
Precipitation	30-1000
Surface water, in areas of igneous rock	30-500
Surface water, in areas of sedimentary rock	10-100
Groundwater, in areas of igneous rock	30-150
Groundwater, in areas of sedimentary rock	>1
Seawater	≈ 0.2
Drinking water (max salt content 0.25%)	>1.8
Water for irrigation and stock watering (max sat content 0.25%)	>0.65

The measurement principle for resistivity survey is carried out by transmitting a controlled current between two electrodes planted into the ground while simultaneously measuring the potential between two potential electrodes [6].The resistance (R) is calculated using Ohm's Law as in Eq.1 :

$$R = \frac{V}{I} \quad \text{... (1)}$$

R = Resistance (Ohm),

V = Electric Potential (Volts), and

I = Current (Ampere).

The apparent resistivity (ρ_a) is calculated from the measured current (I) and potential (V) and electrode configuration coefficient or known as geometric factor (G) by the following formula:

$$\rho_a = G\,\frac{V}{I} \quad \text{... (2)}$$

ρ_a = Apparent resistivity (Ohm),
V = Electric potential (Volts), and
I = Current (Ampere).

The electrodes are set up at constant intervals along each survey line. The electrode configuration influences the data resolution, data sensitivity to lateral and vertical changes, and the depth of data penetration. A pair off two electrode is called as dipole. The electrode separation coefficeint (n) for pole dipole is the ratio of the distance between the current dipole potential and potential dipole while the electrode spacing (a). The electrode configuration used in this survey is pole-dipole and Wenner-Schlumberger. Pole-dipole electrode configurations are chosen due to good vertical data coverage, while the Wenner-Schlumberger electrode configuration is moderately sensitive to vertical and lateral structures[7]. Fig.3 shows the electrode configuration of pole- dipole, while Fig.4 shows the electrode configuration for Wenner-Schlumberger.

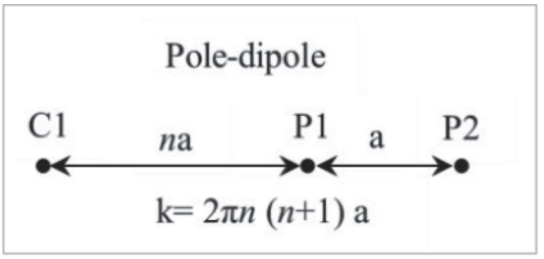

Figure 3: Electrode arrangement for pole – dipole array

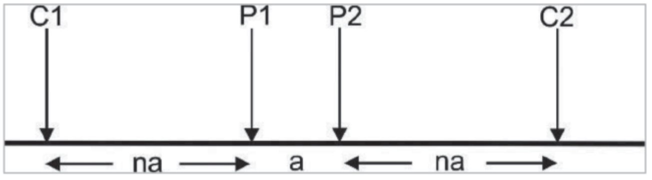

Figure 4: Electrode arrangement for Wenner-Schlumberger array.

3.2 Instrumentation and data acquisition

The instrument used for this survey is an automated multi-electrode resistivity meter, ABEM Terrameter SAS400 system, Electrode Selector (ES10-64C), Lund multicore cables, stainless steel electrodes, and jumper or clips, as shown in Fig.5[7]. Two or four multicore cables with 21 take out each and stainless steel electrodes are clipped using a jumper, then connected with a Terrameter SAS4000 system for the data acquisition[6].

The initial step of resistivity survey is to determine the suitability of ground condition and any potential sources that

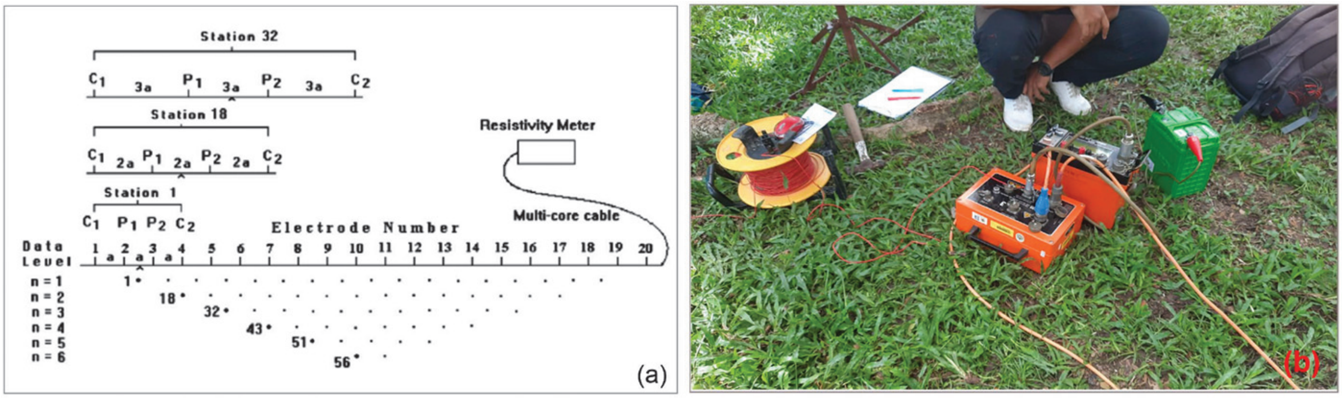

Figure 5: (a) shows the principle of the resistivity methods[7], while (b) shows the resistivity field setup

can disturb the resistivity data measurement such as electricity powerline, radio transmission tower, or any underground cable. Before the resistance measurement, an electrode checking procedure is carried out to detect electrode contact and grounding to allow the flow of current for data measurement to occur properly. During the resistivity measurement, the minimum and maximum current used for this survey is 2mA and 20mA accordingly. The data is stacking twice to improve the signal-to-noise ratio because random noise is averaged out.

After the completion of data acquisition, ABEM Terrameter SAS4000 is connected to a compatible computer to retrieve measured resistivity data. The measured data saved in a binary format with file extension (.s4k) are converted to the readable data format (.dat) for data processing. The information obtained in the data includes survey name, electrode spacing, electrode array used, the total

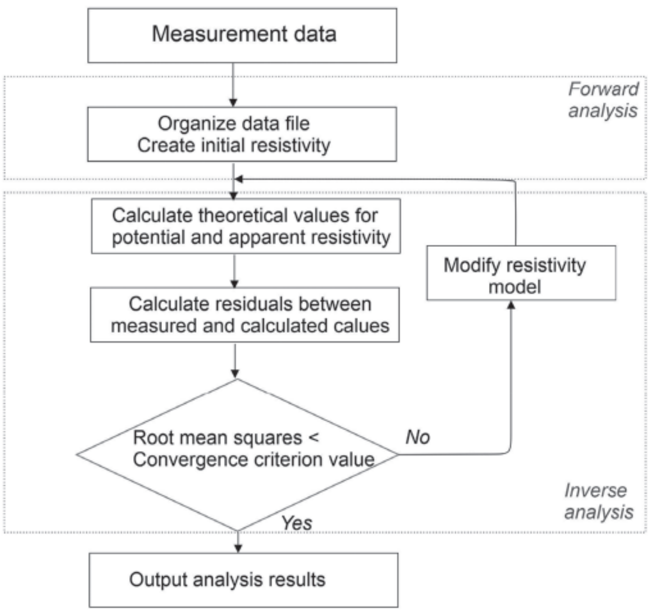

Figure 6: Analysis procedure and check items[8].

number of measured data, and type of resistivity measurement. Electrode location, electrode spacing, and apparent resistivity (ρa) values for each measurement also appeared in each resistivity data file.

3.2 Data processing

Resistivity data undergoes an inversion process to produce the electrical resistivity pseudo section using RES2DINV software[7]. Data processing included the theoretical calculation of the potential Finite Different Method (FDM) and Finite Element Method (FEM). The quality of the inversion result is proportional to the quality of the measured resistivity data. It is indicated by the Root Mean Square (RMS error) on the inverted resistivity models, which is determined by computing the residuals between the measured and computed apparent resistivity values[8]. Fig.6 shows the steps for analysis procedure for data processing.

4.0 Results and Discussion

There are four existing boreholes within the main campus of USM, as shown in Fig.7. The first borehole (BH 01) is located

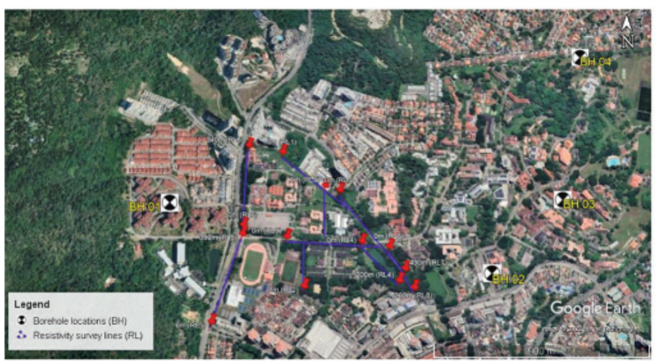

Figure 7: Location of boreholes within the main campus of Universiti Sains Malaysia (USM)
(Source: Google Earth, February 2021)

at the Restu student's residence. In contrast, the second borehole (BH 02) is located at Eureka Complex. The third borehole (BH 03) is located at the School of Communication, while the fourth borehole (BH 04) is located near the USM guest house.

Information obtained from boreholes records was correlated with electrical resistivity profiles to support the interpretation of resistivity results accurately. According to the boreholes record, the study area's subsurface is alluvial deposits consisting of sandy silt, silty sand, clayey sand, and granitic bedrock. The top of granitic bedrock is found at various depths ranging from 15 meters to 33 meters. The thickness of this topsoil varies for all boreholes. The detailed description of each borehole record is shown in Fig.8.

Depth (m)	BH 01		BH 02		BH 03		BH 04	
	LITHOLOGY	SPT	LITHOLOGY	SPT	LITHOLOGY	SPT	LITHOLOGY	SPT
0	sandy SILT	7	Clayey SILT	0	CLAY	0	No recovery	0
1.50	silty SAND	14		7	sandy SILT	9		6
3.00	sandy SILT	17		4		29	Sandy SILT	9
4.50	silty SAND	32	SAND	5	SILT	21	SAND	8
6.00	sandy SILT	35		23	sandy SILT	15	Sandy SILT	10
7.50	SAND	50		15		15		9
9.00		50		10		13		11
10.50	silty SAND	50		9		17		14
12.00		50		7		15		16
13.50		50		9		18		17
15.00	fractured GRANITE	C		6		21		18
16.50				7		22		15
18.00			no recovery	7		22	Silty SAND	18
19.50			silty CLAY	7		22	Sandy SILT	20
21.00			clayey SILT	8		18		21
22.50				11		15		18
24.00				16		18		17
25.50			sandy SILT	17		21	silty SAND	20
27.00				20		35		23
28.50				28		50	Sandy SILT	20
30.00			GRANITE	C		50	silty SAND	26
31.50						50		50
33.00						50	Weathered GRANITE	C
34.50						50		
36.00								
37.5								

Figure 8: Soil profiles of boreholes records BH 01, BH 02, BH 03 and BH 04.

Fig.9(a) to (i) show the electrical resistivity profiles of survey lines RL01 and RL09, respectively. Generally, the subsurface materials are divided into four zones according to their range of resistivity values. Low resistivity value is interpreted as water-saturated zones with resistivity values ranging from 1 Ωm to 300 Ωm, while low to intermediate resistivity value is interpreted as topsoil with resistivity values ranging from 300 Ωm to 500 Ωm[5]. Intermediate to high resistivity values are interpreted as weathered bedrock with resistivity values from 800 Ωm to 2000 Ωm, while fresh granitic bedrock is interpreted with resistivity values higher than 2000 Ωm[9].

The upper layer of resistivity profiles of survey line RL01 (Fig.9a) is interpreted as water-saturated zones (1 Ωm to 300 Ωm) extended until the depth of 20 meters. Fresh bedrock with resistivity values higher than 2000 Ωm was also found at depths from 30 meters to 70 meters and spread along the

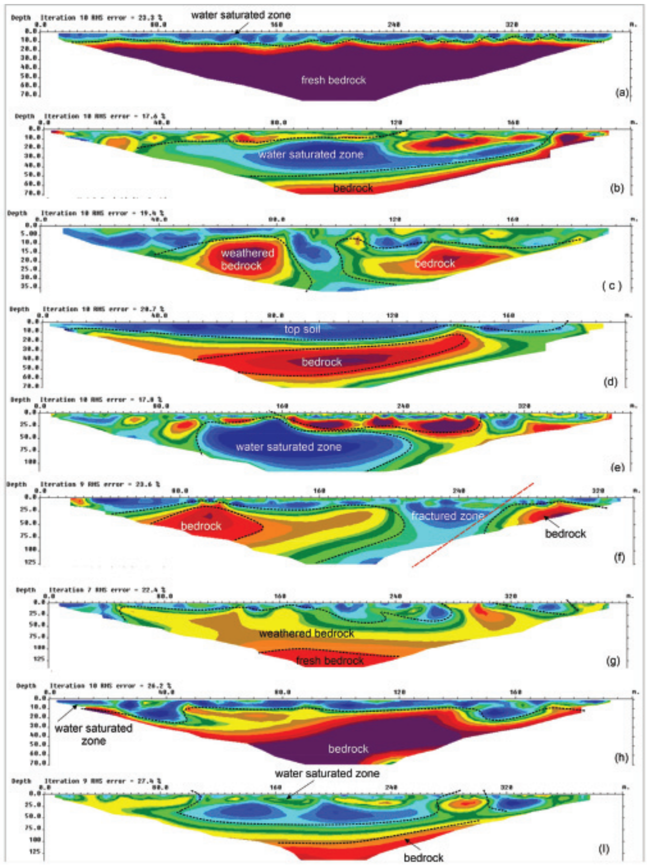

Figure 9 (a) to (i): 2D Electrical resistivity profiles of survey lines RL01 to RL09, respectively

survey line. Survey lines RL02 (Fig.9b) consist of water-saturated zones with resistivity values of 1Ωm to 300 Ωm from surfaces until a depth of 50 meters[10]. This zone is a suitable potential for groundwater exploration. High resistivity values interpreted as fresh granitic bedrock are undulating along the survey line with depths varying from 10 to 70 meters. Survey line RL05 profile (Fig.9e) shows a similar resistivity to RL02. The top layer is heterogeneous with large resistivity variation of the subsurface material. Water saturated zone of resistivity value below 300 Ωm is visible at depths from 25 meters and between lateral distances of 100 and 240 meter. This zone is a favourable potential for groundwater exploration.

At the center of the profile, RL03 (Fig.9c) shows a sharp contrast of structural features from surface to depth of 35 meters, interpreted as the fractured zone. This structure separates high resistivity zone at distances of 40 to 80 meters and 105 to 160 meters. Fig.9f shown a similar sharp structural fracture zone at a distance of 200 to 280meter of survey line RL06. This fractured zone filled with a highly water-saturated zone has the potential for groundwater aquifer[11].

Survey line RL04 reflects a homogeneous layer with resistivity values ranging from 300 Ωm to 500 Ωm interpreted as topsoil (Fig.9d). The high resistivity value extended along the survey line has a sharp structure similar to an intrusion of granitic rock. The extension of the low resistivity value zone at a depth of 70 meter from a distance of 100m of the survey line could not be determined due to the limited depth of data. Survey line RL08 (Fig.9h) shows a similar resistivity profile to survey line RL04. High resistivity granitic bodies are extended along the survey line.

Water saturated zone with resistivity values of 1Ωm to 300Ωm are found from 100 meters to 240 meters of survey line RL05 (Fig.9e). The water-saturated zone depth is 25 meters to 125 meters of survey line RL05. A proposed drilling location for groundwater exploration is suggested in this area.

Survey line RL07 (Fig.9g) shows the gradual increase in resistivity values zones with depth. From the surface to a depth of 25 meters, a low resistivity value zone is interpreted as heterogeneous topsoil. A medium to high resistivity value zone is interpreted as weathered bedrock extended to a depth of 75 meters. The high resistivity values zone is interpreted as fresh bedrock from the depth of 75 meters until 125 meters. This fractured zone is an appropriate location for groundwater exploration.

Survey line RL09 also shows the gradual increase of resistivity values with depth (Fig.9i). Low resistivity water-saturated zone is found at shallower depths from 25 to 75 meter. This location is also suitable for groundwater exploration due to the larger water-saturated zone compared to other resistivity profiles. A high resistivity value body at a distance of 280 to 305m with a depth of 25 meter is interpreted as a rind structure[12].

5.0 Conclusion

2D electrical resistivity methods are successfully carried out to determine the delineation of groundwater potential zone in a granitic hard rock formation in USM. From the electrical resistivity results, it can be concluded that the subsurface materials consist of heterogeneous topsoil, water-saturated zones, weathering bedrock, and fresh granitic bedrock. The fractures in granitic rocks allow the water to accumulate; thus, the saturated zone becomes the potential for groundwater aquifer. There is also a possibility of extension of the aquifer with a depth of more than 125 meters which can be determined for deeper groundwater exploration.

Test wells will be built to obtain geological and hydrogeological information and collection of groundwater samples. Groundwater chemical analyses are also important to identify the chemical composition of groundwater. The groundwater quality is also analyzed to ensure the groundwater is safe for domestic use and to comply with groundwater quality standards.

6.0 Acknowledgement

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