Electrical Resistivity Technique for Groundwater Exploration in Quaternary Deposit

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Abstract. The water security for University Tun Hussein Onn (UTHM) campus was initiated to find alternative sources of water supply. This research began with finding the soil profiles using the geophysical electrical resistivity method across UTHM campus. The resistivity results were calibrated with previous borehole data as well as via groundwater drilling. The drilling work was discovered the groundwater aquifer characterized by the fractured fresh igneous rock at a depth between 43 meter and 55 meter. Further drilling was continued until 100 meter in depth. However, due to not encounter a new rock fractured zone causes the groundwater quantity did not improve even was drilled up to 100 meter depth. In the perspective of water resources, it showed a good potential for water resources for local usages at 104 m³ per day. In addition, the groundwater quality showed the water treatment was required to fulfil the criterion of the national drinking water standards. This study concluded that the first layer of fractured bedrock at UTHM was able to produce significant amounts of groundwater for local consumption usage.

1. Introduction
The exploration for groundwater at Universiti Tun Hussein Onn Malaysia (UTHM) campus was initiated due to intention to prevent a problem in the water supply. In relation to this problem, the second alternative for water supply is needed to overcome that issue. This tube well exploration involved three stages; (1) subsurface investigation, (2) drilling, and (3) water quantity and quality assessment. Subsurface investigation was purposely to identify a layer of the aquifer via geophysical electrical resistivity method. The resistivity method was adopted for scanning the subsurface in order to obtain a 2-dimensional ground profile. This method measures the resistance of the direct electrical current travel through the soil. The resistivity values were then utilized to interpret and correlate the soil properties such as density, porosity and quality of groundwater [1][2][3][4]. Second stage was involved the groundwater drilling, a part of constructing a tube well. The drilling output was used to calibrate the electrical resistivity values with the soil properties. Finally was the assessment on groundwater quantity and quality. The aim of this study was to determine the potential of groundwater as alternative resources for UTHM campus usage. Generally UTHM campus has flatted topography. Geological aspect shows in Figure 1, where UTHM was surrounded by marine clay deposit known as Quaternary deposit [5]. This soil formation was characterized as unconsolidated sediments and largely covered at area of Western Johor coastline. It lies from Muar to Kukup and covering the area of 15 km
to 25 km wide. Igneous intrusive rock occurs in an area of Batu Pahat in the west, meanwhile over-consolidated sedimentary in Triassic-Jurassic aged at Ayer Hitam, eastern part of UTHM campus.

![Geological Map](https://example.com/geo_map.png)

**Figure 1.** Geological map of study area [5].

Soil profiling based on boreholes was carried out by Tenaga Gerudi for the purpose of UTHM’s development [6]. The total numbers of 6 boreholes were drilled to reach hard material, which was indicated by standard penetration test (SPT) more than 50 blows before it terminated. The first layer was characterized from very soft to soft silty clay soil with standard penetration test SPT N blows less than 4 about 16 m depth. For the second layer, at depth of 16 m to 30 m was characterized as firm to very stiff clayey silt soils. Finally, with SPT N blows more than 50 at 30 m deep. Table 1 summarized the borehole profile based on standard penetration and resistivity values. However, hard layers were varied between boreholes which the shallowest was 21 m at borehole 3 and the deepest was 30 m at borehole number 6.

**Table 1.** Summary of borehole profile.

| Soil profile categories          | Depth, m | Standard Penetration Test, SPT (N-blow) | Resistivity, ohm.m |
|----------------------------------|----------|----------------------------------------|--------------------|
| Very soft to soft (SPT: 0-4)     | 0 – 16.0 | < 4                                    | < 10               |
| Firm to very stiff (SPT: 4-30)   | 16.0 – 30.0 | 4 - 30                                  | < 10               |
| Hard layer (SPT: >30)            | > 30.0   | > 50                                   | > 10               |
2. Geophysics electrical resistivity

The resistivity values for rocks and soil materials are significantly dependent on the degree of fracturing, porosity of the rock, and the salinity of the groundwater as shown in Table 2. The resistivity value is different between dry and wet material, and thus is useful for locating the groundwater. In addition, the resistivity of groundwater is controlled by dissolved salt and can be varied between 0.05 ohm.m for saline groundwater to 1000 ohm.m for glacial melt water [7]. New technology in geophysical exploration, especially in electrical resistivity has inspired scientific study on groundwater exploration. The study is able to produce the subsurface resistivity in 2-dimension image. The tube well drilling location was decided via interpreting the surface geological mapping and electrical resistivity results.

Table 2. Typical values of resistivity of different types of rocks, soils and water [1].

| Rock Type                        | Resistivity (ohm.m) | Rock Type          | Resistivity (ohm.m) |
|----------------------------------|---------------------|--------------------|---------------------|
| Distilled water                  | 10000               | Alluvium and sands | 10-800              |
| Natural waters in soil           | 100                 | Seawater           | 0.2                 |
| Natural waters in igneous rocks  | 0.5-150             | Unconsolidated wet clay | 20                  |
| Natural waters in sediments      | 1-100               | Clays              | 1-100               |

In applying for this study, two survey lines were involved near the proposed tube well. The Wenner Long-Short protocol was decided and conducted for all survey lines. The ABEM SAS4000 instrument was used in this study. Since the survey route located in the flatted surface area, thus the topography correction is not necessary. Figure 2 shows the typical setup for a 2-dimensional survey with a number of electrodes along a straight line attached to four multi-core cables. Normally a constant spacing between adjacent electrodes is used. The multi-core cable is attached to an electronic switching unit that is connected to a computer. The sequence of measurements to take, the type of the array to use and other survey parameters such the current to use is normally entered into a text file which can be read by a computer program on a computer. After reading the control file, the computer program, then automatically selects the appropriate electrodes for each measurement.
3. Result of electrical resistivity survey

Line 1
The resistivity imaging result in line 1 was covered about 300 m in length and 52 m depth as shown in Figure 3. Based on the resistivity imaging profile, there were two major layers present on the survey area. The approximated borderline between these two layers was at a depth of 40 m. The top layer with a low bulk resistivity value less than 10 ohm.m with depth and followed by material with bulk resistivity more than 10 ohm.m.

Figure 3. Bulk resistivity values larger than 10 Ωm after depth of 40 m for line 1.

Line 2
The resistivity imaging result in line 2 was covered about 380 m in length and 60 m depth as shown in Figure 4. Based on the imaging section, there were two major layers present on the survey area. The approximated borderline between these two layers was at a depth of 30 m. The top layer with a low bulk resistivity less than 10 ohm.m and followed by material with bulk resistivity more than 10 ohm.m.
4. Drilling of tube well

The result of bulk resistivity values shows more than 10 Ωm for layer deeper than 40 m and 30 m based on the result of line 1 and 2 respectively. At vicinity proposed tube well, the soil profile from previous borehole by Tenaga Gerudi was calibrated with resistivity values as tabulated in Table 1. The results showed at a depth of 30 m was identified as hard layer and was calibrated has bulk resistivity values more than 10 ohm.m. The bulk resistivity was an average value of the resistance current travel laterally and vertically, which measured by potential electrodes. Thus, it was not definite resistivity value of the material at a certain depth. Due to the hard material has bulk resistivity larger than 10 Ωm (see Table 2), meanwhile for the fresh groundwater resistivity values between 10 Ωm to 1000 Ωm. Therefore, it was interpreted that positive result to obtain fresh groundwater in this area. From this justification, decision to drill tube well at this location was made.

The drilling of tube well was using two methods according to a type of ground; a mud rotary method and hammer percussion which are drilled through soft deposit and rock respectively. The diameter of drill bits is 240 mm and 140 mm used in soil and rock respectively. Sampling was carried out during open-holing via collecting the material abraded away at the bottom of the borehole, as it emerges mixed with flush fluid at the top of the hole. Visual observation of that samples show at depth 0 m to 3 m was blackish grey clay; 3 m to 10 m was greenish grey clay with a trace of shell of fossil. This layered was identified as very soft to soft. Continuous drilling at depth 10 m to 22 m was reddish white clay with occurrence of iron gravel. At depth of 22 m to 43 m greyish white of clayey sand layered. At depth 39 m to 43 m, shows in-situ rock weathering with existing quartz mineral. Began at depth 43 m was fresh bedrock and recognized as an extrusive igneous rock with the occurrence of porphyritic texture, a feldspar mineral as phenocryst. At this layer, groundwater was determined. The rock layer shows highly rock fractures, thus considered as an aquifer layer. This aquifer was located between 43 m and 55 m depth. The drilling activity was continued which hoping to obtain second aquifer. However, after drilling beyond 55 m in depth, the rock was less fractured compared with previous rock layers. Then drilling was decided to terminate at 100 m in depth due to no improvement in water quantity.
5. Pump test and water quality
The tube well was constructed until 100 m deep which first 43 m drilling deep (in soil) using 0.2 m casing diameter and the rest of the 57 m without the casing with smaller diameters (in rock). It stands alone by hard rock stabilization. The pump test study was performed by Musa et al. [8][9] for investigating the water quantity and quality. The well pump test was performed by installation 2 hp (horse power) of submersible pump to 42 m depth as shown in Figure 5.

![Submersible pump installation into the tube well.](image)

**Figure 5.** Submersible pump installation into the tube well.

Pumping test was indicated that the well had a sufficient amount to withdrawal for water distribution. This test was pumped from the well at certain time long at least 4 hours and above to determine the tube well characteristics. Normally, a continuous drawdown method widely used to character the tube well system. This performed by manually pumped the groundwater for 4 hours long and then the pump was stopped to recover naturally. During a natural recovery, time was recorded until the groundwater back to the original level. These activities were shown in Figure 6 as pumping and recovery took 240 and 1200 minute, respectively. This pattern also showed that the area had the unconfined layer for limited pore layers. According to well testing, the groundwater was able to produce more than 104 m³ per day. This condition influenced by design of well screened to water input into the tube well case.
The water quality study was conducted in two seasons, wet and dry. Wet season was conducted in November and dry season was conducted in Jun. Based on naturally concept, water was pumped and commonly filtered by soil and rock layers in it moving action. Minerals and particles contacted with groundwater were contributed to the groundwater freshness and flow movement. The water quality results at different seasons are shown in Table 3 by comparison with National Water Drinking Quality Standards (NDWQS).

**Table 3.** Water quality monitoring during two season a year [10].

| Parameter                  | Weather | Standard  | Methods        |
|----------------------------|---------|-----------|----------------|
|                            | WET     | DRY       | NDWQS          |
| Temperature ( °C )         | 27.32   | 28.32     | 27-31          |
| pH                         | 5.85    | 6.36      | 5.5-9          |
| Turbidity (NTU)            | 157.40  | 11.23     | 0-5            |
| Conductivity ( mS/cm)      | 0.03    | 7.38      | 0 - 1000       |
| Salinity ( ppt)            | 0.01    | 3.78      | 0.5-2          |
| Chlorine (ug/L)            | 19.95   | 16.43     | 250            |
| DO (mg/L)                  | 5.85    | 9.77      | 3.0-7.0        |
| Zinc (mg/L)                | 0.062   | 0.01      | 0 - 3          |
| Cadmium (mg/L)             | 0.01    | 0.05      | 0.003          |
| Mangnese (mg/L)            | 8.5     | 0.01      | 0 - 0.1        |
| Iron (mg/L)                | 2.58    | 3.3       | 0 - 1          |
| Lead (ug/L)                | 0.09    | 0.2       | 0.01           |
| Copper (mg/L)              | 0.01    | 2.59      | 1              |
| Nitrate (mg/L)             | 9.1     | 0.03      | 0 - 10         |
| COD (mg/L)                 | 43.5    | 160       | 0 - 10         |
| BOD (mg/L)                 | 29.94   | 58.4      | 0 - 1          |
| Nitrogen Ammonia (mg/L)    | 6.05    | 0.15      | 0 - 1.5        |
| TSS(mg/L)                  | 245     | 208       | 8 - 100        |
6. Discussion and conclusion
The bulk resistivity values less than 10 ohm.m on first layer were due to the effect of the Quaternary marine clay deposit. This soil layer is characterized as unconsolidated sediments and covered UTHM’s land area. Underneath the Quaternary deposit was laid the igneous rock originated from volcanic rock based on its porphyritic texture. The bulk resistivity value higher than 10 ohm.m was influenced by the fresh groundwater and fresh fractured rock. Due to the resistivity information constraint up to 55 m depth, therefore further calibration of the rock layer with resistivity value was not obtained.

In conclusion, groundwater exploration using electrical resistivity study is successful to locate the groundwater layered. The groundwater quantity using pump test was 104 m$^3$ per day. The quality of the groundwater was significantly changed with the season and it required the water treatment to fulfil the drinking water criterion. However the continuity and the volume of fractured layer where the groundwater is revealed yet to explore. Thus the aquifer system yet to understand.

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