Electrical resistivity tomography and induced polarization method applied for tubewell development in Alluvial deposit: A case study in MARDI Seberang Perai

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Abstract. Geophysical data through electrical resistivity tomography (ERT) and induced polarization (IP) can be assisted to understanding hydrogeological characteristic of groundwater aquifer. By knowing the difference in electrical resistivity and induced polarization values in alluvium deposition will facilitate to identify any groundwater occurrence. In agriculture sector, shallow tube well will be option to farmers due to more economic. The resistivity measurements proved to be a good tool for mapping the subsurface in the Alluvium, especially when used in combination with Induced Polarization parameters. Alluvial deposits or fluvial deposits are composed of particles of gravel, sand, silt or clay size that are not bound or hardened by permeable mineral, by pressure, or thermal alteration of the grains. Consideration of gravelly deposition is the higher hydraulic conductivity. Furthermore, coarse to fine sand are the second higher followed by silt and clay are the lowest values. From the case study, the electrical resistivity tomography of these deposits ranged from 40 to 1000 Ωm, while the values of chargeability were 0 to 20 mS/m. The bottom of the aquifer consisted of a layer with gravelly sandy silt, and the resistivity was 260 Ωm, while the chargeability was 6.5 mS/m. The shallow tube well in quaternary aquifer was constructed at 51 m depth with thickness of aquifer was 24 m to 51 m depth into the ground will consider for groundwater resources. The groundwater discharge from tubewell is 6.53 m³/hr in mixed gravel, sandy and silt.

1. Introduction

Groundwater basin can be defined as a hydro geological unit containing one large or several aquifers which are interconnected and interrelated [2]. In the valley between mountain ranges groundwater basins may sit in the middle of the river basin. In addition, in areas of limestone and sand dunes, the drainage basin and groundwater basin may have a whole different configuration. Groundwater basin concept is important because the hydraulic continuity that exists for groundwater resources. To ensure the availability of groundwater continues, groundwater exploration is necessary to know the location and the amount of groundwater [7].

Imaging the aquifer layer in alluvial deposition is scientific process to determine the physical properties such as occurrence of groundwater at difference type of soil formation [1]. This information is important from a hydrogeological point of view to estimate the suitable location of tube well...
development. Surface investigations allow us in deciding the information about type, porosity, water content and the density of subsurface creation [4,5].

It is usually done with the help of electrical and induced polarization without any drilling on the ground. The data supplied by this technique are partly reliable and it is less expensive [7]. It gives only indirect sign of groundwater so that the underground hydrologic records must be inferred from the surface investigations. Right interpretation requires additional data from the sub surface investigations to confirm surface findings [8].

An electrical resistivity of rock formations limit the amount of current flowing through the formation when an electrical potential is applied. The resistivity can be defined as the resistance in ohms of a cubic meter unit (Ωm). The resistivity of rock formations vary over a wide range, depending on the material, density, porosity, size, and shape of the pores, the content and quality of water, and also the temperature [6]. There is no fixed limit to the resistivity of various kinds of rocks. Igneous and metamorphic produce a resistivity in the range between $10^2$ to $10^8$ Ωm, while the sediments and non-consolidated rocks which are electrical resistivity ranging between $10^0$ to $10^4$ Ωm [3]. Groundwater contains various dissolved salts and it is ironically conductive, this enables electric currents to flow into ground. As a result, by calculating the ground resistivity it gives the possibility to the availability of water [3]. The induced polarization effect is a measure of soil ability to be polarized when it is under the influence of an electric field; in other words, it means that during the polarization the energy is stored reversibly in the soil. The measurement of IP was carried out.

The study area is located at MARDI Seberang Perai, Jalan Paya Keladi / Pinang Tunggal, Kampung Permatang Durian, 13200 Kepala Batas, Pulau Pinang. The exact location of the area was at longitudes 100°28'22.72"E and latitudes 5°32'33.56"N (Figure 1) with averagely 10 m from sea level. MARDI Seberang Perai was located at Kepala Batas, Pulau Pinang. Kepala Batas climate is classified as tropical. Kepala Batas is a city with a significant rainfall. Even in the driest month there is a lot of rain. The temperature here averages 27.5 °C. The average annual rainfall is 2409 mm. Precipitation is the lowest in January, with an average of 89 mm. Most of the precipitation here falls in October, averaging 392 mm. At an average temperature of 28.1 °C, March is the hottest month of the year. September is the coldest month, with temperatures averaging 27.1 °C. Between the driest and wettest months, the difference in precipitation is 303 mm. Throughout the year, temperatures vary by 1.0 °C. Tube well MARDI Seberang Perai(TWMSP) located at alluvium deposits area. Main lithology at this quaternary deposits are sand, silt, clay and gravels. It is undifferentiated lithology which means unable to distinguish or not possible to specify finer age divisions.
2. Materials and methods

2.1. Electrical Resistivity Method (ERM)

The electrical resistivity imaging was conducted using ABEM Terrameter LS2 (Figure 2) and Lund electrode selector system ES464. For data collection, 41 electrodes were arranged in a straight line with constant spacing and connected to a multicore cable. In data acquisition, there are various types of array that suitable to be applied which depends on several factors. Gradient, Schlumberger, and Pole-dipole were the common array used in investigates the underground layer. The array configuration has a substantial influence on the resolution, sensitivity and depth of investigation.

During data acquisition, pole dipole array was used as this array is capable in imaging deeper profile data and suitable for areas with homogeneous layer. Protocols array with 5 m equal electrode spacing and two cables with total layout length of 200 m was used in interpret the potential shallow aquifer in this study. The factor influences the ERT based on the principle that the earth material is being tested acts as a resistor in a circuit. Inducing electric current to the ground could be differentiating the ability of material to exhibit characteristics of resistivity value. The images of ERT could be presenting the material exist in the ground. Interpreters should analyse the image to identify for existing groundwater.
The location of groundwater obtained from the layer of shallow groundwater based on the image of resistivity. The parameters of interest include location and depth of initial groundwater positions. In order to verify the availability of water in existing subsurface conditions, tube well drilling was implemented. Tube well depth was measured and pumping test was conducted to validate the availability of water obtained from images from electrical resistivity methods.

2.2. Induced polarization (IP)
The Induced Polarization (IP) effect is a measurement of the soil capability to be polarized when it is under the influence of an electric field [1]. For this research, the measurements of IP have been carried out at the same time with resistivity measurement in the time domain [9]. The Time-Domain IP (TDIP) surveys are carried out by transmitting current into the ground while potential difference is measured to determine the resistivity. The potential decay in the ground is measured to access the chargeability of the subsurface. The volt of decay depends on the material and lithology of the alluvial. Therefore, it is often ambiguous to compare chargeability values between different soils characteristic.

2.3. Data processing and inversion
The data ERT and IP were processed by using inversion software RES2DINV version 3.71 from Geotomo software. This program supports several types of arrays, and has been optimized for the inversion of large data sets. The Robust Inversion (L1-norm) option was used as it is less sensitive to noisy data. For the model discretization, a setup of the model refinement with cell widths of half the unit spacing was used. In addition to ERT and IP surveys, data from drilling reports and geophysical well loggings were used in order to validate and interpret ERT results.

2.4. Sampling and well logging
During drilling works, soil sample were collected every 1.5 m drilling and at certain depth, sample were taken only when there are change in lithology. For this tubewell, 27 samples were collected. Lithological borelog was developed for test wells from the soil samples obtained during the drilling process. Soil type information was derived from data in the borelog as shown in Table 1. This result would be help in understanding and interpretation process on the application of geophysical method to detect the groundwater in the alluvial deposits.

| Depth | Geological Log and Soil Description | Particle size Distribution % | Alluvial categories |
|-------|------------------------------------|-----------------------------|--------------------|
| -1.725| Brownish white, gritty, silty SAND  | 49  43  3                  | Silty SAND         |
| -3.225| White, gritty, silty SAND          | 59  41  0                  | Silty SAND         |
| -4.725| Brownish grey, gritty, silty SAND  | 62  2  3                   | Silty SAND         |
| -6.225| Light grey, loose, gravelly silty SAND | 48  25  0               | Gravelly SAND      |
| -7.725| Brick red, very loose, gravelly SAND | 44  22  3                | Gravelly SAND      |
| -9.225| Greyish brick red, stiff, sandy SILT | 13  80  0               | Sandy SILT         |
| -10.725| Pinkish grey, very stiff, sandy SILT | 9  82  3                 | Stiff sandy SILT   |
| -12.225| Brick red, soft, gravelly sandy SILT | 12  75  6                 | Gravelly sandy SILT |
| -13.725| Brick red, coarse grain, sandy SILT | 5  87  3                 | Sandy SILT         |

Table 1. Grain size distribution and physical properties of soils.
-15.225 Brick red, dense, silty SAND 2 49 47 3 Silty SAND
-16.725 Light brick red, loose, silty SAND 6 53 34 7 Loose Silty SAND
-18.225 Yellowish red, fine, gravelly SILT 23 7 66 3 Gravelly SILT
-19.725 Light brick red, fine, sandy SILT 4 7 86 3 Sandy SILT
-21.225 Yellow, fine, gravelly SILT (water color change to yellow) 14 8 78 0 Gravelly SILT
-22.725 Brick red, fine, sandy SILT 10 8 79 3 Sandy SILT
-24.225 Light yellow, fine, sandy SILT 2 16 83 0 Sandy SILT
-25.725 Light yellow, fine, gravelly sandy SILT 2 18 77 3 Sandy SILT
-27.225 Brownish grey, stiff, silty CLAY 0 17 83 0 Silty Clay
-28.725 Brownish grey, very stiff, CLAY 0 14 82 3 Clay
-30.225 White, hard, clayey SILT. (change to hammer bit) 6 8 43 43 Clayey SILT
-31.725 Brownish white, hard, gravelly CLAY 0 11 42 47 Gravelly CLAY
-35.25 White, hard, gravelly CLAY. (occurrence of water) 0 6 61 34 Gravelly CLAY
-45.725 Brownish grey, coarse grain, silty SAND with gravel 17 50 33 0 Sandy GRavel
-47.25 Brownish grey, stiff, sandy SILT 23 46 24 7 Sandy Silt
-50.25 Brownish grey, hard, gravelly sandy SILT 10 7 81 3 Sandy Silt

2.5. Development of tube well
The exploratory drilling has been conducted for a selective site (100°28'22.72"E, 5°32'33.56"N) for well construction. The site selection is choose based on ERT and IP mapping field investigation and near to the corn farm as the groundwater resources will utilize as irrigation. The main purpose of the field visit is to familiarize with the study and surrounding areas. Furthermore, the assessment of the condition of the existing bores, test wells, and monitoring wells are equally important in planning and determination of the proposed new tests location and sampling points in obtaining the adequate data and parameters for the assessment the feasibility and viability of the project.

2.6. Method of pumping test
The pumping test conducted in order to identify the type of aquifer. Pumping test also to verify the optimum discharge of tubewell can be extracted in m³/hr. Pumping test was conducted to verify the ERT and IP result, carried out immediately after the completion of the well construction. Submersible pumps were used to pump the water from the tube wells, and the discharge rates were measured with a weir tank. The valve was installed to control and vary the discharge rates. The method weir tank based on the standard of procedure.

3. Results and discussion
After the surveys and data inversion with high root mean square (RMS), all the displayed surveys present RMS errors lower than 10.0%. The results of ERT and IP surveys are shown; these profile are selected because the resistivity and chargeability value trending to decrease from ranges 1000 Ωm to 200 Ωm, which means it probability zoning of unconfined aquifer at the certain depth 20 m and below is shown in Figure 3.
Figure 3. Resistivity and induced polarization results at Grain Corn Farm, MARDI Seberang Perai.

For the IP, results show from 4 to 10 mS/m chargeability. At the lowest chargeability 6.4-6.7 mS/m the alluvial deposition are gravel, sand and silt, it is similar to findings at Kampung Paya Rawa, Besut [9] where the lithology in sandy, gravel mixed with clay deposits and also the chargeability in between 3-6 mS/m. According to the data recorded, TWMSMSP consists of alluvium deposits which are gravel, sand, silt and clay. Table 2 showed, the first fractured zone was found within clay layer at the depth of 45.725 m with a value of 4.81 m³/hr water and increasing a bit until last depth of 51.0 m with 6.53 m³/hr water. The depth is in between 45 m – 51 m considered as good aquifer to supply the water resources for agriculture purposes. Drilling end at 51.0 m deep and 4inch PVC screen pipe installed at 24.0m – 51.0m. 4inch PVC blank pipe were installed at 0m – 24.0 m in the tube well. This result shows the significant different of the groundwater occurrence at the low in resistivity and induced polarization.

Table 2. Result of resistivity and induced polarization at tubewell borehole.

| Depth  | Resistivity | Chargeability | Remarks       |
|--------|-------------|---------------|---------------|
| -1.725 | 578         | 9.703520956   |               |
| -3.225 | 514         | 9.840996823   |               |
| -4.725 | 488         | 10.02058721   |               |
| -6.225 | 486         | 10.14279908   |               |
| -7.725 | 482         | 10.32589921   |               |
| -9.225 | 475         | 10.37586737   |               |
| -10.725| 465         | 10.33803114   |               |
| -12.225| 450         | 10.18781645   |               |
| -13.725| 429         | 9.9374463     |               |
| -15.225| 406         | 9.660289251   |               |
| -16.725| 380         | 9.3725916     |               |
| -18.225| 350         | 9.089391916   |               |
| -19.725| 325         | 8.851138749   |               |
| -21.225| 300         | 8.633790109   |               |
| -22.725| 280         | 8.443637185   |               |
4. Conclusion
From the case study, the electrical resistivity tomography of these deposits ranged from 40 to 1000 Ωm, while the values of chargeability were 0 to 20 mS/m. The bottom of the aquifer consisted of a layer with gravelly sandy silt, and the resistivity was 260 Ωm, while the chargeability was 6.5 mS/m. The shallow tube well in Quaternary aquifer was construct at 51 m depth with thickness of aquifer was 24 m to 51 m depth into the ground will consider for groundwater resources. The groundwater discharge from tube well is 6.53 m$^3$/hr in mix gravel, sandy and silt. The groundwater resources mainly recharge from the alluvium deposits. In the deep clay marine consists high silt content which is very low yield of groundwater. Instead of resistivity study, Induced polarization also should be considered for determine the groundwater occurrence before development of tubewell. Further deep study on application of induced polarization for detection of groundwater should be continued to determine the accurate location of groundwater.

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