APPLICATION OF 2-D RESISTIVITY AND SELF-POTENTIAL METHODS IN DELINEATING WATER FLOW

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2022

APPLICATION OF 2-D RESISTIVITY AND SELF-POTENTIAL METHODS IN DELINEATING WATER FLOW

by

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Thesis submitted in fulfilment of the requirements for the degree of Master of Science

January 2022

ACKNOWLEDGEMENT

First and foremost, praise to Allah S.W.T for giving me health, strength and patient to complete this master research successfully. This research has been completed within the time provided through the help and support from many individuals. I would like to express my deepest thanks and appreciation to my supervisor, Dr. Nordiana Mohd Muztaza, for the continuous support and patience, motivation, enthusiasm and immense knowledge. Her guidance helped me in all the time of research and writing of this thesis. Special gratitude goes out to my parents, Mahmud Mohamad and Maznah Hussin, and my siblings for their prayers, encouragement and understanding while completing this research. Many thanks to my colleagues, especially Dr. Muhammad Taqiuddin Zakaria, Alyaa Nadhira Salleh, Iffah Zalikha Roslan and Farid Najmi Rosli, for scarifying their time and energy assisting me in this research. I am blessed to be surrounded by a helpful, friendly and cheerful team. My sincere thanks also go to all staffs in Geophysics lab for their help during the data acquisition. My appreciation goes to my special friend, Ahmad Nasrulnizam Isa, for his continuous support, understanding and motivation in completing this thesis. In addition, I would like to thank the USM Graduate Assistance Scheme and Ministry of Higher Education Malaysia for Fundamental Research Grant Scheme with Project Code: FRGS/1/2018/STG09/USM/03/2 entitle Development of 2-D linear inversion algorithm from geophysical approach for soil or rock characteristics and also Research University grant entitle Integrated geophysical characterization of geothermal exploration and strategy for a sustainable use of geothermal resources' with account no. 1001/PFIZIK/8011110 for their sponsorship of my studies. Last but not least, a million thanks to all those involved directly or indirectly in completing the thesis.

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LIST OF SYMBOLS

%	Percentage
ρ_a	Apparent resistivity
C_c	Coefficient of gradation
C_u	Coefficient of grain uniformity
$CuSO_4$	Copper sulfate
D_{10}	Grain size for which 10% of the material is finer
D_{30}	Grain size for which 30% of the material is finer
D_{60}	Grain size for which 60% of the material is finer
g	Gravitational acceleration
I	Current in Ampere
K	Hydraulic conductivity
k	Geometric factor
Km^2	Kilometer square
m	Meter
mm	Millimeter
mV	Millivolt
n	Porosity
NaCl	Sodium Chloride
s	Second
v	Kinematic viscosity
V	Voltage in Volt
ρ	Resistivity
Ω	Ohm
Ωm	Ohm meter

LIST OF ABBREVIATIONS

AG	Survey lines of Archaeology gallery
ERT	Electrical resistivity tomography
GG	Survey lines of Gelugor
HS	Survey lines of Hamzah Sendut
KJ	Survey lines of Kluang
PH	Survey lines of Puchong
SP	Self-potential
SSA	Soil sample at Archaeology gallery
SSG	Soil sample at Gelugor
SSH	Soil sample at Hamzah Sendut
USM	Universiti Sains Malaysia

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APLIKASI KAEDAH KEBERINTANGAN 2-D DAN KEUPAYAAN KENDIRI DALAM MEMPERINCIKAN ALIRAN AIR

ABSTRAK

Aliran air adalah penting bagi para jurutera dalam membina apa jua struktur. Salah satu faktor yang perlu dipertimbangkan adalah proses aliran air dalam tanah yang boleh memberikan kesan negatif kepada aspek kejuruteraan dan persekitaran. Beberapa tahun kebelakangan ini, kaedah keupayaan kendiri (SP) jarang ditemui dalam menangani masalah aliran air. Dalam kajian ini, kaedah keberintangan 2-D dan SP telah dipilih untuk mengenalpasti kawasan yang berpotensi mempunyai aliran air. Kaedah geofizik adalah kaedah tidak mandiri kerana data tersebut boleh dipengaruhi oleh kawasan persekitaran. Persepaduan kaedah geofizik dan geoteknik telah dijalankan bagi memperincikan ciri-ciri sub-permukaan dan aliran air. Keberintangan 2-D boleh mengenalpasti kedudukan bahan konduktif di dalam sub-permukaan. SP mengukur keupayaan semula jadi Bumi, seperti keupayaan elektrokinetik, yang wujud apabila air mengalir di sub-permukaan. Sampel auger and data lubang bor telah digunakan bagi menyokong interpretasi geofizik. Sebagai keputusan, kawasan air yang berpotensi dikenal pasti pada kawasan yang mempunyai nilai resistiviti rendah (< 200 Ωm) dan nilai SP rendah yang menunjukkan sebagai zon aliran masuk. Arah aliran air juga dapat dilihat dari peta vektor, yang mana air mengalir dari zon aliran keluar ke aliran masuk. Di Hamzah Sendut, air mengalir dari Barat Laut ke pusat kawasan kajian dan di galeri Arkeologi, air mengalir dari Tenggara ke Barat Laut. Sementara itu, di Gelugor arah aliran air dari timur ke barat dan untuk kawasan Puchong, air mengalir dari tenggara ke barat laut. Akhir sekali, di Kluang aliran air dari Barat Laut dan Tenggara ke Barat Daya. Daripada persepaduan antara keputusan keberintangan 2-D

dan keupayaan kendiri dengan profil klasifikasi tanah, Hamzah Sendut dan galeri Arkeologi menunjukkan aliran air secara menegak yang begitu ketara berbanding di kawasan Gelugor. Aliran air secara menegak menunjukkan pengaliran air yang baik ke dalam sub-permukaan. Berdasarkan keseluruhan keputusan SP, perbezaan julat SP mungkin menjadi penanda terhadap masalah kejuruteraan dan persekitaran. Kawasan Hamzah Sendut, galeri Arkeologi, dan Gelugor mempunyai julat SP yang rendah dan tanah berpasir, menunjukkan risiko yang rendah terhadap masalah kejuruteraan dan persekitaran. Sementara itu, kawasan Puchong dan Kluang pula menunjukkan risiko yang tinggi terhadap aspek kejuruteraan dan persekitaran oleh kerana julat SP yang besar dan juga nilai SP yang negatif. Oleh itu, persepaduan antara keputusan kaedah geofizik dan geoteknik boleh mengenalpasti keterterapan SP terhadap masalah kejuruteraan dan persekitaran yang berkaitan dengan aliran air bawah tanah.

APPLICATION OF 2-D RESISTIVITY AND SELF-POTENTIAL METHODS IN DELINEATING WATER FLOW

ABSTRACT

Water flow is essential for engineers when constructing any form of structure. A vital factor to consider is water flows through the soil can impact the engineering and environmental aspects. In recent years, the self-potential (SP) method was rarely found in dealing with the water flow issue. In this research, 2-D resistivity and SP methods have been chosen to detect the potential area of water flow. Geophysical methods are non-standalone methods as the data might be affected by the surrounding environment. The integrations of geophysical and geotechnical methods are performed to increase the understanding of subsurface features and water flow. 2-D resistivity can identify the position of conductive materials in the subsurface. SP measures the natural potential of the Earth, such as electrokinetic potential, which arises when water flows through the subsurface. The auger samples and borehole data were used to support the geophysical interpretation. As a result, the potential area of water was identified at low resistivity area (< 200 Ωm) and low SP value which indicate as recharge zone. The direction of water flow also can be seen from the vector map, which flow from the discharge to recharge zone. At Hamzah Sendut, the water flows from the Northwest to the centre of the study area and at Archaeology gallery, the water flows from Southeast to Northwest. Meanwhile, at Gelugor the direction of water flow from east to west and for Puchong area, the water flow from southeast to northwest. Lastly, at Kluang the water flow from Northwest and Southeast to Southwest. From the integration result of 2-D resistivity, self-potential results with soil classification profile, Hamzah Sendut and Archaeology gallery results show that the vertical water flow is significant compared to

Gelugor area. This vertical water flow shows a good flow of water to the subsurface. Based on the overall SP results, the difference of SP range might be an indicator towards the engineering and environmental problem. Hamzah Sendut, Archaeology gallery, and Gelugor areas show low range of SP with sandy soil, which indicate a low risk of engineering and environmental problem. Meanwhile, Puchong and Kluang areas show a high risk of engineering and environmental effects due to the large range of SP and highly negative SP values. Therefore, the integration of geophysical and geotechnical results can identify the applicability of SP towards engineering and environmental problems, which is related to the water flow in the subsurface.

CHAPTER 1

INTRODUCTION

1.1 Background

Water flow that happens on the surface and in the subsurface is a part of the hydrological cycle. The precipitation falls into the ocean or onto the ground surface due to gravity. As water accumulates on the ground, it seeps into the soil and appears as surface runoff. The water flow is critical in retaining the groundwater, especially during rainless periods (Winter, 2007). Besides, the water flow in the earth's subsurface is a critical topic in engineering and environmental studies. The water flow is essential for engineers when constructing any form of structure. An important fact to address is that when the water flows through the, it has the potential to cause harm. The continuity of water flow in a long period may also have a substantial effect that could contribute to the engineering and environmental problems such as landslide, erosion, and subsidence. This may lead to the increasing saturation of soil, which will reduce the soil strength (Brönnimann, 2011). For example, when this happens in an urban area with improper piling, the stability of the building will be worsened. This effect can be immediately seen when cracks start to show on the roads or buildings at the early stage.

Water flow plays a crucial role in water circulation, slope stabilisation, soil nutrient cycling, and soil-water-vegetation exchange processes. However, owing to spatial variability and hydrology catchment, the transport mechanism of the subsurface flow is very complicated. Even the tiny catchments can vary significantly in their ability to conduct and support water because of the heterogeneity of the soil, vegetation, and topography. Many researchers believe that soil characteristics (soil texture, soil moisture, grain sizes, and soil structures), rainfall characteristics, topography, biological characteristics, and land use can affect the occurrence and intensity of water flow. Any potential natural disaster can be identified by studying the factors that affect the water flow (Hu and Li, 2019).

The geophysical approach is widely used today to address infrastructure and environmental issues in a number of case studies, including flat surfaces, sloping slopes, reclaimed areas, groundwater, and geothermal sources. 2-D resistivity and self-potential methods have been brought into the research to enlighten the water flow investigation. 2-D resistivity is an active method that measures apparent resistivity by injecting current into the subsurface through two current electrodes and recording the electrical potential difference between the electrodes (Loke, 1999). Meanwhile, self-potential or spontaneous polarisation surveys are a form of electrical survey that is conducted passively. By utilising self-potential surveys, only the existing potential differences in the ground are recorded, and thus, this approach appears among the natural-source methods.

In order to validate the geophysical results, additional data from geotechnics methods such as borehole records and auger samples were used. The subsurface information from the borehole and auger samples from the soil will help to enhance the interpretations. The hydraulic conductivity of the auger sample was calculated using the Terzaghi equation. It is used to relate it with the magnitude of SP, which represents the speed of water flow. Therefore, the interpretation of the data will be more reliable. A combination of different methods for the same site often led to a successful geophysical survey due to the various features of the subsurface structure detected by utilising different methods.

1.2 Problem statements

Water flow is one of the most crucial flows in the subsurface, and it may cause engineering and environmental problems such as landslides, flooding, and subsidence. The source of water and the water flow paths take place in the subsurface and are hardly accessible. Therefore, it is necessary to get the image of the subsurface by delineating the water flow.

Self-potential anomalies are generated by a different types of source mechanisms produced from the subsurface. These mechanisms might be due to electrokinetic, thermoelectric, electrochemical and mineralization potential. Therefore, the interpretation of SP result is unpredictable. By integrating 2-D resistivity, self-potential and soil classification models, the interpretation will be more reliable.

The SP method is the most ancient of all geophysical methods, and it has been actively used in mining exploration, oil well logging, and geothermal exploration. Nowadays, as other geophysical approaches take over the market, this SP method is increasingly scarce. However, this method is the best tool for detecting the natural potentials in the subsurface. Thus, the applicability of SP will be identified to provide a better understanding of the water flow, which may trigger engineering and environmental complications.

1.3 Research objectives

The objectives of this research are listed as follow:

i. To delineate the water flow by using 2-D resistivity and self-potential methods.

ii. To analyse the relationship between 2-D resistivity, self-potential and soil properties in delineating water flow.

iii. To identify the applicability of SP towards engineering and environmental complications, which is related to the water flow in the subsurface.

1.4 Scope of the research

The geoelectrical methods of 2-D resistivity and self-potential methods were used in each subsurface study area, including Hamzah Sendut, Archaeology Gallery, Gelugor, Puchong, and Kluang areas. The primary goal of this survey is to delineate subsurface flow by integrating geophysical and geotechnical methods. Furthermore, the properties of subsurface soil are defined by the geotechnical method correlated with the subsurface flow. The geophysical methods used in this research were 2-D resistivity and self-potential (SP) methods with ABEM SAS4000 Terrameter and ABEM ES 10-64C electrode selector. The RES2DINV software was used to produce the 2-D resistivity inversion models. The contour maps of the SP were created using Surfer 8. Both 2-D resistivity and SP results were studied and analysed to assess the subsurface features and delineate subsurface flow. Subsurface details from borehole records or auger data may identify the risk of engineering and environmental effects. As a result, the subsurface data would be more reliable. A combination of different methods for the same site leads to a successful geophysical survey because the different features of the subsurface structure are detected by different methods.

1.5 Significance of the research

Water flow in the subsurface has a dramatic implication in engineering and environmental studies. It is essential in planning and constructing a structure to prevent any harm in the future. This study determined the delineation of water flow by integrating 2-D resistivity, self-potential, and geotechnical methods. The saturated area shown by the low resistivity value could be a concern with the possible cause of engineering and environmental effects (Wong et al., 2016).

In this research, the relation between the range of SP, charging and discharging activity, description of soil and risk towards engineering and environmental effect will be analysed. Based on the SP results, the range of SP values at different study areas shows a diverse range. The range of SP might indicate the activity of water flow in the subsurface. The large range of SP shows a high charging and discharging activity of water in the subsurface. The presence of water flow might disturb the structure of the soil in the subsurface. Besides, the soil properties such as the sandy soil act as a good permeable layer. The presence of fine soil grains such as silt and clay might disturb soil stability and thus increase the risk of engineering and environmental aspects such as landslides and the collapse of the retaining wall. Consequently, the large range of SP and highly negative SP value could be an indicator towards the high risk of engineering and environmental problems.

1.6 Thesis outline

The five chapters of this study are presented in order as follows: The first chapter outlines the purpose of the research structure, including background, problem statements, as well as the significance and novelty of the research.

Chapter two covered the theory of 2-D resistivity and self-potential methods. Besides, it is a tonne of information read regarding the literature review. It is beneficial to look at prior studies utilising geophysical methods to see if they differ from the current study.

The contents of chapter three deal with the geology aspect and the geomorphology aspect of the survey. Further details on 2-D resistivity and SP survey are provided in this part. In the last section of this chapter, data acquisition and data processing techniques are discussed in detail.

Chapter four includes the results and the discussion of the 2-D resistivity and SP surveys. The discussion of the 2-D resistivity results was discussed first, followed by the results of the SP. Next, the discussion continues with the correlation between the two methods. The auger results were used as supporting data to enhance the interpretation.

Last but not least, chapter five would conclude this thesis by analysing and explaining the recommended directions to improve future research further.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Over a century, the primary mechanism of water flow has already been discovered. However, this topic was started to be studied in the past few years due to the engineering and environmental issues aroused. The non-invasive approach such as the geophysical methods is widely used to address the issues. Geophysics applies physics principles in obtaining information about the earth's subsurface by taking measurements at or near the ground surface that is affected by the distribution of physical properties in the subsurface (Mariita, 2010). 2-D Resistivity and Self-potential (SP) are complementary electrical methods. 2-D Resistivity can identify the position of conductive bodies in the subsurface, including water. It may also discriminate between conductivity contrasts in lithology. Meanwhile, SP would include a general description of the impact on the surface caused by the body of interest in the subsurface. SP shows the position of the water flow and the general region in which the water is situated, while resistivity pinpoints the depth of the water. Therefore, 2-D resistivity in cooperation with SP will portray the presence of water, whether it can be groundwater flow, contaminant plumes or any other materials (Mao et al., 2015).

There is an alternate way of detecting subsurface material that requires digging a borehole; however, this method is costly and only offers information at a particular location. Geophysical surveying may provide full land coverage at a reasonable cost. All geophysical methods depend on the detection of contrasts in the physical properties of materials. Nonetheless, supplementary data from other sources, such as borehole or auger data, aid in geophysical interpretation. Consequently, geophysics is an essential method in the analysis of subsurface geology utilising geotechnical knowledge (Mariita, 2010; Sudha et al., 2009).

2.2 Water flow in the subsurface soil

Water is one of the most abundant elements on the earth. It is essential for survival since it influences the Earth's ecosystem. The water that remains now is the same as the water that existed a million years earlier. It can be present on and under the surface, as well as in its environment with three different phases of matter (solid, liquid or gas). As a consequence, it is temporarily accumulated in different reservoirs (oceans, atmosphere, streams, ponds, and groundwater) as it shifts and moves through the hydrologic cycle.

The properties of the soil influenced how the water is flowing through it. The primary properties of soil are soil texture and structure, which affect soil behaviour, such as porosity and permeability of soil. Soil textures is the percentage of sand, silt or clay in the soil. The texture differences are the result of the fineness or coarseness of grains in the soil. Sand, silt and clay percentage are related together in a triangular diagram, as shown in Figure 2.1. The arrangement of sand, silt and clay found in aggregated form is known as soil structure. There are various types of soil structure such as granular, blocky, prismatic, columnar, platy and single-grained. For example, single-grained soil found in sandy soil does not stick together (Balasubramanian, 2017).

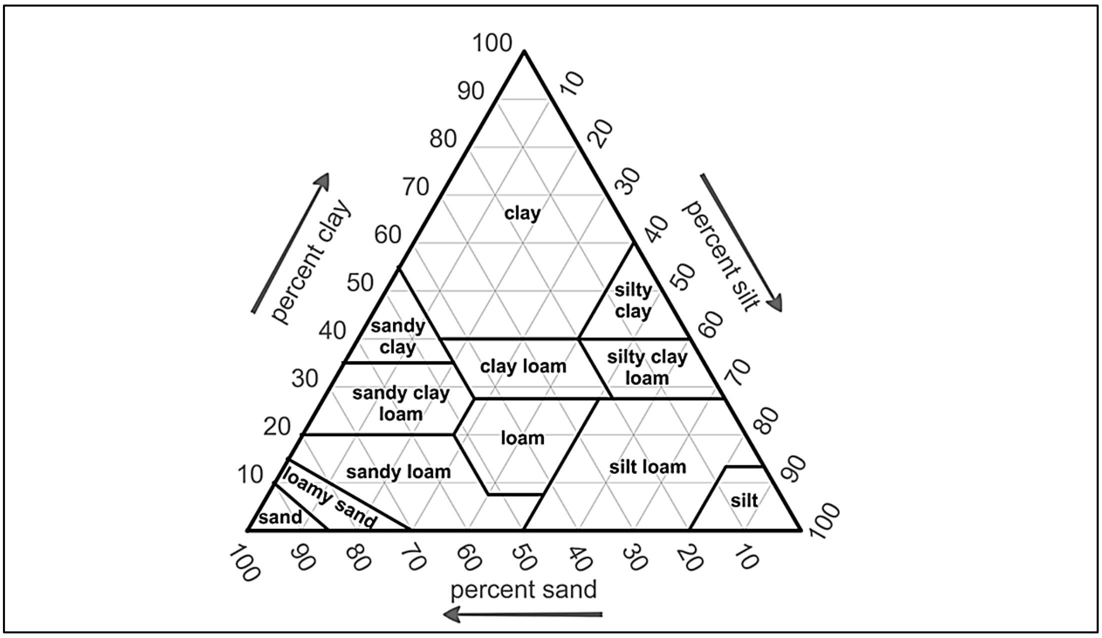

Figure 2.1 Soil textural triangle used for determining soil texture (modified from Groenendyk et al., 2015)

The pore spaces are spaces occupied by air and water between the grain in a given soil volume. The percentage of the soil occupied by the pore spaces or interstitial spaces is known as soil porosity. Sand is a coarse grain with a large pore space and thus, it has a high porosity. Water can hold together in small pores than in large pores, and therefore fine grain such as clay can store large amount of water. The permeability refers to the movement of water through the pore spaces. When the water passes through the large pore spaces such as sand, the permeability will be higher. The large pores allow a high amount of water to pass through compared to the fine pores in clay (Balasubramanian, 2017).

2.3 Grain size distribution and hydraulic conductivity (K)

The grain size distribution of soil is one of the soil mechanic properties that affect the hydrogeological conductivity. The grain size analysis is widely utilized in the classification of soils. The results of sieve analysis are often plotted to indicate the distribution of grain sizes. Soils with an even distribution of grain sizes are called well-graded, and soils with predominantly one grain size are called poorly-graded. Well-graded soils, having various grain sizes, often packed "tighter" than poorly-graded soils resulting in higher unit weight and thus higher strength and lower settlement potential. Information obtained from the grain size analysis is accustomed predict the water within the subsurface.

The soil classification either well-graded or poorly graded sand will be identified consistent with the factors. For well-graded sand, the calculated Cu > 6 and 1 < Cc < 3 or else the soil is classed as poorly-graded sand. The Cu and Cc are calculated based on the grain size distribution curve. Equation 2.1 and 2.2 show the calculation of Cu and Cc, respectively.

$$C_u = \frac{D_{60}}{D_{10}} \tag{2.1}$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} \tag{2.2}$$

The hydraulic conductivity (K) parameter plays a vital role in many disciplines within the earth sciences. It serves to assist quantify the number of fluids that may flow through rocks and soils. A sorted soil with larger grains contains a high hydraulic conductivity. If sediment contains a combination of grain sizes, a more multi-graded soil, the porosity is lowered and also the hydraulic conductivity. This is because the void between the larger grains is filled up with smaller grains. Many researchers have conducted studies to develop mechanistic models that can predict the hydraulic conductivity value of clay-sand mixtures. Almost all currently available models are based on empirical formulations that use various physical properties of the materials used to develop the mixture and relate them to the effective hydraulic conductivity value of the mixture. (Cabalar & Akbulut 2016; Ishaku et al., 2011).

In this study, the Terzaghi equation was used to estimate the hydraulic conductivity, as shown in Equation 2.3. It is represented by a unit mm/s related to permeability and is usually applied for the simulation of infiltration processes.

$$K = 0.0083 \times \frac{g}{v} \times \left[\frac{n-0.13}{\sqrt[3]{1-n}}\right]^2 \times {d_{10}}^2 \tag{2.3}$$

Where:

K : Hydraulic conductivity (mm/s)

g : Gravitational acceleration (9.8 m/s^2)

v : Kinematic viscosity (0.89 x 10^{-6} m^2/s)

n : porosity

d_{10} : The grain size for which 10% of the material is finer (mm)

Milan and Andjelko (1992) state that porosity (n) can be derived from the empirical relationship with the coefficient of grain uniformity (C_u), as shown in equation 2.4 (Odong, 2007).

$$n = 0.255(1 + 0.83^{\mathrm{Cu}}) \tag{2.4}$$

The applicability of this formula depends on the type of soil of the study area. From the auger samples, the major percentage of sand is the highest. Thus, this equation is the most applicable for sand (Cheng and Chen, 2007). The hydraulic conductivity is determined from the grain size information of the auger samples. Besides the grain size, hydraulic conductivity can also be affected by the degree of compaction, porosity, and grain shape (Svensson, 2014).

2.4 2-D resistivity Method

2-D Resistivity is an active method used to determine the variation of subsurface resistivity by measuring the ground surface. The difference in subsurface resistivity values is due to many factors such as soil type, bedrock fractures, contaminants and ground water. Besides, this variation in resistivity value may indicate changes in composition, layer thickness or contaminant levels. Hence, this method has widely been utilised in hydrogeological, mining, geotechnical investigation and environmental survey (Griffiths and Barker, 1993; Loke, 1999).

2.4.1 Resistivity theory

2-D resistivity surveys work by injecting current into the subsurface through C_1 and C_2, and recording the electrical potential difference between two other points P_1 and P_2 as shown in Figure 2.2. The current pumped into the ground flows through conductive bodies in the subsurface and will create a voltage difference measured at the surface. The voltage difference depends on the distribution of resistivity of the bodies. Data from resistivity surveys are customarily presented and interpreted in the apparent resistivity (ρ_a).

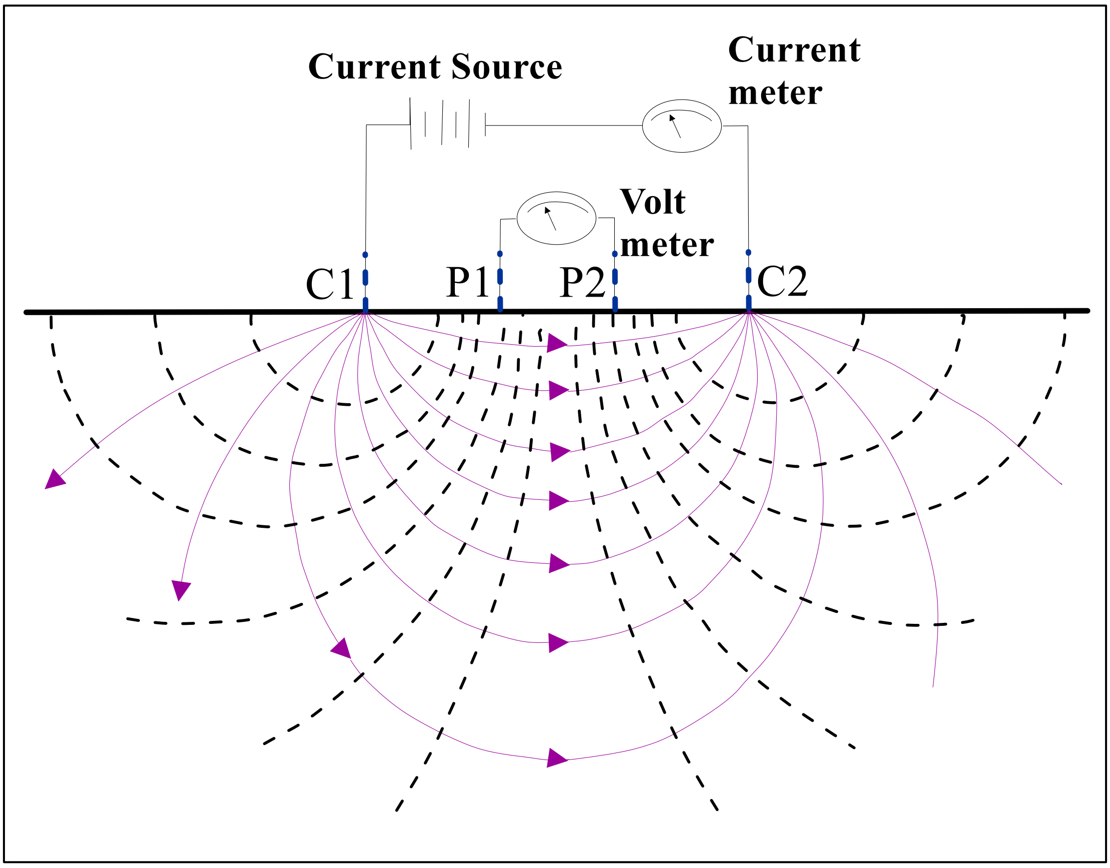

Figure 2.2 Electrical resistivity configuration overview (Muchingami et al., 2012).

From the current and potential different values, an apparent resistivity (ρ_a) value is calculated as Equation (2.5):

$$\rho_a = k\frac{V}{I} \tag{2.5}$$

Where;

ρ_a : Apparent resistivity

k : Geometric factor

V : Voltage in Volt

I : Current in Ampere

The apparent resistivity (ρ_a) is not the true resistivity of the subsurface that has been calculated by using the formula above. The apparent resistivity is the resistivity of a homogenous ground, giving the same resistance value for the same electrode arrangement. Thus, to determine the true subsurface resistivity, an inversion of the measured apparent resistivity values using computer software must be carried out (Loke, 1999).

2.4.2 Resistivity values

The resistivity value of any material may not be characterised precisely. Igneous rocks might have the highest resistivity values, while sedimentary rock tends to be the most conductive material. It is due to the high pore fluid content, reducing the resistivity values. Besides, the age of a rock is crucial to take into consideration. For example, a resistivity value of Quaternary volcanic rock in the range of 10 – 200 Ωm but for a Precambrian volcanic rock may have a higher value. This is due to the older rock have a longer time to be exposed to secondary infilling of interstices by mineralisation and compaction that reduce the porosity and permeability. Therefore, different types of rock with different properties have a specific range of resistivity values. Table 2.1 shows various types of rocks and soil, which related to this research.

Table 2.1 Resistivity values of rocks and soil (Telford et al., 1990).

Materials	**Resistivity (Ωm)**
Granite	$5 \times 10^3 - 10^8$
Weathered granite	$1 - 10^2$
Sandstone	$8 - 4 \times 10^3$
Limestone	$50 - 4 \times 10^2$
Clay	1 – 100
Clay (wet)	20
Alluvium	10 – 800
Fresh water	10 – 100
Salt water	0.2

2.5 Self-potential (SP) method

Self-Potential (SP) is a passive method that measures Earth's natural potential (Skianis, 2012; Nyquist and Osiensky, 2002). The natural potentials can be generated by sulfides, fluid streaming, bioelectrical activity in vegetation, varying electrolytic concentration and other geochemical reactions (Telford et al., 1990). Thus, the SP method has been applied for various applications such as mineral exploration, oil well logging, geothermal exploration and groundwater exploration.

2.5.1 Mechanism of Self-potential (SP)

Self-potentials anomalies are generated by a different type of source mechanisms produced from the subsurface. These mechanisms might be due to electrokinetic potential, thermoelectric potential, electrochemical potential and mineralization potential (Wightman et al., 2003). However, in the presence of fluid pressure as the primary driving gradient, the electrokinetic potential is the main source. Electrokinetic potential, also known as streaming or zeta potential, arises when water flows through the subsurface.

In this study, the primary mechanism is streaming potential. The saturated system is in equilibrium under static no-flow conditions, with a balance of electrical charge around the solid water interface. Mineral grain surface typically has a negative electric charge. This attracts positively charged ions in adjacent pore water, creating an electrical double layer. As pore water flows to a solid surface, positive charges from the water are attracted and collected at the solid surface. The effect is an electrical double layer or a diffuse layer of positive charges over negative charges in the vicinity of the solid surface. When the pore water travels due to a pressure gradient, the excess positive charge within the diffuse layer is pulled along with the water flow creating electrical convection. This convection current causes mobile positive charges to deplete upstream and accumulate downstream; generating an electrical potential difference shown schematically in Figure 2.3. The streaming potential is the voltage difference parallel to the flow path that is describing the convection current (Mainali et al., 2015).

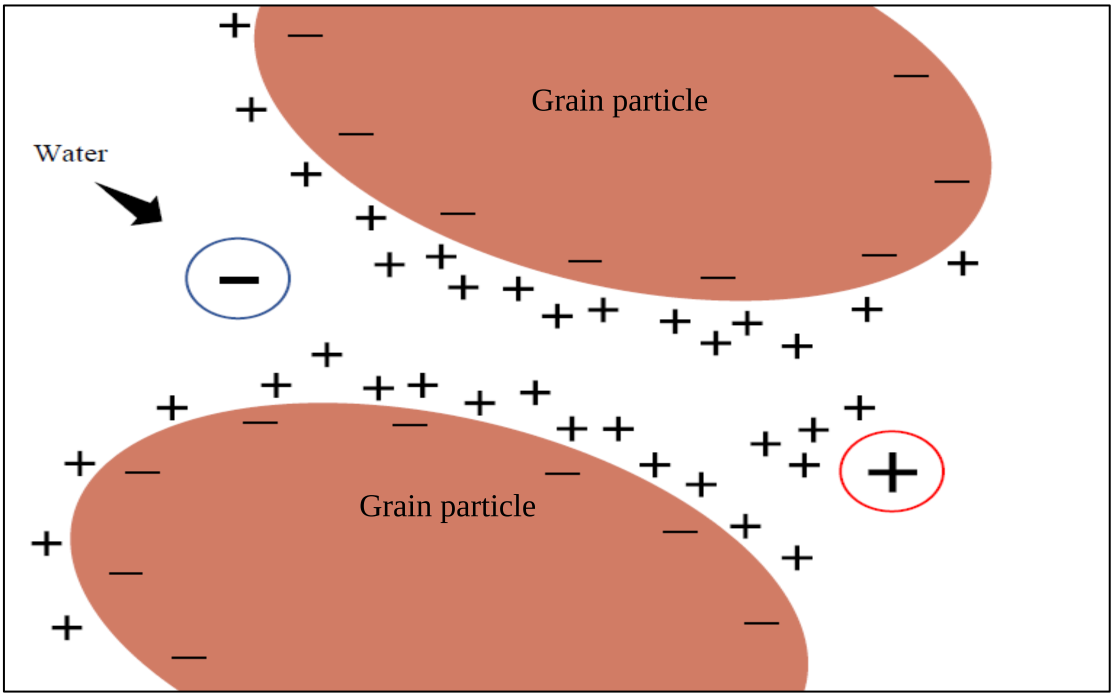

Figure 2.3 The schematic diagram of the electrical potential difference (Mainali et al., 2015).

2.5.2 Symmetrical and asymmetrical signal of Self-potential (SP)

In general, the symmetrical signal of SP indicates the vertical resistivity changes, as shown in Figure 2.4. The consequence of different subsurface features can change the resistivity values and control the movement of water flow. When the resistivity value changes vertically, the direction of the water flow will be horizontal (Schiavone and Quarto, 1983).

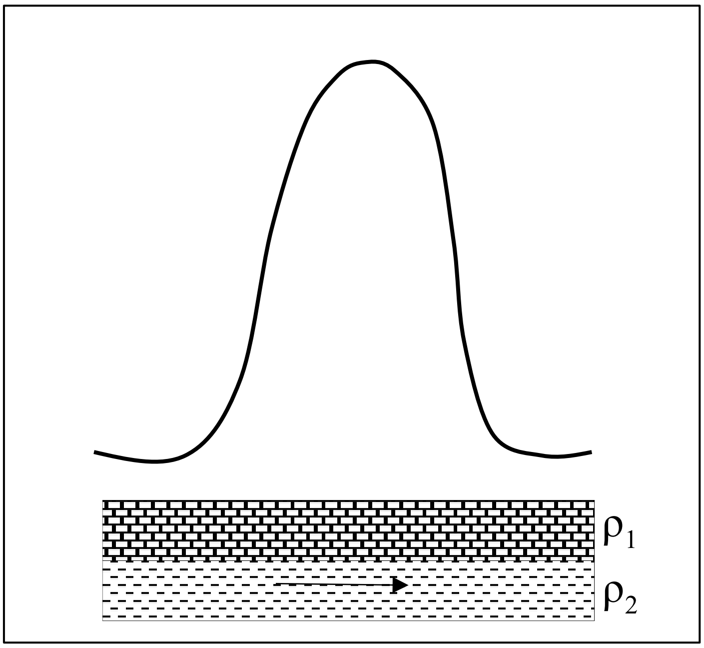

Figure 2.4 The section of SP signal at horizontal water flow. The arrow shows the direction of water flow (Schiavone and Quarto, 1984).

Meanwhile, the asymmetrical signal of SP is always related to structural discontinuities in the subsurface. It is due to the lateral resistivity changes because of the different subsurface features, thus cause vertical subsurface flow (Schiavone and Quarto, 1984). Figure 2.5 shows the section view of SP signal generated by vertical water flow (indicate by the arrow) at different lateral resistivity.

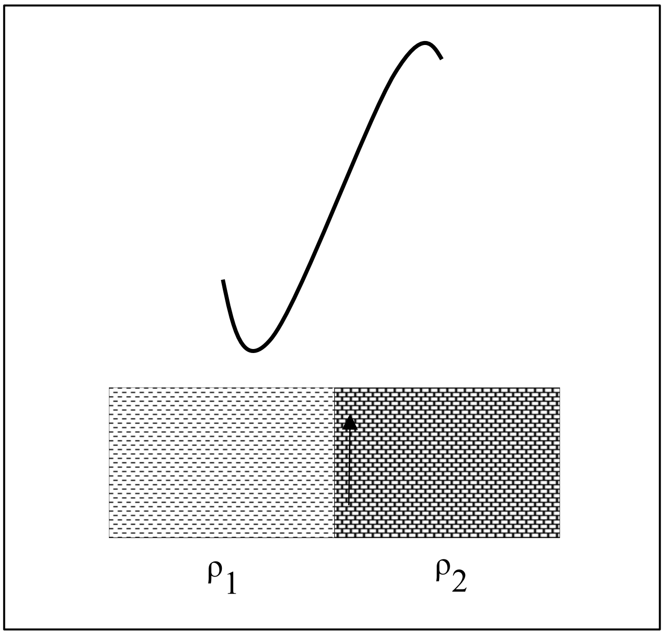

Figure 2.5 The section of SP signal at vertical water flow; the arrow shows the direction of water flow (Schiavone and Quarto, 1984).

2.6 Previous study

The subsurface activity is a critical factor in engineering and environmental problems such as landslides, subsidence, and erosion (Hu et al., 2020). Among various effecting factors, water is known as one of the major triggers for these problems. The properties of the soil determined how the water is flowing through it. The type of soil (texture and structure of soil) is very important to identify the porosity and permeability of soil (Balasubramanian, 2017). According to Liu and Li (2013), the impacts of water may present themselves in a variety of ways, including soil suction decrease, pore pressure increase, water table lifting, and soil unit weight rising, as well as anti-shear strength weakening (Iverson, 2000; Xu et al., 2005; Sun et al., 2007). As a consequence, the interactions of water and subsurface should be investigated and understood in a broader sense.

The extreme weather such as heavy rain can give effect to the water flow in the subsurface (Li et al., 2015). It is important to identify the location of water discharge and recharge after the rain. The water will be discharge through the permeable soil such as sand (Muztaza et al., 2018) and flow into the deeper layers as a result of gravity. The water table and groundwater are the recharge area where the water accumulate. However, at near subsurface environment also can be a recharge area when the groundwater level increased due to the highly disturbed soil (Pozdnyakova, 2001). Therefore, the study of water flow is essential to prevent any serious problems, which can cause severe destruction from time to time as the water is flowing slowly through the soil.

Infiltration act as an indicator of the soil ability to allow water flow into and through the soil profile. Yusof et al. (2017) had conducted a survey to describe about the water infiltration process that occur vertically and horizontally at the subsurface layer. A well-developed soil structure facilitates fluxes of water and oxygen through the soil, making it available for uptake by plants, soil organisms and recharge of groundwater (Haghnazari et al., 2015; Beven & Germann, 2013; Köhne et al., 2009; Rabot et al., 2018). A poor soil structure, on the other hand, is one that hinders water penetration and gas exchange, resulting in water runoff, soil erosion, and unfavorable anoxic conditions that limit plant development and may trigger greenhouse gas emissions via anaerobic bacterial respiration (Berisso et al., 2012; Chen et al., 2014; Jordanova et al., 2011; Nawaz et al., 2013).

Evaluation of hydrology and soil properties is important to identify any potential of engineering and environmental problem in the subsurface. The selection of method for data acquisition plays the main role especially in urban area to avoid any severe destruction. Direct destructive sampling method is not suitable for data acquisition at the urban area. This area consists of highly disturbed soil that different from the natural soil due to the municipal activities (Pozdnyakova et al., 2001). Therefore, geophysical methods have been used to assess subsurface features and delineate water flow. The role of geophysical methods is vital in groundwater exploration. These methods measure the contrast between the physical properties of the subsurface. The variation of the value will indicate the geology and structure of the subsurface.

According to Hazreek et al. (2018), Azman et al. (2017), and Muztaza et al. (2018), the 2-D resistivity were chosen to study the subsurface features. Hazreek et al. (2018) used this method to identify the weak zone of slope failure. The water flow phenomenon can affect the slope strength, which tend to cause slope failure. The low resistivity value was interpreted as the weak zone. This weak zone consists of loose materials, which will allow the flow of water and make it easier to collapse. This feature found has a high tendency for slope failure phenomena to occur. Figure 2.6 shows the saturated layer indicated by the low resistivity value. From Muztaza et al. (2018), the presence of boulders showed a high resistivity value. The variation of resistivity value indicates the presence of a fracture. All these features can trigger the landslide to occur. Thus, it shows a successful study for slope failure purpose by using 2-D resistivity method as it is able to identify the weak zone by the low resistivity value.

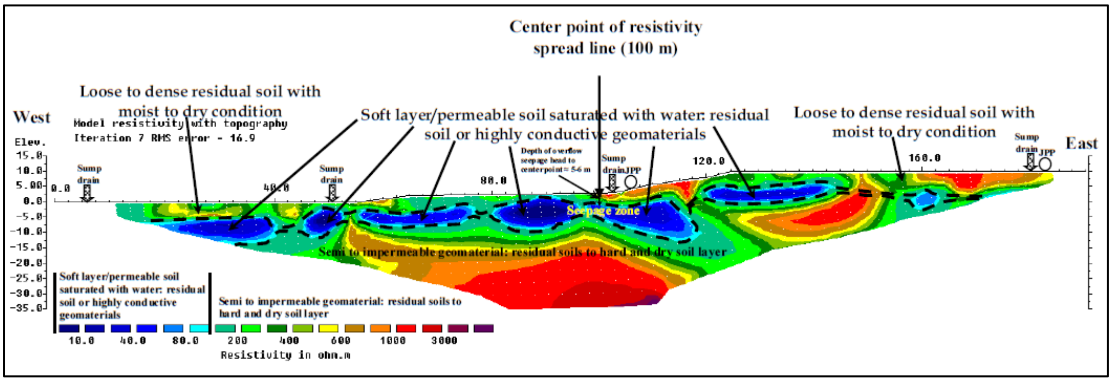

Figure 2.6 Resistivity result shows the saturated layer indicated by the low resistivity value (Hazreek et al., 2018).

For many years, 2-D resistivity has been extensively used to understand the subsurface hydrological condition adequately. The resistivity method is related to the soil water content, salinity and clay (Saad et al., 2012). After studying the area's geology, the low resistivity value indicates the saturated area, which will be interpreted as groundwater (Asry et al., 2012; Saad et al., 2012). Based on Zakaria et al. (2018), groundwater exploration was conducted in fractured reservoirs using self-potential (SP) and 2-D resistivity. Generally, the rock unit in this area is composed of granite, adamellite and minor granodiorite from Belumut granite. The SP result shows the direction of groundwater from southeast to northwest. The 2-D resistivity result also identify the potential of groundwater area with low resistivity < 100 Ωm at depth of >50 m. The high contrast of resistivity values was interpreted as fracture/fault, which may be the pathway for the groundwater to seep upward due to the difference of pressure gradient.

Integrating two or more geophysical methods increases understanding of subsurface features. There is a possibility of ambiguity if only one approach is conducted. Titov et al. (2000), Revil et al. (2005), Song et al. (2005) and Metwaly et al. (2006) have chosen resistivity and self-potential methods in dealing with the presence of water in the soil. Revil et al. (2005) had utilized these methods with in situ samplings to delineate the position of a wide Saint-Ferreol paleo-channel of the Rhone River. The river is one of the most important drainage systems in Western Europe. The negative SP value of – 15 mV indicated the ground water flow inside the paleo channel. The SP result provides the boundaries of the channel while resistivity and drilling information are used to show the depth of the paleo channel. Thus, the paleo-channel is characterised by a negative SP anomaly with respect to a reference taken outside the paleo-channel. Another study in Indonesia to overcome the drought as an alternative source of water, the underground identification river was conducted. From the result, the low potential value between 0 to -1 mV indicates the underground water. The depth of carbonate rock shows the expected presence of groundwater with resistivity value between 1819 – 29482 Ωm on Line 1, Line 2 and Line 6. This result is supported by a low SP value and it shows that the river flows from line 2 to line 1 or North-West direction.

Titov et al. (2000) and Song et al. (2005) employed the resistivity and self-potential (SP) methods to investigate the water leakage. Both of the study areas show the low resistivity value indicates the saturated area. The strong negative anomaly from the self-potential result provides information about the potential area of water. This helps to detect any water leakage from the dam, which might lead to the stability problem of the dam. Based on Titov et al. (2000), the result of the second resistivity (May) was similar to the first result (April) and there is only a small difference in the resistivity value, which may be due to the different water content of the soils. A dramatic change in SP value occurred due to the adjacent soil had thawed out by May. Thus, the near-surface water flow was able to discharge near to the river. Hence, both study areas show that the low resistivity area is potentially dangerous for water seepage and the SP anomaly shows the actual water seepage pathway.

Arsene et al. (2018) had performed a geophysical survey at Meiganga area, Adamawa, Cameroon. The aim of this survey is to identify the effect of lithology on the quality and flow of groundwater by mapping the geological structure, hydrogeological features and delineating areas of recharge and discharge of groundwater. The geological formations of the study area are part of the central Panafrican belt of Cameroon, which underlain by synthectonic, late-tectonic and post-tectonic granitoids that intrude in older metamorphic rocks. The methods used were electrical resistivity tomography (ERT) and self-potential (SP). For resistivity data acquisition, eight survey line were carried out with 5 m electrode spacing by using Syscal Junior Switch 72. Schlumberger array was used in this survey. RES2DINV version 3.71 of Loke and Dahlin software was used to determine the true resistivity of subsurface geological formation and structure. Meanwhile, SP data was acquired linearly along the resistivity profiles. From the resistivity results, five deeper groundwater zone were delineated at Yelwa, Ngoa-

Ek´el´e, Sabongari, Nasiriya, and Gbakoungu´e respectively. The analysis of SP revealed the area of recharge and discharge across the study area. The groundwater head map also shows the groundwater flow pattern inward from the flanks to center and south-central parts of the study area.

There are many landslides have been triggered by extreme rainfall or snowmelt. Electrical resistivity tomography (ERT) and self-potential (SP) were carried out to identify the complex geometry of Bosco Piccolo landslide by Naudet et al. (2008). Generally, the slope is characterized by the oldest Apennine formation units which mainly represented by clayey-marly-arenaceous deposits and by marly limestones of the Corleto Perticara Formation. The resistivity result shows that the clayey deposited involved in the old mass movement. The sliding surface was occurred inside the clayey formation by integrating the geoelectrical and stratigraphical data. The landslide boundaries have been identified from the transversal profile even the SP magnitude are weak. Gelisli and Ersoy (2017) utilized the same methods to investigate the structure of Havuzlu landslide and the groundwater condition in the reservoir area in Northeast Turkey. Several areas in Northeast Turkey undergo a frequent landslide due to the geomorphological structure and excessive rainfall. From the results, low resistivity areas indicate the content of clayey, silty, sandy and moisture contents. These have been proved by the sample taken from HSK-5 borehole. The relatively high resistivity area ($> 115\ \Omega$) indicates as bedrock after correlated with the borehole data. The SP result shows poor groundwater movement in the area close to the bedrock. From laboratory test results show the landslide materials mainly consist of sand and gravel. Small amount of silt and clay also found from the laboratory test that can cause low cohesion and high internal friction angle to the landslide. The correlation of resistivity and self-potential methods have shown a good result in studying the landslide.

The geotechnical method such as borehole data help to validate the geophysical results. A survey has been conducted to identify the lithology of the subsurface by using 2-D resistivity imaging and borehole methods in Penang, Malaysia by Bery et al. (2017). Penang area is located at the Northern part of Peninsula Malaysia and it is made up of granitic rocks. From the results, there are four different subsurface structure such as sandy silt, silty sand, sand and weathered granite. The resistivity value of 65 – 220 Ωm indicated sandy silt meanwhile silty sand showed a resistivity value of 120 – 770 Ωm. Sand material is presented by resistivity value of 220 – 1400 Ωm. The higher range of resistivity value of 410 – 2600 Ωm indicated as weathered granite. The interpretation of subsurface structure is more reliable with the aid of two inline boreholes as geological reference.

Anuar and Muztaza (2018) had conducted 2-D resistivity at two survey area in Selangor and Kelantan to detect the potential area of water with the aid of porosity calculation from Archie's Law and borehole records. The survey area at Selangor is formed during the Devonian period and its lithology is composed of sandstone or metasandstone. While Kelantan is situated between Triassic Kemahang granite and Permian Taku Schist boundary. From the results, low resistivity value of 1-100 Ωm considered as saturated areas were suspected to be an aquifer. The saturated areas were validated by the borehole records. The porosity of subsurface was calculated for all 2-D resistivity lines and an imaging was created for each line. A productive sedimentary aquifer should have porosity percentage of >20% and the saturated area at both study areas have the porosity percentage of >20% as expected.

2.7 Chapter summary

In this chapter, the fundamental theories and concept of 2-D resistivity and SP methods are well explained. 2-D resistivity method measured the resistivity of the subsurface material while SP can measure the conductivity whether it is high or low. Various reading about the previous study in this chapter can be used as reference. They utilized several methods to acquire useful information about the Earth's layer and its composition.

Water is recognised as one of the fundamental causes of engineering and environmental problems. The properties of soil govern how water flows through it. There are some previous findings that were explained in this chapter. Yusof et al. (2017) conducted a survey to describe the water infiltration process that occurs vertically and horizontally at the subsurface layer. Pozdnyakova et al. (2001) evaluate hydrology and soil properties by using geophysical methods, especially at the urban area, to avoid severe destruction.

A geophysical method such as 2-D resistivity is well known to identify the subsurface features. According to Asry et al. (2012), Saad et al. (2012), Zakaria et al. (2018), Revil et al. (2005), Anuar and Muztaza (2018), and Arsene et al. (2018), the low resistivity value was interpreted as a potential area of water. Hazreek at al. (2018), Azman et al. (2017) and Muztaza et al. (2018) identified the weak zone at the low resistivity value, which tends to cause a slope failure.

Integration of 2-D resistivity and SP methods were chosen to enhance the interpretation in dealing with water flow. Zakaria et al. (2018) conducted a survey in fractured reservoirs using self-potential (SP) and 2-D resistivity. The SP result shows the direction of groundwater from southeast to northwest and 2-D resistivity result identify the potential of groundwater area with low resistivity < 100 Ωm at depth of >

50 m. The high contrast of resistivity values was interpreted as fracture/fault for the groundwater pathway. Besides, water leakage at the dam was detected, which shows low resistivity and SP value by Titov et al. (2000) and Song et al. (2005). Naudet et al. (2008) and Gelishi and Ersoy (2017) identified the landslide by utilizing 2-D resistivity and SP methods. From 2-D resistivity result, the low resistivity value represents the presence of silt and clay, which cause low cohesion and high internal friction angle to the landslide. The SP result also shows a low SP value at the weak area.

Additional data from a geotechnical method, such as borehole data, help to validate the results. Anuar and Muztaza (2018) and Bery et al. (2017) utilised a 2-D resistivity method with borehole records to identify the subsurface's potential area and lithology, respectively. The low resistivity value of 1-100 Ωm considered as saturated areas were suspected to be an aquifer, which has been validated by the borehole records (Anuar and Muztaza, 2018). From Bery et al. (2017) results, there are four different subsurface structure such as sandy silt, silty sand, sand and weathered granite with the aid of inline boreholes as geological reference.

Based on these previous studies, the SP method was rarely found in dealing with the water flow issue. In spite of that, the SP method is the best tool for detecting the natural potentials in the subsurface. It can provide a better understanding of water flow in the subsurface. In addition, lack of cooperation with other related expert may cause some unreliable outcome as geophysics results provide the qualitative anomaly changes. Most of the geophysical results and justification was too abstract which always changes relative to the individual interpreter. Therefore, the borehole records and auger samples are needed in order to provide a clearer information about the soil.