IDENTIFICATION OF SURFACE WATER AND GROUNDWATER RELATIONSHIPS AT UNIVERSITI TUN HUSSEIN ONN MALAYSIA (UTHM) CAMPUS

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To The Love of My Life My Parents Riwayat Yunus and Maznah Muda

Thank You for Loves, Support and Encouragement

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ABSTRACT

Descriptions of the surface water and groundwater relationships are required for enhanced water resource management. The increase in population and rapid development has boosted the demand and use of water supply each year in Parit Raja. Moreover, no further research related to relationships between both sources has been carried out in this flat topography area. Thus, the descriptions of surface water and groundwater relationships are required to enhance water resource management in UTHM campus in order to meet the future demands. The Schlumberger array was used for Electrical Resistivity Imaging (ERI) during data acquisition to identify potential shallow aquifers and suitable locations for boreholes which function as observation wells. Three new boreholes were installed and the ERI results showed that this area recorded low resistivity values less than 10 Ωm with potential groundwater at varying depths between 10 to 30 m. Meanwhile, in hydrochemical analysis the chemical properties of major cations (Na^+, Mg^{2+}, K^+, Ca^{2+}) and anions (Cl^-, SO_4^{2-}, NO_3^-) were analysed to characterise surface water and groundwater. The result showed that all surface water is characterized by Ca^{2+} - Mg^{2+}- Cl^- - SO_4^{2-} types of fresh water, while the groundwater is characterized by Na-Cl type of saline water due to seawater intrusion which indicated that the interaction of surface water and groundwater were not occur in this study area and the recharge areas might be located outside this area. This result interpreted that the lakes and swale were remained in good quality whereas groundwater at this aquifer was seriously intruded by seawater. Even though, the isotopic composition for $\delta^{18}O$ and δ^2H values of surface water were relatively similar to that of groundwater samples in Station A and Station C as they varying between -4.32%o to -9.74%o for $\delta^{18}O$ and from -33.86%o to -65.82%o for δ^2H, these surface water samples had low salinity ($Cl^- < 20$ mg/l) compared with that of groundwater ($Cl^- > 3000$ mg/l). This result could be explained by effects of evaporation and seawater intrusion on these groundwater samples rather than interaction with surface water. Thus, the relationships of surface water and groundwater might not occur in UTHM campus and the recharge areas might be located outside this area.

ABSTRAK

Pemahaman berkaitan hubungkait antara air permukaan dan air bawah tanah adalah penting bagi pengurusan sumber air lestari. Peningkatan penduduk telah meningkatkan permintaan dan penggunaan bekalan air setiap tahun di Parit Raja. Selain, tiada penyelidikan lanjut mengenai hubungan antara kedua-dua sumber telah dijalankan di kawasan bertopografi rata ini. Oleh itu, hubungkait antara air permukaan dan air bawah tanah adalah diperlukan bagi pengurusan sumber air yang lebih baik di kampus UTHM. '*Schlumberger'* digunakan dalam *Electrical Resistivity Imaging (ERI)* bagi mengkaji potensi akuifer dan lokasi yang sesuai bagi tujuan pengorekan lubang jara sebagai kawasan kajian. Tiga lubang jara baru dikorek dan melalui imej *resistivity* menunjukkan bahawa kawasan ini dominan dengan nilai rintangan yang rendah iaitu kurang daripada 10 Ωm dengan potensi air bawah tanah pada kedalaman antara 10 hingga 30 m. Sementara itu, dalam analisis hidrokimia sifat kimia kation (Na^+, Mg^{2+}, K^+, Ca^{2+}) dan anion (Cl^-, SO_4^{2-}, NO_3^-) dianalisa sebagai indikasi untuk mencirikan air permukaan dan air bawah tanah. Hasil daripada analisis menunjukkan bahawa sampel air permukaan dicirikan oleh jenis campuran Ca^{2+} - Mg^{2+}- Cl^- - SO_4^{2-} iaitu jenis air tawar, manakala air bawah tanah dicirikan oleh jenis Na-Cl iaitu jenis air garam kerana pencerobohan daripada air laut. Hal ini menunjukkan bahawa interaksi air permukaan dan air bawah tanah tidak berlaku di kawasan kajian ini. Hal ini menerangkan mengapa air permukaan berada dalam kualiti yang baik manakala air bawah tanah dipengaruhi oleh air laut. Walaupun, komposisi isotop untuk nilai $\delta^{18}O$ dan $\delta^{2}H$ sama dengan nilai sampel air bawah tanah di Stesen A dan Stesen C iaitu diantara -4.32%o hingga -9.74%o untuk $\delta^{18}O$ dan dari -33.86%o hingga -65.82%o untuk $\delta^{2}H$, sampel air permukaan mempunyai nilai Cl^- < 20 mg/l berbanding dengan air bawah tanah dengan nilai Cl^- > 3000 mg/l. Hasil ini mungkin dijelaskan oleh kesan penyejatan dan penyusupan air laut pada sampel air tanah ini berbanding interaksi dengan air permukaan. Oleh itu, perhubungan air permukaan dan air bawah tanah mungkin tidak berlaku di kampus UTHM dan kawasan resapan berkemungkinan terletak di luar kawasan ini.

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LIST OF ABBREVIATIONS

ERI	-	Electrical Resistivity Imaging
MRSO	-	Malayan Rectified Skew Orthomorphic
RMS	-	Root Mean Square
IP	-	Induced Polarization
ICP	-	Inductively Coupled Plasma
IC	-	Ion Chromatography
AAS	-	Atomic Absorption Spectrometer
IAEA	-	International Atomic Energy Agency
GMWL	-	Global Meteoric Water Line
LMWL	-	Local Meteoric Water Line
INQWS	-	Interim National Water Quality Standards for Malaysia
SO_4^{2}	-	Sulphate
Cl^-	-	Chloride
NO_3^-	-	Nitrate
HCO_3	-	Bicarbonate
Ca^{2+}	-	Calcium
Mg^{2+}	-	Magnesium
Na^+	-	Sodium
K^+	-	Potassium
EC	-	Electric Conductivity
DO	-	Dissolved Oxygen
pH	-	Potential of Hydrogen
TDS	-	Total Dissolved Solids
IRMS	-	Isotope Ratio Mass Spectrometer
UTHM	-	Universiti Tun Hussein Onn Malaysia

CHAPTER 1

INTRODUCTION

1.1 Background of study

Since water covers more than 70% of the earth, water sources have always been a precious commodity for all living things for a variety of purposes such as domestic uses, industrial uses, irrigation and recreation. Both surface water and groundwater are the main sources of water supply and play a key role in eco-environmental maintenance and socio-economic development in arid and semi-arid regions (Zhang *et al.,* 2007). Continuous availability of water is open to changes such as natural variation and human activities. Hence, the way humans consume and manage water nowadays could influence the availability and quality of water for all users of the resource in the future.

The important connection that has been traditionally overlooked in water resource management is the interaction between surface water and groundwater (Dixon-jain, 2008). Water management is concerned with maintaining water quality and quantity in both surface water and groundwater. Surface water and groundwater are two interconnected components of one single resource and impacts on either of these components will inevitably affect the quality or quantity of the other (Winter *et al.,* 1998). Surface water features could gain water and solutes from the groundwater system while other types of surface water could be a source of groundwater recharge which can cause changes in groundwater quality.

Groundwater is a very important component of water resource in nature. Groundwater is defined as water that lies beneath the earth’s surface in soil pore spaces and in the fracture of rock formations (Muchingami *et al.,* 2012). It is known as an alternative water supply for all living things. The problem faced by engineers is to determine the exact location of groundwater in the subsurface layer. The geophysical method is seen as the most suitable tool for the exploration of groundwater as this method has been widely applied in geotechnical and geo-environment investigations. Geophysics is the application of physics that studies the earth by taking measurements at or near the surface of earth (Nazri *et al.*, 2016). Electrical Resistivity Imaging (ERI) is part of geophysics used as a preliminary step in any groundwater exploration. ERI has been applied for many years to determine the thickness of layered media as well as to map geological environment of existing aquifers. It has been effectively used for groundwater due to the simplicity of the technique and its efficiency in producing subsurface imaging (Dor *et al.*, 2011). Furthermore, the support borehole data and profile image produced using this method provide reliable information regarding groundwater and the location of underground layers.

Hydrochemistry is a subdivision of hydrology that deals with the chemical characteristics of water (Nazri *et al.*, 2016). Studies on hydrochemistry provide insight into the interaction between groundwater and its environment which leads to better groundwater management and planning (Adams *et al.*, 2001). Based on the hydrochemical similarities between surface and groundwater, it can be identified that groundwater is either a source of water to rivers, lakes, ponds or it is discharged by precipitation or surface water. The hydrochemistry of surface and subsurface water is mainly influenced by geology and the contact time that water has with geological materials (Dixon-jain, 2008). A hydrochemical analysis was to determine the potential and suitability of aquifers as water supply.

The evaluation of the origin of water, especially groundwater systems, often utilises the stable isotope approach to determine hydraulic parameters (Nazri *et al.*, 2012). An isotope is a geochemical tool used to identify the origin of groundwater, determine its residence time and how it is affected by geo-hydrologic and meteorological factors (North *et al*, 2004). The most commonly isotopes used are Oxygen-18 (^{18}O) and Deuterium (^{2}H). Both isotopes are excellent parameters for determining the origin of water in aquifer layers and are often used for studying natural water circulation and groundwater movement (Subyani, 2004). Hence, understanding the hydrochemical characteristics and correlating with isotope compositions are necessary for the precise interaction between surface water and groundwater.

1.2 Problem statement

The developing district of Batu Pahat is experienced an increase population (Musa, 2015). Since the establishment of Universiti Tun Hussein Onn Malaysia (UTHM), the population in Parit Raja has also been increasing. The increase in population and rapid development has boosted the demand and use of water supply each year. Data obtained from Pejabat Pembangunan dan Penyelenggaraan (PPH) UTHM in Figure 1.1 represent the water consumption at UTHM starting from 2011 until March 2018. The highest water consumption in the past 7 years was in 2016 with a value of 1,035,543 m^3, an increase of about 25% from the previous year 2015. The water consumption rapidly increasing every year since 2011 in line with an increasing number of staff and student with increment about 10% – 25% in every 3 years.

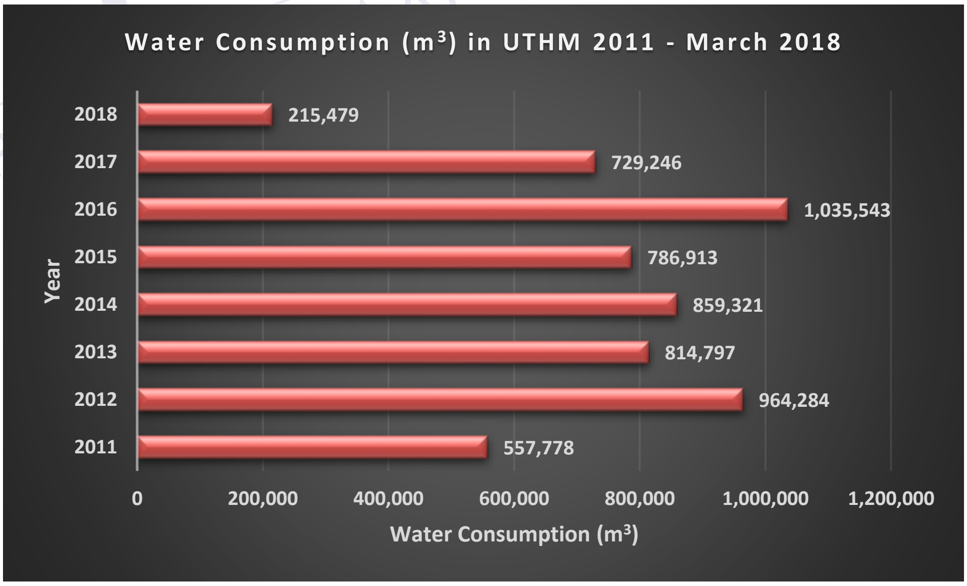

Figure 1.1: Water consumption at UTHM campus from 2011 to March 2018

Generally, surface water is critically important for water streams and wetlands, irrigation, manufacturing, electrical supply and other uses. Meanwhile, groundwater plays a crucial role in the global hydrological cycle. The necessity to manage surface water and groundwater as a single resource has steadily grown with the growing demands on water resources and increasing uncertainties in water supply (Fleckenstein *et al.*, 2010).

In recent years, many researches have been conducted in Parit Raja focusing on aspects related to the quality and quantity of surface water and groundwater. However, no further research related to relationships between both sources has been carried out in this area. Effective water management requires a clear understanding of the linkages between these sources as it applies to any given hydrologic setting. The assessment of relationships between surface water and groundwater provides information on water resource management. Thus, the descriptions of surface water and groundwater interactions are required to enhance water resource management in the UTHM campus in order to meet future demands. Based on the systematic analyses and interpretations of the resistivity technique, hydrochemical analyses and stable isotope, conclusions are drawn for improving water resource management and to find the alternative water source as to support the existing water supply in this area. Thus, a better understanding on the interconnections and relationships between the two water bodies is essential to improve water resource management (Dor *et al.*, 2011).

1.3 Objectives of study

The purpose of this study is to further understand the relationship between surface water and groundwater in the UTHM campus. Three main objectives of this study are:

a. To examine potential shallow aquifer and suitable boring location for observation well at UTHM campus.

b. To characterize surface water and groundwater by using hydrochemical analyses for identify surface water and groundwater relationships.

c. To identify surface water and groundwater relationships using the stable isotope approach: Oxygen-18 (^{18}O) and Deuterium (^{2}H).

1.4 Scope of study

This study focused on the interaction between surface water and groundwater in the UTHM campus. The ERI applied the Schlumberger array due to its capability in imaging deeper profile data which is suitable for areas with homogeneous layers. The interest in this study is shallow aquifers as it is more reliable in identify the relationships between surface water and groundwater. Secondly, the hydrochemical analyses were conducted to determine the characteristics of surface water and groundwater as an early prediction of the relationship between both sources. The chemical properties of major cations (Na^+, Mg^{2+}, K^+, Ca^{2+}) and anions (CI^-, SO_4^{2-}, NO_3^-) of groundwater and surface water were analysed using the Atomic Absorption Spectrometer (AAS) and Ion Chromatography (IC) to link them to hydrochemical facies according to similarities in water chemistry. Lastly, the isotope approach was conducted at the Malaysian Nuclear Agency, Bangi, for Oxygen-18 (^{18}O) and Deuterium (^2H) by using Continuous Flow-Isotope Ratio Mass Spectrometer (CF-IRMS). The $H/^2H$ and O^{18}/O^{16} ratio used as to know the altitude at which the sources of groundwater came from and the relationships between surface water and groundwater.

1.5 Significance of the study

Surface water and groundwater are hydraulically interrelated. Thus, interpretations of hydrochemical analyses and the stable isotope approach were required in this research to reinforce the findings and to prove the interconnection between surface water and groundwater. The outcomes from this study were used to determine the hydraulic interrelationships as well as to situate the potential use of water in order to comply with the rise in water demand. The conclusion from this study could also be used as a reference in future studies to improve the effectiveness of water resource management and the quality of water in the UTHM campus.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter reviews previous studies related to Electrical Resistivity Imaging (ERI), hydrochemical analysis and the stable isotope approach. The first section of this chapter describes the ERI which includes the background, theory, fundamentals of electrode configuration and its applications in groundwater exploration. Meanwhile, the second section explains the hydrochemical analyses related to surface-groundwater interaction, as well as physical and hydrochemical interaction. Finally, this chapter elucidates the background and case studies that comply with the stable isotope approach to identify the relationships between surface water and groundwater.

2.2 Hydrological cycle

The water cycle, also known as the hydrological cycle or the hydrologic cycle, describes the continuous movement of water on, above and below the surface of the earth. Inflow to the hydrologic system arrives as precipitation, while the outflow takes place as streamflow or runoff. The most important process is when the precipitation is delivered to streams by overland flow and interflow which are also known as subsurface flow and base flow respectively, following infiltration into the soil. Various factors could influence water quality at each stage of the hydrologic cycle. During the rainfall event, rain will react with soluble particles and gases in the atmosphere. Thus, when it reaches the surface, it is non-devoid of chemicals. The water will then infiltrate or seep through soil into the flow system in underlying geologic materials which is groundwater. Figure 2.1 illustrates the hydrological cycle process.

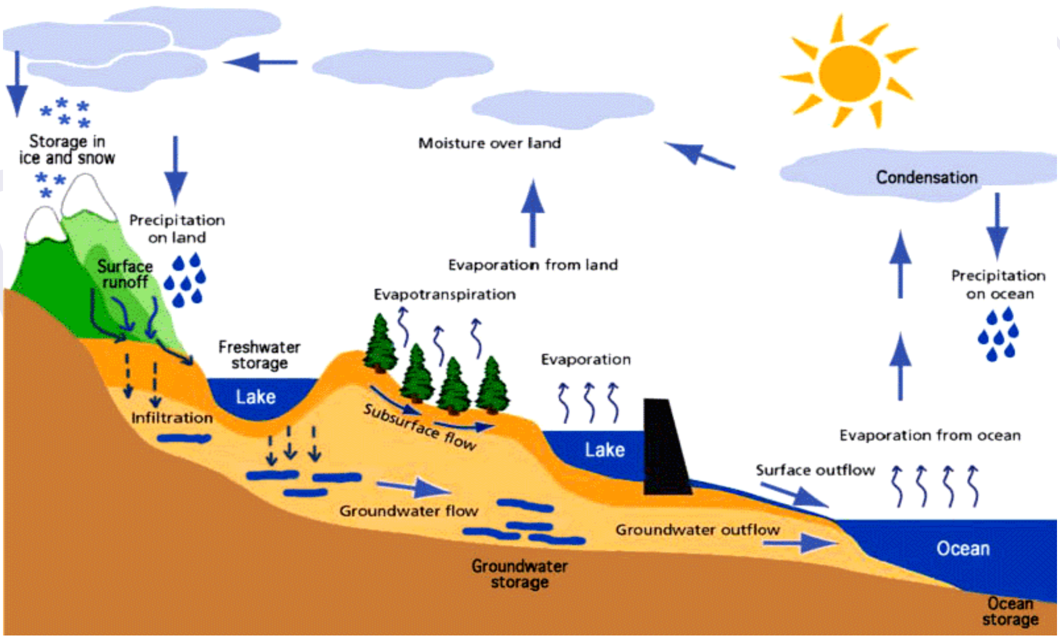

Figure 2.1: Hydrological cycle process (Fwr, 2005)

2.2.1 Surface water

Surface water is fresh water on the earth’s land surface and it is found in lakes, rivers, streams and wetlands. It can be contrasted with groundwater and atmospheric water. Surface water plays an important role as a basic national water resource. The quality of water is affected by a wide spectrum of natural and human influences (Mohd *et al.*, 2016). The quality and quantity of surface water vary from one place to another due to several factors such as climate, geology and surrounding land use. In addition, surface water is also a source of water replenishment and causes changes in groundwater quality (Guggenmos, 2010). A lake is an enclosed body of water with a considerable size. It is totally surrounded by land with non-direct access to sea except for rivers or streams that feed or drain the lake (Huang *et al.*, 2015). The main characteristic of lakes which makes its unique is that it has long water retention and complex response dynamics. Lakes can occur anywhere within a river basin as natural or man-made lakes. Generally, lakes are an important source of freshwater which account for only 0.01 % of the global amount of water.

Meanwhile, rivers are defined as natural water flow moving under the force of gravity along the channels which is fed by surface and underground runoff. Rivers are classified based on topographic features and hydrological regime. These in turn are influenced by soils, climate, relief and vegetation. The main criterion for the evolution of rivers is the dependence of runoff variation on the seasonal variation in rainfall and air temperature (Khublaryan & Sketch, 2003). While, retention ponds are designed with additional storage capacity to attenuate surface runoff during rainfall events. They are required in areas with high groundwater tables. This pond holds a permanent body of water and is also known as wet ponds or wet basins. The volume of water in retention ponds is treated by natural vegetation in the pond to remove sediments and pollutants.

2.2.2 Groundwater

Groundwater is defined as water beneath the earth's surface which can be found in soil pore spaces and in the fractures of rock formations (Muchingami *et al.*, 2012). In line with Todd *et al.* (2005), the term 'groundwater' commonly refers to mean water occupying all the voids and fractures within a geologic stratum. The unconsolidated deposit is classified as an aquifer when it is able to yield a usable amount of water. Meanwhile, a water table is known as the depth at which soil pore spaces, fractures and voids in rocks become completely saturated with water. It is important for the engineering field, especially in geological studies and water supply management. Meanwhile, the unsaturated layer is usually found above the saturated layer and extends upwards to the ground surface. The lack of information, the perception that the supply is non-suitable, and the lack of expertise are some of the factors resulting in the underutilization of groundwater resources. However, in Malaysia, groundwater resources are underutilized. The use of groundwater for domestic purpose is mainly confined to rural areas. Especially in Kelantan and Perlis, groundwater is being significantly utilized for potable water supply. Groundwater is treated before bottling in the mineral water industry. For industrial purposes, groundwater is usually utilized in cleaning and cooling. Groundwater utilization for agricultural purposes is not very well developed and is normally confined to isolated agricultural areas or areas outside the many irrigation schemes. In theory, ground water resources have not yet been fully developed through exploration and research for maximum utilization of the precious resource. At general, existing data are not sufficient or reliable enough to plan regional actions for the sustainable use of groundwater. The lack of sufficient and reliable data causes a considerable risk of deterioration of groundwater status, both quantity and quality (Zamri, 2011).

2.3 Surface-groundwater interactions

Groundwater is part of the water resources for human needs. The water table could be shallow or deep and could rise or fall depending on several factors such heavy rain or snow. Groundwater which moves slowly through layers of soils, sand and rocks is known as an aquifer. The speed of groundwater flow depends on the size of spaces in soil or rocks and how well the space is connected. Groundwater is brought to the surface naturally through a spring and it can flow into lakes and streams (Sunday, 2012). This water can also be extracted through wells drilled into aquifers. The source of groundwater is fed by rainfall and surface waters (lakes, streams, oceans, ponds and rivers). Both surface water and groundwater form parts of one interlinked system (Jackson, 2007). Groundwater and surface water are not isolated components of the hydrological cycle as they interact in the range of topographic, geologic and climatic landscapes (Sophocleous, 2002).

Surface water and groundwater interact in two ways. First, groundwater flows through the streambed into a stream known as a gaining stream. On the other hand, the losing stream is where stream water infiltrates through sediments into groundwater. Groundwater offers a more stable water resource and rich groundwater areas play a vital role in regional water resources (Ho, 2011). The connectivity is basically controlled by the permeability of the streambed, aquifers and the channel position with regards to the groundwater, and the geometry and size of the contact area. Under low and intermediate flow conditions, the contact area is usually determined by the channel geometry. During floods however, the water level can rise above the river bank and the geometry of the floodplain controls the exchange interface (Sophocleous, 2002).

The effective management of water requires an understanding of the components of the hydrological cycle as well as the relations between those components. One of the important relations that has traditionally been overlooked in water resource management is the relationship between surface water and groundwater. The observation and measurement of surface-groundwater relationships are complex as they required an understanding on how they interact both temporally and spatially. In contrast, water movement on the surface is usually in response to rainfall events while the movement of water beneath land surface can vary, making it difficult to predict (Dixon-jain, 2008).

The interaction between surface water and groundwater is the key process in the hydrological cycle and an understanding of their connection is vital for sustainable water resource management. An understanding of the basic principle of interactions between surface water and groundwater is needed for the effective management of water resources. Thus, maintaining water quality and quantity is vital for the management of both surface and sub-surface reservoirs.

2.3.1 Hydrochemical interactions

The chemical composition of surface and subsurface water is mainly influenced by geology and the contact time that water has with geological materials (Dixon-jain, 2008). The microorganisms contained in soil, sediments and water could also affect the chemical characteristics of surface water and groundwater. In shallow environments, groundwater is mostly exposed to a large store of salts and contamination from anthropogenic sources (Dixon-jain, 2008). Hence, the interaction between the local flow system and surface water is important for water quality management. In local flow systems, groundwater is in contact with aquifer materials for a short time which results in minimal chemical changes prior to surface water discharge (Winter *et al.*, 1998). Different from water in deeper layers, flow systems have longer flow paths and a longer contact time with subsurface materials for the products of geochemical weathering to accumulate.

2.4 Geophysical Survey

The geophysical method is a common technique used by geophysicists to discover the earth’s surface. It applies the principles of physics to study the earth. Geophysics has been developing rapidly throughout the years and it has been selected for the investigation of the subsurface in many studies. It is used to explore various ground resources such as groundwater, minerals and hydrocarbon. This method is involved in the interpretation of soil properties, layering and composition of the subsurface, and cavities, structures or water bodies generally found underground which have different physical characteristics from their geological surroundings (Dor *et al.*, 2011). The geophysical method is known for its effectiveness in civil engineering compared to most conventional methods due to the concern of time, cost and quality (Abidin *et al.*, 2011). It plays an important part in preliminary surveys, especially in determining subsurface conditions.

2.4.1 Electrical Resistivity Imaging (ERI)

The most common geophysical method used is Electrical Resistivity Imaging (ERI). The ERI survey is carried out basically to determine subsurface resistivity distribution by making measurements on the ground surface (Asry *et al.*, 2012). Other than that, ERI helps to illustrate the geological environment to indicate the existence of the aquifer layer. It has been used for decades to identify the thickness and resistivity of layered media. Known as a non-destructive method, this technique is able to reduce interruption and damage to sites as it is a surface technique (Azhar *et al.*, 2016). Hence,

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