THE INFLUENCE OF PARTICLE SIZE TOWARDS RESISTVITY AND CHARGEABILITY VALUE FOR GROUNDWATER INVESTIGATION INTERPRETATION

AHMAD KHAIRUL BIN ABD MALIK

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I dedicate this effort towards my beloved parents,
Abd Malik Bin Yusof & Aminah Binti Abd Mohid.
my wife,
Najwanisa Binti Tusin.
and my siblings,
Azmin, Nisa, Khairunee & Khairiah.
Thank you for the unrelenting patience and supports.

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ABSTRACT

Electrical resistivity tomography is a non-destructive method of groundwater surveying where the current is being injected into the ground and the value of the subsurface resistivity and chargeability were determined. One of the major problems in groundwater surveying is the interpretation of the groundwater aquifer under saturated condition. The overlapping resistivity and chargeability value under a saturated condition is a major concern in groundwater aquifer interpretation. In this study, the effects of particle size and the interrelationship between the different particle sizes were assessed towards the resistivity and chargeability value. There were 17 samples used in this study ranges from gravel, sand, silt and clay sizes. The materials used to conduct the testing were granitic rock and river sand. Quartz and kaolinite dominated samples were used for the silt and clay sample. The device used for the experiment is Terrameter LS 2 to conduct the resistivity and induced polarization tests. The electrical testing follow the ASTM G57 and ASTM G187/AASHTO T-288 standards for the soil box with volume of 270 cm^3 and soil cylinder with volume of 2714 cm^3 respectively. The resistivity value for the gravel ranges from 177 Ωm at its highest to 128 Ωm at its lowest. The resistivity value for the sand ranges from 121 Ωm at its highest to 86 Ωm at its lowest. The resistivity value of the two silt and clay samples were 37 Ωm and 56 Ωm at the point of liquid limit. The chargeability value for the gravel ranges from 5.6 ms to 7.9 ms with decreasing particle size. The highest chargeability value for sand is 12.3 ms and the lowest is 2.0 ms. The silt and clay samples chargeability were 1.7 ms and 1.2 ms, respectively. The resistivity and chargeability for water used in this study were 101.7 Ωm and 0.41 ms. This study helps in clarifying the effect of particle size for resistivity and chargeability value as the larger particle size increases the resistivity value and decreases the chargeability value of water due to porosity and improve the understanding of the electrical resistivity tomography for groundwater investigation interpretation.

ABSTRAK

Pengimejan rintangan elektrik (ERT) adalah kaedah penyiasatan air bawah tanah yang tidak merosakkan kondisi tanah di mana arus eletrik disuntik ke dalam tanah dan nilai ketahanan dan daya pengecasan kandungan bawah tanah ditentukan. Salah satu masalah utama dalam peninjauan air bawah tanah adalah tafsiran akuifer air bawah tanah yang mempunyai paras air yang tinggi. Nilai-nilai rintangan eletrik dan daya pengecasan bawah tanah yang bertindih membuat penafsiran akuifer bawah tanah menjadi rumit. Dalam kajian ini, kesan saiz zarah dan hubungan diantara kesemua partikel berhubung rintangan dan penyahcasan eletrik dikaji. 17 sampel ujian digunakan di dalam kajian ini yang terdiri daripada kerikil, pasir, kelodak, dan tanah liat. Bahan yang digunakan untuk melakukan pengujian adalah dalam bentuk batu granit dan pasir sungai. Sampel dominan kuarza dan kaolinit digunakan untuk sampel kelodak dan tanah liat. Peranti yang digunakan untuk ujian eletrik ini adalah “Terrameter LS 2”. Ujian eletrik yang dijalankan adalah mengikuti standard ASTM G57 untuk “soil box” yang berukuran 270 cm^3 dan ASTM G187/AASHTO T-288 untuk “soil cylinder” yang berukuran 2714 cm^3. Nilai ketahanan eletrik bagi kerikil adalah di antara 177 Ωm pada nilai yang tertinggi dan 128 Ωm pada nilai yang terendah. Nilai ketahanan bagi pasir adalah di antara 121 Ωm pada nilai tertinggi dan 86 Ωm pada nilai terendah. Nilai ketahanan bagi dua sampel kelodak dan tanah liat ialah 37 Ωm dan 56 Ωm pada titik had cecair. Nilai pengecas untuk kerikil adalah di antara 5.6 ms hingga 7.9 ms. Nilai pengecasan tertinggi untuk pasir ialah 12.3 ms dan terendah ialah 2.0 ms. Muatan sampel kelodak dan tanah liat adalah 1.7 ms dan 1.2 ms. Nilai kerintangan dan polarisasi induksi untuk air yang digunakan dalam kajian ini adalah 101.7 Ωm dan 0.41 ms. Kajian ini membantu menjelaskan kesan ukuran partikel bagi nilai-nilai rintangan dan penyahcasan eletrik di mana partikel yang besar menyebabkan nilai rintangan meningkat dan mengurangkan nilai penyahcasan kandungan air disebabkan oleh faktor keliangan dan menambah baik kualiti pentaksiran air bawah tanah bagi pengimejan rintangan eletrik.

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LIST OF SYMBOLS / ABBREVIATIONS

AC	-	Alternating current
DC	-	Direct current
ERT	-	Electrical resistivity tomography
ERV	-	Electrical resistivity value
GIS	-	Geographic information system
IP	-	Induced polarization
USCS	-	Unified soil classification system

CHAPTER 1

INTRODUCTION

1.1 Research background

Groundwater exists in the inter-particle pore spaces and the fractured rocks (Mézquita González *et al*., 2021). This unseen water resources can be utilized for the water security for the nation that protecting people against drought or the unavailability of conventionally treated water. The usage of groundwater for domestic usage is minimal in some part of Malaysia mostly because of the unsuitable lithology on site and the over reliant of surface water sources from most people apart from industrial area, schools, mosque and rural area (Mridha *et al*., 2020). There are four types of geological groundwater formations (aquifers, aquitard, aquiclude, and aquifuge) and the difference in between the formations are their ability to transmit water (Ma *et al*., 2020). Determining the right type of groundwater formation for extraction purposes is really important and the right methods for subsurface identification needs to be employed to minimize resources.

There are multiple methods for groundwater exploration which has been used to find the location of potential groundwater. Groundwater exploration can be separated into three methods, namely geologic and hydrologic methods, surface methods and subsurface methods. Geophysical methods can be used in the surface and subsurface methods for groundwater investigations. Over the years, with the introduction of several methods and techniques, the technology of geophysics has been rapidly improved. In geological and geotechnical investigation settings, a large area is usually investigated and geophysical method will provide useful tools in helping the survey of the earth without expending too many resources. One of the reliable methods of surveying the groundwater is by using the electrical resistivity tomography (ERT). Electrical resistivity tomography is one of the reliable methods of exploring and visualizing the tomography of the subsurface in search of groundwater without having to disturb the condition of the ground subsurface (Mainoo *et al*., 2019). ERT is a non-destructive method of groundwater surveying where the electrical current is being injected into the ground and the value of the subsurface resistivity and chargeability are determined by applying the geophysical electrical technique survey, i.e., resistivity and induced polarization technique.

The resistivity and the chargeability value are influenced by the lithology and the water content of the sub-surface area which are being monitored (Aladejana *et al*., 2020). A difference in resistivity value in the absence of moisture is really obvious, and this makes it easier to determine the position of water in the subsoil when there are rock fractures, as the difference in between the dry and wet condition of soil can easily be differentiated by using the electrical resistivity methods (Zhou & Che, 2020). In saturated subsurface formation however, the interpretation data for potential groundwater aquifer is challenging and at times requires both the resistivity and chargeability value (Ahmad *et al*., 2020). This is because the differences in between the dry and wet condition of the soil are diminished because of the high groundwater table making the soil to be fully saturated. However, interpretation tasks to decide the aquifer layer is unable to directly refer to the earth material-resistivity-charge ability chart due to the overlapping values. Past study shows, there are overlapping resistivity values between the geomaterials in an inhomogeneous subsurface for the same type of soil as shown in **Table 1.1**.

The subsurface may consists of different type of rocks which may be classified as igneous, sedimentary or metamorphic. Depending on their origin, each type of rocks differs from one another in term of their relative reaction towards the resistivity and chargeability. The difference reaction towards the electrical resistivity and chargeability is due to the different type of minerals within the rock which has different electrical properties. Archie (1942) propose a theory that the measured resistivity is affected by the water resistivity and the geometric factor. The theory is later called Archie’s law. Archie’s law states there are few factors that may effects the measured resistivity of an aquifer such as porosity, water saturation and water resistivity.

This study helps improve the interpretation for groundwater which enhanced the understanding of the interpretation of the subsurface exploration in the relation of groundwater surveying. With an improved groundwater survey quality, the usage of treated water can be reduced and the untapped groundwater resource can be utilized and provided to the area where the treated water may not be supplied.

Table 1.1: Resistivity value for the same type of soil from multiple study

Type of soil	Resistivity value (Ohm-m, Ωm)	Author
Sandy clay	296 – 1117	Oyeyemi *et al* (2021)
Clayey sand layer (confining bed)	260 – 5140	
Sand (main aquifer)	115 – 530	
Sandy layer	205 - 891	Bayewu *et al* (2018)
Sandy clay	122 - 154	
Clayey layer	34 - 98	
Clayey sand layer	19 - 175	
sand and clay lenses	20 - 84	Othman *et al* (2018)
Clay layer	<20	
Sand layer	28 - 70	
Clay and clayey sand deposits	< 20	
Gravelly sand	58 - 2029	Mohamaden *et al* (2016)
Sand and gravel	188 - 518	
Sand (Aquifer)	17 -111	

1.2 Problem statement

In a quaternary geological formation, it is challenging to identify the sandy body for the groundwater aquifer as the water table is high. The ground is in saturated condition, resulting in the resistivity value of the subsurface to be very low for any material i.e., sand or clay (Gnanachandrasamy *et al*., 2020). In the case of very low resistivity value, the chargeability parameter could be utilized to recognize the change of soil parameters. Past research shows the resistivity of groundwater aquifer has wide range of resistivity value and overlapping resistivity for different type of materials under saturated condition. The overlapping resistivity value makes it difficult to give precise identification and interpretation of the groundwater aquifer within the subsurface. The overlapping value makes it hard for the prediction of the location of the potential groundwater aquifer especially in a saturated condition. In the subsoil, the parameters that differentiate the type of soil are the different ratio of particle sizes and different type of soil provides different resistivity and chargeability value. Thus, it is important to understand the influence of the particle size towards the resistivity and chargeability values as the soil profile are determined by the different ratio of particle sizes. It is expected that this study improves the understanding of resistivity and chargeability value and improve the earth material-resistivity-chargeability chart. This study may help in the interpretation of the actual groundwater aquifer when dealing with saturated earth materials especially in the quaternary formation by understanding the effect of particle size towards the electrical resistivity testing. Besides, there is yet study to revise the earth materials resistivity and chargeability based on the variable of moisture content and grain sizes in controlled condition. With the added controlled condition towards the resistivity and induced polarization testing, the outcome of the experiments can further enhance the resistivity and chargeability interpretation of the electrical resistivity testing. Furthermore, with the availability of the controlled study parameters such as water saturation, porosity and water resistivity better understanding on the effect of particle size towards the resistivity and chargeability value under saturated condition can be established.

1.3 Aim and objectives of the study

The purpose of this research is to analyse the effect of different particle sizes towards the chargeability and resistivity value under fully soaked condition for the purpose of interprating the groundwater electrical exploration. To achieve this aim, this research intends to fulfil the following objectives:

i. To establish the effect of grain sizes on the resistivity value under fully soaked condition
ii. To demonstrate grain size effect on the chargeability value under fully soaked condition
iii. To determine the resistivity and chargeability of different type of soil under fully soaked condition

1.4 Scope of research

Multiple site investigation studies have been conducted concerning the chargeability and resistivity of the subsurface. However, for this particular study, the testing is performed in a lab-scale environment in Engineering Geology and geophysics laboratory for the electrical testing and Geotechnical engineering laboratory for the geotechnical parameter testing such as particle size distribution and Atterberg limit tests. Two-terminal and four-terminal resistance meter were used to obtain the value for resistivity and chargeability and the electrical testing parameters is by using Abem Terrameter LS 2. The electrical testing follows the ASTM G57 soil box with a volume of 270 cm^3 and ASTM G187/AASHTO T-288 standards for the soil cylinder with a volume of 2714 cm^3. There are minimum total of 3 stackings for each testing, the total amount of testings are then being averaged into one value, and the value are then representing the resistivity or chargeability value of the samples.

The materials tested are in the form of multiple sized particles ranging from gravel, sand, silt and clay. The total numbers of sample for gravel are 7, the sand has a total of 8 samples and the total sample for silt and clay are 2. In total the amount of sample tested are 17 samples. First, a gravel-sized particle is tested from granitic rocks which was collected from Batu Pahat Lian Huat Granite Quarry Sdn Bhd located at Jalan Minyak Beku, Batu 2 3/4, Johor. Secondly, a much smaller particle is tested in the form of sand which were collected from a river at Sungai Bantang Bekok located in Segamat, Johor to avoid the effect of salinity. Lastly, the silt and clay samples were collected from Kaolin (Malaysia) Sdn. Bhd. which is based in Tapah, Perak for sample ranging from 63 µm and below.

Aside from the aforementioned particles, the amount of moisture content is varied until the samples are in a fully soaked condition. Unified Soil Classification System clarifies that the type of soils are determined by the ratio of the different particle sizes within the samples. Hence, the different individual particle size sample are later combined to form a different type of soil according to the Unified Soil Classification System to further understand the effect of different grain sizes in determining the resistivity and chargeability value of the soil sample. The type of soils prepared in this study are well graded gravel, poorly graded gravel, poorly graded gravel-sand-silt/clay mixture, well graded sands gravelly sands, poorly graded sands gravely sands, poorly graded sand-silt/clay mixture, inorganic silts and silty clays.

The results obtained from the testing may not be directly used as a reflection of the resistivity value at site condition as the resistivity value and chargeability value of the subsurface is also attributed by the condition of the groundwater itself, the low resistivity and chargeability value of the groundwater itself might diminish the effect of the particle size. In term of the chargeability testing, different experiments may give different outcome based on the electrical parameters used during the testing. Few parameters that may alter the outcome of the results are the voltage usage, observation time and the amount of windows selected for the particular testing. Hence, using the results obtained from this study as a direct interpretation of the site subsurface is unadvisable.

1.5 Significant of research

This study is important to improve the resistivity and chargeability chart of different type of multiple particle sizes. This chargeability and resistivity value can help the sub-surface groundwater surveys by using the electrical methods during the interpretation stages of the survey The contributions of this research are as follow;

i. This research fills the gap in knowledge and adds values to the chargeability and resistivity chart for minerals and rocks and different type of soil.
ii. With the availability of the improved resistivity and chargeability chart, the interpretation of groundwater can add confidence in subsurface exploration in interpreting and predicting the availability of groundwater.
iii. Further focus and efforts by multiple organization may be directed towards the groundwater exploration as an alternate water supply with the availability of better subsurface electrical data.

iv. The quality of national study in the subsurface area will be enhanced, especially in the field of electrical resistivity.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the information of the resistivity and chargeability of minerals and rocks are provided. The discussion on the behaviour of a different type of minerals and grain sizes are imperatively reviewed. This chapter arranges a general review of resistivity value of the different type of rocks highlighting the important influence that affects the resistivity of different type of rocks, grain sizes and minerals. The testing and application of the minerals, rocks, and grain sizes were explained further in chapter 3.

2.2 Groundwater in the rock formation

Groundwater is water that exists in the pore spaces and fractures in rock and sediment beneath the Earth's surface. It originated from various sources coming from rainfall or snow and then moves through the soil into the groundwater system, where it eventually makes it way back up again into the surface streams, lakes or oceans. Natural groundwaters vary widely in composition. However, the common constituent in all such solution is sodium chloride, along with other salts and oxides. Relatively low concentration of dissolved salt is found in surficial waters, while connate waters may be very saline. The resistivity of natural water is determined mainly by the salinity (González-Quirós & Comte, 2020).

2.2.1 Groundwater origin

Groundwater originates from rainfall and infiltration within the hydrological cycle (Gamboa *et al*., 2019). Groundwater encountered at great depth in sedimentary rocks as the result of water being trapped in marine sediments at the time of the deposition. This type of groundwater is called connate water (Thibodeau *et al*., 2003). These water are normal saline. Understandably, the water is derived from entrapped seawater as the original seawater has moved from its original place.

The hydrological cycle is the fundamental principle of groundwater hydrology. One of the major forces that cause the cycle comes from the radiant energy of coming from the sun (Dayon *et al*., 2018). Water evaporates and travels into the air and becomes part of the cloud. It falls to the earth as precipitation. Then, it evaporates again. This occurs repeatedly in a never-ending cycle which is called the hydrological cycle. This cycle is illustrated in **Figure 2.1**.

Precipitation creates runoff that travels over the ground surface and helps to fill lakes and rivers. It also percolates or moves downward through openings in the soil or rocks to replenish the aquifers under the ground (El-Kaliouby & Abdalla, 2015). Some area receives more precipitation than other places and this is due to the location which is close to the ocean or large bodies of water that allows water to evaporates and form clouds. Some area may receive less precipitation than others, mostly because of the distance from the ocean and near a mountain.

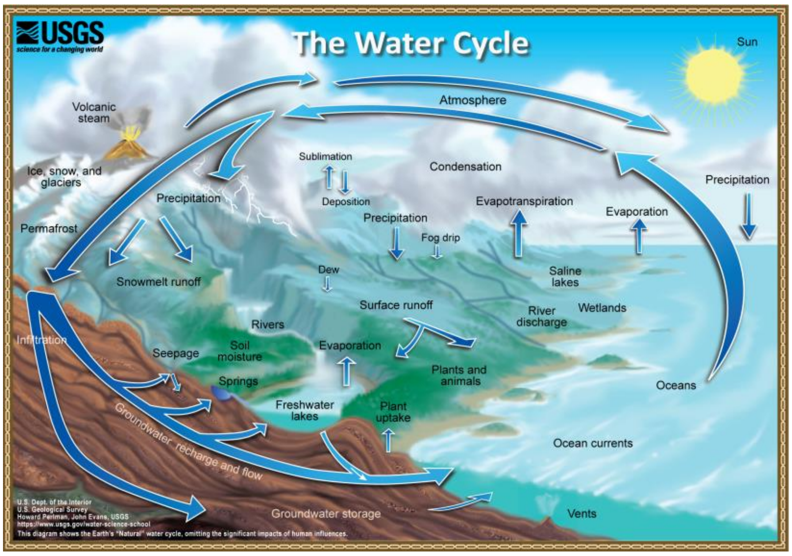


Figure 2.1: Schematic representation of the hydrological cycle (Perlman & Evans, 2019)

2.2.2 Geological formation and aquifers

There are four types of geological formations (aquifers, aquitard, aquiclude, and aquifuge). An aquifer is a groundwater reservoir composed of geologic units that are saturated with water and sufficiently permeable to yield water in a usable quantity to wells and springs. Sand and gravel deposits, sandstones, limestones, and fractured, crystalline rocks are examples of geological units that form aquifers. Aquifers provide two important functions to transmit groundwater from areas of recharge to areas of discharge and they provide a storage medium for usable quantities of groundwater (Dragon, 2021). The amount of water a material can hold and transfer depends upon its porosity (Worthington *et al*., 2019). The size and degree of interconnection of those openings determine the materials ability to transmit fluid as shown in **Figure 2.2**.

Aquitard is a partly permeable geologic formation. It transfers water at such a slow rate that the yield is insufficient. Pumping by wells is not possible. For example, sand lenses in a clay formation will form an aquitard. For aquiclude, the composition is of rock or sediment that acts as a barrier to groundwater flow. Aquicludes are made up of low porosity and low permeability rock/sediment such as shale or clay. Aquicludes have normally good storage capacity but low transmitting capacity. Lastly, an Aquifuge us a geologic formation which doesn't have interconnected pores. It is neither porous nor permeable. Thus it is neither store water nor transmit it. Examples of aquifuge are rocks like basalt and granite (Ma *et al*., 2020).

For groundwater research, it is important to identify the difference between this different type of geological formation through a thorough examination of the lithological formation of the survey area. This is important because, although most of the ground subsurface might show a potential of groundwater presence, not all of the available water might be able to be extracted. This is because the water that can be extracted are mostly the ones that are located within a sand lens or large sand structure within the subsurface (Abd Malik *et al*., 2019). The Unified Soil Classification System (USCS) classified a plethora of soil types which consists of a combination of not only sand but also gravel, silt and clay. The different soil type caused by the combination of grain sizes demands a much better understanding of the effects of grain size towards the resistivity and chargeability value. One of the other major factors is the rate of recharge of the groundwater (Viaroli *et al*., 2019), which affects the quantity of the available groundwater. All of this factor is mainly derived from the type of lithology of the area. The importance of knowing the type of the lithological area and type of soil for the potential groundwater is very important for locating the extraction point of the groundwater.

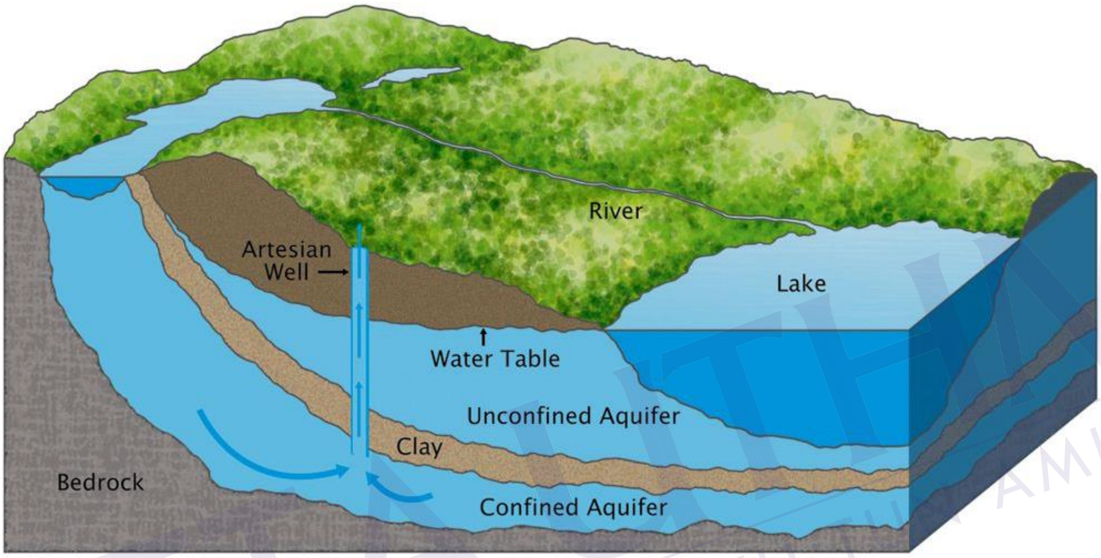


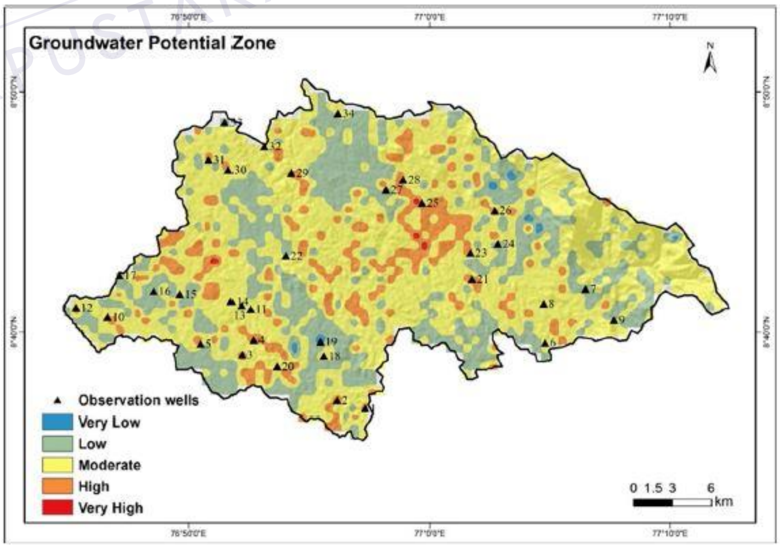
Figure 2.2: Schematic representation of Groundwater aquifer (Gunther, 2011)

2.3 Groundwater exploration technique

There are multiple methods for groundwater exploration which has been used to find the location of potential groundwater. Groundwater exploration can be separated into three methods, namely geologic and hydrologic methods, surface methods and subsurface methods.

2.3.1 Geologic and hydrologic methods

Preliminary conclusions on the occurrence of groundwater can often be made with the aid of aerial photographs, regional geological maps, and geological field reconnaissance. The use of the aerial photograph to obtain geologic information is commonly called photogeology. The main objective of photogeology is to contribute to geologic mapping, some of the examples of the geologic mapping is plotting the distribution of rock types and structures. Interpretation of aerial photograph permits inferences as to the composition of rock types but does not permit the identification of mineral types of estimates of absolute ages of rocks. Rock types with distinctive water-yielding properties can be identified through petrographic studies. The position, thickness and continuity of aquifers, aquitards and aquiclude can be determined with stratigraphic techniques. Over the years the application of Geographic Information System (GIS) has been used intensively concerning the groundwater potential zone (Srinivasa Rao & Jugran, 2003). However, relying only on the topographical information only gives us a rough estimate of where the position of the groundwater may be (Saint *et al.*, 2020). Other methods need to be applied to help provide much better information concerning the position of the groundwater aquifer. **Figure 2.3** shows the application of the topographical information being used to determine the position of the groundwater, the potential groundwater zones are predicted from the multiple information of the surface where the geological formation of the site are studied to predict where the possible type of rocks that might holds groundwater as in **Figure 2.3 (b)**, in **Figure 2.3 (c)** the slope condition of the area might indicates where the direction of the water migh flows With all the information given are known, the possible zone for groundwater can be estimated as shown in **Figure 2.3 (a)** and this information increases the confidence for groundwater extraction processes.



(a)

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