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The Influence of Clay Minerals Towards Resistivity and Chargeability Value for Groundwater Interpretation

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Abstract: Electrical Resistivity Method (ERM) and Induced Polarization (IP) is suitable for geophysical technique to groundwater interpretation due to non-destructive methods. It is difficult in determining the precise identification or classification of soil beneath the surface. The purposes of this study is to measure the electrical resistivity and chargeability with different type of clay minerals such as Kaolinite, Illite and Montmorillonite, measure the electrical resistivity and chargeability for clay minerals with different moisture content, and develop the earth-material-resistivity-chargeability interpretation table. This study consists setting of laboratory using ABEM Terrameter LS2 with 4 electrode principle connected with soil box in order to determine the resistivity and chargeability value towards clay minerals. This study will develop the earth material-resistivity-chargeability interpretation table for groundwater purposes and increase the knowledge about the flow of groundwater. However, with the presence of different amounts of moisture content in clay minerals shows that the values were greatly responded which was slightly reduced the value of resistivity and chargeability. By comparing the results, it shows that the Kaolinite clay mineral has the highest value of resistivity and chargeability which is 40.8 Ωm and 1.59 ms respectively compare to Illite and Montmorillonite. In addition, when the samples added with different amounts of moisture content, the samples were tested from dry-moist-saturated-oversaturated condition, at some point the resistivity and chargeability values become constant because the samples passing the liquid limit value which means the samples passes from liquid state to plastic state. Hence, the result shows the influence and the importances of clay minerals toward resistivity and chargeability towards minerals for groundwater interpretation purposes.

Keywords: Groundwater , Electrical Resistivity, Induced Polarization

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1. Introduction

Groundwater is the water found at the subsurface either in granular soil pore spaces or in rock fractures formations [1]. A fractured rock formation or an unconsolidated granular layer was considered an aquifer when it was capable of yielding a usable volume of water. The depth at which spaces or fractures or voids of soil pore in rock become completely saturated with water was called the aquifer. An aquifer was an underground layer of water-bearing permeable rock, rock fractures or unconsolidated granular materials. Groundwater was most frequently extracted by the construction and operation of extraction wells for agricultural, urban, and industrial use. The method that use for groundwater exploration was Electrical Resistivity Method and Induced Polarization.

Electrical Resistivity Method (ERM) and Induced Polarization (IP), are the methods that injecting the current into the ground and the resistivity value and chargeability value were determined[2]. The resistivity value describes how well the material can inhibit current flow while chargeability value describes how well the material tends to retain electrical charging.

Alluvium and clay soils are formed by various sizes of grains and minerals. The objectives of this study is to measure the electrical resistivity and chargeability with different type of clay minerals, measure the electrical resistivity and chargeability for clay minerals with different moisture content, and develop the earth-material-resistivity-chargeability interpretation table. Changes and differences in resistivity values are influenced by the types of rock, soil and chemical content of water [3]. Furthermore, The presence of various clay minerals also affects electrical resistivity besides understanding the resistivity response of various clay minerals [4]. Therefore, this study will investigate the changes in the mineralogy towards the value of resistivity and chargeability.

2. Literature Review

2.1 Electrical Resistivity Method

Electrical Resistivity Method (ERM) is basically a geophysical surface method and it helps to calculate or classify the apparent resistivity of soils and rocks as a function of depth or location in the sub-surface imaging [5]. Conventional method such as drilling was used in obtaining groundwater position and to determine soil sampling, but this method is weak as the method itself was expensive, time-consuming and have a limited data coverage [6]. Current was injected into the Earth through a pair of current electrodes during resistivity surveys. An apparent resistivity (pa) value was measured from the current (I) and voltage (V) values by using pa=kV/AI, where k was the geometric factor depends on the arrangement of the electrodes. By using ABEM Terrameter LS2 with soil box and 4-electrod principle were used to evaluate the data by allowing the voltage current to flew through it (soil box) and the result will appeared at the screen of ABEM Terrameter LS2. The electrical resistivity method has followed the fundamental physical law of Ohm's Law and determined the value of resistivity in Ohm meter (Ωm) [7].

2.2 Induced Polarization

Induced polarization is a technique of geophysical imaging used to determine the electrical chargeability of subsurface materials. It has practical importance as a method of exploring the subsurface for buried mineral deposits. The primary advantage of the Induced Polarization method is its capability under favorable conditions to detect the presence of even very small amounts of minerals [8]. According to (Loke et al., 2013), resistivity measurement are in combination with Induced Polarization for complex minerals [9]. The chargeability is a measurement of a current retained in a substance with after the inducing current was turned off. The primary voltage almost immediately drops to a secondary response level and then the decay voltage will diminishes with time [10]. The theoretical measure of Induced Polarization, M = Vs / Vp in milliseconds (ms). Testing follows the ASTM G57 standard and ASTM G187/AASHTO T-288 standard by using ABEM Terrameter LS2 connected with 4 electrod to the soil box.

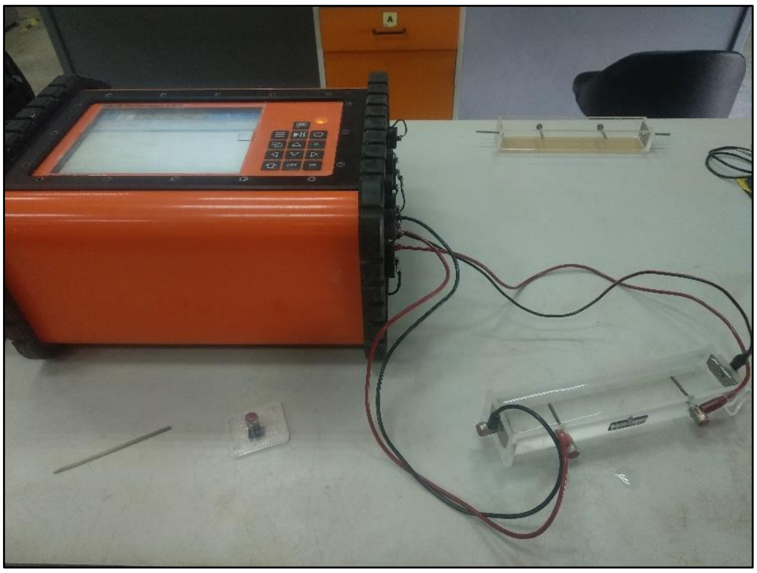

Figure 1: ABEM Terrameter LS2 connected with soil box

2.3 Sample Preparation

By using X-Ray Diffraction which also known as XRD, all of the sample Kaolinite, Illite, and Montmorillonite were tested for its minerals compound. The functions of this experiment is to identify the crystalline structure that present in a material and reveal the chemical [11]. To reach the size of silt and clay, the materials need to be sieve below 63 μm to equate all of the material to its particle size.

Figure 2: XRD Equipment

By referring BS 1377: Part 2: 1990, the specific gravity of the soil by using a small Pycnometer were used to calculate the density of the soil. The Specific Gravity refers to the mass of solids in the soil compared to the mass of water at the same volume. An average of the Specific Gravity is actually the value of Specific Gravity of soil solids [12]. The formula for determined the specific gravity were:

$$SG = \frac{(w2 - w1)}{(w4 - w1) - (w3 - w2)}$$

Hydrometer test were conducted to classify the grain size distribution of the samples used in this experiment. Besides, the uses of hydrometer test is to determine the particle size distribution for sample particles of size below than 75 µm [13]. Furthermore, this test calculates the size of soil particles which settled by speed that suspension from a liquid by using a hydrometer bulb and measuring cylinder. The detail test procedure can be referred to BS 1377: Part 2: 1990.

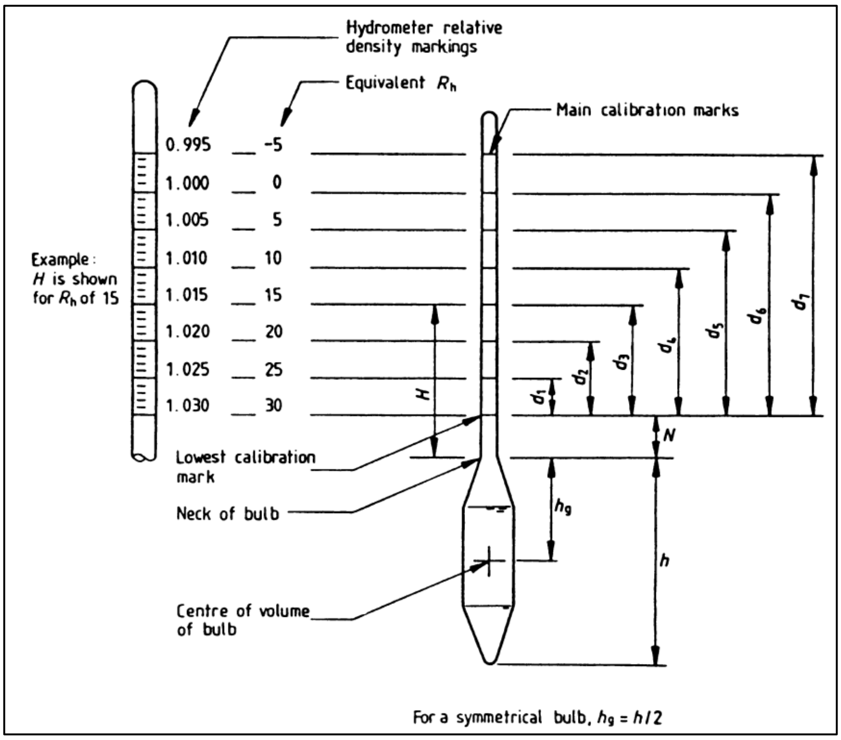

Figure 3: The essential for calibration of hydrometer

Atterberg limit test can be conducted to evince their physical properties and this experiment one of the important aspects of moisture and salinity control. The penetrometer test has been used to find the liquid limit of clay soils [14].

Table 1: The classification of soil according to plasticity

Plastic Index (PI)	Degree of Plasticity	Type of Soil
0	Non Plastic	Sand
<7	Low Plastic	Silt
7-17	Medium Plastic	Silt Clay
>17	Highly Plastic	Clay

Hence, with the obtain moisture content for the mineral used, the experiment of resistivity and chargeability value can be conducted. This research may be established as the moisture content used in the substance of the materials would become saturated since the complication of groundwater interpretation typically arises in a saturated subsurface. In determination of moisture content of clay particles, the particles must be fully hydrated because the moisture content may exerts the density of clay in aqueous suspension [15].

3. Results and Discussion

This study acquired the parameters of resistivity and chargeability towards clay minerals which included Kaolinite, Illite and Montmorillonite. For the primary phase, the identification of mineralogy was obtained to identify the crystalline structure that present in a material by using a XRD testing. On the secondary phase, properties of soil were obtained by determined the physical properties through Atterberg Limit testing. This test obtained to determine the Liquid Limit and Plastic of the clay minerals. For the last phase, the values of resistivity and chargeability was obtained by referred the data obtained from Atterberg Limit. By exploitations of graphs, the data and results produced were analyzed using graphs to achieve the goals of this study and conclusions can be drawn from the analysis.

3.1 X-Ray Diffraction Test

All of the sample Kaolinite, Illite, and Montmorillonite were tested for its minerals compound and to ensure the minerals are as similar quality as found on a residual soil. As shown in figures in **APPENDIX A**, a peak of the graph proving the existance of a crystalline structure on the mineral. The peak intensity tells about the position of atoms within a lattice structure and peak width tells about crystallite size and lattice strain for Kaolinite, Illite and Montmorillonite. The black line in the graphs indicates the most components contained in the mineral samples and the degree of crystallinity increases the hardness and density of the materials. A peak in intensity occurs when the mineral contains lattice planes with d-spacings appropriate to diffract X-rays at that value of θ.

3.2 Atterberg Limit Test

Table 2 below shows the data of the Atterberg Limit including Liquid Limit, Plastic Limit and Plastic Index for all of the mineral sample which is Kaolinite, Illite and Montmorillonite. The Liquid Limit obtained from Montmorillonite has excellent absorption capabilities towards water compared to Kaolinite and Illite where it absorb less water which is 185%,71% and 37% respectively. The Plastic Limit result for Montmorillonite was higher than Kaolinite and Illite. This is because the content of inorganic Monmorillonite clay has high plasticity than Kaolinite and Illite which has medium plasticity.

Table 2: Data of Atterberg Limit for clay minerals

Minerals	Liquid Limit (LL), %	Plastic Limit (PL), %	Plastic Index (PI), %
Kaolinite	71.20	36.58	34.62
Illite	37.00	22.37	14.63
Montmorillonite	185.00	55.05	129.95

3.3 Specific Gravity Test

The data were obtained by repeating three times to get the average values of specific gravity. There are ranges of specific gravity values for Kaolinite, Illite and Montmorillonite [16]. As refer to Table 4, all of the data were in range of specific gravity which means the values of specific gravity for Kaolinite, Illite and Montmorillonite is acceptable.

Table 3: Average specific gravity values for clay minrals

Clay Minerals	Average Specific Gravity
Kaolinite	2.59
Illite	2.65
Montmorillonite	1.95

3.4 Hydrometer Test

Hydrometer test was obtained to calculates the size of clay minerals particles. As shown below, the table shows the percentage of silt and clay for Kaolinite, Illite and Montmorillonite clay mineral. Besides, particle size of the three minerals shows different particle size distributions and this indicates that size does not affect resistivity and chargeability data when passing a 63 μm sieve as shown in Table 4 below.

Table 4: Percentage values of particle size for clay minerals

Minerals	Particle Size	Percentage, %
Kaolinite	Silt	67
	Clay	33
Illite	Silt	90
	Clay	10
Montmorillonite	Silt	40
	Clay	60

3.5 Resistivity and Induced Polarization Measurement

ABEM Terrameter LS2 with soil box was used towards Kaolinite, Illite and Montmorillonite. Besides, distilled water also mixed in the clay minerals with 10 % increment respectively until the samples becomes overly saturated. Furthermore, the relation between moisture content and density is taken into attention whether there are changes in density value when the amount of moisture content were increase or otherwise.

For Kaolinite clay mineral, it can be seen that the resistivity and chargeability values slightly decrease when the amount of moisture content increased, until reaching 60 % moisture content where the resistivity values is 44 Ωm and the reading begane to platue. For Illite clay mineral, it can be seen that the resistivity and chargeability values slightly decreased when the amount of moisture content increased and until reaching 30% moisture content where the resistivity values is 23 Ωm and the reading begane to platue. For Montmorillonite clay mineral, it can be seen that the resistivity and chargeability values greatly decreased when presence of moisture content and the resistivity values become slightly constant at around 50 % of water with the value of 3.17 Ωm.

However, the values of sample bulk density for Kaolinite and Illite were increase when the amount of moisture content increases which means Kaolinite and Illite mineral has a shrinkage behaviour. While, the values of sample bulk density for Montmorillonite were decreased when the amount of moisture content increase which means Montmorillonite mineral has a swelling behaviour. The electrical resistivity and chargeability of Kaolinite, Illite and Montmorillonite against moisture content can be summarized in Figure 4. Its seems that Kaolinite has the highest value of resistivity and chargeability compared to Illite and Montmorillonite.

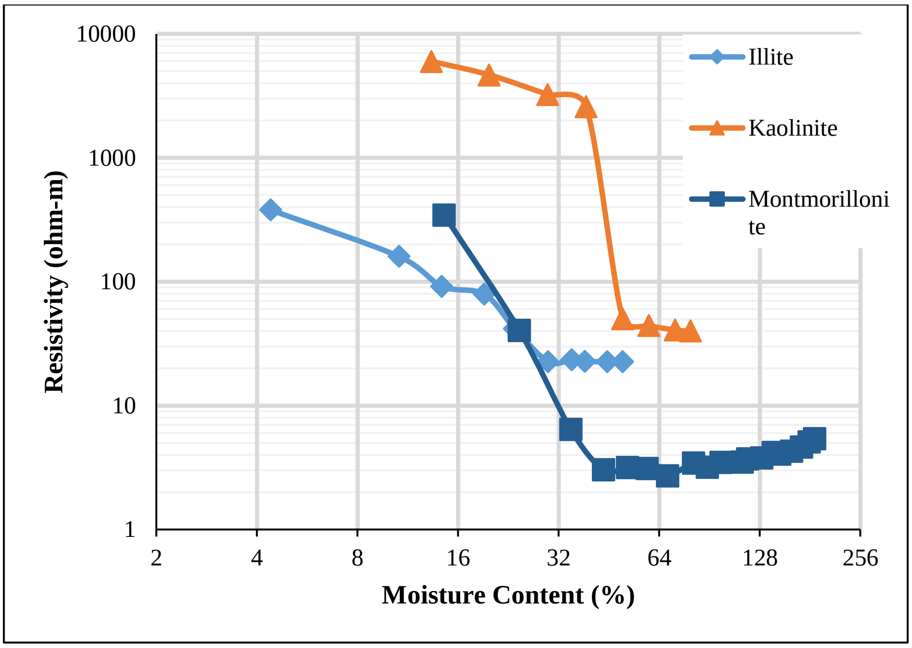

Figure 4: Data of resistivity for clay minerals

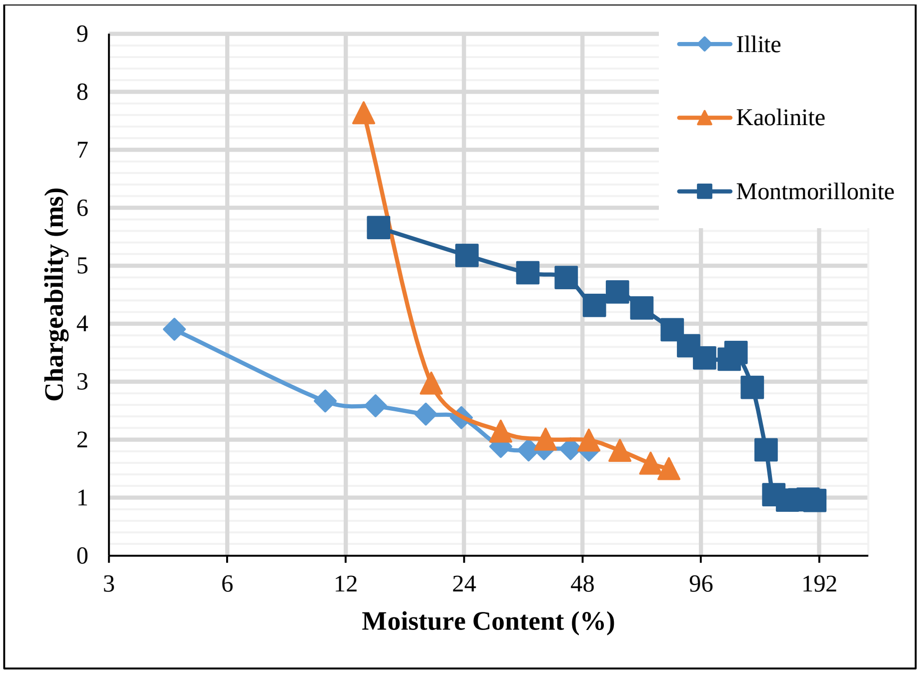

Figure 5: Data of chargeability for clay minerals

4. Conclusion

This research is to describe the effects of clay minerals on the resistivity and chargeability values throughout different amounts of moisture content for groundwater interpretation. By comparing the results of Kaolinite, Illite and Montmorillonite, it shows that the Kaolinite clay mineral has the highest value of resistivity and chargeability.

In addition , when the samples added with different amounts of moisture content, the samples were tested from dry-moist-saturated-oversaturated condition, at some point the resistivity and chargeability values become constant because the samples passing the liquid limit value which means the samples passes from liquid state to plastic state. It shows that, moisture content gave an effect on resistivity and chargeability values. Moreover, the new table was created for interpretation tables of resistivity and chargeability for alluvium material, clay minerals such as Kaolinite, Illite and Montmorillonite.

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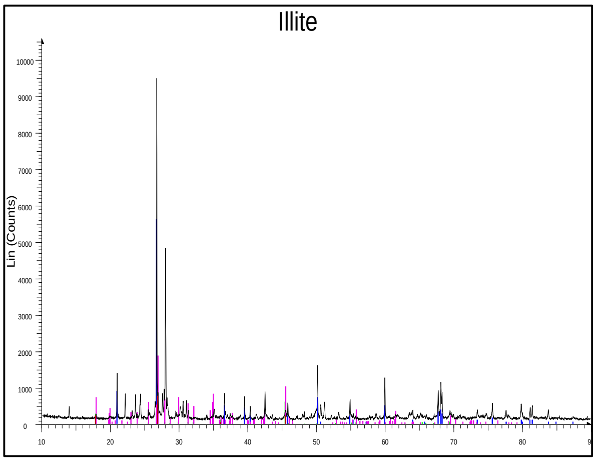
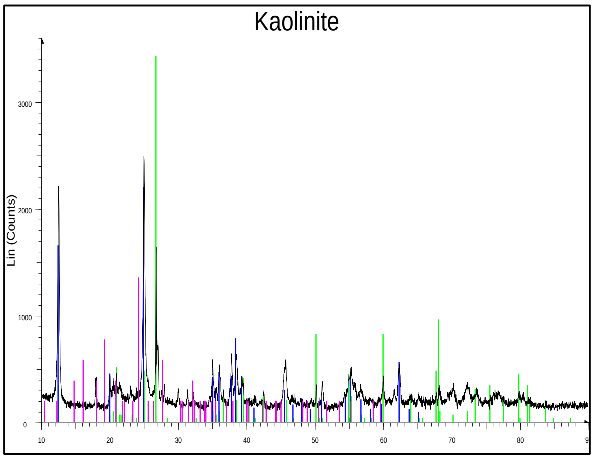
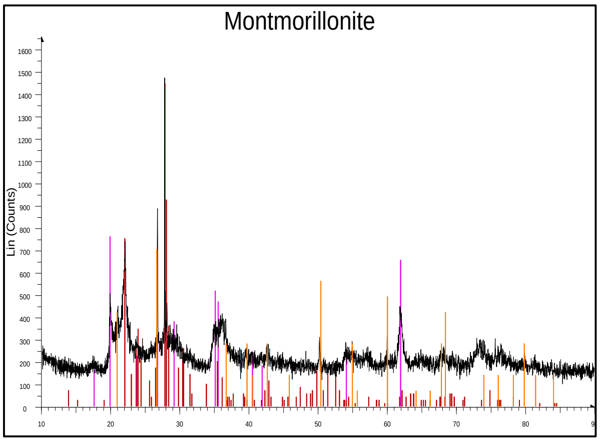
Appendix A







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