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The Effect of Salinity Towards Resistivity for Groundwater Interpretation

Nur Aimi Sufiana Mohammad Hilmi[1], **Aziman Madun**[1]*

[1]Department of Civil Engineering, Faculty of Civil Engineering and Built Environment,
Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, 86400, MALAYSIA

*Corresponding Author Designation

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Abstract: The groundwater exploration in Malaysia is used widely to meet the increasing demand for domestic, agricultural, and industrial purposes. The problems with groundwater exploration are seawater intrusion, where the mixture of freshwater and seawater occurred in groundwater aquifers. If this is not avoided, groundwater supplies of water become contaminated, necessitating additional treatment. The objectives of this research were to determine the effect of salinity concentration towards the resistivity value and determine the concentrations of saline solutions when the effect of soil particle sizes diminishes. The groundwater interpretation was carried out through lab-based approaches and analytical instruments. The sodium chloride (NaCl) solutions were the indicator of the saline solutions. The soil samples used in this experiment were sand and gravel samples. The method used for groundwater interpretation was through Electrical Resistivity Method using M.C Miller Resistivity Meter, 400A. The two-pinned electrodes are connected to the resistivity meter and the resistivity value acting upon the soil sample was observed. The resistivity value shows a negative relationship against the salt concentrations for the sand sample. However, for gravel sample shows the constant value for each salt concentration which proved on the second objective where the effect of soil particle size diminishes. The study found that the increasing number of salt content (NaCl) reduced the resistivity value because of the presence of ions and electrolytes which allows more conductivity. The study for groundwater interpretation where the saline water and freshwater interferes was necessary for groundwater supplies.

Keywords: Salinity, Soil Resistivity, Groundwater

1. Introduction

Groundwater has been one of the water resources to meet the escalating demand of domestic, agricultural, and industrial needs. Therefore, these sectors depend mainly on quality water resources [1]. However, the freshwaters have been quality-degraded over the last several decades due to rising

*Corresponding author: aziman@uthm.edu.my

sea levels. It caused salt water intrusion and freshwater salinization that endangers the whole ecosystem [2]. Based on the daily occasions, nature and human-related activities created this occurrence, such as over extraction of groundwater, variations in groundwater recharge, sea-level rise, and tide effects. Following that, the recent global climate change also strongly affects the dynamics of water availability and variability [3]. The fresh groundwater found near the coastal aquifers tends to get intruded by the sea water. At Tumpat and Bachok, the areas consisted of unconsolidated alluvium and near the coast, thus subjected to salt water intrusion. Therefore, for hydrogeological investigations and groundwater, potential assessments need to evaluate the water salinity due to sea water intrusion [4].

Salinity in water is defined based on the chloride content (milligram per liter) or total dissolved solids content (TDS, mg/l or g/l). The salinization process is recognized as the total number of salts accumulated in the subsurface (soil or water). When there are intrusions of seawater, the interpretation and data analysis for potential groundwater aquifers will be complicated. The contamination of seawater into freshwater aquifers affects the freshwater resources that are used as water supply. The high salinity in groundwater is also not feasible for producing domestic water sources and used for irrigation purposes. Therefore, the electrical resistivity method is one of the geophysical methods to evaluate fresh and saline groundwater. The resistivity values can be affected by several factors such as groundwater salinity, saturation, aquifer lithology and porosity [5].

The aim of this research is to determine the effect of salinity concentrations towards the resistivity value for different soil particle sizes and to determine the concentration of salinity when the effect of soil particle size diminishes. The groundwater interpretation was carried out through lab-based approaches and analytical instruments. The process starts from differentiating the concentration of solution to represent the distinctive features of freshwater and seawater. Generally, the total ionic salinity of the water constituted of the four major cations, Ca^{++}, Mg^{++}, Na^{+}, and K^{+}, and four major ions, HCO^{-}, CO_3^{-}, SO_4^{-} and Cl^{-}. The other minor ionized components such as nitrogen (N), iron (Fe) and phosphorus (P) and others also contribute to total salinity [6].

Through this study, the sodium chloride (NaCl) has been used as the salt indicator because the major ions in seawater is composed of table salt (NaCl). The sample used included distilled water and sodium chloride (NaCl) to form the solution. Following that, the salinity in water is based on the molarity (mol/L) as the concentrations of sodium chloride (NaCl). The soil particles involved consisted of gravel and sand where each of them were retained at 2.36mm and 0.425mm sieve size respectively. The resistivity can then be established using M.C.Miller Soil Resistivity Meter, 400A with 2-pinned electrodes in the laboratory. The understanding of the relationship between salt content and resistivity is necessary for this study. The other contributing factors such as particle size effects towards the resistivity also were discussed since there were to types of soil samples. This research will be beneficial to expand the knowledge and add contributing values to the groundwater surveys in hydrogeology aspects.

2. Materials and Methods

The methodology to obtain the resistivity value under the influences of different salinity concentrations are provided in this section with the related materials and procedures. The preparation of salinity solutions was using the method of preparing salt solutions with different molarity. Following that, the geophysical method that was chosen for this research is the Resistivity method. The physical properties of the soil samples were identified first for geophysical evaluation when calculating the resistivity value. The experiment were carried out in laboratory and in a controlled environment to observe the variables.

2.1 Sampling Preparation

The first sample preparation starts with the salinity test where the salt solutions have been prepared using sodium chloride (NaCl) and distilled water. The salt solutions produced were ranging from 0.001mol/L – 0.20mol/L with different of mass of salts dissolved in it using the concept of total dissolved solids (TDS) to indicate the salinity status of the solution. The materials required for the salt preparations were sodium chloride (NaCl), distilled water, analytical balance, weighing dish, beaker, plastic bottles, refractometer as shown in Figure 1.

The procedures involved in the salt preparations were made by firstly, the mass of sodium chloride in milligrams was weighted based on the Molarity equation referring to Equation 1 and the total dissolved solids equation as stated in Equation 2 where it was used to indicate salinity status. Next, the sodium chloride was weighted by using electrical balance after referring to the mass required and the salt was inserted into the beaker. Furthermore, the saltwater mixture was swirled until the NaCl dissolved. After the salt has dissolved completely, the refractometer was used to measure the fluid concentrations for each salinity. The saltwater solutions were then transferred into the plastic bottles, and they were labeled into their molarity.

$$Mass\ of\ NaCl\ (g) = Volume\ of\ solution\ (ml)\ x\ \frac{X\ mol\ NaCl}{1000mL\ solution}\ x\ \frac{58.44g\ NaCl}{1\ mol\ NaCl}\ \text{Eq. 1}$$

$$Total\ Dissolved\ Solids\ (TDS) = \frac{Mass\ of\ salt\ (g)}{Volume\ of\ Solution\ (L)}\ \text{Eq. 2}$$

Figure 1: Materials for the preparation of sodium chloride (NaCl) solutions.

The second sampling preparation was the sieve analysis test where the soil particle sizes were divided into their respective size using the Mechanical Sieve Shaker. The soil samples chosen were gravel and sand where they were retained at 2.36mm and 0.425mm sieve size as tabulated in Table 1. This preparation allowed the observation for different types of particle sizes to be observed under different types of saline solutions. The sieve analysis equipment is displayed in Figure 2.

Table 1: The soil content for each type of soil sample.

Types of Soil	Sieve size retained (mm)
Gravel	2.36
Coarse Sand	0.425

Figure 2: Mechanical Sieve Shaker

2.2 Resistivity Method

The Resistivity testing was tested out by using a soil box and M.C.Miller Soil Resistivity Meter, 400A. The 2-electrode principle was used to connect with the Miller resistivity meter. The soil box was filled with the soil sample and each saline solution with different concentrations to determine its resistivity value. The standard for this test is using the guidance from AASHTO (T-288-91) Standard for two-electrode. The equipment for the resistivity testing is shown in Figure 3. The equations for the above method are demonstrated in Equation 3.

$$Resistivity, \rho = \frac{(area\ of\ one\ electrode\ face,\ \ A)(Resistance,\ \ R)}{distance\ between\ electrodes,\ \ d} \text{ Eq. 3}$$

Figure 3: Soil box and M.C. Miller Resistivity Meter, 400A

3. Results and Discussion

The results and the analysis of data with the related discussions were discussed according to the objectives of this research. The correlation between the two objectives of this research will be further elaborated in this section. The salinity measures were being compared between the two sizes of particles for their resistivity value and the concentration where the size of particle size diminished were found based on the results. The data were tabulated and plotted in graph to observe the trends between the variables.

3.1 Resistivity for different types of concentrations

There were six samples used for the observation for the effect of different concentrations towards the resistivity value. The sodium chloride (NaCl) concentrations range from 0.001-0.20 mol/L, which represented the salt solutions. In Table 1, the chemical properties of the sodium chloride (NaCl) were stated. The molar mass represents the sum of atomic number for $Na^{+}$and Cl^{-} ions which they are 22.99 g/mol and 35.45 g/mol, respectively. The different molarity indicated the increasing number of salt in the solutions. The physical properties of sand used for the resistivity test are also tabulated in Table 2.

Table 2: The chemical properties of the sodium chloride (NaCl) used for testing.

Molar Mass (g/mol)	Molarity (mol/L)	Total Dissolved Solids (mg/L)
58.44	0.001	58
58.44	0.020	1169
58.44	0.050	2922
58.44	0.070	4091
58.44	0.100	5844
58.44	0.200	11688

Table 3: The physical properties of sand used for the resistivity test.

Physical Properties	Values
Material	Sand
Grain Size (mm)	0.2 – 0.6
Dry Density (kg/m^3)	1037.04
Specific Gravity	2.65

The results for the resistivity test for different molarity or concentrations of salts (mol/L) are shown in Figure 4. The sand samples were thoroughly soaked at this condition, where the salt solutions poured into the soil box were at full level. The trends of resistivity showed negative relationship in which the resistivity value (Ωm) decreases with increasing number of concentrations (mol/L). The relationship between the presences of ions in the solution will affect the resistivity value as they carry electricity in the water. The highest amount of resistivity recorded was 14 Ωm at 0.001 mol/L, while the lowest amount of resistivity value was 1.8 Ωm at 0.2 mol/L. The mechanism of two ions which are Na^{+} and Cl^{-} ions attracted together in water scientifically will be appeared as crystal structure. They will be held together since, by nature, they are electrolytes and known as water-soluble ionic compounds. The oppositely charged ions stick together by the ionic bond. Once the ions get dissolved in the solution, the ions will dissociate and move freely in the solution to conduct electricity. The increasing amount of salts dissolved in the solution affect the resistivity of water hence it's proved by the decreasing value of resistivity value in Ωm.

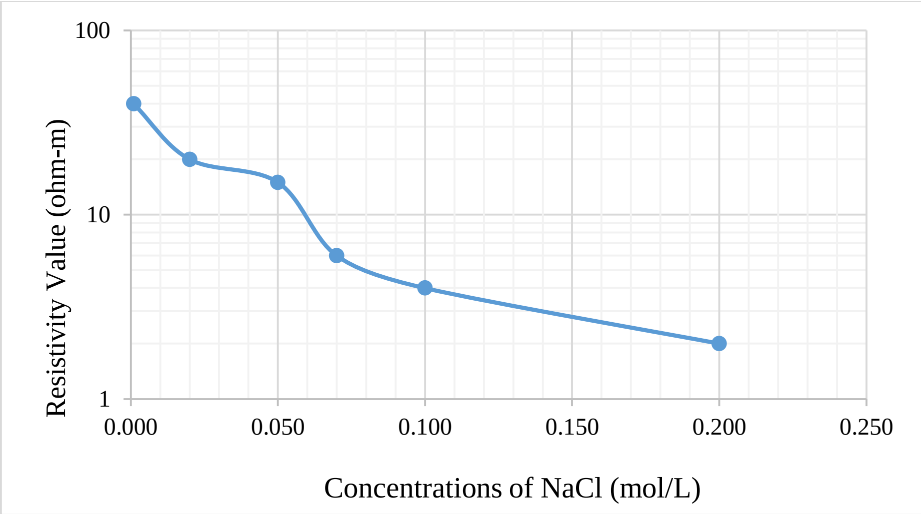

Figure 4: The resistivity value at different concentrations of NaCl for sand sample.

3.2 Resistivity for different types of saturation

The sand sample was observed at different conditions to observe the trends of water saturation in different moisture levels mixed with the soil sample based on different concentrations of sodium chloride (NaCl). The water poured at different amounts into the sand sample named as unsoaked condition, and soaked condition. The trends of resistivity value (Ωm) against the variety of sodium chloride concentrations (mol/L) under two different water conditions are plotted in Figure 5. The presence of moisture gives slight effects towards the resistivity value. Based on Figure 4.4, the unsoaked condition displayed the value of resistivity value ranging from 100 - 10 Ωm scale while at soaked condition the resistivity values range at much lower scale from 40 – 1.8 Ωm. The condition that contains most water has a smaller scale of resistivity value, therefore allowing all the salt ions to move freely in the sample to conduct more electricity. From the Archie's Law, the saturation-resistivity relationship still depends on other factors such as saturation history, wettability, distribution of water and salinity of the brine phase [7] therefore, the saturation factor was considered in the resistivity testing showing slightly different result.

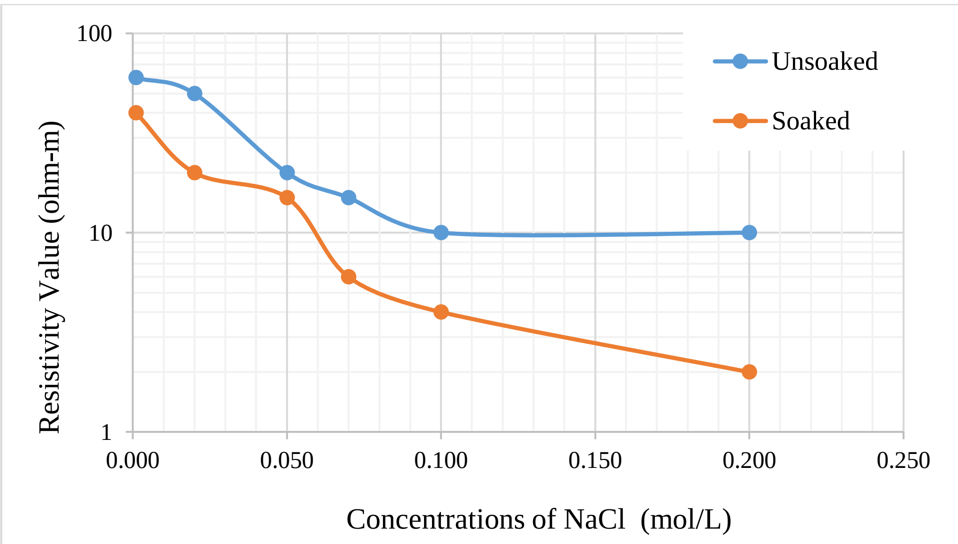

Figure 5: The sand's resistivity value against the concentrations of NaCl at two different water conditions.

3.3 Resistivity for different category of water

The water solutions used in the experiment were categorized as distilled water, freshwater, brackish water, and saline water from all of the prepared salts solutions. The difference for each of them are seen as distilled water contains no salt dissolved in the solution as it's purified and boiled out of its contaminants. The other solutions had their salts depending on the mass of salts dissolved in the solution ranging from small to a high number of salts dissolved. The resistivity value for each type of water are shown in Figure 4.5. Based on Figure 6, the soil sample soaked with distilled water recorded the value of 300 Ωm showing the highest amount of resistivity followed by fresh water at 40 Ωm. The range for brackish water for the sand sample is at 20 – 6 Ωm, and saline water had a value of 1.8 Ωm. The concentrations of salts in the solution had helped to distinguish the category of water. Fresh water at 0.001 mol/L had the least amount of salts dissolved, in which the amount of TDS range from 0 – 1000 mg/L. Furthermore, brackish water (0.02 – 0.10 mol/L) have the TDS value from 1,000 – 10,000 mg/L and saline water (0.2 mol/L) have the TDS value from 10,000 mg/L and greater. The total dissolved solids values as conducted on site [8] helped in categorizing the type of water considering that there are many levels of dissolved salts in water bodies.

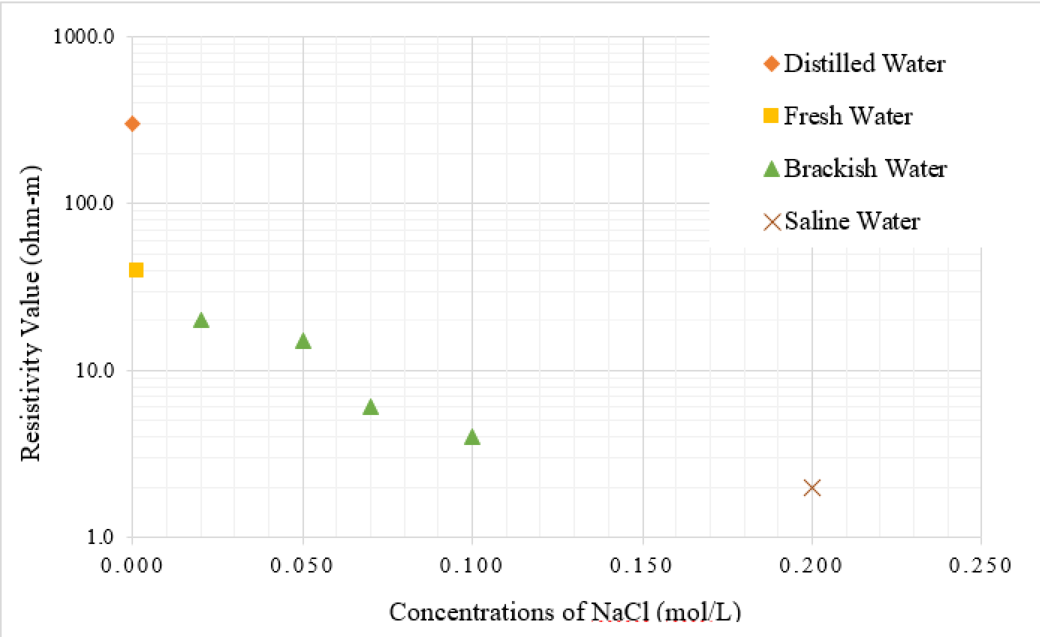

Figure 6: The combination of resistivity value for different types of water against the concentrations of NaCl for sand sample.

3.4 Resistivity for different soil particle sizes

The prepared salt solutions have been tested for two types of soil particles to observe the possible trends considering the particle size factor, affecting the resistivity value apart from salinity value. In the term of groundwater aquifer, the accessible groundwater is found in gravel and sand bodies. Hence, in this study, gravel and sand samples were considered. The soil samples are soaked, and the combination of data for both samples is summarized in Table 3.

Table 4: The resistivity value for gravel and sand for 0.2mol/L NaCl solution.

Soil Sample	Grain size (mm)	Resistivity Value (Ωm)
Gravel	2.36	75
Sand	0.425	1.8

Based on Table 3, the highest concentrations of sodium chloride at 0.2 mol/L were used to measure the differences between the particle sizes. The resistivity value shown in the table had about 94% differences between each other for these two types of soil samples considering the particle size effects. The trends for both of the samples were also illustrated in Figure 7. However, from the graph, the effect of particle size is seen to be diminished at the concentration of 0.07 mol/L NaCl for gravel's sample despite being soaked under different concentrations of sodium chloride. Therefore, the gravel's resistivity value started to show constant value despite the increased sodium chloride concentration.

The sand samples still showed its influences under different salinity, while the gravel sample stopped. The gravel in nature has a bigger particle size than the sand sample; therefore, the sand can retain more electrical charges, hence explaining the negative relationship with the concentration of salts. Based on a research [9], they addressed that the pore spaces of soil material will hold the chemical composition of water. Therefore, when there was a higher concentration of dissolved ions in the pore fluids, the conduction of electric current will be facilitated quickly. Hence the resistivity value will be lower. The gravel and sand samples both have different arrangements and geometry of pores; hence, the influences of the salinity concentrations towards the electrical resistivity show some contrast relationship. From the prepared salt solutions, the highest level of saline water was 0.2 mol/L only.

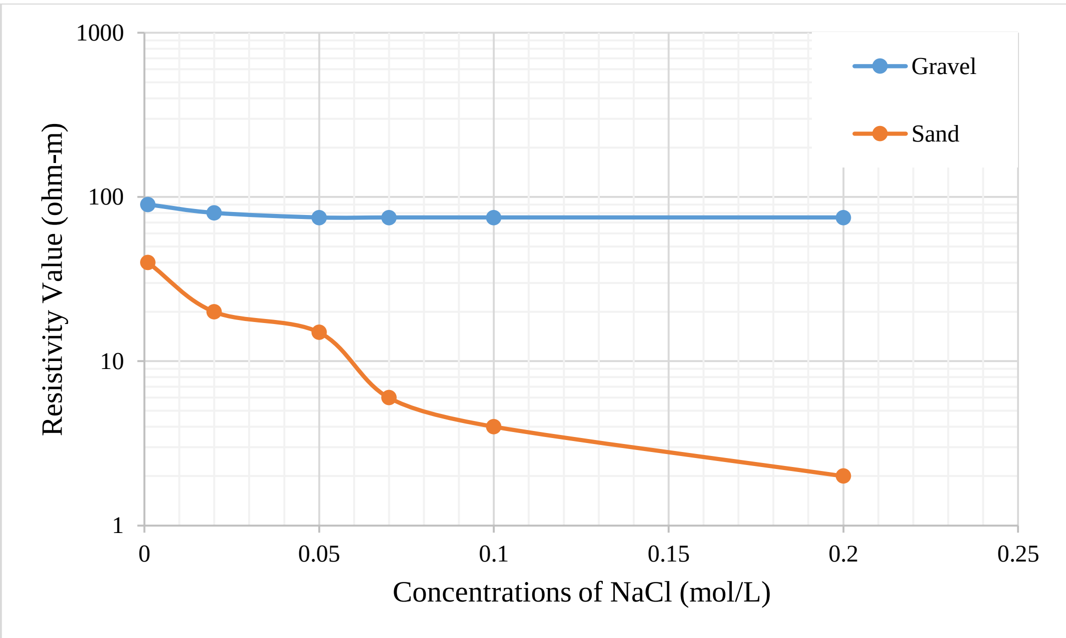

Figure 7: The gravel and sand resistivity values against the concentrations of NaCl (mol/L) under soaked condition.

4. Conclusion

This research focuses on the salinity effects towards resistivity value for different soil particle sizes, particularly gravel and sand sample. The results shown fulfilled this study's objectives: to determine the effect of salinity concentrations for different soil particle sizes and determine the concentration of solution when the effect of particle size diminishes. The effect of salinity concentrations were demonstrated as the sodium chloride solutions were prepared as 0.001 mol/L, 0.020 mol/L, 0.050 mol/L, 0.070 mol/L, 0.10 mol/L and 0.20 mol/L. From this study, the salt concentrations poured into the soil sample have recorded their resistivity value.

The prepared salt solutions have been categorized as freshwater, brackish water, and saline water as the results varied for each water type. The water category having its resistivity ranges can help distinguish the zones of water for the unconfined and unconfined aquifer on the aspect of groundwater interpretation. The negative relationship between the concentrations of sodium chloride (mol/L) against resistivity value (Ωm) was seen for the soil sample to highlight the objective. The resistivity value also proved differently when they were put in different moisture conditions. The effect of particle size diminishes for the gravel sample at 0.070 mol/L while for the sand sample at 0.2 mol/L since there were no further changes of the resistivity value after increasing the salt concentrations. The salinity factor does not surpass the effect of particle sizes when considering the resistivity value because there are other supporting factors such as mineralogy, water saturation, porosity, and others that will make the resistivity value varies under different circumstances.

For advanced studies on the topic of salinity effect towards resistivity value for groundwater interpretation, it is recommended that in future research more researchers will conduct the resistivity test for the mixture of soil particle sizes (gravel, sand, silt, and clay) under various salt concentrations and perform the resistivity tests for other chloride solutions such as potassium chloride (KCl) and magnesium chloride ($MgCl_2$). The significance of this study was seen when the resistivity values can be achieved for different zones of water at the coastal areas which contain different salinity concentrations especially in groundwater interpretation.

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