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The Effect of Particle Size and Type of Soil Towards the Resistivity for Groundwater Interpretation

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Abstract: Electrical resistivity tomography (ERT) is a non-destructive method of groundwater surveying where the current is being injected into the ground and the value of the subsurface resistivity are determined. One of the major problems in groundwater surveying is the interpretation of the groundwater aquifer under saturated condition. The overlapping resistivity value under a saturated condition is a major concern in groundwater aquifer interpretation. The interpretation data in the previous research was lack in resistivity for soil data. Hence, by using soil box and soil cylinder connected with ABEM Terrameter LS2, resistivity value 7 sample of soils which were well graded gravel, poorly graded gravel, poorly graded gravel-sand-silt/clay mixture, well graded sands gravelly sands, poorly graded sands gravelly sands, poorly graded sand-silt/clay mixture and silty clays can be recorded in this study. A data of resistivity values of for the soils were established by conducting laboratory tests in saturated conditions. The main objective of this study was to identify the effect of particle size towards the resistivity value. Besides that, the second objective of this study was to establish the effect of type of soil towards the resistivity value and lastly to analyze the resistivity value for particle size/type of soil under different resistivity value of water which were distilled water (5700 Ωm), tap water (500 Ωm) and groundwater (52 Ωm). The highest resistivity value in this study was well graded gravel with 288.6 Ωm and the lowest resistivity value was the silty clay with 6.2 Ωm that tested with distilled water. The presence of silt/clay in the soil samples reduced the resistivity value amount as shown from both sample of poorly graded gravel-sand-silt/clay mixture that tested with distilled water and groundwater as each sample had a low resistivity value of 63.50 Ωm and 97.67 Ωm. This study helps in clarifying the effect of particle size for resistivity value as the larger particle size increases the resistivity value

Keywords: Groundwater , Electrical Resistivity, Particle Size, Type of Soil

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1. Introduction

Water is available in many places around the world, including oceans, rivers, streams, mountains glaciers, rainfall, and groundwater. In addition to the quantities represented by seas and polar ice, groundwater is another of the most important sources. Groundwater is abundant in particle pore spaces and in eroded rocks. Malaysia is one of the richest countries in term of water resource, this fact has been a leading cause to a lot of water wastage amongst Malaysians. The groundwater is not a main source of water in Malaysia as most of water source is in the form of rivers or rain. These unseen water supplies could be used to secure the water quality for a nation that protect consumers from drought or the poor accessibility of typical treated water.

One of the key reasons why the use of groundwater is so limited in Malaysia is that it has taken actions to obtain groundwater and develop it into accessible everyday water. The demand for clean water supply is already a major issue in certain places in Malaysia, particularly in Selangor, Kuala Lumpur, Johor Bahru, and Pulau Pinang [7]. Recently, usable water supplies in the state of Selangor, Malaysia, have been under pressure due to the rising demands of industry and domestic water use, as well as the depletion of water quality due to pollution. Groundwater quality has become a big concern due to increased demand for water in the Langat basin [4]. Poor water accessibility can be happened because of the shortage sources from rivers, rains and pollution like case in Selangor water treatment plants were shut down can be one of the reasons for the water shortage. The water accessibility can be solved by groundwater surveying at the targeted area.

One of the most reliable methods of surveying the groundwater is through the electrical resistivity tomography (ERT). ERT is a non-destructive method of groundwater surveying where the current is being injected into the ground and the value of the sub surface resistivity and chargeability are determined by adopting the geophysical electrical technique survey, i.e., resistivity and induced polarization. The resistivity and the chargeability value are determined by the lithology and the water content of the sub-surface area which are being monitored. However, interpretation tasks to decide the aquifer layer is unable to directly refer to the earth material-resistivity-chargeability chart due to the overlapping values. Thus, it is important to understand the influence of the particle size and mineralogy towards the resistivity and chargeability values. It is challenging to identify the sandy body for the groundwater aquifer in the Quaternary geological formation due to the ground is below the groundwater table. The ground is in saturated condition and thus, resulting the resistivity value is lowered for any material i.e., sand or clay. Therefore, the chargeability parameter could be utilized to recognize the change of soil parameters such as the soil moisture, particle size and mineralogy. Multiple site investigation studies have been conducted in relation towards the chargeability and resistivity of the sub surface. However, for this particular study the testing will be performed in a lab scale environment where the important factor which affects the resistivity values only are identified and determined. There are multiple factors which may influence the analysis results of the resistivity, especially the mineralogy, soils, rocks and water content and during this study these parameters will be controlled and tested to define the major factors which may affects the resistivity value.

This study will further understand the resistivity value in relation to different type of rocks, mineral and particle size. The resistivity of various soil depends primarily on their moisture content and also on the concentration of dissolved ions in them. It is expected that this study will improve the understanding of resistivity value and improve the earth material-resistivity chart. This information will help in interpretation of the actual groundwater aquifer when dealing with saturated earth materials especially in the Quaternary formation. This study will also help improve the quality of data for groundwater interpretation which will further improve the quality of sub surface exploration in relation of groundwater surveying in Malaysia. With an improved groundwater survey quality in Malaysia, the usage of treated water can be reduced and the untapped groundwater resource can be utilized and provided to area where the treated water cannot be supplied.

2. Literature Review

2.1 Electrical Resistivity Method

The definition of resistivity is the ability of materials to act as resistance in presence of electrical current flow. For a subsurface research, several of the primary elements in determining the resistivity are actually based on the geological parameters such as for example mineral composition, mineral structures, fluid content, porosity, and degree of water saturation in rocks [3]. By injecting electric current to the soil through electrode, it offers estimated resistivity value of ground that is impacted by ground parameters like the minerals, fluid content, porosity and degree of water saturation in the rock [5]. The resistivity is able to be utilized to explore boundary between crystalline and sedimentary rocks, small quartzite rocks with pyrite or schist where differentiation between rocks could be viewed in horizontal path meanwhile the optimum resistivity value can easily improve within vertical direction [2]. By applying the Ohm's Law, the resistivity of the different type of material were obtained. The formula for the resistivity value (ρ) followed Ohm's law which was expressed the current (I) and voltage (V) values by using ρ=V/I. The value of resistivity was determined in Ohm meter (Ωm). A four-terminal resistance cable and two-terminal resistance cable was used in connection with ABEM Terrameter LS2. The sample to determine the resistivity was prepared filled into the soil box and soil cylinder by allowing the voltage-current to flew through it, and the result of resistivity was analyzed.will appeared at the screen of ABEM Terrameter LS2

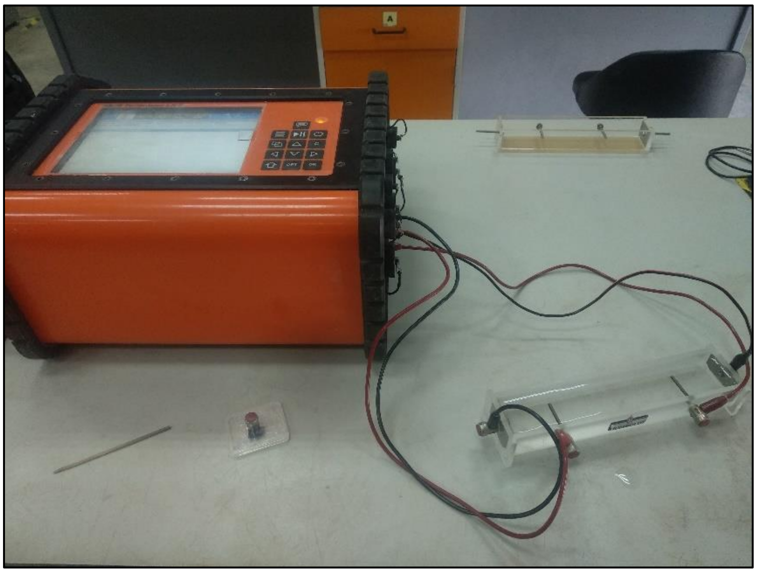

Figure 1: ABEM Terrameter LS2 connected with soil box

2.2 Sample Preparation

The combination of gravel, sand, silt and clay was the process of the sieve analysis and sampling preparation. The combination of the samples shown in Table 1 alongside their respective ratio. Combining the materials was to define further the effects of the particles sizes towards the resistivity.

Table 1: The combination of different sized particles

Typical names	Group symbols	Soil content (All soil passing 50 mm)	Content ratio (%)
Well graded gravel	GW	Gravel (50-37.5, 28, 20, 11.2, 6.7, 5.0, 2.4, 2 mm)	24: 20: 14: 14: 15: 7: 2.5: 3.5
Poorly graded gravel	GP	Gravel (11.2 - 6.7 mm)	100
Poorly graded gravel-sand-silt/clay mixture	GM/GC	Gravel (50 - 37.5 mm), Sand (1.18 - 0.85 mm), Silt + clay (smaller than 2 mm)	34:34:32
Well graded sands gravelly sands	SW	Sand (2 - 1.18, 0.85, 0.60, 0.43, 0.30, 0.20, 0.15, 0.063 mm)	32: 12: 16: 12: 8: 7: 3: 8
Poorly graded sands gravelly sands	SP	Sand (0.20 - 0.15 mm)	100
Poorly graded sand-silt/clay mixture	SM/SC	Sand (0.20 - 0.15 mm), Silt + Clay (smaller than 0.0063 mm)	70: 30
Silty clays	CL	Silt + clay (smaller than 0.0063 mm)	73: 27 (Refer to **Table 4)**

Hydrometer test were used to determine the particle size distribution for soil particles of size below 75 microns, as shown in . Furthermore, this test calculated the size of soil particles which settled by the speed that suspension from a liquid. The liquid was used to perform this experiment is distilled water. The detail test procedure can be referred to BS.1377: Part 2: 1990.

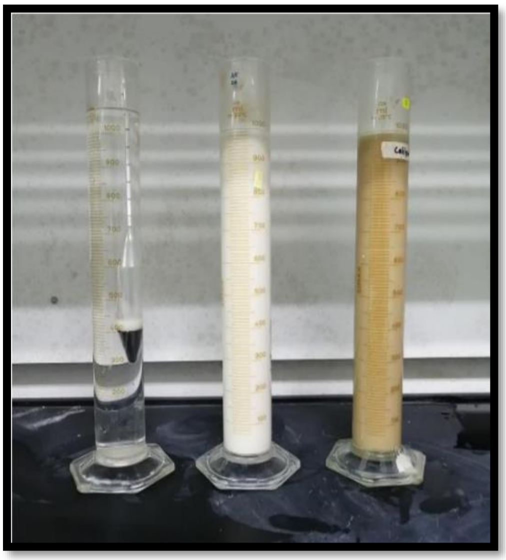

Figure 2: The apparatus to perform Hydrometer Test

Atterberg limit test was used to determine the liquid limit (LL), plastic limit (PL) and plasticity index (PI) of the silt and clay. One of the important aspects of this experiment is moisture and control. The derivation to determine moisture content was used to measure the dry sample as follows:

$$\text{Moisture content, } w = \frac{m2 - m3}{m3 - m1} X\ 100\%$$

The value of the plastic index was determined with the equation below:

Plastic index (PI) = Liquid limit (LL) – Plastic Limit (PL)

By referring to 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. Specific Gravity referred to the mass of solids in the soil compared to the mass of water at the same volume. The formula for determined the specific gravity were:

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

Hence, with the obtain moisture content for the silt and clay used, the testing of resistivity 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. The resistivity value of the wettest state tends to be lower when compared with the driest site state of the experiment. This implies that the existence of moisture content inside a subsurface influence the resistivity value of the composition of the subsurface materials.

3. Results and Discussion

This study acquired resistivity parameters towards particle size and type of soil, including gravel, sand, silt, and clay. For the primary phase, the properties of soil were obtained by determined the physical properties through physical properties testings which are sieve analysis, hydrometer, Atterberg Limit, and specific gravity. These tests were obtained to determine particle size, liquid limit, and plastic limit. For the last phase, resistivity values were obtained by referred the data obtained from ABEM Terrameter LS2. 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 Sieve Analysis Test

The samples were designed and graded range from gravel, sand, silt, and clay. Table 2 below shows the data of D50 from the graded sample. The particle distribution chart for the D50 of the samples can be referred to Figure 3 and Figure 4.

Table 2: Data of D50 for different type of soil

No.	Type of soil	D50 (mm)
1	Well Graded Gravel	25
2	Poorly Graded Gravel	6.7
3	Poorly Graded Gravel Sand-Silt/Clay	0.95
4	Well Graded Sand	0.82
5	Poorly Graded Sand	0.20
6	Poorly Graded Sand Silt Clay	0.17
7	Silty Clays	0.0039 (Refer to **Figure 4**)

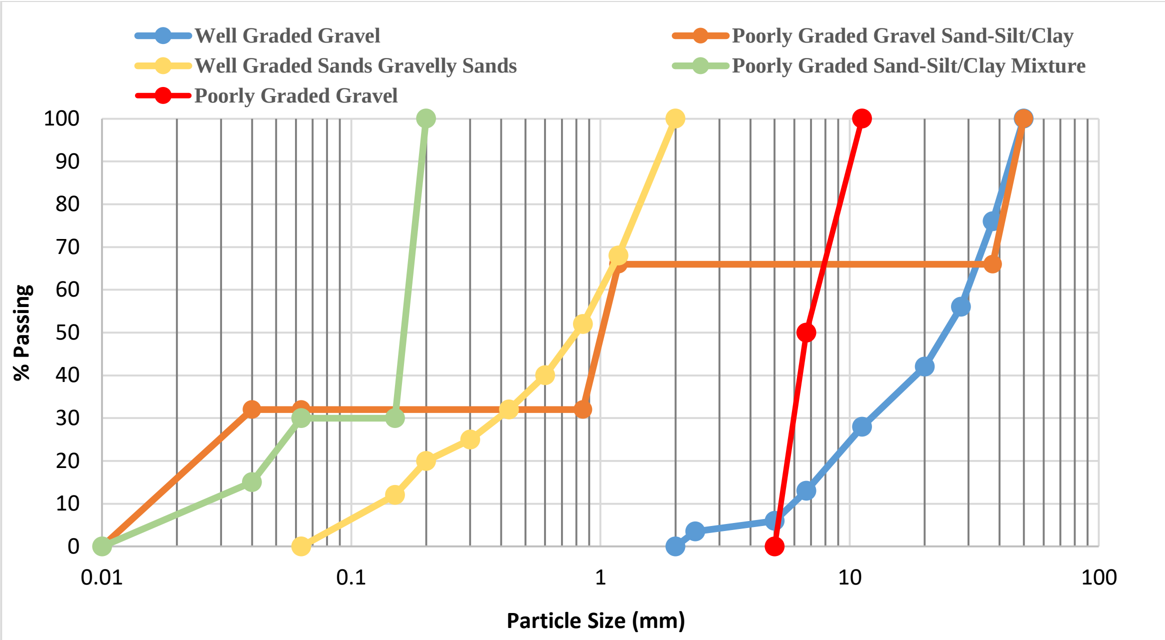

Figure 3: Data of Particle Size Distribution

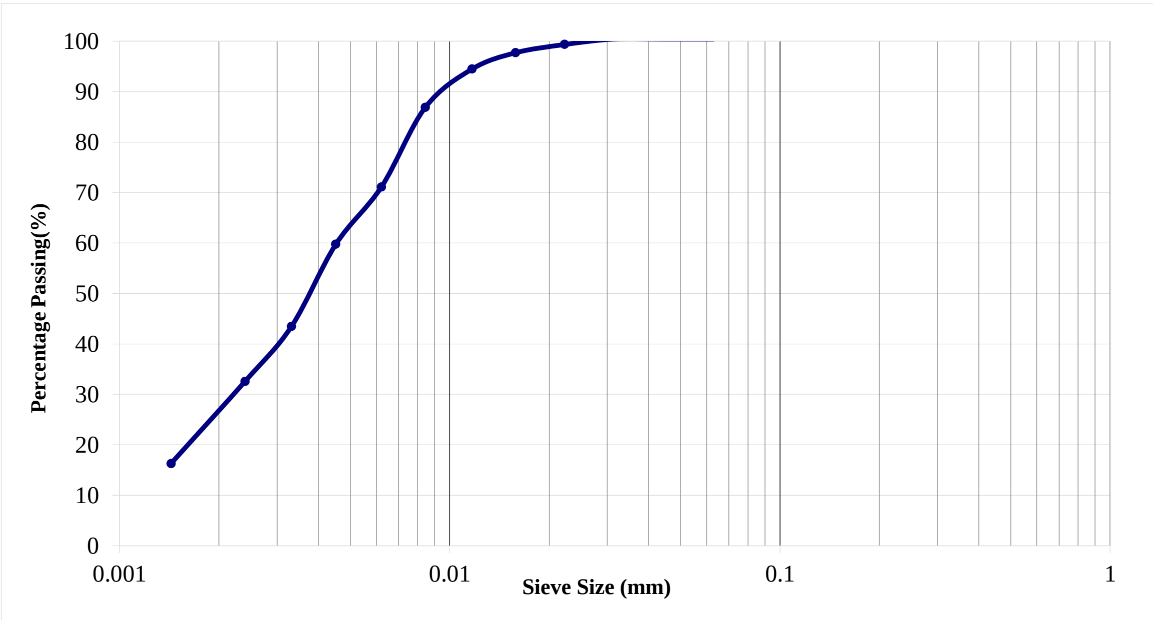

Figure 4: Data of Particle Size Distribution for Silty clay.

3.2 Atterberg Limit Test

Table 2 below shows the data of the Atterberg Limit including Liquid Limit, Plastic Limit and Plastic Index for Kaolinite.

Table 3: Data of Atterberg Limit for clay minerals

Minerals	Liquid Limit (LL), %	Plastic Limit (PL), %	Plastic Index (PI), %
Kaolinite	70.89	33.66	37.23

3.3 Specific Gravity Test

The data were obtained by repeating three times to get the average values of specific gravity. From Table 3 below, all of the data were in the range of specific gravity, which means the specific gravity values for Kaolinite were acceptable.

Table 4: Average specific gravity values for clay minerals

Minerals	Specific Gravity
Kaolinite	2.16 – 2.68

3.4 Hydrometer Test

Hydrometer test was obtained to calculates the size of clay minerals particles. As shown below, the Table 4 shows the percentage of silt and clay for Kaolinite clay minerals.

Table 5: Percentage values of particle size for Kaolinite

Minerals	Particle Size	Percentage, %
Kaolinite	Silt	73
	Clay	27

3.5 Resistivity value of different particle size and type of soil under different resistivity value of water.

ABEM Terrameter LS2 with soil cylinder and soil box was used towards the seven different types of soil samples (Well graded gravel, poorly graded gravel, poorly graded gravel-sand-silt/clay mixture, well-graded sands gravelly sands, poorly graded sands gravelly sands, poorly graded sand-silt/clay mixture, and silty clays). Besides, all of the sample was fully saturated mixed with distilled water, tap water and groundwater. Furthermore, the relation between moisture content and density is taken into attention whether there are changes in resistivity value.

All the sample tested were in the fully saturated condition which can be seen from **Appendix A** that the value of the moisture content is almost the same. In this study, the sample's bulk density was in the range of 1650 – 1664 kg/m3, which showed that the density of the sample was roughly the same. Different resistivity values of water were also influenced the resistivity value. The highest resistivity value of the sample was tested with distilled water, and the lowest resistivity value of the sample was with groundwater, as shown in Figure 4.

From Figure 4, the highest resistivity value is the well-graded gravel (GW) with 288.6 Ωm, and the lowest resistivity value is the silty clay with 6.2 Ωm that tested with distilled water. The huge differences between the gravel and the mixture of silt/clay sample have a good agreement with a site study conducted by [6] where a mixture of gravel and sands has a resistivity from 600 to 1150 Ωm while a mixture of sand and clay has a resistivity of 200 – 500 Ωm and a clay layer has a resistivity of 20 – 150 Ωm. It shows that the presence of silt/clay within any soil samples reduced the resistivity value amount as shown from both samples of poorly graded gravel-sand-silt/clay mixture (GM/GC) and also the poorly graded sand-silt/clay mixture (SM/SC) as each sample has a low resistivity value of 63.5 Ωm that tested with distilled water and 97.67 Ωm that tested with groundwater respectively.

This result shows, soil mixture with involvement of larger particle such as gravel still showed slightly higher resistivity effects compared to smaller sample such as sand mixture in the presence of silt and clay sample the effect of silt and clay mixture is has a good agreement from a study demonstrated from conducted by [1] where a clayey sand deposit has a very low resistivity value of less than 50 Ωm.

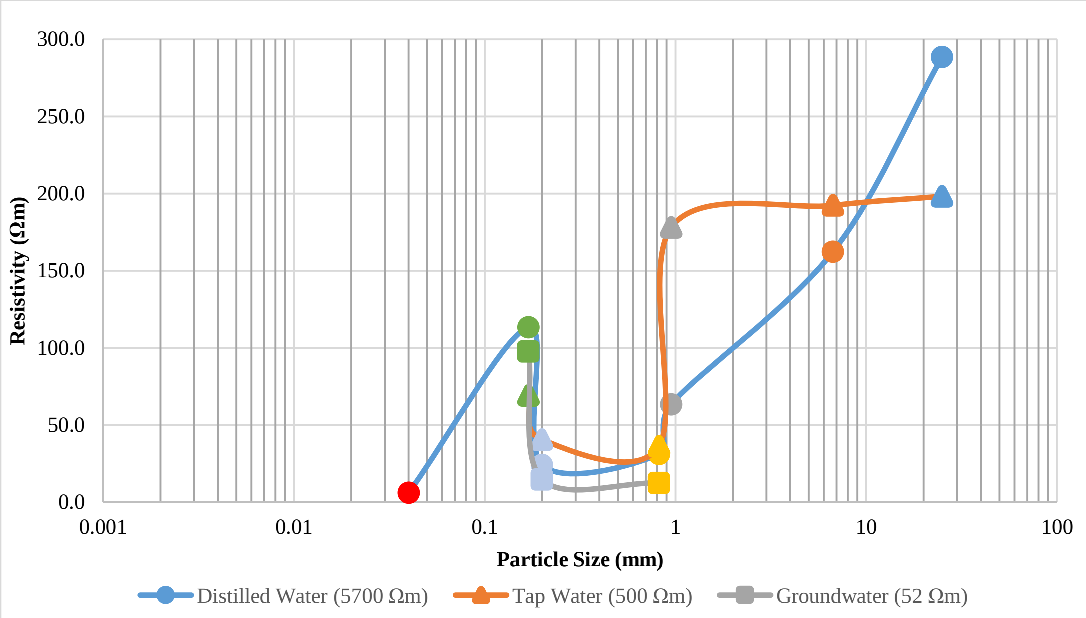

Figure 5: Data resistivity by different type of water

4. Conclusion

This study describes the effects of particle size and type of soils on the resistivity values for groundwater interpretation. A laboratory setting was conducted to obtain the resistivity values on the samples. By comparing the results of the samples, it shows that the well graded gravel sample has the highest value of resistivity.

Determining the difference between the particle size samples was important in saturated conditions as the size difference played a huge factor in determined the groundwater aquifer. This study highlighted the difference in between the particle sizes with larger particle sizes such as gravel and sand had higher resistivity value compared to the smaller particle sizes such as silt and clay, which had very low resistivity value. Different resistivity of water which were distilled water (5700 Ωm), tap water (500 Ωm) and groundwater (52 Ωm) also was highlighted in this study. The outcome from this study may be used in improving the prediction of the position of the groundwater aquifer on-site by comparing the highest and lowest resistivity value and predicting where the position of sand or gravel might be in between the electrical resistivity tomography results.

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Appendix A

Different resistivity of water	Type of soil	Moisture content (%)	Bulk density (kg/m3)	D_{50} (mm)	Resistivity (Ωm)
Distilled water (5700 Ωm)	Well graded gravel	-	-	25	288.6
	Poorly graded gravel	-	-	6.7	162.4
	Poorly graded gravel sand silt	-	-	0.95	63.5
	Well graded sand	57.08	1658.36	0.82	31.2
	Poorly graded sand	57.03	1657.83	0.20	24.3
	Poorly graded sand silt clay	56.37	1650.87	0.17	113.3
	Silty clays	56.54	1652.66	0.0039	6.2
Tap water (500 Ωm)	Well graded gravel	-	-	25	198.3
	Poorly graded gravel	-	-	6.7	192.4
	Poorly graded gravel sand silt	-	-	0.95	178.1
	Well graded sand	57.17	1659.28	0.82	36.3
	Poorly graded sand	57.12	1658.82	0.20	40.5
	Poorly graded sand silt clay	1660.58	1660.58	0.17	69.3
Groundwater (52 Ωm)	Well graded sand	57.56	1663.43	0.82	12.39
	Poorly graded sand	57.48	1662.58	0.20	14.68
	Poorly graded sand silt clay	56.47	1651.96	0.17	97.67

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