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Evaluation of Thermal Resistivity Response to Lithology, Gradational Soil Water Content and Ambient Soil Temperature

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Abstract**—***Thermal resistivity survey was recently carried out with the aim of ascertaining its response to different lithologies, degree of soil water content, and ambient soil temperature within a specified location. The methodology employed in the determination of soil thermal resistivity and soil water content involves measuring the rate of temperature changes with time, and the use of Gravimetric method. The outcome of this study has shown that the range of thermal resistivity in the study area is between 0.075798824 °Cm/W to 0.455356332 °Cm/W, which incidentally falls within the thermal resistivity range of sand and clay. The results obtained revealed that the site is characterized with a central low thermal resistivity region that is flanked by relatively high thermal resistivity on both side. It also revealed that the distribution pattern of the soil water content is in consonant with the distribution of soil thermal resistivity. It was observed that the western region of the model which is predominately clay, registered a high thermal resistivity in parts where its water content is low, and low soil thermal resistivity where its soil water content is high. The eastern region which is predominately sand also registered range of soil thermal resistivity base on the degree of soil water content. The results have helped to establish the fact that soil water content has a very great influence on the observed response of soil thermal resistivity, and it also revealed that the disparity of thermal resistivity response within soil of the same lithological composition is due to degree of water content in it. The direct comparison of ambient soil temperature model, and thermal resistivity model revealed that thermal resistivity model, registered the least value at the points where the soil ambient temperature registered highest value, and vice versa. It was therefore concluded that soil water content and lithology have greater influence on thermal resistivity response, than soil ambient temperature, which effect on thermal resistivity is also a function of variation of soil water content induced by the sun intensity.*

Keywords**—***Lithology; Soil water Content; Temperature; Thermal Resistivity.*

I. INTRODUCTION

This research work was carried out to evaluate soil thermal resistivity response to lithology, soil water content, and soil ambient temperature. Soil thermal resistivity is applied in the area of pipeline and cable protection [7], and more recently in the area of agriculture, hence, the need to study its response to lithology and soil water content cannot be over emphasize. Thermal resistivity is a measure of the soil ability to dissipate or resist the flow of heat. It is express as:

$$\sigma = \frac{4\pi}{Q}\left[\frac{T_2 - T_1}{ln\left(\frac{t_2}{t_1}\right)}\right] \quad (1)$$

Where
$\sigma = Soil\ Thermal\ Resistivity\ °C\ m/W$
$Q = Heat\ Input\ in\ W/m$
$T_1 = Temperature\ at\ time\ t_1$
$T_2 = Temperature\ at\ time\ t_2$

The percentage soil water content refers to the amount of water contain in the soil at any specific time. It is mathematically express as:

$$WC = \left(\frac{W_1 - W_2}{W_2}\right) \times 100 \quad (2)$$

Where
$WC = percentage\ soil\ water\ content$
$W_1 = waight\ of\ wet\ soil\ in\ Kg$
$W_2 = waight\ of\ dry\ soil\ in\ Kg$

To examine the previous work carried out by other researchers; "Soils and other porous materials vary in density, water content, temperature and composition" [8]. "The water content as well as the bulk density has a significant influence on the electrical and thermal conductivity" [2]. [1], stated that "the degree of saturation was also found to influence the thermal resistivity of soil".

The instruments used for this survey include high precision Digital thermometer with probe, 0.08 m heating element probe, 12 volts battery, multichannel multimeter, digital stopwatch timer, small drilling tools, cylindrical container, weighing balance and a shovel.

II. GEOLOGY OF THE AREA

The Formation of the present Niger Delta started during Early Paleocene as a result of the built up of fine grained sediments eroded and transported to the area by the River Niger and its tributaries. The regional geology of the Niger Delta consists of three lithostratigraphic units; Akata, Agbada and Benin Formations, overlain by various types of Quaternary Deposits [10], [9], [3]. These Quaternary Sediments, according to [11] are largely alluvial and hydromorphic soils and lacustrine sediments of Pleistocene age.

III. LOCATION OF STUDY AREA

The study area is located at Yenagoa, Bayelsa State, Nigeria, with an average elevation of 15 m, above mean sea level, after [5]. The imagery map indicating the origin of the sampled points with latitude 4°55'30.87"N and longitude 6°17'56.80"E, is shown in Fig. 1.

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Fig. 1. Imagery map of the area under investigation showing the grid origin

IV. Data Acquisition

The data acquisition for thermal resistivity data started with mapping out the area under investigation in gridded form (Fig. 2). 12 m was measured from the origin toward eastern direction, which was followed by measurement of 20 m southward from the same origin. The major grid lines were graduated into 1 m interval on both sides. The major selected points are at interval of 6 m eastward and interval of 10 m southward along the lines. The intermediary points are at a distance of 3 m and 5 m from the major corners, and at interval of 6 m and 10 m from each other. Thermal resistivity measurements were carried out at each of these selected gridded points at definite intervals. The process was carried out at each point by excavating out the top soil majorly composed of humus organic material. The soil was dug up to a depth of 0.5 m with a shovel, followed by drilling of a hole of about 0.1 m deep. The probe made up of the thermocouple digital thermometer and heating element was inserted into the hole, and good contact between the hole and the probe was ensured. The current flowing in the circuit and voltage of the battery was measured and recorded with the help of the Digital Multimeter. The ambient temperature of the soil was recorded when the reading on the digital thermometer was steady. The circuit was completed by connecting the terminals of the heating element to the battery, at the same time the stop watch was started simultaneously. The readings on the digital thermometer after 0, 5, 10, 15, 30, 45 and 60 s were noted and recorded, subsequently readings were taken every 30 s up to 30 minutes. The same process was repeated at the remaining 12 points in acquiring the thermal resistivity data for those points. The recorded data were taken to the laboratory for further processing.

The Gravimetric method was used to determine the water content of the soil. Thirteen cylindrical containers where weighed empty, and reweighed when filled with soil samples collected in situ at the gridded points. The various weight of the wet soil samples were noted, after subtracting the weight of the container. The Soil samples where arranged in an oven, and allowed to dry for 12 hours, and reweighed again, to determine the weight of the dry sample.

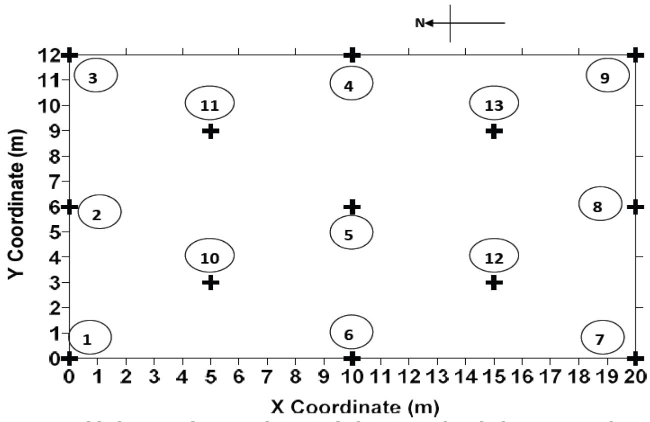

Fig. 2. Gridded area indicating the sampled point with a dark cross, numbered according to data collection sequence.

V. Data Processing

The Data processing of thermal resistivity started by entering the recorded data of temperature changes with time on a spread sheet which was used to plot a graph of temperature in degrees versus time in seconds. The Measured voltage of the battery and the current flowing in the circuit were used to calculate the heat input, which in turn was used to calculate the thermal resistivity of the earth material making used of "(1)", and temperature values recorded against 12 and 24 minutes respectively, since the temperature recorded between these time interval falls within the steady state of the graph. The tables and graphs of the measured thermal resistivity at various points are show in table 1 to 26 and Fig. 3 to 15.

The percentage moisture content for each soil was calculated using "(2)". This was carried out by subtracting the weight of the dry sample from the weight of wet sample, divided by the weight of the dry sample multiplied, by hundred.

Table 1: Data Acquisition Parameters for TRP1

Heat Input Parameters	Heat Input Parameters Values
Current (A)	0.1637
Resistance (Ohms)	73.3
Voltage (V)	12.46
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	24.55338346
Date	18/12/2019
Ambient Soil Temperature	28.3 °C
Time of Recording	10 am

Table 2: Measured temperature increase with time for TRP1

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	28.3	23	540	32.2	45	1200	32.6
2	5	28.3	24	570	32.2	46	1230	32.7
3	10	28.4	25	600	32.3	47	1260	32.7
4	15	28.5	26	630	32.3	48	1290	32.7
5	30	29.1	27	660	32.3	49	1320	32.7
6	45	29.5	28	690	32.3	50	1350	32.7
7	60	29.9	29	720	32.3	51	1380	32.7
8	90	30.5	30	750	32.5	52	1410	32.7
9	120	30.9	31	780	32.5	53	1440	32.7
10	150	31.2	32	810	32.5	54	1470	32.8
11	180	31.3	33	840	32.5	55	1500	32.8
12	210	31.5	34	870	32.5	56	1530	32.8
13	240	31.6	35	900	32.5	57	1560	32.8
14	270	31.8	36	930	32.5	58	1590	32.8
15	300	31.8	37	960	32.5	59	1620	32.8
16	330	31.9	38	990	32.5	60	1650	32.8
17	360	31.9	39	1020	32.5	61	1680	32.8
18	390	32.0	40	1050	32.6	62	1710	32.8
19	420	32.1	41	1080	32.6	63	1740	32.8
20	450	32.2	42	1110	32.6	64	1770	32.8
21	480	32.2	43	1140	32.6	65	1800	32.8
22	510	32.1	44	1170	32.6	Thermal Resistivity 0.295466206 °Cm/W		

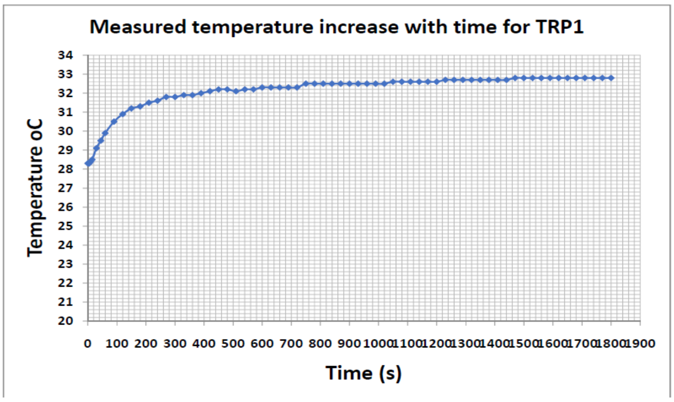

Fig. 3. Graph of Temperature oC versus Time (s) for TRP1. Calculated Thermal Resistivity value of 0.295466206 °Cm/W.

Table 3: Data Acquisition Parameters for TRP2

Heat Input Parameters	Heat Input Parameters Values
Current (A)	0.1614
Resistance (Ohms)	73.3
Voltage (V)	12.4
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	23.86827585
Date	18/12/2019
Ambient Soil Temperature	29.9 °C
Time of Recording	11 am

Table 4: Measured temperature increase with time for TRP2

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	29.9	23	540	32.2	45	1200	32.5
2	5	29.9	24	570	32.2	46	1230	32.5
3	10	29.9	25	600	32.2	47	1260	32.5
4	15	30.1	26	630	32.3	48	1290	32.5
5	30	30.2	27	660	32.3	49	1320	32.5
6	45	30.5	28	690	32.3	50	1350	32.5
7	60	30.8	29	720	32.3	51	1380	32.5
8	90	31.1	30	750	32.3	52	1410	32.5
9	120	31.3	31	780	32.4	53	1440	32.5
10	150	31.5	32	810	32.4	54	1470	32.5
11	180	31.7	33	840	32.4	55	1500	32.5
12	210	31.8	34	870	32.4	56	1530	32.5
13	240	31.8	35	900	32.4	57	1560	32.5
14	270	31.9	36	930	32.4	58	1590	32.5
15	300	31.9	37	960	32.4	59	1620	32.5
16	330	32	38	990	32.5	60	1650	32.5
17	360	32.1	39	1020	32.5	61	1680	32.5
18	390	32.1	40	1050	32.5	62	1710	32.5
19	420	32.1	41	1080	32.5	63	1740	32.5
20	450	32.2	42	1110	32.5	64	1770	32.5
21	480	32.2	43	1140	32.5	65	1800	32.5
22	510	32.2	44	1170	32.5	Thermal Resistivity 0.151973588 °Cm/W		

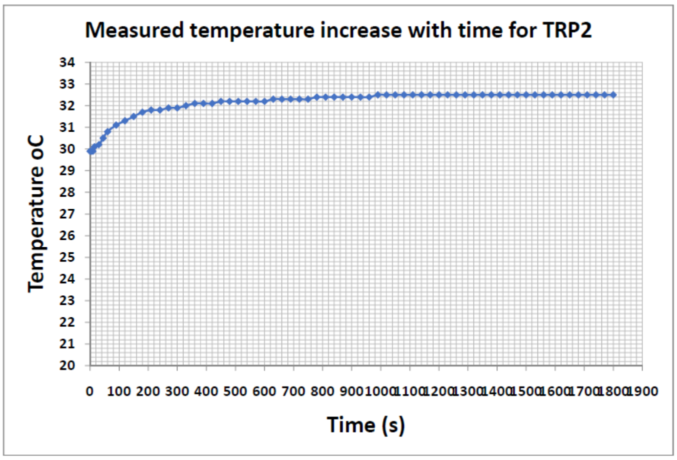

Fig. 4. Graph of Temperature oC versus Time (s) for TRP2. Calculated Thermal Resistivity value of 0.151973588 °Cm/W.

Table 5: Data Acquisition Parameters for TRP3

Heat Input Parameters	Heat Input Parameters Values
Current (A)	0.1624
Resistance (Ohms)	73.3
Voltage (V)	12.39
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	24.1649576
Date	18/12/2019
Ambient Soil Temperature	29.7 °C
Time of Recording	12 pm

Table 6: Measured temperature increase with time for TRP3

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	29.7	23	540	33.3	45	1200	33.8
2	5	29.7	24	570	33.3	46	1230	33.8
3	10	29.7	25	600	33.4	47	1260	33.8
4	15	29.9	26	630	33.4	48	1290	33.8
5	30	30.3	27	660	33.5	49	1320	33.9
6	45	30.8	28	690	33.5	50	1350	33.9
7	60	31.1	29	720	33.5	51	1380	33.9
8	90	31.7	30	750	33.6	52	1410	33.9
9	120	31.9	31	780	33.6	53	1440	33.9
10	150	32.2	32	810	33.6	54	1470	33.9
11	180	32.4	33	840	33.7	55	1500	33.9
12	210	32.5	34	870	33.7	56	1530	33.9
13	240	32.7	35	900	33.7	57	1560	33.9
14	270	32.8	36	930	33.8	58	1590	33.9
15	300	32.9	37	960	33.8	59	1620	33.9
16	330	32.9	38	990	33.8	60	1650	33.9
17	360	33.1	39	1020	33.8	61	1680	33.9
18	390	33.1	40	1050	33.8	62	1710	33.9
19	420	33.2	41	1080	33.8	63	1740	33.9
20	450	33.2	42	1110	33.8	64	1770	34.1
21	480	32.2	43	1140	33.8	65	1800	34.1
22	510	32.2	44	1170	33.8	Thermal Resistivity 0.30021551 °Cm/W		

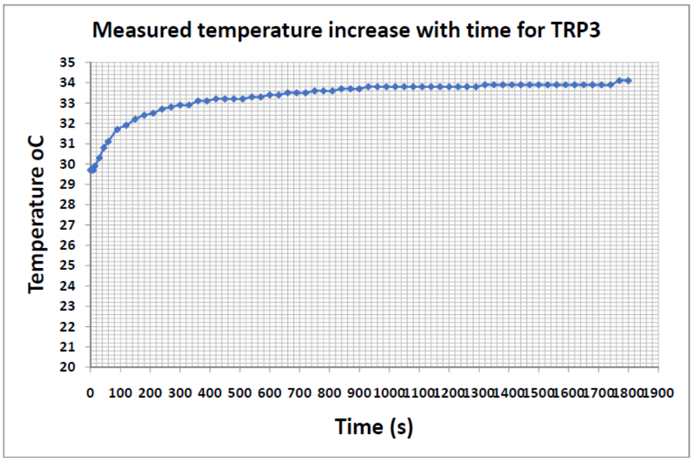

Fig. 5. Graph of Temperature oC versus Time (s) for TRP3. Calculated Thermal Resistivity value of 0.30021551 °Cm/W.

Table 7: Data Acquisition Parameters for TRP4

Heat Input Parameters	Heat Input Parameters Values
Current (A)	0.1628
Resistance (Ohms)	73.3
Voltage (V)	12.4
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	24.2841434
Date	18/12/2019
Ambient Soil Temperature	28.8 °C
Time of Recording	1 pm

Table 8: Measured temperature increase with time for TRP4

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	28.8	23	540	31.7	45	1200	32.3
2	5	28.8	24	570	31.8	46	1230	32.3
3	10	28.9	25	600	31.8	47	1260	32.3
4	15	29.0	26	630	31.9	48	1290	32.3
5	30	29.3	27	660	31.9	49	1320	32.3
6	45	29.5	28	690	31.9	50	1350	32.3
7	60	29.9	29	720	31.9	51	1380	32.3
8	90	30.2	30	750	32.0	52	1410	32.3
9	120	30.5	31	780	32.0	53	1440	32.3
10	150	30.7	32	810	32.0	54	1470	32.3
11	180	30.9	33	840	32.0	55	1500	32.3
12	210	31.0	34	870	32.0	56	1530	32.3
13	240	31.1	35	900	32.1	57	1560	32.3
14	270	31.2	36	930	32.1	58	1590	32.3
15	300	31.2	37	960	32.2	59	1620	32.3
16	330	31.3	38	990	32.2	60	1650	32.4
17	360	31.4	39	1020	32.2	61	1680	32.4
18	390	31.5	40	1050	32.2	62	1710	32.4
19	420	31.5	41	1080	32.2	63	1740	32.4
20	450	31.6	42	1110	32.2	64	1770	32.4
21	480	31.6	43	1140	32.2	65	1800	32.4
22	510	31.7	44	1170	32.2	Thermal Resistivity 0.298742062 °Cm/W		

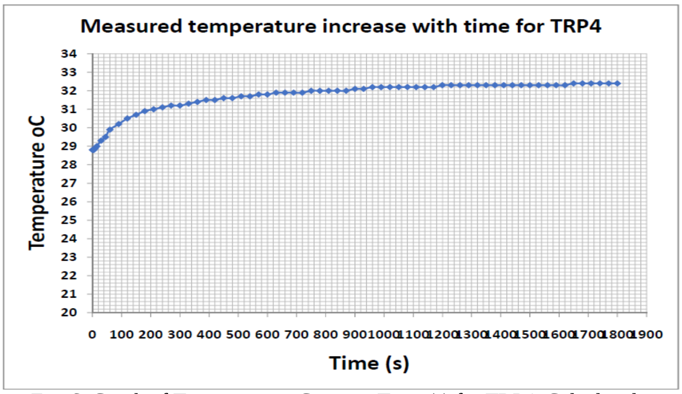

Fig. 6. Graph of Temperature oC versus Time (s) for TRP4. Calculated Thermal Resistivity value of 0.298742062 °Cm/W.

Table 9: Data Acquisition Parameters for TRP5

Heat Input Parameters	**Heat Input Parameters Values**
Current (A)	0.1616
Resistance (Ohms)	73.3
Voltage (V)	12.35
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	23.9274656
Date	18/12/2019
Ambient Soil Temperature	29.8 °C
Time of Recording	2 pm

Table 10: Measured temperature increase with time for TRP5

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	29.8	23	540	34.8	45	1200	35.2
2	5	29.9	24	570	34.8	46	1230	35.2
3	10	29.9	25	600	34.8	47	1260	35.2
4	15	30.1	26	630	34.9	48	1290	35.2
5	30	30.8	27	660	34.9	49	1320	35.2
6	45	31.3	28	690	34.9	50	1350	35.2
7	60	31.8	29	720	35.0	51	1380	35.2
8	90	32.4	30	750	35.0	52	1410	35.1
9	120	32.9	31	780	35.0	53	1440	35.1
10	150	33.2	32	810	35.1	54	1470	35.1
11	180	33.5	33	840	35.1	55	1500	35.1
12	210	33.7	34	870	35.1	56	1530	35.1
13	240	33.9	35	900	35.1	57	1560	35.1
14	270	34.0	36	930	35.1	58	1590	35.2
15	300	34.2	37	960	35.1	59	1620	35.2
16	330	34.2	38	990	35.1	60	1650	35.2
17	360	34.4	39	1020	35.1	61	1680	35.2
18	390	34.4	40	1050	35.1	62	1710	35.2
19	420	34.5	41	1080	35.2	63	1740	35.2
20	450	34.5	42	1110	35.2	64	1770	35.2
21	480	34.7	43	1140	35.2	65	1800	35.2
22	510	34.7	44	1170	35.2	Thermal Resistivity 0.075798824 °Cm/W		

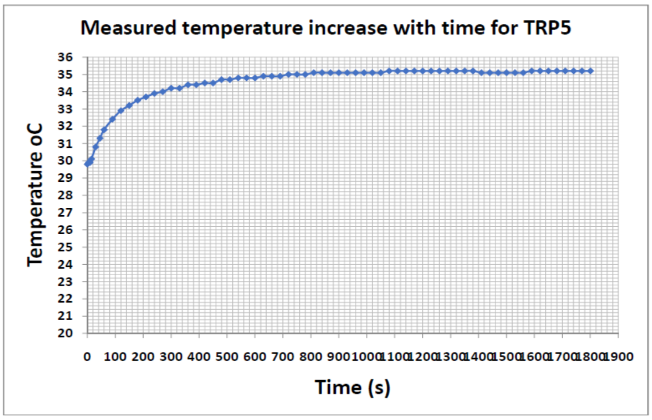

Fig. 7. Graph of Temperature oC versus Time (s) for TRP5. Calculated Thermal Resistivity value of 0.075798824 °Cm/W.

Table 11: Data Acquisition Parameters for TRP6

Heat Input Parameters	**Heat Input Parameters Values**
Current (A)	0.1615
Resistance (Ohms)	73.3
Voltage (V)	12.32
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	23.89786156
Date	18/12/2019
Ambient Soil Temperature	29.3 °C
Time of Recording	3 pm

Table 12: Measured temperature increase with time for TRP6

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	29.3	23	540	34.1	45	1200	34.8
2	5	29.5	24	570	34.1	46	1230	34.8
3	10	29.5	25	600	34.2	47	1260	34.8
4	15	29.7	26	630	34.2	48	1290	34.8
5	30	29.9	27	660	34.3	49	1320	34.8
6	45	30.5	28	690	34.3	50	1350	34.8
7	60	31.1	29	720	34.3	51	1380	34.8
8	90	31.8	30	750	34.3	52	1410	34.8
9	120	32.2	31	780	34.4	53	1440	34.9
10	150	32.5	32	810	34.4	54	1470	34.9
11	180	32.9	33	840	34.5	55	1500	34.9
12	210	33.1	34	870	34.5	56	1530	34.9
13	240	33.2	35	900	34.5	57	1560	34.9
14	270	33.4	36	930	34.6	58	1590	34.9
15	300	33.5	37	960	34.6	59	1620	34.9
16	330	33.5	38	990	34.6	60	1650	34.9
17	360	33.7	39	1020	34.7	61	1680	34.9
18	390	33.8	40	1050	34.7	62	1710	34.9
19	420	33.8	41	1080	34.7	63	1740	34.9
20	450	33.9	42	1110	34.7	64	1770	34.9
21	480	34.0	43	1140	34.8	65	1800	34.9
22	510	34.1	44	1170	34.8	Thermal Resistivity 0.455356332 °Cm/W		

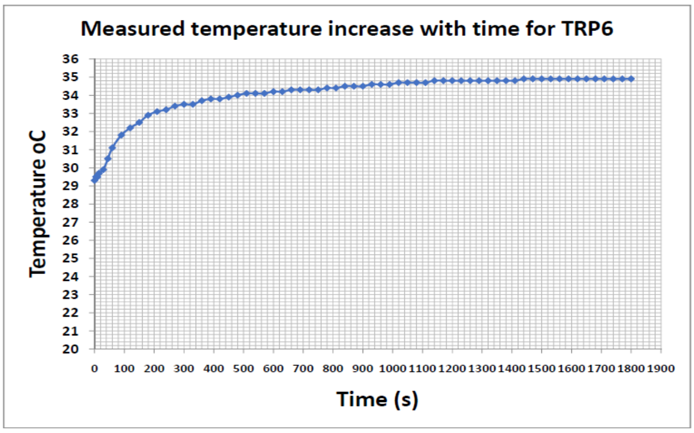

Fig. 8. Graph of Temperature oC versus Time (s) for TRP6. Calculated Thermal Resistivity value of 0.455356332 °Cm/W.

Table 13: Data Acquisition Parameters for TRP7

Heat Input Parameters	**Heat Input Parameters Values**
Current (A)	0.1608
Resistance (Ohms)	73.3
Voltage (V)	12.29
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	23.6911464
Date	18/12/2019
Ambient Soil Temperature	29.6 °C
Time of Recording	4 pm

Table 14: Measured temperature increase with time for TRP7

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	29.6	23	540	33.2	45	1200	33.8
2	5	29.6	24	570	33.2	46	1230	33.8
3	10	29.7	25	600	33.2	47	1260	33.8
4	15	29.9	26	630	33.3	48	1290	33.8
5	30	30.2	27	660	33.3	49	1320	33.8
6	45	30.6	28	690	33.4	50	1350	33.8
7	60	30.9	29	720	33.4	51	1380	33.8
8	90	31.3	30	750	33.4	52	1410	33.8
9	120	31.7	31	780	33.4	53	1440	33.8
10	150	31.9	32	810	33.5	54	1470	33.8
11	180	32.1	33	840	33.5	55	1500	33.8
12	210	32.2	34	870	33.5	56	1530	33.8
13	240	32.4	35	900	33.5	57	1560	33.8
14	270	32.6	36	930	33.5	58	1590	33.9
15	300	32.7	37	960	33.5	59	1620	33.9
16	330	32.8	38	990	33.5	60	1650	33.9
17	360	32.9	39	1020	33.7	61	1680	33.9
18	390	32.9	40	1050	33.7	62	1710	33.9
19	420	32.9	41	1080	33.7	63	1740	33.9
20	450	33.0	42	1110	33.7	64	1770	33.9
21	480	33.1	43	1140	33.7	65	1800	33.9
22	510	33.1	44	1170	33.7	Thermal Resistivity 0.306219671 °Cm/W		

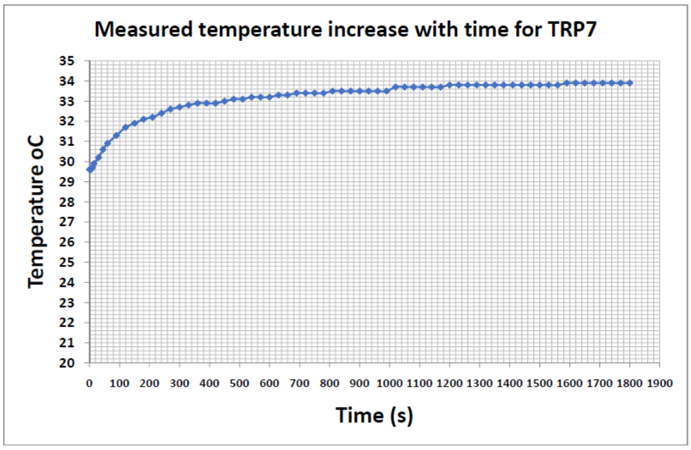

Fig. 9. Graph of Temperature oC versus Time (s) for TRP7. Calculated Thermal Resistivity value of 0.306219671 °Cm/W.

Table 15: Data Acquisition Parameters for TRP8

Heat Input Parameters	**Heat Input Parameters Values**
Current (A)	0.1607
Resistance (Ohms)	73.3
Voltage (V)	12.27
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	23.66168896
Date	18/12/2019
Ambient Soil Temperature	28.5 °C
Time of Recording	5 pm

Table 16: Measured temperature increase with time for TRP8

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	28.5	23	540	30.6	45	1200	31.1
2	5	28.5	24	570	30.7	46	1230	31.1
3	10	28.5	25	600	30.7	47	1260	31.1
4	15	28.5	26	630	30.8	48	1290	31.1
5	30	28.7	27	660	30.8	49	1320	31.2
6	45	29.0	28	690	30.8	50	1350	31.2
7	60	29.2	29	720	30.9	51	1380	31.2
8	90	29.3	30	750	30.9	52	1410	31.2
9	120	29.5	31	780	30.9	53	1440	31.2
10	150	29.8	32	810	30.9	54	1470	31.3
11	180	29.9	33	840	31.0	55	1500	31.3
12	210	30.0	34	870	31.0	56	1530	31.3
13	240	30.1	35	900	31.0	57	1560	31.3
14	270	30.2	36	930	31.1	58	1590	31.3
15	300	30.2	37	960	31.1	59	1620	31.3
16	330	30.3	38	990	31.1	60	1650	31.3
17	360	30.3	39	1020	31.1	61	1680	31.3
18	390	30.4	40	1050	31.1	62	1710	31.3
19	420	30.4	41	1080	31.1	63	1740	31.3
20	450	30.5	42	1110	31.1	64	1770	31.3
21	480	30.5	43	1140	31.1	65	1800	31.3
22	510	30.6	44	1170	31.1	Thermal Resistivity 0.229950673 °Cm/W		

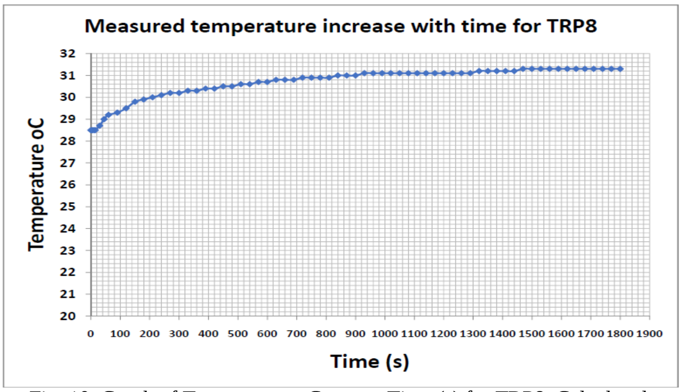

Fig. 10. Graph of Temperature oC versus Time (s) for TRP8. Calculated Thermal Resistivity value of 0.229950673 °Cm/W.

Table 17:Data Acquisition Parameters for TRP9

Heat Input Parameters	**Heat Input Parameters Values**
Current (A)	0.16
Resistance (Ohms)	73.3
Voltage (V)	12.25
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	23.456
Date	18/12/2019
Ambient Soil Temperature	28.6 °C
Time of Recording	6 pm

Table 18: Measured temperature increase with time for TRP9

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	28.6	23	540	31.2	45	1200	31.8
2	5	28.6	24	570	31.3	46	1230	31.8
3	10	28.6	25	600	31.3	47	1260	31.9
4	15	28.8	26	630	31.3	48	1290	31.9
5	30	29.1	27	660	31.4	49	1320	31.9
6	45	29.3	28	690	31.4	50	1350	31.9
7	60	29.5	29	720	31.5	51	1380	31.9
8	90	29.9	30	750	31.5	52	1410	31.9
9	120	30.1	31	780	31.5	53	1440	31.9
10	150	30.3	32	810	31.5	54	1470	31.9
11	180	30.3	33	840	31.5	55	1500	31.9
12	210	30.5	34	870	31.5	56	1530	31.9
13	240	30.7	35	900	31.6	57	1560	31.9
14	270	30.8	36	930	31.6	58	1590	31.9
15	300	30.8	37	960	31.6	59	1620	31.9
16	330	30.9	38	990	31.7	60	1650	31.9
17	360	31	39	1020	31.7	61	1680	31.9
18	390	31.1	40	1050	31.7	62	1710	31.9
19	420	31.1	41	1080	31.7	63	1740	31.9
20	450	31.1	42	1110	31.7	64	1770	31.9
21	480	31.2	43	1140	31.8	65	1800	31.9
22	510	31.2	44	1170	31.8	Thermal Resistivity 0.309289523 °Cm/W		

Volume 4, Issue 5, pp. 55-63, 2020.
International Journal of Scientific Engineering and Science
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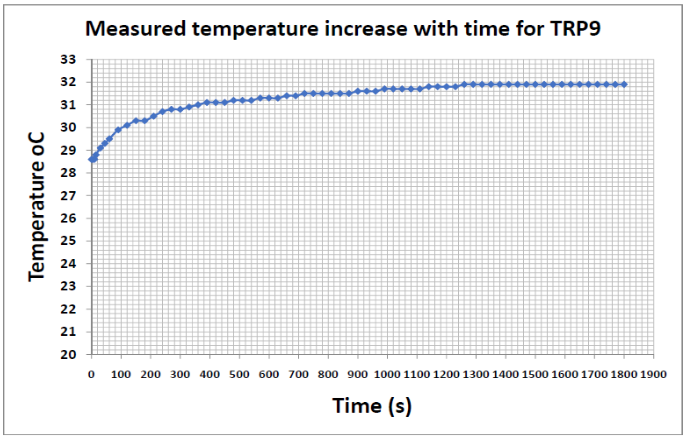

Fig. 11. Graph of Temperature oC versus Time (s) for TRP9. Calculated Thermal Resistivity value of 0.309289523 °Cm/W.

Table 19:Data Acquisition Parameters for TRP10

Heat Input Parameters	**Heat Input Parameters Values**
Current (A)	0.1589
Resistance (Ohms)	73.3
Voltage (V)	12.2
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	23.13458866
Date	18/12/2019
Ambient Soil Temperature	29.1 °C
Time of Recording	7 pm

Table 20: Measured temperature increase with time for TRP10

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	29.1	23	540	32.1	45	1200	32.6
2	5	29.1	24	570	32.2	46	1230	32.6
3	10	29.1	25	600	32.2	47	1260	32.6
4	15	29.2	26	630	32.2	48	1290	32.6
5	30	29.5	27	660	32.3	49	1320	32.6
6	45	29.8	28	690	32.3	50	1350	32.6
7	60	30.1	29	720	32.3	51	1380	32.7
8	90	30.5	30	750	32.3	52	1410	32.7
9	120	30.9	31	780	32.3	53	1440	32.7
10	150	31.0	32	810	32.3	54	1470	32.7
11	180	31.2	33	840	32.3	55	1500	32.7
12	210	31.3	34	870	32.5	56	1530	32.7
13	240	31.5	35	900	32.5	57	1560	32.7
14	270	31.8	36	930	32.5	58	1590	32.7
15	300	31.8	37	960	32.5	59	1620	32.7
16	330	31.8	38	990	32.5	60	1650	32.8
17	360	31.9	39	1020	32.5	61	1680	32.8
18	390	31.9	40	1050	32.5	62	1710	32.8
19	420	32.0	41	1080	32.5	63	1740	32.8
20	450	32.1	42	1110	32.5	64	1770	32.8
21	480	32.1	43	1140	32.6	65	1800	32.8
22	510	32.1	44	1170	32.6	Thermal Resistivity 0.313586516 °Cm/W		

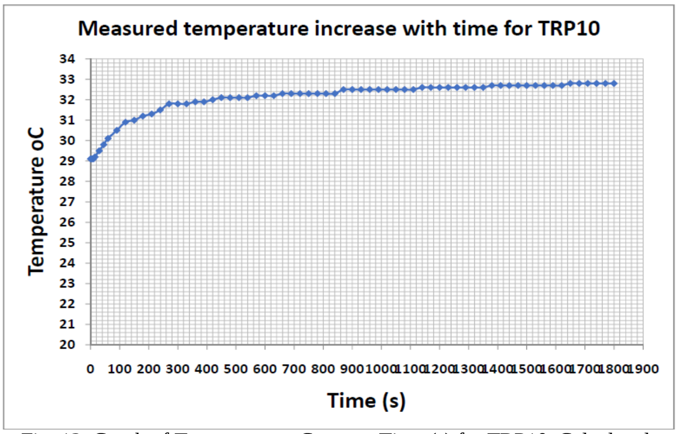

Fig. 12. Graph of Temperature oC versus Time (s) for TRP10. Calculated Thermal Resistivity value of 0.313586516 °Cm/W.

Table 21: Data Acquisition Parameters for TRP11

Heat Input Parameters	**Heat Input Parameters Values**
Current (A)	0.1594
Resistance (Ohms)	73.3
Voltage (V)	12.2
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	23.28040985
Date	18/12/2019
Ambient Soil Temperature	28.7 °C
Time of Recording	8 pm

Table 22: Measured temperature increase with time for TRP11

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	28.7	23	540	31.9	45	1200	32.3
2	5	28.8	24	570	32.0	46	1230	32.4
3	10	28.8	25	600	32.0	47	1260	32.4
4	15	29	26	630	32.1	48	1290	32.4
5	30	29.2	27	660	32.1	49	1320	32.4
6	45	29.6	28	690	32.1	50	1350	32.4
7	60	29.8	29	720	32.1	51	1380	32.4
8	90	30.2	30	750	32.2	52	1410	32.4
9	120	30.5	31	780	32.2	53	1440	32.4
10	150	30.9	32	810	32.2	54	1470	32.5
11	180	31.1	33	840	32.2	55	1500	32.5
12	210	31.2	34	870	32.2	56	1530	32.5
13	240	31.3	35	900	32.2	57	1560	32.5
14	270	31.4	36	930	32.2	58	1590	32.5
15	300	31.5	37	960	32.2	59	1620	32.5
16	330	31.5	38	990	32.3	60	1650	32.5
17	360	31.7	39	1020	32.3	61	1680	32.6
18	390	31.8	40	1050	32.3	62	1710	32.6
19	420	31.8	41	1080	32.3	63	1740	32.6
20	450	31.8	42	1110	32.3	64	1770	32.6
21	480	31.9	43	1140	32.3	65	1800	32.6
22	510	31.9	44	1170	32.3	Thermal Resistivity 0.233716731 °Cm/W		

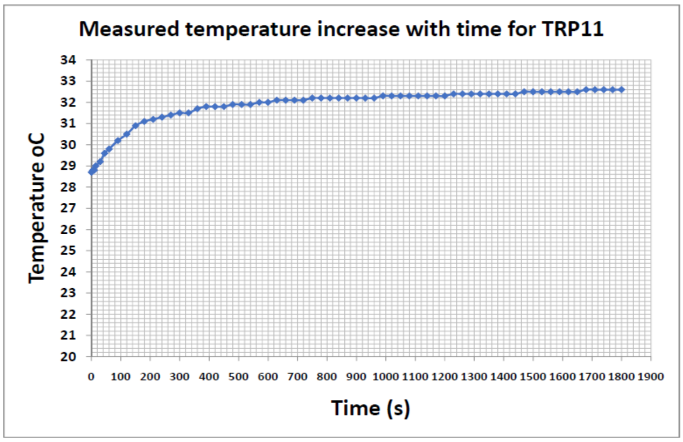

Fig. 13. Graph of Temperature oC versus Time (s) for TRP11. Calculated Thermal Resistivity value of 0.233716731 °Cm/W

Table 23: Data Acquisition Parameters for TRP12

Heat Input Parameters	**Heat Input Parameters Values**
Current (A)	0.1591
Resistance (Ohms)	73.3
Voltage (V)	12.21
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	23.19286216
Date	18/12/2019
Ambient Soil Temperature	29.2 °C
Time of Recording	9 pm

International Journal of Scientific Engineering and Science
Volume 4, Issue 5, pp. 55-63, 2020. ISSN (Online): 2456-7361

Table 24: Measured temperature increase with time for TRP12

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	29.2	23	540	31.9	45	1200	32.5
2	5	29.2	24	570	32.1	46	1230	32.5
3	10	29.2	25	600	32.1	47	1260	32.5
4	15	29.3	26	630	32.1	48	1290	32.5
5	30	29.5	27	660	32.1	49	1320	32.5
6	45	29.8	28	690	32.1	50	1350	32.5
7	60	29.9	29	720	32.2	51	1380	32.6
8	90	30.3	30	750	32.2	52	1410	32.6
9	120	30.5	31	780	32.2	53	1440	32.6
10	150	30.8	32	810	32.3	54	1470	32.6
11	180	30.9	33	840	32.3	55	1500	32.6
12	210	31.1	34	870	32.3	56	1530	32.6
13	240	31.2	35	900	32.3	57	1560	32.7
14	270	31.3	36	930	32.3	58	1590	32.7
15	300	31.4	37	960	32.3	59	1620	32.7
16	330	31.5	38	990	32.3	60	1650	32.7
17	360	31.6	39	1020	32.4	61	1680	32.7
18	390	31.7	40	1050	32.4	62	1710	32.7
19	420	31.8	41	1080	32.4	63	1740	32.7
20	450	31.8	42	1110	32.4	64	1770	32.7
21	480	31.9	43	1140	32.4	65	1800	32.7
22	510	31.9	44	1170	32.5	**Thermal Resistivity 0.312798611 °Cm/W**		

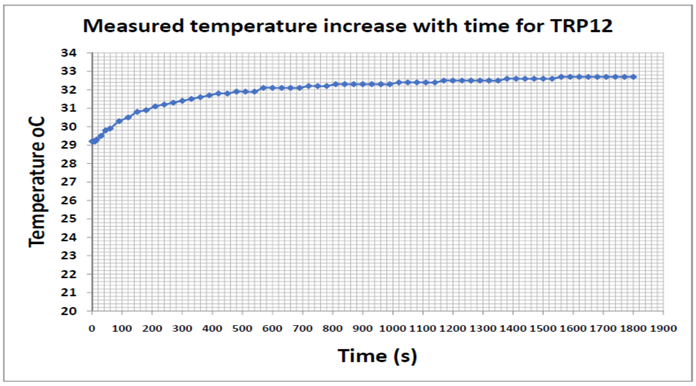

Fig. 14. Graph of Temperature oC versus Time (s) for TRP12. Calculated Thermal Resistivity value of 0.312798611 °Cm/W.

Table 25:Data Acquisition Parameters for TRP13

Heat Input Parameters	**Heat Input Parameters Values**
Current (A)	0.1602
Resistance (Ohms)	73.3
Voltage (V)	12.22
Length of probe (m)	0.08
	Heat Input q (W/m)
Heat input Calc using Current and Resistance	23.51467665
Date	18/12/2019
Ambient Soil Temperature	28.7 °C
Time of Recording	10 pm

Table 26: Measured temperature increase with time for TRP13

S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C	S/N	Time (s)	Temperature °C
1	0	28.7	23	540	31	45	1200	31.4
2	5	28.7	24	570	31	46	1230	31.4
3	10	28.7	25	600	31	47	1260	31.4
4	15	28.8	26	630	31	48	1290	31.4
5	30	29.1	27	660	31.1	49	1320	31.4
6	45	29.2	28	690	31.1	50	1350	31.4
7	60	29.4	29	720	31.1	51	1380	31.4
8	90	29.6	30	750	31.2	52	1410	31.4
9	120	29.9	31	780	31.2	53	1440	31.4
10	150	30.1	32	810	31.2	54	1470	31.5
11	180	30.1	33	840	31.2	55	1500	31.5
12	210	30.3	34	870	31.3	56	1530	31.5
13	240	30.4	35	900	31.3	57	1560	31.5
14	270	30.5	36	930	31.3	58	1590	31.5
15	300	30.6	37	960	31.3	59	1620	31.5
16	330	30.7	38	990	31.3	60	1650	31.5
17	360	30.7	39	1020	31.3	61	1680	31.5
18	390	30.8	40	1050	31.3	62	1710	31.5
19	420	30.9	41	1080	31.3	63	1740	31.5
20	450	30.9	42	1110	31.3	64	1770	31.5
21	480	30.9	43	1140	31.4	65	1800	31.6
22	510	30.9	44	1170	31.4	**Thermal Resistivity 0.23138831 °Cm/W**		

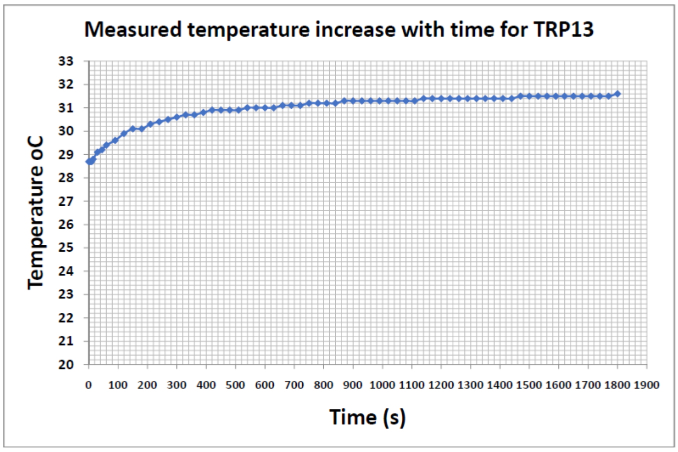

Fig. 15. Graph of Temperature oC versus Time (s) for TRP13. Calculated Thermal Resistivity value of 0.23138831 °Cm/W

VI. RESULTS

Table 27 indicates that the measure thermal resistivity values are within the range of 0.075798824 °Cm/W to 0.455356332 °Cm/W, which by implication falls within the thermal resistivity range of sand and clay, after [12]. These values where contoured into a 2D model shown in Fig. 16. The model depicts region of low thermal resistivity that is flanked by regions of relatively high resistivity on both side. The near surface geology indicated that the western part of the survey area is predominately silty clay, while the eastern side is predominantly silty sand. A close examination of thermal resistivity model of Fig. 16 indicates that, the western region which is predominately clay registered the highest and the least thermal resistivity value of 0.45 °Cm/W to 0.08 °Cm/W respectively. This is typical of clay soil that will register high thermal resistivity in the region where it is dry and cracked, and very low thermal resistivity when saturated and consolidated. The eastern region that is predominantly sand registered a resistivity range 0.18 °Cm/W to 0.30 °Cm/W, which are typical values for sand. The thermal resistivity response of sand was low in region closer to the center of the model, with high water content and higher at the model periphery with low water content.

The percentage soil water content values (Table 28) were also developed into a 2D model for the purpose of comparison. It was obvious from Fig. 16 and 17, that the thermal resistivity response is higher at the points were the soil water content is least, and lower where the soil water content is higher. It was glaring from the comparison of both models that soil water content, has a remarkable influence on the determined thermal resistivity response.

The ambient soil temperature values (Table 29) were also developed into 2D model for the purpose of comparison, and to examine the effect of temperature on the response of soil thermal resistivity in a 2Dimentional grid. [6], base on the thermal resistivity measurement carried out at a single point, have earlier reported that "The soil thermal resistivity increases with Soil ambient temperature." However, a comparison of Fig. 16 and 18 has revealed that the ambient soil temperature is highest at the points where the thermal resistivity is least, which appear like a deviation from early

International Journal of Scientific Engineering and Science
Volume 4, Issue 5, pp. 55-63, 2020. ISSN (Online): 2456-7361

observation. A critical observation revealed that the thermal resistivity of the soil is influence more by soil water content and lithology than ambient soil temperature. Hence, the result obtained earlier by [6] on "Impact of ambient soil temperature on the result of determined soil thermal resistivity" may have been influence by the effect of the Sun intensity on the soil water content that varied continuously as a result of redundant measurement at the same point and depth. However, [4] has stated how the effect of ambient soil temperature changes could be completely eliminated from thermal resistivity measurement by taking advantage of depth.

Table 27: The determined thermal resistivity at each grid points

S/N	X(m)	Y(m)	Thermal Resistivity
1	0	0	0.295466206
2	0	6	0.151973588
3	0	12	0.300215510
4	10	12	0.298742062
5	10	6	0.075798824
6	10	0	0.455356332
7	20	0	0.306219671
8	20	6	0.229950673
9	20	12	0.309289523
10	5	3	0.313586516
11	5	9	0.233716731
12	15	3	0.312798611
13	15	9	0.231388310

Table 28: Percentage Soil Water Content

S/N	X(m)	Y(m)	Water Content
1	0	0	12.57
2	0	6	43.57
3	0	12	11.36
4	10	12	11.73
5	10	6	72.84
6	10	0	3.57
7	20	0	9.88
8	20	6	40.39
9	20	12	15.15
10	5	3	8.15
11	5	9	32.8
12	15	3	8.33
13	15	9	39.78

Table 29: Ambient Soil temperature recorded just before the thermal resistivity measurement

S/N	X(m)	Y(m)	Ambient Soil Temperature in (°C)
1	0	0	28.3
2	0	6	29.9
3	0	12	29.7
4	10	12	28.8
5	10	6	29.8
6	10	0	29.3
7	20	0	29.6
8	20	6	28.5
9	20	12	28.6
10	5	3	29.1
11	5	9	28.7
12	15	3	29.2
13	15	9	28.7

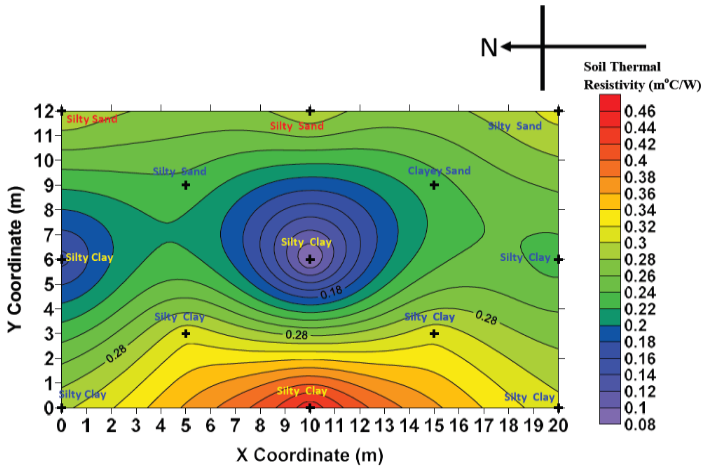

Fig. 16. 2D Model of Soil thermal resistivity, with indicated underlying geology

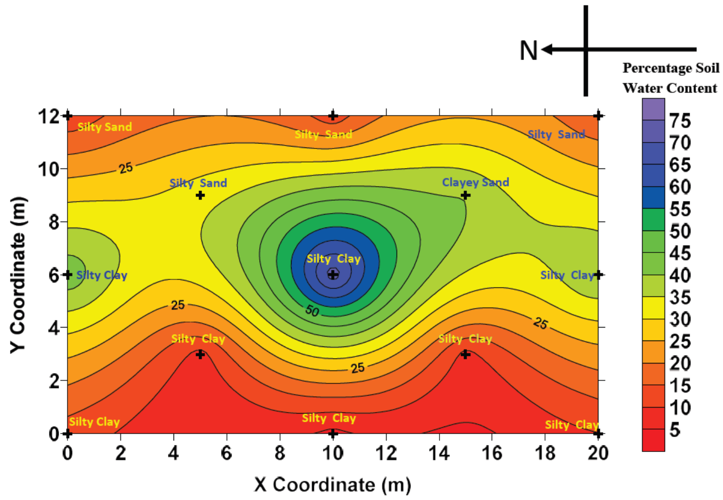

Fig. 17. 2D Model of Percentage Soil Water Content, with indicated underlying geology.

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International Journal of Scientific Engineering and Science

Volume 4, Issue 5, pp. 55-63, 2020. ISSN (Online): 2456-7361

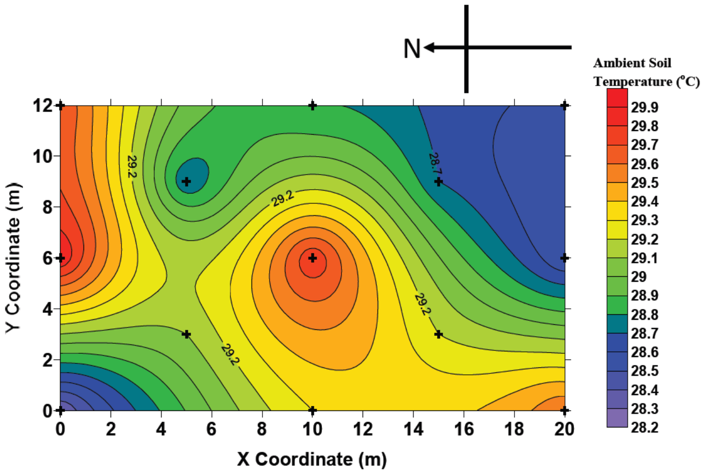

Fig. 18. 2D Model of ambient soil temperature recorded just before the thermal resistivity measurement.

VII. Discussion

The results so far obtain have clearly indicated that the soil lithology has a significant role to play in determining the type of soil thermal resistivity response. The soil thermal resistivity registered by clay and sand falls within their typical range, hence, helped in distinguishing the two lithologies. Clay with very low water content registered relatively high thermal resistivity, while fully saturated clay registered very low soil thermal resistivity. It also gave a strong indication that percentage soil water content has a stronger influence on the thermal resistivity response than the effect of lithology and ambient soil temperature put together. It was obvious from the 2D models of Fig. 16 and 17 that the distribution pattern of soil water content is almost one to one correspondence to the thermal resistivity distribution pattern. Hence, one can categorically project that thermal resistivity response will be an effective tool for ascertaining time lapse level of water content in the soil and a confirmation of lithological distribution within a give region, and it also revealed that the disparity of thermal resistivity response within soil of the same lithological composition is determined by degree of water content it contain. It was established that soil thermal resistivity signature in the face of lithology, water content and ambient soil temperature, is majorly influence by soil water content and lithology, than ambient soil temperature. The effect of ambient soil temperature on thermal resistivity is still a function of variation of soil water content induces by the sun intensity.

VIII. Conclusion

The result has shown that the area under investigation is characterized with central low thermal resistivity that is flanked on both sides with relatively high thermal resistivity. It also revealed that the distribution pattern of soil thermal resistivity tallies appreciably with the distribution of soil water content within the area under survey. It was established that the soil water content has great influence on the observed soil thermal resistivity response, and it also revealed that the disparity noticed in thermal resistivity response within soil of the same lithological composition was determined by degree of water content it contain. The direct comparison of the models of ambient soil temperature and soil thermal resistivity indicated that in regions where the soil ambient temperature recorded the highest value, soil thermal resistivity registered a correspondingly the least value, and vice versa. It was therefore concluded that soil water content and lithology have much influence on soil thermal resistivity response tham ambient soil temperature.

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