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Examination of Soil Thermal Resistivity Distribution Pattern, Within a Gridded Zone.

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Abstract:

The essence of carrying out thermal resistivity survey is to measure the capacity of the ground to conduct or dissipate heat. However, most often, soil thermal resistivity are determined at a point or along straight line, where an electrical cable or a pipeline is to be laid; information regarding the thermal resistivity distribution of the adjoining soil materials and their effect are not often put into consideration. Hence, this research work is aim at examining the nature of soil thermal resistivity distribution pattern, within a specified location. The obtained results has shown that the rang of thermal resistivity at the survey area is between 0.075798824 ^{o}Cm/W to 0.455356332 ^{o}Cm/W. The generated 2D model was able to depict a very low thermal resistivity at the center of the model that stretched North South, that is flanked by region of high thermal resistivity in the west and relatively low thermal resistivity to the East, also stretching North South. The model result gave a clear indication that any heat generated by a pipeline or electrical cable placed within the center of the model will be more effectively dissipated toward the Eastern region with low thermal resistivity than the Western region with high thermal resistivity that will naturally resist the flow of heat. The result has shown that this effect has to be put into cognizance during thermal resistivity measurement, because the effect could be catastrophic if the thermal resistivity of the adjoining soil, next to a thin layer of low thermal resistivity soil surrounding a pipeline or electrical cable goes beyond the optimum safety limit of 0.9 ^{o}Cm/W. The one dimensional thermal resistivity graph extracted from the model along the straight line where the pipeline or electrical cable is to be laid only registered relatively low thermal resistivity values. It could not delineate the high thermal resistivity adjacent to the lowest thermal resistivity it measured. It was therefore concluded that 2D thermal resistivity measurement that will take into consideration the thermal resistivity distribution of the adjoining soil is a more effective tool for thermal resistivity measurement, than a one dimensional thermal resistivity measurement carried out on a single line or at a point.

Keywords

Thermal Resistivity, distribution pattern, gridded zone, 2D and 1D Thermal Resistivity

1. Introduction

The Major reason why thermal resistivity survey is carried out is to measure the ability of the ground to conduct or dissipate heat. It is express mathematically as;

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

Where

$\sigma = Soil\ Thermal\ Resistivity\ ^{o}C\ m/W$
$Q = Heat\ Input\ in\ W/m$
$T_1 = Temperature\ at\ time\ t_1$
$T_2 = Temperature\ at\ time\ t_2.$

Thermal resistivity survey most time is either determined at a point or carried out along a straight line, where electrical cable or pipelines are to be laid. Most times the thermal resistivity of the adjoining soil material and their effect are not put into consideration. This research work therefore is aim at examining the thermal resistivity distribution pattern within a gridded zone. Considering the research work carried out by others,

[3], stated that, "soil and backfill thermal properties must be known for a safe and successful underground power cable installation". [4], stated that, "the same field tests often used to determine soil thermal resistivity may provide additional information that can help to determine the amount of dried soil surrounding a cable that may be expected for varying heat rates". "Soil temperature around the buried pipe decreases with the increase of soil thermal conductivity" [10]. "Temperature played a significant role in the corrosion rate of A350LF2 steel in hydrogen sulphide environment" [9].

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 and a small drilling tool.

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2. 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 [7], [8], [5]. These Quaternary Sediments, according to [6] are largely alluvial and hydromorphic soils and lacustrine sediments of Pleistocene age.

3. Location of study area

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

Figure 1: Imagery Map of the Survey area showing the origin of the first sampled point.

4. Data Acquisition

The data acquisition started by 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 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 specified 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, as recommended by [2], 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.

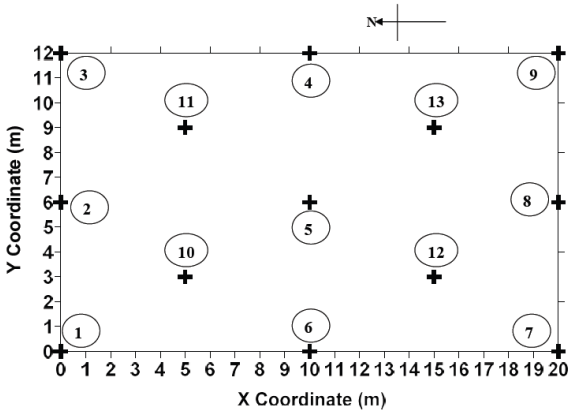

Figure 2: Gridded area indicating the sampled point, with a dark cross, numbered according to data collection sequence.

5. Data Processing

The Data processing of thermal resistivity started by entering the recorded data of temperature increase with time on a spread sheet, that 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 temperature values recorded against 12 and 24 minutes respectively. The temperature recorded between these time interval falls within the steady state of the graph. The determined thermal resistivity values were contoured into a model, to evaluate the distribution of thermal resistivity within the area under investigation.

6. Results

The results of the thermal resistivity measurement carried out to determine the distribution pattern within a gridded area is shown in table 1 to 26, and in figure 3 to 15. Note, TRP connotes Thermal Resistivity Point.

Table 1: Data Acquisition Parameters for TRP1

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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		

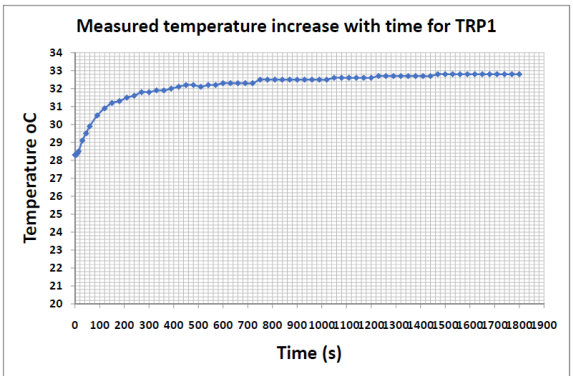

Figure3 : Graph of Temperature oC versus Time (s) for TRP1. Calculated Thermal Resistivity value of 0.295466206 °Cm/W.

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		

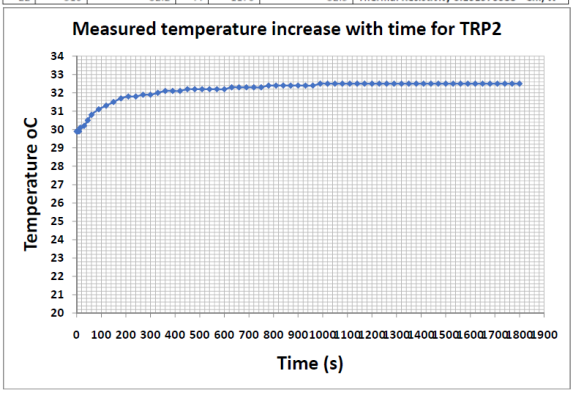

Figure 4 : Graph of Temperature oC versus Time (s) for TRP2. Calculated Thermal Resistivity value of 0.151973588 °Cm/W.

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		

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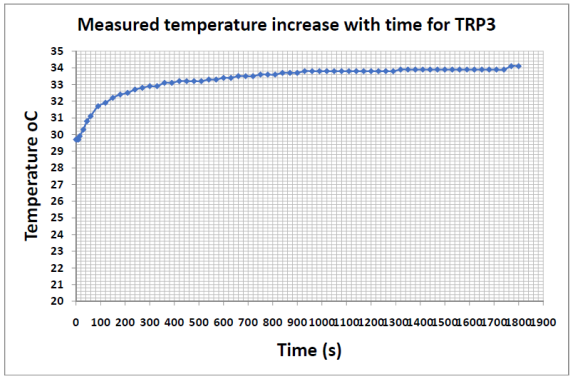

Figure 5: Graph of Temperature oC versus Time (s) for TRP3. Calculated Thermal Resistivity value of 0.30021551 ^{o}Cm/W.

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 ^{o}C
Time of Recording	1 pm

Table 8: Measured temperature increase with time for TRP4

S/N	Time (s)	Temperature ^{o}C	S/N	Time (s)	Temperature ^{o}C	S/N	Time (s)	Temperature ^{o}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 ^{o}Cm/W		

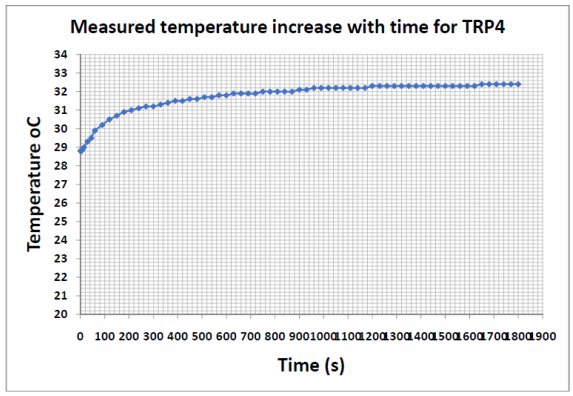

Figure 6: Graph of Temperature oC versus Time (s) for TRP4. Calculated Thermal Resistivity value of 0.298742062 ^{o}Cm/W.

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 ^{o}C
Time of Recording	2 pm

Table 10: Measured temperature increase with time for TRP5

S/N	Time (s)	Temperature ^{o}C	S/N	Time (s)	Temperature ^{o}C	S/N	Time (s)	Temperature ^{o}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 ^{o}Cm/W		

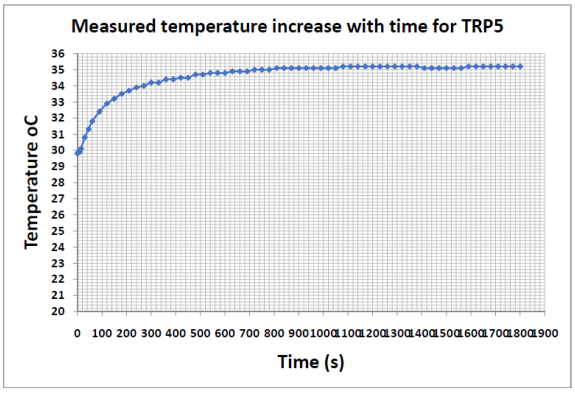

Figure 7: Graph of Temperature oC versus Time (s) for TRP5. Calculated Thermal Resistivity value of 0.075798824 ^{o}Cm/W.

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 ^{o}C
Time of Recording	3 pm

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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		

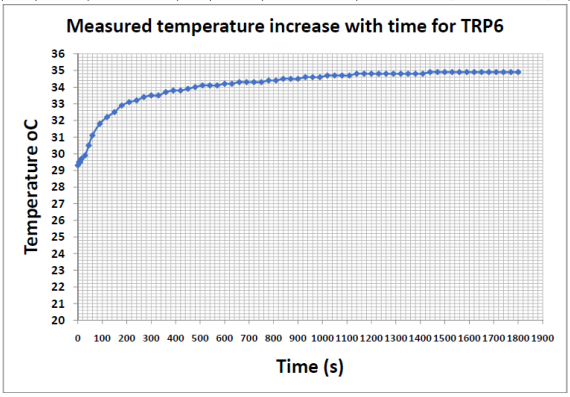

Figure 8: Graph of Temperature oC versus Time (s) for TRP6. Calculated Thermal Resistivity value of 0.455356332 ^{o}Cm/W.

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		

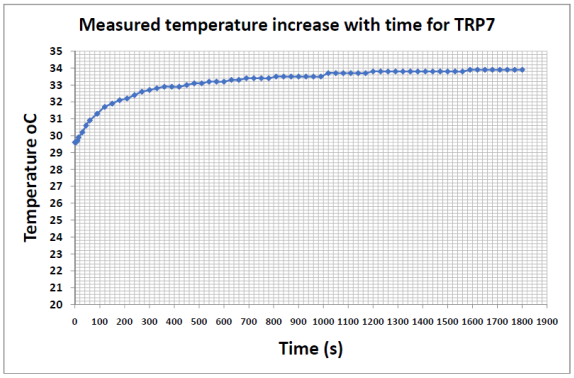

Figure 9: Graph of Temperature oC versus Time (s) for TRP7. Calculated Thermal Resistivity value of 0.306219671 ^{o}Cm/W.

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		

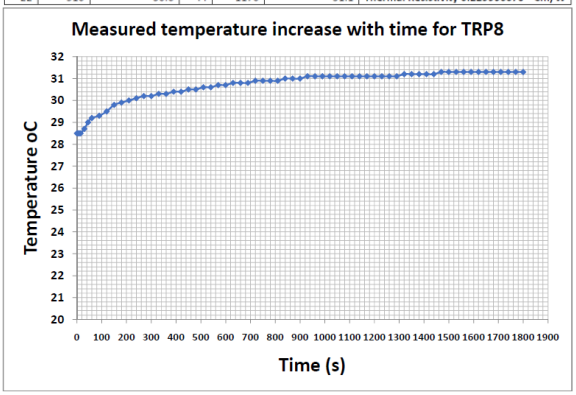

Figure 10: Graph of Temperature oC versus Time (s) for TRP8. Calculated Thermal Resistivity value of 0.229950673 ^{o}Cm/W.

Table 17:Data Acquisition Parameters for TRP9

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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		

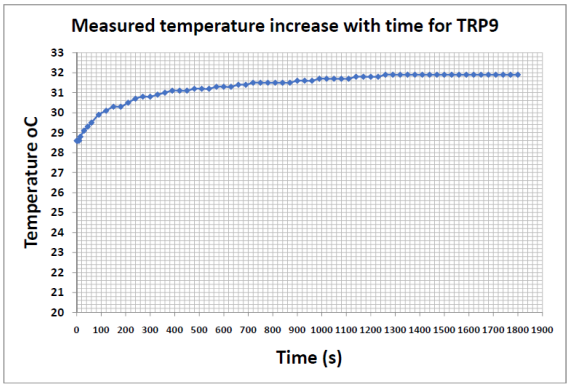

Figure 11: Graph of Temperature oC versus Time (s) for TRP9. Calculated Thermal Resistivity value of 0.309289523 °Cm/W.

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		

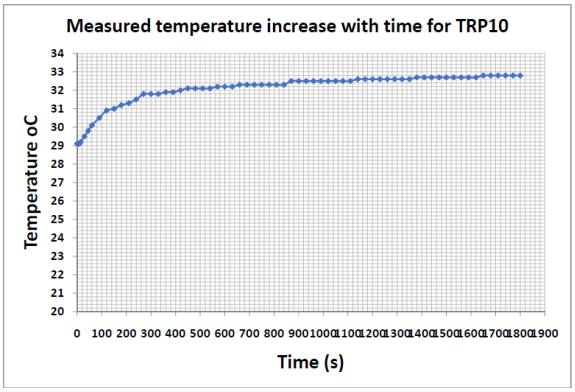

Figure 12: Graph of Temperature oC versus Time (s) for TRP10. Calculated Thermal Resistivity value of 0.313586516 °Cm/W.

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		

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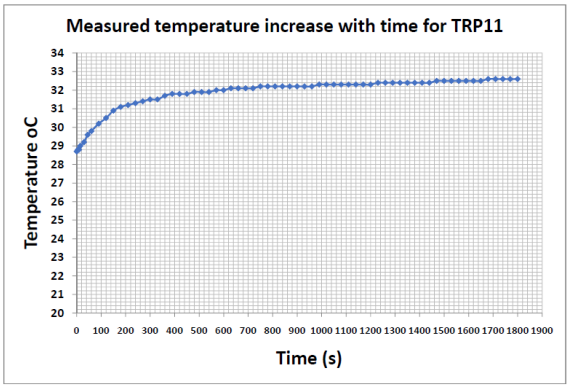

Figure 13: Graph of Temperature oC versus Time (s) for TRP11. Calculated Thermal Resistivity value of 0.233716731 ^{o}Cm/W

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 ^{o}C
Time of Recording	9 pm

Table 24: Measured temperature increase with time for TRP12

S/N	Time (s)	Temperature ^{o}C	S/N	Time (s)	Temperature ^{o}C	S/N	Time (s)	Temperature ^{o}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 ^{o}Cm/W		

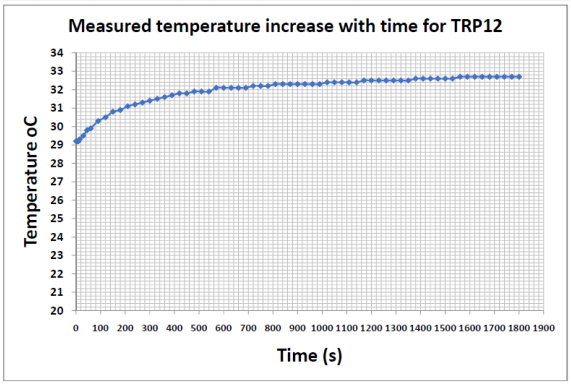

Figure 14: Graph of Temperature oC versus Time (s) for TRP12. Calculated Thermal Resistivity value of 0.312798611 ^{o}Cm/W.

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 ^{o}C
Time of Recording	10 pm

Table 26: Measured temperature increase with time for TRP13

S/N	Time (s)	Temperature ^{o}C	S/N	Time (s)	Temperature ^{o}C	S/N	Time (s)	Temperature ^{o}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 ^{o}Cm/W		

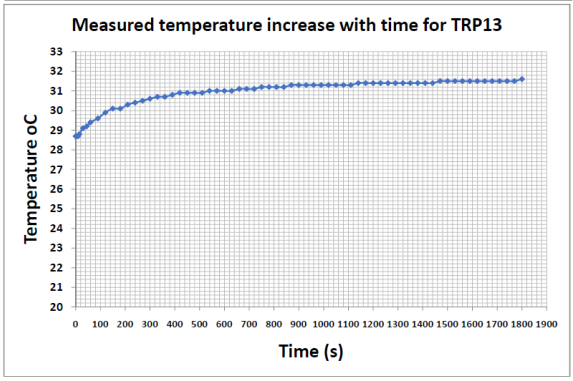

Figure 15: Graph of Temperature oC versus Time (s) for TRP13. Calculated Thermal Resistivity value of 0.23138831 ^{o}Cm/W

The range of determined thermal resistivity values at the test site characterized majorly of sand and clay is between 0.075798824 oCm/W to 0.455356332 oCm/W as shown in table 27. These values are clear indication that the survey area is characterize with regions of very low and high thermal resistivity values relative to each other. The contoured model of the thermal resistivity distribution pattern within the gridded zone is shown in figure 16. The model depicts regions of low thermal resistivity and region of high thermal resistivity. The low thermal resistivity depicted by the model within a range of 0.07 ^{o}Cm/W to 0.18 ^{o}Cm/W, is emplaced at the center of the model, and it runs North South. It is flanked by high thermal resistivity in the range of 0.30 ^{o}Cm/W to 0.46 ^{o}Cm/W in the Western part of the model, and relatively low thermal resistivity in the range of 0.08 ^{o}Cm/W to 0.28 ^{o}Cm/W in the Eastern part that also stretch North South.

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If a pipeline or electrical cable that generate heat is buried underground in the direction of North South as shown in the model figure 16, at 5 m above the Y coordinate. A close examination of the model thermal resistivity distribution will indicate that the generated heat by the pipeline or cable will be more effectively dissipated in eastern part of the model, than the western part that has higher soil thermal resistivity that will naturally resist the flow of heat.

The result has shown that this effect has to be put into consideration during thermal resistivity measurement, because the effect could be disastrous if the thermal resistivity of the adjoining soil, next to a thin layer of low thermal resistivity soil surrounding a pipeline or electrical cable goes beyond the optimum safety limit of 0.9 ^{o}Cm/W.

Table 27: The determined thermal resistivity ^{o}Cm/W at each grid points.

S/N	X(m)	Y(m)	Thermal Resistivity ^{o}Cm/W
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

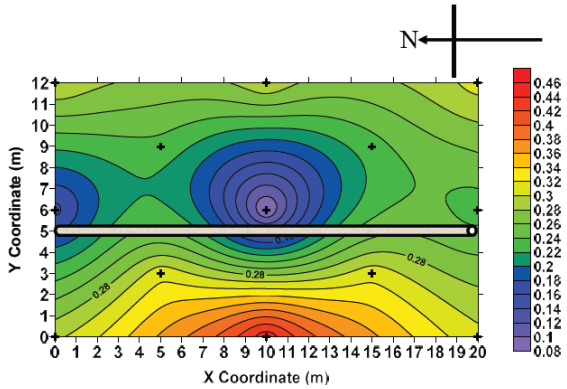

Figure 16: Thermal resistivity distribution model within a grid, with a hypothetical pipeline placed across.

Table 28 and Figure 17 shows a one dimensional thermal resistivity graph extracted from the model along a straight line, to indicate what the thermal resistivity would look like if it was measured at a point or on a straight line where the hypothetical pipeline or cable is laid. It was obvious from figure 17, base on the range of thermal resistivity values (0.14 ^{o}Cm/W to 0.24 ^{o}Cm/W) of one dimensional thermal resistivity graph, that the one dimensional survey could not detect the high thermal resistivity that exist at a relatively small distance of (2 to 5 m) in the western region of the gridded zone. In fact, the point of least thermal resistivity on the one dimensional graph is just adjacent to the point where the highest thermal resistivity value is registered in the model of figure 16.

Therefore taking the center of the model as reference point, it could be observed that any heat generated by a pipeline or cable laid horizontally at the center of the model, will be easily dissipated through the eastern region, compared with the western region that has high thermal resistivity.

This research work has revealed that it is only plane distributed (2D) thermal resistivity measurement that can effectively delineate the actual pattern of thermal resistivity distribution for effective heat dissipation, as against one dimensional thermal resistivity measurement, that that can provide information only at a point or along straight line.

Table 28 One dimensional thermal resistivity, extracted along x axis in the model.

X Coordinate	Thermal Resistivity
0	0.16
2	0.18
4	0.22
6	0.22
8	0.2
10	0.14
12	0.18
14	0.22
16	0.24
18	0.24
20	0.24

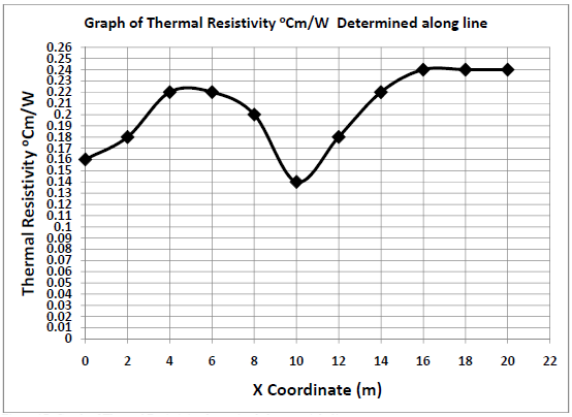

Figure 17: Graph of Thermal Resistivity determined along straight line.

7. Conclusion

The research work has revealed that, the range of determined thermal resistivity values at the gridded site under investigation is between 0.075798824 ^{o}Cm/W to 0.455356332 ^{o}Cm/W. The 2D model was able to depict a clear distribution pattern for thermal resistivity within the survey area. A very low thermal resistivity that stretched North South is emplaced at the center, which is flanked by region of high thermal resistivity to the west, and relatively low thermal resistivity to the East, that also stretched North South. It was pointed out that any heat generated by pipeline or electrical cable laid within the center of the model will be more effectively dissipated in the eastern region with low thermal resistivity, than the western region with higher thermal resistivity that will resist the flow of heat. The one dimensional thermal resistivity graph extracted from the model on a straight line where the hypothetical pipe was laid, only registered relatively low thermal resistivity. It could not delineate the high thermal resistivity adjacent to the lowest thermal resistivity it measured. It was therefore concluded that 2D thermal resistivity measurement that will take into cognizance the thermal resistivity distribution of the adjoining soil is a more effective tool for thermal resistivity measurement, than a one dimensional thermal resistivity measurement carried out on a single line or at a point.

8. References

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