FUDMA Journal of Sciences (FJS)
ISSN online: 2616-1370
ISSN print: 2645 - 2944
Vol. 9 No. 4, April, 2025, pp 324 – 334
DOI: https://doi.org/10.33003/fjs-2025-0904-3320

IMPACT OF CRUDE OIL POLLUTION ON SOIL THERMAL PROPERTIES (THERMAL CONDUCTIVITY, THERMAL DIFFUSIVITY AND THERMAL RESISTIVITY) IN OGONILAND RIVERS STATE SOUTH-SOUTH NIGERIA

***[1,2]Mohammed Maina, [2]Othniel Kamfani Likkason, [2]Sani Ali and [3]Nuhu K. Samaila**

[1]Department of Science Laboratory Technology, Ramat Polytechnic Maiduguri, P.M.B. 1070, Nigeria
[2]Department of Physics, Abubakar Tafawa Balewa University, Bauchi, P.M.B. 0248, Nigeria
[3]Department of Geology, Abubakar Tafawa Balewa University, Bauchi, P.M.B. 0248, Nigeria

*Corresponding authors' email: mohammedmina1971@gmail.com

ABSTRACT

Soil thermal properties are required in many areas of engineering, agronomy, and soil science, and in recent years considerable effort has gone into developing techniques to determine these properties. Seed germination, seedling emergence, and subsequent stand establishment are influenced by the microclimate. Thermal properties of soils play an important role in influencing microclimate. In this study, the effect of soil thermal properties were assessed based on thermal conductivity, thermal diffusivity and thermal resistivity of soil samples polluted by crude oil and its spillage in Ogoniland Rivers State South-South Nigeria. Soil samples at different test points (locations) were collected at depths of 0 – 15 cm for topsoil and 15 – 30 cm for subsoil with the aid of Dutch stainless steel hand auger from four (4) sites (impacted) within the study area and one (non-impacted) control site (outside) the study area. Thermal properties (diffusivity, conductivity and resistivity) were determined and the soils at these specified depths and their values were compared to those outside the study areas (control sites). The results show that there are negligible effects of crude oil pollution on soil thermal properties in both impact site and non-impact site at different test points. The soils in Eleme, Gokana and Tai Local Government Areas were found to be fitted for agricultural activities, laying of gas pipeline and buried of cable for telecommunication industries. The thermal properties of the soil are within the values previously reported by previous researchers.

Keywords: Thermal Conductivity, Thermal Diffusivity, Thermal Resistivity, Soil, Spillage

INTRODUCTION

For the past decade, human life and agricultural activities of crop farming, cattle rearing (livestock) and fish farming are greatly affected by petroleum and its byproducts in most parts of the oil producing states in Nigeria. On these notes, many scientists, engineers, technologists and agronomists are making effort to address this crisis of crude oil and its spillage effect on agriculture. Consequently, it is important to explore modern farming techniques through experimental works to mitigate effects by improving on the thermal properties of the soils which play an important role in influencing microclimate and micro-organism activities with the help of improving crop yields during planting and harvest Ghuman *et al.* (1985).

Thermal conductivity of a soil depends on several factors. These factors can be classified into two broad groups: those which are inherent to the soil itself, and those which can be managed or controlled at least to a certain extent by human management. Those factors or properties that are inherent to the soil itself include the texture and mineralogical composition of the soil Wierenga *et al.* (1969).

Factors that influence soil's thermal conductivity such as water content can be managed externally Yadav *et al.* (1973). The major factor that is crucial in determining soil thermal conductivity is through water content and is difficult to be managed by most farmers.

In managing soils, the soil can be compacted and on the same note, it will improve bulk density and decreases porosity of the soil.

Description of the study area

The study area lies between latitudes 4° 05′ to 4° 20′ N and longitudes 7° 10′ to 7° 30′ E with a total land area of about 1000 km² containing up to 116 drilled oil wells and 5 flow stations (Figure. 1).

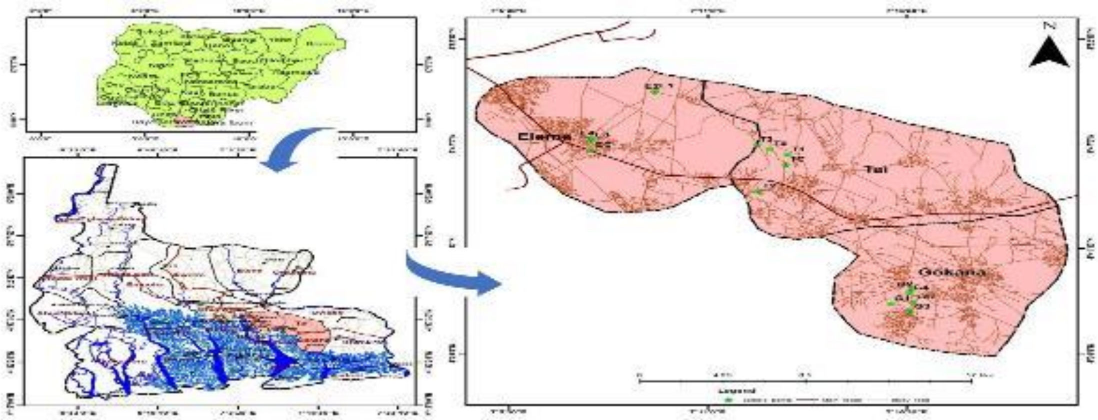

Figure 1: Locator Map showing Map of Nigeria, Rivers State, and the study areas

This study is tailored towards assessing the effect of soil pollution by petroleum or petroleum byproducts in soil which is persistent toxic compounds, salts, radioactive materials, or disease-causing agents that have adverse effect on plant growth and animal health Pepper *et al.* (1996). The problem is not unconnected to both agriculture and engineering. However, spillage of crude oil on the soil greatly affects the thermal conductivity, thermal resistivity and thermal diffusivity of the soil samples.

MATERIALS AND METHODS

Materials

The materials used in this studies are, transparent bottles, soil auger, soil samples from impacted and non-impacted sites, crude oil, portable digital balance, small containers, polythene bags, Lee Disc Apparatus, thermometers, stop-watch, steam supply, stand and clamp, shovel, mould, water.

Methods

The followings are the mathematical models used for the purpose of this study to estimate the effect of crude oil pollution and its spillage on the soil samples in the study areas at different locations.

$$Thermal\ Conductivity(k) = \frac{mc\left(\frac{dT}{dt}\right)x}{A(T_2 - T_1)} \quad (1)$$

Where m and c are mass and specific heat capacity of the lower disc $\frac{dT}{dt}$ is the rate of cooling at temperature T_2; $T_2 - T_1$ is the temperature difference across the soil samples of thickness $'x'$.

$$\text{Thermal Resistivity(R)} = \frac{1}{Thermal\ Conductivity(k)} \quad (2)$$

$$\text{Thermal diffusivity(D)} = \frac{Thermal\ Conductivity(K)}{Density \times Specific\ Heat\ Capacity(\rho C)} \quad (3)$$

Heuristic Pollution Index Measurement

$$\text{Pollution index} = \frac{\text{Difference in reading for the control area}}{\text{Difference in reading for the other stations}} \quad (4)$$

Experimental Analyses

The thermal conductivity was determined based on experiment and later subjected to empirical model Fourier's Law of heat conduction at two different locations within the ranges of 0-15 cm and 15-30 cm at both impact and non-impacted sites respectively across three local government areas (Eleme, Gokana and Tai) using Lee's Disc Apparatus at Analytical Physics Laboratory, Department of Physics, University of Maiduguri, Nigeria according to Ilouno *et al.* (2018); while thermal resistivity, thermal diffusivity and pollution Index were computed using equations (2), (3) and (4) above.

RESULTS AND DISCUSSION

Table 1: Soil Physical, Thermal and Chemical Properties of contaminated and uncontaminated soil samples per Local Govt.

Parameters	Locations					
	Eleme Contaminated & Uncontaminated		Gokana (Contaminated & Uncontaminated)		Tai(Contaminated & Uncontaminated)	
	Range	Range	Range	Range	Range	Range
Thermal Conductivity (W/m^{2o}C)	1.233-2.663	1.354-1.765	1.084-2.455	1.341-1.397	1.083-1.598	1.341-1.614
Thermal Resistivity (m^{2o}C/W)	0.375-0.811	0.566-0.738	0.407-0.922	0.715-0.746	0.629-0.923	0.619-0.745
Thermal Diffusivity (m^2/s)	0.642-1.907	0.571-0.842	0.245-1.169	0.478-0.751	0.835-4.311	0.895-1.154
Specific Heat Capacity (J//kg^{o}C)	884-1645	1396-1579	860-2978	1239-1867	245-930	932-998
Volumetric Heat Capacity (J/m^{3o}C)	1.326-2.465	2.094-2.368	1290-4468	1858-2800	0.364-1.395	1.398-1.497
Moisture Content (%)	6.42-27.07	18.93-19.39	13.55-21.76	16.57-17.74	6.82-36.06	6.82-15.93S
pH	5.0	7.5	5.0	7.5	5.0	7.5
Temperature (^{o}C)	31-34	31-32	32-37	35-36	33-38	33-34

Table 2: Comparison of Thermal, Chemical and Physical Properties of Oil Contaminated Soil in this study with other reports

Parameter	Present Study Range	Other Report Range	Source
Thermal Conductivity (W/m^2 ^{o}C)	1.083-2.715	0.02-4.00	Oladunjoye *et al.,* (2013)
Thermal Resistivity (m^2 ^{o}C/W)	0.378-0.923	NA	
Thermal Diffusivity(m^2/s)	0.254-4.321	NA	
Specific Heat Capacity (J//kg ^{o}C)	245-2978	NA	
Volumetric Heat Capacity (J/m^3 ^{o}C)	0.364-4.468	0.5 – 4	[DPR-Oladunjoye *et al.*, (2013)]
Volumetric Heat Capacity (J/m^3 ^{o}C)	0.364-4.468	0.5 – 4	[DPR- Onwuka *et al.*, (2021)]
Moisture Content (%)	6.42-36.06	13-26	[DPR- Onwuka *et al.*, (2021)]
pH	5.0	5.50-6.50	[DPR- Onwuka *et al.*, (2021)]
Temperature (^{o}C)	31-38	6-55	Decagon Devices Inc. (2011)

Key: NA-Not Available

Heuristic Pollution Index Measurement

Tables 3, 4 and 5 below give the Heuristic Pollution Index of Soil Samples in Eleme, Gokana and Tai Local Area.

Table 3: Heuristic Pollution Index (Thermal Conductivity) of Soil Samples in Eleme, Gokana and Tai Local Government Areas, Rivers State Nigeria

Eeme	Range	Pollution Index	Gokana	Range	Pollution Index	Tai	Range	Pollution Index
Okulu Ebo	1.233-1.405	-2.389**	Goi Waterfront	2.455-1.084	-0.040**	Baratora	1.352-1.264	3.151*
Ogale	2.663-2.236	0.962*	Kegbara Dere	1.137-1.509	0.150*	Bara-Ale	1.586-1.423	1.674*
Nsisoken	2.396-2.236	2.568*	Kpor Community	1.214-1.655	0.126*	Norkpo	1.257-1.211	5.934*
Ajeokpor	2.964-1.474	0.696*	Kegbara Dere 2-Joo	1.626-1.573	-1.056**	Omowawoh Sime	1.083-1.589	-0.539**
Akenta (Control)	1.765-1.354	0.411*	Kegbara Dere 2-Joo (control)	1.341-1.397	-0.056**	Gbiwoh Sime (Control)	1.614-1.541	0.273*

Key: *= Positively related (poorly contaminated)
**= Negatively related (moderately contaminated)

Table 4: Heuristic Pollution Index (Thermal Resistivity) of Soil Samples in Eleme, Gokana and Tai Local Government Areas, Rivers State Nigeria

Eeme	Range	Pollution Index	Gokana	Range	Pollution Index	Tai	Range	Pollution Index
Okulu Ebo	0.811-0.711	-0.172**	Goi Waterfront	0.407-0.922	-0.060**	Baratora	0.739-0.791	2.423*
Ogale	0.375-0.447	2.388*	Kegbara Dere	0.879-0.662	0.142*	Bara-Ale	0.603-0.702	1.750*
Nsisoken	0.417-0.447	5.733*	Kpor Community	0.823-0.604	0.141*	Norkpo	0.795-0.825	4.200*
Ajeokpor	0.484-0.678	0.886*	Kegbara Dere 2-Joo	0.615-0.635	-1.550**	Omowawoh Sime	0.923-0.629	-0.428**
Akenta (Control)	0.566-0.738	-0.172**	Kegbara Dere 2-Joo (Control)	0.746-0.715	0.031*	Gbiwoh Sime (Control)	0.619-0.745	-0.126**

Key: *= Positively related (poorly contaminated)
**= Negatively related (moderately contaminated)

Table 5: Heuristic Pollution Index (Thermal Diffusivity) of Soil Samples in Eleme, Gokana and Tai Local Government Areas, Rivers State Nigeria

Eeme	Range	Pollution Index	Gokana	Range	Pollution Index	Tai	Range	Pollution Index
Okulu Ebo	0.683-0.642	6.609*	Goi Waterfront	1.410-0.601	-0.292**	Baratora	1.751-0.923	0.312*
Ogale	1.907-0.905	0.270*	Kegbara Dere	0.254-1.169	0.259*	Bara-Ale	4/321-1.477	0.091*
Nsisoken	1.778-1.401	0.718*	Kpor Community	0.839-0.920	2.925*	Norkpo	1.494-1.240	1.019*
Ajeokpor	1.357-1.317	6.775*	Kegbara Dere 2-Joo	0.873-0.859	-16.500**	Omowawoh Sime	0.835-1.139	-0.851**
Akenta (Control)	0.842-0.571	0.271*	Kegbara Dere 2-Joo (Control)	0.478-0.715	-0.237**	Gbiwoh Sime (Control)	1.154-0.895	0.259*

Key: *= Positively related (poorly contaminated)
**= Negatively related (moderately contaminated)

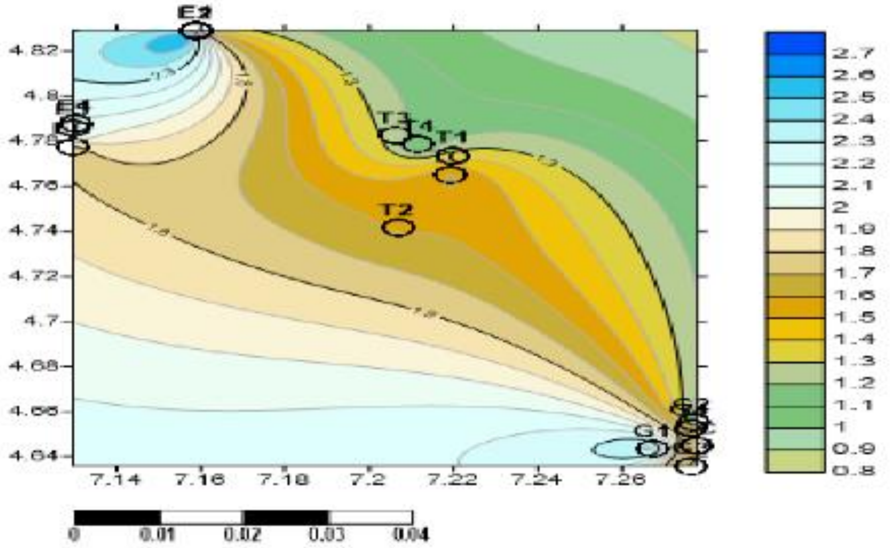

Figure 2a: 2D Map of Thermal Conductivity 0 – 15 cm depth: Eleme, Gokana and Tai

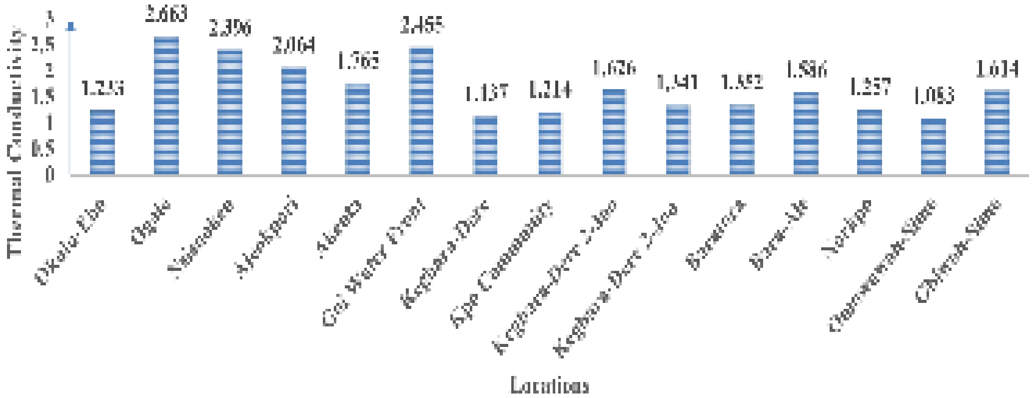

Figure 2b: 2D Bar Chart of Thermal Conductivity 0 – 15 cm depth: Eleme, Gokana and Tai

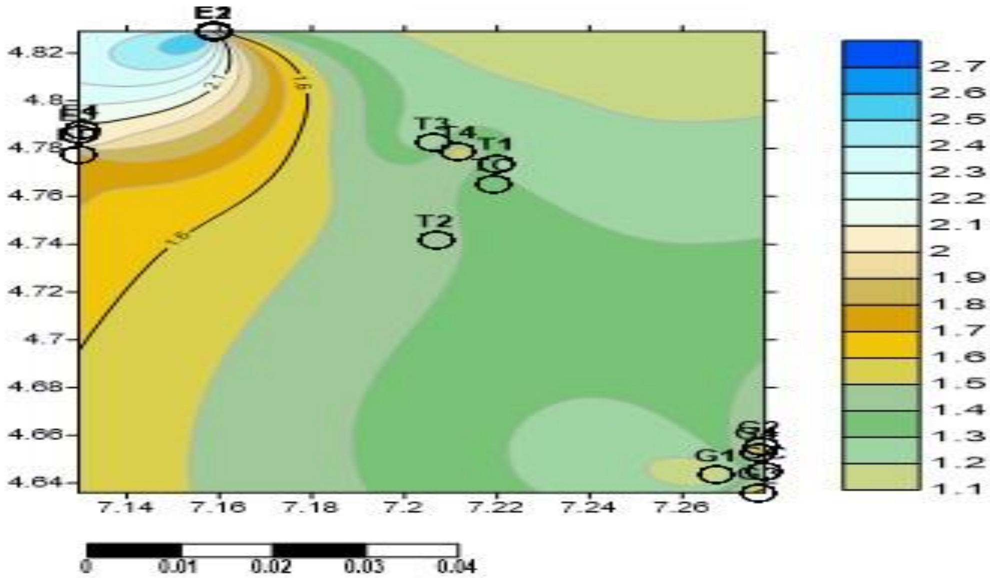

Figure 3a: 2D Map of Thermal Conductivity 15 – 30 cm depth: Eleme, Gokana and Tai

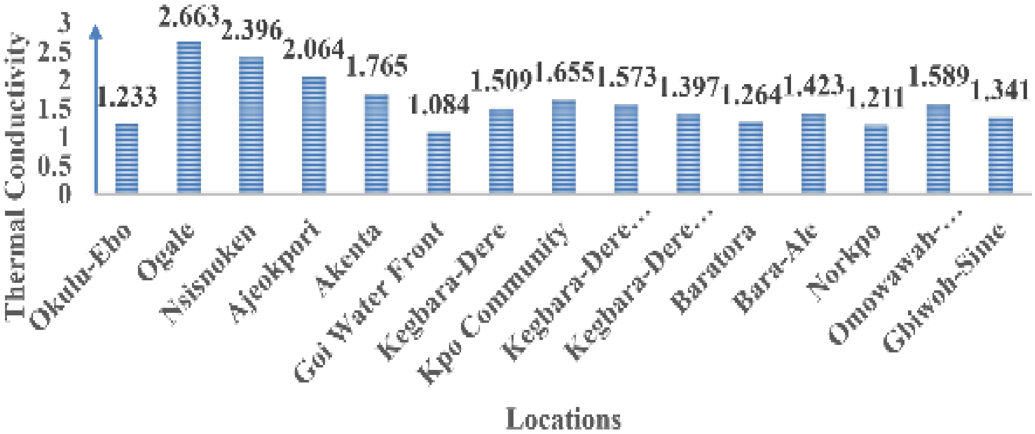

Figure 3b: 2D Bar Chart of Thermal Conductivity 15 – 30 cm depth: Eleme, Gokana and Tai

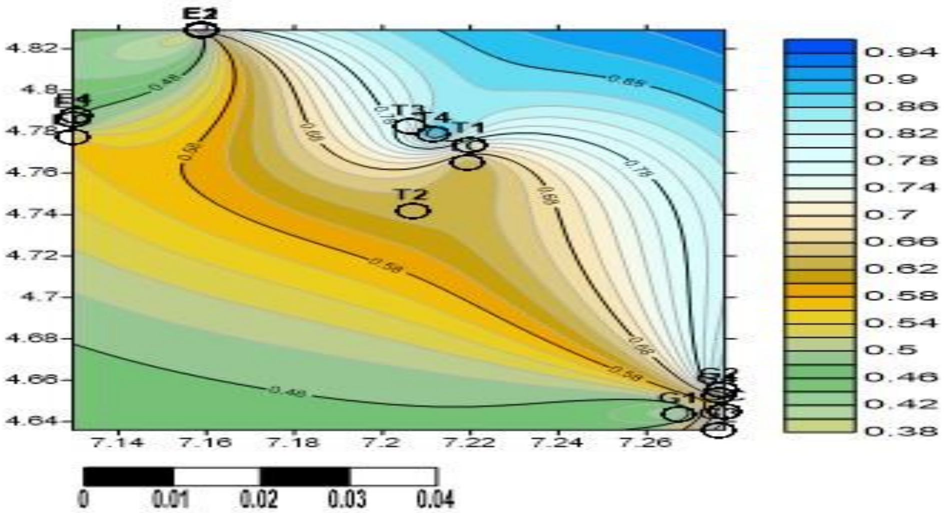

Figure 4a: 2D Map of Thermal Resistivity 0 – 15 cm depth: Eleme, Gokana and Tai

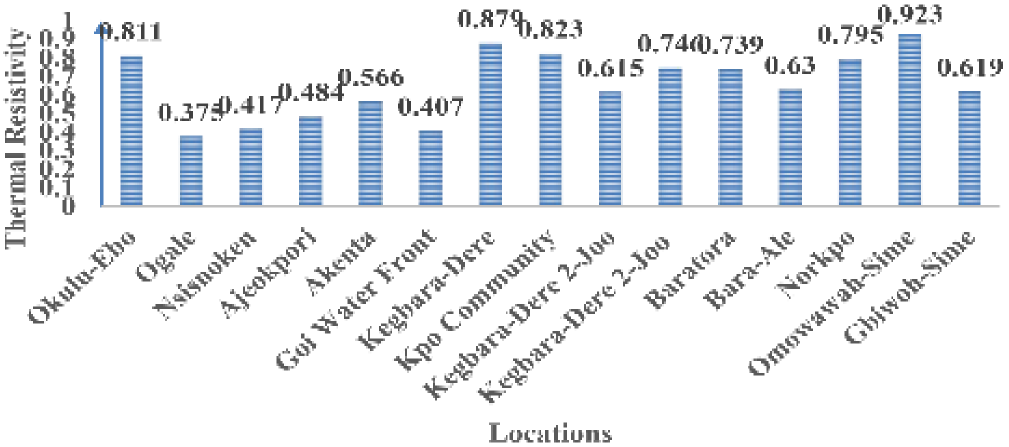

Figure 4b: 2D Bar Chart of Thermal Resistivity 0 – 15 cm depth: Eleme, Gokana and Tai

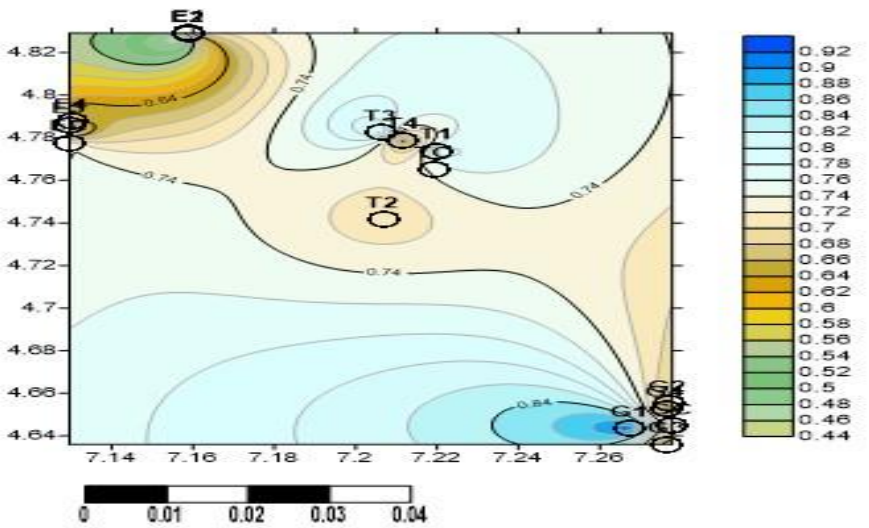

Figure 5a: 2D Map of Thermal Resistivity 15 – 30 cm depth: Eleme, Gokana and Tai

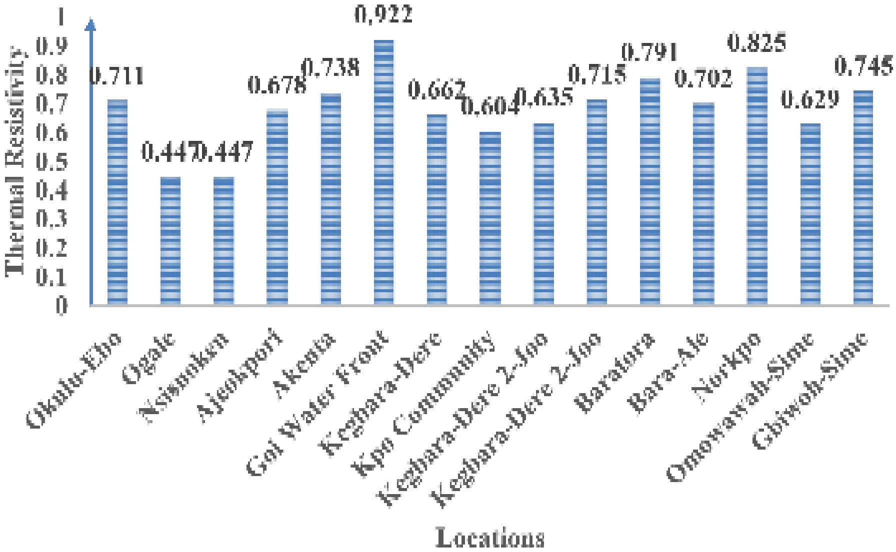

Figure 5b: 2D Map of Thermal Resistivity 15 – 30 cm depth: Eleme, Gokana and Tai

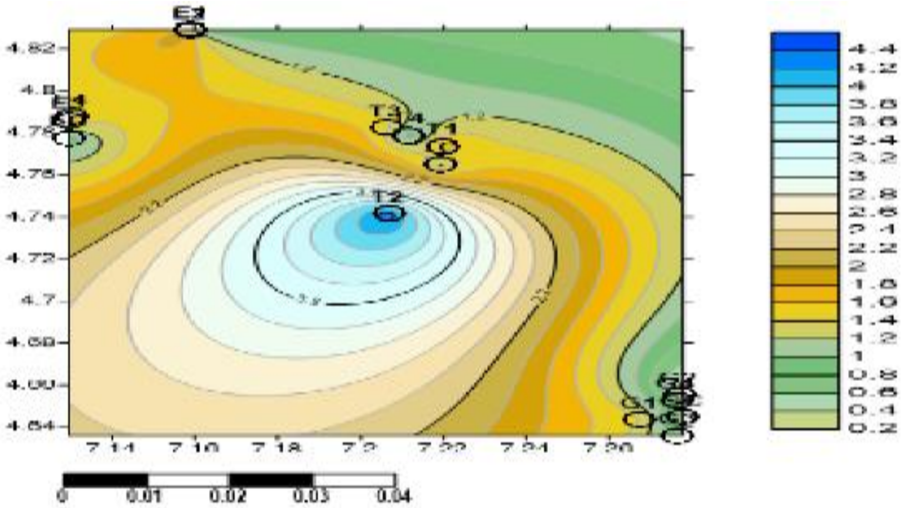

Figure 6a: 2D Map of Thermal Diffusivity 0 – 15 cm depth: Eleme, Gokana and Tai

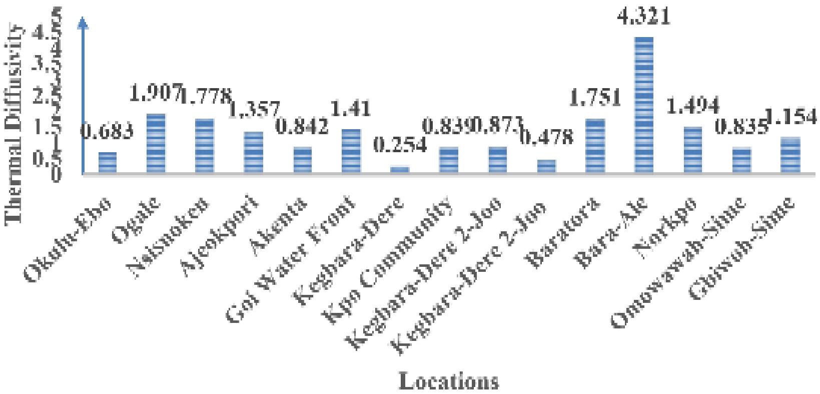

Figure 6b: 2D Bar Chart of Thermal Diffusivity 0 – 15 cm depth: Eleme, Gokana and Tai

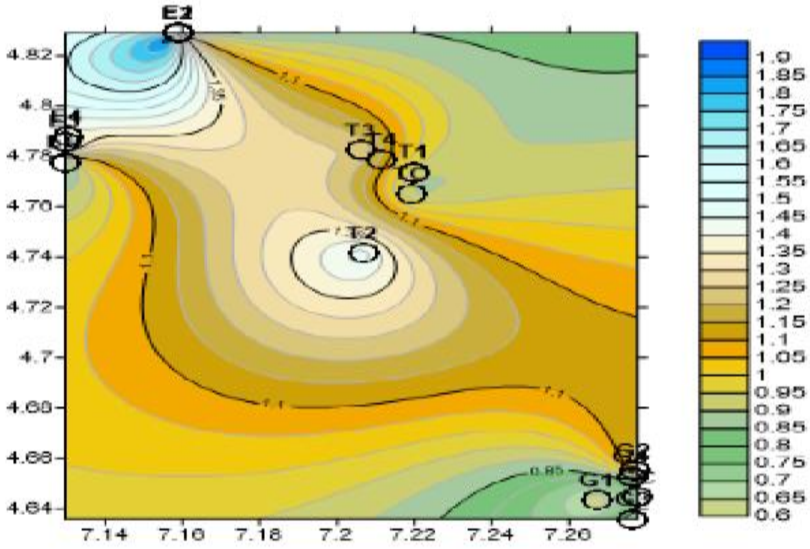

Figure 7a: 2D Map of Thermal Diffusivity 15 – 30 cm depth: Eleme Gokana and Tai

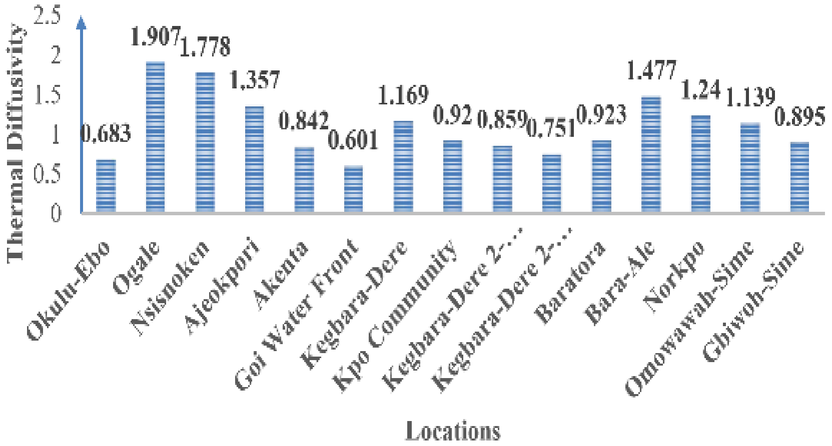

Figure 7b: 2D Bar Chart of Thermal Diffusivity 15 – 30 cm depth: Eleme, Gokana and Tai

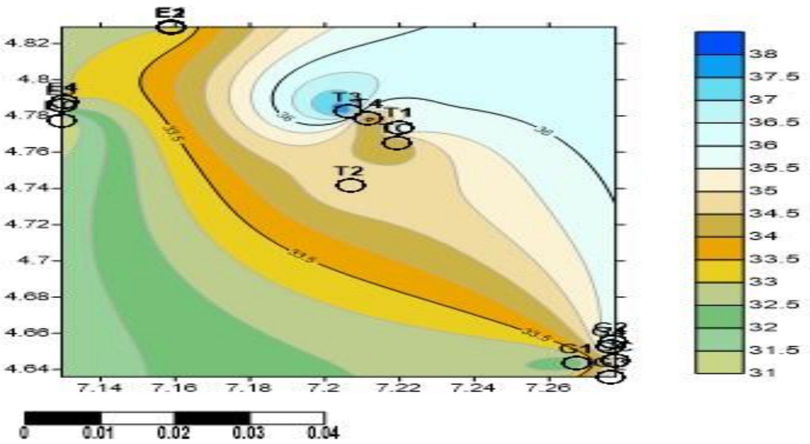

Figure 8a: 2D Map of Temperature 0 – 15 cm depth: Eleme, Gokana and Tai

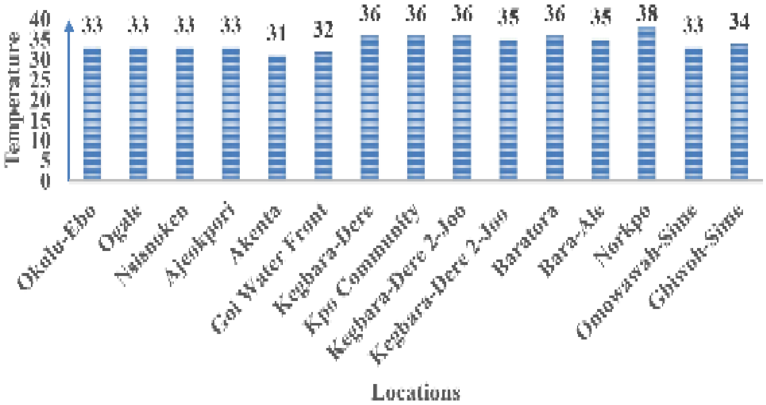

Figure 8b: 2D Bar Chart of Temperature 0 – 15 cm depth: Eleme, Gokana and Tai

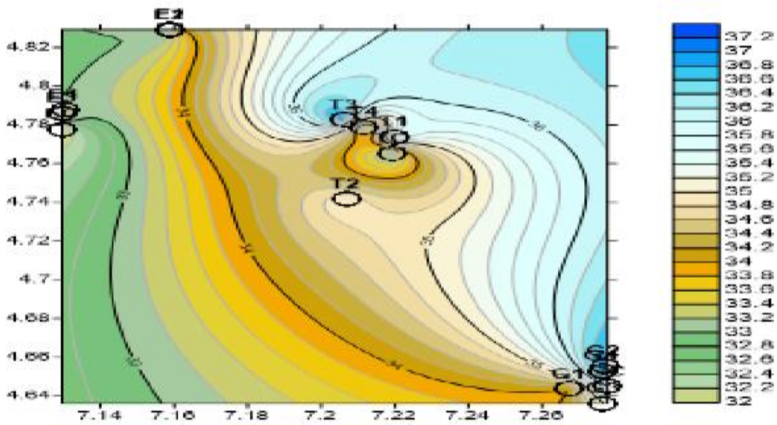

Figure 9a: 2D Map of Temperature 15 – 30 cm depth: Eleme, Gokana and Tai

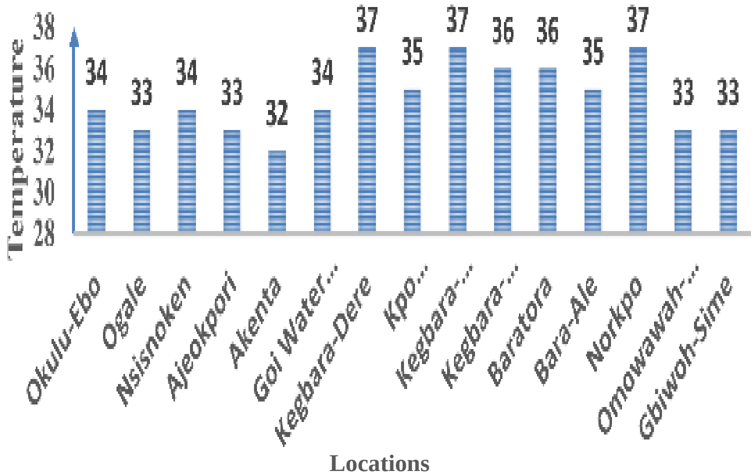

Figure 9b: 2D Bar Chart of Temperature 15 – 30 cm depth: Eleme, Gokana and Tai

Discussions

Table 1 gives the soil physical, thermal and chemical properties of contaminated and uncontaminated soil samples for the three Local Government Areas. Table 2 represents the comparison of thermal, chemical and physical properties of oil contaminated soil obtained in this study with values obtained by other researchers. Accordingly, tables 3, 4 and 5 give the heuristic pollution index of soil samples in Eleme, Gokana and Tai Local Government Areas.

Figures (2a - 2b) show the results of contour lines on the basis of thermal conductivity. It can be seen in figure 2a that the highest thermal conductivity at a depth of (0-15) cm is at Eleme and lowest is at Tai and Gokana. Figure 2b, shows that the highest values of thermal conductivity for the three local governments; Eleme, Gokana and Tai recorded as 2.663 W/m^{0}C, 2.455 W/m^{0}C and 1.586 W/m^{0}C at the locations: Ogale, Goi Water Front and Bara-Ale respectively. While the lowest values of thermal conductivity were 1.233 W/m^{0}C, 1.137 W/m^{0}C and 1.083 W/m^{0}C at the locations: Okulu-Ebo, Kegbara-Dere and Omowawah-Sime respectively. Similarly, in figure 3b, the highest thermal conductivity at a depth of (15-30) cm recorded same values in Eleme; while for Gokana and Tai local Governments were recorded as 1.655 W/m^{0}C and 1.589 W/m^{0}C at locations: Kpo Community and Omowawah-Sime respectively. In the same vein, the lowest values were recorded as 1.084 W/m^{0}C and 1.211 W/m^{0}C at locations: Goi Water Front and Norkpo respectively. However, these variations from one location to another may be as a result of variations in soil moisture content and soil bulk density which agrees with the finding of Oladunjoye *et al.* (2013). This therefore means that the distribution of thermal conductivity in all locations was determined mainly by soil moisture content and partly by soil bulk density. High thermal conductivity ensures movement of heat into the ground. Interestingly, soils with lower thermal conductivity retain more heat than those with higher thermal conductivity once the sun goes down as noted by Oladunjoye *et al.* (2013). Therefore, a balance neither too high nor too low (optimum) is necessary to ensure proper conditions for seed germination, root development and emergence as reported by (Tan 2013).From the thermal conductivity values of all the study areas in the three Local Government Areas (Eleme, Gokana and Tai) in Ogoniland Rivers State-Nigeria, it could be observed that the values are moderate which range from 1.083 – 2.663 W/mC, ensuring proper conditions for seed germination, root development and emergence as noted by (Tan 2013). (Standard Range of measurement is 0.02 – 4 W/mK) (Oladunjoye *et al.* 2013)

Figure 4a gives the contour lines on the basis of thermal resistivity at (0-15) cm. Figure 4b shows that the highest values of thermal resistivity for the three local governments; Eleme, Gokana and Tai recorded as 0.811 $(W/m^0C)^{-1}$, 0.879 $(W/m^0C)^{-1}$ and 0.923 $(W/m^0C)^{-1}$ at the locations: Okulu-Ebu, Kegbara-Dere and Omowawah-Sime respectively. While the lowest values of thermal resistivity were 0.375 $(W/m^0C)^{-1}$, 0.407 $(W/m^0C)^{-1}$ and 0.619 $(W/m^0C)^{-1}$ at the locations: Ogale, Goi Water Front and Gbiwoh-Sime respectively. Similarly, in figure 5b, the highest thermal resistivity for the three local governments; Eleme, Gokana and Tai at a depth of (15-30) cm recorded the values of 0.738 $(W/m^0C)^{-1}$, 0.922 $(W/m^0C)^{-1}$ and 0.825 $(W/m^0C)^{-1}$ at locations: Akenta, Goi Water Front and Norkpo respectively. In the same vein, the .lowest values were recorded as 0.447 $(W/m0C)^{-1}$, 0.604 $(W/m0C)^{-1}$ and 0.629 $(W/m0C)^{-1}$ at locations: Ogale and Nsisoken, Kpor Community and Omowawah-Sime respectively. The soil which contains pure soil samples and the polluted ones with crude oil, it can be seen that all the thermal properties are affected by crude oil spilled on them. The specific heat capacity and the density of the soil samples are generally decreased, while the thermal resistivity is noticeably increased in the observed soil sample which is in agreement with the findings of Oladunjoye *et al.* (2012). Also some factors have been found to influence the thermal properties of soils.

As porosity and temperature increase, thermal resistivity also increases. Large-sized grains were found to have higher thermal resistivity while the small sized grains have lower thermal resistivity as reported by Oladunjoye *et al.* (2012)

Figure 6a gives the contour lines on the basis of thermal diffusivity at (0-15) cm. Figure 6b shows that the highest values of thermal diffusivity for the three local governments; Eleme, Gokana and Tai recorded as 1.907 J/m^2s, 1.41 J/m^2s and 4.321 J/m^2s at the locations: Ogale, Goi Water Front and Bara-Ale respectively. While the lowest values of thermal diffusivity were 0.683 J/m^2s, 0.254 J/m^2s and 0.835 J/m^2s at the locations: Okulu-Ebu, Kegbara-Dere and Omowawah-Sime respectively. Similarly, in figure 7b, the highest thermal diffusivity for the three local governments: Eleme, Gokana and Tai at a depth of (15-30) cm recorded the values of 1.907 J/m^2s, 1.169 J/m^2s and 1.477 J/m^2s at locations: Ogale, Kegbara-Dere and Bara-Ale respectively. Whereas, the lowest values were recorded as 0.683 J/m^2s, 0.601 J/m^2s and 0.895 J/m^2s at locations: Okulu-Ebu, Goi Water Front and Gbiwoh-Sime respectively. This variations (range), in thermal diffusivity from one location to the other whose values are observed to be moderate to high since range of measurement of SH-1 for thermal diffusivity is 0.1 to 1 mm^2/s. This variations (range), in thermal diffusivity from one location to the other may be as a result of high coefficient of permeability which could make less heat to be dispersed at moderate to high that point compared to other points which is in tendon with Oladunjoye & Sanuade (2012b). Substances with high thermal diffusivity rapidly adjust their temperature to that of their surroundings because they conduct heat quickly in comparison to their

Volumetric heat capacity or volumetric heat capacity or 'thermal bulk' and they generally do not require much energy from their surroundings to reach thermal equilibrium as noted by (Abu-Hamdeh 2003).

Figure 8a gives the contour lines on the basis of temperature at (0-15) cm. Figure 8b shows that the highest values of temperature for the three local governments; Eleme, Gokana and Tai recorded as 33 ^{0}C, 36 ^{0}C and 38 ^{0}C at the locations: Okulu-Ebu, Ogale, Nsisoken and Ajeokpor for Eleme, Kegbara-Dere, Kpor- Community, and Kegbara-Dere 2-Joo for Gokana, and Norkpo for Tai. While the lowest values of temperature were 31 ^{0}C, 32 ^{0}C and 33 ^{0}C at the locations: Akenta, Goi Water Front and Omowawah-Sime respectively. Similarly, in figure 9b, the highest temperature for the three local governments: Eleme, Gokana and Tai at a depth of (15-30) cm recorded the values of 34 ^{0}C, 37 ^{0}C and 37 ^{0}C at locations: Okulu-Ebu, and Nsisoken for Eleme; Kegbara-Dere and Kegbara-Dere 2-Joo for Gokana: Norkpo for Tai respectively. Whereas the lowest values were recorded as 32 ^{0}C, 34^{0}C and 33 ^{0}C at locations: Akenta, Goi Water Front and Omowawah-Sime and Gbiwoh-Sime respectively. It can be seen from result above that the temperature ranges from 31-38 ^{0}C for the whole locations which means that these values do not reach the maximum. At these temperatures, most if not all plants can live and grow well, if other conditions for plant growth are met which agrees with (Chima *et al.* 2011, Oladunjoye *et al.* 2013, Onwuka & Brown 2018). Increase in soil temperature improves root growth because of the increase in metabolic activity of root cells and the development of lateral roots as reported by (Repo *at el.* 2004). Low soil temperature results in reduced tissue nutrient concentrations and as such decreases root growth as noted by (Lahti *at el.,* 2002) Standard Range of Measurement for Temperature is 6-55^{0}C Decagon Devices Incorporated. (2011)

CONCLUSION

In conclusion, the aim and the objectives of this research work have been achieved, after considering the findings and the results obtained. Thus, the thermal conductivity, thermal diffusivity and thermal resistivity of the soil samples have been measured and analyzed. The effect of depth (test points) on the soil thermal conductivity, thermal diffusivity and thermal resistivity were also observed. They can be used in engineering, agriculture, geotechnical and environmentally related issues if other conditions for plant growth are met. The soil samples have the same or similar engineering and agricultural behaviour. The growth and development of a crop may be determined to a large extent by soil thermal capacity. The practical significance of knowing the soil thermal capacity is very important as it is one of the most important factors controlling rates of soil warming and cooling.

It has been observed that the thermal conductivity, thermal diffusivity and thermal resistivity of soil in the study areas and their variation with test points agree with the results reported in the literature. Hence, it can be concluded that the soils in

Eleme, Gokana and Tai Local Government Areas may be recommended, but, with caution, for agricultural activity, laying of gas pipeline, or buried cable in the areas, since the values of these properties observed were within the range of standard values.

REFERENCES

Abu-Hamdeh, N. H. & Reeder R. C (2000). Soil thermal conductivity: effects of density, moisture, salt concentration, and organic matter. Soil Science Society of America Journal, 64, 1285–1290

Adjepong, S. K., (1997). Investigation of the variation of the specific heat capacity of three texture types of soil with moisture content, Journal of Applied Science and Technology, 2: 7-12

Agbonifo, J. (2009). Development as conflict: Ogoni movement, the state and oil resources in the Niger Delta, Nigeria. Published Doctoral Dissertation, Institute of Social Studies

Alex Tan, (2013). The effects of thermal conductivity of soil. www.ehow.com/list-5931951-effectsthermal-conductivity-soil.html

Balouga, J. (2016). The Niger Delta: Defusing the Time Bomb. International Association for Energy Economics, 2009. Available online: https://www.iaee.org/documents/newsletterarticles/109balouga.pdf (accessed on 27 December 2016).

Buswell J. A. (1994). Potential of spent mushroom substrate for biore mediation purposes. Compost Sci. Util. 2:31-36.

Chima, G. N., Ijeoma, M. A., Nwagbara, M. O. & Nwaugo, V. O. (2011). Sensitivity of vegetation to decadal variations in temperature and rainfall over Northern Nigeria. *Journal of Soil Science and Environmental Management Volume. 2(8):* pp228-236.

Decagon Devices Incoporated (2011) Pullman, WA. AccuPAR PAR/LAI Ceptometer Operator's Manual.

Engelking, P. (2000). Pollution, Microsoft Encarta Online Encyclopedia.

Environmental Rights Action/Friends of the Earth Nigeria; Center for the Environment, Human Rights and Development; Friends of the Earth Europe. Amnesty International No Progress (2017): An Evaluation of the Implementation of UNEP's Environmental Assessment of Ogoniland, Three Years On. 2015. Available online: https://www.amnesty.org.uk/files/unep_briefing_2014_niger_delta.pdf (accessed on 25 February 2017).

Gaskin S. E, & Bentham. R. H (2010). Rhizoremediation of hydrocarbon contaminated soil using Australian native grasses. Sci. Total Environ.408:3683-3688.

George, N. J, V. I. Obioanwu, G. T., Akpabio & I. B Obot (2010) Archives of Applied Science Research 2(3), 253 – 259, 2010.

George, N. J.; Akpabio, G. T. & Udofia, K.M. (2010) The implication of oil spillage on the thermal properties of soil samples in the Niger delta, southern Nigeria. Archives of Physics. Research, 2010, 1 (4): 64-72 http://scholarsresearchlibrary.com/archive.html

Ghauman, B. S. & Lal R. (1985). Thermal conductivity, thermal diffusivity, and thermal capacity of some Nigerian soils. Soil Sci. 139:74–80.

IEEE, (1998). Guide for soil thermal resistivity measurements. Inst. of Electrical and Electronics Engineers, Inc. New York

Ilouno, J., Okpara, N. & Fom, T. P. (2018), Determination of Thermal Conductivity of Abraka Soil: A Case Study. International Journal of Innovative Environmental Studies Research 6(2):24-31.

Kang. J.W (2014). Removing environmental organic pollutants with bioremediation and phytoremediation. Biotechnol. Lett. 36:1129- 1139.

Lahti, M., Aphalo, P. J. & Finer, L. (2002) Soil temperature, gas exchange and nitrogen status of 5 year old Norway spruce seedlings. *Tree physiol*.; volume 22(18):pp1311–1316.

Rubio, M. C. Cobos, D. R. Josa R. & Ferrer F. (2009). A new analytical laboratory procedure for determining the thermal properties in porous media, based on the American standard D5334-05, pp18-20.

Marinescu, M., Toti, M., Tanase, V., Plopeanu, G., Calciu, I., & Marinescu, M., (2001). The effects of crude oil pollution on physical and chemical characteristics of soil. Resaerch Journal of Agricultural Science, 43(3), 125-129.

Masakorala K, Yao J, Chandankere R, Liu H. Liu W, Cai M & Choi MF (2014). A combined approach of physicochemical and biological Methods for the characterization of petroleum hydrocarbon- contaminated soil. Environ. Sci. Pollut. Res. 21:454-463.

Michael Adeyinka Oladunjoye & Oluseun Adetola Sanuade (2012).Research Article: In Situ Determination of Thermal Resistivity of Soil: Case Study of Olorunsogo Power Plant, Southwestern Nigeria International Scholarly Research Network ISRN Civil Engineering Volume 2012, Article ID 591450, 14 pages doi:10.5402/2012/591450

Nichols. E. G, Cook. R. L, Landmeyer. J.E, Atkinson ,B,Malone, D.R, Shaw ,G, & Woods, L (2014). Phytoremediation of a petroleum-hydrocarbon contaminated shallow aquifer in Elizabeth City, North Carolina, USA. Remediat. J. 24(2):29-46.

Nidal H & Abu-Hamdeh (2003): Thermal Properties of Soils as affected by Density and Water Content, Biosystems Engineering (2003) 86 (1), 97–102 doi:10.1016/S15375110(03)00112-0) SW+Soil and Water Available online at www.sciencedirect.com.

Nwilo, P. C., & Badejo, O.T., (2005). Impacts and Management of Oil spill Pollution along the Nigerian coastal area.flawww.fig.net/pub/fig pub/pub36/chapters/chapter-8pdf.

Odu, C. T. L., (1997). Microbiology of soils contaminated with petroleum hydrocarbons Natural rehabilitation and reclamation of soil affected. Inst. Petroleum@ Technol., Publ.1, 77-105.

Okpowasili, G. C, & Odokuma, L.O., (1990). Effect of Salinity on Biodegradation of oil spills dispersants. Waste Manage.10 (12)141-146.

Oladunjoye, M.A., Sanuade, O.A. & Olaojo, A.A. (2013) Variability of Soil Thermal Properties of a Seasonally Cultivated Agricultural Teaching and Research Farm, University of Ibadan, South- Western Nigeria Article May 2013

Onwuka, B. & Mang, B. (2018) Effects of Soil Temperature on Some Soil Properties and Plant Growth. Advances in Plants & Agriculture Research, *Journal of Agricultural Sciences, volume 8,* pp 34-37.

Pepper, L. L., Gerbal, C.P., and Brusseau, M.L., (1996). Pollution Science, Academic Press.

Repo, T.I. Leinonen, A.R & Finer L. (2004). The effect of soil temperature on bid phenology, chlorophyll fluorescence, carbohydrate content and cold bardiness of Norway spruce seedlings. *Physio Plant*.;volume 121:pp93–100.

Salomone L. A., Kovacs W. D. and Kusuda T.(1984).Thermal performance of fine-grained soils. J Geotech Eng ASCE 110.3:359–74.

Salomone, L. A. & Kovacs W. D. (1984). Thermal resistivity of soils. J Geotech Eng ASCE 3 (1984) 375–89.

Salomone, L.A. & Marlow, J. I. (1989). Soil rock classification according to thermal conductivity. EPRI CU-6482. Palo Alto, CA: Electric Power Research Institute.

Singh, D.N. & Devid, K. (2000). Generalized relationships for estimating soil thermal resistivity. Experimental Thermal and Fluid Sci. 22: 133-143.

Tanee, F. & Albert E. (2011). Post remediation assessment of crude oil pollution site at KegbareDere community, Gokana LGA, Rivers State, Nigeria. Journal of Bioremediation and Biodegradation, 2:3.

Tang .J, Wang .R, Niu X, Wang .M and Zhou .Q (2010a). Characterization on the rhizoremediation of petroleum contaminated soil as affected by different influencing factors. Biogeosci. 7:4665-4688.

Udo, E. J. & Fayemi, A. A. (1975). Effect of oil pollution of soil in germination, growth and nutrient update of corn. Journal of Environmental quality, 4(4):537-540.

UNEP (2011). Environmental Assessment of Ogoniland. Nairobi, Kenya: United Nations Environment Programme.

United Nations Environment Program UNEP (2016). Environmental Assessment of Ogoniland. Available online: http://postconflict.unep.ch/publications/OEA/UNEP_OEA.pdf (accessed on 29 December 2016).

Uquetan U. I. Osang J. E. EgorA. O. Essoka P. A. Alozie S. I. Bawan A. M. (2017): A case study of the effects of oil pollution on soil properties and growth of tree crops in cross river state, Nigeria International Research Journal of Pure and Applied Physics Vol.5, No.2, pp.19-28 www.eajournals.org

Weast R C (1983). Handbook of Chemistry and Physics. CRC Press, Boca Raton, FA

Nidal H. Abu-Hamdeh & Randall C. Reeder (2000): Soil Thermal Conductivity: Effects of Density, Moisture, Salt Concentration, and Organic Matter Published in Soil Sci. Soc. Am. J. 64:1285–1290. Corresponding author (nidal@just.edu.jo).

Zahed M. A, Aziz H. A, Isa M. H, & Mohajeri .L (2010). Enhancement biodegradation of nalkanes from crude oil contaminated seawater Int. J. Environ. Res. 4(4):1735-6865.