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Thermal conductivity of soils with heavy metals concentration from the Niger Delta region of Nigeria

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Abstract: This paper presents the characteristic thermal and chemical properties of some surface soil samples from the oil-producing regions of Nigeria. A microprocessor-based thermal analyzer was used to determine the thermal conductivity while spectrophotometric procedure was employed to conduct the heavy metal concentration analysis. Thermal conductivity values were compared with heavy metal concentrations in each soil sample. The values of lead and cadmium and their respective measured thermal conductivities were highly correlated, with their correlation coefficients both greater than 0.900, while other metals showed no correlation.

Key words: Soil, Thermal conductivity, Heavy metals, Nigeria
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INTRODUCTION

Knowledge of soil thermal properties is an important factor in understanding mass and energy exchange processes in the soil-atmosphere system. The chemical composition of the soils will therefore indirectly relate to their thermal conductivities. According to Usowicz (1993), this knowledge can also help in controlling the thermal-moisture regime of soils. Soil properties often correlated with metal adsorption include soil pH (Christensen, 1984; Harter, 1983), soil CEC (cation exchange capacity) (Harter, 1979; Soldatini *et al*., 1976), soil organic matter (Gerriste and van Driel, 1984; Zimdahl and Skogerboe, 1977), and clay content (Korte *et al*., 1976). The functional relationship between thermal conductivity and the heavy metal contents has however received very little attention. This study was aimed at investigating the relationship between soil thermal conductivity and some chemical composition of the soils from the oil-producing states of Nigeria.

MATERIALS AND METHODS

The scope of this research work covers some areas of the oil-producing region in Nigeria (Fig.1) i.e. the Niger Delta region which according to Aaron (2005), contains 20 billion of Africa's proven 66 billion barrels of oil reserves and more than 3 trillion cubic meters of gas reserves. Oil and gas resources of the Niger Delta account for over 85% of the national gross domestic product (GDP), over 95% of the national budget, and over 80% of the national wealth. In order to ensure good coverage of this region, seven cities from the region were selected using codes 1~7 to represent their collection points, as explained in Table 1.

Five 1-m apart samples and with similar soil classifications, were collected from each site. They were later oven-dried, sieved in a 1-mm mesh, and then packed to a uniform bulk density of 1.5 mg/m^3 in a plastic container placed in the laboratory to get the same bulk densities and water contents, which are the

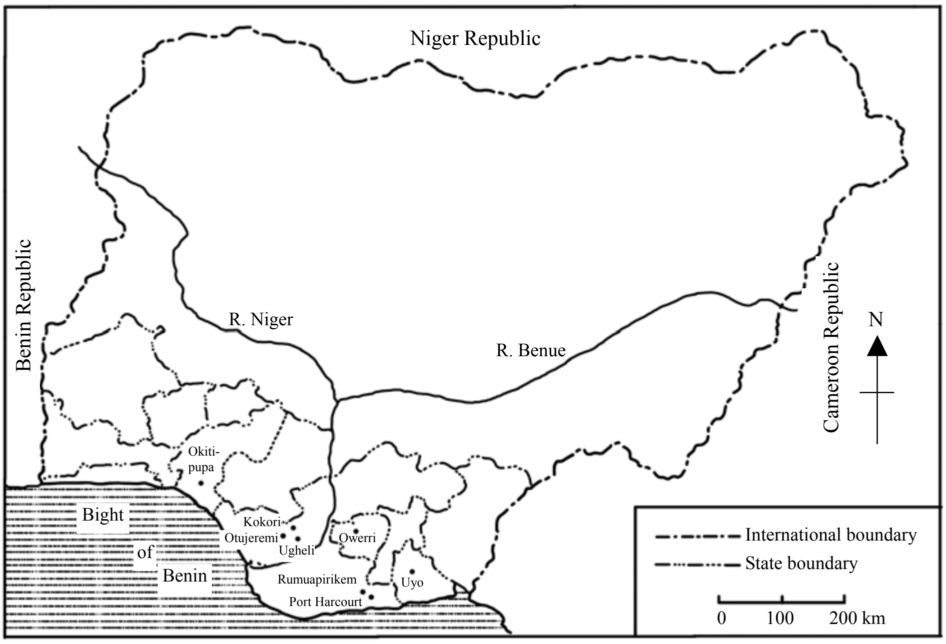

Fig.1 Map of Niger Delta region of Nigeria

Table 1 Code names for the collection points

Code	Collection points	States
1. Imo	Imo River Bank	Rivers
2. Uyo	Uyo University	Akwa Ibom
3. Choba	Uniport	Rivers
4. Calabar	Calabar	Cross River
5. Igbokoda	Igbokoda	Ondo
6. Jeremi	Jeremi	Delta
7. Kokori	Kokori	Delta

basic parameters affecting thermal properties (Bristow *et al.*, 1993; 1994; Akinyemi *et al.*, 2004; Sauer *et al.*, 2003; Lu *et al.*, 2005).

A KD2 thermal analyzer manufactured by Decagon Devices, Inc. (Pullman WA, USA) was used for the thermal conductivity measurements. It is a compact portable meter consisting of a hand held read-out unit and a 60 mm single needle sensor with diameter of 0.9 mm that can be inserted into the medium being investigated. A 72-cm long cable joins the read-out unit with the needle sensor. The theory is based on the assumption that the heat source placed in an isotropic and homogenous medium is infinitely long under a uniform initial temperature. The governing equation according to Carslaw and Jaeger (1959) is:

$$\frac{\partial T}{\partial t}=\alpha\left\{\frac{\partial^2 T}{\partial r^2}+r^{-1}\frac{\partial T}{\partial r}\right\},$$

where r is the radial distance (m), T is the temperature (°C), α is the thermal diffusivity (m^2/s), and t is the time (s).

A reading is initiated by pressing the left button on the readout. The controller waits for 90 s to ensure temperature stability, and then heats the probe for 30 s. At the end of the reading, the controller computes the thermal properties based on the measurement of temperature rise in the needle during the heating period of the probe. The temperature change was used to calculate thermal conductivity using the expression $k \cong q/(4\pi m)$, where $k=\alpha\rho c_p$ is the thermal conductivity (W/(m·K)), ρ is the material dry-basis bulk density, c_p is the specific heat at constant pressure (J/(kg·K)), q is the heat produced per unit time per unit length (W/m) and m is the slope of the linear relationship between ΔT and $\ln t$.

Analysis of the digested samples was performed with Alpha 4 Atomic Absorption Spectrophotometer. One gram of each of the samples considered was weighed into a Teflon beaker while 10 ml of concentrated nitric acid (HNO_3) was added and heated on a hot plate. About 70% of the mixture was allowed to dry off and 10 ml of hydrofluoric acid (HF) was added to the mixture, followed by evaporation to about 20% total volume. After 5 ml of perchloric acid ($HClO_4$) was added, the whole mixture was allowed to dry by evaporation. One millilitre nitric acid was added to dissolve the residue and about 10 ml distilled water was added, and allowed to boil and later transferred with a 25 ml standard flask filled to the mark with distilled water.

DISCUSSION OF RESULTS AND CONCLUSION

The soils from Imo, Uyo, Choba, Calabar, Igbokoda, Jeremi and Kokori were labelled as codes 1~7 for easy identification (Table 1). The generally low standard deviations in the heavy metal concentrations and the thermal conductivity values showed that the five soils collected from each location had similar chemical and thermal properties which we were interested in. They all had very high concentrations of Fe and As and relatively very low concentrations of Cu, Ni and Cr.

The mean concentrations of the heavy metal contents in soils codes 1~7 and the mean values of the measured thermal conductivity are also included in Table 2 with their variations. Thermal conductivity (*k*) was found to be very high in the soils with low concentration of Cu, Ni, Cr and Zn but found to be very low in the soils with low concentration of Cd and Pb. Also there was high correlation between the mean concentration values of Cd and Pb and their respective thermal conductivities. Fig.2 shows their functional relations, where the correlation coefficients were calculated as 0.9491 and 0.9076 for Pb and Cd respectively.

Further attempts were made to study their relationships more closely by linearly regressing Fig.2 with values of R^2 determined as 0.7094 and 0.8232 for Pb and Cd respectively. The presence of these metals may therefore increase the effective thermal conductivity of soils to a considerable level. This complements the paper of Basta *et al.*(1993) and Almas *et al.*(2000) on the adsorption of Pb and Cd by soil organic matter through complexation reaction with organic matter, and Abu-Hamdeh and Reeder (2000) whose useful attempts to study the relationship between percentage increment of organic matter in clay loam soil and thermal conductivity yielded an inverse relation.

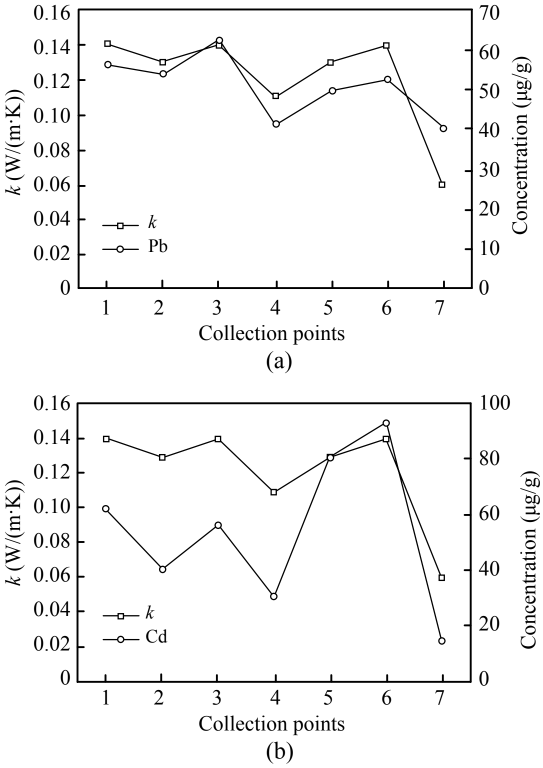

Fig.2 Functional relationships between thermal conductivity and concentrations of Pb (a) and Cd (b)

Table 2 Heavy metal concentrations and thermal conductivity (means±*SD*)

Code	Fe (μg/g)	Cu (μg/g)	Ni (μg/g)	Cr (μg/g)	Cd (μg/g)	Zn (μg/g)	Mn (μg/g)	Pb (μg/g)	As (μg/g)	*k* (W/(m·K))
1	11023.00±0.27	14.25±0.01	30.25±0.01	19.75±0.01	62.15±0.10	21.25±0.03	156.50±0.08	56.75±0.01	555.00±0.10	0.14±0.00
2	11683.75±0.91	9.50±0.00	24.00±0.02	21.75±0.02	41.03±0.02	22.00±0.02	30.75±0.01	54.25±0.03	340.00±0.30	0.13±0.01
3	20057.00±0.96	9.50±0.01	28.75±0.02	25.00±0.02	56.75±0.02	30.75±0.02	57.75±0.00	62.50±0.01	467.50±0.60	0.14±0.00
4	17917.50±2.51	7.25±0.01	33.00±0.04	20.25±0.01	30.63±0.41	38.00±0.02	91.50±0.06	41.50±0.08	622.50±0.20	0.11±0.00
5	711.50±0.55	3.00±0.01	18.00±0.04	7.00±0.02	80.68±0.07	6.00±0.01	28.25±0.05	49.75±0.01	462.50±0.90	0.13±0.01
6	52221.00±0.48	6.50±0.01	21.00±0.00	16.50±0.04	92.98±0.00	17.50±0.01	35.75±0.01	52.50±0.01	350.00±0.50	0.14±0.00
7	5855.25±1.65	5.50±0.02	21.50±0.01	14.00±0.01	15.13±0.03	7.00±0.00	23.00±0.03	40.45±0.00	572.50±0.30	0.06±0.00

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