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Comparative Study of Thermal Conductivity and Density of Three Landforms in Akwa Ibom State

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ABSTRACT

The thermal conductivity (K) and density (ρ) of some selected soil samples collected from three different landforms, namely Beach Ridge Sand (BRS), Coastal Plane Sand (CPS) and Shale/Sandstone Hill Ridges (SHR) from Akwa Ibom State of the Federal Republic of Nigeria were measured, the result obtained indicate that the density (ρ) of the study area falls within the range of 1964.35kgm^{-3} and 2485.26kgm^{-3} while the thermal conductivity, between 0.272w/mk and 0.501w/mk. Comparison with the theory and other researches shows that the density (ρ) of soil sample varies; which will also have effect on crops or construction works.

Key Words: Thermal Conductivity, Density and Soil Samples.

INTRODUCTION

The study of soil properties is very important and useful to determine the thermal conductivity and density of a particular land before cultivation or construction work is done. This is because soil thermal properties are required in many areas of engineering agronomy and soil science. It enables the engineer to determine the proper soil for road construction, water drilling, it also help farmer to determine the best soil suitable for planting of some special crops.

The conductivities and densities of the ground (soil) vary with types of soil. Sandy soil is not as good as conductor as a black soil. The higher the moisture of the soil, the poorer the conductor the soil is.

Thermal conductivity is a property of a material that expresses the heat flux (f) that will flow through the material if a certain temperature gradient ΔT exists over the materials. It is usually expressed on w/mk; given as f = K. ΔK => K = $\frac{f}{\Delta T}$ (w/mk).

Density is the mass per unit volume. We know from experience that equal volumes of different materials have different masses, therefore different weights. The convenient method of describing a substance is to give its density. The density (ρ), of a substance is given as m/v (kg/m^{-3}).

Similar studies of soil properties in recent times include: comparison of the thermal properties of soil samples for a passively cooled building design, (Ekpe and Akpabio, 1994) and thermal properties of soil samples in Uyo Local Government Area of Akwa Ibom State, (Ekpe et al, 1996). This study is therefore directed towards measuring the thermal conductivity and density of soil samples in Akwa Ibom State, Nigeria.

THEORY

Soil temperatures are determined by a number of factors, some of which include the location characteristics and thermal physical properties of the soil samples. The amount of radiant energy absorbed or reflected depends on the material colouration. The proportion of energy absorbed causes changes in temperature of the soil samples. This energy absorbed by the surface may be used in: (a) heating the air out side the soil; (b) increasing surface temperature; (c) heating the interior layers of the soil or (d) radiating to the atmosphere.

Let, heat flow through the material = heat absorbed from atmosphere + absorbed solar radiation - Re-emitted radiant energy- 1.1

Equation 1.1 is called the heat budget equation.

Also, in one dimension, the above energy balance equation can be rewritten as:

$$-K\left(\partial T/_{\partial x}\right)_{x=0} = h\,(T_{atm} - T_{(x=0)}) + \propto I - \in \Delta R \text{ – – – – –} \qquad 1.2$$

Where K = thermal conductivity of the soil sample; T = soil temperature, h = heat transfer coefficient at the surface; T_{atm} = atmospheric air temperature; ∝ = solar radiation absorptivity, I = intensity of solar radiation, E = long – wave emmisvity of the surface, and ΔR = difference between the incident long wave radiation and the radiation emitted from the surfa*ce*

Solar temperature is given be;

$$T_s = T_{atm} \times (\propto \tfrac{1}{h}) - (\in \Delta\, R/_{h}) \qquad 1.3$$

With this, Moustafa, S; et al (1981); assumed a general solution of the form;

$$T_{(x,t)} = \omega + \sum_{m=1}^{..}\{am \exp\,[m\omega t + \alpha\, m^{x}]\} \qquad 1.4$$

Where $\propto m = (^{MWPC}/_{2K})^{1/2}\,(1-i)$

C = specific heat capacity of the soil sample, ρ = density of the sample, and ω =

$\frac{2\pi}{\text{period}}$ T.

Equation (1.4) shows the dependence of material temperature with thickness of the periodic variation of temperature at the surface.

The real part of equation (1.4) can be expressed as $T_{(x,t)} = ao + \sum \{am \exp(-\propto mx) \cos(m\omega t - \alpha mx)\}$ 1.5 Equation (1.5) can be modified as:

$$T_{(x,t)} = T_m - A_s \exp(-\propto x) \cos\left\{\omega\left(t - t_0 - \alpha\frac{x}{\omega}\right)\right\} - \quad 1.6$$

Where, A_s = daily temperature amplitude at x = 0^0c; t = time of the day in hours and t_0 = time of maximum temperature at the surface. The temperature T_m can be calculated from the hourly material surface temperature average.

$$Th_{ss},\ ^0C \text{ as: } T_m = \sum_{m=1} \left(\frac{T_{hss}}{24}\right) - \quad 1.7$$

On 24 hour period, equation (1.6) can be written as

$$T_{(x,t)} = T_m A_s \exp(-\propto x \cos\left[\left(\frac{2\pi}{24}\right)\left(t - t_0 - 12 \propto \frac{x}{\pi}\right)\right] \quad 1.8$$

EXPERIMENTATION

Sample collection and preparation;

Soil samples used for the experiments were collected from three landforms in Akwa Ibom State. The landforms are; Beach Ridge Sand (BRS), Coastal Plane Sand (CPS) and Sandstone/Shale Hill Ridges (SHR) the soil samples were collected using “soil ogre” from different depth (0 – 20cm).

Six different soil samples were collected; locations and sources of collection are showing in the table below:

Table 1: Showing Landforms and Sources of Soil Samples

LANDFORMS	LOCATION
Beach Ridge Sand (BRS 1)	Ikot Akpan Mkpe, Onna L.G.A
Beach Ridge Sand (BRS 2)	Ikot Akpan Mkpe, Onna L. G. A
Coastal Plane Sand (CPS 1)	Ikot Akpan, Nsit Ubium L.G.A
Coastal Plane Sand (CPS 2)	Uniuyo Annex, Uyo L.G.A
Sandstone/Shale Hill Ridges (SHR 1)	Ibiaku Ntok Okpo, Ikono L.G.A
Sandstone/Shale Hill Ridges (SHR 2)	Ntak Inyang, Itu L.G.A

MEASUREMENT OF DENSITY

The following were used during the analysis:

Weighting balance, measuring cylinder (beaker), liquid (Hept), thread, and soil samples; each sample was weighed directly using a weighing balance, to obtain the mass M, of the samples which was recorded. The measuring cylinder was filled with water and the level of water noted and recorded as Vo. Each of the soil samples was immersed in the water, as it sank completely, it's displaced the volume of water; the new level of the water was recorded as V_1. The actual volume of the sample was obtained by subtracting the volume V_0 from V_1.

MEASUREMENT OF THERMAL CONDUCTIVITY

The following were used during the experiment:

Lee's disc apparatus, thermometer, steam can, venire caliper, strings, retort stand with clamp, heat source and rubber tubings.

Thermal conductivity was determined for each of the soil samples using the steady state method. Lee's disc apparatus was modified and adapted for use. Dry soil samples were used to avoid the problem of redistribution of water under the influence of temperature gradient; (Jackson. R. D. and Taylor, S. A;1965). At the steady state, the heat conducted across the soil sample is equal to the rate which it is emitted from the exposed surface.

Table 2: Results Showing Values of Thermal Conductivity and Density of Different Soil Sample in Akwa Ibom State

LANDFORMS	THERMAL CONDUCTIVITY (W/MK)	DENSITY (KGM^{-3})
BRS 1	0.363	2212.04
BRS 2	0.451	2430.43
CPS 1	0.302	2432.38
CPS 2	0.331	2412.03
SHR 1	0.501	2263.08
SHR 2	0.404	2485.26

Using the value of thermal conductivity (k) and density (ρ) in table 2, and spearman rank correlation coefficient, (DASS, H.K; 2006);

$$\gamma = 1 - \frac{6\sum d^2}{n(n^2-1)} - \qquad (1)$$

Where n = 6, (number of soil samples) $d = K_R - \rho_R$ and $d^2 = (K_R - \rho_R)^2$, K_R and ρ_R are correlation coefficient of thermal conductivity and density read from correlation table respectively.

Table 3: Showing Result of Calculating $K_R - \rho_R$

Landforms	K ($\frac{\omega}{mk}$)	ρ(kgm^{-3})	K_R	ρ_R	$d = K_R - \rho_R$	d^2
BRS 1	0.363	2212.04	3.00	1.00	2.00	4.00
BRS 2	0.451	2430.43	5.00	4.00	1.00	1.00
CPS 1	0.302	2432.38	1.00	5.00	-4.00	16.00
CPS 2	0.331	2412.03	2.00	3.00	-1.00	1.00
SHR 1	0.501	2263.08	6.00	2.00	4.00	16.00
SHR 2	0.404	2485.26	4.00	6.00	-2.00	4.00

But $\sum d^2 = 43$
And n = 6, then;
From equation (1) $\gamma = 1 - \frac{6\sum d^2}{n(n^2-1)}$
$\gamma = 1 - \frac{6 \times 42}{6(6^2-1)}$
$= 1 - \frac{252}{6(35)}$
$= 1 - \frac{252}{210}$
$= 1 - 1.2$
$= -0.2000$

By using ANOVA to determine thermal conductivity values for the three landforms in Akwa Ibom State were the soil samples was collected are the same.

Null hypothesis (H_N): $K = \rho$, if $\gamma_{cal} > \gamma_{table}$

Alternative hypothesis (H_A): $K \neq \rho$; if $\gamma_{cal} < \gamma_{table}$

Where γ_{cal}, calculated value of γ and γ_{table} = values of γ from correlation table with degree of freedom γ_{table} at 0.05 and $\gamma_{table} = 0.8860$, (Gerald, K. and Brian, W. 2003); Since $\gamma_{cal} = 0.2000$ $\gamma_{table} = 0.8860$; we upheld the alternative hypothesis and concluded that there is no significant different in the K values of the three land form observed in Akwa Ibom State.

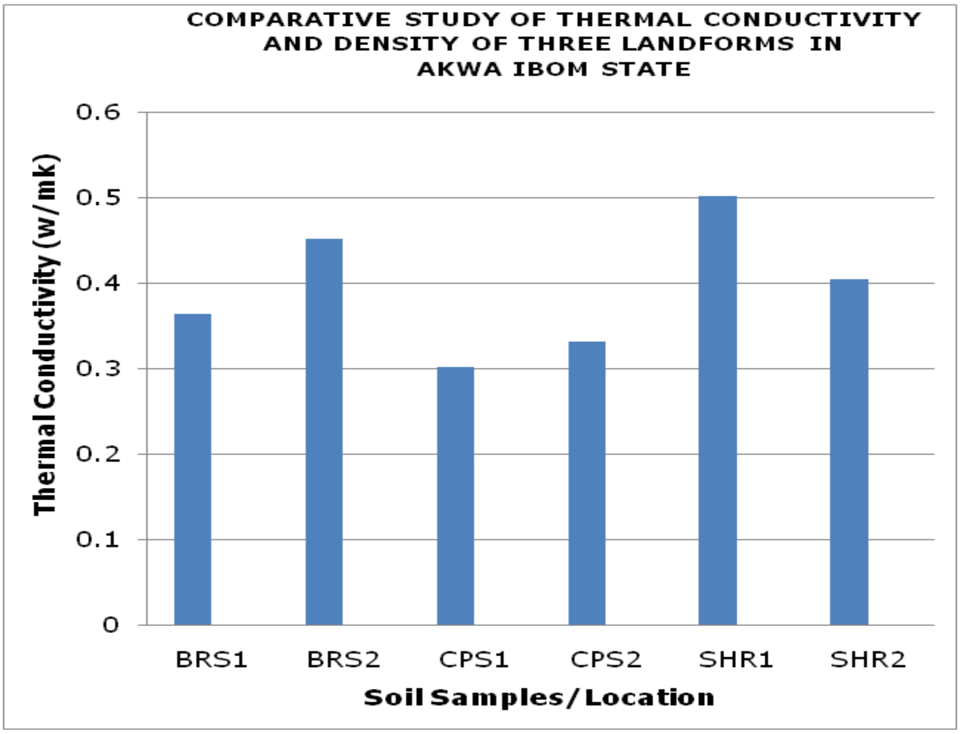

Figure 1: Showing measurement of thermal conductivity of different landforms

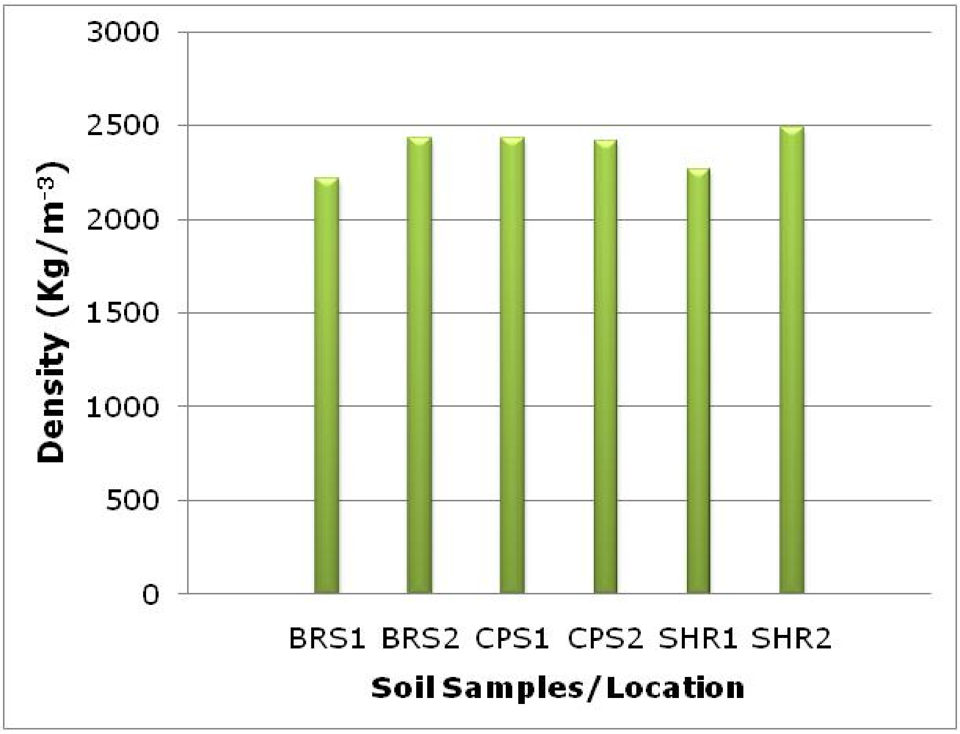

Figure 2: Showing measurement of density of different landforms

SUMMARY AND CONCLUSION

From the experiment on the thermal conductivity and density of the three landforms in Akwa Ibom State, the K – values ranges from 0.302 (w/mk) to 0.501 (w/mk) while the ρ-values have the range of 2212.04 (kgm^{-3}) to 2485.26 (kgm^{-3}). By using the comparative study of the thermal conductivity and density it is observed that SHR 1 has the highest thermal conductivity and CPS 1 has the smallest thermal conductivity. Also, SHR 2 has the highest density and BRS 1 has the smallest density. Generally, an increase in the soil thermal conductivity k has a corresponding decrease in the soil density ρ and vice versa.

It is a fact that the thermal conductivity data were less than 1.5w/mk which indicates that the land where the soil samples were collected are suitable for cultivation and the signal strength of the density measurement decreases with increase in k.

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