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Archives of Physics Research, 2010, 1 (4): 64-72
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ISSN 0976-0970
CODEN (USA): APRRC7

The implication of oil spillage on the thermal properties of soil samples in the Niger delta, southern Nigeria.

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ABSTRACT

Thermal implication of oil spillage on select soil samples obtained from different locations of the Niger Delta was performed. Three different soil samples of Beach ridge sand; medium coarse sand and sandstone interlaced with shale of the geologic formation known as Benin Formation were used. The study shows that spills on soil samples reduce the density of sandstone interlaced with shale, Beach ridge sand and medium coarse sand by 17.7%, 13.3% and 15.0% on the average respectively. In the same vein, crude oil-rich beach ridge sand, sandstone interlaced with shale and medium coarse sand are respectively on the average decreased by 4.4%, 9.9% and 15.2% of the original value of the specific heat capacity of the unmixed samples, while the thermal conductivity of the crude oil beach ridge sand, medium coarse sand and sandstone and shale derivative have their values increased by 9.8%, 2.6% and 12.3% respectively on the average. The departures on these thermal properties when the samples were smeared with crude oil as shown on the graph is a clear proof of the effect of oil spillage on the soil samples. This has effect on the use of land (soil) for agriculture and habitation in addition to the effect on the geologic controls.

Keywords: crude oil, oil spillage, soil samples, thermal properties and Niger Delta.

INTRODUCTION

The thermal state of Niger Delta is influenced by natural phenomena such as weather, climate, radioactivity and green house effect as well as the artificial phenomena such as oil spillage, deforestation and burning of materials which are either flammable or non-flammable [1]

Although the thermal gradient increases with depth, the exposed surface Benin Formation is predominantly made to depart from its natural thermal state through man's activities which are either deliberate or in-deliberate. Apart from the uncontrollable means or the agricultural contributions to the departure of the thermal silicic soil built on the deposits of the high energy

Niger Delta, oil spillage has among other things contributed greatly to the thermal destabilisation. The impacts of oil spillage and gas flare have been experienced in Nigeria in the recent years and its occurrence is at very fast and alarming rate in the oil producing communities. The threshold limit of the natural thermal state is exceeded as a result of the integral contributions of the energy – loaded spill and gas flaring in the study area where the samples used in this research was collected.

Soil or landform is greatly important in agriculture. Its temperature depends on the pore spaces and the material making up the formation [3]

In all ramifications, soil temperature depends on the environmental temperature [4]. However, spillage of crude oil on the soil greatly affects the thermal properties of the soil samples and on this basis; the research was conceived to investigate the effect of oil spillage on the soil samples.

Location of the study area and the specific geology: The study area extends between latitudes 4^o20^1 and 5^o00^1 and longitudes 7^o10^1 and 8^005^1 (Fig. 1.). The area is located on the sedimentary basin of the Niger Delta of Akwa Ibom State, Southern Nigeria. It belongs to low-lying coastal deltaic plain of southern Nigeria. The terrain is virtually flat to gently undulating, sloping generally towards the Atlantic Ocean.

Vegetation in the study area is of the rain forest type. It is sustained by the tropical climate characterized by high temperature with annual mean temperature of 27^oC [5]. The monthly mean temperature varies between 28^oC – 30^oC during March and minimum daily mean temperature is between 23^o – 24^oC during July and August [5].

Geologically, the study area is composed mainly of Benin Formation otherwise known as the Continental Plain Sands. This coastal plain sand is intercalated with minor clay to form sand-clay sequence in the study area. The clay formation usually absorbs heat more than the sandy formation and as such clay acts as heat sink in most cases.

Heat propagated through the soil or rock sample is partly through the grains and partly through the fluid contained in the pores of the sample. The propagation of heat may be by conduction or radiation [1, 3]. The sensitivity of soil sample to thermal properties like conductivity, diffusivity, absorptivity, and emisivity reflects the thermal properties of the soil [1, 3]. The electrical sensitivity of the soil or rock sample, which is dependent on the moisture content of the soil or rock, reflects the electrical properties of soil or rock. Again, those properties of soil or rock relating to its resistance to deformation by applied forces signify the mechanical properties of rock. For the purpose of this study, thermal properties of rock/soil are particularly considered. The thermal conductivity of soil sample increases with density, moisture content and temperature [1, 3]. The thermal conductivity of soil sample increases with about 0.25% per degree Celsius [6].

MATERIAL AND METHOD

In six locations of the study area, shown in table 1, three soil samples which were Beach ridge sand or fine sand coded as BRS, medium coarse sand, coded as MCS and sandstone minimally interlaced or interacted with shale, coded as SHR were collected. All these samples constitute the Benin Formation of the Niger Delta [5]

Table 1: Names and sources of soil samples used in the analysis

Sample	Name	Source
BRS1	Beach Ridge Sand	*Ikot Ibiok, Eket* L. G. A
BRS2	Beach Ridge Sand	*Ikot Akpan Nkpe, Onna* L. G. A
MCS1	Medium Coarse Sand	*Ikot Akan, Nsit Ubium* L. G. A
MCS2	Medium Coarse Sand	*University of Uyo Annex, Uyo* L. G. A
SHR1	Sandstone interlaced with shale	*Ikpe Ikot Nkon, Ini* L. G. A
SHR2	Sandstone interlaced with shale	*Ibiaku Ntuk Okpo, Ikono* L. G. A

In each of the above samples, two portions of 140g (0.14kg) were measured out with the use of a metre balance. One of the portions was mixed with 10ml of crude oil (control sample). Table 2 gives the names and reference alphabets for each of the samples. These samples were moulded into cylindrical disc shapes to take the shape of the Lee's disc and both the mixed and the unmixed soil samples for each of the different soils were kept for an observation time of 24 hours (one day) before the experiment was performed to find the 'dog-leg' on the thermal properties of the samples due to effect of oil smeared on them spillage.

Table 2: Name of soil samples and their reference alphabets

Sample	Reference alphabet	Name
BRS1	A	BRS1 without crude oil
BRS1	Ac	BRS1 with crude oil
BRS2	B	BRS2 without crude oil
BRS2	Bc	BRS2 with crude oil
MCS1	C	MCS1 without crude oil
MCS1	Cc	MCS1 with crude oil
MCS2	D	MCS2 without crude oil
MCS2	Dc	MCS2 with crude oil
SHR1	E	SHR1 without crude oil
SHR1	Ec	SHR1 with crude oil
SHR2	F	SHR2 without crude oil
SHR2	Fc	SHR1 with crude oil

The diameter and thickness of each of the specimens were finally processed to be 6.04± 0.05cm and 2.50 ± 0.05cm respectively. The usual procedures for determining thermal conductivities of the above samples using Lee's disc by steady state method was used. Heat conducted across the samples, at the steady state equals the rate at which it is emitted from the exposed surface [7]. The principle of conservation of energy and other precautionary practices were strongly upheld in order to reduce the experimental error to the barest minimum.

The specific heat capacity was also determined for each sample by method of cooling correction described by [8, 9] which takes care of any heat that might be lost due to radiation. In this experiment, copper-constant thermocouple was used for temperature measurement.
The bulk density for each of the samples was also considered as one of the fundamental relevance in the analysis and so it was obtained by weighing and displacement methods [10]. Thermal diffusivity λ,absorptivity α and resistivity r were calculated directly for each of the pure soil samples and the sample treated with crude oil using the equations (1), (2) and (3) respectively, shown below:

$$\lambda = \frac{K}{\rho c} \quad (1)$$

$$\alpha = \left(\frac{w}{2\lambda}\right)^{\frac{1}{2}} \quad (2)$$

$$r = \frac{1}{k} \quad (3)$$

where $w = 2\pi$ /period, λ = thermal diffusivity, α = thermal absorptivity, K = thermal conductivity, C = specific heat capacity, ρ = density of the sample and r = thermal resistivity.

The heat flow in any solid material is governed by the following one-dimensional unsteady state heat conduction equation

$$\frac{\partial^2 y}{\partial x^2} = \frac{\rho c}{k}\frac{\partial T}{\partial t} \quad \text{or} \quad \frac{\partial^2 T}{\partial x^2} = \alpha \frac{\partial T}{\partial t} \quad (4)$$

For a semi-infinite homogeneous solid with constant thermal properties, equation (4) can be solved when the boundary conduction a the material surface is known. The energy balance equation at the material surface is used as a boundary equation, which is expressed according to [11] as

$$-K\left(\frac{\partial T}{\partial x}\right)_{x=0} = h\left(T_A - T_{x=0}\right) \quad (5)$$

where $T_A = \left(T_{atm} + \alpha I - \varepsilon \Delta R\right)$ (6)

T_A is known as the solar temperature, k = thermal conductivity of the material, T = temperature of the material; h = heat transfer coefficient of the material, T_{atm} = atmospheric temperature; α = solar radiation absorptivity at the surface; I = intensity of solar radiation; ε = long wave emisivity of the surface, and ΔR = difference between the incident long wave radiation and the radiation emitted from the surface. The general solution of one-dimensional heat flow conduction equation (assuming T is finite when $x \to \infty$) may be written as

$$T(x,t) = A_0 + \sum_{m=1}^{\infty} Am \ \exp\ \left[i\left(mwt + \delta mx\right)\right] \quad (7)$$

where $\delta m = m^{\frac{1}{2}}\alpha(1-i)$, $\lambda = (w\rho c/2k)^{\frac{1}{2}}$, c = specific heat capacity of the material, ρ = density of the material and $w = 2\pi$ /period. Equation (7) gives the dependence of material temperature with thickness on the periodic variation of temperature of the surface. T_A can be expressed as Fourier series, thus:

$$T_A = a_0 + \sum_{m=1}^{\infty}\left[a_{m1}\cos(mwt) + a_{m2}\sin(m\varpi t)\right] \quad (8)$$

equation (8) is equivalent to (9)

$$T_A = a_0 + \sum_{m=1}^{\infty} a_m\left[i(mwt - \partial m)\right] \quad (9)$$

Substituting for T(x,t) in (7) and for T_A in (8) according to [12, 13],

$$T(x,t) = a_0 + \sum_{m=1}^{\infty}\beta_m \ \exp\ \ (-m^{\frac{1}{2}}\alpha x)\cos(mwt - m^{\frac{1}{2}}\alpha x - \delta m - \beta_m) \quad (10)$$

where $\beta = \delta_m (1 + m^{\frac{1}{2}}\mu)^2 + m\mu^2)^{-\frac{1}{2}}$ (11)

$$\mu = k\alpha / h = (kw\rho c/2)^{\frac{1}{2}} / h \quad (12)$$

$$\beta_m = \tan^{-1}\left(m^{\frac{1}{2}}\mu(1+m^{\frac{1}{2}}\mu) \right) \quad (13)$$

a_0 represents the average daily material temperature. The daily temperature variation at different depths of the material is given by equation (10). With $\beta_m = 0$, $w = 2\pi/24hr$, $\beta_m = a_m$; the equation above is modified into the convenient form in (15) according to [14]

$$T(x,t) = T_m - A_s \exp(-\alpha x)\cos\left[w\left\{(t-t_0) - \alpha x/w\right\}\right] \quad (15)$$

where A_s = daily temperature amplitude at the surface of the soil sample, that is at x = 0;
t = time of the day in hours
t_0 = time of minimum temperature at the surface in hours
x = coordinate through the thickness of the soil sample
λ = thermal absorptivity and w = angular velocity (365 day cycle)

T_m is calculated from the hourly surface temperature average T_{hss} (^oC) as $T_m = \sum_{m=1}^{24} T_{hss}/24$

(16)

Thus, on 24 hours period, equation (10), takes the form in (15) as

$$T(x,t) = T_m - A_s \exp(-\alpha x)\cos[(2\pi/24)\{t-t_0\} - 12\alpha x/\pi\}] \quad (17)$$

the measurement of the thermal conductivity k, density ρ and specific heat capacity c, of any material enables the determination of the value of the thermal diffusivity λ, for such a material using the equation given by [15, 16] in equation (1). The thermal diffusivity λ, is used in calculating thermal absorptivity in (2).

In this study, table 2 was obtained as the error treated mean value of the thermal variables measured and calculated as the case may be.

RESULT AND DISCUSSION

Table 2: Statistics of the thermal properties of the different soils

Soil sample code	Specific heat capacity ($Jkg^{-1}k^{-1}$)	Density ρ (kgm^{-3})	Thermal diffusivity (λ x 10^{-8} m/s^2)	Thermal conductivity, K($Wm^{-1}k^{-1}$)	Thermal resistivity r ($W^{-1}mk$)	Thermal absorptivity $\alpha(m^{-1})$
A	1501 ± 150	1618 ± 80	14.7	0.3593 ± 0.0182	2.6490	247.35
A_c	1453 ± 140	1417 ± 56	18.8	0.3881 ± 0.0193	2.4545	193.41
B	1541 ± 150	1807 ± 72	12.3	0.3436 ± 0.0178	2.7586	295.62
B_c	1472 ± 160	1550 ± 46	16.7	0.3831 ± 0.0189	2.4875	217.73
C	1150 ± 130	1945 ± 58	15.3	0.3434 ± 0.0175	2.7709	237.65
C_c	1033 ±120	1654 ± 33	21.0	0.3590 ± 0.0183	2.6504	173.15
D	1871 ± 272	1914 ± 57	9.8	0.3539 ± 0.0182	2.6874	249.05
D_c	1491 ± 150	1627 ± 32	14.6	0.3561 ± 0.0181	2.6724	249.05
E	1615 ± 150	1821 ± 54	9.6	0.2836 ± 0.0140	3.3602	378.76
E_c	1375 ± 140	1473 ± 4	17.1	0.3470 ± 0.0176	2.7427	212.64
F	2170 ± 200	1865 ± 55	8.4	0.341 ± 0,0170	2.8003	432.87
F_c	2058 ± 180	1563 ± 31	11.2	0.3631 ± 0.0184	2.6212	324.65

The heat conduction across the soil sample, at the steady temperature, equals the rate at which it is emitted from the exposed surface [5]. The specific heat capacity on the soil sample was determined by the method of cooling correction described by [8], which takes care of any heat lost due to radiation. A copper-constantan thermocouple was used for temperature measurement. Again, the bulk density was measured for each of the soil samples using the weighing and displacement methods [16]. Thermal diffusivity λ, and thermal absorptivity α, for each soil sample were calculated using equation (1) and (2) respectively. From the thermal conductivity, thermal resistivity was equally calculated for the different soil samples, in which some were mixed with crude oil while some were not mixed.

Table 2, shows the experimental results of the error-treated mean thermal conductivity k, specific heat capacity c, density ρ, and the calculated thermal diffusivity λ, thermal absorptivity α and thermal resistivity r. From table 2, which contains pure soil samples and the ones treated 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 by varying percentages, while the thermal conductivity is noticeably increased in the observed soil sample by varying percentages. The density of sandstone intercalated with shale seems to be greatly reduced by 17.7% on the average. The density of the treated beach ridge sand is averagely 13.3% less than the pure sample, while the density of medium coarse sand treated with crude oil is 15.0% less than its pure sample. In the same vein, crude oil – treated sample of beach ridge sand, sandstone intercalated with shale and medium coarse sand are respectively decreases by 4.4%, 9.9%, and 15.2% of the unmixed sample. On the contrary, the thermal conductivity of the oil-treated beach ridge sand, medium coarse sand and the sandstone interlaced with shale have their values increased by 9.8%, l2.6% and 12.3% respectively on the average. This is because in accordance with [17], the introduction of extract atoms (crude oil) into the soil samples increases the rate of collision thereby increasing thermal conductivity of mixed soil sample. Moreover, the fluid (crude oil) content of mixed samples affects the soil samples and decreases the air pores thereby increasing the thermal conductivity while the porosity and the density are decreased. The higher values of the specific heat capacity of the unmixed soil sample when compared to the one mixed with crude oil show that the unmixed samples have higher absorption energy per unit mass per degree rise in temperature than the mixed samples.

The thermal absorptivity of the crude oil mixed samples is lower than that of the unmixed samples. This indicates that with the crude oil, the soil samples can absorb and emit heat faster. The thermal diffusivity on the other hand equally increases for the crude oil mixed sample more than the unmixed sample. This high value makes the soil sample to be conducting more heat.

Graphs 2 – 5 also show the variations in the thermal properties which are functions of temperature when soil samples entangle with crude oil, may be through oil spillage. The different graphs for different thermal properties for the three soil samples can be used to predict what could be the effect of oil spillage on the agricultural land since the variation can easily be read and interpreted in terms of the associated variability of the thermal properties.

With equation (27), models can be developed to compare the effects of oil spillage on soil samples in terms of temperature which is dependent on the time (t) and the soil layer thickness (x). The envisaged thermal properties depend on temperature. Therefore, the prediction of the temperature based on the effect of oil spillage that influences the thermal properties is very important to the agriculturists and the other land users as this is a direct means of detecting a departure of the soil temperature from normal [18]. The model can be represented as shown below in equations (28) – (39)

$$T(x,t)_A = T_m - A_s \exp\ (-243..35x)\cos\{0.262(t-t_o)-243.35x\} \quad (28)$$
$$T(x,t)_{Ac} = T_m - A_s\ \exp\ (-193.41x)\cos\{0.262(t-t_o)-193.41x\} \quad (29)$$
$$T(x,t)_B = T_m - A_s\ \exp\ (-295.62x)\cos\{0.262(t-t_o)-295.62x\} \quad (30)$$
$$T(x,t)_{Bc} = T_m - A_s\ \exp\ (-217.73x)\cos\{0.262(t-t_o)-217.73x\} \quad (31)$$
$$T(x,t)_C = T_m - A_s\ \exp\ (-237.65x)\cos\{0.262(t-t_o)-237.65x\} \quad (32)$$
$$T(x,t)_{Cc} = T_m - A_s\ \exp\ (173.15x)\cos\{0.262(t-t_o)-173.15x\} \quad (33)$$
$$T(x,t)_D = T_m - A_s\ \exp\ (371.03x)\cos\{0.262(t-t_o)-371.03x\} \quad (34)$$
$$T(x,t)_{Dc} = T_m - A_s\ \exp\ (249.05x)\cos\{0.262(t-t_o)-249.05x\} \quad (35)$$
$$T(x,t)_E = T_m - A_s\ \exp\ (378.76x)\cos\{0.262(t-t_o)-378.76x\} \quad (36)$$
$$T(x,t)_{Ec} = T_m - A_s\ \exp\ (212.64x)\cos\{0.262(t-t_o)-214.64x\} \quad (37)$$
$$T(x,t)_F = T_m - A_s\ \exp\ (432.87x)\cos\{0.262(t-t_o)-432.87x\} \quad (38)$$
$$T(x,t)_{Fc} = T_m - A_s\ \exp\ (324.65x)\cos\{0.262(t-t_o)-324.65x\} \quad (39)$$

Equations (28) – (31) represent the state of the temperature conditions for the beach ridge sand collected from the two locations shown in table 1. The letters A and B represent samples from the two locations which were not mixed with crude oil while A_C and B_C represent those that were mixed with crude oil. Equations (32) – (35) represent the temperature state of the medium coarse sand collected from two locations in the study area as indicated in table 1. C and D stand for the unmixed sample of medium coarse sand while the C_C and D_C represent the samples mixed with crude oil. Again, equations (36) – (39) represent sandstone interlaced with shale which was also collected in two different locations as table 1 show. E and F and E_C and F_C respectively represent samples of sandstone interlaced with shale which were not mixed with crude oil and those mixed with crude oil.

With the model prediction of temperature of a particular layer thickness and the particular time, it is clearly seen that spillage usually affects the thermal properties of the soil samples and this causes a departure of the soil thermal properties from normality to abnormality. To the soil microbes, the departure of thermal conditions may be harmful and this would reduce their activities. This may also affect the crops planted on land and the entire geologic system or control.

CONCLUSION

Generally, the implication of the soil spillage on the thermal properties of the soil samples is that there would be a great departure of the thermal properties from normality to abnormality. As we can see, from the graphs, tables and temperature prediction based on thermal properties, soil sample thermal properties are usually affected when oil spills irrespective of the soil type. When oil spills, the density and the absorptivity are noticeably reduced for the different soil samples while the thermal conductivity and thermal diffusivity are sufficiently increased for all the three soil samples experimented upon. Besides, specific heat capacities are equally affected as each soil sample studied shows a departure from the values mixed with crude. The oil companies operating in the Niger Delta areas where oil usually spills should be cautious of these thermal state departure implications of oil spills on the soil which hosts both the plants and animals. The cumulative effect of oil spillage in Niger Delta is deadly and this announces a clamour by all for oil spillage to be mitigated as this would be one of the conditionalities for continued agricultural development in the region.

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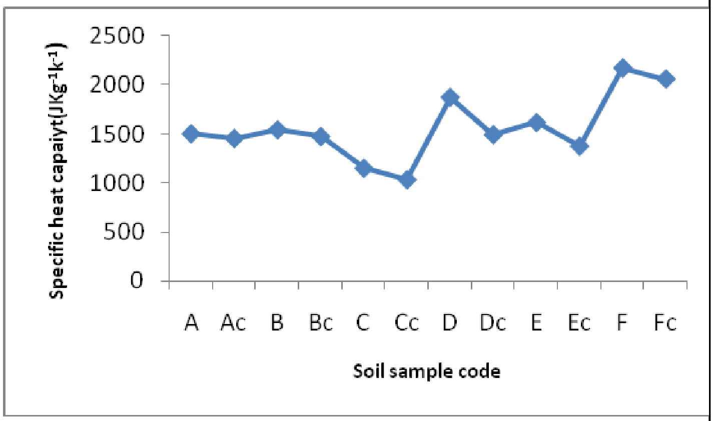

Fig.2: Variation of Specific heat capacity with soil sample codes

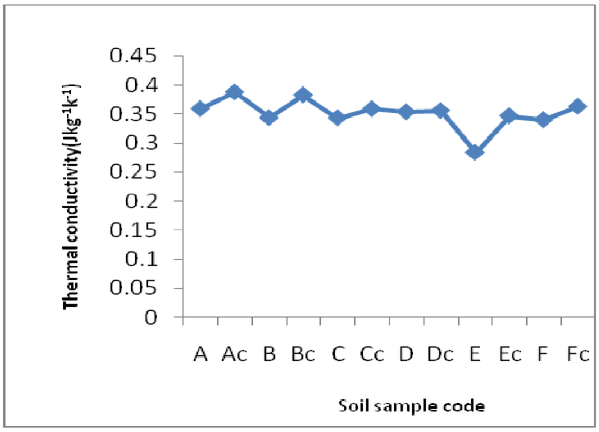

Fig.3: Variation of thermal conductivity with soil sample codes

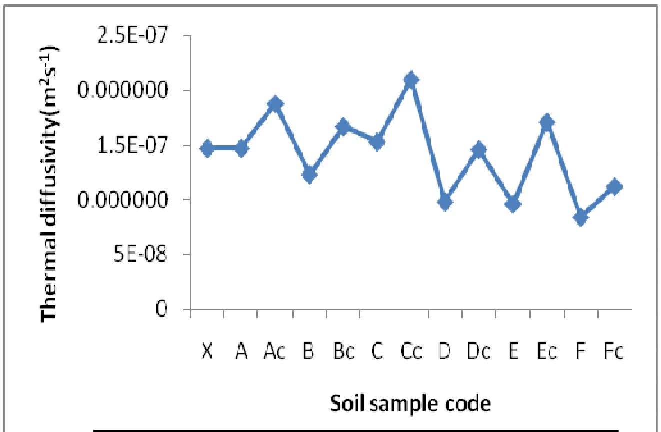

Fig.4: Variation of thermal diffusivity with soil sample

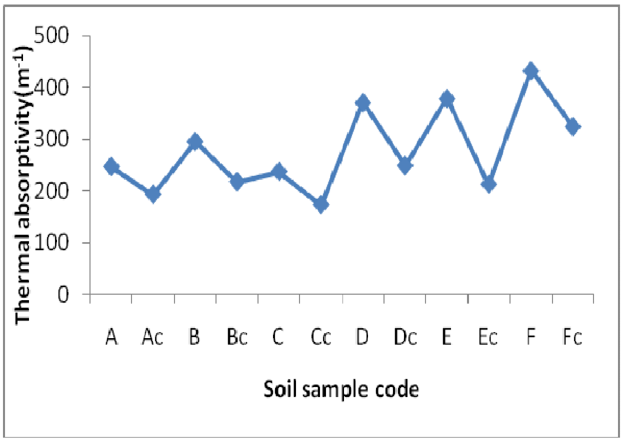

Fig.5: Variation of thermal absorptivity with soil sample

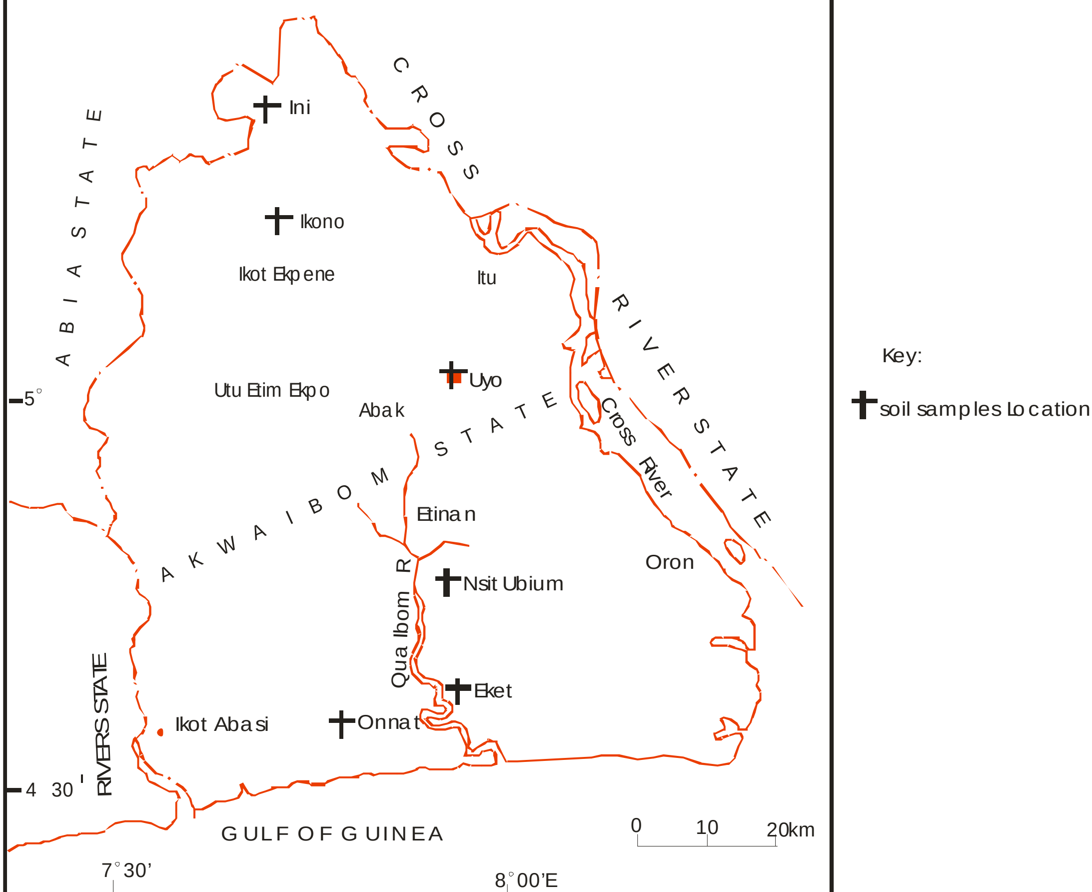

Fig. 1 Map of Akwa Ibom showing the locations of the soil samples used in the study