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DEPENDENCE OF THERMOPHYSICAL PROPERTIES OF CLAY ON CONCENTRATION OF SOME HEAVY METALS

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ABSTRACT

This paper presents the relationship between thermo physical properties (thermal conductivity and thermal diffusivity) and heavy metal concentration of some surface clay from six local governments in Ibadan, oyo state, Nigeria. An atomic absorption spectrometer (AAS) was used in analyzing the concentration of heavy metals present in each sample by measuring the intensity of external radiation absorbed by the atom produced from the same sample at a wavelength characteristic to that element. A transient measurement technique was used to determine the thermal conductivity and thermal diffusivity. Thermal conductivity of each sample was compared with the concentration of heavy metals present in the sample. Based on the results obtained from AAS, Manganese has the highest concentration in all the samples. It was followed by Zinc and the least was lead. The values of temperature, time and their respective measured thermal conductivity were highly correlated; with correlation coefficients between 0.9 and 1.

Keywords: Thermal Conductivity, Heavy Metals, Atomic Absorption, Wavelength, Intensity.

INTRODUCTION

The weathering of parent rocks and the decomposition of organic matter form soils. The fact that soil is so fundamental in life; it has been studied intensively for more than a century. Clay, one of the major types of soil is primarily formed by precipitation. The term, clay, is applied both to materials having a particle size of less than 2μm and to the family of minerals that has similar chemical composition and common crystal structural characteristics. Kaolin is the fine white clay found in the most weathering zone (Velde, 1995). The fact that clay soil allows the flow of heat energy when there is temperature difference; the knowledge of soil thermal properties are necessary in understanding mass and energy exchange process. The conductivity of the soils therefore depends majorly on the moisture condition of soils (Usowicz, 1993), the metals present in the soil (Alloway, 1995), the Soil cation exchange capacity (Rhoades, 1982), Soil pH (Koch and Merinenko, 1983), Soil organic matter (Gerriste and Van Driel, 1984), and clay content (Korte et al., 1976). The practical and useful relationship between heavy metal contents and the thermal conductivity and thermal diffusivity of the surface clay soil has however received very little attention. The main objective of this study is to investigate the relationship between thermo physical properties and heavy metal concentration of some surface clay soil from regions in Ibadan, Oyo state, Nigeria. In this work, greater emphasis was placed on surface heat distribution in clay soils and how the presence of heavy metals affects it.

MATERIALS AND METHODS

The clay used in this study was obtained from different local government in Ibadan, oyo state, Nigeria. Code S_1 - S_{10} were used to represent collection point in the ten selected areas, as shown in Table 1.Sample preparation included air –drying, crushing by mortal and pestle, passing through a 1mm mesh sieve and distilled water. Analysis of the digested samples was performed using Atomic Absorption Spectrophotometer. The following elements were analyzed; Aluminium, Al, Lead, Pb, Zinc, Zn, Chromium, Cr, Copper, Cu, Arsenic, As, Cadmium, Cd Nickel, Ni, and Manganese, Mn. During the digestion experiment, one gram of each sample was weighed into a Teflon beaker while 10ml of conc. Nitric acid (HNO_3) was added and heated. About 70% of the mixture was allowed to dry off and 10ml Hydrofluoric acid (HF) was added to the mixture, followed by direct heating to about 20% total volume. A 5ml Perchloric acid ($HClO_4$) was then added and the whole mixture was allowed to dry by evaporation. 1ml of Nitric acid was then added and allowed to boil and latter transferred to a 25ml standard flask filled to the mark with distilled water (Akinyemi et al., 2006) the results obtained are showed in Table 2. A Nickel-Chromium wire was used as the heat source. The temperature was measured with a k-type thermocouple probe centered at the base of the sample clay slab at an interval time of 30s up to 150s. The probe passed through a hole under the insulating box stuck with glass wool (Middleton, 1993). The K-type thermocouple was connected to a digital multimeter (AVD890G). The thickness of the slab was measured using micrometer screw gauge and the mass was measured with a digital weighing machine. The temperature change and other thermo physical parameter were used to calculate thermal conductivity using the expression

$$K = \frac{Ivt}{A\theta}\frac{dx}{dt}$$

Where k is the thermal conductivity (W/m°k), I is the electric current, v is the potential difference, t is the time, x is the thickness, A is the base area of the slab and θ is the temperature. The thermal diffusivity α was calculated from $\alpha = K/\rho c$, where ρ is the density of the slab (Kg/m^3) and c is the specific heat capacity at constant pressure (J/Kgk). The error analyses for thermo-physical parameters were calculated using differential method.

RESULTS AND DISCUSSION

The results obtained from the analysis of heavy metals showed that manganese has the highest concentration in all the samples. It was followed by zinc and the least was lead. This may be due to geological degradation of rock in the soil formation. Manganese released in high quality into the soil by rock weathering and deposited in various forms of Mn oxides, e,g. Pyrolusite (MnO2), Braunite, ($Mn_2 O_3$) and Manganite, (MnO(OH). Pyrolusite is a mineral that belongs to the rutile group. It is a mineral in crystalline rocks (Tan, 1994). Because of its ionic nature, Mn^{+2} is usually absorbed on the negatively charged surfaces of soil colloids; known as exchangeable manganese. The high concentration of manganese as was obtained by this work is an essential micronutrient and needed by plant to activate a number of enzymes. From Table 2, the concentration of all analyzed heavy metals has not reached the toxic level when compared with the standard value. The normal Mn content in plant tissue is approximately 20 – 500 µg/g in dry matter. The average zinc content in normal agricultural soils is 50µg/g (Brady, 1990). In plant growth, Zinc is an essential material for seed and grain production, and development of growth hormones. The result for thermal conductivity, k, specific heat capacity, c, density, ρ, and thermal diffusivity are summarized in Table 3. Table 3 shows that sample 2 has the highest thermal conductivity of 4.845 ± 0.242 W/M°K, followed by sample 8 and sample 9 with 3.494 ± 0.241W/M°K and 3.493 ± 0.242 W/M°K respectively. The least of all is sample 1 with a thermal conductivity of 1.747 ± 0.241 W/M°K. The thermal diffusivity was high for sample 4 and followed by sample 8. It was followed by sample 3. The plot of temperature – time relation helps in calculating the thermal conductivity and thermal diffusivity. This graph shows a linear relationship between the temperature and the time. The results obtained showed that sample 2 can conduct heat faster than other samples. As can be seen from Table 3, the samples have the thermal diffusivity ranges between 8.00 to 24.89 µm^2/s, which confirms the fact that the samples collected have the same physical and chemical properties. The experimental results obtained from Table 2 and Table 3 show that sample 2 have the highest thermal conductivity. This is due to high concentration of copper, Aluminium and Zinc. (They are good conductor of heat). See Table 4.

CONCLUSION

The differences observed in the result of thermal conductivity, density and thermal diffusivity depend on the percentage of chemical compositions, quantity of the minerals and geological formation of the soil of the selected areas. Manganese was the metal detected with high concentration in all the selected areas with the peak concentration of 114.179µg/g at Omi Adio Brick industry. The concentration of Manganese was least at Oojo Barrack with 0.27µg/g. The thermal conductivity thermal diffusivity at Omi Adio Brick industry will be high because of high concentration of the following metals; Copper, Aluminium, Zinc e.t.c.

Table 1: Selected locations and their local governments.

Code	Location	Local Government
S_1	Omi village	Iddo
S_2	Block Industry Omi	Iddo
S_3	Alaafia Estate	Akinyele
S_4	Ojoo Barrack	Akinyele
S_5	Bodija mkt.	Ibadan West
S_6	University of Ibadan	Ibadan West
S_7	Oluyole	Oluyole
S_8	Elewuro village	Lagelu
S_9	Idi oro village	Lagelu
S_{10}	Gate (PHCN)	Ibadan East

Table 2: Concentration of analyzed heavy metals at different selected area

S/N	Al	Pb	Zn	Cr	Cu	As	Cd	Ni	Mn
S1	Nd	Nd	2.302	0.337	Nd	0.256	ND	Nd	2.358
S2	0.713	Nd	17.528	1.012	28.352	0.767	ND	1.11	114.179
S3	Nd	Nd	3.187	0.675	0.148	Nd	ND	0.694	10.96
S4	Nd	Nd	0.708	0.337	0.148	Nd	ND	Nd	0.27
S5	0.357	0.52	8.853	0.675	Nd	0.383	ND	0.971	51.054
S6	0.357	Nd	19.12	0.337	0.576	0.383	ND	0.277	56.049
S7	Nd	Nd	4.072	0.843	0.295	Nd	ND	0.416	25.25
S8	Nd	0.26	1.062	0.675	0.148	Nd	ND	Nd	0.273
S9	0.357	Nd	5.489	0.337	6.202	0.639	ND	1.665	94.062
S10	Nd	Nd	1.593	0.506	0.443	0.128	ND	0.277	13.318

Table 2a:Standard limit of the Concentration of Heavy metals in soil.

Element	*Number range in soil*	*Critical soil range concentration*
Ag	0.01 – 8	2
As	0.1 – 40	20 – 50
Au	0.001 – 0.02	-
Cd	0.01 – 2.0	3 – 8
Co	0.5 – 6.5	25 – 50
Cr	5 – 1500	75 – 100
Cu	2 – 250	60 – 125
Hg	0.01 – 0.5	0.3 – 500
Mn	20 – 10,000	1500 - 3000

Sample	**Thermal conductivity W/m°K**	**Specific heat capacity J/Kg/K**	**Thermal diffusivity $m^2/s \times 10^{-6}$**
S_1	1.747 ± 0.241	70.34 ± 16.87	15.22 ± 1.87
S_2	4.845 ± 0.242	189.07 ± 16.95	16.47 ± 1.79
S_3	3.239 ± 0.239	133.04 ± 16.96	16.94 ± 1.80
S_4	3.570 ± 0.240	103.52 ± 16.91	24.89 ± 1.81
S_5	1.900 ± 0.243	174.85 ± 16.92	8.21 ± 1.76
S_6	2.295 ± 0.239	204.00 ± 16.93	8.00 ± 1.82
S_7	3.188 ± 0.241	148.01 ± 16.94	13.89 ± 1.81

S_8	3.494 ± 0.241	128.95 ± 16.91	18.27 ± 1.84
S_9	3.493 ± 0.242	174.39 ± 16.90	15.04 ± 1.80
S_{10}	2.104 ± 0.244	'98.80 ± 16.91	14.67 ± 1.73

Fig 1: Concentration of selected heavy metals at different locations.

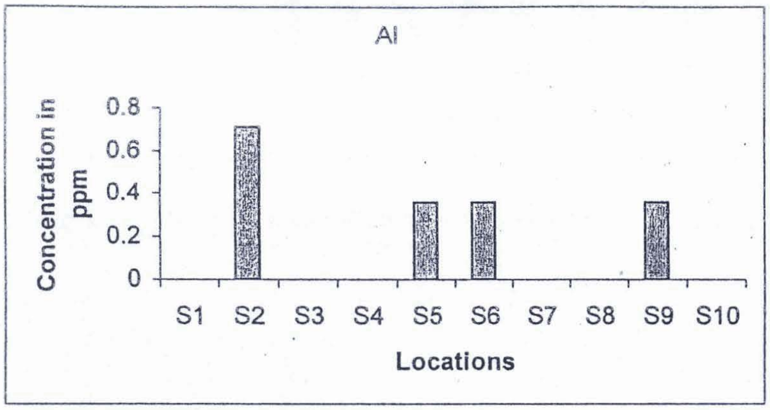


Fig 1.1: concentration of Aluminium at selected locations

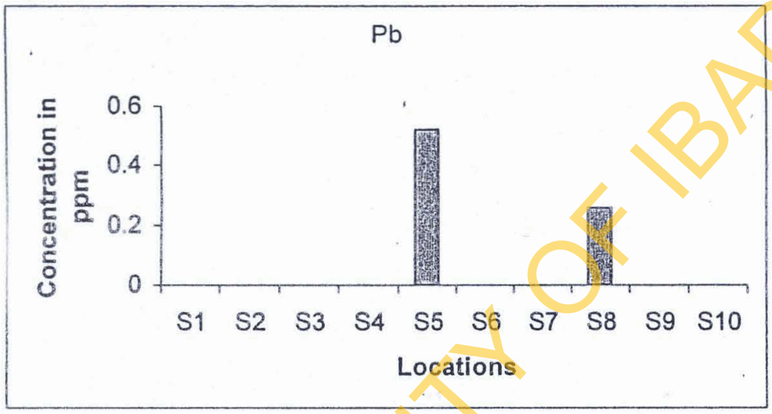


Fig 1.2: concentration of Lead selected locations

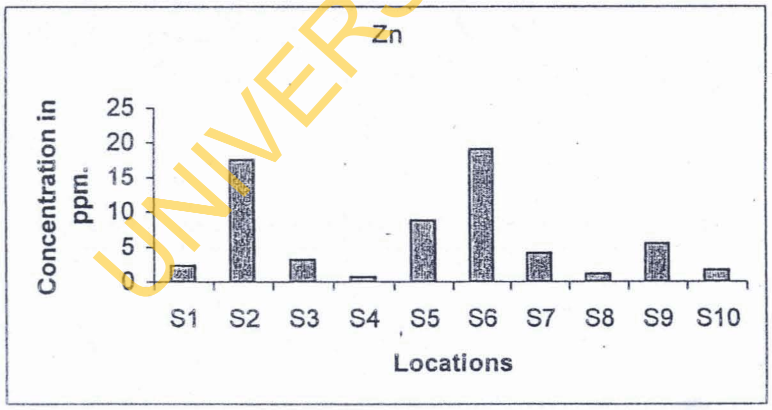


Fig 1.3: concentration of Zinc at selected locations

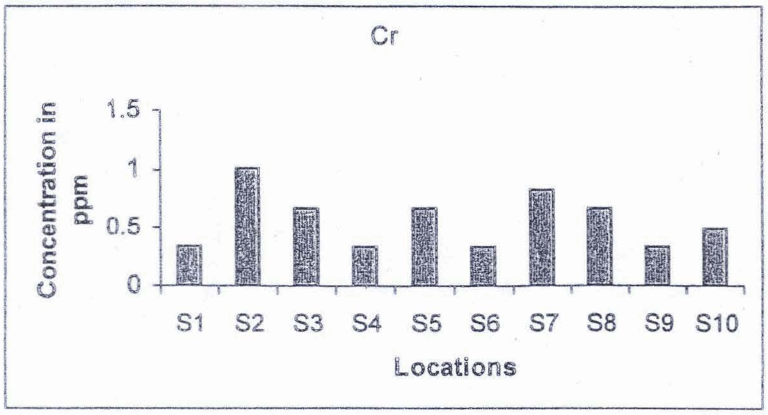


Fig 1.4: concentration of Chromium at selected locations

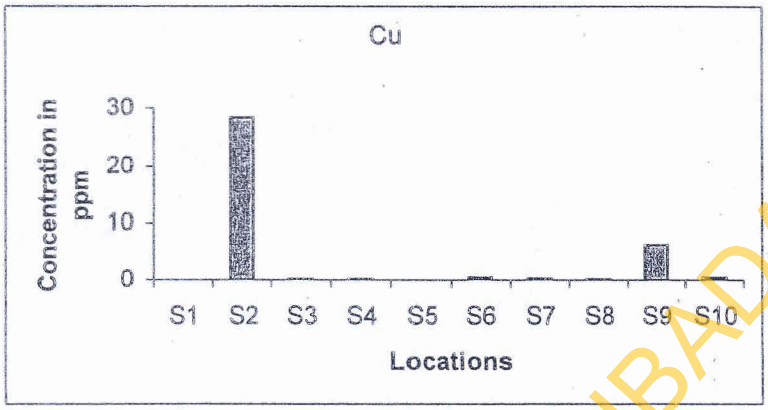


Fig 1.5: concentration of Copper at selected locations

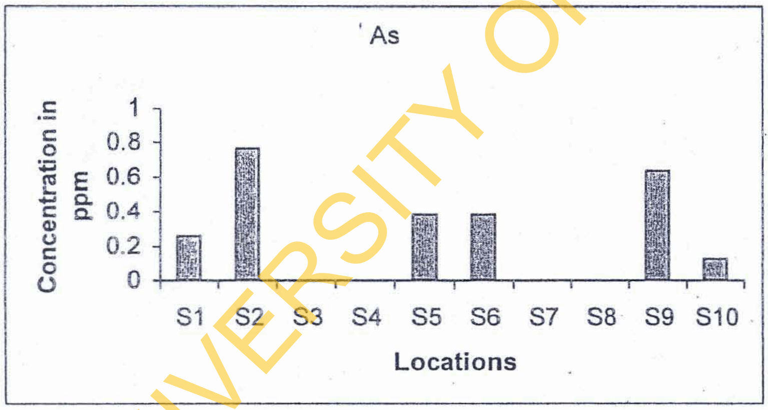


Fig 1.6: concentration of Arsenic at selected locations

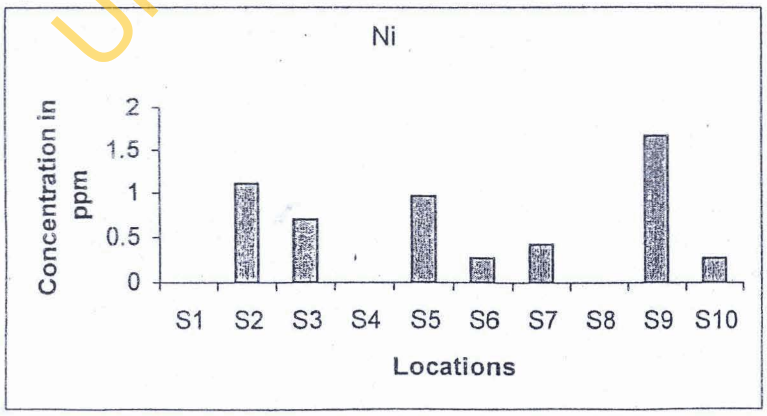


Fig 1.7: concentration of Nickel at selected locations

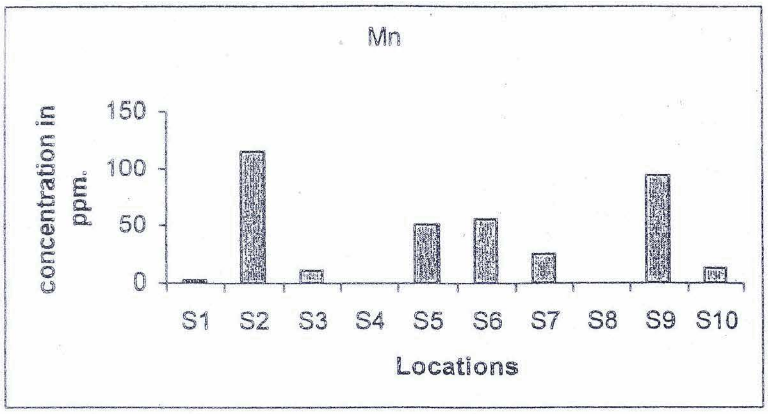


Fig 1.8: concentration of Manganese at selected locations

Table3: Data graph of temperature measurements on the Samples (S_1 –S_{10}).

Time (s)	Temp. (oC)
0	0
30	0
60	1
90	1
120	2
150	2

Time (s)	Temp. (oC)
0	0
30	0
60	0.5
90	1
120	1
150	1.5

Time (s)	Temp. (oC)
0	0
30	0.5
60	1
90	2
120	2.5
150	3

Time (s)	Temp. (oC)
0	0
30	0
60	0.5
90	1
120	1.5
150	2

Time (s)	Temp. (oC)
0	0
30	1
60	2
90	2.5
120	3
150	4

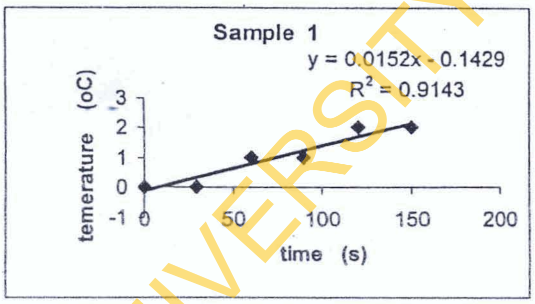
Time (s)	Temp. (oC)
0	0
30	0.5
60	0.5
90	1
120	1.5
150	1.5

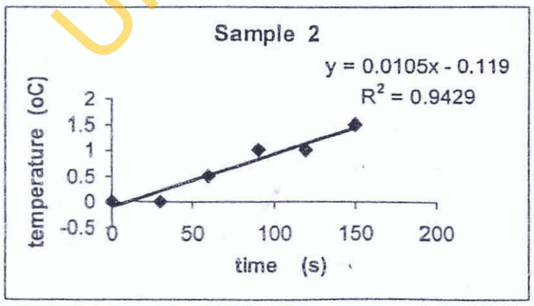
Time (s)	Temp. (oC)
0	0
30	0
60	1
90	1.5
120	2
150	2.5

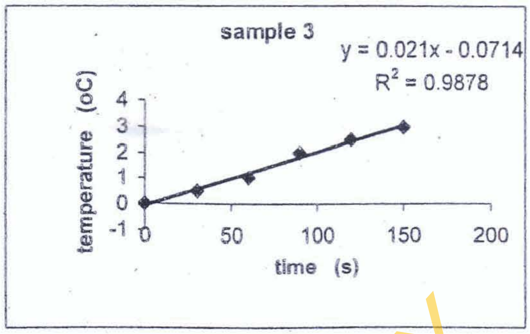
Time (s)	Temp. (oC)
0	0
30	0.5
60	1
90	1.5
120	2
150	2.5

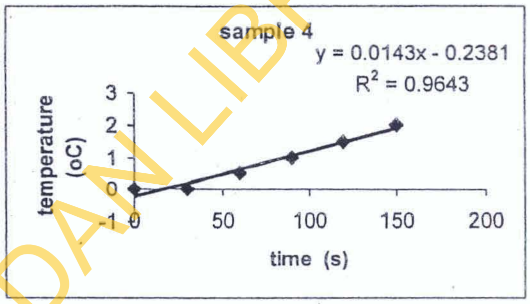
Time (s)	Temp. (oC)
0	0
30	1
60	1.5
90	2
120	3
150	4

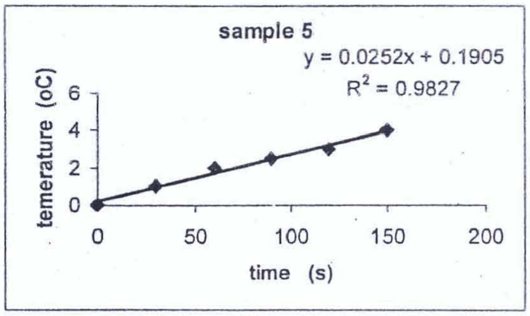
Time (s)	Temp. (oC
0	0
30	1
60	2
90	3
120	4
150	5

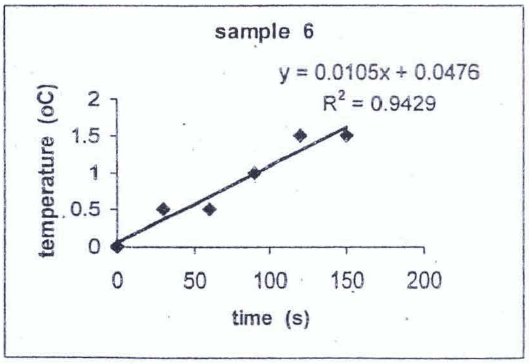












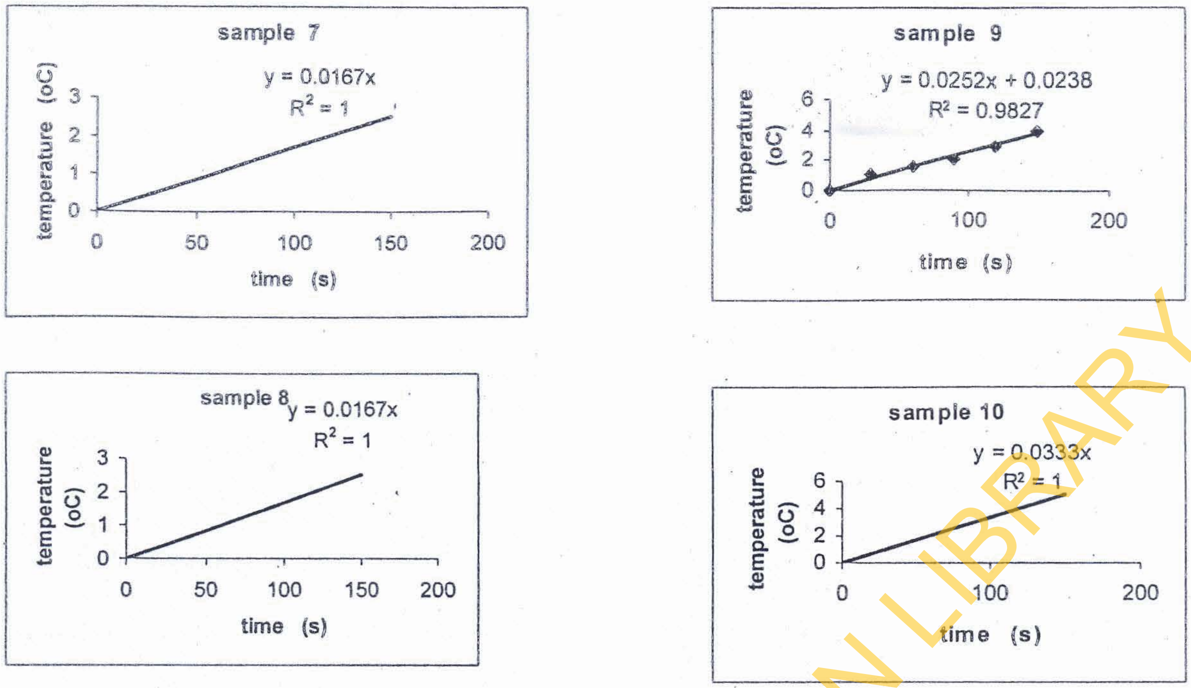


Fig 2: Graph of temperature against time for selected samples (S_1- S_{10}).

Table 3: Thermal properties of samples from the study area.

Sample	Thermal conductivity W/m°K	Specific heat capacity J/Kg/K	Density Kg/ m^3	Thermal diffusivity m^2/s x10^{-6}
S_1	1.747 ± 0.241	70.34 ± 16.87	1631.25 ± 6.24	15.22 ± 1.87
S_2	4.845 ± 0.242	189.07 ± 16.95	1555.62 ± 6.25	16.47 ± 1.79
S_3	3.239 ± 0.239	133.04 ± 16.96	1437.50±6.26	16.94 ± 1.80
S_4	3.570 ± 0.240	103.52 ± 16.91	1385.63 ± 6.15	24.89 ± 1.81
S_5	1.900 ± 0.243	174.85 ± 16.92	1325.00 ± 6.18	8.21 ± 1.76
S_6	2.295 ± 0.239	204.00 ± 16.93	1406.25 ± 6.26	8.00 ± 1.82
S_7	3.188 ± 0.241	148.01 ± 16.94	1550.62 ± 6.24	13.89 ± 1.81
S_8	3.494 ± 0.241	128.95 ± 16.91	1483.12 ± 6.23	18.27 ± 1.84
S_9	3.493 ± 0.242	174.39 ± 16.90	1331.25 ± 6.28	15.04 ± 1.80
S_{10}	2.104 ± 0.244	98.80 ± 16.91	1451.87 ± 6.29	14.67 ± 1.73

Table 4: Thermal conductivity of some known elements ($Wm^{-1} K^{-1}$)

Material	K – value
Al	237.786
Cd	97.149
Cr	95.912
Cu	402.106
Fe	81.111
Mn	7.759
Ni	91.088
Pb	35.363
Zn	115.443

(Hesse 1972)

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