Analysing the impact of soil parameters on the sensible heat flux using simulated temperature curve model

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Simulated Analysis of Soil Heat Flux Using Temperature Deviation Curve Model

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Abstract

Soil heat flux have shown prospects for researchers not only in the agricultural and infrastructure standpoint but also in the health sector. The temperature curve model was applied to determine the soil heat flux from a given data of soil temperature. Beyond the purpose of the research, it was discovered that soil heat flux has some other unknown parameters to aid its measurement.

Keyword: soil heat temperature, soil heating frequencies, resonating phase, temperature deviation curve.

Introduction

Beyond using modern tool for measuring heat flux e.g the use of soil heat flux plate and sensor, the problems associated with it (Van Loon et al., 1998) are quite numerous. Therefore the old theoretical methods seem to be very useful in calculating soil heat flux - not for academic discuss alone, but its affordability by research institute in developing countries. Sensible heat flux was at the center of discuss until it was proofed to have the same order as the Soil heat flux (Kustas et al., 1990; Cheng et al., 2009). Albertson et al.(1995) worked on the use of atmospheric similarity theory (which was pioneered by Tillman (1972)to estimate the sensible heat flux from arid regions. In the same vein, reseachers (Allen et al., 2007; Olejnik et al.,2001) have shown that soil heat flux can be used to calculate evapotranspiration which is a vital factor for agriculture. The traditional sinusoidal analytical method and the half-order time derivative method (Wang and Bras 1999) was one of the methods of calculating soil flux density which has now been elaborated by Cheng et al., (2009). Mikova et al., (2005) suggest a simulation model and numerical procedure for soil temperature and soil heat flux calculation. Eulenstein et al.,(2005) suggested a method for calculating soil heat flux density as a function of net radiation for the three active surfaces. The temperature deviation curve model was first used (Uno et al., 2012) to determine the susceptibility of Abuja metropolis to soil compaction. It showed great success in that it accurately determined the soil compaction of five developmental areas of Abuja. Among its successes was its efficiency to determine the annual amplitude of the surface soil temperatures of the same region. The model is financially low to be afforded in developing countries.

2.0 Theory

An alternative approach to estimating daily positive heat flux density based upon the soil heat transfer theory was first described by Wijk et al.,(1963) and Sellers (1965) as

$$G(0,t) = \Delta T_0 (C\omega\gamma)^{0.5} \sin(\omega t + \pi/4)$$

where *G(0,t)* = instantaneous surface soil heat flux density (W m-^{2}); *T* = the amplitude of the surface temperature (°C) wave (Tmax - Tmin)/2, *t* = time of day (sec); λ = the soil thermal conductivity (W m-^{1} K-^{1}); *C* = the volumetric heat capacity (J m-^{3} K-^{1}) ω = frequency.
The temperature deviation curve model introduced by Unoh *et al.,*(2012) is given by

$$\Delta T = A_0 e^{-\rho_s/\rho_b} \sin\left(-\frac{\rho_s}{\rho_b} - \frac{\pi}{2}\right)$$

ρ_s = soil particle density which is a approximately 2.66gcm-^{3} by Gupta *et al.,*. (2011), ρ_b = soil bulk density. ΔT= temperature deviation, A_0 is the annual amplitude of the surface soil temperature. We made an assumption that if the phase angles (at resonance) are equal for both equations (1&2)written above. Therefore

3.0 Methods

The study area is Minna -Niger State, central part of Nigeria . The soil samples were collected from four regions. The subsoil for the five group of soil were identified within the particles range 62±1% sand,28±4% clay,6±1% silt, 0.6±0.2% organic carbon,1.5±0.5% organic matter. The observations were carried out at the laboratory of the Soil Physics laboratory of the above university (table 1-10). The sample soil was initially dried in the sun for six days in order to have uniform moisture content. The samples were packed into four PVC tubes after taking the mass of the tubes when empty. The tops covered with black polythene material to avoid moisture loss by evaporation. Thermometers (0^0C – 100^0C range) was inserted at level 20cm on each of the tubes representing the soil depth level below the earth surface. The volume of each of the PVC tubes was taken in order to help in the calculation of the bulk density. Then, the samples were placed in an open space in the evening prior to the day of the measurement in order to have uniform and stabilized

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distribution of the heat by the solar energy. The soil temperature was monitored at a level of 20cm with intervals of 60 minutes ranging from 8.00am to 5.00pm for a period of ten days in order to obtain the minimum and maximum temperatures. The observation were taken according to the Al – Nadhabandi and Kohnke (1965) The samples for soil heat flux were taken using the calometric method (Kluitenberg *et al.,*., 1993).

4.0 Results

The results of the experiments for the four samples of soil (PVC1, PVC2, PVC3 &PVC4)are shown in table 1, table 2, table 3, and table 4.

TABLE 1: DAILY TEMPERATURE VARIATION WITH BULK DENSITY AND MOISTURE CONTENT, DAY 1.

TIME (24HR)	Tpvc 1 (0^0 C)	Tpvc 2 (0^0 C)	Tpvc 3 (0^0 C)	Tpvc 4 (0^0 C)	BD (kg m-^{3})	MC (%)	T_{Max} (0)
8:00	28·00	29·00	28·00	29·00	1.42	11.1	47
9:00	32·50	32·00	32·00	31·00			
10:00	38·00	37·50	37·50	36·50	1.51	18.2	46.5
11:00	41·00	40·00	40·50	39·50			
12:00	43·00	42·50	42·50	41·50	1.54	10.1	46
13:00	44·50	43·50	43·50	43·00			
14:00	46·00	45·50	45·50	44·00	1.66	7.4	45.5
15:00	47·00	46·50	46·00	45·50			
16:00	46·50	46·50	46·00	45·50	1.75	15	46
17:00	44·50	44·50	42·50	44·00			

TABLE 2:DAILY TEMPERATURE VARIATION WITH BULK DENSITY AND MOISTURE CONTENT, DAY 2.

TIME (24HR)	Tpvc 1 (0^0 C)	Tpvc 2 (0^0 C)	Tpvc 3 (0^0 C)	Tpvc 4 (0^0 C)	BD (kg m-^{3})	MC (%)	T_{Max} (0)
8:00	28·00	29·00	30·00	30·50	1.37	18.2	47.5
9:00	34·00	32·00	33·00	34·00			
10:00	39·00	38·00	40·00	39·50	1.38	23.1	46
11:00	42·00	41·00	41·50	42·00			
12:00	45·00	44·50	43·00	43·50	1.43	26.7	46.5
13:00	46·50	44·50	45·50	44·00			
14:00	47·00	46·00	46·50	45·00	1.46	16.1	46.5
15:00	47·50	45·00	44·00	44·00			
16:00	46·50	44·00	43·50	45·00	1.64	21.6	46
17:00	46·00	43·50	43·50	46·50			

TABLE 3: DAILY TEMPERATURE VARIATION WITH BULK DENSITY AND MOISTURE CONTENT, DAY 3.

TIME (24HR)	Tpvc 1 (0^0 C)	Tpvc 2 (0^0 C)	Tpvc 3 (0^0 C)	Tpvc 4 (0^0 C)	BD (kg m-^{3})	MC (%)	T_{Max} (0)
8:00	30·00	28·50	28·00	29·00	1.34	15	47
9:00	36·50	34·00	34·00	34·50			
10:00	43·00	40·00	41·00	40·50	1.38	25	47.5
11:00	45·50	43·00	42·50	43·00			
12:00	46·00	43·50	43·00	43·00	1.48	10	46.5
13:00	44·00	43·00	43·00	44·00			
14:00	47·00	45·50	45·00	45·00	1.53	15	47.5
15:00	46·50	47·00	46·00	46·00			
16:00	47·00	47·50	46·50	47·50	1.56	24.1	48
17:00	46·00	46·50	46·00	46·50			

TABLE 4: DAILY TEMPERATURE VARIATION WITH BULK DENSITY AND MOISTURE CONTENT DAY, 4

TIME (24HR)	Tpvc 1 (0^0 C)	Tpvc 2 (0^0 C)	Tpvc 3 (0^0 C)	Tpvc 4 (0^0 C)	BD (kg m-^{3})	MC (%)	T_{Max} (0)
8:00	30·00	28·50	28·00	29·00	1.33	15.4	47
9:00	36·50	34·00	34·00	34·50			
10:00	43·00	40·00	41·00	40·50	1.49	1.49	47.5
11:00	45·50	43·00	42·50	43·00			
12:00	46·00	43·50	43·00	43·00	1.62	1.62	46.5
13:00	44·00	43·00	43·00	44·00			
14:00	47·00	45·50	45·00	45·00	1.67	16.4	47.5
15:00	46·50	47·00	46·00	46·00			
16:00	47·00	47·50	46·50	47·50	1.75	23	48.5
17:00	46·00	46·50	46·00	46·50			

TABLE 5:DAILY TEMPERATURE VARIATION WITH BULK DENSITY AND MOISTURE CONTENT, DAY 5.

TIME (24HR)	Tpvc 1 (0^0 C)	Tpvc 2 (0^0 C)	Tpvc 3 (0^0 C)	Tpvc 4 (0^0 C)	BD (kg m-^{3})	MC (%)	T_{Max} (0)
8:00	30·00	30·00	30·50	30·50	1.28	24.4	48
9:00	32·50	33·00	32·00	33·50			
10:00	44·00	43·00	43·50	42·00	1.30	36.4	47
11:00	45·00	43·00	43·00	43·00			
12:00	45·00	44·00	45·50	44·00	1.42	20.5	47.5
13:00	46·00	44·50	46·00	45·00			
14:00	46·50	46·00	47·00	47·00	1.50	30	47.5
15:00	47·00	46·50	46·00	47·50			
16:00	48·00	47·00	47·50	46·00	1.68	40	47
17:00	46·00	46·50	46.00	45.00			

TABLE 6: DAILY TEMPERATURE VARIATION WITH BULK DENSITY AND MOISTURE CONTENT, DAY 6.

TIME (24HR)	Tpvc 1 (0^{0} C)	Tpvc 2 (0^{0} C)	Tpvc 3 (0^{0} C)	Tpvc 4 (0^{0} C)	BD (kg m^{-3})	MC (%)	T_{Max} (0)
8:00	29·00	30·00	28·00	28·00	1.3	12.5	47.5
9:00	30·00	31·00	32·00	30·00			
10:00	32·00	34·00	33·00	32·00	1.42	20	47
11:00	38·00	39·00	37·00	36·00			
12:00	44·00	42·00	41·00	42·00	1.45	29	46.5
13:00	45·00	43·00	45·00	44·00			
14:00	47·00	46·00	45·50	45·00	1.57	15.1	45
15:00	47·50	47·00	46·00	44·00			
16:00	47·00	46·00	46·50	45·00	1.65	37.5	47
17:00	45·00	44·50	44·00	44·50			

TABLE 7:DAILY TEMPERATURE VARIATION WITH BULK DENSITY AND MOISTURE CONTENT, DAY 7.

TIME (24HR)	Tpvc 1 (0^{0} C)	Tpvc 2 (0^{0} C)	Tpvc 3 (0^{0} C)	Tpvc 4 (0^{0} C)	BD (kg m^{-3})	MC (%)	T_{Max} (0)
8:00	29·00	28·50	28·50	29·00	1.26	15.4	48.5
9:00	37·00	36·50	36·00	36·00			
10:00	42·50	41·50	41·00	41·00	1.37	26.7	51
11:00	44·50	43·50	42·50	43·00			
12:00	46·00	45·00	44·00	44·50	1.42	10.1	49
13:00	46·50	46·00	45·00	45·00			
14:00	47·50	46·50	46·00	46·00	1.51	9	48
15:00	48·50	51·00	47·50	47·00			
16:00	48·00	49·00	49·00	48·00	1.61	21.1	51
17:00	46·50	48·00	48·00	47·00			

TABLE 8: DAILY TEMPERATURE VARIATION WITH BULK DENSITY AND MOISTURE CONTENT, DAY 8.

TIME (24HR)	Tpvc 1 (0^{0} C)	Tpvc 2 (0^{0} C)	Tpvc 3 (0^{0} C)	Tpvc 4 (0^{0} C)	BD (kg m^{-3})	MC (%)	T_{Max} (0)
8:00	29·50	29·00	29·00	29·00	1.3	15.4	49
9:00	36·00	35·00	34·00	34·50			
10:00	41·00	39·50	39·00	40·00	1.42	21.4	48
11:00	43·00	42·00	41·50	42·00			
12:00	43·50	43·00	42·50	43·00	1.49	30	47
13:00	46·00	45·00	44·00	45·00			
14:00	48·00	47·00	46·00	46·50	1.54	18.1	47
15:00	49·00	48·00	47·00	47·00			
16:00	47·50	46·50	46·00	46·50	1.61	22.9	46
17:00	45·00	44·00	44·00	43·50			

TABLE 9:DAILY TEMPERATURE VARIATION WITH BULK DENSITY AND MOISTURE CONTENT, DAY 9.

TIME (24HR)	Tpvc 1 (0^0 C)	Tpvc 2 (0^0 C)	Tpvc 3 (0^0 C)	Tpvc 4 (0^0 C)	BD (kg m-^{3})	MC (%)	T_{Max} (0)
8:00	28·00	29·00	28·00	29·00	1.26	20.1	49.5
9:00	34·00	35·00	35·00	33·00			
10:00	42·00	41·00	40·50	41·50	1.37	25·0	49
11:00	43·00	43·00	42·00	42·00			
12:00	44·50	43·50	44·00	45·00	1.39	10.5	48.5
13:00	47·00	46·50	46·00	46·00			
14:00	48·50	48·00	47·00	47·00	1.45	23	48
15:00	43·00	47·00	46·00	46·00			
16:00	49·50	49·00	48·50	48·00	1·60	29.4	47
17:00	48·00	47·00	46·00	46·50			

TABLE 10 :DAILY TEMPERATURE VARIATION WITH BULK DENSITY AND MOISTURE CONTENT, DAY 10.

TIME (24HR)	Tpvc 1 (0^0 C)	Tpvc 2 (0^0 C)	Tpvc 3 (0^0 C)	Tpvc 4 (0^0 C)	BD (kg m-^{3})	MC (%)	T_{Max} (0)
8:00	29·00	28·00	29·00	29·00	1.34	13.4	48
9:00	32·00	30·00	31·00	30·00			
10:00	34·00	31·00	32·00	32·50	1.45	18.8	49
11:00	36·00	34·00	35·00	34·00			
12:00	45·50	44·50	44·00	44·50	1.51	9.1	49
13:00	46·00	45·00	44·00	43·50			
14:00	47·50	46·50	46·00	46·50	1.6	7.4	48.5
15:00	47·50	48·00	48·00	48·00			
16:00	48·00	49·00	49·00	48·50	1.62	16.1	50
17:00	47·00	48·00	48·00	47·00			

5.0 Discussion

Equation (3) was investigated under four conditions as shown in figure 1. The soil frequency heating was investigated against the bulk density when time, t=3600s (figure[1A]),it showed a curve which signifies positive parabolic relationship. The same result was obtained when soil frequency heating was investigated against the bulk density when time, t=36000s (figure[1B]).Generally, the result of both figure[1A&B], revealed that under the resonating phase, an increase in the time(t) reduces the soil heat frequency. Also, soil frequency heating was investigated against time (t) when $\frac{\rho_s}{\rho_b} < 1$ (figure[1C]), a Boltzmann distribution curve was obtained. The same relationship was obtained when $\frac{\rho_s}{\rho_b} > 1$ (figure[1D]).The Boltzmann distribution curve expresses the rate of heat flow which signifies the tendency of obtaining a high soil heat flux under the resonating phase

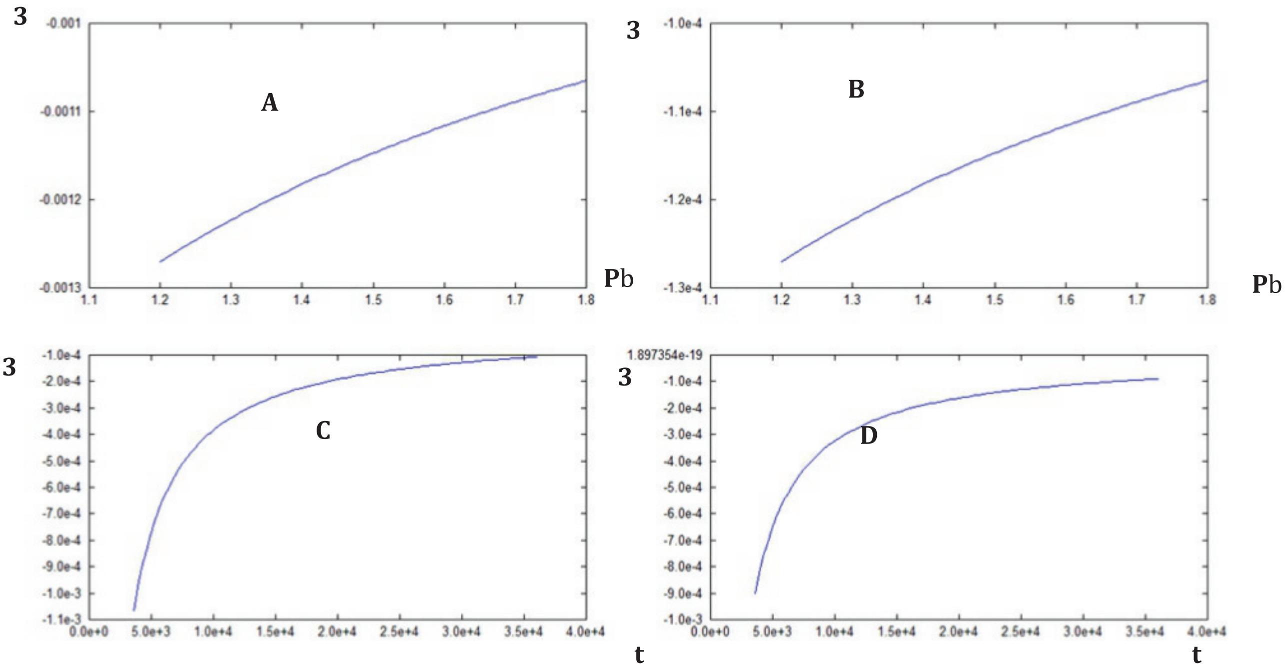
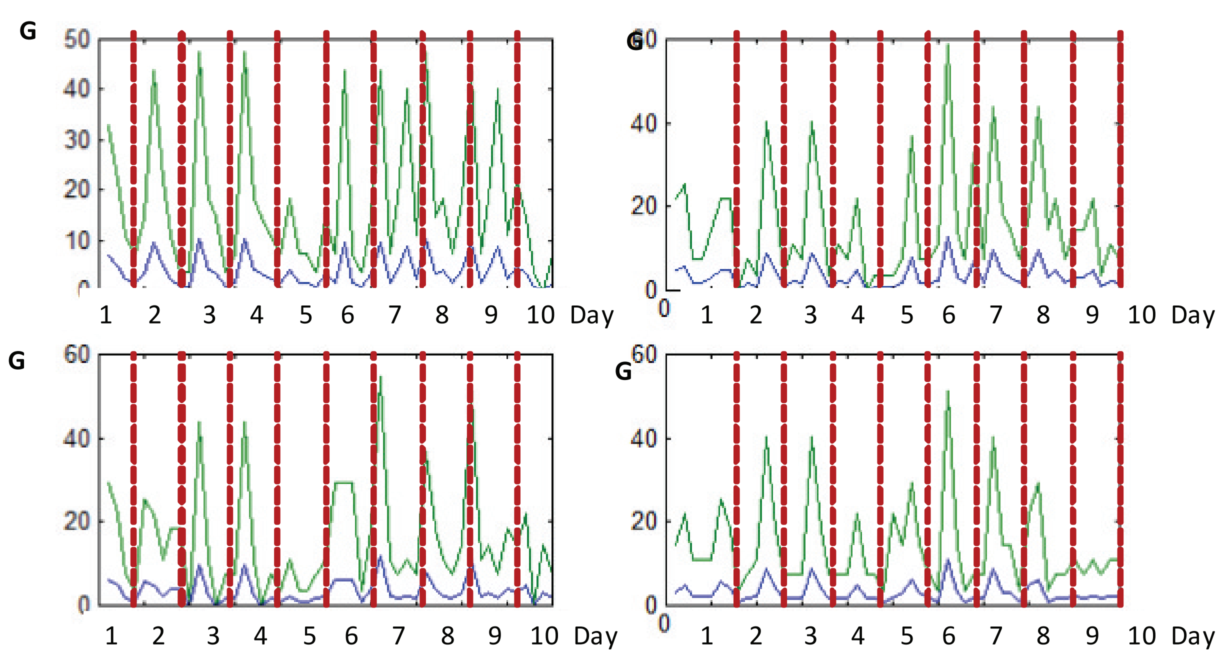


Figure 1[A]: soil frequency heating was investigated against the bulk density when time, t= 3600s. **1[B]:** soil Frequency heating was investigated against the bulk density when time, t = 36000 s. **1[C]:** soil frequency Heating was investigated against time (t) when $\frac{\rho_s}{\rho_b} < 1$ **1[D]:** soil frequency heating was investigated against Time (t) when $\frac{\rho_s}{\rho_b} > 1$

The daily soil heat flux was analyzed (figure [2]) using calorimetric method under two heating frequencies 1.5 X 10^{-3}Hz (green line) and 1.5 X 10^{-4}Hz (blue line). At higher frequency, the Soil heat flux showed significant increase. Soil sample A (figure [2A]), had the highest soil heat flux followed by sample B (figure [2B]), D (figure [2D]), C (figure [2C]) in descending order. The temperature deviation curve was plotted (figure [3,4,5&6]) against the soil bulk density (at suitable phase angle- $\frac{\pi}{5}$ and the annual amplitude of the surface soil temperatures is within the range -120< Ao >120). The scattering of the experimental soil deviation on the theoretical temperature deviation curve model affirm the soil compaction of the soil samples and soil heat flux. For example the number of dots on the line reveals the soil compaction of the soil samples and the number of intersection of the experimental deviation points signifies the heat flux of the sample which follows the same descending order as figure [2].

Figure [2]: daily soil heat flux for the four soil samples



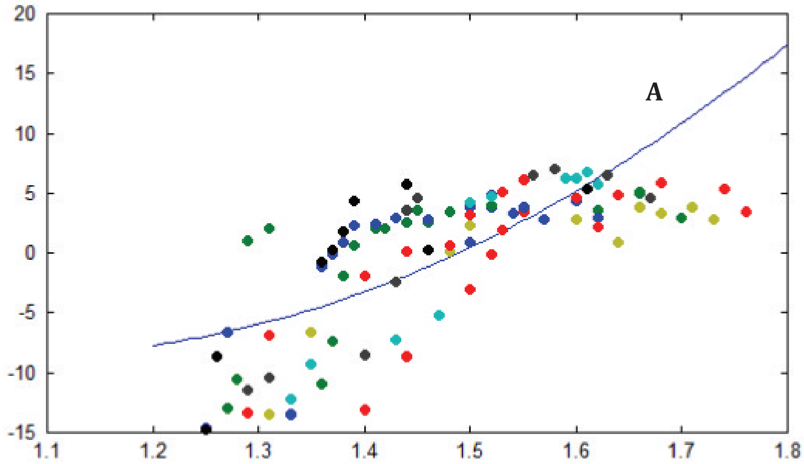


Figure [3]: temperature deviation curve for soil sample A. At suitable phase angle-$\frac{\pi}{5}$ and the annual amplitude of the surface soil temperatures is within the range -120< Ao >120

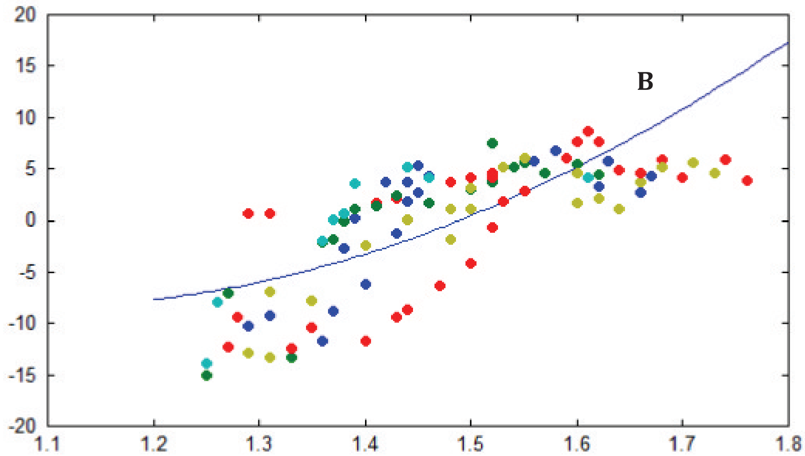


Figure [4]: temperature deviation curve for soil sample B. At suitable phase angle-$\frac{\pi}{5}$ and the annual amplitude of the surface soil temperatures is within the range -120< Ao >120

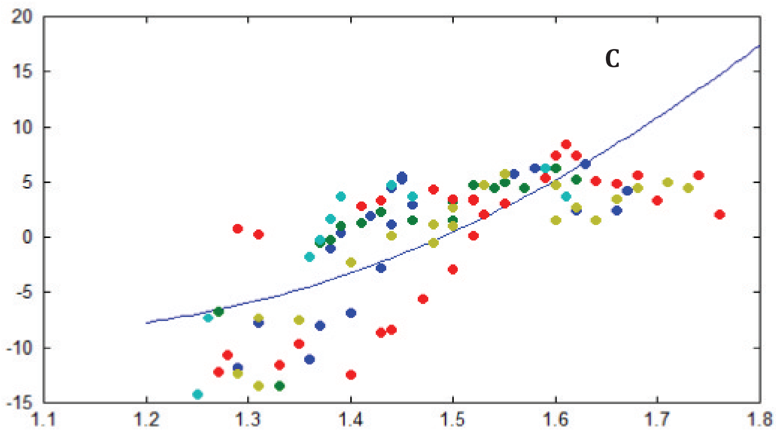


Figure [4]: temperature deviation curve for soil sample **C.** At suitable phase angle-$\frac{\pi}{5}$ and the annual amplitude of the surface soil temperatures is within the range -120< Ao >120

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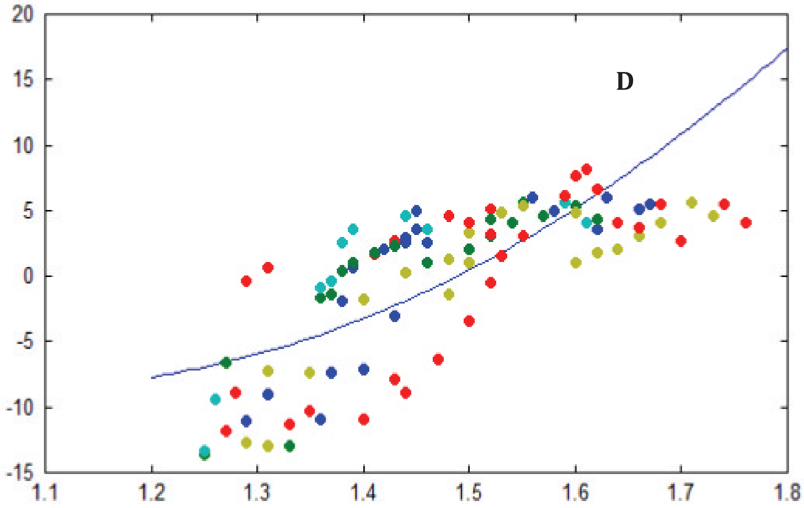
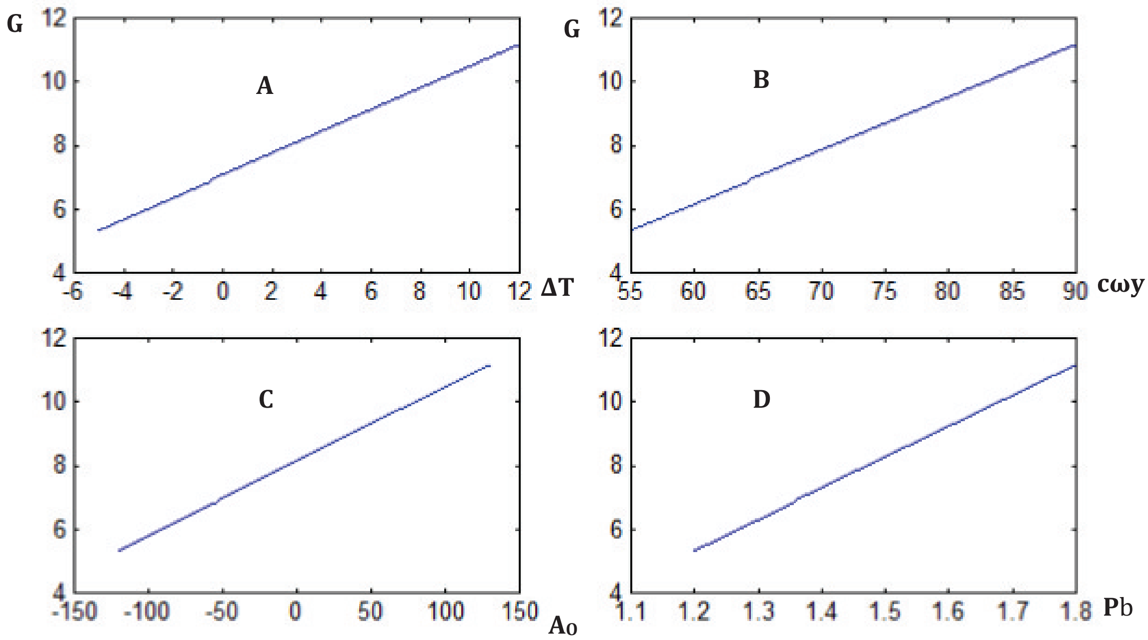


Figure [6]: temperature deviation curve for soil sample D. At suitable phase angle- $\frac{\pi}{5}$ and the annual amplitude of the surface soil temperatures is within the range -120< Ao >120

The theoretical analysis of equation [3] which related soil heat flux to temperature deviation (figure [7A] revealed that the soil heat flux is directly proportional to the temperature deviation which means an increase in the temperature deviation, there is an increase in the soil heat flux which conformed to the work of Malek (1993). In figure [7B], the soil heat flux was plotted against the products of soil thermal conductivity (y), volumetric heat capacity (C) and frequency (ω). It was also discovered that the relationship was directly proportional. The soil heat flux was plotted against the annual amplitude of the surface soil temperature (figure [7C]), the relationship was directly proportional which was opposite the arrangement in equation[3] and conformed to the postulation of Michael *et al.,*(1981). Figure [7D], revealed that if there is an increase in the bulk soil density, there is an increase in the soil heat flux.



Figure[7]:analysis of equation[3] of soil heat flux to vital soil parameter

6.0 Conclusion

The calorimetric method used in this work has proved to be more suitable for short-term estimation of soil heat flux data. The Boltzmann distribution curve represented the rate of heat flow which is dependent on the soil heating frequency. Soil heat flux has also been related to the bulk soil density which simply means that the soil type in Minna-Nigeria is suitable for agricultural use among other applications. The annual amplitude of the surface soil temperature was discovered to have impact on the soil heat flux. More importantly, the temperature deviation curve model has been found to estimate soil heat flux from both short and long-term remotely sensed surface temperature. Through surface soil temperatures, temperature deviation curve model can be applied in metrological predictions, geological data analysis and interpretation of natural mineral deposits data.

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