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INVESTIGATION OF THERMAL AND HYDRAULIC PROPERTIES OF SANDY-LOAM SOILS UNDER DIVERSE LAND-USE SYSTEMS

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ABSTRACT

Information about soil thermal properties (STPs) based on different land-use patterns will support optimum utilization of ground-based thermal energy. This study quantified in-situ soil thermal properties (STPs) and some associated hydraulic parameters under different land practices in parts of Abeokuta, Southwest Nigeria. Five sampling points for thermal and hydraulic properties were established within 80 m by 40 m on each of grassland (GL), oil palm plantation site (OPS), football pitch (FP), dumpsite (DS), automobile mechanic workshop (AMW), and block making site (BMS). Thermal properties were measured *in situ* using KD2 Pro Thermal Properties Analyzer while topsoil hydraulic parameters were determined using standard laboratory procedures. Pearson's correlation and analysis of variance (ANOVA) were employed to determine the interrelationships and variations of measured STPs among the diverse land use patterns. Results of assessed STPs indicated that the average values of thermal conductivity (λ_s) were higher in AMW and DS (1.77 and 1.53 W/mK, respectively) relative to that of other land uses (0.37- 0.79 W/mK). In the investigated land uses, highest and lowest mean values of thermal diffusivity (TD) (0.850 and 0.209) were recorded in AMW and GL, respectively. The OPS had lowest mean specific heat capacity (C_s) (1.381 MJ/m^{3}K) and bulk density (BD) of ≈1.5 Mg/m^3 while DS topsoil had maximum value of average C_s (3.930 MJ/m^{3}K) but least BD of 1.17 Mg/m^3. The highest values of average thermal admittance (μ_s), saturated hydraulic conductivity (K_{sat}) and soil moisture content (MC) were observed in FP while least values of μ_s, K_{sat} and MC were recorded in AMW. The mean thermal resistivity (TR) values in DS and AMW were within the 90 °C-cm/W recommended for safe cable engineering practices. Correlation analysis revealed strong direct relation between λ_s and TD while ANOVA results showed that most of the measured STPs were significantly different ($p<0.05$) among the six land-use systems. Most of the measured STPs can be regarded as dynamic characteristics that are intensely swayed by land uses.

Keywords: Soil thermal properties, Hydraulic properties, Land-use patterns, Thermal conductivity, Specific heat capacity, ANOVA.

INTRODUCTION

Land can be used for several purposes by humans at the outlay of its appropriateness, thereby leading to land degradation and alteration in inherent soil properties of the landscape (Ganiyu, 2018). In most developing countries (especially in Africa continent), land has been intensively used for developmental and economic activities such as construction of commercial edifices, recreational centers and housing estates to cater for increasing population, resulting in the loss of agricultural lands (Ganiyu, 2018; Tesfahunegn and Gebru, 2020). Land use refers to the administration practice controlling the use of land resources for specific activity (Quentin *et al*., 2010; Ganiyu, 2018). Different land use systems affect soil characteristics separately. Thus, the capacity of a specific land to perform optimally may be persistent, enhanced or declined according to the extent of the alteration of soil quality parameters in reaction to land use management (Karlen, 1997; Ganiyu, 2018; How Jin Aik *et al*., 2021).

Heat flow from or into the soil medium occurs via transfer mechanism of conduction, long wave radiation, and by convection process due to existence of thermal gradients within the soil matrix (Hamdhan and Clarke, 2010; Rutten *et al*., 2010; Abbes *et al*., 2019; Yaowen *et al*., 2021). However, temperature gradients, not only serve as condition for heat flow but also considerably sway soil hydraulic properties (Gao and Shao, 2015). The bulk of heat transfer in soil matrix happened through conduction process (Alrtimi *et al*., 2016; Zhu *et al*., 2019). The conduction of heat in the soil assumes uniform and constant soil medium and it can be described by one dimensional Fourier's law (Yershov, 1998; Zhu *et al.*, 2019). Thermal characteristics of soil such as thermal conductivity (λ_s), volumetric heat capacity (C_s), thermal resistivity (TR), and thermal diffusivity (TD) are collectively influenced by soil factors such as particle size distribution, bulk density (BD), moisture content (MC), organic matter content, mineral composition, grains size distribution and temperature (Ju *et al.*, 2011; Oladunjoye *et al.*, 2013; Mengistu *et al.*, 2017; Li *et al.*, 2019). The soil thermal properties (STPs) that are regularly of attention are thermal conductivity (λ_s) and the volumetric heat capacity (C_s) (Tokoro *et al.*, 2016; Alrtimi *et al.*, 2016). However, λ_s is one of the most important thermal properties associated with the heat exchange at the ground surface (Haigh, 2012; Bai *et al.*, 2014; Zhang and He, 2016; Bertermann and Schwarz, 2017).

Thermal conductivity (λ_s) is defined as the amount of heat flow due to the unit temperature gradient in unit time under steady conditions in a direction normal to the unit surface area (Bristow 2002, Faitli *et al.*, 2015). The volumetric heat capacity (C_s) is defined as the quantity of heat needed to raise the temperature of a unit volume of soil by one degree Celsius (Hillel, 2004; Roxy *et al.*, 2014; Haruna *et al.*, 2017). The thermal diffusivity (TD) is the ratio of thermal conductivity to its volumetric heat capacity (Hanson *et al.*, 2000; Gladwell and Hetnarski, 2009). Soil thermal diffusivity (TD) is regarded as an important thermal property needed for proper estimation of soil temperature dispersion and heat flux in the soil matrix (de Jong van Lier and Durigon, 2013; Roxy *et al.*, 2014; An *et al.*, 2016). Another interconnected soil thermal property is the thermal admittance (μ_s), which describes the ability of soil surface to accept or release heat to the immediate surrounding (Roxy *et al.*, 2014).

The knowledge of soil thermal properties found useful applications in many engineering projects such as ground source heat pumps, design of energy piles, laying of telecommunication cables, underground oil/gas storage, buried power lines, waste contaminant, irrigation process, agricultural meteorology, and earthquake precursors to mention a few (Oladunjoye and Sanuade 2012a, b; Rózański and Sobótka, 2013; Amaludin *et al.*, 2016; Roxy *et al.*, 2014; Mengistu *et al.*, 2017). The feasibility of a good subsurface geothermal system requires supporting and enhancing soil thermal properties in addition to adequate MC of the soil (Bertermann and Schwarz, 2017). The STPs (especially λ_s) depend strongly on the MC of the soil as the latter enhances the thermal connection amongst the soil particles (Hanks and Ashcroft, 1986; Tokoro *et al.*, 2016; Tong *et al.*, 2019). The extent of the thermal properties reaction to the MC level was however variable. For instance, some researchers reported direct relation between each of the STPs and MC (Oladunjoye *et al.*, 2013; Roźański and Stefaniuk, 2016) while curve linear response was reported by Tarnawski and Leong (2000), and Rubio (2013).

Several scientists have studied the impacts of different land use systems on soil physico-chemical properties and soil nutrients availability (Senjobi *et al.*, 2013; Chemeda *et al.*, 2017; Tellen and Yerima, 2018; Nanganoa *et al.*, 2019; Tesfahunegn and Gebru, 2020), and on hydraulic properties (Horel *et al.*, 2015; Ganiyu, 2018; Kalhoro *et al.*, 2018; Dionizo and Costa, 2019). Velichenko and Arkhangelskaya (2015) reported that changes in land use influence soil physico-chemical properties, and hence affect soil thermal properties. However, the quantitative expression of the trend of variation of thermal variables may differ in different soils due to different land use systems (Velichenko and Arkhangelskaya, 2015). Scientists have reported that STPs can be changed by land use practices (Abu-Hamdeh and Reader, 2000; Adhikari *et al.*, 2014; Haruna *et al.*, 2017). Specifically, the effects of land use systems on STPs based on different tillage systems have also been reported (Dec *et al.*, 2009; Shen *et al.*, 2018). There appears to be pintsized or inadequate details on the levels of *in situ* STPs based on non-agricultural land use systems. This is worth considering as the characterization of thermal properties of a particular land use pattern is vital in assessing the heat extraction potential of the site (Faitli *et al.*, 2015).

The purpose of this study is to evaluate the effects of selected land use patterns on *in situ* measured STPs. The objectives include assessment of levels of *in situ* measured STPs associated with six different land-use systems (grassland, football pitch, oil palm plantation site, block-making site, dumpsite, and automobile mechanic workshop site), application of statistical analyses to study the interrelationships among the analyzed variables, as well as comparison of the differences in means of analyzed STPs based on selected land-use systems.

MATERIALS AND METHODOLOGY

Study Area

The study was conducted within Abeokuta in Ogun state, southwest zone of Nigeria, which covers an estimated area of about 40.63 km^2 (Ufoegbune *et al.*, 2010). Abeokuta lies between latitudes 7°09'43″N - 7°15'22″N and longitudes 3°23'24″E - 3°29'22″E.The city is within humid tropical climate zone (Ganiyu, 2018). The rainy season is from March to October, while the dry season is from November to February under the influences of north-eastern winds from Sahara desert (Badmus and Olatinsu, 2010; Ganiyu, 2018). Yearly rainfall in Abeokuta and its environs spans between 1400 and 1500 mm with a mean of 1238 mm (Akinse and Gbadebo, 2016; Ganiyu, 2018), while the maximum temperatures (average 29 °C) occurred in March and average minimum temperature of 25 °C in August (Ganiyu, 2018). Abeokuta is categorized as Aw (winter dry season) according to Köppen and Geiger system classification (Essenwanger, 2003; Ganiyu *et al.*, 2021). Six land-use practices are considered in the present study. These are GL, OPS, FP, DS, BMS, and AMW. The grassland (GL) and oil palm plantation site (OPS) have been in existence for more than 30 years, the BMS has been in operation for more than 10 years, the football pitch (FP) has been under continuous use since 2005 while DS and AMW have been in existence since 2005 and 1995, respectively. The soils in OPS belong to Plinthic eutrudalf/Plinthosols, Ferric cambisols/Oxic ustopept for GL, soil type in BMS belongs to Typic eutrudalf/Rhodic luvisols, FP as Ferric cambisols/Oxic ustopept; Ferric Lavisols/Oxic Paleustalf for DS and Rhodic paleaqualf/Rhodic fluvisol for the AWS according to the United States Department of Agriculture (USDA) and Food and Agricultural Organization (FAO) grouping system (FAO, 2015). Even though the soil type of different land uses are different but the land use types were carefully chosen based on surface (0-30 cm) textural classification (sandy loam). Figure 1 displays the location map of the study site.

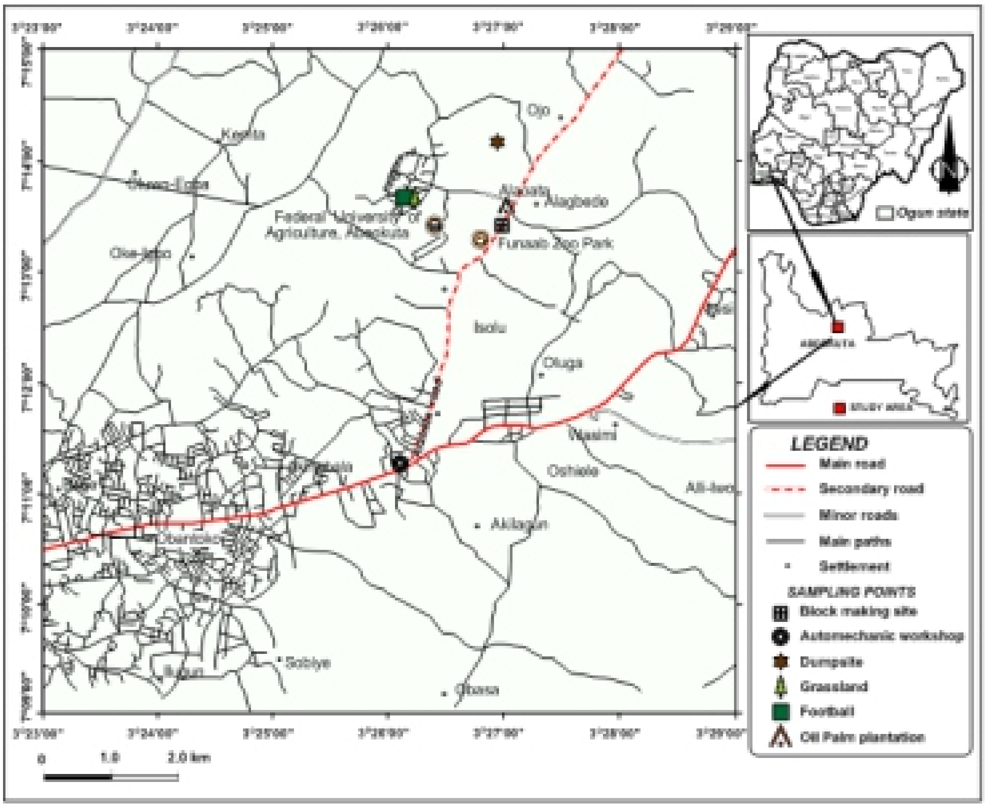

Figure 1: Location map of the study area showing the land use patterns.

Geology of the Study Area

Abeokuta falls within the Basement complex formation of southwest Nigeria. The basement complex rocks are loosely catergorized into migmatite-gneiss complex, the schist belt and pan African (Ca 600 Ma) older granite series (Elueze, 2000). The northern part of Abeokuta is described by pegmatitic veins supported by granite whereas the southern part arrives the transition region with the sedimentary formation of the eastern Dahomey basin (Ganiyu *et al.*, 2021). The western part of Abeokuta is categorized by granite gneiss of fewer permeable feature as well as various quartzite intrusions (Key, 1992). The foremost rock nature in the study area as shown in Figure 2 is migmatite gneiss.

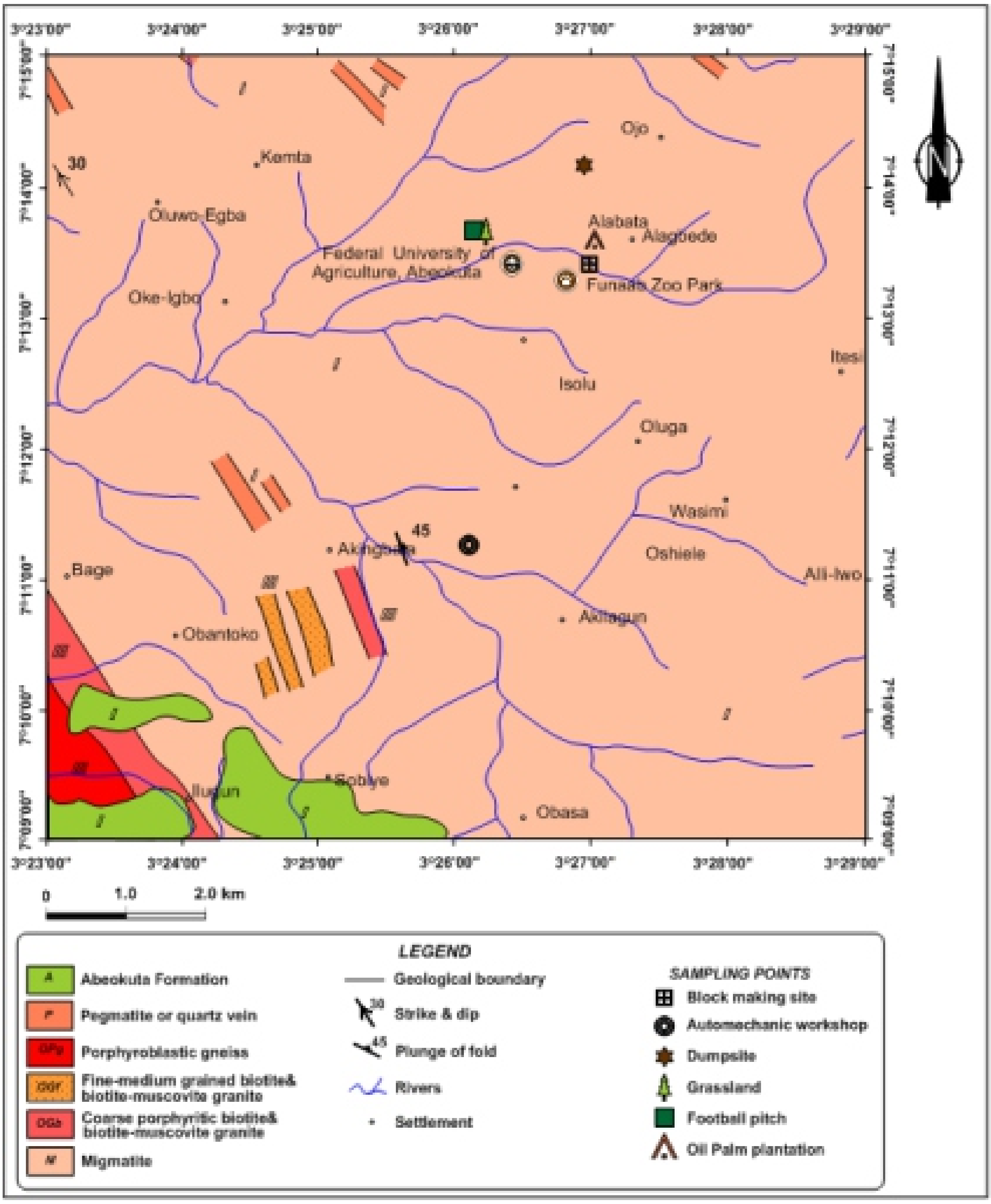

Figure 2: Geological map showing the land use types in the study area.

Measurements of soil thermal properties (STPs), Soil Samples Collection and Analyses

At every studied land use pattern, an 80 m by 40 m land area was recognized with the use of a measuring tape. This was distributed into five sampling points. The KD2 Pro thermal properties analyzer (manufactured by Decagon Devices, Inc, Pullman, WA, USA) connected with SH-1 dual probe sensor was used to measure the STPs (λ_s, C_s, TR, TD, and temperature) at each of the five sampling points on each land use type. The measurements were performed in February, 2020. The sixth parameter, thermal admittance (μ_s) was calculated through the expression:

$$\mu_s = C_s \lambda_s^{-1/2} \quad (1)$$

The KD2 Pro uses the transient line heat source method to measure the STPs (Zheng *et al.*, 2017; Oyeyemi *et al.*, 2018) The SH-1 probe sensor consists of two 30 mm long parallel needle probes with 6 mm spacing and 1.3 mm diameter. Prior to taking measurement, the dual-probe sensor was calibrated by inserting the sensor into the two-hole Delrin block for 15 minutes for temperature equilibration (Amaludin *et al.*, 2016; Mengistu *et al.*, 2017). Furthermore, the topmost shallow of the ground was ladled in order to allow firm positioning of the sensor on the ground. The measurements of STPs were made by inserting the KD2 Pro connected with the sensor into the scooped ground surface. The KD2 Pro Thermal properties Analyzer connected with the sensor was then turned on to take the measurement at each sampling point. After the first reading, about 20 minutes waiting was allowed before taking the next reading (Oyeyemi *et al.*, 2018, Tong *et al.*, 2019). Soil samples (disturbed and undisturbed) were also collected at each of the five sampling points of measured STPs on each land use. The disturbed topsoil (0–30 cm) samples were collected with the use of soil auger for determination of particle size distribution (PSD), while undisturbed soil samples were collected inside cylindrical metal core (5 cm height and 5 cm diameter) for the determination of hydraulic properties. The disturbed near surface soil samples on each land use were put in polythene nylon, appropriately coded to prevent confusion. After the collection of the core sample at each sampling point, the soil was trimmed, protected with plastic caps at both ends using masking tape. All the collected soil samples were analyzed at the Soil Physics laboratory of Institute of Agricultural Research and Training (IAR&T), Moor Plantation, Ibadan, Nigeria. At the laboratory, the disturbed soils were air dried, mildly crushed, and filtered with 2 mm sieve ahead commencement of PSD analysis. The PSD was examined by improved Bouyoucous hydrometer method as described by Gee and Or (2002) with soil textural categorization done by USDA textural triangle. The soil saturated hydraulic conductivity (K_{sat}) was evaluated using the constant head permeameter method after Reynolds and Elrick (2002) while the bulk density (BD) was determined using the gravimetric soil core method with assumed particle density of 2.65 g/cm^3.

The porosity (in %) was extrapolated from the measured BD using the equation (2) depicted by Hillel (2004),

$$\text{Porosity} = 1 - \frac{\rho_b}{\rho_{particle}} \quad (2)$$

Where ρ_b denotes bulk density in g/cm^3 and $\rho_{particle}$ is 2.65 g/cm^3 (Hillel, 2004). The soil moisture content (MC) was determined on the same day with the STPs by the method of weight loss in accordance with ASTM D4959-07 (ASTM D4959, 2007).

Statistical Analysis

Analysis of variance (ANOVA) was used to evaluate and compare the impacts of selected land use patterns on mean values of STPs. All the data in the ANOVA were reported as means. The nature of relationships among the considered STPs was examined by the Pearson's correlation analysis. All the analyses were done with the SPSS statistical software package 20.0.

RESULTS AND DISCUSSIONS

The results of PSD and textural classes of collected soil samples in all investigated sites are presented in Table 1. The measured STPs and hydraulic variables at all the sampling points are listed in Table 2 whereas Table 3 has the average values of thermal and hydraulic parameters from six diverse land-use types. Table 1 indicates that soils in all six investigated land uses belong to sandy loam texture. The results of PSD revealed that the average sand fractions is higher than clay/silt content in all investigated land uses. This suggests resemblance of geological materials and meteorological situations in the soil making process at the study site (Ganiyu, 2018). From Table 3, the average BD and porosity fluctuated from 1.17 to 2.10 Mg/m^3 and 20.7 to 55.7%, respectively. The highest mean BD (2.10 Mg/m^3) was recorded in AMW while DS samples had least value of BD (1.17 Mg/m^3). The BD values of soil in OPS, FP, and GL lie within the range 1.48 – 1.54 Mg/m^3 while the range of mean BD values in non-agricultural land use types (AMW, DS, and BMS) was 1.17 – 2.10 Mg/m^3. The BD values in OPS, FP, and GL fall within the typical density for a field soil that can maintain plant growth which is around 1.5 Mg/m^3 (Campbell and Bristow, 2014). Result of lowest BD in DS soil could be due to the fact that continuous addition of soil organic carbon decreases soil BD (Njoku, 2015; Agbeshie and Banunle, 2020). To buttress the inverse relation between BD and porosity, the lowest mean porosity was obtained in AMW while DS soils had highest mean porosity. The range of mean K_{sat} in all investigated land–use systems is from 9.67 to 50.86 cm/hr. The maximum average K_{sat} value was noticed in FP whereas AMW has lowest mean K_{sat}. The highest mean value of K_{sat} at FP site may be due to bridging of sand particles and the calcined clay (CC) usually used as amendment in natural sport turf, which possibly provided connecting pores, thus resulting in greater K_{sat} (Goodall *et al.*, 2005). The lowest value of K_{sat} at AMW may be due to the fact that water could not displace spent engine oil /petroleum hydrocarbon from the soil pore spaces due to hydrophobicity of oil (Ahamefule *et al.*, 2017; Hewelke *et al.*, 2018; Hewelke and Gozdowski, 2020). The spent oil in the AMW occupied the macropores and coated macro aggregates, thus retarding the movement of water into soil aggregates (Ahamefule *et al.*, 2017; Devatha *et al.*, 2019). Similar result of reduced K_{sat} in hydrocarbon contaminated soil (like AMW) relative to control soil was reported by Ganiyu *et al.* (2019), Devatha *et al.* (2019) and Hewelke and Gozdowski (2020). Furthermore, substantial lowest K_{sat} (9.67 cm/h) at the highest BD (2.10 Mg/m^3) observed in AMW site concurs with comparable significant reduction in K_{sat} at the high BD in petroleum lean oil sand overburden reported by Pernitsky *et al.* (2016). It was also observed that the mean K_{sat} at FP was twice its value in OPS and almost thrice its mean value in GL site. Furthermore, the mean K_{sat} at FP increases significantly when compared to that of other studied land uses. This may indicate the highest MC observed at FP (51.08%) will be transmitted as rapidly as possible and return the soil to its maximum aeration state. The results of MC revealed that the mean soil MC ranged from 21.80 to 51.08% in all studied land use-types. The results of MC further revealed that highest mean MC (51.08%) was observed in topsoil of FP while the lowest mean MC (21.80%) was recorded at AMW. This is in agreement with similar result of reduced MC in diesel-treated soils relative to untreated control soil as reported by Ganiyu *et al.* (2019). There is lower value of mean MC (33.69%) in soil of OPS relative to that of either GL (37.26%) or FP (51.08%). This is because soil surface protected by a crop canopy reflects extra solar radiation and vaporize more water from the topsoil layer than a bare surface (Adhikari *et al.*, 2014).

Table 1: The mean particle size distribution and soil textural class in selected land-use systems.

Land Use System	% sand	% silt	% clay	Soil Textural Class
GL	70.04	21.36	8.60	SANDY LOAM
FP	69.70	22.70	7.60	SANDY LOAM
OPS	66.80	22.60	10.60	SANDY LOAM
AMW	75.84	13.84	10.32	SANDY LOAM
DS	58.48	27.92	13.68	SANDY LOAM
BMS	72.40	18.80	8.80	SANDY LOAM

Table 2: Values of measured thermal and hydraulic parameters on land use patterns.

Land uses	**TR (°C-cm/W)**	**λ_s (W/mK)**	**TD (mm^2/s)**	**C_s (MJ/m^{3}K)**	**Temp (°C)**	**μ_s (W/m^{2}K)**	**K_{sat} (cm/h)**	**MC (%)**	**BD Mg/m^3**	**Porosity (%)**
OPS 1	385.0	0.260	0.217	1.196	33.20	2.346	28.43	32.75	1.54	41.9
OPS 2	384.0	0.260	0.225	1.159	32.77	2.273	24.36	32.23	1.63	38.4
OPS 3	139.4	0.717	0.449	1.559	30.70	1.841	27.39	32.65	1.71	35.5
OPS 4	269.3	0.371	0.283	1.313	36.28	2.156	13.12	28.25	1.54	41.9
OPS 5	316.7	0.316	0.189	1.674	33.57	2.978	27.41	42.60	1.30	50.8
FP 1	260.7	0.316	0.246	1.560	37.30	2.517	57.9	60.1	1.59	40.1
FP 2	425.5	0.236	0.128	1.845	37.81	3.798	48.3	62.7	1.51	43.2
FP 3	116.6	0.857	0.227	3.784	37.04	4.088	61.8	64.2	1.49	44.0
FP 4	124.6	0.803	0.307	2.617	39.66	2.920	60.6	34.2	1.40	47.2
FP 5	200.4	0.499	0.204	2.451	42.83	3.470	25.7	34.2	1.45	45.3
GL 1	283.7	0.352	0.207	1.704	42.38	2.872	19.09	32.21	1.61	39.3
GL 2	229.7	0.435	0.189	2.310	42.68	3.502	14.05	38.26	1.54	42.0
GL 3	274.1	0.365	0.242	1.505	33.37	2.491	18.94	38.34	1.44	45.6
GL4	314.8	0.318	0.193	1.642	31.89	2.912	15.33	32.59	1.29	51.2
GL 5	270.0	0.370	0.218	1.701	45.77	2.796	17.79	44.92	1.62	38.8
AMW 1	97.31	1.028	0.511	2.013	31.31	1.985	0.02	12.6	1.81	31.7
AMW 2	53.07	1.884	1.113	1.693	26.14	1.233	2.43	39.5	2.36	10.9
AMW 3	58.38	1.713	0.928	1.847	25.93	1.411	22.81	36.4	2.14	19.2
AMW 4	38.16	2.621	0.563	2.880	26.59	2.262	1.29	8.3	2.15	18.9
AMW 5	61.70	1.621	0.563	2.880	26.59	2.262	1.29	8.3	2.15	18.9
DS 1	46.61	2.145	0.489	4.384	32.07	2.993	28.7	40.1	1.22	54.0
DS 2	68.88	1.452	0.340	4.273	31.40	3.546	20.2	34.8	1.12	57.7
DS 3	91.42	1.094	0.369	2.964	31.27	2.834	20.7	50.0	1.15	56.6
DS 4	80.97	1.235	0.359	3.444	33.12	3.099	20.1	49.1	1.16	56.4
DS 5	57.44	1.741	0.380	4,577	31.91	3.469	21.0	47.6	1.23	53.6
BMS 1	116.2	0.861	0.473	1.820	40.14	1.961	1.6	29.2	1.69	36.3
BMS 2	124.9	0.801	0.577	1.388	40.42	1.551	3.9	35.2	1.60	39.6
BMS 3	233.5	0.428	0.325	1.317	48.45	2.013	4.6	22.6	1.58	40.4
BMS 4	102.6	0.975	0.682	1.430	36.73	1.448	4.8	22.6	1.55	41.4
BMS 5	112.0	0.893	0.600	1.489	38.58	1.576	39.0	21.8	1.65	37.7

Table 3: Means values of thermal and hydraulic parameters on land use types.

Land uses	STPs						Hydraulic properties			
	TR (°C-cm/W)	λ_s (W/mK)	TD (mm^2/s)	C_s (MJ/m^3K)	Temp (°C)	μ_s (W/m^2K)	K_{sat} (cm/h)	MC (%)	BD (Mg/m^3)	Porosity (%)
OPS	298.9	0.385	0.273	1.381	33-30	2.319	24.14	33.69	1.54	41.7
FP	225.6	0.556	0.222	2.451	38.93	3.358	50.86	51.08	1.48	44.0
GL	274.5	0.368	0.209	1.772	39.22	2.915	17.13	37.26	1.50	43.4
BMS	137.8	0.792	0.531	1.489	40.86	1.709	10.78	26.28	1.61	39.1
DS	69.1	1.530	0.387	3.930	31.95	3.190	22.14	44.32	1.17	55.7
AMW	61.7	1.770	0.850	2.159	27.97	1.670	9.67	21.80	2.10	20.7

In terms of STPs, the mean λ_s ranged from 0.368 to 1.770 W/mK in all investigated land uses. The highest mean λ_s was observed at AMW while GL had least value of λ_s. The lowest value of λ_s in GL could be due to the fact that λ_s of organic soil is typically lower than that of mineral soils (O'Donnel *et al.,* 2009). According to Adhikari *et al.* (2014), Hewins *et al.* (2018) and Poeplau (2021), grassland soil stores large amounts of terrestrial SOC per unit area. Therefore, lowest mean value of λ_s/TD in GL could be as a result of insulating actions of SOC that acts as an obstruction to thermal transport (Adhikari *et al.*, 2014). Highest mean value of λ_s (1.770 W/mK) in AMW could be due to its highest BD (2.10 Mg/m^3), resulting in increase in number of contact points between the soil particles (Salomone and Kovacs, 1984). Salomone and Kovacs (1984) reported that this rise in contact points offers a greater heat flow path, an indication of rise in λ_s value. Similar appropriate increase in λ_s and TD at petroleum hydrocarbon-polluted soil was also reported by George *et al.* (2010). In case of DS site, higher value of λ_s (1.530 W/mK) coupled with maximum value of C_s could be due to the fact that heat losses at DS occurred through some physical, chemical and microbiological processes (Faitli *et al.*, 2015). Moreover, the kind of wastes deposited on the investigated DS, located within the University campus were non-degradable wastes (e.g glass bottles, plastics, nylons, books, fabrics and plastic food containers) that did not support supply of fresh organic matter (Bartkowiak *et al.*, 2018). A further scrutiny of λ_s values in Table 3 revealed that the mean value of λ_s in BMS was about 2.2 times larger than that of GL while the mean values of λ_s in AMW and DS were about 5 and 4 times higher than its corresponding value in GL. Specifically, average λ_s value in BMS (0.792 W/mK) was compared with various reported λ_s values for bricks/ blocks (Ganiyu *et al.*, 2021). For instance, the range of λ_s of bricks as a reported by Yehuda (2003) was 0.60 - 0.73 W/mK, that of hollow shale block was 0.726 W/mK (Bai *et al.*, 2017); recycled constructions and demolition waste blocks (RCDW) had λ_s within the interval of 0.60 - 0.78 W/mK (Callejas *et al.*, 2017), λ_s of soil-cement block was found to lie in the range of 0.842-1.097 W/mK (Balaji *et al.*, 2015) while λ_s of pure mansory block was reported by Ashraf *et al.* (2020) to be 0.81 W/mK. In this study, the mean λ_s that we got for soils under BMS was 0.792 W/mK and compares fairly with aforementioned reported λ_s values for blocks.

The values of λ_s (less than 0.65 W/mK) in OPS, FP, and GL are indications that organic material source is never suitable for dissipating heat from buried cable, no matter how dense (Campbell and Bristow, 2014). However, commonly used buried PVC pipes as heat exchanger can be used successfully at shallow depths in soils at all investigated sites. This is because λ_s values in all investigated land uses were higher than the reported range of λ_s values in most PVC pipes used as heat exchanger (0.14 – 0.45 W/mK) (Song *et al.,* 2006). Generally, the mean values of λ_s in AMW and DS (1.77 and 1.53 W/mK) were higher than those of the other land use types (0.38 – 0.79 W/mK). Specifically, the lower value of λ_s in BMS (0.79 W/mK) compared to its values in AMW and DS may be due to the fact that addition of quarry dusts (commonly used in cement-block industry) aids reduction of λ_s (Ramesh *et al.*, 2014., Ganiyu *et al.*, 2021). Furthermore, the mean values of λ_s in topsoils under AMW and DS were slightly higher than the range of typical λ_s of normal soil (0.15-1.50 W/mK) (Andersland and Ladanyi, 1994). The BD value has important role in the determination of λ_s value of soil (Faitli *et al.*, 2015). In this study, highest values of λ_s mean and BD with corresponding lowest mean MC characterized soil under AMW. Our result in this present study revealed that DS with least BD (1.17 Mg/m^3) had λ_s value that closely follows that of AMW. The lowest mean BD in DS may be due to nature of solid wastes deposited on selected DS used in this study.

The mean TR values in investigated land uses ranged from 61.72 to 298.90 °C-cm/W. The lowest and highest TR values were obtained in AMW and OPS, respectively. Table 3 further shows that mean TR values were <150 °C-cm/W in non-agricultural land uses (DS, AMW, and BMS). However, TR values were >150 °C-cm/W in GL, FP, and OPS. Furthermore, the mean TR values in DS and AMW (69.06 and 61.72 °C-cm/W, respectively) fall within the safe value of 90 °C-cm/W recommended for cable engineering practices and laying of gas/oil pipelines (Campbell and Bristow, 2007, 2014; Oladunjoye and Sanuade, 2012a, b). The range of mean C_s in studied land-use systems is from 1.381 to 3.930 MJ/m^{3}K. The highest mean C_s was recorded in DS while OPS had lowest mean C_s (1.381MJ/m^{3}K). Generally, the mean C_s (in MJ/m^{3}K) decreased in the order of DS (3.930) > FP (2.451) > AWS (2.159) > GL (1.772) > BMS (1.489) > OPS (1.381). The FP had higher C_s than that of either OPS or GL, probably because it has significantly higher MC (51.08%) than either GL or OPS. The higher value of C_s in FP compared to OPS or GL obtained in this study is in agreement with similar result of higher C_s of perennial switch grass reported by Haruna *et al.* (2017). Furthermore, the lower value of average λ_s in OPS (0.385 W/mK) with corresponding lowest mean C_s (1.381 MJ/m^{3}K) may be due to crop covers evaporating additional moisture from the topsoil horizon, hence decreasing λ_s and C_s (O'Connell and Snyder, 1999).

The highest mean C_s (3.930 MJ/m^{3}K) observed in near surface layer of DS may be due to the fact that heat generated in DS is as a result of several physical, chemical and microbial processes within the DS soils (Faitli *et al.,* 2015). In addition, it has been reported that landfill/DS represents large heat reservoir (Faitli *et al.,* 2015; Nocko *et al.*, 2020). The results of mean λ_s and C_s in DS are compared with the estimated values of λ_s and C_s of various solid fractions in the DS wastes as reported by Faitli *et al.* (2015). Adopting these estimates, C_s and λ_s of collective paper, glass, and plastic materials (which form the major components of wastes on studied DS) were 3.85J/g/K and 1.170 W/mK. The results of average C_s and λ_s obtained through KD2 Pro-thermal properties analyzer in DS are 3.930 MJ/m^{3}K and 1.530 W/mK. This means that our values of C_s and λ_s agrees fairly with estimated C_s and λ_s of combined plastic + glass + paper materials estimates as given by Faitli *et al.* (2015). However, according to the estimated values of material properties (solid phase of municipal waste) as given by Faitli *et al.* (2015), the reported value of λ_s for municipal waste was 3.90 W/mK while mean λ_s by KD2 Pro in DS was 1.530 W/mK. This means that our mean value of λ_s in DS is lower than the average λ_s reported by Faitli *et al.* (2015) at municipal solid waste landfill in Gyal-Hungary. The reported C_s for solid phase of municipal waste was 1.80 J/g/K while our mean C_s for topsoil as measured by KD2 Pro in DS was 3.930 MJ/m^{3}K. The disparity in values of mean C_s and λ_s in studied DS relative to that of estimated C_s and λ_s based on material properties of the solid phase, may be due to the nature of wastes deposited on our selected DS and its few material components of household wastes. The estimated BD (in kg/dm^3) for solid phase in landfill as reported by Faitli *et al.* (2015) was 1.297 kg/dm^3

while the mean BD for DS in this study was 1.17 Mg/m^3. This means that the obtained average BD of DS agrees with assertion by Faitli *et al.* (2015) that experimental BD value may be lower than the BD value of landfill after compaction and long retention time.

The mean TD values ranged from 0.209 to 0.850 mm^2/s. The lowest TD was found in GL while highest mean TD was observed in AMW. Specifically, the mean TD values were < 0.35 mm^2/s in agricultural related soils (FP, GL, and OPS) while TD values were > 0.35 mm^2/s in AMW, BMS, and DS. The lowest TD value on GL agrees with similar result of reduced TD on the top soil of virgin Chernozem reported by Velichenko and Arkhangelskaya (2015). Highest value of mean TD (0.850 mm^2/s) in AMW with corresponding lowest MC (21.80%) concurs with similar result of maximum TD at lowest MC as reported by Potter *et al.* (1985) and Usowicz *et al.* (2009).

The mean thermal admittance (μ_s) ranged from 1.670 to 3.358 W/m^{2}K when the soil MC varies from 21.80 to 50.86%. The results of average μ_s as shown in Table 3 revealed that lowest μ_s was recorded in AMW while FP had highest μ_s. In this study, direct relation exists between μ_s and MC (the higher the soil MC, the higher the μ_s). Similar positive relation between μ_s and MC was also reported by Roxy *et al.* (2014). However, it must be stated here that the direct relation between μ_s and soil MC was not visible when the soil MC was greater than 22% in the work of Roxy *et al.* (2014). The mean soil temperature in selected land uses ranged from 27.97 to 40.86 °C. The minimum and maximum mean temperatures were chronicled in AMW and BMS, respectively. However, the mean temperatures in all studied sites were lesser than the maximum temperature of 55 °C beyond which most plants cannot survive without water (Chima *et al.*, 2011). Furthermore, the values of mean temperatures obtained in this study showed little or no effect on soil hydraulic conductivity values. This may be due to low clay content (<15%) in all collected soil samples (Gao and Shao, 2015). In addition, the lowest mean K_{sat} (9.67 cm/h) with corresponding lowest mean temp (27.97 °C) in AMW may be due to presence of various contaminants (i.e petroleum-derived hydrocarbons) that are used on daily basis in AMW (Gao and Shao, 2015).

Generally, this study revealed highest mean values of λ_s, TD, and BD were obtained in AMW while lowest mean values of λ_s and TD were recorded in GL. Moreover, vegetation cover such as GL, FP, and OPS had lesser amount of λ_s and TD relative to their values in non-agricultural land-use types (BMS, DS, and AMW). This is because soil organic matter/vegetation does not pass on heat readily as mineral soils (Roxy *et al.*, 2014).

The implication of the detected correlation results was presented in Table 4 while Table 5 listed the results of ANOVA. Table 4 revealed strong inverse correlation at 1% level between λ_s and TR (-0.825**) while strong direct correlation exists between λ_s and TD (0.789**). The negative relation between λ_s and TR is as anticipated because the higher the λ_s, the lower the value of TR (Tokoro *et al.*, 2016). The positive correlation between λ_s and TD obtained in this study was also reported by Xiaoqing *et al.* (2018) in their analysis of the thermo physical properties of various rocks types. At 1% level, moderate negative correlation exists between TR and TD (-0.678**), TR and C_s (-0.546**), TD and temperature (-0.678**) as well as between λ_s and temp. (-0.586**). The inverse relation between temperature and each of TD and λ_s was also reported by Miao *et al.* (2014). However, direct relation between λ_s and soil temperature of Genhe silty clay was reported by Xu *et al.* (2020). A weak negative association occurs between C_s and temperature (-0.249) whereas weak positive correlation at 5% level exists between TR and temperature (0.381*). The weak negative correlation between temperature and C_s concurs with earlier similar correlation between temperature and C_s for granite (our study area is granitic area) reported by Miao *et al.* (2014). Similar weak positive correlation found between TR and temperature (0.381*) in this study was also reported by Oladunjoye and Sanuade (2012a). Negative correlation was also found between μ_s and TD (-0.731**). Moderate positive correlation exists between C_s and λ_s (0.575**) as well as between μ_s and C_s (0.579**).

Table 5 revealed that most of the investigated STPs were significantly different ($p<0.05$) among the six land-use systems. In particular, the mean values of λ_s in AMW and DS were significantly higher than λ_s of the other four land-use systems (i.e. OPS, FP, GL, and BMS).

Table 4: Correlation coefficient matrix of measured STPs.

	Resistivity	Conductivity	Diffusivity	SHC	Admittance	Temperature
Resistivity	1					
Conductivity	-.825**	1				
Diffusivity	-.678**	.789**	1			
SHC	-.546**	.575**	-.012	1		
Admittance	.275	-.260	-.731**	.579**	1	
Temperature	.381*	-.586**	-.504**	-.249	.241	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 5: ANOVA result of measured STPs in selected land use systems.

Thermal Properties	**OPS**	**FP**	**GL**	**AMW**	**DS**	**BMS**
Resistivity	298.88 ± 101.5978^{a}	225.56 ± 126.4012^{ab}	274.46 ± 30.5621^{a}	44.12 ± 21.4462^{c}	69.06 ± 17.8947^{c}	137.84 ± 54.0743^{bc}
Conductivity	0.38 ± 0.1913^{a}	0.56 ± 0.2678^{a}	0.37 ± 0.0426^{a}	1.77 ± 0.5730^{b}	1.53 ± 0.4201^{b}	0.79 ± 0.2127^{a}
Diffusivity	0.27 ± 0.1044^{a}	0.22 ± 0.0652^{a}	0.21 ± 0.0214^{a}	0.85 ± 0.2916^{c}	0.39 ± 0.0587^{ab}	0.53 ± 0.1374^{b}
SHC	1.38 ± 0.2268^{a}	2.45 ± 0.8610^{c}	1.77 ± 0.3112^{abc}	2.16 ± 0.4733^{bc}	3.93 ± 0.6913^{d}	1.49 ± 0.1955^{ab}
Admittance	2.32 ± 0.4160^{a}	3.36 ± 0.6400^{b}	2.91 ± 0.3675^{b}	1.67 ± 0.4338^{c}	3.19 ± 0.3076^{b}	1.71 ± 0.2582^{c}
Temperature	33.30 ± 2.0003^{a}	38.93 ± 2.4097^{c}	39.22 ± 6.1808^{c}	27.97 ± 2.4606^{b}	31.95 ± 0.7331^{ab}	40.86 ± 4.4882^{c}

CONCLUSIONS

This present study was conducted to assess the effects of vegetative management-related land uses (FP, OPS and GL) and non-agricultural land-uses (BMS, DS and AMW) on soil thermal properties within surface layer of sandy loam soils. The thermal conductivity and thermal diffusivity values of vegetative management (FP, OPS and GL) were low compared to non-agricultural land uses indicating that they are good natural environmental-friendly insulator. The vegetative management are of low price but unsuitable for safe and efficient dissipation of heat from underground power cable system. Of non-agricultural land-uses studied, AMW had highest λ_s and was closely followed by that of DS. However, the benefit of highest λ_s in AMW was dwarfed by lowest values of porosity, MC and K_{sat}. Furthermore, DS had highest volumetric heat capacity (C_s) while OPS had lowest C_s. The findings of this study will assist land users to make best choice of suitable land management practices for sustainable agriculture and environmental management.

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