ISSN: 2579-5821 (Print)
ISSN: 2579-5546 (Online)
URL address: http://journal.unhas.ac.id/index.php/geocelebes
DOI: 10.20956/geocelebes.v6i2.21866

Jurnal Geocelebes Vol. 6 No. 2, October 2022, 152 – 165

INVESTIGATING SEASONAL VARIATIONS OF SOIL THERMAL PROPERTIES (STPS) UNDER DIFFERENT LAND USE PATTERNS IN ABEOKUTA, SOUTHWEST NIGERIA

Saheed Adekunle Ganiyu*, Oluwafemi Ayomide Shobowale, Yaya Korede Sikiru

Department of Physics, Federal University of Agriculture, Abeokuta, Ogun State, Nigeria

*Corresponding author. Email: ganiyusa@funaab.edu.ng

Manuscript received: 25 July 2022; Received in revised form: 25 August 2022; Accepted: 26 September 2022

Abstract

Soil thermal properties (STPs) command the storage and transfer of thermal energy through the soil matrix, which can be changed by land use systems and seasonal changes. Depiction of STPs based on land uses and seasonal changes eases better understanding of trend of periodic disparity of soil heat flux across varied land use practices. This study assesses the seasonal and land use prompted variability of STPs such as thermal conductivity (λ_s), thermal resistivity (TR), specific heat capacity (C_s), thermal diffusivity (TD) and temperature of sandy loam topsoils under different land uses: Dumpsite (DS), block-making site (BMS), abattoir site (ABS), and grassland (GL). Seasonal changeability of the STPs was determined by two reiterations of aforementioned STPs measurements during the wet (April/May, 2019) and dry (January/February, 2020) seasons. The STPs were measured in situ utilizing KD2 Pro Thermal Analyzer. The research discloses that STPs are impacted by land use substantially. All the observed STPs were not differ significantly among the studied land uses during the wet season. However, statistically substantial variations in C_s and TD of topsoils under all investigated land uses were recognized during the dry season. Moreover, no significant alteration in the mean soil temperature was observed among the sampling land uses during the dry season. The result of the present study inspires more studying the seasonal changeability of STPs based on a more agricultural and economically related land uses as well as broad sampling design to account for their spatial changeability. The findings of this study will assist land users to make best choice of appropriate land management practices for viable agriculture and environmental management.

Keywords: land uses; soil thermal properties; wet and dry seasons thermal conductivity; seasonal variation.

Introduction

Land can be used for agricultural, economic and developmental purposes all over the world (Ritchie and Roser, 2013; Bjornlund et al., 2020). In most developing countries, lately, most available land has been used intensively for various developmental and economical activities resulting in loss of productive land that could have been put into agricultural use (Tesfahunegn and Gebru, 2020). Different land-use systems impact soil quality variables distinctively, therefore the capacity of particular land to perform ideally may be persistent, enhanced or waned according to the degree of the alteration of soil quality variables in regards to land use practices (Szoboszlay et al., 2017; Ganiyu, 2018).

Heat flow into/from the soil medium can occur through transport mechanism of conduction, radiation, and convection processes (Zhang et al., 2017). However,

© 2022 Dept. of Geophysics Hasanuddin University

the bulk of heat transfer in soil matrix occurred through conduction process (Alrtimi et al., 2016; Zhang et al., 2017). The conduction of heat in the soil, assuming uniform and constant soil medium can be described by one dimensional Fourier's law (Zhu et al., 2019). Thermal properties of soil include λ_s, TR, C_s, thermal diffusivity (TD) and soil temperature. However, λ_s is one of the most important thermal properties related to the heat exchange at the ground surface (Zhang and He, 2016; Bertermann and Schwarz, 2017). It has been reported by several researchers that the λ_s of soils depends on soil factors such as soil texture, moisture content, bulk density, temperature, organic matter content, mineralogical content, volumetric proportions of the soil constituents, and grain size distribution (Alrtimi et al., 2016; Zhang et al., 2017; Rasimeng, 2020).

Thermal conductivity (λ_s) is defined as the amount of heat flow due to unit temperature gradient in unit time under steady conditions in a direction normal to the unit surface area (Faitli et al., 2015). The C_s represents the amount of heat needed to raise the temperature of a unit volume of soil by one degree Celsius (Haruna et al., 2017; Wang et al., 2019). The TD is the ratio of thermal conductivity to its volumetric heat capacity (Hetnarski and Eslami, 2009; Fuchs et al., 2015; Rasimeng, 2020).

The detailed information about soil thermal properties found useful applications in designing of energy piles, ground source heat pump, buried power/ telecommunication cables, irrigation, agricultural meteorology and earthquake precursors amongst others (Roxy et al., 2014; Amaludin et al., 2016; Liu et al., 2018). A number of scientists have investigated the impacts of various land-use patterns on soil physico-chemical properties and soil nutrient availability (Spurgeon et al., 2013; Chandel et al., 2018; Nanganoa et al., 2019; Maini et al., 2020). Scientists have also reported that soil thermal properties (STPs) can be altered by agricultural related land-use systems (Adhikari et al., 2014; Haruna et al., 2017; Shen et al., 2018). Seasonal variation of soil physico-chemical properties on land uses was also well cited (Sacco et al., 2012; Patel et al., 2015; Olatunji et al., 2016; Netha et al., 2020). Ganiyu et al. (2021a,b) assessed the impact of land use and land abandonment on STPs of dumpsite and block making site in Abeokuta, southwest, Nigeria. There appears to be inadequate information on seasonal variability of STPs based on different land-use patterns. This is worth considering as we believe that characterization of thermal properties of a particular land-use pattern on seasonal basis is important in estimating the trend of periodic variations in heat flow and heat storage potentials of the site (Faitli et al., 2015).

The present study was carried out during dry and wet seasons in Nigeria from four different land uses for better understanding of spatial and seasonal variability of soil thermal properties. The objectives include evaluation of levels of STPs in selected land uses during wet and dry seasons; assessment of the seasonal variations of STPs based on land use patterns and application of statistical analysis to study the significances of the variations of measured STPs among sampling sites based on wet and dry seasons.

Methods

Study Area

The research was carried out in Abeokuta city of Ogun state, southwest part of Nigeria. Abeokuta is bordered by latitudes 7°10' and 7°15'N and longitudes 3°17' and 3°25'E (Ufoegbune et al., 2009; Ganiyu et al., 2021a,b). It has an estimated size of about 40.63 km^2 (Ufoegbune et al., 2010). Abeokuta, located in the southern part of the country is within moist tropical region

© 2022 Dept. of Geophysics Hasanuddin University

climate, average annual rainfall and temperature of 1238 mm and 27.1°C, correspondingly (Ganiyu, 2018). The rainy season in the study area commences from March and ends in October, while the dry season starts from November and ends in February under the influences of north-easternly winds from Sahara deserts (Badmus and Olatinsu, 2010; Balarabe et al., 2015). The amount of rainfall during wet season in Nigeria varies from one place to another. Froidurot and Diedhiou (2017) and Shiru et al. (2020) reported that yearly mean rainfall during wet season diverges from <500 mm in the northern dry region to more than 2000 mm in the southern part of the country. The threshold value of < 1 mm was used by Odekunle (2006) and Froidurot and Diedhiou (2017). Yearly rainfall amount in Abeokuta and its environs varies between 1400 and 1500 mm (Akinyemi et al., 2011; Akinse and Gbadebo, 2016). The average daily temperatures in Abeokuta metropolis are maximum in March at about 29.1°C while the coolest month is August with average temperature of 26.7°C on average (Ganiyu et al., 2021a,b).

The four land uses considered in the study includes Block-making site (BMS), Dumpsite (DS), Abattoir site (ABS), and grassland (GL) (as control). The DS is a facility designed for effective disposal of solid wastes, BMS is the workplace where soil-cement blocks used in the construction of buildings are being produced while ABS is a facility where animals are slaughtered to provide meat for human consumption. The grassland (GL) has been existing since early 1990s, the BMS has been in operation since 2010, the ABS has been under continuous use since 1999 while the DS has been in existence since 2005. Figure 1 shows the location map of the study area.

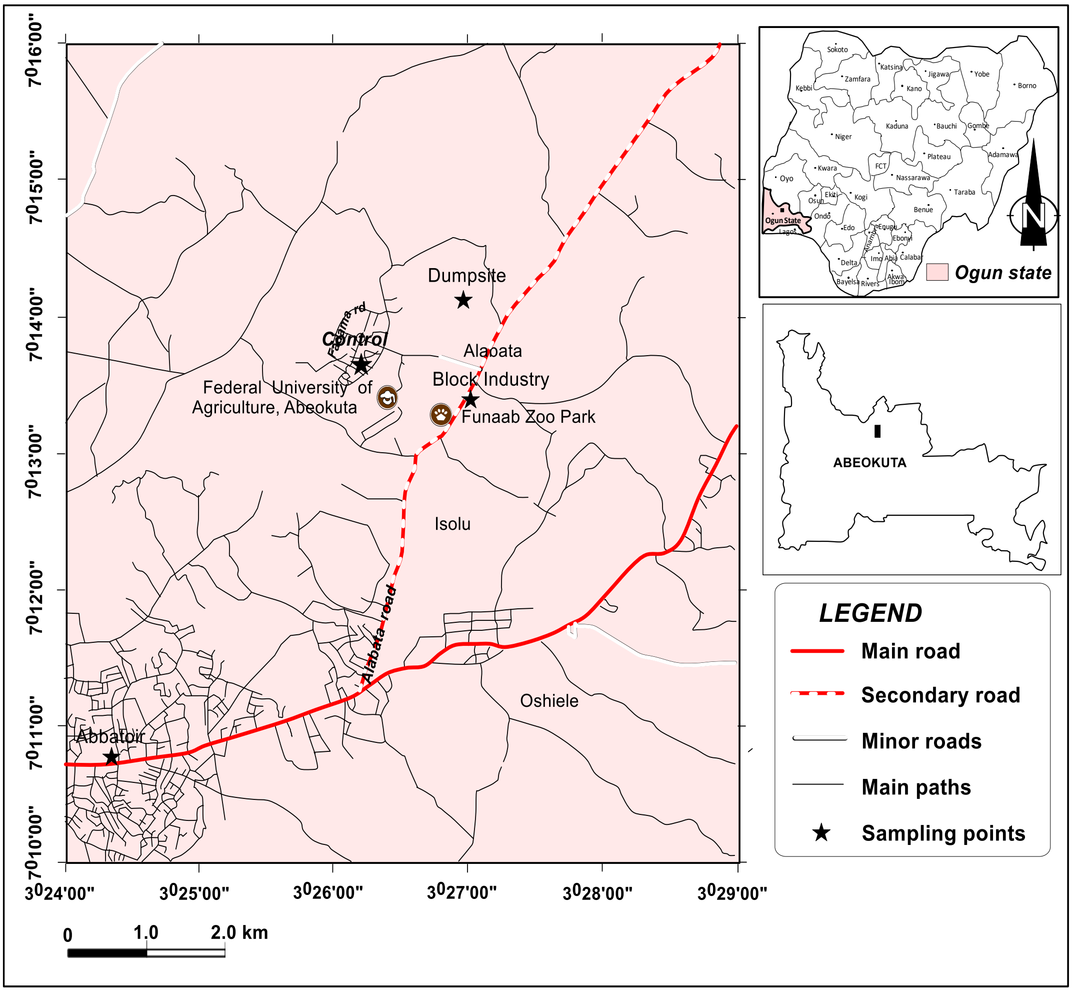

Figure 1. Location map of the study area.

© 2022 Dept. of Geophysics Hasanuddin University

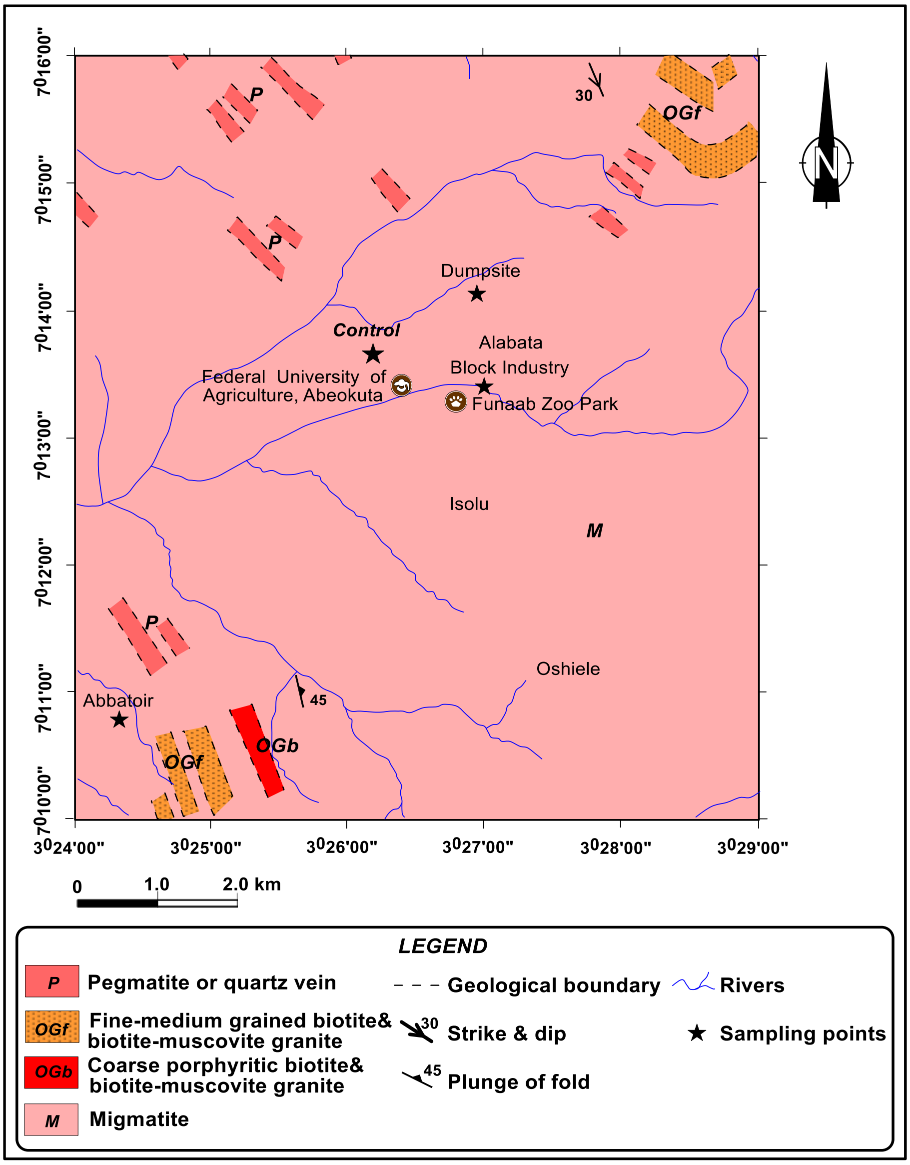

Figure 2. Geological map of the study area manifesting the land-use system.

Geology of the Study Area

Abeokuta falls within the Basement complex formation of southwest Nigeria. The northern part of Abeokuta is described by pegmatitic veins underlain by granite whereas the southern part arrives the transition region with the sedimentary formation of the eastern Dahomey basin. The western part of Abeokuta is categorized by granite gneiss of fewer permeable nature as well as several quartzite intrusions (Bolarinwa, 2018; Ganiyu et al., 2020). At the southwest and southeast parts of Abeokuta is the anomaly of the Ise formation of Abeokuta group which composed of conglomerates and grits at base and in turn overlain by granular medium grained loose sand (Aladejana and Talabi, 2013). The main rock type in the study area as exemplify in Figure 2 is migmatite gneiss.

Measurement of Soil Thermal Properties

At every studied land use system, a 100 m by 50 m was recognized with the use of a tape measure. This was then distributed into five sampling points. The in situ thermophysical properties at each point (λ_s, C_s, TR, TD, and temperature) were measured by KD2 Pro Thermal Properties Analayzer (Decagon Devices Inc, Pullman, USA) with the attached SH-1 dual probe

© 2022 Dept. of Geophysics Hasanuddin University

sensor. The STPs measurements on each land use were taken twice (April and May, 2019, for wet season and in the months of January and February, 2020 for dry season). The mean values of assessed STPs from selected land uses are presented in the study.

The KD2 Pro Thermal analyzer utilizes the transient-line heat source technique to measure the STPs (Zheng et al., 2017; Oyeyemi et al., 2018). The SH-1 probe sensor consists of two 30 mm parallel needle probes with 6 mm spacing and 1.3 mm diameter. Before the measurements were taken at each sampling point, the top surface of the ground was scooped in order to allow for firm positioning of the sensor on the ground. The measurements of STPs were made by inserting the KD2 probe sensor into the scooped ground surface. The KD2 Pro Thermal properties Analyzer connected with the sensor was then turned on to take the measurements. After the first reading, about 20 minutes waiting was granted before the taking of the next reading (Oyeyemi et al., 2018; Tong et al., 2019). In situ soil temperature was measured at surface soil layer (0 – 30 cm) depth.

The sixth parameter (thermal admittance (μ_s)), which is a measure of the capacity of soil surface to accept or release heat to the immediate surrounding (Roxy et al., 2014) was calculated through the expression:

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

where C_s is the specific heat capacity (in MJ/m^3K) and λ_s is the thermal conductivity (in W/mK).

Statistical Analysis

Descriptive statistical analysis was applied to the soil thermal data for each season. Analysis of variance (ANOVA) was used on the soil thermal measurements to assess and compare the effects of wet and dry seasons on STPs in investigated land uses. All the statistical analyses were done with the SPSS statistical software package version 20.0.

Results and Discussion

The results of mean values of in situ and calculated μ_s in the four investigated land-use systems during wet and dry seasons are presented in Tables 1 and 2. During wet season, the mean λ_s ranged from 1.23 to 1.89 W/mK in all studied land uses with highest mean λ_s (1.89 W/mK) found in soils under GL while least λ_s (1.23 W/mK) was observed in ABS. However, in dry season, lowest value of mean λ_s (0.37 W/mK) was obtained in GL while DS had highest mean λ_s (1.53 W/mK). Generally, the values of λ_s were above 1.00 W/mK during wet season while its values during dry season were below 1.00 W/mK in all studied land uses except DS. Moreover, the mean λ_s in each of studied land uses except DS during wet season was greater than its corresponding value in the dry season. This is in agreement with similar trend of variation of λ_s in wet season as reported by Li et al. (2012) and Curado et al. (2013). However, the mean λ_s of soils under DS during wet season was lower than its value in the dry season, the cause for this occurence could not be understood. The lowest value of average λ_s in GL soils during dry season was probably due to increase in soil organic carbon (SOC) in dry season as a result of reduced soil respiration (Rohr et al., 2013). In addition, highest λ_s (1.89 W/mK) in GL during wet season was due to reduction in SOC during wet season. Low SOC during wet season may be due to more of heterotrophic respiration (Rohr et al., 2013; Hewins et al., 2018).

It has been reported by Yun et al. (2013) that the mean λ_s of light weight concrete (LWC) ranges from 0.2 to 1.9 W/mK and from 0.6 to 3.3 W/mK for normal weight concrete (NWC). Our results of mean λ_s at BMS during both seasons lie within the aforementioned range of λ_s in both LWC and NWC. The mean λ_s of near surface soils

© 2022 Dept. of Geophysics Hasanuddin University

under BMS in wet season was higher (almost twice) than its value in the dry season. This observation concurs with previous study that revealed similar higher λ_s value of cement-based materials in wet/saturated condition than in the dry condition as reported by Asadi et al. (2018). However, the less than 0.65 W/mK for average λ_s in GL during dry season indicated that GL is not suitable for dissipating heat from buried cable (Campbell and Bristow, 2014).

The mean TRs in investigated sites during wet and dry seasons ranged from 61.67 - 93.01°C-cm/W and from 69.06 – 274.46°C-cm/W, respectively. The mean TR values during wet season in all visited sites except DS fall within the safe value 90C°-cm/W recommended for cable engineering practices (Campbell and Bristow, 2007). However, in dry season, the topsoils of GL, BMS, and ABS had TR values > 90°C-cm/W while mean TR value of DS lies below 90°C-cm/W. It was also noticed that GL had highest value of mean TR (> 200°C-cm/W) during dry season but had least TR (61.67°C-cm/W) during wet season.

The mean TD values of studied land uses during wet and dry seasons ranged from 0.38 to 0.63 mm^2/s, and from 0.21 to 0.53 mm^2/s, respectively. During wet season, the maximum and minimum TD values were recorded in GL and ABS, respectively. However, the maximum and minimum values of mean TD in dry season (Table 2) were recorded in BMS and GL, respectively. The values of volumetric heat capacity in investigated land uses during wet and dry seasons ranged from 2.28 to 3.38 MJ/m^{3}K, and from 1.49 to 3.93 MJ/m^{3}K, respectively. In wet season, highest value of means C_s was found in ABS while the lowest mean C_s (2.28 MJ/m^{3}K) was recorded in DS. Furthermore, during wet season, topsoil under ABS was characterized by highest value of mean C_s (3.38 MJ/m^{3}K) coupled with least values of λ_s and TD. The variations of λ_s, C_s, and TD under ABS topsoil are in line with reported similar increase in C_s but with decrease in λ_s and TD on soil amended with chicken manure by Chishala et al. (2019). In this study, the STPs were measured in section of ABS where animal wastes such as cow dungs and bones were being kept. The mean C_s in dry season ranged from 1.49 to 3.93 MJ/m^{3}K, with maximum and minimum values observed in DS and BMS, respectively.

During wet season, mean μ_s values ranged from 2.07 to 3.13 W/m^{2}K while it ranged from 1.71 to 3.19 W/m^{2}K in dry season. In wet season, highest mean μ_s (3.13 W/m^{2}K) was found in GL while lowest μ_s (2.07 W/m^{2}K) was noticed in topsoil under DS. However, it was noticed that during dry season, highest mean μ_s was recorded for soil under DS whereas lowest μ_s was observed in topsoil of BMS. The mean temperature during wet season ranged from 29.37 to 31.28°C while it ranged from 31.95 to 40.86°C in dry season. Specifically; the lowest soil temperature during each season was recorded in DS land use pattern.

Table 1. Mean values of STPs in land-use systems during wet season.

Land-use system	**λ_s (W/mK)**	**TR ^{O}C-cm/W**	**TD (mm^2/s)**	**C_s (MJ/m^{3}K)**	**μ_s (W/m^{2}K)**	**Temperature (°C)**
Grassland (GL)	1.89	61.67	0.63	2.99	3.13	29.83
Block-Making site (BMS)	1.48	69.84	0.62	2.54	2.12	30.47
Abattoir site (ABS)	1.23	84.87	0.38	3.38	3.06	31.28
Dumpsite (DS)	1.27	93.01	0.57	2.28	2.07	29.37

© 2022 Dept. of Geophysics Hasanuddin University

Table 2. Mean values of STPs in land use systems during dry season**.**

Land-use system	λ_s (W/mK)	TR ^{O}C-cm/W	TD (mm^2/s)	C_s (MJ/m^{3}K)	μ_s (W/m^{2}K)	Temperature (^{O}C)
Grassland (GL)	0.37	274.46	0.21	1.77	2.91	39.22
Block-making site (BMS)	0.79	137.84	0.53	1.49	1.71	40.86
Abattoir site (ABS)	0.79	150.74	0.30	2.57	3.06	36.84
Dumpsite (DS)	1.53	69.06	0.39	3.93	3.19	31.95

Table 3. Descriptive statistics of analyzed STPs during wet season.

Parameters	Locations	Mean	Std. Deviation	Std. Error	Coefficient of Variation (%)
TR	Grassland	61.67	31.7205	14.1858	51.4
	Block Making Site	69.84	14.3308	6.4089	20.5
	Abattoir Site	84.87	19.8978	8.8986	23.4
	Dumpsite	93.01	42.8425	19.1597	46.1
λ_s	Grassland	1.90	0.7195	0.3218	37.9
	Block Making Site	1.48	0.3228	0.1444	21.8
	Abattoir Site	1.23	0.2996	0.1340	24.3
	Dumpsite	1.27	0.5640	0.2522	44.5
TD	Grassland	0.63	0.1217	0.0544	19.5
	Block Making Site	0.62	0.2146	0.0960	34.7
	Abattoir Site	0.38	0.1160	0.0519	30.2
	Dumpsite	0.57	0.2175	0.0973	37.9
C_s	Grassland	3.00	0.9787	0.4377	32.7
	Block Making Site	2.54	0.5864	0.2623	23.1
	Abattoir Site	3.38	1.0696	0.4784	31.6
	Dumpsite	2.28	0.7874	0.3521	34.5
μ_s	Grassland	3.13	2.1384	0.9563	68.3
	Block Making Site	2.12	0.5976	0.2672	28.2
	Abattoir Site	3.06	0.8754	0.3915	28.6
	Dumpsite	2.08	0.6433	0.2877	31.0
Temperature	Grassland	29.84	1.0717	0.4793	3.6
	Block Making Site	30.47	1.3599	0.6081	4.5
	Abattoir Site	31.28	5.6160	2.5116	18.0
	Dumpsite	29.37	1.4738	0.6591	5.0

Results of Statistical Analyses

The descriptive statistics of observed STPs in wet and dry seasons are listed in Tables 3 and 4 while Tables 5 and 6 display the outcomes of ANOVA of measured STPs during wet and dry seasons, respectively.

Results of ANOVA

Table 5 revealed that all observed STPs (λ_s, C_s, TR, TD, μ_s, and temperature) during the wet season did not differ significantly among the four land-use systems. However, the results of ANOVA in Table 6 for dry season revealed that significant variation at 5% ($p<0.05$) occurred in measured λ_s and TR among the locations with the exception of those of BMS and ABS that did not differ significantly at 5% level ($p<0.05$).

Table 6 further reveals that there were significant variations in the mean values of C_s and TD of the topsoil under investigated land-use systems at 5% level ($p<0.05$). From Table 6, the mean thermal admittance (μ_s) of topsoil under BMS was significantly lower than those of the other three land-use systems (i.e GL, DS, and ABS). Table 6 further revealed that there was no significant variation in the mean temperature of near-surface soils among the sampling land-uses.

© 2022 Dept. of Geophysics Hasanuddin University

Table 4. Descriptive statistics of analyzed STPs during dry season.

Parameters	Locations	Mean	Std. Deviation	Std. Error	Coefficient of Variation (%)
TR	Grassland	274.46	30.5621	13.6678	11.1
	Block Making Site	137.84	54.0743	24.1828	39.2
	Abattoir Site	150.74	68.0006	30.4108	45.1
	Dumpsite	69.06	17.8947	8.0027	25.9
λ_s	Grassland	0.37	0.0426	0.0190	11.6
	Block Making Site	0.79	0.2127	0.0951	26.9
	Abattoir Site	0.79	0.3527	0.1577	44.8
	Dumpsite	1.53	0.4201	0.1879	27.4
TD	Grassland	0.21	0.0214	0.0096	10.2
	Block Making Site	0.53	0.1374	0.0614	25.8
	Abattoir Site	0.30	0.1243	0.0556	41.0
	Dumpsite	0.39	0.0587	0.0262	15.1
C_s	Grassland	1.77	0.3112	0.1392	17.6
	Block Making Site	1.49	0.1955	0.0874	13.1
	Abattoir Site	2.57	0.2551	0.1141	9.9
	Dumpsite	3.93	0.6913	0.3092	17.6
μ_s	Grassland	2.91	0.3675	0.1644	12.6
	Block Making Site	1.71	0.2582	0.1155	15.1
	Abattoir Site	3.06	0.6241	0.2791	20.4
	Dumpsite	3.19	0.3076	0.1375	9.6
Temperature	Grassland	39.22	6.1808	2.7642	15.8
	Block Making Site	40.86	4.4882	2.0072	11.0
	Abattoir Site	36.84	7.3097	3.2690	19.8
	Dumpsite	31.95	0.7331	0.3279	2.3

Table 5. ANOVA result of measured STPs in wet season.

Parameters	Grassland	Block Making Site	Abattoir Site	Dumpsite
Resistivity	61.67 ± 31.7205^a	69.84 ± 14.3308^a	84.87 ± 19.8978^a	93.01 ± 42.8425^a
Conductivity	1.90 ± 0.7195^a	1.48 ± 0.3228^a	1.23 ± 0.2996^a	1.27 ± 0.5640^a
Diffusivity	0.63 ± 0.1217^a	0.62 ± 0.2146^a	0.38 ± 0.1160^a	0.57 ± 0.2175^a
Specific Heat Capacity	3.00 ± 0.9787^a	2.54 ± 0.5864^a	3.38 ± 1.0696^a	2.28 ± 0.7874^a
Admittance	3.13 ± 2.1384^a	2.12 ± 0.5976^a	3.06 ± 0.8754^a	2.08 ± 0.6433^a
Temperature	29.84 ± 1.0717^a	30.47 ± 1.3599^a	31.28 ± 5.6160^a	29.37 ± 1.4738^a

Values show mean ± standard deviation. Values along the same row with different superscripts are significantly different at 5% ($p<0.05$) level.

Table 6. ANOVA result of measured STPs in dry season.

Parameters	Grassland	Block Making Site	Abattoir Site	Dumpsite
Resistivity	274.46 ± 30.5621^a	137.84 ± 54.0743^b	150.74 ± 68.0006^b	69.06 ± 17.8947^c
Conductivity	0.37 ± 0.0426^a	0.79 ± 0.2127^b	0.79 ± 0.3527^b	1.53 ± 0.4201^c
Diffusivity	0.21 ± 0.0214^a	0.53 ± 0.1374^c	0.30 ± 0.1243^{ab}	0.39 ± 0.0587^b
Specific Heat Capacity	1.77 ± 0.3112^a	1.49 ± 0.1955^a	2.57 ± 0.2551^b	3.93 ± 0.6913^c
Admittance	2.91 ± 0.3675^a	1.71 ± 0.2582^b	3.06 ± 0.6241^a	3.19 ± 0.3076^a
Temperature	39.22 ± 6.1808^a	40.86 ± 4.4882^a	36.84 ± 7.3097^a	31.95 ± 0.7331^a

Values show mean ± standard deviation. Values along the same row with different superscripts are significantly different at 5% ($p<0.05$) level.

Conclusions

There were seasonal variations of examined STPs in the study area based on different land-uses. The thermal conductivity values in the wet season were higher than in the dry season for most of studied land-uses except DS. Comparatively, the top soils of GL and DS had highest values of λ_s during wet and dry seasons, respectively. On seasonal basis, a relatively highest value of mean C_s during wet season was noticed in ABS while maximum C_s (3.93 MJ/m^{3}K) was recorded in DS during dry season. The

© 2022 Dept. of Geophysics Hasanuddin University

ANOVA results show that the mean values of measured STPs did not differ significantly as 5% level ($p<0.05$) among the land uses during the wet season, Soil temperature is the only thermal property that did not vary significantly among the sampling land uses during dry season. Further assessment of STPs under more agricultural and economically related land uses on seasonal basis is highly suggested. The outcomes of this study will help land users to make best choice of suitable land management practices for sustainable agriculture and environmental management.

References

Adhikari, P., Udawatta, R.P. and Anderson, S.H. 2014. *Soil thermal properties under Prairies, conservation buffers and corn-soyabean land-use systems*. Soil Science Society American Journal. 78, pp.1977 – 1986. https://doi.org/10.2136/sssaj2014.02.0074

Akinse, A.G. and Gbadebo, A.M. 2016. *Geological mapping of Abeokuta metropolis, Southwestern Nigeria*. International Journal of Science and Engineering Research. 7(8), pp.979 – 983. https://www.ijser.org/researchpaper/Geologic-Mapping-of-Abeokuta-Metropolis-Southwestern-Nigeria.pdf

Akinyemi, O.D., Bello, R., Ayodeji, A.T., Akanbi, D.E., Ibine, M.M. and Popoola, J.A. 2011. *Evaluation of water quality in Abeokuta, Southwest Nigeria*. International Journal of Water Resources and Environmental Engineering. 3(13), pp.341 – 369. http://dx.doi.org/10.5897/IJWREE11.099

Aladejana, J.A. and Talabi, A.O. 2013. *Assessment of groundwater quality in Abeokuta, southwestern Nigeria. Research Inventory*. International Journal of Engineering and Science. 2(6), pp.21 – 31. http://www.researchinventy.com/papers/v2i6/E026021031.pdf

Alrtimi, A., Rouainia, M. and Haigh, S. 2016. *Thermal conductivity of a sandy soil*. Applied Thermal Engineering, 106, pp.551 – 560. https://dx.doi.org/10.1016/j.applthermaleng.2016.06.012

Amaludin, A., Marto, A., Satar, M.H.M., Amaludin, I.T. and Dullah, S. 2016. *Thermal properties of Malaysian cohesive soils*. Jurnal Teknologi. 78(8-5), pp.53 – 58. https://doi.org/10.11113/jt.v78.9623

Asadi, I., Shafigh, P., Abu Hassan, Z.D. and Mahyaddin, N.B. 2018. *Thermal conductivity of concrete – A review*. Journal of Building Engineering. 20, pp.81 – 93. https://doi.org/10.1016/j.jobe.2018.07.002

Badmus, B.S. and Olatinsu, O.B. 2010. *Aquifer characteristics and groundwater recharge pattern in a typical basement complex, southwestern Nigeria*. African Journal of Environmental Science and Technology. 4(6), pp.328 – 342. http://dx.doi.org/10.5897/AJEST09.214

Balarabe, M., Abdullah, K. and Nawawi, M. 2015. Long-term trend and seasoned variability of horizontal visibility in Nigerian Troposphere. Atmosphere. 6(10), pp.1462 – 1486. https://doi.org/10.3390/atmos6101462

Bertermann, D. and Schwarz, H. 2017. *Laboratory device to analyze the impact of soil properties on electrical and thermal conductivity*. International Agrophysics. 31(2), pp.157 – 166. https://doi.org/10.1515/intag-2016-0048

© 2022 Dept. of Geophysics Hasanuddin University

Bjornlund, V., Bjornlund, H. and van Rooyen, A.F. 2020. *Why agricultural production in sub-saharan Africa remains low compared to the rest of the world- a historical perspective*. International Journal of Water Resources and Development. 36(sup1), pp.S20 – S53. https://doi.org/10.1080/07900627.2020.1739512

Bolarinwa, A.T. 2018. *Seasonal variations of groundwater chemistry in the Basement and Sedimentary rocks of Ibadan and Lagos areas, southwestern Nigeria*. Earth Science Research. 7(1), pp.55 – 66. https://doi.org/10.5539/esr.v7n1p55

Campbell, G.S. and Bristow, K.L. 2007. *Underground Power Cable Installations: Soil Thermal Resistivity*. Application Note: Thermal Decagon Devices. http://www.monitoring-mena.com/pdf/Case%209%20Underground%20Power%20Cable%20Installations%20Soil%20Thermal%20Resistivity.pdf

Campbell, G.S. and Bristow, K.L. 2014. *The effect of soil thermal restivity (RHO) on underground power cable installations*. Application Note: Thermal Decagon Devices. http://library.metergroup.com/Application%20Notes/13943_Effect%20of%20Soil%20Thermal%20Resistivity%20on%20Underground%20Cable%20Installation_Print.pdf

Chandel, S., Hadda, M.S. and Mahal, A.K. 2018. *Soil quality assessment through minimum dataset under different land uses of Submontane Punjab*. Communications in Soil Science and Plant Analysis. 49(6), 658-674. https://doi.org/10.1080/00103624.2018.1425424

Chishala, M.W., Phiri, E. and Chabala, L.M. 2019. *Influence of chicken manure amendment on the thermal properties of selected benchmark soils in Zambia*. Open Journal of Soil Science. 9(2), pp.35 – 46. https://doi,org/10.4236/ojss.2019.92002

Curado, L.F.M., Rodrigues, T.R., de Oliveira, A.G., Novais, J.W.Z., de Paulo, I.J.C., Biudes, M.S. and Nogueira, J.S. 2013. *Analysis of thermal conductivity in a seasonal flooded forest in the northern Pantanal*. Revista Brasileira de Meteorologia. 28(2), pp.125 – 128. https://doi.org/10.1590/S0102-77862013000200001

Faitli, J., Magyar, T., Erdélyi, A. and Murányi, A. 2015. *Characterization of thermal properties of municipal solid waste landfills*. Waste management. 36, pp.213 – 221. https://dx.doi.org/10.1016/j.wasman.2014.10.028

Froidurot, S. and Diedhiou, A. 2017. *Characteristics of wet and dry spells in the West African monsoon system*. Atmospheric Science Letter. 18, pp.125 – 131. https://doi.org/10.1002/asl.734

Fuchs, S., Balling, N., Förster, A. 2015. *Calculation of thermal conductivity, thermal diffusivity and specific heat capacity of sedimentary rocks using petrophysical well logs*. Geophysical Journal International. 203(3), pp.1977 – 2000. https://doi.org/10.1093/gji/ggv403

Ganiyu, S.A. 2018. *Evaluation of soil hydraulic properties under different non-agricultural land use patterns in a basement complex area using multivariate statistical analysis*. Environmental Monitoring and Assessment. 190(10), pp.595. https://doi.org/10.1007/s10661-018-6959-x

Ganiyu, S.A., Olurin, O.T., Oladunjoye, M.A. and Badmus, B.S. 2020. *Investigation of soil moisture content over a cultivated farmland*

© 2022 Dept. of Geophysics Hasanuddin University

in Abeokuta Nigeria using electrical resistivity methods and Soil analysis. Journal of King Saud University-Science. 32(1), pp.811 – 821. https://doi.org/10.1016/j.jksus.2019.02.016

Ganiyu, S.A., Mabunmi, A.A., Olurin, O.T., Adeyemi, A.A. and Jegede, O.A. Okeh, A. 2021a. *Assessment of microbial and heavy metal contamination in shallow hand-dug wells bordering Ona River southwest Nigeria*. Environmental Monitoring and Assessment. 193(3), pp.126(1-22). https://doi.org/10.1007/s10661-021-08910-9

Ganiyu, S.A., Olurin, O.T. and Shobowale, O.A. 2021b. *Assessing the impacts of land use and land abandonment on soil thermal properties: A case study of Dumpsite and Cement Block making site*. Journal of Mining & Geology. 57(2), pp.441 – 448. https://nmgs-journal.org/wp-content/uploads/journal/published_paper/volume-57/issue-2/YNGn9GXl.pdf

Hetnarski, R.B. and Eslami, M.R. 2009. *Thermal Stresses -- Advanced Theory and Applications*. Springer Dordrecht. https://doi.org/10.1007/978-1-4020-9247-3

Haruna, S.I., Anderson, S.H., Mkongolo, N.V. Reinbott, T. and Zaibon, S. 2017. *Soil thermal properties influenced by perennial biofuel and cover crop management*. Soil Science Society American Journal. 81(5), pp.1147 – 1156. https://doi.org/10.2136/sssaj2016.10.0345

Hewins, D.B., Lyseng, M.P., Schoderbek, D.F., Alexander, M., Willms, W.D., Carlyle, C.N., Chang, S.X. and Bork, E.W. 2018. *Grazing and climatic effects on soil organic carbon concentration and particle size association in northern grasslands*. Scientific Report. 2018 8, pp.1336. https://doi.org/10.1038/s41598-018-19785-1

Li, Y., Wu, C., Xing, X., Yue, M. and Shang, Y. 2012. *Testing and Analysis of the soil thermal conductivity in tropical desert and grassland of West Africa*. In: Proceedings of the 2012 9th International Pipeline Conference, IPC 2012. September 24-28, 2012. IPC 2012-90291, pp.149 – 157. https://doi.org/10.1115/IPC2012-90291

Liu, Q., Du, Z. and Fan, Y. 2018. *Heat and mass transfer behavior prediction and thermal performance analysis of Earth to-Air Heat exchanger by finite volume methods*. Energies. 11(6), pp.1542. https://doi.org/10.3390/en11061542

Maini, A., Sharma, V. and Sharma, S. 2020. *Assessment of soil carbon and biochemical indicators of soil quality under rain fed land use systems in northeastern region of Punjab India*. Carbon Management. 11(2), pp.169 – 182. https://doi.org/10.1080/17583004.2020.1721976

Nanganoa, L.T., Okolle, J.N., Missi, V., Tueche, I.R., Levai, L.D. and Njukeng, J.N. 2019. Impact of different land use systems on soil physico-chemicals properties and macro fauna abundance in the humid tropics of Cameroon. Applied and Environmental Soil Science. 2019(5701278), pp.1 – 9. https://doi.org/10.1155/2019/5701278

Netha, Bhople, B.S. and Sharma, S. 2020. *Seasonal variation of rhizospheric soil properties under different land use systems at lower Shivalik foothills of Punjab, India*.

© 2022 Dept. of Geophysics Hasanuddin University

Agroforestry Systems. 94, pp.1959 – 1976. https://doi.org/10.1007/s10457-020-00512-7.

Odekunle, T.O. 2006. *Determining rainy season on set and retreat over Nigeria from precipitation amount and number of rainy days*. Theoretical and Applied Climatology. 83, pp.193 – 201. https://doi.org/10.1007/s00704-005-0166-8

Olatunji, O.A., Komolafe, E.T. and Oke, S.O. 2016. *Seasonal variation in physicochemical properties of soil within the vicinity of an iron smelting factory- Implication on standing vegetation*. Notulae Scientia Biologicae. 8(2), pp.220 – 225. https://doi.org/10.15835/nsb829794

Oyeyemi, K.D., Sanuade, O.A., Oladunjoye, M.A., Aizebeokhai, A.P., Olaojo, A.A., Fatoba, J.O., Olofinnade, O.M., Ayara, W.A. and Oladapo, O. 2018. *Data on the thermal properties of soil and its moisture content*. Data in Brief. 17, pp.900 – 906. https://doi.org/10.1016/j.dib.2018.02.018

Patel, M.P., Gami, B. and Patel, B. 2015. *Seasonal impact on physical chemical properties of soil in North and South Gujarat*. IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS). 8(6), pp.26 – 36. https://iosrjournals.org/iosr-javs/papers/vol8-issue6/Version-2/F08622636.pdf

Rasimeng, S. 2020. *Characterization of soil thermal properties for designs of underground cable routes at the wind farm power plant area, Panyipatan and Pelaihari, sub-district, south Kalimantan*. Jurnal Geocelebes. 4(1), pp.61 – 69. https://doi.org/10.20956/geocelebes.v4i1.9599

Ritchie, H. and Roser, M. 2013. *Land Use*. https://ourworldindata.org/land-use

Rohr, T., Manzoni, S., Feng, X., Menezes, R.S.C. and Porporato, A. (2013). *Effect of rainfall seasonality on carbon storage in tropical dry ecosystems*. Journal of Geophysical Research: Biogeosciences. 118(3), pp.1156 – 1167. https://doi.org/10.1002/jgrg.20091

Roxy, M.S., Sumithranand, V.B. and Renuka, G. 2014. *Estimation of soil moisture and its effect on soil thermal characteristics at Astronomical Observatory, Thiruvananthapuram, South Kerala*. Journal of Earth System Science. 123(8), pp.1793 – 1807. https://doi.org/10.1007/s12040-014-0509-x

Sacco, D., Cremon, C., Zavattaro, L. and Grignani, C. 2012. *Seasonal variation of soil physical properties under different water management in irrigated rice*. Soil and Tillage Research. 118, pp.22 – 31. https://doi.org/10.1016/j.still.2011.10.011

Shen, Y., McLaughlin, N., Zhang, X., Xu, M. and Liang, A. 2018. *Effect of tillage and crop residue on soil temperature following planting for a black soil in northeast China*. Scientific Reports. 8(4500), pp.1 – 9. https://doi.org/10.1038/s41598-018-22822-8

Shiru, M.S., Shahid, S., Dewan, A., Chung, E.-S., Alias, N., Ahmed, K. and Hassan, Q.K. 2020. *Projection of meteorological droughts in Nigeria during growing seasons under climate change scenarios*. Scientific Reports. 10(10107), pp.1 – 18. https://doi.org/10.1038/s41598-020-67146-8

Spurgeon, D.J., Keith, A.M., Schmidt, O., Lammertsma, D.R. and Faber, J.H. 2013. *Land use and land management change: Relationships with earthworm and fungi*

© 2022 Dept. of Geophysics Hasanuddin University

communities and soil structural properties. BMC Ecology. 13(46), pp.1 – 12. https://doi.org/10.1186/1472-6785-13-46

Szoboszlay, M., Dohrmann, A.B., Poeplau, C., Don, A. and Tebbe, C.S. 2017. *Impact of land-use change and soil organic carbon quality on microbial diversity in soils across Europe*. FEMS Microbiology Ecology. 93(12), fix146 pp.1 – 12. https://doi.org/10.1093/femsec/fix146

Tesfahunegn, G.B. and Gebru, T.A. 2020. *Variation in soil properties under different cropping and other land use systems in Dura catchment, northern Ethiopia*. PLOS ONE 15(2), e0222476. https://doi.org/10.1371/journal.pone.0222476

Tong, B., Kool, D., Heithman, J.L., Sauer, T.J., Gao, Z. and Horton, R. 2019. *Thermal property values of a control Iowa soil as a function of soil water content and bulk density or of soil air content*. European Journal of Soil Science. 71, pp.169 – 178. https://doi.org/10.1111/ejss.12856

Ufoegbune, G.C., Lamidi, K.I., Awomeso, J.A., Eruola, A.O., Idowu, O.A. and Adeofun, C.O. 2009. *Hydro-geological characteristics and groundwater quality assessment in some selected communities of Abeokuta southwestern Nigeria*. Journal of Environmental Chemistry and Ecotoxicology. 1(1), pp.10 – 22. https://academicjournals.org/article/article1379428050_Ufoegbune%20et%20al.pdf

Ufoegbune, G.C., Oyedepo, J., Awomeso, J.A. and Eruola, A.O. 2010. *Spatial analysis of municipal water supply in Abeokuta metropolis, southwestern Nigeria*. In: REAL CORP 2010. Proceedings/ Tagungsband, Vienna, 18-20th May, 2010, pp.1267 – 1273. https://www.corp.at/archive/CORP2010_6.pdf

Wang, Y., Lu, Y., Horton, R. and Ren, T. 2019. *Specific heat capacity of soil solids: Influences of clay content, organic matter, and highly bound water soil*. Soil Science Society of America Journal. 83, pp.1062 – 1066. https://doi.org/10.2136/sssaj2018.11.0434

Yun, T.S., Jeong, Y.J., Han, T.-S. and Youm, K.-S. 2013. *Evaluation of thermal conductivity for thermally insulated concretes*. Energy and Buildings. 61, pp.125 – 132. https://doi.org/10.1016/j.enbuild.2013.01.043

Zhang, N. and He, H.T. 2016. *Comparative performance of soil thermal conductivity prediction models for geothermal applications*. Geo-China 2016: Innovative and Sustainable Use of Geomaterials and Geosystems. GSP 263, ASCE pp.9 – 16. https://doi.org/10.1061/9780784480069.002

Zhang, T., Cai, C., Liu, S. and Puppala, A.J. 2017. *Investigation on thermal characteristics and prediction models of soil*. International Journal of Heat and Mass Transfer. 106, pp.1074 – 1086. https://doi.org/10.1016/j.ijheatmasstransfer.2016.10.084

Zheng, L., Zhang, W. and Liang, F. 2017. *Experimental study on thermal conductivity of microcapsule phase change suspension applied to solar powered air conditioning cold storage system*. Procedia Engineering. 205, pp.1237 – 1244. https://doi.org/10.1016/j.proeng.2017.10.364

Zhu, D., Ciais, P., Krinner, G., Maignan, F., Puig, A.J. and Hugelius, G. 2019. *Controls of soil organic matter on*

© 2022 Dept. of Geophysics Hasanuddin University

soil thermal dynamics in the northern high latitudes. Nature communications. 10(3172), pp.1 – 9. https://doi.org/10.1038/S41467-019-11103-1

© 2022 Dept. of Geophysics Hasanuddin University