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

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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 ($\lambda_s$), 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 (Szoboszlai 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,
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 \( \lambda_s \), TR, \( C_s \), thermal diffusivity (TD) and soil temperature. However, \( \lambda_s \) 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 \( \lambda_s \) 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 (\( \lambda_s \)) 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 km² (Ufoegbune et al., 2010). Abeokuta, located in the southern part of the country is within moist tropical region
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 Olaitinsu, 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.

![Location map of the study area](image)

**Figure 1.** Location map of the study area.
**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 ($\lambda$, $C_p$, TR, TD, and temperature) were measured by KD2 Pro Thermal Properties Analyzer (Decagon Devices Inc, Pullman, USA) with the attached SH-1 dual probe.
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 ($\mu_s$)), 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:

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

where $C_s$ is the specific heat capacity (in MJ/m$^3$K) and $\lambda_s$ 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 $\mu_s$ in the four investigated land-use systems during wet and dry seasons are presented in Tables 1 and 2. During wet season, the mean $\lambda_s$ ranged from 1.23 to 1.89 W/mK in all studied land uses with highest mean $\lambda_s$ (1.89 W/mK) found in soils under GL while least $\lambda_s$ (1.23 W/mK) was observed in ABS. However, in dry season, lowest value of mean $\lambda_s$ (0.37 W/mK) was obtained in GL while DS had highest mean $\lambda_s$ (1.53 W/mK). Generally, the values of $\lambda_s$ 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 $\lambda_s$ 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 $\lambda_s$ in wet season as reported by Li et al. (2012) and Curado et al. (2013). However, the mean $\lambda_s$ of soils under DS during wet season was lower than its value in the dry season, the cause for this occurrence could not be understood. The lowest value of average $\lambda_s$ 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 $\lambda_s$ (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 $\lambda_s$ 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 $\lambda_s$ at BMS during both seasons lie within the aforementioned range of $\lambda_s$ in both LWC and NWC. The mean $\lambda_s$ of near surface soils...
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 $\lambda_s$ 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 $\lambda_s$ 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 90°C-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 mm²/s, and from 0.21 to 0.53 mm²/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/m³K, and from 1.49 to 3.93 MJ/m³K, respectively. In wet season, highest value of means $C_s$ was found in ABS while the lowest mean $C_s$ (2.28 MJ/m³K) was recorded in DS. Furthermore, during wet season, topsoil under ABS was characterized by highest value of mean $C_s$ (3.38 MJ/m³K) coupled with least values of $\lambda_s$ and TD. The variations of $\lambda_s$, $C_s$, and TD under ABS topsoil are in line with reported similar increase in $C_s$ but with decrease in $\lambda_s$ 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/m³K, with maximum and minimum values observed in DS and BMS, respectively.

During wet season, mean $\mu_s$ values ranged from 2.07 to 3.13 W/m²K while it ranged from 1.71 to 3.19 W/m²K in dry season. In wet season, highest mean $\mu_s$ (3.13 W/m²K) was found in GL while lowest $\mu_s$ (2.07 W/m²K) was noticed in topsoil under DS. However, it was noticed that during dry season, highest mean $\mu_s$ was recorded for soil under DS whereas lowest $\mu_s$ 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.

| Land-use system           | $\lambda_s$ (W/mK) | TR 90°C-cm/W | TD (mm²/s) | $C_s$ (MJ/m³K) | $\mu_s$ (W/m²K) | 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           |

Ganiyu, Shobowale and Sikiru / Jurnal Geocelebes Vol. 6 No. 2, October 2022, 152 – 165
Table 2. Mean values of STPs in land use systems during dry season.

| Land-use system               | $\lambda_s$ (W/mK) | TR (°C·cm/W) | TD (mm/s) | $C_s$ (MJ/m³K) | $\mu_s$ (W/m²K) | Temperature (°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                        |
| $\lambda_s$| 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                        |
| $\mu_s$   | 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 ($\lambda_s$, $C_s$, TR, TD, $\mu_s$, 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 $\lambda_s$ 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 ($\mu_s$) 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.
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                          |
| λs         | 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                          |
| Cs         | 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                          |
| μs         | 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 ± 31.7205a  | 69.84 ± 14.3308a  | 84.87 ± 19.8978a  | 93.01 ± 42.8425a  |
| Conductivity       | 1.90 ± 0.7195a  | 1.48 ± 0.3228a  | 1.23 ± 0.2996a  | 1.27 ± 0.5640a   |
| Diffusivity        | 0.63 ± 0.1217a  | 0.62 ± 0.2146a  | 0.38 ± 0.1160a  | 0.57 ± 0.2175a   |
| Specific Heat Capacity | 3.00 ± 0.9787a | 2.54 ± 0.5864a | 3.38 ± 1.0696a | 2.28 ± 0.7874a |
| Admittance         | 3.13 ± 2.1384a  | 2.12 ± 0.5976a  | 3.06 ± 0.8754a  | 2.08 ± 0.6433a   |
| Temperature        | 29.84 ± 1.0717a  | 30.47 ± 1.3599a  | 31.28 ± 5.6160a | 29.37 ± 1.4738a |

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

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 $\lambda_s$ 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
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.

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