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Assessing the Impacts of Land Use and Land Abandonment on Soil Thermal Properties: A Case Study of Dumpsite and Cement Block Making Site

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Abstract
Information about soil thermal properties (STP_S) based on different land-use patterns will assists in optimum utilization of ground-based thermal energy. The status of soil thermal properties (STPs) in two different land uses (Dumpsite (DS) and Cement-block making site (BMS) in their active and abandoned states is presented in this study. Five sampling points within 100 m by 50 m were established on each land use where in-situ measurements of STPs were carried out using KD2 Pro thermal properties analyzer. The STPs of interest are thermal conductivity (λ_s), thermal resistivity (TR), specific heat capacity (C_s), thermal diffusivity (TD), temperature and thermal admittance (μ_s). Analysis of variance (ANOVA) was used to study the variations of measured STPs based on land use and land abandonment. The results of STPs revealed that mean λ_s in active DS was quadruple its value in abandoned DS while λ_s value in active BMS was twice its value in abandoned BMS. The average C_s value in active DS (3.928 MJ/m^{3}K) was approximately 2.5 times its value in abandoned DS while there is no significant difference in mean C_s recorded at both active and abandoned BMS. The soils under active DS were characterized by maximum values of λ_s, C_s, and μ_s while abandoned BMS records lowest values of mean λ_s and TD. Near surface soil under active BMS had lowest average values of C_s and μ_s (1.489 MJ/m^{3}K and 1.709 mm^2/s, respectively) among the studied land uses. The mean TR in active DS was <90^{0}C-cm/w and the least among the investigated land uses, suggesting its suitability for cable engineering practices. The results of ANOVA show soil temperature as the only STP that is not significantly different based on activity and abandonment of each land use pattern.

Keywords: *Activity and abandonment, Cement-block making site, Dumpsite, Specific heat capacity, STPs, Thermal conductivity.*

Introduction

Land use refers to the management process controlling the utilization of land resources for particular activity while land use change refers to any form of physical-chemical and biological state of land as a result of current management practice (Quentin *et al.*, 2006). Different land use systems influence soil characteristics differently, thus the ability of a particular land to function optimally may be enhanced, reduced or sustained based on the degree of the alteration of soil characteristics in response to land use management (Karlen *et al.*, 1997; Ganiyu 2018). In most developing countries (especially in Africa), most lands that should have been put into agriculture have been intensively used for developmental and economic purposes (Ganiyu, 2018: Tesfahunegn and Gebru, 2020).

Human beings need shelters and these are accomplished with the construction of buildings where soil-cement blocks constitute major part of building materials. Cement-blocks are used right from foundation level to the completion of load bearing structures such as flat, bungalow mansion etc that serve as apartments for people (Venkatara Reddy and Gupta, 2005). On the other hand, solid wastes are usually generated on daily basis as a result of various human activities. There have been continuous increases in the volume of generated solid wastes due to rise in population, urbanization and industrialization (Bello and Adegoke 2013, Badmus *et al.*, 2014). These wastes must be disposed properly in order to safeguard health of human beings. Dumpsites/landfills are created on large hectares of lands by government/relevant agency in environmental management to cater for efficient dumping of solid wastes. However there are instances where active dumpsites have been closed/abandoned due to environmental concerns raised by residents living close to the waste disposal sites. It must be noted that municipal solid wastes dumpsites not only act as deposition sites for wastes and source of landfill gases but also act as good sources of thermal energy as well (Faitli *et al.*, 2015).

Heat flow from/into the soil medium occurred through transport mechanism of conduction or convection process as a result of presence of thermal gradient within the soil matrix (Hamdhan and Clarke, 2010). However, the bulk of heat transfer in soil matrix occurs through conduction process (Alrtimi et al 2016). The conduction of heat in the soil, assuming a uniform and constant soil medium can be described by the one dimensional Fourier's law (Zhu *et al.*, 2019).

Soil thermal properties (STPs) such as thermal conductivity (λ_s), thermal resistivity (TR) and thermal diffusivity (TD) are influenced by soil factors such as particle size distribution, bulk density (BD), moisture content (MC), mineral composition, organic matter content, grain size distribution, and temperature (Mengistu *et al.*, 2017; Li *et al.*, 2019). The STPs that are usually of interest are λ_s and C_s (Roxy *et al.*, 2014; Tokoro *et al.*, 2016). Thermal conductivity (λ_s) is defined as the amount of heat flow due to unit temperature gradient in unit time under stable conditions in a direction normal to the unit surface area (Bristow, 2002, Faitli *et al.*, 2015). The volumetric heat capacities (C_s) is the quantity of heat needed to raise the temperature of a unit volume of soil by one degree Celsius (Roxy *et al.*, 2014; Haruna *et al.*, 2017). The thermal diffusivity (TD) is the ratio of $\boldsymbol{\lambda_s}$ to its volumetric heat capacity (Gladwell and Hetnarski, 2009). It is regarded as an important thermal property needed for proper determination of soil temperature distribution and heat flux in the soil matrix (de Jong van Lier and Durigon, 2013; An *et al.*, 2016). Another related property of soil thermal characteristics is the quantity known as thermal admittance ($\boldsymbol{\mu_s}$) which is a measure of the capability of a particular soil surface to release or accept heat to the immediate surrounding (Roxy *et al.*, 2014).

The characterization of soil thermal properties status assists in estimating its heat removal efficiency as well as revealing the heat storage capacity of the near surface soil under the land use (Faitli *et al.*, 2015). The knowledge of soil thermal properties found useful application in agricultural meteorology, earthquake precursors and many engineering projects such as design of energy piles, ground-source heat pumps, laying of telecommunication cables, underground oil/gas pipelines, waste contaminant etc (Oladunjoye *et al.*, 2013; Ghader, 2014; Roxy *et al.*, 2014; Amaludin *et al.*, 2016; Mengistu *et al.*, 2017). The feasibility of a good sub-surface geothermal system requires supporting soil thermal properties in addition to adequate moisture content of the surrounding backfill soil (Bertermann and Schwarz, 2017).

Several scientists have studied the impacts of various land uses on soil physico-chemical and hydraulic properties of (Senjobi *et al.*, 2013; Ganiyu, 2018 Nanganoa *et al.*, 2019, Tesfahunegn and Gebru, 2020). Scientists have also quantified levels of physico-chemical, microbiological, heavy metals content as well as geotechnical suitability of soils under active/abandoned dumpsites (Bello and Adegoke, 2013; Badmus *et al.*, 2014; Akoto *et al.*, 2016; Adesewa and Morenikeji, 2017; Somani *et al.*, 2018, Essienubong *et al.*, 2019; Wemedo *et al.*, 2020). Researchers have also reported that soil thermal properties (STPs) can be altered by land use systems (Adhikari *et al.*, 2014; Velichenko and Arkhangelskaya, 2015; Haruna et al; 2017; Shen et al, 2018).

Faitli *et al.* (2015) characterized thermal properties of active municipal waste land fill sites in Gyal- Hungary while Różański (2018) evaluated the thermal conductivity co-efficient of the coal mining waste in the upper Silesian Coal Basin. However, there seems to be sparse information on the thermal properties of soils based on current use and abandonment of land uses. For instance, Lucas-Borja *et al.* (2019) evaluated the effects of abandoned farmland, intensive agriculture and forest on soil hydrological properties in southern Spain.

The analysis of soil thermal properties in active and abandoned states of two different land use systems (Dumpsite (DS) and Cement-block making site (BMS)) forms the basis of this present study.

The objectives include assessment of levels of measured STPs in active and abandoned states of dumpsite and block making site, evaluation of effects of land use and land abandonment on measured STPs, and application of statistical analysis to study the significance of the variations of measured STPs based on states of land uses.

Description of the Study Area

The four land use patterns considered in this study (active and abandoned dumpsites, active and abandoned block making sites) were located within Abeokuta metropolis in Odeda local government, southwest Nigeria. Abeokuta lies between latitudes $7^{0}10^{1}$ and $7^{0}15^{1}$N and longitudes $3^{0}17^{1}$ and $3^{0}25^{1}$E and covers an approximate area of about 40.63 km^2 (Ufoegbune *et al.*, 2010). Abeokuta is within the humid tropical zone climate and has mean annual rainfall and temperature of 1238 mm and 27.1^{o}C, respectively (Ganiyu, 2018). The rainy season in the study area starts from March and runs till October, this is connected with moist maritime southernly monsoon coming from Atlantic ocean while the dry season commences from November and ends in February under the control of dust-laden north-easternly winds from Sahara desert (Badmus and Olatinsu, 2010; Balarabe *et al.*, 2015).

The temperatures in Abeokuta are highest on average in March at around 29.1^{o}C and lowest on average in August with 25.1^{o}C. Abeokuta is classified as Aw (tropical savanna climate) by Kö ppen and Geiger system classification (Essenwanger, 2003). The active dumpsite is located within University campus, abandoned dumpsite along Ibadan-Abeokuta road while active and abandoned block-making sites were along Isolu-University road (Figure 1). Non degradable wastes such as plastics, glass bottles, books, and plastic food containers are common on investigated active DS while soil cements blocks of sizes 6 and 9 inches produced with the aid of manually operated block making machine were noticed on active BMS. The active DS has been in existence since 2005, abandoned DS was closed late 2018; active BMS has been in existence since 2010 while abandoned BMS (not far from active BMS) stopped operation since 2018.

Geology of the Study Area

Abeokuta city belong to basement complex formation of southwest Nigeria. The basement complex rocks are loosely categorized into migmatite-gneiss complex, the schist belt and pan African (Ca 600Ma) Older grante series (Elueze, 2000). The northern part of Abeokuta is characterized by pegmatitic veins underlain by granite while the southern part enters the transition zone with the sedimentary formation of the eastern Dahomey basin (Key, 1992). The western part of Abeokuta is characterized by granite gneiss of less permeable characteristics in addition to different quartize intrusions (Key, 1992). At the southwest and southeast parts of the city is outlier of the ise formation of Abeokuta group which consists of conglomerates and grits at base and in turn overlain by coarse intermediate grained loose sand (Aladejana and Talabi, 2013; Ganiyu, 2018). The dominant rock type in the study area and the investigated land uses are shown in Figure 1.

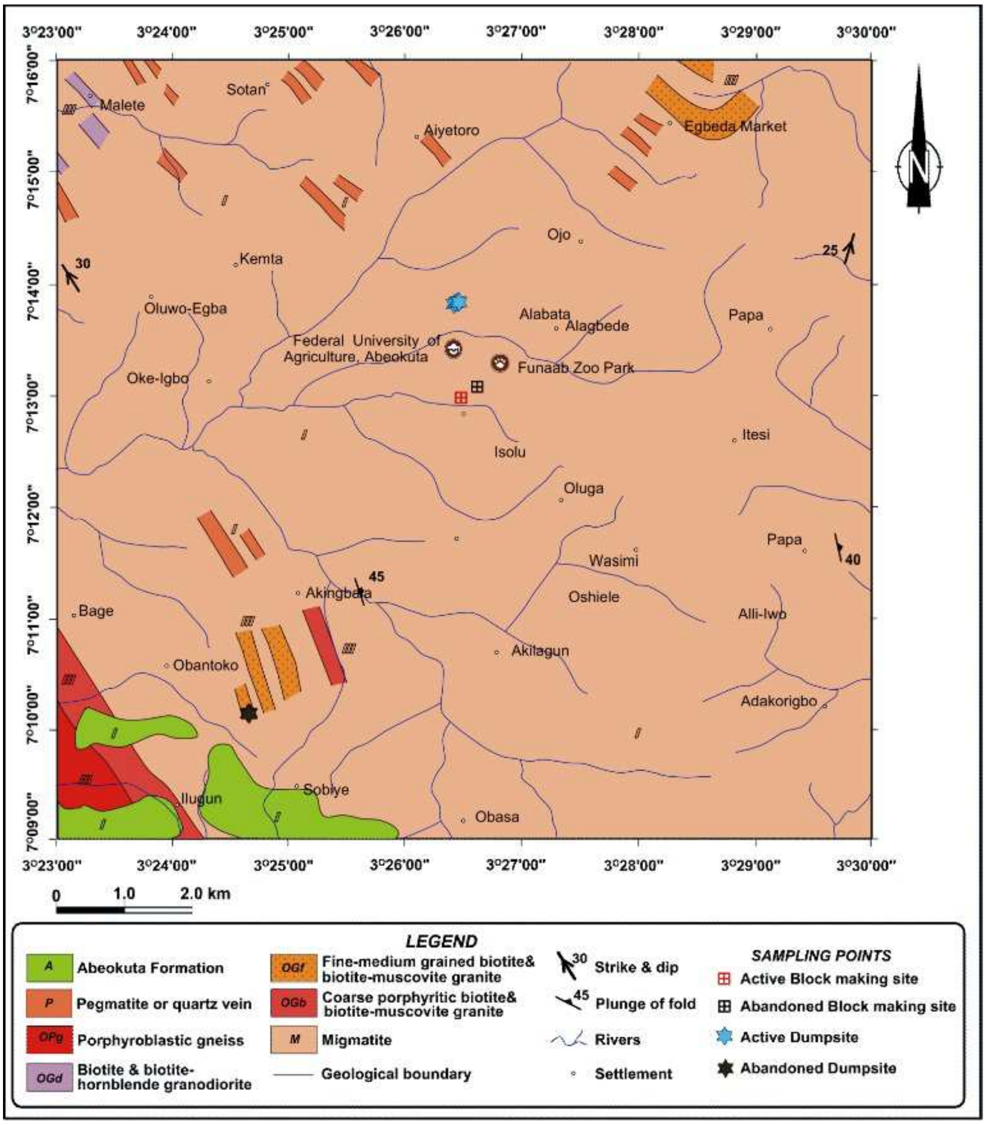

Fig. 1: Geological map showing active and abandoned land uses (after NGSA, 2016)

Materials and Methods

In-situ measurements of Soil Thermal Properties

On each investigated land use system, a 100 m by 50 m was identified with the aid of tape measure. This was divided into five sampling points where the KD2 Pro-thermal properties analyzer (Decagon devices inc, Pullman, WA, USA) with the attached SH-1 dual probe sensor was used to measure five STPs (C_s, λ_s, TR, TD, and temperature) at each of the five sampling points. The KD2 Pro thermal analyzer uses the transient-line heat source technique to measure the STPs (Zheng *et al.*, 2017, Oladunjoye and Sanuade, 2012). The SH-1 probe sensor consists of two 30 mm long parallel needle probe with 6 mm spacing and 1.3 mm diameter. Before the measurements were taken, the dual probe sensor was calibrated by inserting the sensor into the two-hole Delrin block for 15 minutes for temperature equilibrium (Amaludin *et al.*, 2016; Mengistu *et al.*, 2017). The top surface of the ground was scooped so as to allow for firm positioning of the sensor on the ground. The measurement of STPs was made by inserting the KD2 pro-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 of equilibration time was granted before the taking of the next reading (Oyeyemi *et al.*, 2018; Tong *et al.*, 2019). The sixth thermal properties considered in this study, thermal admittance (μ_s) of each sampling point was calculated using the expression:

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

where C_s is the soil volumetric heat capacity and λ_s is the soil thermal conductivity.

Statistical Analysis

Analysis of variance (ANOVA) was used as data treatment to evaluate and compare the impacts of activity and abandonment on each land use. The results of ANOVA were reported as mean ± standard deviation where the means were separated at the p 0.05 level of significance. The statistical analysis on the soil thermal data was done with the SPSS statistical software package version 20.0.

Results and Discussions

The results of measured STPs at all the sampling points on the four investigated land uses are presented in Table 1 while Table 2 listed the mean values of thermal properties under the soils of studied land uses. From Table 2, the mean value of λ_s in active DS was 1.533 W/mK while that of the abandoned DS was 0.424 W/Mk. The mean λ_s obtained on active DS was approximately 4 times higher than its value on abandoned DS. The mean C_s in active DS (3.928 MJ/m^3K) was about 2.5 times higher than its value (1.563MJ/m^3K) in abandoned DS. The average TD values in active and abandoned DS were 0.387 and 0.286 mm^2/s, respectively. The active DS had average μ_s (3.188 W/m^2K) that is approximately 1.3 times its value (3.397 W/m^2K) in abandoned DS. The mean thermal resistivity (TR) in active DS is roughly a quarter of its average value in abandoned DS (Table 2). However, the mean temperature value in active DS (31.95°C) was not significantly lower than the temperature value (33.78°C) in abandoned DS.

The results of mean λ_s and C_s on active 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 combined paper, glass, and plastic materials (which form the major components of wastes on investigated active DS) were 3.85J/g/K and 1.170 W/mK. Our own results of mean C_s and λ_s obtained through KD2 Pro-thermal properties analyzer in active DS are 3.930 MJ/m^3K 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).

The topsoil under active and abandoned BMS had mean λ_s values of 0.792 and 0.397 W/mK, respectively. Specifically, the average λ_s in active BMS is twice its value in abandoned BMS. Our λ_s value in active BMS was compared with various reported λ_s values of bricks/ blocks. For example, 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 wall was 0.726W/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 active BMS was 0.792 W/mK and compares fairly with aforementioned reported λ_s values for blocks. The mean TR in active and abandoned BMS were greater than 100°C-cm/W (Table 2).

Table 1: Soil thermal properties at dumpsite and block making site (active and abandoned)

Land uses	TR (^{o}C-cm/w)	λ_s (W/mK)	TD (mm^2/s)	C_s (MJ/m^{3}K)	μ_s (W/m^{2}K)	Temp (^{0}C)
ABANDONED DS 1	327.7	0.305	0.413	0.739	1.338	33.45
ABANDONED DS 2	382.6	0.261	0.217	1.206	2.361	37.07
ABANDONED DS 3	172.4	0.580	0.315	1.841	2.417	33.05
ABANDONED DS 4	173.2	0.577	0.293	1.960	2.580	33.13
ABANDONED DS 5	252.7	0.396	0.191	2.071	3.291	32.19
ACTIVE DS 1	46.61	2.145	0.489	4.384	2.993	32.07
ACTIVE DS 2	68.88	1.452	0.340	4.273	3.546	31.40
ACTIVE DS 3	91.42	1.094	0.369	2.964	2.834	31.27
ACTIVE DS 4	80.97	1.235	0.359	3.444	3.099	33.12
ACTIVE DS 5	57.44	1.741	0.380	4.577	3.469	31.91
ABANDONED BMS 1	476.63	0.210	0.248	0.845	1.844	37.12
ABANDONED BMS 2	243.82	0.410	0.199	2.064	3.223	33.38
ABANDONED BMS 3	281.61	0.355	0.225	1.578	2.648	40.03
ABANDONED BMS 4	197.30	0.507	0.194	2.615	3.673	40.55
ABANDONED BMS 5	198.20	0.504	0.192	2.625	3.698	43.15
ACTIVE BMS 1	116.2	0.861	0.473	1.820	1.961	40.14
ACTIVE BMS 2	124.9	0.801	0.577	1.388	1.551	40.42
ACTIVE BMS 3	233.5	0.428	0.325	1.317	2.013	48.45
ACTIVE BMS 4	102.6	0.975	0.682	1.430	1.448	36.73
ACTIVE BMS 5	112.0	0.893	0.600	1.489	1.576	38.58

Table 2: Mean values of STPs on dumpsite and block making site (Active and Abandoned)

Land uses	TR (^{O}C-cm/w)	λ_s (W/mK)	TD (mm^2/s)	C_s (MJ/m^{3}K)	μ_s (W/m^{2}K)	Temp (^{0}C)
ABANDONED DS	261.72	0.424	0.286	1.563	2.397	33.78
ACTIVE DS	69.06	1.533	0.387	3.928	3.188	31.95
ABANDONED BMS	279.50	0.397	0.212	1.945	3.017	38.85
ACTIVE BMS	137.84	0.792	0.531	1.489	1.709	40.86

The mean TD values in active and abandoned BMS were 0.531 and 0.212 mm^2/s, respectively. The average C_s values of soils under active and abandoned BMS are 1.489 and 1.945 MJ/m^{3}K, respectively. This indicates that C_s value in abandoned BMS is approximately 1.3 times higher than its value in active BMS. The average μ_s in abandoned BMS (3.017 W/ m^{2}K) was significantly higher than its value (1.709 W/m^{2}k) in active BMS. The mean temperature values in active and abandoned BMS were 40.86 and 38.85^{o}C, respectively.

Generally, λ_s and TD values in abandoned DS and abandoned BMS were lower than their corresponding values in active sites. Specifically, the lower values of λ_s in both active and abandoned BMS compared to its counterparts in 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). However, the mean λ_s in topsoil under active DS was slightly higher than the range of typical λ_s of normal soil (0.15-1.50 W/mK) (Andersland and Ladanyi, 1994). Furthermore, the mean λ_s recorded for soil under active DS falls within the range of 0.90 -1.55 W/mK for filled condition of sandy-loam soils by Ghader (2014). The TR of soils under active DS (<90^{o}C-cm/W) was significantly lower than its values in any of the three remaining sites, an indication of its suitability as backfill materials for cable engineering practices and laying of gas/oil pipes (Campbell and Bristow, 2014).

Results of Statistical Analysis

Tables 3 and 4 show the results of ANOVA for DS and BMS, respectively. Table 3 shows that the TR in abandoned DS was significantly higher than that of active DS. The mean values of λ_s, C_s and μ_s in abandoned DS are significantly lower than their values in active DS. However, the TD and temperature at abandoned DS were not significantly different from soil TD and temperature recorded at active DS.

In case of BMS (Table 4), the TR and μs in abandoned BMS were significantly higher than their corresponding values in active BMS at 5% level. However, λ_s and TD in abandoned BMS were significantly lower than λ_s and TD in active BMS. The values of C_s and temperature in abandoned BMS were not significantly different from mean C_s and temperature values in active BMS.

Table 3: ANOVA result for assessed parameters in DS based on Activity and Abandonment

Parameters	Abandoned Dumpsite	Active Dumpsite
TR	261.72 ± 93.3549^a	69.06 ± 17.8947^b
λ_s	0.42 ± 0.1494^a	1.53 ± 0.4201^b
TD	0.29 ± 0.0878^a	0.39 ± 0.0587^a
C_s	1.56 ± 0.5700^a	3.93 ± 0.6913^b
μ_s	2.40 ± 0.6993^a	3.19 ± 0.3076^b
Temperature	33.78 ± 1.8985^a	31.95 ± 0.7331^a

Table 4: ANOVA result for assessed parameters in DS based on Activity and Abandonment

Parameters	Abandoned Block Site	Active Block Site
TR	279.50 ± 115.6437^a	137.84 ± 54.0743^b
λ_s	0.40 ± 0.1229^a	0.79 ± 0.2127^b
TD	0.21 ± 0.0243^a	0.53 ± 0.1374^b
C_s	1.95 ± 0.7534^a	1.49 ± 0.1955^a
μ_s	3.02 ± 0.7824^a	1.71 ± 0.2582^b
Temperature	38.85 ± 3.7323^a	40.86 ± 4.4882^a

Conclusions

The levels of STPs at two land use systems (DS and BMS) in active and abandoned states have been investigated and results presented in this study. The results indicate that λ_s in active DS (1.533 W/mK) was approximately 4 times higher than its value (0.424 W/mK) in abandoned DS. The mean λ_s in active BMS (0.792 W/mK) was twice its value in abandoned BMS (0.397 W/mK).The average value of C_s in active DS was approximately 2.5 times higher than its value in abandoned DS while there is no significant difference in mean values of C_s at active and abandoned BMS. Generally, the abandoned BMS had lowest values of mean λ_s and TD (0.397 W/mK and 0.212 mm^2/s) while active DS had highest mean values of λ_s, C_s and μ_s (1.533 W/mK, 3.928 MJ/m^3K, and 3.188 W/m^2K, respectively). However, soils under active BMS had lowest level of average C_s and μ_s (1.489 MJ/m^3K and 1.709 mm^2/s, respectively) among the investigated land use systems. The mean TR in topsoil under active DS was 69.06°C-cm/W and is the lowest among the TR values of investigated sites. The ANOVA results discovered soil temperature as the common STPs that did not differ significantly based on activity and abandoned states of the studied land uses. The study recommends further assessment of STPs under agricultural and more economically related land uses in their active and abandoned states.

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