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Impacts of land use patterns on soil thermal and physical properties in basement complex and sedimentary terrains of Ogun State, Nigeria

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Abstract

Soil thermal properties (STPs) are critical for managing soil thermal regions under different land uses. Therefore, this study focused on measuring field STPs and the physical properties of soils across various land use patterns (football pitch (FP), abattoir site (AS), dumpsite (DS), and cement brick making (CBM) in basement complex (Odeda) and cretaceous sedimentary formation (Sagamu) in Ogun State, Nigeria. The results revealed that the highest mean thermal conductivity values observed in the basement and sedimentary formations were 1.53 and 1.98 W/mK, recorded in DS and FP, respectively. In terms of specific heat capacity (C_s), the maximum and minimum mean values of 3.93 and 1.49 MJ/mK were recorded in DS and BM within the basement complex lithology. Additionally, the highest and lowest thermal admittance (μ_s) values of 3.36 and 1.71 mm^2/s, along with soil moisture contents (MC) of 51.08 % and 26.28 %, were observed in FP and BM, respectively, within the basement complex. However, the sedimentary area exhibited the opposite trend. The mean thermal resistivity (TR) values for FP, AS and CBM soils in the sedimentary formation, as well as for DS soil in the basement complex, were within the recommended threshold (90 °C cm/W) for safe telecommunication signals and buried objects. The results revealed that nearly all the soil thermal properties were considerably influenced by lithology and land management practices. The outcomes of this study will assist land users to make best select of suitable land management practices for sustainable agriculture and environmental preservation.

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1. Introduction

The knowledge of STPs found useful applications in agriculture, ground source heat pumps, laying of telecommunication cables, underground oil/gas storage, buried power lines, waste contaminant, irrigation process as well as earthquake precursors to mention a few [1–4]. The viability of a good subsurface geothermal system requires supportive and improving soil thermal properties in addition to sufficient moisture content (MC) of the soil [1]. The STPs, especially thermal conductivity (λ_s) depends strongly on the

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MC of the soil as the latter enhances the thermal connection among the soil particles [5, 6]. The extent of the soil thermal properties reaction to the level of MC was however variable [1].

Thermal conductivity governs the rate of heat transfer, whereas the change in temperature is dependent on the volumetric heat capacity. Moreover, the latent heat of fusion is a key factor in transient problems that experience gradual phase changes related to unfrozen water content [5]. Flow of heat energy to or from the soil medium occurs through conductive/diffusion or convention process, driven by thermal gradient within the soil matrix [1, 7, 8]. Notably, an appreciable amount of thermal movement within soil particles occurs by the conductive mechanism [1, 9]. The diffusion mechanism of thermal transfer in soil, assuming unvarying soil material constituents, can be defined by the Fourier's law [8, 10]. The thermal properties of soil, including thermal conductivity (λ_s), volumetric thermal capacity (C_s), thermal diffusivity (TD) and thermal resistivity (TR) are all influenced by soil properties such as dry bulk density, gradation, soil moisture content, soil organic carbon, mineralogical constituents and temperature [1, 2, 8]. Thermal conductivity (λ_s) is an important thermophysical property that plays a significant role in estimating heat flow within geoscientific materials and thus controlling the temperature distribution in the earth's subsurface [11]. The λ_s property of soil, sediment, and rock is influenced by mineralogical content, soil texture, compaction, porosity, degree of saturation, organic matter content, temperature, and grain size [8, 11]. Since most anthropogenic activities occur on land surface, therefore, land use patterns, soil management practices and prevailing anthropogenic activities can affect these aforementioned factors, leading to considerable impacts on STPs [12]. Specifically, studies by Refs. [13, 14] have documented the impacts of land use and soil management practices on STPs. Knowledge of soil thermal conductivity (λ_s) is strategically useful in various environmental applications, including geotechnical/engineering construction, geothermal heat pump installation, buried power transmission cables, nuclear wastes repositories, agro meteorology, underground oil and gas storage amongst others [15, 16].

Land use refers to the arrangements, actions, and inputs that individuals employ within specific land cover types to induce change or sustain the current state [17]. Land is indispensable for human existence, offering essential living environments, food, and a variety of raw materials for the fulfillment of various needs [18]. Understanding land use within its spatial setting is essential for identifying both the ideal land use zones and areas that have suffered degradation. A detailed study of land use holds significant value in ensuring improved returns from the land to meet future requirements for food and industrial raw materials, while also supporting effective agricultural practices, integrated urban planning, and regional development, thus propelling the advancement of a nation [19].

Human activities such as urbanization, infrastructure expansion, transportation and sports contribute to significant depletion of natural resources. Key raw materials, including soil and cement-blocks are essential, constitute large part of the building materials [20]. However, there are associated long term impacts of cement production/cement-block making sites on both humans and the environment [21]. Cement factories are one of the most common sources of contaminants including potentially toxic elements (PTEs) in soil. Essentially, cement factories/ cement block making sites contribute to environmental pollution by PTEs via the emission of cement dusts and different gases [22]. Abattoir contributes significant amount of nutrient loads, rich microbial diversity, organic matter and PTEs into the environment, potentially exposing biodiversity and upsetting ecological equilibrium [23]. On the other hand, daily wastes generated by households are rising as a result of rise in population, heightened demand for food and other essential goods, rural-urban migration, and industrialization [24]. These wastes that are of various types, sizes and characteristics need to be properly disposed off in order to preserve healthy living and safe environment devoid of pollution and outbreak of epidemics [25]. Many peoples in most developing nations (especially in Africa) often dispose generated municipal solid wastes (MSWs) indiscriminately with little or no concern for public human health and the environment [26]. It is therefore, important, to ensure proper disposal of solid wastes generated from daily human activities in open dumpsite and landfills established by government in order to safeguard public health and preserve the fragile ecosystem [27, 28]. Apart from detrimental health and ecological impacts of dumpsites on human beings and the environment, it must be noted that dumpsites also act as good sources of thermal energy [20, 29].

Several scientists have studied the impacts of different land use systems on soil physico-chemical properties, hydraulic properties and soil nutrients availability [30–34]. Ref. [35] reported that changes in land use impact soil physico-chemical attributes, and hence STPs. However, the quantitative expression of the trend of alteration of thermal properties may differ in different soils due to various land use patterns [35]. Scientists have also reported that STPs can be swayed by prevailing land use practices [36–38]. Additionally, numerous research articles have also been published on the effect of geological formation/mineralogy on rock and soil properties [11, 39, 40]. Furthermore, several studies have been published on thermal properties of soil and rock, along with their related physical properties, by different researchers [3, 41, 42].

There is still paucity of documented investigations on the impact of land use patterns on soil thermal and physical properties of soils underlained by two different geological formations. This is worthwhile to study as the depiction of thermal characteristics of a particular land use pattern is significant in evaluating the heat extraction prospective of the land.

The main focus of the present work is to evaluate how specific land uses (football pitch (FP), abattoir site (AS), dumpsite (DS), and cement brick making (CBM)) and geological settings (basement complex and cretaceous sedimentary formations) affect field-measured soil thermal properties. Knowledge of the spatial changeability of STPs and their spatial inconstancy relationships with soil physical properties in different land use patterns under different geological formations remains limited in Nigeria.

In this present study, we applied the in situ measurements of STPs and laboratory measurements of soil physical characteristics across different land uses over two geological settings. As per the dataset, the variations in STPs and soil physical attributes across the two geological formations of Ogun State, Southwest Nigeria were examined. To the authors' knowledge, this investigation represents the first attempt to assess the effects of land management practices and lithological backgrounds on the thermal energy attributes of soils derived from two distinct geomorphological settings in Ogun State, southwestern Nigeria. This study is very important as it aims to generate and compare data on soil thermal properties from two sandy loam soils of different land uses originating from different geological formations within Ogun State, Southwest Nigeria. The aims are realizable with the following specific objectives: (i) assessment of the levels of thermal and physical properties of soils associated with selected land use patterns (football field, abattoir site, dumpsite, and cement block production site) underlain by basement complex and sedimentary parent materials, (ii) appraisal of the differences in means of analyzed thermal and physical properties with respect to selected land uses and (iii) analyzing the variations in thermal properties across the two samples locations based on underlying rock types.

2. Materials and methods

2.1. Study areas

Two locations were selected for the study. The first location is Odeda within Abeokuta, Ogun state, Nigeria as shown in (Figure 1). Odeda is located in a well-pronounced undulating topography and prominent hills with steep slopes [43]. It is defined by latitudes ranging from $7°10'N7°15'N$ and longitudes from $3°17'E3°26'E$ [1]. In Abeokuta, the average rainfall is 1238 mm and the average temperature is 27.1°C, respectively [1]. Abeokuta has two distinct seasons: a dry season from November to February characterized by dusty north-eastern winds from the Sahara Desert, and a wet marine influenced by the southern monsoon from the Atlantic Ocean, which begins in March and continues until October [44].

The second location for the research is Sagamu, recognized as the third-largest community in Ogun state, following Abeokuta and Ijebu-Ode [45]. This study area is defined by its geographical coordinates, with latitudes ranging from 6°50' to 7°00' N and longitudes 3°45' to 4°00' E (Figure 1). Sagamu is located 32 kilometers to the west of Ijebu ode, 63 km southeast of Abeokuta, 72 km southeast of Ibadan and 67 km northwest of Lagos [46]. The region lies on a gently rolling low-lying terrain, with elevations between 30 and 61 meters above sea level. It is also characterized by a humid tropical climate that experiences high annual temperature, rainfall, evapotranspiration, and relative humidity [47].

2.2. Geological settings of the study areas

Both basement complex and sedimentary formation were represented in Ogun State, Southwest Nigeria. Igneous and metamorphic rock units constitute the Precambrian basement complex while sedimentary formation composed of layered, often unconsolidated rocks formed from the accumulation and lithification of sediments [48]. The city of Abeokuta, which encompasses Odeda study area, belongs to the crystalline basement complex of Southwestern Nigeria [49]. The rocks of Nigerian crystalline basement complex are classified into diateexite (migmatite), proterozoic schist belt, older granites, porphyritic granite, hornblende-biotite gneiss, porphyroblasts gneiss, and pegmatitic intrusions which collectively define the subsurface geology of the area [50]. The Shagamu study area is a transitional zone, partly covered by the massive cretaceous sedimentary rocks of the Dahomey formation, as well as crystalline basement complex rocks of southwest Nigeria [51, 52]. The primary rock types underlying the sampling locations in Abeokuta and Sagamu are migmatite and Ewekoro/Ilaro formation, respectively as exemplified in Figure 2.

2.3. Thermal property measurements

For each land use pattern examined, five sample points were set up within a grid of 80 m by 40 m. The soil STPs were assessed between February and March, 2020. At each sample point, measurements were conducted using KD2 Pro Thermal Properties Meter (Decagon Devices Incorporated, Pullman, United States of America) attached with the SH-1 Dual-needle thermal characteristics sensor [1]. The in-situ thermal properties measured at each point were λ_s, C_s, TR, TD and soil temperature. The SH-1 dual-needle sensor comprises of two parallel probes, each 30 mm long, spaced 6 mm aparts and with a diameter of 1.3 mm [1, 54]. Prior to testing, the probe was calibrated using glycerol and water stabilized with 5g agar plate [55]. Also, before the measurements of STPs at every sample location, the surface soil of the land was first gouged so as to permit secure placing of the sensor on the ground [1, 8]. The STPs readings were obtained by inserting the KD2 dual thermal sensor on the scooped soil surface [1, 8]. The KD2 Pro meter coupled with the dual-needle sensor, was turned on to record the thermal properties readings [1, 3]. Following the initial measurements, a waiting period of approximately 1200 seconds was observed before recording the thermal properties from the next sampling point [1, 6, 8]. Thermal admittance (μ_s) which depicts soil's ability to receive or release thermal energy to the immediate surroundings was calculated using the relation described by Ref. [4] as:

$$\mu_s = C_s \lambda_s^{-1/2}. \tag{1}$$

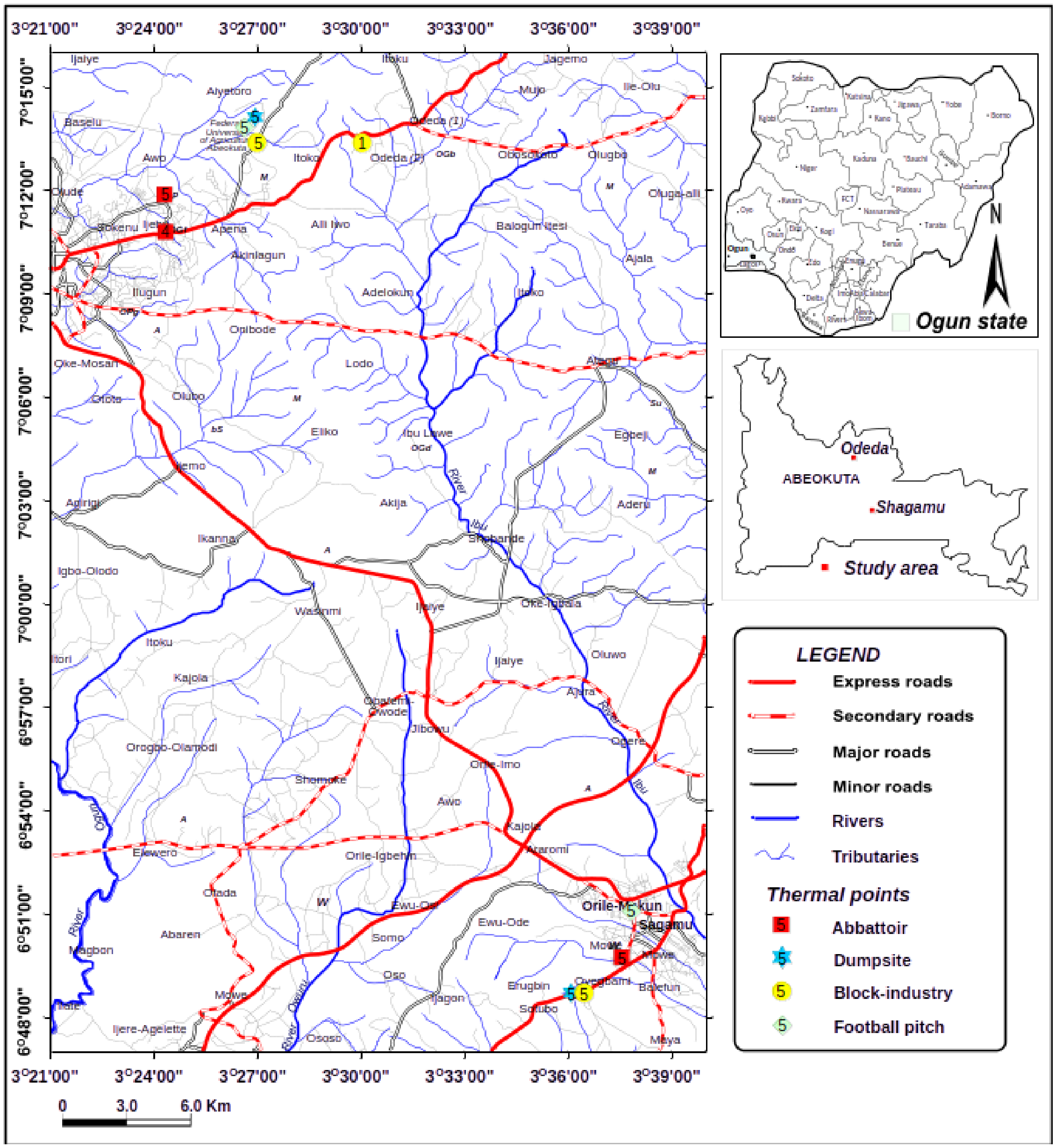

Figure 1: Site map of the study sites displaying the investigated land uses.

2.4. Soil sampling

Topsoil (0 - 30 cm) was collected from each of the 5 clusters representing different soil thermal characteristics across the land use types. The disordered surface soil samples were collected using a standard soil auger to estimate particle size distribution while undisturbed soil samples (collected with metal rings, height of 5 cm and a diameter of 5 cm) were utilized for the determination of bulk density (BD), porosity, and soil moisture content [1, 8]. The disturbed surface soils from each of the sampling points were put in poly vinyl chloride bags, properly labeled to avert mix-up [1, 8]. After the collection of the undisturbed soil samples at each location, the samples in the cylindrical core sampler were capped with polyethylene at both ends and secured with adhesive tape [1, 8]. Analyses for the moisture content, saturated permeability, bulk density, porosity and particle size distribution of the soil samples were carried out at the Soil Science Laboratory Centre of the Institute of Agricultural Research & Training (IAR&T), Ibadan, Nigeria. The soil BD was determined by gravimetric method, assuming a soil particle density of 2.65 g/cm^3 [56], while total porosity was deduced from the BD using the relationship outlined by Ref. [57] as:

$$\text{Total Porosity} = 1.0 - \frac{\rho_b}{\rho_{\text{particle}}}, \tag{2}$$

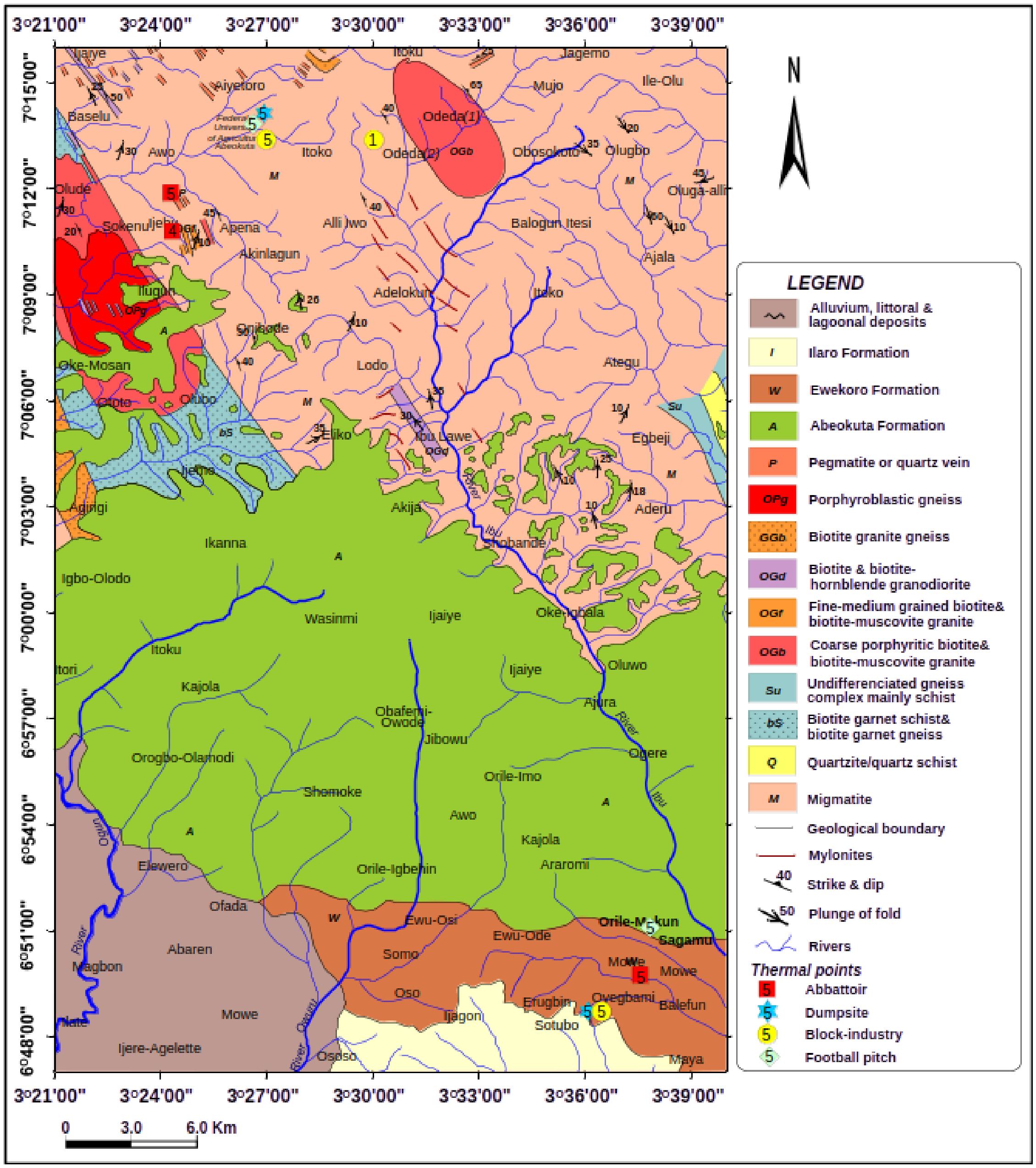

Figure 2: Geological map of the study areas showing the investigated land uses (modified after Ref. [53]).

where ρ_b represents the bulk density (g/cm^3) and ρ_{particle} equals 2.65 g/cm^3. Particle size distribution was determined using a modified Bouyoucous Hydrometer method as described by Ref. [58]. The soil textural classification was done using the United States Department of Agriculture (USDA) soil classification triangle. The saturated permeability (K_{sat}) was carried out using the Constant Head Permeameter method described by Ref. [59]. The degree of saturation (soil moisture content) was measured on the same day as the soil thermal characteristics employing the process of weight loss in accordance with ASTM [60].

2.5. Statistical analysis

Descriptive and inferential statistics such as mean, standard deviation and ANOVA were used to analyze the soil thermal data using the statistical software package (SPSS version 20.0, IBM SPSS statistical, Chicago, Illinois, USA). The impacts of land use types on the average values of measured soil thermal and physical properties were analyzed and compared using a one-way analysis of variance (ANOVA). Analysis of Variance (ANOVA) was performed on the soil data (thermal and physical properties) in order to appraise the significance of all analyzed soil variables according to geological formations and different land uses. All data in the ANOVA were presented as average ± standard deviation where the averages were separated at the p≤0.05 level of significance.

3. Results and discussions

Table 1 shows the values of soil physical parameters at different sampling points across four different land-use patterns, while Table 2 details the STPs at each sampling point for all investigated land uses with the average STPs for both basement and cretaceous sedimentary locations.

3.1. Soil physical properties in basement complex

The results showed that the soils from different land use patterns except abattoir in the basement complex were sandy loam (Table 1). This soil textural distribution in the basement complex area agrees with the earlier assertion by Ref. [61], which indicated that loamy sand or sandy loam is the dominant soil textures in these areas. The sand fraction dominated the particle size distribution, as also observed by Ref. [62]. Specifically, average sand content for collected topsoils over the entire investigated land use patterns in basement complex was 69.7%. This concur with the mean sand content of 69.3% reported for surface soils of basement complex [62]. The mean bulk density (BD) of soil samples from basement complex ranged from 1.08 to 1.61 Mg/m^3. In the basement complex area, the highest BD was recorded in CBM while the lowest was found in AS. The elevated BD in CBM within the basement complex may be attributed to the high percentage of sand content, the use of block molding equipment and the movement of vehicles for transporting of blocks and offloading of sands/cements, which likely compacted the surface soil, especially in the presence of low organic carbon content [63]. The mean BD value in CBM (1.61Mg/m^3) exceeds the British Standard (BS) minimum recommended value of 1.50 Mg/m^3 for sand Crete blocks by 7.3%. The lower BD observed in AS soil within the basement complex area is likely due to the presence of animal waste, which contributes to a decrease in soil BD [1, 64]. Furthermore, constant addition of animal waste (an abundant source of soil organic matter) to soil surface lowers its BD and increases porosity [64]. Meanwhile, the high soil BD in FP at Odeda site may be due to constant operation of lawn mower, grazing cattle trampling and low soil organic carbon in the football pitch [8]. A relatively high BD at FP site under basement complex parent material could be due to soil crusting and the absence of vegetation cover [1, 65]. In general for the two study locations, both the highest and lowest BD values were recorded in BML and AS within the basement complex area.

The mean porosities observed in the basement complex ranged from 39.1 to 58.9%. In the basement complex area, the highest porosity (58.9%) was obtained in the AS soil and the least porosity (39.1%) in the CBM soil. Maximum porosity value in AS soil of basement complex parent material indicates that organic matter in AS encourages soil aggregation, favours formation of pores and thus storage of water [66]. It was further observed that AS in the basement complex with highest porosity value corresponds with soil of lowest mean clay content (6.20%), suggesting more profound effect of organic matter [67]. The mean K_{sat} values (56.56 and 50.86 cm hr^{-1}) recorded in AS and FP, respectively, within the basement complex location were significantly greater than in other land uses in the two studied geological formations. Furthermore, the results showed that AS in the basement complex area had the highest K_{sat} value among the various land uses in both study areas. The elevated value of K_{sat} at AS in the basement complex area may be attributed to the large presence of sand particles, which typically create larger pore spaces in the soil [68, 69]. Variability in K_{sat} results may also stem from differences in the number of macro-pores and pore continuity within the soil samples [70]. A comparison of the mean K_{sat} values across the studied land use patterns in both the basement and sedimentary formations reveals that the K_{sat} values for each land use in the basement complex area surpass those of the corresponding land use in the sedimentary formation (Table 1).

Meanwhile, the highest MC was recorded in FP soil in the basement complex formation. This finding likely reflects lower surface hardness of the playing field [71]. Similar higher MC in FP soil in the basement complex area was also documented in our previous studies [1, 8]. The lowest MC was observed in CBM soil under basement complex lithology, which corresponds to its highest BD value. The MC results further revealed that the mean value of soil MC in each of studied land use patterns in basement complex area is significantly higher than the corresponding MC value in similar land use pattern under sedimentary formation. This may be due to differences in mineralogical compositions of soils under the two studied geological formations [72, 73].

3.2. Soil physical properties in sedimentary formations

Soil textural distribution showed that the soils from studied land uses in sedimentary location were sandy loam (Table 1). The average sand content for collected surface soils over the entire investigated land uses in sedimentary formation was74.4%. This is in agreement with average sand particles content of 74.8% reported for surface soils in sedimentary formation [62]. The mean bulk density (BD) of soil samples from sedimentary formations ranged from 1.14 to 1.55 Mg/m^3. In sedimentary formation, the highest and lowest BD values were obtained in AS and DS, respectively. It must be noted that the mean bulk density in AS under the sedimentary formation was greater than the soil bulk density in AS within the basement complex area. The discrepancy may be due to the lower values of porosity and MC recorded in AS soil from Sagamu compared to their corresponding values in AS within basement complex area. This probably indicates more leaching away of organic material in AS soil within highly weathered sedimentary location (Sagamu) than that of AS in basement complex formation [72]. Furthermore, increased microbial respiration in AS soil (due to addition of cow manure to soil surface) in sedimentary location can be designated as the source of the likely decrease in SOC, thus its higher BD relative to that of AS in basement complex location [74]. In general, bulk densities averaged 1.33 and 1.36 Mg/m^3 for surface soils collected from investigated land use patterns in basement complex and sedimentary formations, respectively.

This is in agreement with similar result of higher mean BD in surface soil derived from sedimentary lithology than that of basement complex parent material [62]. The mean porosities observed in sedimentary formations ranged from 41.6 to 56.9%. Furthermore, highest mean porosity was recorded under the DS, while the lowest mean porosity (probably due to more leaching of organic matter) was recorded in the AS within the sedimentary formation. In sedimentary location, the highest and lowest mean K_{sat} values were recorded in DS and CBM, respectively (Table 1). In the sedimentary formation area, the mean MC across all investigated land uses ranged from 16.94 to 35.02%, with DS having the highest moisture content and CBM showing the least MC value. Further scrutiny of MC results of soil samples in sedimentary location revealed that the mean value of soil MC in each of studied land use patterns in basement complex area is significantly higher than the corresponding value in similar land use pattern under sedimentary formation. This may be due to differences in mineralogical compositions of soils under the two studied geological formations [72, 73].

4. Soil thermal properties

4.1. Soil thermal property in basement complex

In terms of STPs, the mean thermal conductivity values observed across different land use patterns in the basement complex varied from 0.56 to 1.53 W/mK (Table 2). Within the basement complex, the highest mean (1.53 W/mK) was obtained in DS while the least mean (0.56 W/mK) was recorded in FP soil. The lower and thermal diffusivity (TD) values in FP within the basement complex formation (Table 2) may be due to the insulating effect of soil organic carbon that acts as an impediment to heat energy transfer in the soil [1, 8, 75]. This phenomenon holds considerable importance, given that grass-lands are recognized their copious soil organic carbon per one square metre [76]. The lowest in FP may also be attributable to the assertion that stable organic soil had lower than mineral matter-enriched soil [1, 29]. Furthermore, the average (0.56W/mK) obtained in FP, being less than 0.65W/mK is an indication that humus enriched-soil is not appropriate for dispersing thermal energy from buried pipe irrespective of its density [1, 77].

The highest values of mean and were obtained in DS within the basement complex (Table 2). This could probably due to earlier findings [29] that thermal energy losses at landfill happened via certain physico-chemical and biological reactions. Furthermore, the various types of wastes deposited on the studied dumpsite in basement lithology are non- biodegradable refuse (e.g. glass, bottles, plastics, books and fabrics). The mean in DS within basement complex was slightly above the normal limit of natural soil thermal conductivity (1.5E-1 to 1.50 W/mK) according to [78] as well as average field (1.14) of twelve different mineral soils from Trinidad [79]. However, the mean of DS soil in basement complex is within the range of 0.90 -1.55 W/mK reported for the filled state of sandy-loam soils [80]. Furthermore, the mean value in DS in the basement complex lithology is approximately 2.4 times higher than in DS in sedimentary formation area (Table 2). Specifically, the disparity in values at the investigated dumpsites in the two locations may be due to different types of waste materials dumped on the respective DS. In the basement complex area, the selected DS is located within Federal University of Agriculture, Abeokuta campus. Furthermore, comparing the ranges of values obtained at the two study locations, with values of some commonly used building materials as reported by Ref. [41], it was discernible that soils in all the investigated land uses can be used effectively for building construction purpose.

The thermal resistivity values in all the investigated land use patterns in both geological formations buttressed inverse relationship with values (Table 2). The mean TR values in all investigated land use patterns in the basement complex area ranged from 69.06 to 225.6°C–cm/W. The lower TR value (69.1°C–cm/W) in DS soil in the basement complex area may be due to its higher soil moisture content. The mean TR values in all the land use patterns except DS in the basement complex area are within the safety value of 90°C cmW^{-1} recommended for telecommunication signals and positioning of oil and gas conduits [1, 8, 81]. It must be noted that higher mean TR (225.6°C–cm/W) was recorded in FP located in the basement complex area. The range of mean TD in studied land use patterns in the basement complex was 0.22 - 0.53 mm^2/s. The lower mean TD recorded in FP in the basement complex area may be due to high organic carbon content in the football pitch [10]. The higher mean TD value in CBM (with corresponding lower value of soil moisture content (26.3%)) in the basement complex area agrees with earlier comparable finding of greater thermal diffusivity at lower moisture content [1, 66].

The values in land use patterns in the basemnt complex ranged from 1.49 (in CBM) to 3.93 (in DS) MJ/m^3K. It was observed that the highest values of and were recorded in DS in the basement complex area. The elevated value of mean in the DS amongst other land use patterns in the basement complex area concurs with the findings of [29] and [82] that DS represents big heat reservoir.

In the basement complex location, CBM had the highest mean soil temperature. This could be due to the higher net radiation absorbed by the exposed soil surface [83]. The lowest soil temperature in DS in the basement complex area probably arises as a result of presence of trees which could have lower the temperature by transpiration, evaporation and moisture influenced by the vegetation covers [84]. The values of mean temperature in all the studied land use patterns were lower than the reported highest temperature of 55°C, outside which most floras cannot endure devoid of moisture [1, 85]. Furthermore, the mean temperature values obtained in all the investigated land use patterns in the basement complex area were below the upper limit of land surface temperature (about 70°C) for desert vegetation [86].

In the basement complex area, the highest and the lowest mean values were recorded in FP and BM, respectively (Table 2). Materials with high thermal admittance cannot retain heat for a long period as heat will quickly dissipate from their surfaces if the temperature around them lowers. Conversely, materials with poor will retain heat for a considerably longer time. In light of this, it

Table 1: Soil physical properties of the study areas under different land uses.

Location	Sample Code	Sand (%)	Silt (%)	Clay (%)	K_{sat} (cm/s)	MC (%)	BD (Mg/m^3)	Porosity (%)	Soil type
Basement Complex	FP1	74.8	19.2	6	57.9	60.1	1.59	40.1	
	FP2	70.8	23.2	6	48.3	62.7	1.51	43.2	
	FP3	58.8	31.2	10	61.8	64.2	1.49	44	
	FP4	71.2	20.8	8	60.6	34.2	1.4	47.2	
	FP5	72.8	19.2	8	25.7	34.2	1.45	45.3	
	Mean	69.7	22.7	7.6	50.86	51.08	1.48	43.9	SL
	AS1	82.8	10.8	6.4	58.3	28.8	1.09	58.8	
	AS2	78.8	14.8	6.4	44.6	32.5	1.07	59.5	
	AS3	76	18.8	5.2	64.4	36.7	1.08	59.3	
	AS4	77.6	15.2	7.2	50.5	40.1	1.06	59.9	
	AS5	76.8	17.2	6	65	44.3	1.14	57	
	Mean	78.4	15.4	6.2	56.5	36.5	1.08	58.9	LS
	DS1	50.8	35.2	14.0	28.7	40.1	1.22	54.0	
	DS2	60.8	25.2	14.0	20.2	34.8	1.12	57.7	
	DS3	64.8	21.2	14	20.7	50	1.15	56.6	
	DS4	57.2	30.8	12	20.1	49.1	1.16	56.4	
	DS5	58.8	27.2	14	21	47.6	1.23	53.6	
	Mean	58.48	27.9	13.6	22.1	44.3	1.18	33.6	SL
	CBM1	70.8	19.6	9.6	16.0	29.2	1.69	36.3	
	CBM2	72.8	17.6	9.6	3.9	35.2	1.6	39.6	
	CBM3	72	20.4	7.6	4.6	22.6	1.58	40.4	
	CBM4	73.6	18.8	7.6	4.8	22.6	1.55	41.4	
	CBM5	72.8	17.6	9.6	39	21.8	1.65	37.7	
	Mean	72.4	18.8	8.8	10.78	26.3	1.61	39.1	SL
Cretaceous Sedimentary	FP1	72.6	20.9	6.48	10.9	27.7	1.13	57.5	
	FP2	72.6	20.9	6.48	10.7	24.3	1.33	49.9	
	FP3	65.7	27.3	7.02	22.5	68.8	1.07	59.6	
	FP4	70.6	22.9	6.48	13	36.2	1.24	53.3	
	FP5	78.6	14.9	6.48	10.8	18.1	1.26	52.4	
	Mean	72.02	21.4	6.5	13.6	32.5	1.21	54.5	SL
	AS1	73.1	19.3	7.56	4.1	13	1.68	36.6	
	AS2	69.1	21.3	9.56	6.2	14.5	1.63	38.4	
	AS3	74.6	17.8	7.56	6.7	3.8	1.64	38.3	
	AS4	69.1	23.3	7.56	14.3	45.1	1.22	54	
	AS5	72.6	18.9	8.48	7.1	14.3	1.57	40.7	
	Mean	71.7	20.21	8.14	7.68	18.14	1.55	41.6	SL
	DS1	69.7	21.3	9.02	18.2	16.9	1.28	51.7	
	DS2	82.6	2.9	14.48	22	30.5	1.25	52.7	
	DS3	82.6	4.9	12.48	24	39.8	1.08	59.4	
	DS4	74.6	10.9	14.48	25.5	35.4	1.05	60.4	
	DS5	75.1	17.3	7.56	28.3	30.6	1.04	60.7	
	Mean	76.92	11.46	11.46	22.6	35.02	1.14	56.98	SL
	CBM1	74.6	16.9	8.48	6.6	13.2	1.62	39	
	CBM2	79.1	13.3	7.56	8.4	11.3	1.59	39.8	
	CBM3	75.1	15.3	9.56	3.3	12.8	1.59	40	
	CBM4	80.6	6.9	12.5	9.2	33.2	1.27	52.1	
	CBM5	74.6	16.9	8.48	8.5	14.2	1.5	43.3	
	Mean	76.8	13.86	9.31	7.2	16.94	1.51	42.84	SL

Note: SL: Sandy Loam; LS: Loamy Sand.

can be argued that soil in the research area with low will retain heat for a lot longer [3]. No clear direct relationship between and MC in this study may be due to earlier assertion by Ref. [4] that positive correlation between and MC may not manifest if the water content is higher than 22%.

4.2. *Soil thermal properties in sedimentary terrains*

The mean thermal conductivity values recorded across different land uses in the sedimentary formation ranged from 0.64 to 1.98 W/mK (Table 2). Among the studied land uses in sedimentary location, FP had the highest value while the DS had the lowest mean value (Table 2). Comparatively, the mean in FP, AS and CBM soils in the sedimentary formation area were 3.6, 2.4 and 1.6 times respectively, greater than their matching average values in basement complex area (Table 2). It was observed that the average in DS in the sedimentary location was comparatively lower than the mean in DS within basement complex (Table 2). This could be probably due to the fact that the selected DS in sedimentary formation area receives varied municipal solid wastes. The thermal conductivities obtained on selected land use patterns in both locations were moderate as they fall within the standard range of measurement (0.02 - 4.00W/mK) [3].

The mean TR values in all investigated land uses in the sedimentary formation area area ranged from 52.33 to 179.70°C–cm/W. It was observed that in the cretaceous sedimentary formation area, the mean TR values in FP, AS and CBM were below 90°C cmW^{-1} whereas the average TR value in DS was greater than 90°C cm/W (Table 2). It must be noted that highest and lowest mean TR values in sedimentary location were recorded in DS and FP, respectively Lower mean TR value in FP in the sedimentary formation area concurs with the earlier assertion by Ref. [87] that all other factors being equal, surface soil with high percentage of quartz had lower TR than those with lower percentage of quartz. Our result of low TR in FP under the sedimentary formation is further corroborated by findings of [88] and [72] that surface soil developed over the sedimentary formation (Ewekoro formation) had higher percentage of quartz (thus low TR) than soils developed over the basement complex rock. However, higher mean TR value in DS in the sedimentary formation area may be due to possible segregation of different grain sizes of fine sand fraction during dry compaction period [87].

The range of mean TD in studied land uses within the sedimentary formation was 0.36 - 1.28 mm^2/s. For the studied land uses in the sedimentary formation area, the highest and the lowest TD values were obtained in AS and DS, respectively (Table 2). It was further observed that the mean TD value in AS in the sedimentary formation area was significantly higher when compared to mean TD values in all other visited land use patterns under the sedimentary formation. It was clearly observed that the lowest and values were recorded in DS in the sedimentary formation area. The discrepancy in mean values of and in the two investigated DSs may be due to the nature of deposited solid wastes and underlying geological formation. As observed in basement complex area, CBM had the highest mean soil temperature in sedimentary location. In the sedimentary formation area, the highest and the lowest values were obtained in CBM and FP, respectively (Table 2).

Measured thermal conductivities in DS at basement complex location is in the range of 1.094 to 2.145 W/mK while that of sedimentary terrain from 0.345 to 1.027 W/mK, Our range of in DS (municipal solid waste disposal site) at Sagamu location is in good agreement with the ranges of 0.30 -1.50 and 0.24 -1.15 W/mK published by Ref. [89] and [29]. This is a further indication that types of waste materials on the DS had influence on thermal conductivity values. The average values in CBM from the two locations were compared with various reported values of bricks/blocks. For example, recycled constructions and demolition waste blocks (RCDW) had within the range of 0.60 to 0.78 W/mK [90], soil-cement block was found to lie in the range of 0.84-1.09 W/mK [91] while of pure mansory block was reported by Ref. [92] to be 0.81 W/mK. In this present study, the mean values that we got for soils under CBM at the two locations were 0.980 and 1.270 W/mK and fall within the range of for soil-cement blocks [91]. Furthermore, [93] reported that the average of light weight concrete (LWC) ranged 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 in CBMs at both locations lie within the aforementioned ranges of in both LWC and NWC. The value in Sagamu FP soil is comparable to the average value (1.88 W/mK) in soils at Olorunsogo Power Plant (underlain by alluvium, littoral and lagoonal deposits), Ogun State, Nigeria [94].

The mean thermal conductivity (λ) of sampling points in all investigated land uses in Abeokuta (basement complex) varied from 0.56 to 1.53 W/mK. However, the values of all land uses except DS in Abeokuta location were lower than ¡ 1.00 W/mK. This might be due to variability in soil sampling, instrument calibration, land use pattern, climatic condition and number of sampling points. In Sagamu location, values ranged from 0.64 to 1.98 W/mK. The average in each of investigated land use patterns in Sagamu was relatively lower than the mean of sandstone (3.06 W/Mk); Shale (2.48 W/mK) and mudstone (2.57 W/mK) [95]. This could be attributed to the fact that of rock/sediment differs significantly with different lithology types [40]. Cretaceous formation that underlies Sagamu comprises of unconsolidated sands with intercalations of grey shale, mudstone, silt and shale-clay [47]. Therefore, the disparity in of soils in investigated land uses in Sagamu location to those described by Ref. [95] might be due to variability in soil sampling, instrument calibration, prevailing land use pattern, climatic condition, difference in nature of samples observed and number of sampling points. Generally, the ranges of average values of in topsoils of studied land use patterns under both litologies were slightly higher than the range of typical of normal soil (0.15-1.50 W/mK) reported by Ref. [78].

Tables 3 and 4 detailed the findings of the ANOVA in the basement complex and sedimentary formations, respectively. Table 3 shows that all the observed parameters varied significantly at 5% ($p < 0.05$) among the different land use patterns at Odeda in basement complex lithology. In other words, land use patterns have substantial impacts on the observed parameters in basement complex area. The results (Table 3) also showed that substantial disparity at 5% ($p < 0.05$) appeared in λ_s and temperature in the DS located in the basement complex area. Specifically, the mean λ_s value in DS was remarkably greater than λ_s in FP, AS and CBM. This is an indication that amount of heat generated in the DS outweigh those in other land use patterns and this could due to the kind of waste materials (glass, books, fabrics and bottles). In fact, Faitli *et al*. [11] reported that the extent of thermal energy losses in DS could be influenced by some physical, chemical and microbiological processes. Table 3 further revealed noteworthy variations in the average measurements of TR, TD, C_s and all the considered soil physical parameters in topsoils of investigated land use patterns in the basement complex area at 5% level. The mean C_s and μ_s values in BM under the basement complex lithology were significantly lower compared to the other land use patterns (Table 3). This shows that land use patterns have significant effects on all the observed

Table 2: Soil thermal properties at different land use patterns in Odeda and Shagamu study areas.

Location	Sample Code	λ_s (W/mK)	TR (°C cm/W)	TD (mm^2/s)	C_s (MJ/m^{3}K)	Temp (°C)	μ_s (W/m^{2}K)
Odeda	FP1	0.384	260.7	0.246	1.560	37.30	2.517
	FP2	0.236	425.5	0.128	1.845	37.81	3.798
	FP3	0.857	116.6	0.227	3.784	37.04	4.088
	FP4	0.803	124.6	0.307	2.617	39.66	2.920
	FP5	0.499	200.4	0.204	2.451	42.83	3.469
	Mean	0.560	225.56	0.220	2.450	38.93	3.360
	AS1	0.463	215.8	0.171	2.702	35.74	3.971
	AS2	0.440	227.4	0.201	2.188	33.05	3.299
	AS3	1.163	85.99	0.404	2.875	32.48	2.666
	AS4	0.729	137.1	0.285	2.557	49.72	2.995
	AS5	0.782	127.9	0.321	2.432	41.00	2.750
	Mean	0.720	158.8	0.280	2.550	38.40	3.140
	DS1	2.145	46.61	0.489	4.384	32.07	2.993
	DS2	1.452	68.88	0.340	4.273	31.4	3.546
	DS3	1.094	91.42	0.369	2.964	31.27	2.834
	DS4	1.235	80.97	0.359	3.444	33.12	3.099
	DS5	1.741	57.44	0.380	4.577	31.91	3.469
	Mean	1.530	69.06	0.390	3.930	31.96	3.190
	CBM1	0.861	116.2	0.473	1.820	40.14	1.961
	CBM2	0.801	124.9	0.577	1.388	40.42	1.551
	CBM3	0.428	233.5	0.325	1.317	48.45	2.013
	CBM4	0.975	102.6	0.682	1.430	36.73	1.448
	CBM5	0.893	112.0	0.600	1.489	38.58	1.576
	Mean	0.980	137.8	0.530	1.490	40.86	1.710
Shagamu	FP1	1.872	53.44	0.578	3.255	38.28	2.379
	FP2	2.520	39.69	0.961	2.621	41.72	1.651
	FP3	1.432	69.82	0.517	2.769	38.88	2.314
	FP4	1.911	52.34	0.904	2.114	35.02	1.529
	FP5	2.157	46.35	0.841	2.564	37.54	1.746
	Mean	1.980	52.33	0.760	2.660	38.29	1.920
	AS1	4.070	24.57	4.894	0.832	40.71	0.412
	AS2	1.652	60.54	0.419	3.940	36.02	3.065
	AS3	1.209	82.70	0.426	2.836	37.43	2.579
	AS4	0.550	181.8	0.248	2.220	36.97	2.993
	AS5	1.248	80.15	0.393	3.176	34.91	2.843
	Mean	1.750	85.95	1.280	2.600	37.21	2.380
	DS1	1.027	97.39	0.586	1.751	40.62	1.728
	DS2	0.345	289.7	0.232	1.486	37.65	2.530
	DS3	0.692	144.4	0.260	2.659	31.03	3.196
	DS4	0.682	146.7	0.431	1.582	36.06	1.915
	DS5	0.454	220.1	0.276	1.643	46.51	2.438
	Mean	0.640	179.7	0.360	1.820	38.37	2.360
	CBM1	1.009	99.08	0.417	2.421	40.98	2.410
	CBM2	1.455	68.72	0.549	2.650	38.16	2.197
	CBM3	1.177	84.98	0.297	3.959	36.82	3.649
	CBM4	1.051	95.12	0.401	2.620	38.9	2.556
	CBM5	1.651	60.57	0.512	3.221	38.63	2.507
	Mean	1.270	81.69	0.440	2.970	38.70	2.660

parameters in the basement complex area.

In the sedimentary formation area, the result of the analysis of variance (Table 4) revealed that land use patterns only have significant effects on some of the observed parameters. The parameters that are significantly influenced by land use pattern include: thermal conductivity (λ_s), TR, silt fraction, clay fraction, BD and porosity. However, TD, C_s, μ_s, temperature, sand fraction and MC did not vary considerably amongst the land use patterns. Specifically, mean TD in AS in the sedimentary formation area was significantly higher than its corresponding values in other land use patterns. In addition, the mean values of λ_s and C_s in DS within

Table 3: ANOVA of the investigated parameters under different land use patterns in basement complex location

Parameters	Abattoir	Dumpsite	Brick industry	Football field
λ_s	0.72 ± 0.2935^a	1.53 ± 0.4201^b	0.79 ± 0.2127^a	0.56 ± 0.2678^a
TR	158.84 ± 60.5845^{ab}	69.06 ± 17.8947^a	137.84 ± 54.0743^{ab}	225.56 ± 126.4012^b
TD	0.28 ± 0.0937^{ab}	0.39 ± 0.0587^b	0.53 ± 0.1374^c	0.22 ± 0.0652^a
C_s	2.55 ± 0.2616^a	3.93 ± 0.6913^c	1.49 ± 0.1955^b	2.45 ± 0.8610^a
Temp	38.40 ± 7.1702^a	31.95 ± 0.7331^b	40.86 ± 4.4882^a	38.93 ± 2.4097^a
μ_s	3.14 ± 0.5276^a	3.19 ± 0.3076^a	1.71 ± 0.2584^b	3.36 ± 0.6396^a
% Sand	78.40 ± 2.6683^a	72.40 ± 1.0583^b	69.68 ± 6.2827^b	58.48 ± 5.1490^c
% Silt	15.36 ± 3.0146^a	18.80 ± 1.2329^{ab}	22.72 ± 5.0152^{bc}	27.92 ± 5.3471^c
% Clay	6.24 ± 0.7266^a	8.80 ± 1.0954^b	7.60 ± 1.6733^{ab}	13.60 ± 0.8944^c
K_{sat}	56.56 ± 8.8810^a	10.78 ± 15.8266^b	50.86 ± 15.0307^a	22.14 ± 3.6855^b
MC	36.48 ± 6.1059^{ab}	26.28 ± 5.8148^a	51.08 ± 15.4789^c	44.32 ± 6.6013^{bc}
BD	1.09 ± 0.0311^a	1.61 ± 0.0559^b	1.49 ± 0.0709^c	1.18 ± 0.0472^d
Porosity	58.90 ± 1.1336^a	39.08 ± 2.0633^b	43.96 ± 2.6350^c	55.66 ± 1.7743^d

Table 4: ANOVA outcome of the investigated parameters under different land use patterns in sedimentary formation location

Parameters	Abattoir	Dumpsite	Brick industry	Football field
λ_s	1.75 ± 1.3580^a	0.64 ± 0.2626^b	1.27 ± 0.2757^{ab}	1.98 ± 0.3999^a
TR	85.95 ± 58.4050^a	179.66 ± 75.5681^b	81.69 ± 16.6424^a	52.33 ± 11.2101^a
TD	1.28 ± 2.0238^a	0.36 ± 0.1496^a	0.44 ± 0.0993^a	0.76 ± 0.1999^a
C_s	2.60 ± 1.1676^a	1.82 ± 0.4765^a	2.97 ± 0.6260^a	2.66 ± 0.4107^a
Temp.	37.21 ± 2.1830^a	38.37 ± 5.7239^a	38.70 ± 1.5058^a	38.29 ± 2.4170^a
μ_s	2.38 ± 1.1148^a	2.36 ± 0.5770^a	2.66 ± 0.5678^a	1.92 ± 0.3941^a
% Sand	71.70 ± 2.4850^a	72.02 ± 4.6349^a	76.80 ± 2.8417^a	76.92 ± 5.5979^a
% Silt	20.12 ± 2.1822^{ab}	21.38 ± 4.4668^a	13.86 ± 4.1627^{bc}	11.46 ± 7.8669^c
% Clay	8.14 ± 0.8862^{ab}	6.59 ± 0.2415^a	9.31 ± 1.9073^{bc}	11.60 ± 3.1757^c
K_{sat}	7.68 ± 3.8771^a	13.58 ± 5.0771^b	7.20 ± 2.3822^a	23.60 ± 3.7941^c
MC	18.14 ± 15.7074^a	35.02 ± 19.9829^a	16.94 ± 9.1492^a	30.64 ± 8.5932^a
BD	1.55 ± 0.1875^a	1.21 ± 0.1045^b	1.51 ± 0.1436^a	1.14 ± 0.1155^b
Porosity	41.60 ± 7.0834^a	54.54 ± 3.9374^b	42.84 ± 5.4317^a	56.98 ± 4.4042^b

the sedimentary formation were significantly lower than their corresponding values in FP, AS and CBM. There is no significant variation in the average surface soil temperature in all the investigated land use patterns in the sedimentary formation area.

5. Conclusions

In this study, the impacts of non-agricultural related land use patterns (CBM, AS, FP and DS) from two different lithologies - basement complex and sedimentary formations were evaluated on soil heat and physical characteristics within topsoil horizon of sandy soils. The mean thermal conductivity (λ_s) and TD values in FP in the basement complex area were low compared to their corresponding values in FP within the sedimentary formation area. This is an indication that FP in the basement complex area is of good natural environmental friendly insulator but inappropriate for harmless and effective dissipation of thermal energy from underground power lines. Of all land use patterns investigated in the basement complex area, DS had highest values of $\lambda_s$and $C_s$but lowest surface temperature and porosity. Nevertheless, highestλ_s and K_{sat} values characterized FP in the cretaceous sedimentary formation area. The ANOVA result reveals that all the observed parameters varied significantly at 5% level across different land use patterns in basement complex area while studied land use patterns only have significant effects onλ_s, TR, BD, porosity and K_{sat} in the sedimentary location. Further assessment of STPs under more agricultural and non-agricultural related land uses on seasonal basis is highly suggested. This is important because it will assists land users manage soil under the impact of climate change. The results of the study will be beneficial to land users for good selection of suitable land management practices for maintainable environmental preservation.

Data availability

Data will be made available upon reasonable request from the corresponding author.

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