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Evaluation and Modeling of Shallow Subsurface Temperature in Parts of Akwa Ibom State, Nigeria

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ABSTRACT:

Background: Soil temperature is one of the most important factors affecting plant growth. Until soil reaches a certain critical temperature neither seeds germinate nor plants have a normal growth because it affects root and shoot growth and availability of water and nutrients.

Methods: Temperature measurements have been carried out at different depths in the soil in parts of Akwa Ibom State of Nigeria. Different locations were chosen, (Ikot Obong Edong, Ikot Otu, Abiakpo). Results of measurements were taken at different depths and times using a soil thermometer over a one year. The diurnal soil temperature cycles are being modeled with fairly good accuracy. Differences in measured and modelled soil temperatures are determined at daily levels at depths 0cm which is the top soil, 10cm, 30cm and 50cm.

Results: The daily soil temperature ranges from 29.7℃ – 42.9℃ for months covering dry season with a simple mean of 36.3℃; 21.2℃– 29℃ for months covering rainy season with a simple mean of 25.1. The mean temperature for all season is 30.7℃, indicating that these locations are favourable for farming.

Conclusion*:* The results can be valuable in planning and developing soil practices and other agricultural activities in the areas studied. It was found that in dry season, the soil temperature increases with depth and in rainy season, it first decreases up to certain depth and then starts to increase with depth. This is due to the effects of solar thermal energy and ground thermal energy.

Keywords: Agricultural Activities, Depth, Measurement, Modeled, Soil temperature.

1. INTRODUCTION

The activities that occur in the soil have a profound effect on the world's ecosystems, ranging from water pollution[1] and rainforest destruction to ozone depletion and global warming. An important part of the Earth's ecosystem is soil; soil is a significant carbon reservoir within Earth's carbon cycle and may be highly sensitive to human disturbance and climate change[2]. As the world warms, soils are projected to contribute to a positive feedback loop by releasing carbon dioxide into the atmosphere due to increased biological activity at higher temperatures[2]. However, in light of more recent findings about soil carbon turnover, this prediction has been called into question. A vital source of ecosystem services, soil serves as an engineering medium, a home for soil organisms, a system for recycling nutrients and organic wastes, a regulator of water quality, a moderator of atmospheric composition, and a medium for plant growth. The majority of the genetic variety on Earth is found in soil because it offers a vast array of niches and habitats. Billions of creatures from thousands of species, primarily microbial and largely undiscovered, can be found in a gram of soil. In contrast to the ocean, which has no more than 107 procaryotic organisms per milliliter (gram) of seawater, soil has an average prokaryotic density of about 108 organisms per gram[3]. Heterotrophic organisms' respiration process eventually releases the organic carbon stored in the soil back into the atmosphere, but a significant portion is kept in the soil as soil organic matter; tillage typically speeds up soil respiration, which causes soil organic matter to be depleted. Ventilation is a crucial aspect of soil because plant roots require oxygen. Networks of interconnected soil holes can be used to achieve this ventilation. These pores also collect and retain rainfall, making it easily accessible for plant absorption. The ability of soils to retain water is essential for plant viability since plants need a virtually constant supply of water, yet most areas only receive intermittent rainfall. Natural attenuation is the term for the ability of soils to efficiently eliminate toxins, eradicate disease-causing agents, and break down pollutants. Soils normally experience a net emission of carbon dioxide and nitrous oxide and a net absorption of

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oxygen and methane. Soils offer plants physical support, air, water, temperature moderation, nutrients, and protection from toxins[4]. Soils provide readily available nutrients to plants and animals by converting dead organic matter into various nutrient forms.

Soil temperature is one of the most important factors affecting plant growth. Until soil reaches a certain critical temperature neither seeds germinate nor plants have a normal growth because it affects root and shoot growth and availability of water and nutrients[5]. The ideal soil temperature range for plant growth is 20 to 30°C. Temperatures below 20°C (suboptimal) and above 35°C (supraoptimal) significantly slow down plant growth. Furthermore, temperature affects every soil action. Thus, the edaphic environment is significantly influenced by the soil's thermal regime. The soil temperature regime also affects the release of nutrients for root absorption. Therefore, it is crucial to determine the depth and temperature of the soil for the growth and germination of specific crops. The soil's physicalcomposition[6] and the stability of structures in polar and cold regions[7] are both impacted by the dynami c transition of the liquid state from water to ice brought on by solar radiation, air temperature fluctuations, and heat transfer. Low ground temperatures have been explored by a number of authors [8]. As part of this study, it is considered that the model of soil temperature variations is instantaneous (considering that the temperature can change at any time of the day), which differs from the thermal model of Hillel's, which based only on annual (considering that the temperature remains constant throughout the day) and thermal [9].

Location of the Study Area: Ikot Ekpene is in the south of Nigeria and is a Local Government Area of Akwa Ibom State. Ikot Ekpene local government area has a total land mass of 240.7 sq.km and is bounded in the North by Obot Akara Local Government Area, in the west by Essien Udim Local government area and in the east by Ikono Local Government Area. Ikot Ekpene is located within the oil palm forest belt of Nigeria and high returns for agro-allied industries are anticipated in the region. It has a latitude of 5.17938 (Lat (DMS) 5°10'55" N) and longitude of 7.7148099 (Long (DMS) 7°42'53.3"E). Its elevation is 24 meters / 78.74 feet. The precise study location was Ikot Obong Edong, a town located in Ikot Ekpene, Nigeria. Furthermore, geologically verified sources have suggested the existence of certain solid mineral deposits, including clay for ceramic items, diamonds, and sand for glassmaking.

2. MATERIALS AND METHODS

2.1 Materials

Field accessories included: Soil thermometer, Screwdriver, Torch, Pen and Notebook. The Microsoft Excel software was used for all structural analyses.

2.2 Methods

This study adopted a systematic, process-based approach to fieldwork, involving daily, monthly, and annual measurements, as well as the production of datasets for analysis. Prior to the field survey, preliminary visits were conducted to assess accessibility and identify measurement points. These visits also provided an opportunity to obtain the necessary permissions from local farmers and village chiefs to traverse their farmlands. During interactive forums with elders and community leaders, the nature, duration, and scope of the research were explained to ensure local cooperation.

A one-year field study was planned for the survey. The data for this experiment were sourced from temperature measurements taken in the field using a soil thermometer. Several measurement points were carefully selected within each patch to account for variations in sunlight and shade. At each chosen point, a screwdriver was used to create a hole approximately 5 cm deep to prevent potential damage from hidden stones or other obstructions. The thermometer was then inserted into the hole to the required depth, and sufficient time was allowed for the readings to stabilize. The location, time, and recorded temperature were documented for each measurement. To ensure accuracy, the procedure was repeated at the same point, and an average value was calculated.

2.3 Data Analysis:

Given the practical nature of this study, a descriptive and quantitative approach was adopted for data analysis. Effective fieldwork begins with a thorough physical site assessment, followed by the measurement of temperature and heat flow. Microsoft Excel was used for structural analysis, with all collected data input into the software for processing. The resulting model is presented and discussed in the results section.

3. RESULT

The temperature data collected from the measurement plots at the three locations—Ikot Obong Edong, Ikot Otu, and Abiakpo—were analyzed. The recorded values across these locations were nearly identical, with only minor variations. Therefore, a single location was selected as the primary reference point for analysis, while the findings

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and contributions to knowledge remain applicable to all three locations. The temperature variation plots for Ikot Obong Edong in February are presented below:

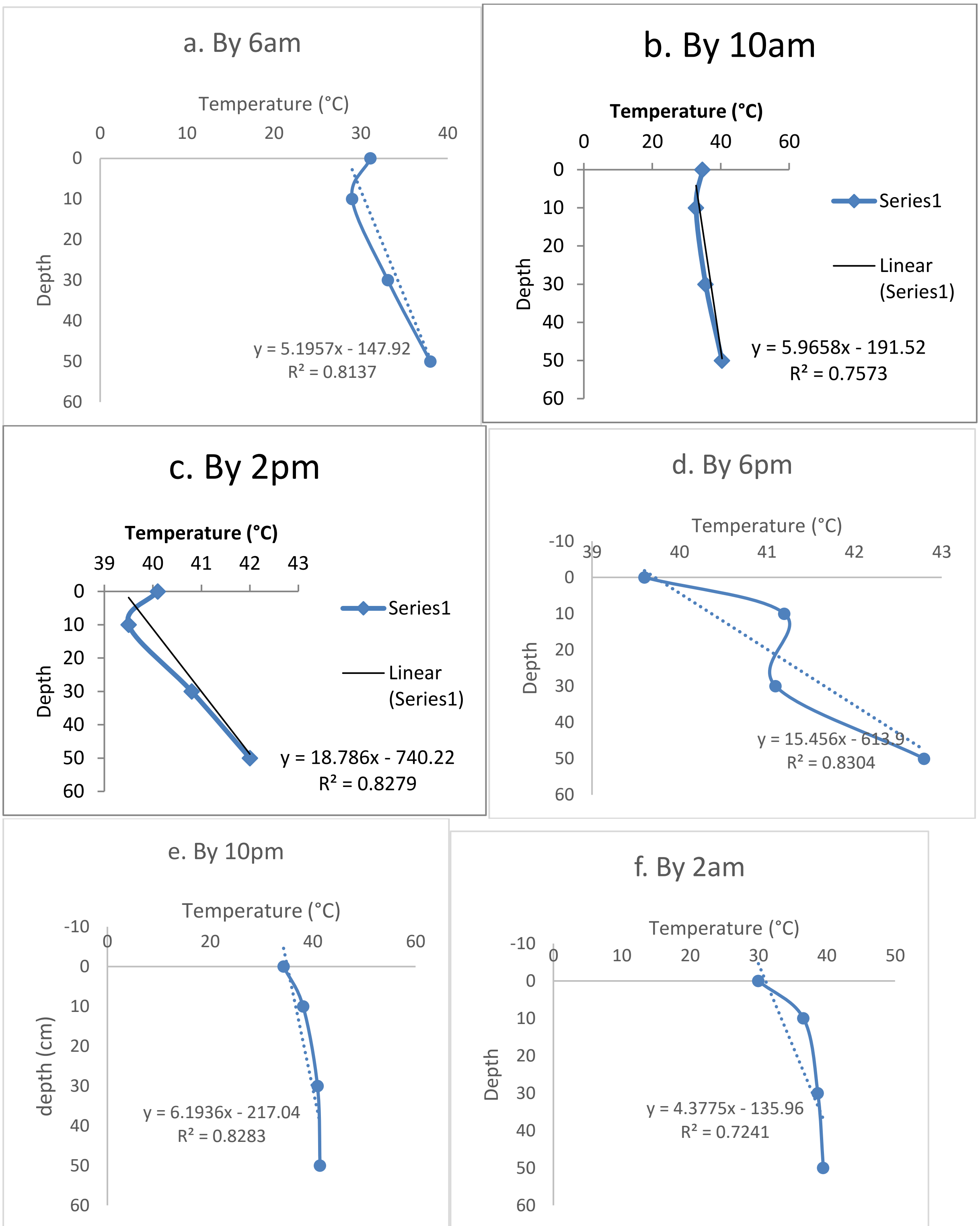

Fig 1: Graph showing Diurnal Variation of temperature with depth for Ikot Obong Edong at 6am, 10am 2am, 6pm, 10pm and 2am in February.

For the month of July, which is the typical wet season, the following plots were obtained:

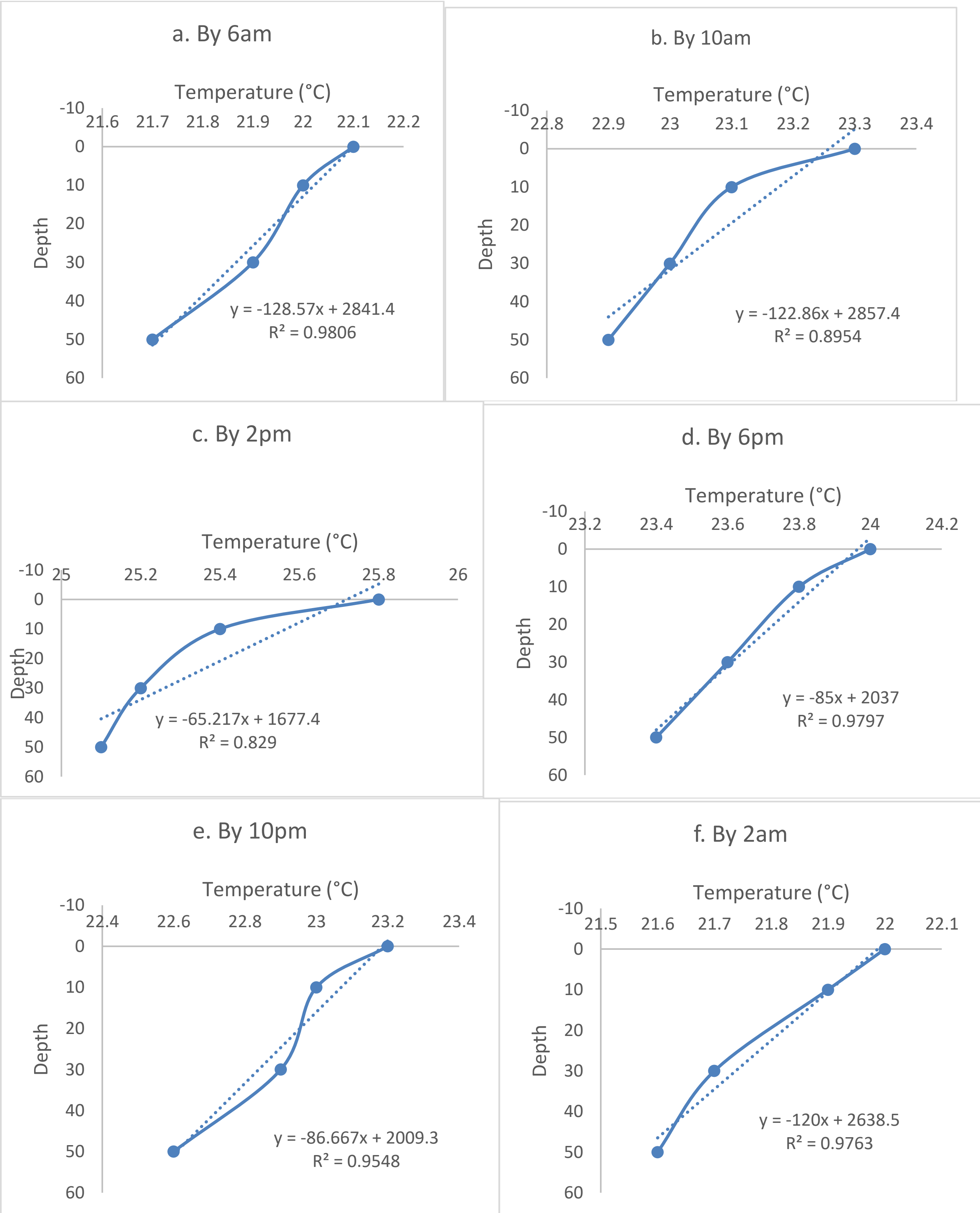

Fig 2: Graph showing Diurnal Variation of temperature with depth for Ikot Obong Edong at 6am, 10am 2am, 6pm, 10pm and 2am for July.

4. DISCUSSION

The graphs show a generally linear relationship between temperature and depth at different times of the day, with the rate of temperature change with depth varying throughout the day. The most rapid increase occurs around 2pm, suggesting a stronger temperature gradient at this time. This could be due to various factors such as solar radiation and mixing within the water body. The high R^2 values indicate a good fit of the linear regression models to the data. From these curves for dry season (February) and rainy season (July) we found that soil temperature variation with depth is not same in both cases and has different pattern. If we look closely the individual data of February, the temperature increases with depth continuously and in case of July curves, the temperatures for 10 cm depth are higher than that of 30 cm depth and then temperature increases with depths. From the plots, it was observed that the soil temperature is usually higher than the temperature at the surface during the night especially during the dry season. This is due to the fact that the soil holds more heat than air as it has higher heat capacity than air and also because of its dense composition[10]. From fig. 1, it is observed that soil temperature gradually decreases for about 4 hours from midnight. At sunrise, around 6 am (Local time), the surface temperature starts increasing by a factor of 1.3°C, while the soil temperature still decreases very slowly by 0.3°C up to 10 am (Local time) when the soil has absorbed energy and then increases gradually. So, a response time of the soil temperature to an increase in surface temperature is 4 hours. This phase lag in the diurnal variation of soil temperature relative to surface temperature indicates energy propagation downward as a wave through the soil. The surface temperature increases faster than the soil temperature up till 10 am (Local time) when the reverse situation occurs and the soil temperature increases by about 2°C per hour. The maximum daily soil temperature is observed between 2 and 6 pm (Local time) above which the both temperatures reduce steadily as the sun sets and steeply through the night due to radiation cooling that takes place at the top and cool air comes downward, with the surface temperature dropping faster than the soil temperature. This shows an increase in solar energy absorption and higher heat storage capacity during the month of February. So, the overall balance in both the soil and surface temperature shows that there is net heat gain during the day due to the absorption of solar radiation and net heat loss during the night due to convection which has greater effect on soil activities.[11] In February, the soil retained more heat due to its thermal capacity, resulting in higher soil temperatures, as seen in the plots. Minor deviations observed in wet months like July (Fig. 2) may be attributed to climatic variations. However, the selection of the months to be analyzed was based on the fact that these months duly represent the seasons (dry and wet) experienced in the location of study. The temperature difference between the surface and the soil has remained positive. However, from the findings of this analysis, a significant relationship exists between the surface temperature and soil temperature at the shallow depth of 10-50 cm as the soil temperature followed a similar pattern of the surface temperature with the magnitude of the soil temperature, different from that of the surface temperature. This behaviour is expected, since it is in direct contact with the soil surface. Also, there is observable trait in the trend of the daily variations which is the response time of the soil to the increase in surface temperature. A delay in the surface temperature was also noted during cooling, as it cools for nearly an hour following the apparent decrease in soil temperature. There were fewer plant species found as soil temperature increased, which likely reflects the dearth of species with higher thermal optima in the regional species pool[12]. As warming has been shown to reduce the species diversity of sprouting seedlings, early plant growth stages are likely more sensitive to environmental constraints[13]. This may be particularly true for maize, which was rarely found during dry season and is most susceptible to heat stress following germination[14], with a lower thermal tolerance.[15]. It has been reported that the optimal soil temperature range for maize growth in the tropics lies between 25℃ and 34℃. Since a significant relationship has been established between the surface and soil temperature at the depth of 0 to 50 cm as successfully explained in this work, the development of models for direct estimation and prediction of the soil temperature from the air temperature is very possible. This will help create a large database of soil temperature which can be localized in specific areas and used by different researchers.

The work has shown that certain amount of soil temperature is necessary for plant growth, germination and production. The knowledge of temperature variation will help farmers to determine which type of crop will he cultivate in each season to ensure and improve optimum production. The result has also shown that the technique adopted is effective in measuring soil temperature and determining the flow of heat in the soil.

5. CONCLUSION

This study investigated seasonal variations in soil temperature at different depths (0 cm, 10 cm, 30 cm, and 50 cm). The results indicated that during the dry season (e.g., December, January, and February), temperature consistently increases with depth. However, during the rainy season (e.g., June and July), temperature initially decreases up to a depth of 10 cm before increasing with depth. This pattern can be explained by the influence of two primary energy sources: solar thermal energy and ground thermal energy. During the dry season, ground thermal energy dominates at all depths, and its intensity increases with depth. In contrast, during the rainy season, solar thermal energy plays a more significant role in the upper soil layers, resulting in higher temperatures near the surface. However, beyond a certain penetration depth, ground thermal energy becomes dominant again, causing the temperature to rise with depth. The temperature values recorded at various measurement points suggest that the studied areas are generally favorable for agricultural activities. However, farmers in Ikot Obong Edong and Abiakpo should adopt soil protection strategies to minimize direct exposure to intense sunlight, thereby reducing excessive surface heating. The findings of this study can also contribute to improved soil temperature prediction, aiding in the planning and implementation of agricultural projects. Given the diverse soil compositions across Nigeria, further studies should be conducted to establish correlations between soil temperatures in different regions. These results can then be compared with those obtained for parts of Ikot Ekpene, Akwa Ibom State, to enhance our understanding of regional soil temperature dynamics and their implications for agriculture.

Declarations

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Conflict of Interest*:* There was no conflict of interest as the corresponding author is the sole funder of the research. No external funding was received.

Authors' Contributions: All authors commented on previous versions of the manuscripts and read and approved the final manuscripts.

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