

Research Article

The Study of Soil Temperature Variations and Thermal Diffusivity in Wet and Dry Seasons at Ibadan, Oyo State, Nigeria

Emenike Nwaokoro* 

Department of Physics, Abia State University, Uturu, Nigeria

Abstract

Soil temperature is the temperature of the soil at different depths beneath the soil surface and does not only indicate climate change. Agricultural practices are strongly impacted by soil temperature making it a very important variable for soil conditions. Thermal diffusivity is the ratio of thermal conductivity to volumetric heat capacity. It tells how materials conduct thermal energy relative to how they store thermal energy. Soil temperature is strongly affected by thermal diffusivity. Therefore the purpose of this study is to investigate soil temperature variations and thermal diffusivity during the wet and dry seasons in Ibadan, Oyo State, Nigeria. Soil temperature data at depths of 5 cm, 10 cm, and 30 cm were obtained from the Nigeria Mesoscale Experiment (NIMEX) site for the period July to December 2006, covering both wet (July–September) and dry (October–December) seasons. Thermal diffusivity was estimated using the Horton numerical method. Results show clear seasonal and depth-dependent variations in soil temperature, with lower temperatures recorded during the wet season due to increased soil moisture and cloud cover, and higher temperatures during the dry season associated with reduced moisture and increased solar radiation. Temperature amplitude decreased with depth, indicating attenuation of surface thermal signals. Thermal diffusivity exhibited significant variability, with maximum values recorded in September and minimum (including negative) values also occurring within the wet season. The negative diffusivity values are attributed to rapid temporal temperature fluctuations linked to soil moisture dynamics and the sensitivity of the numerical method used. Overall, the study highlights the strong influence of seasonal climatic conditions and soil moisture on soil thermal regimes in tropical environments.

Keywords

Soil Temperature, Thermal Diffusivity, Seasons

1. Introduction

There are two major seasons in Nigeria, the wet or rainy seasons and the dry seasons. Relative humidity is usually greater than 87% in the study site during the wet season due to the south-westerlies that are prevalent during this period. This season is the planting season. The warm and moist flow

is associated with convective-type clouds and water vapor which are the most important attenuators of solar radiation. The dry season is determined by the cold, dry and dusty north-easterly winds blowing from the Sahara Desert into West Africa [6, 8]. The dry season is usually the period of harvest. The

*Correspondence: Emenike Nwaokoro (nwaokoro.emenike@abiastateuniversity.edu.ng)

Received: 7 May 2026; Accepted: 21 May 2026; Published: 29 May 2026



Copyright: © The Author(s), 2026. Published by Science Publishing Group. This is an **Open Access** article, distributed under the terms of the Creative Commons Attribution 4.0 License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

exchange of energy and mass between the soil and the atmosphere, as noted by [12], is mostly influenced by soil temperature and soil thermal properties. Soil temperature is the temperature of the soil at different depths under the surface and does not just indicate climate change [14]. [2] observed that the impact of soil temperature on soil can be observed at soil formation, through the weathering of bedrock to produce mineral particles. Agricultural practices are strongly impacted by soil temperature making it a very important variable for soil conditions [14]. When soil temperature changes together with other physical and chemical characteristics of soil in the end affects crops [10]. The soil surface experience very high degree of temperature changes and as soil depth increases these changes are transferred to sub-surface layers at reduced rate [5]. Some factors that affect soil temperature include location (latitude), the time of the year, and surface weather conditions [1].

Thermal diffusivity (α) is the ratio of thermal conductivity to volumetric heat capacity. It has the SI unit of $\text{m}^2 \text{s}^{-1}$. It tells how materials conduct thermal energy relative to how they store thermal energy. Substances with high thermal diffusivity rapidly adjust their temperature to that of their surroundings [3]. Therefore, soil temperature is strongly affected by thermal diffusivity [7]. The purpose of this work is to investigate soil temperature variations and thermal diffusivity in wet and dry season in Ibadan, Oyo State Nigeria. The months investigated are from July to December, 2006 which covers the wet season (July, August and September) and dry season (October, November and December).

2. Materials and Methods

This study was done at Nigeria Mesoscale Experiment (NIMEX) site located within the campus of the University of Ibadan in Ibadan, Nigeria about 145 km from the Gulf of Guinea (lying at 7.3776°N and 3.9471°E). Ibadan lies to the south-western part of the country, and thus experiences a tropical weather of wet and dry climate.

Soil temperature data for the period of study was provided by a 15-m mast, which also provided data for other micro-meteorological parameters sampled every 1 second and stored as a 1 minute averaged value [7].

Thermal diffusivity was estimated using Horton Numerical method [4] as shown in the equation below

$$\frac{T_{10\text{cm}}^{t+1} - T_{10\text{cm}}^t}{\alpha * \Delta t} = \frac{T_{30\text{cm}}^t - 2T_{10\text{cm}}^t + T_{5\text{cm}}^t}{(\Delta z)^2} \quad (1)$$

where T is the soil temperature at 5cm (centimeter), 10cm and

30cm depth, α is the thermal diffusivity, t is time in seconds and Δz is the depth of the soil subsurface. Δz used for this study is 25cm (the difference between 30cm and 5cm depths).

3. Results

This study was carried from July to December 2006. These months covers the wet and dry seasons in the area of investigation. Figures 1-6 show the monthly soil temperature variations for months of July, August, September, October, November and December. Tables 1 and 2 are the maximum, minimum and mean values of soil temperature at the three different depths and estimated thermal diffusivity respectively.

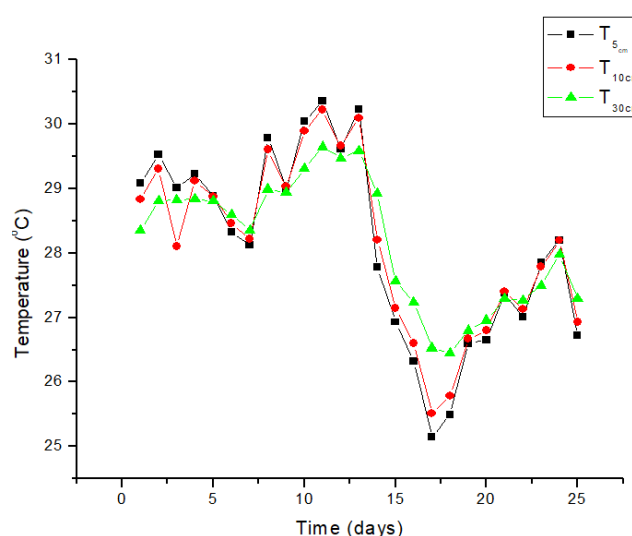


Figure 1. Soil temperature variations for July, 2006.

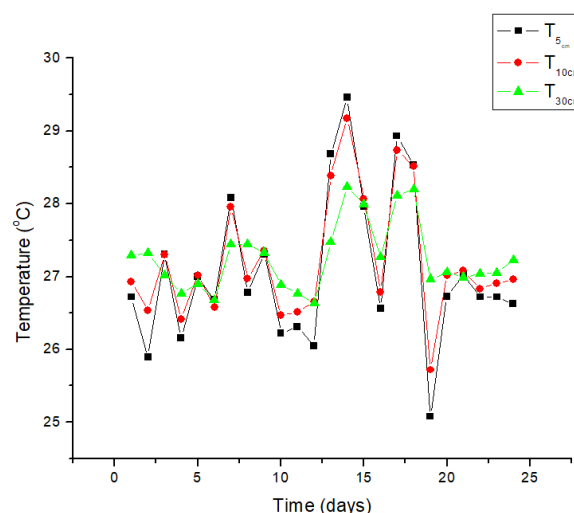


Figure 2. Soil temperature variations for August, 2006.

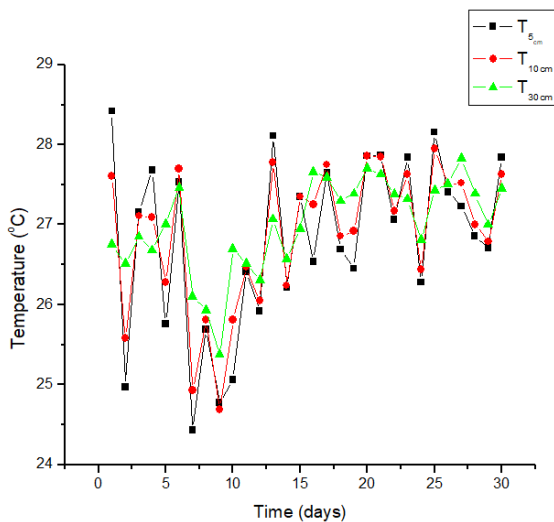


Figure 3. Soil temperature variations for September, 2006.

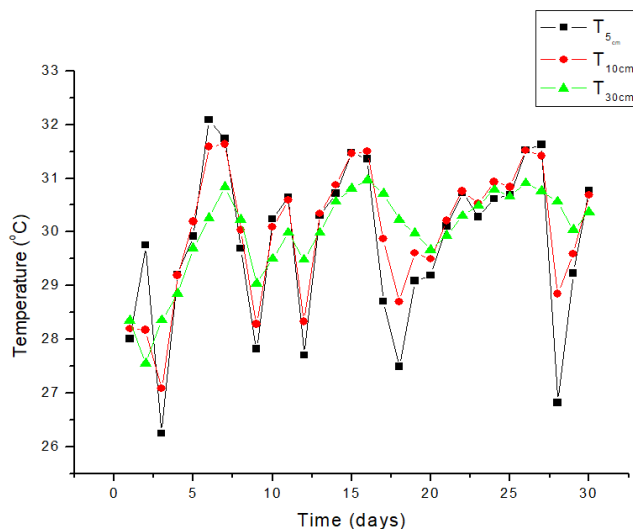


Figure 5. Soil temperature variations for November, 2006.

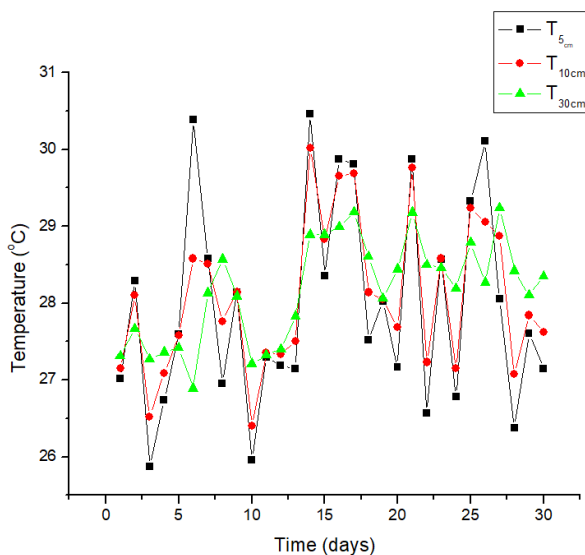


Figure 4. Soil temperature variations for October, 2006.

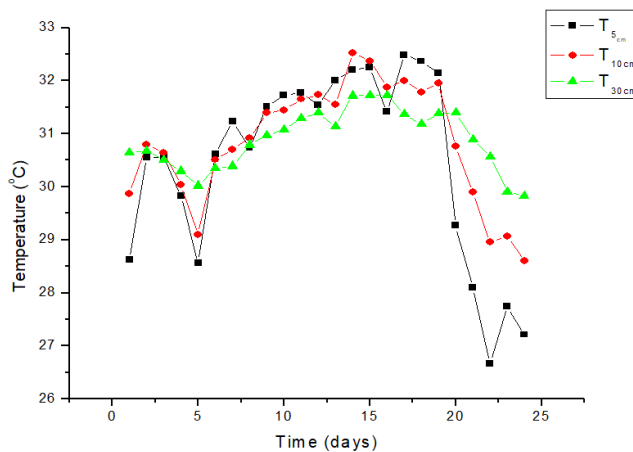


Figure 6. Soil temperature variations for December, 2006.

Table 1. Minimum, Maximum and Mean Soil Temperature (degree celsius, °C) Values from July, 2006 to December, 2006.

		July	Aug	Sept	Oct	Nov	Dec
Max	T _{5cm}	30.36	29.46	28.42	30.46	32.09	32.49
	T _{10cm}	30.23	29.17	27.95	30.02	31.64	32.53
	T _{30cm}	29.65	28.23	27.83	29.24	30.97	31.73
Min	T _{5cm}	25.15	25.08	24.43	25.87	26.25	26.67
	T _{10cm}	25.51	25.72	24.69	26.40	27.08	28.60
	T _{30cm}	26.45	26.64	25.38	26.89	27.55	29.83
Mean	T _{5cm}	27.76	27.27	26.43	29.67	29.17	29.58
	T _{10cm}	27.87	27.45	26.32	28.21	29.36	30.57
	T _{30cm}	28.05	27.44	26.61	28.07	29.26	30.78

Table 2. Estimates of Thermal Diffusivity ($\times 10^{-8} \text{m}^2 \text{s}^{-1}$, meter square per second) from July, 2006 to December, 2006.

	July	Aug	Sept	Oct	Nov	Dec
Max	9.36	16.40	49.40	21.10	39.60	15.40
Min	-3.40	-1.73	-30.00	-15.10	-16.00	1.70
Mean	2.29	4.02	0.10	0.90	2.90	10.70

Figure 1 shows that the maximum temperature for July occurred on the Julian day 192 but at different temperatures: at 5cm depth, the value is 30.36 °C, at 10cm depth, the value is 30.23 °C, while at 30cm depth the mean maximum temperature is 29.65 °C. The minimum temperatures for the month of July for the 3 depths are thus: at the depths of 5cm and 10cm, the mean minimum temperature of 25.15 °C and 25.51 °C occurred on the Julian day 202 while at depth 30cm mean minimum temperature of 26.45 °C occurred on Julian day 230.

For the month of August (Figure 2), the maximum mean temperature for 3 depths also occurred on the Julian day 232 but at different temperatures: at 5cm depth, the mean maximum temperature is 29.46 °C, at 10cm depth, the mean maximum temperature is 29.17 °C, while at 30cm depth the mean maximum temperature is 28.23 °C. The minimum temperatures for the month of August for the 3 depths are thus: at the depth of 5cm, the mean minimum temperature of 25.08 °C is on Julian day 237, at depth 10cm the mean minimum temperature of 25.72 °C also occurred also on the Julian day 237 while at depth 30cm mean minimum temperature of 26.64 °C occurred on Julian day 230. From the middle of July to the beginning of this month there was decrease in temperature due to increase in soil moisture caused by rainfall.

In Figure 3, the maximum mean temperature for the month of September for the 3 depths are thus: at 5cm depth, the mean maximum temperature of 28.42 °C occurred on Julian day 244, at 10cm depth, the mean maximum temperature of 27.95 °C occurred on Julian day 269, while at 30cm depth, the mean maximum temperature of 27.83 °C occurred on Julian day 271. The minimum temperatures for the month of September for the 3 depths are thus: at the depth of 5cm, the mean minimum temperature of 24.43 °C is on Julian day 251, at both 10cm and 30cm depth minimum temperature values 24.69 °C and 25.38 °C occurred on Julian day 253. September has the lowest values of maximum temperature. This shows that there was much rainfall in this month and from Figure 3, the temperature at the different depths decreased.

Figure 4 shows that the maximum mean temperature for October for the 3 depths are thus: at 5cm depth and 10cm depths, the mean maximum temperatures occurred on Julian day 288 with values 30.46 °C and 30.02 °C respectively, while at 30cm depth, the mean maximum temperature of 29.24 °C occurred on Julian day 301. The corresponding minimum temperatures at the 5cm, 10cm and 30cm depths with values 25.87 °C, 26.40 °C and 26.89 °C occurred on Julian days 277,

284 and 280 respectively.

The month of November, in Figure 5, has its maximum mean temperature for the 3 depths as thus: at 5cm depth, the mean maximum temperature of 32.09 °C occurred on Julian day 310, at 10cm depth, the mean maximum temperature of 31.64 °C occurred on Julian day 311, while at 30cm depth, the mean maximum temperature of 30.97 °C occurred on Julian day 320. The minimum temperatures for the month of November are thus: at 5cm and 10cm depth, the mean minimum temperature of 26.25 °C and 27.08 °C occurred on Julian day 307, while at depth 30cm mean minimum temperature of 27.55 °C occurred on 306 Julian day.

For the month of December, Figure 6 shows that the maximum mean temperature for the 3 depths are thus: at 5cm depth, the mean maximum temperature of 32.49 °C occurred on Julian day 354, at 10cm depth, the mean maximum temperature of 32.53 °C occurred on Julian day 351, while at 30cm depth, the mean maximum temperature of 31.73 °C occurred on the Julian day 352. The minimum temperatures for the month of December are thus: at the depth of 5cm, the mean minimum temperature of 26.67 °C is on Julian day 362 and at 10cm and 30cm depth, the mean minimum temperature occurred on Julian day 364 with values 28.60 °C and 29.83 °C.

In Table 2, thermal diffusivity, has its maximum values ranging from $9.36 \times 10^{-8} \text{m}^2 \text{s}^{-1}$ in July, 2006 to $49.40 \times 10^{-8} \text{m}^2 \text{s}^{-1}$ in September, 2006 and its minimum values ranges from $-30.00 \times 10^{-8} \text{m}^2 \text{s}^{-1}$ in September, 2006 to $1.70 \times 10^{-8} \text{m}^2 \text{s}^{-1}$ in December, 2006. The negative values obtained are due to the fact that Horton numerical method used is based on temperature difference between two time steps with Δt being equal to 1 minute. If the temperature at 10cm depth of the next minute is greater than the one before then there is a negative value for thermal diffusivity. This is the reason why September has the highest maximum thermal diffusivity also has very low thermal diffusivity value. Also the above negative values are due to the increase in soil moisture caused by increased rainfall associated with this month the temperature at the near soil surfaces were low given rise to negative thermal diffusivity.

4. Discussion and Conclusion

This study has examined the seasonal and vertical variability of soil temperature and thermal diffusivity in Ibadan, Oyo

State, Nigeria, using observational data from July to December 2006, which spans both wet and dry seasons. The findings clearly demonstrate that soil thermal behavior in the study area is strongly controlled by seasonal climatic conditions, particularly variations in rainfall, cloud cover, solar radiation, and atmospheric moisture content.

During the wet season (July–September), soil temperatures were generally lower across all observed depths due to increased cloudiness, high relative humidity, and elevated soil moisture levels. These conditions significantly reduced the amount of incoming solar radiation reaching the soil surface and enhanced latent heat flux processes, thereby limiting soil heating [12]. September, in particular, recorded the lowest maximum soil temperatures, coinciding with peak rainfall activity in the region. This does not completely agree with [13], their study showed a decrease in soil temperature, followed by an increase in soil temperature, especially in the upper layer.

In contrast, the dry season (October–December) was characterized by progressively higher soil temperatures, especially at shallow depths in agreement with [13] and [14]. This increase is attributed to reduced cloud cover, lower soil moisture content, and stronger incoming solar radiation associated with clearer atmospheric conditions. The gradual rise in temperature from October through December reflects the increasing influence of dry continental air masses and reduced atmospheric attenuation of solar energy [12].

The study also confirms a strong vertical gradient in soil temperature response. Surface layers (5 cm depth) exhibited rapid responses to atmospheric forcing, while deeper layers (30 cm depth) showed dampened and delayed temperature variations. This pattern highlights the role of soil as a thermal buffer, where heat transfer occurs primarily through conduction and is moderated by soil physical properties [1, 9].

Thermal diffusivity exhibited substantial temporal variability, reflecting dynamic changes in soil thermal conductivity and heat storage capacity. The wet seasons generally have lower mean thermal diffusivity values (except for August, 2006) and the dry seasons have higher mean thermal diffusivity values (except for October, 2006, which is actually the month that transition from the wet season to the dry season) in agreement with [5] and [11]. In their study, they found that thermal diffusivity has an inverse seasonal variation with soil temperature. Elevated diffusivity values during certain wet-season periods, particularly in September, indicate rapid heat transfer associated with fluctuating moisture conditions. However, the occurrence of negative thermal diffusivity values reveals limitations in the Horton numerical method when applied to high-frequency soil temperature datasets. These negative values are not physically realistic but rather result from short-term reversals in temperature gradients driven by rapid atmospheric or soil moisture changes [15].

Furthermore, the weak correlation observed between thermal diffusivity and soil moisture suggests that soil moisture alone does not fully explain thermal behavior in the study area.

Other factors such as soil texture, structure, porosity, and compaction likely play significant roles in governing heat transfer processes in tropical soils.

In conclusion, the study emphasizes the dominant influence of seasonal climatic variability on soil thermal regimes in tropical environments such as Ibadan. It also highlights the importance of considering methodological limitations when estimating soil thermal properties from observational data. The results have important implications for agricultural management, land–atmosphere interaction studies, and climate modeling, particularly in understanding energy exchange processes within tropical soil systems.

Abbreviations

cm	Centimeter
M	Meter
T _{5cm}	Temperature at 5cm
T _{10cm}	Temperature at 10cm
T _{30cm}	Temperature at 30cm
°C	Degree Celsius
α	Thermal Diffusivity
Δz	Depth of Soil Subsurface
Km	Kilometer
N	Degree North
E	Degree East
m ² s ⁻¹	Meter Square per Second

Author Contributions

Emenike Nwaokoro: Conceptualization, Data curation, Investigation, Methodology, Resources, Writing – original draft

Conflicts of Interest

The author declares no conflict of interest.

References

- [1] Arya, S. P. (2001). *Introduction to micrometeorology* (2nd ed). Academic Press. [https://doi.org/10.1016/S0074-6142\(01\)80020-6](https://doi.org/10.1016/S0074-6142(01)80020-6)
- [2] Dec, D., Dorner, J., & Horn, R. (2009). Effect of soil management on their thermal properties. *J. Soil Sc. Plant Nutr.* 9(1), 26–39. <https://doi.org/10.4067/S0718-27912009000100003>
- [3] Holman, J. P. (2002). *Heat Transfer*. 9th Edition. McGraw-Hill International Book Company, Boston.
- [4] Horton R., Wierenga P. J. & Nielsen D. R. (1983). Evaluation of methods for determining the apparent thermal diffusivity of soil near the surface. *Soil Science Society of America Journal.* 47. 25- 32. <https://doi.org/10.2136/sssaj1983.03615995004700010005x>

- [5] Nadir C., Imed E. N., Abdelmadjid K., Samia L., Abdessalam K., Dzo M. S. A., & Younes M. (2026) Experimental analysis of soil thermal diffusivity for optimizing surface geothermal energy systems in arid environments, *International Journal of Low-Carbon Technologies*, 21, 1 - 12.
<https://doi.org/10.1093/ijlct/ctag046>
- [6] Nwaokoro, E., & Nymphas, E. F. (2019). Temperature variations and soil thermal properties at the Nigeria Mesoscale Experiment site, Ibadan, Nigeria. *International Research Journal of Pure and Applied Physics*, 6(2), 34–43.
<https://doi.org/10.37745/irjppap.13>
- [7] Nwaokoro, E., & Nymphas, E. F. (2021). Comparison analyses of different models used to determine soil thermal conductivity and diffusivity at NIMEX site, Ibadan. *EJERS – European Journal of Engineering Research and Science*, 4(2), 1–13.
<https://doi.org/10.25103/jesr.2021.04.01>
- [8] Nymphas E. F., Adeniyi M. O., Ayoola M. A. & Oladiran E. O. (2009). Micrometeorology measurements in Nigeria during the total solar eclipse of 29 March, 2009. *Journal of Atmospheric and Solar Terrestrial Physics*. 71. 1245-1253.
<https://doi.org/10.1016/j.jastp.2009.04.014>
- [9] Ochsner, T. E., Horton, R., & Ren, T. (2001). A new perspective on soil thermal properties. *Soil Science Society of America Journal*, 65(6), 1648–1653.
<https://doi.org/10.2136/sssaj2001.1648>
- [10] Patah, S. F. A., & Othman, N. M. I. (2024). Influence of Soil Temperature on Root Development and Microbial Diversity in Paddy Fields: A Comprehensive Review. *Trends in Ecological and Indoor Environment Engineering*, 2(4), 1–9.
- [11] Tam fés Z., Vanessa de Arruda S., Leugim C. R., Lidiane B., Gustavo P. V., Michel B. S., & D ébora R. R. (2023). Estimation of soil thermal properties using conduction and conduction–convection heat transfer equations in the Brazilian Pampa biome. *Agricultural and Forest Meteorology*, 338.
<https://doi.org/10.1016/j.agrformet.2023.109517>
- [12] Tyson, P. D., Preston-Whyte, R. A., & Schulze, R. E. (2001). *The climate of South Africa: Climatology and atmospheric circulation*. Oxford University Press.
- [13] Umoh, E. S., Emujakporue, G. O., Sofolabo, A. O., & Mkpese, U. U. (2025). Evaluation of annual soil temperature cycles at different pedology and times over a period of one year in Ikot Ekpene Local Government Area, Akwa Ibom State, Nigeria. *J. Appl. Sci. Environ. Manage.* 29(4) 1023-1027.
<https://dx.doi.org/10.4314/jasem.v29i4.2>
- [14] Wang Y., Wu J., Zhang J., Guan T., Wang G., Jin J., & Wang Z. (2025). Depth distributions of soil temperature: Seasonal sensitivity and simulation across dryness/wetness conditions. *Agricultural Water Management*. 316.
<https://doi.org/10.1016/j.agwat.2025.109571>
- [15] Whittington, A. G., Hofmeister, A. M., & Nabelek, P. I. (2009). Temperature-dependent thermal diffusivity of the Earth’s crust and implications for magmatism. *Nature*, 458, 319–321.
<https://doi.org/10.1038/nature07818>