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ANALYSIS OF SOIL AND SURFACE AIR TEMPERATURES IN MAKURDI LOCAL GOVERNMENT AREA, BENUE STATE, NIGERIA

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ABSTRACT

This study analyzed soil and surface air temperatures in Makurdi LGA, Benue State, Nigeria, using data from the Nigerian Meteorological Agency (NiMet) for 1991–2020. Surface air temperatures (maximum and minimum) and soil temperatures at 30 cm depth were examined. Time series analysis, using the Least Square Regression Model, revealed fluctuations and trends, with the trend significance tested at a 0.05 confidence level. The highest monthly average maximum, minimum, and mean surface air temperatures of 37.0°C, 25.2°C, and 31.1°C, respectively, were observed in March. Annual maximum and minimum surface air temperatures showed a significant upward trend, increasing by 0.0144°C and 0.0164°C per year, with R^2 values of 0.1541 and 0.1944, and correlation coefficients of 0.3926 and 0.3800. The peak soil temperature at 30 cm depth was 33.1°C in March, with an annual downward trend at a rate of 0.0628°C ($R^2 = 0.2207$, $r = 0.470$). A weak negative correlation ($r = -0.040$) was found between soil temperature at 30 cm depth and maximum air temperatures, while a slight positive correlation ($r = 0.013$) was observed between soil temperature and minimum surface air temperatures. The study concludes that there is a weak negative relationship between soil temperatures at 30 cm depth and maximum air temperatures, while a positive correlation exists between soil temperatures and minimum air temperatures. The study recommends the implementation of adaptive agricultural practices in Makurdi LGA, such as crop rotation and the use of heat-tolerant crop varieties, to help mitigate the potential adverse effects of rising surface air temperatures and declining soil temperatures.

KEYWORDS: Soil, Surface Air Temperature, Time Series, Analysis, Makurdi.

INTRODUCTION

Temperature dynamics in Earth's ecosystems are crucial for understanding the intricate relationships between climate patterns, soil properties, various ecological processes, and human activity, such as agriculture. Two essential components of temperature monitoring are soil temperature and surface air temperature, which provide valuable insights into the thermal characteristics of terrestrial environments (Liu, 2011). Soil temperature refers to a measure of heat energy within the soil matrix, which influences critical processes, such as plant growth, nutrient availability, microbial activity, and soil respiration. Surface air temperature, on the other hand, represents the temperature of the air in direct contact with the Earth's surface, influencing weather patterns, human comfort, and the overall climate system (Minick, 2013; Lu, Liu, Zhou, Yue, Li, and Liu, 2015).

Comparative analysis of soil and surface air temperatures has been the subject of numerous empirical studies in different parts of the globe. These studies aim to understand the relationship between soil and air temperatures, their variations, and the factors influencing their differences. Liu (2011), for instance, investigated the differences between soil and air temperatures in various ecosystems across North America and reported that soil temperatures generally lag behind air temperatures due to differences in their thermal properties and heat transfer mechanisms. The time lag varied depending on factors such as vegetation cover, soil moisture, and depth. The study also highlighted the importance of considering soil temperature dynamics in climate change research. Similarly, Minick (2013) in his study of the relationship between soil and air temperatures in an arid ecosystem reported that soil temperature can differ significantly from air temperature due to factors such as solar radiation, soil moisture, and evaporative cooling. The study emphasized the need to account for soil temperature variations when assessing ecosystem processes and plant growth in arid environments. Also, Lu,et al, (2015) investigated the differences between soil and air temperatures across different land cover types in a subtropical region. The study found that soil temperatures were generally lower than air temperatures during daytime but higher during nighttime. The variations were attributed to differences in energy absorption, thermal properties, and heat exchange processes between soil and air. The study highlighted the importance of considering soil temperature dynamics in ecological and environmental studies. In the same vein, Li, Liu, Pan, Zhuang, Miralles, Teuling, Zhang, An, Dong, Zhang, and He, (2017) conducted a study in a forested area to analyze the temporal and spatial variations of soil and air temperatures. The research revealed that soil temperatures exhibited a stronger seasonality and lower variability compared to air temperatures.

In recent years, studies designed to understand soil and surface temperature dynamics have been receiving increasing attention, especially in the tropics. This is partly because rising temperatures in the tropics including Makurdi have far-reaching consequences on ecosystems, including altered rainfall patterns, increased frequency and intensity of extreme weather events, and shifts in species distributions (Nobre, Borma, Castilla-Rubio, Cunha, Malagutti, Marengo, and Sampaio, 2016; Oliveras, Girardin, Doughty, Cahuana, Arenas, Oliver and Malhi, 2018; Intergovernmental Panel on Climate Change, 2021). For instance, temperature plays a pivotal role in shaping the structure and functioning of tropical ecosystems. Soil temperature affects nutrient cycling, microbial activity, and plant growth, thereby influencing primary productivity and carbon sequestration (Zhao, Li, Ganjurjav, Cui, Wu, and Ge, 2019). Surface air temperature regulates physiological processes in organisms, including photosynthesis, respiration, and reproductive cycles. By analyzing these temperatures, researchers can investigate ecological responses such as changes in species phenology, shifts in species composition, and alterations in ecosystem services (Oliveras et al., 2018).

In agriculture, soil and surface air temperatures are crucial for global food security due to their control on soil chemical and microbial processes (Mengistu, Smith, and Lal, 2020). Monitoring soil temperature is vital for optimizing crop production, as it directly affects seed germination, nutrient availability, and root development. Analyzing surface air temperature helps estimate potential crop yields, optimize irrigation schedules, and predict the risk of pests and diseases (Mengistu et al., 2020). By understanding temperature patterns and their impact on agricultural productivity, farmers and policy-makers can make informed decisions to enhance food production and reduce yield losses in the face of climate variability (Mengistu et al., 2020).

Besides agriculture, temperature plays a significant role in human health, especially in tropical regions with high population densities. Knowledge of surface air temperatures helps identify heat stress risks, enabling the development of early warning systems to protect vulnerable populations (Kovats, Hajat, and Wilkinson, 2014). Soil temperature analysis is crucial for understanding disease vectors' behavior, such as mosquitoes transmitting diseases like malaria or dengue fever, as temperature influences their reproductive rates and survival

(Hales, Kovats, and Lloyd, 2014). Consequently, research on the variability of soil and surface air temperatures in tropical areas is essential for understanding climate change impacts, ecosystem dynamics, agricultural productivity, and human health considerations. The knowledge gained from such analysis can shape adaptation and mitigation at local communities and even national levels.

In Makurdi local government area, the agrarian communities, soil, and surface air temperatures are among the weather and climate elements with profound impact on human activity, such as agriculture. Onah, Akuratse, Ali, Mage, and Tarzoho (2021) report that temperatures over the Makurdi local government area have a periodicity of ten (10) years which means that Makurdi usually experiences cooling and warming phases in a cyclic pattern of ten years with maximum temperatures currently going through upward oscillation (warming phase) after a downward oscillation of just six years instead of the usual 10-year periodicity. The rising surface air temperatures over Makurdi can impact on human health and the environment. Consequently, gaining up-to-date knowledge of variability and trends of these climate elements on a temporal scale is important to understanding the nature of different climate systems and their impact on the environment and society (Onah, Akuratse, Ali, Mage & Tarzoho, 2021). This study, therefore, seeks to analyze soil and surface air temperatures in Makurdi Local Government Area (LGA), Benue State, Nigeria.

This study is very crucial due to the lack of comprehensive analysis and understanding of soil and surface air temperatures in Makurdi LGA, Benue State, Nigeria as previous studies in this area focused mostly on surface air temperatures (Onwuka, Olaniran & Ikya, 2020; Onah, Akuratse, Ali, Mage & Tarzoho, 2021). Also, the available studies on temperature variations in Benue State primarily concentrate on larger spatial scales or focus on other climatic variables, such as rainfall or humidity (Owonubi & Nnabo, 2021; Ibe & Ukoha, 2021; Adikwu & Okoh, 2022; Rukwiede, 2022). It, therefore, follows that despite the importance of temperature data for climate change adaptation and informed decision-making, there is a paucity of recent research focusing specifically on this area. Consequently, there is a critical knowledge gap regarding the variability in soil and surface air temperatures in Makurdi LGA. Therefore, understanding temperature trends and patterns, especially the long-term trends and interannual variations in soil and surface air temperatures within Makurdi LGA, is fundamental to policy and climate change adaptation programme, particularly in agriculture, as this remains largely unexplored. This study will, no doubt, contribute to the scientific knowledge base on temperature dynamics, provide valuable insights for climate change adaptation, and support sustainable development planning in Makurdi LGA, Benue State, Nigeria.

MATERIALS AND METHODS

Study Area

Makurdi LGA is located at the bank of River Benue in the flood plain of Benue trough of the middle belt region of Nigeria. The area is located between latitude 7º 35' 0'' and 7º 50' 0'' N; and longitude 8º 25' 0'' and 8º 40' 0'' E with a mean elevation of 92 meters above sea level (Figure 1).

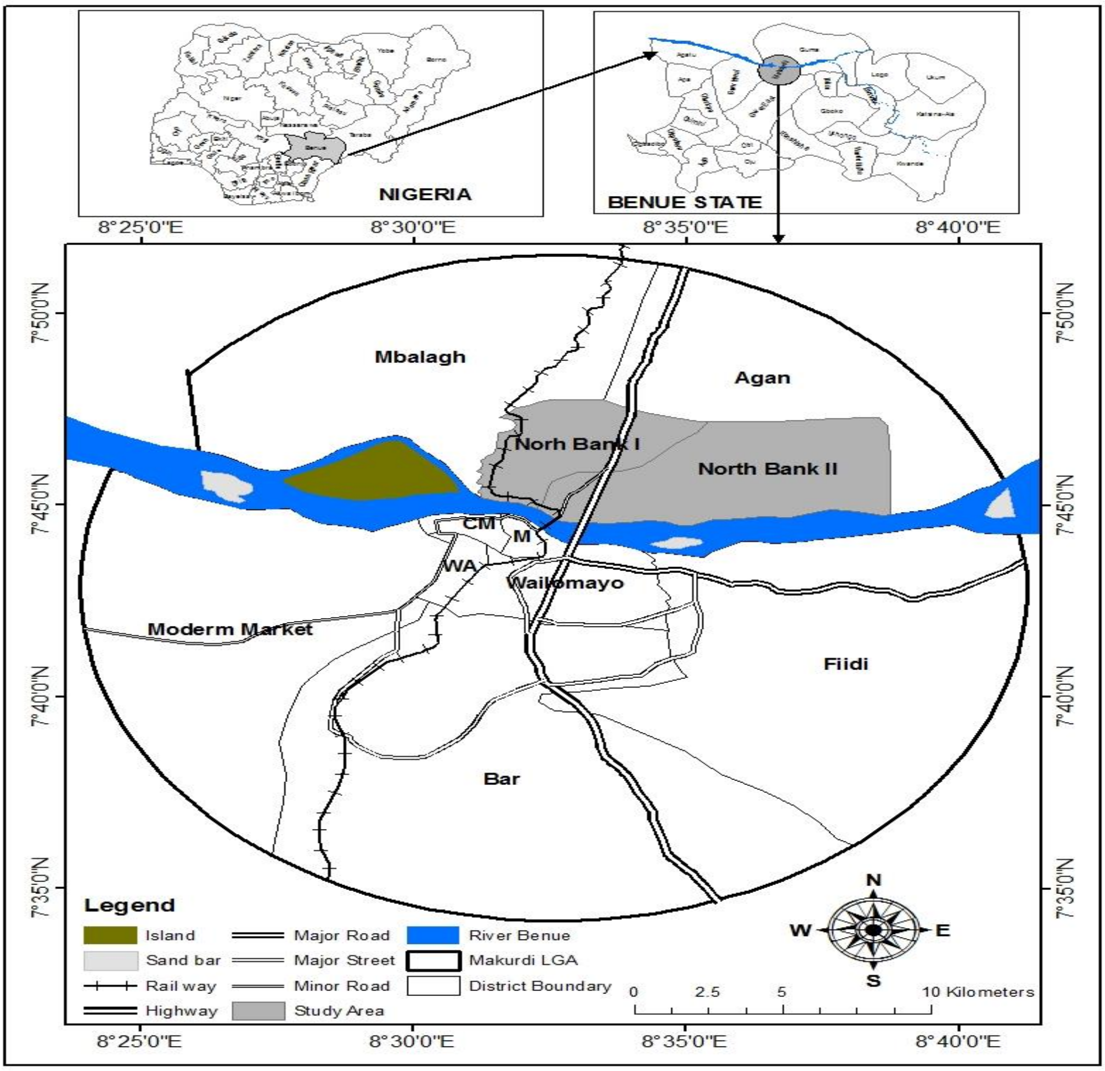

Figure 1: Makurdi Local Government Area ***Cartography Studio, Department of Geography, Benue State University, Makurdi 2021.***

Makurdi, located in the tropical wet and dry savanna (Aw) climate zone, experiences mean annual temperatures of 28°C, with December and March as the coolest (26°C) and hottest (31°C) months, respectively. Relative humidity peaks at 92% during the rainy season (April to October), with the dry season lasting from November to March. Annual rainfall averages 1,190mm, with the highest monthly rainfall (262mm) in September. The region's savanna vegetation has been modified by urbanization, though natural vegetation remains on the outskirts. Makurdi's geology is characterized by Cretaceous sediments, predominantly sandstone, with a thickness reaching 900m in some areas. The soils, classified as Typic Haplustuit and Orthic Acrisol, are generally acidic, well-drained, and vary from sandy loam to clay loam. The city's elevation ranges from 12m near the River Benue to 153m in surrounding areas, with the river serving as the primary drainage system. Economic activities include agriculture, fishing, and commerce, with crops grown primarily along riverbanks and the city's periphery. Makurdi's population, approximately 319,797, is concentrated in several urban districts, supported by commercial centers and an industrial layout established to reduce environmental impact.

Methods

The study utilized archival data from the NiMet synoptic weather station at Fiidi, Makurdi, Nigeria. Soil temperature measurements are recorded at depth 30 cm using soil thermometers, while surface air temperatures are measured with thermometers in a Stevenson screen. For trend analysis of soil and air temperatures, the study applied the Least Square Regression Model, expressed as:

$$Y = a + bx \quad (1)$$

Where:

Y = Dependent Variable

x = Independent Variable

a = the intercept

b = the slope coefficient, indicating the rate of change.

$$b = \frac{n \sum xy - (\sum x)(\sum y)x^2}{n \sum x^2 - (\sum x)^2} \quad (2)$$

$$a = \frac{(\sum y) - b (\sum x)}{n} \quad (3)$$

The standard deviation was calculated to assess the spread in the soil and surface air temperature data. This spread analysis provides insight into the variability within the dataset. The formula is expressed as:

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}} \qquad (4)$$

To determine average values, the arithmetic mean was used in calculating the mean maximum and minimum temperatures from the raw data. The coefficient of variation (CV) was also applied to measure the percentage variation relative to the mean. CV is calculated as the ratio of the standard deviation to the mean and shows variability to the population mean. These statistical tools offered a detailed analysis of soil and surface air temperature trends. The significance of the trendline was tested at a 0.05 (95%) confidence level.

RESULTS AND DISCUSSION

4.2 Variation in Surface Air Temperatures over Makurdi

The result of the mean monthly maximum, minimum and mean temperatures over Makurdi is presented in Figure 2. The result shows that the highest mean maximum, minimum and mean temperatures of 37.0^{0}C, 25.2^{0}C and 31.1^{0}C all occurred in the month of March indicating that March is the warmest month in Makurdi. On the other hand, the lowest mean maximum, minimum and mean temperatures of 30.0^{0}C, 17.9^{0}C and 25.7^{0}C were recorded in the months of August, December and November respectively. The general pattern therefore shows that maximum and mean temperatures are higher during dry season and lower during wet season. The lower maximum and mean temperatures during wet season can be attributed to huge cloud cover and high relative humidity, while the lower minimum temperatures during dry season could be connected with minimal cloud cover and high radiative cooling, especially at nights.

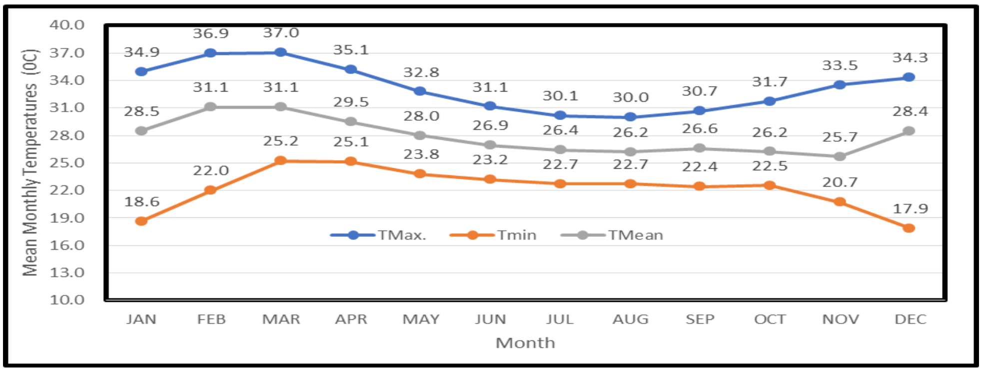

Figure 2: Variability in Mean Monthly Temperatures over Makurdi. (1991-2020)

Table 1: Summary of Statistical Value of Variables

Variable	**TMax**	**TMin**	**Soil Temp. at 30cm**
Standard Deviation	0.317	0.375	1.2
Mean	33.4	22.9	29.1
Coefficient of Variation	0.949	1.637	4.1%
R^2	0.1541	0.1444	0.2207
R	0.3926	0.3800	0.46978
Calculated value of *t*	2.26	2.35	2.814
Critical Value of *t*	1.70	1.70	1.70
Remarks	**	**	**

** Significant at 0.05 Confidence Level

The result of annual variation in mean maximum temperatures is presented in Figure 3 and Table 1. The result indicates an increasing trend ii mean maximum temperatures over Makurdi between 1991 and 2020 at an annual rate of 0.0144°C with a regression coefficient of determination (R^2) of 0.1541 and correlation coefficient of 0.3926. The coefficient is found to be significant at 0.05 (95%) confidence level using student's ‘t’ test statistics, given that the calculated value of 't' of 2.26 is greater than the critical value of 1.70.

The result further shows that the mean maximum temperatures for the study period was found to be 33.4°C, while the lowest and highest values mean maximum temperatures were found to be 32.8°C (1991) and 34.2°C (2012) respectively. The 3-year moving average indicate downward oscillations between 1991 and 2005 (10 years), 2004 and 2011 (8 years), and 2016 and 2019 (3 years), while upward oscillations occurred between 2001 and 2004 (4 years) and 2007 and 2016 (10 years). The ongoing high temperature phase started in 2019 and may persist for the next 10 year since the increasing trend in the mean maximum temperature is found to be statistically significant. The result also suggests that the low temperature phases continued to decline progressively from 10 years to 3 years, while the high temperature phase increased progressively from 4 years to 10 years thereby providing clear evidence of increasingly warmer atmosphere over Makurdi and its environs which can be attributed to the on-going global warming and climate change phenomena.

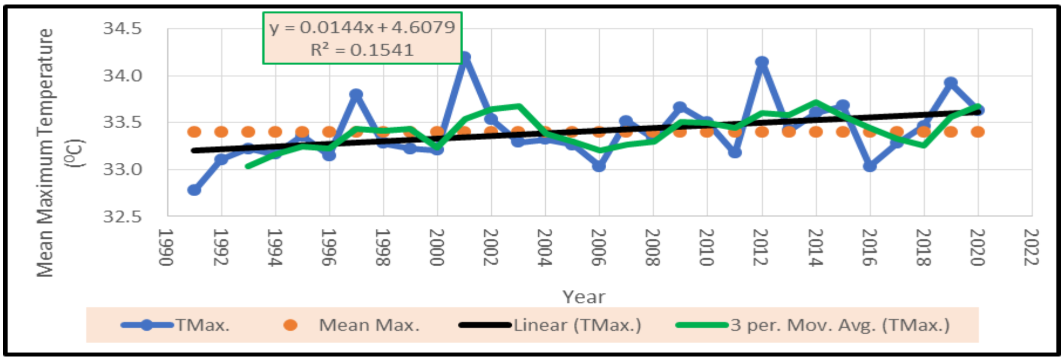

Figure 3: Annual Mean Maximum Temperature over Makurdi. (1991-2020)

The result of the annual variations in mean minimum temperatures over the study area is presented in Figure 4 and Table 1. The result indicates an increasing trend at an annual rate of 0.0164℃ with R^2 and r values of 0.1944 and 0.3800. The regression coefficient is found to be significant at 0.05 (95%) confidence level, given that, the calculated 't' value of 2.35 is greater than the critical 't' value of 1.70. The result further shows that lowest, average and highest values of minimum temperatures were 22.3^{0}C (2006 and 2011), 22.9^{0}C and 23.7^{0}C (2019). The result of the 3-year moving average indicates downward oscillations of minimal amplitude below the long-term mean value from 1993 to 2001 (8 years) and 2003 to 2013 (10 years), while the upward swing occurred from 2001 to 2003 (2 years) and 2013 to 2020 (7 years).

The major distinguishing features of the downward and upward oscillation is that, the downward oscillations have low amplitudes which is an indication of how high temperatures were during these periods. Conversely, the upward oscillations have high amplitudes, but lasted for shorter duration which overall translated to a significant increase mean minimum temperatures during the study period.

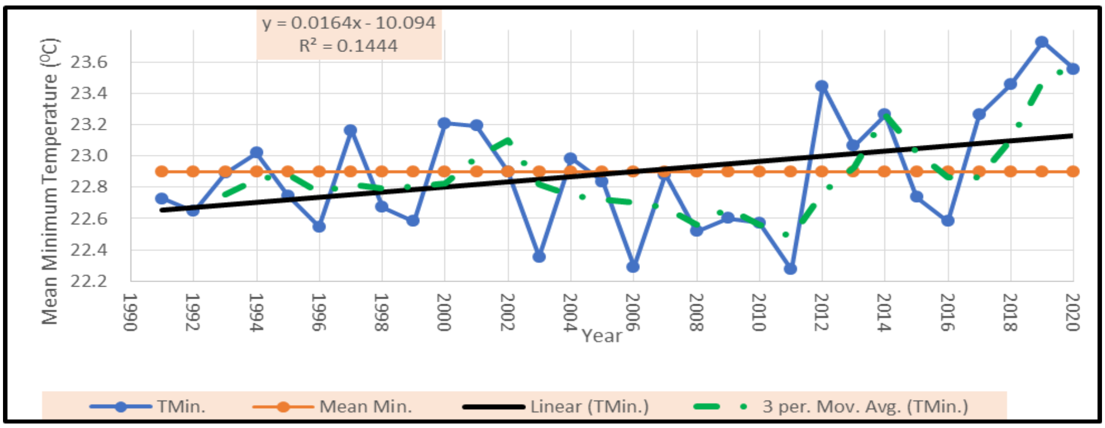

Figure 4: Annual Mean Minimum Temperature over Makurdi. (1991-2020)

The findings of this study are consistent with that of Onuche, Adah & Ibobee (2023) who in their analysis of daily air temperature variation in Makurdi metropolis reported that means that the daily air temperature of Makurdi metropolis are statistically significance across the Months (January – December) and years (1984-2021). They also month of March has the highest mean value of daily air temperature, which also agree with the finding of this presents study. Similarly, the Audu, Ejembi & Omaba (2021) in the investigation of trends in climate extreme over Makurdi (1979-2013), using climate indices reported significant increase in maximum and minimum temperature and hot extreme temperature indices, which equally agreed with the findings of this present study, thereby providing additional evidence of warming Makurdi atmosphere. Again, Mage & Agber (2017) in their study on temperature variability, intensity of wind speed and visibility during harmattan in Makurdi Town, Nigeria reported that temperature within the harmattan months has fluctuated but showed an increasing trend in all the months, which is consistent which the findings of this present study. Similarly, Onah, *et al*, (2021) on their study of trend in temperature and wind speed characteristics over Fidii area of Makurdi Local Government Area of Benue State, reported that mean minimum, maximum and mean temperatures over Fiidi area of Makurdi indicates negative trends which were not significant at 0.05 confidence level. Also. The authors, reported that temperatures in Makurdi have periodicity of ten (10) years which means that Makurdi usually go through cooling and warming phases in cyclic pattern of ten years with maximum temperatures currently going through upward oscillation (warming phase) after a downward oscillation of just six years instead of the usual 10-year periodicity. These findings agreed with the 10-year temperature periodic found in this study. However, the declining temperatures found by Onah el al (2021) is at variance with the findings of this present study, which can be attributed to differences in temporal scale.

Variation in Soil Temperatures

The result of monthly variations in soil temperatures at 30cm depth in the study area is presented in Figure 5 and Figure 6. The result shows that mean soil temperature at 30cm depth in January was 27.9°C and increased sharply to peak in the month of March with 33.1°C. Thereafter, soil temperatures decreased gradually from 33.1°C in the month of March to 26.8°C in the month of August. From the month of August, temperatures increased gradually to 29.1℃ in the month of October and then declined slightly to 27.9℃ in the month of December. The soil temperature in the month of December is same as that of January. The result generally suggests that soil temperatures at 30cm are higher during dry season months of January, February, March and April, while wet season months have relatively lower soil temperatures. This may be attributed to Moisture content of the soils that tends to moderates soil temperatures during wet season. From the result, it is evident that soil temperatures at 30cm follow the similar monthly and seasonal pattern as that of mean maximum air surface temperatures (Figure 4.1).

The result in Figure 6 shows the monthly soil temperatures for each year during the study period. The result indicates that extremely high temperature of 39.4°C was recorded in April, 2009, while the lowest (23.3°C) for the study period was recorded in June, 2015. Besides these extremes temperatures years, the monthly mean soil temperature at 30cm depth presented in Figure 4.4 adequately represents other years of the study period.

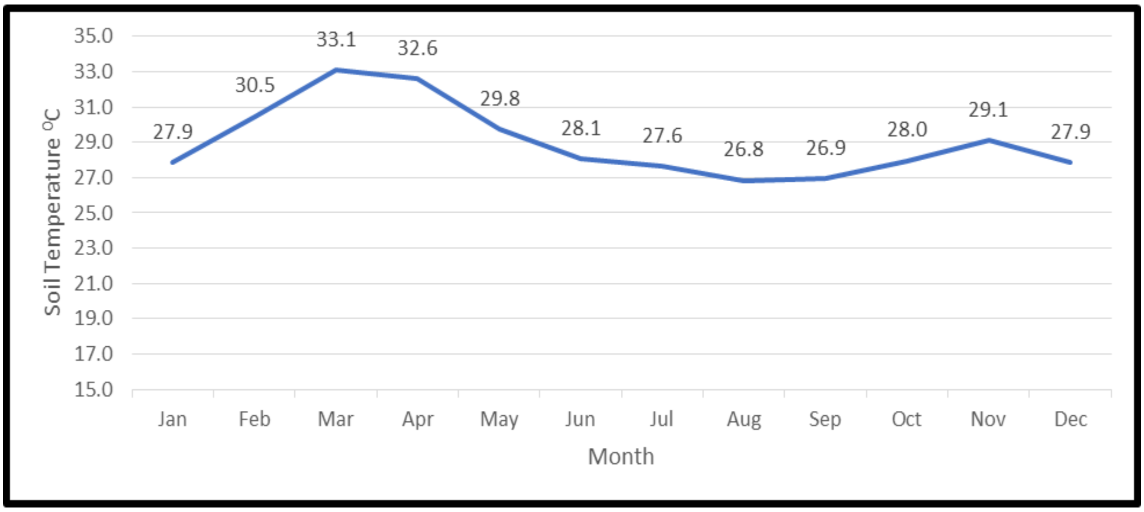

Figure 6: Variation in Monthly Mean Soil Temperature at 30cm depth in Makurdi (1991-2020).

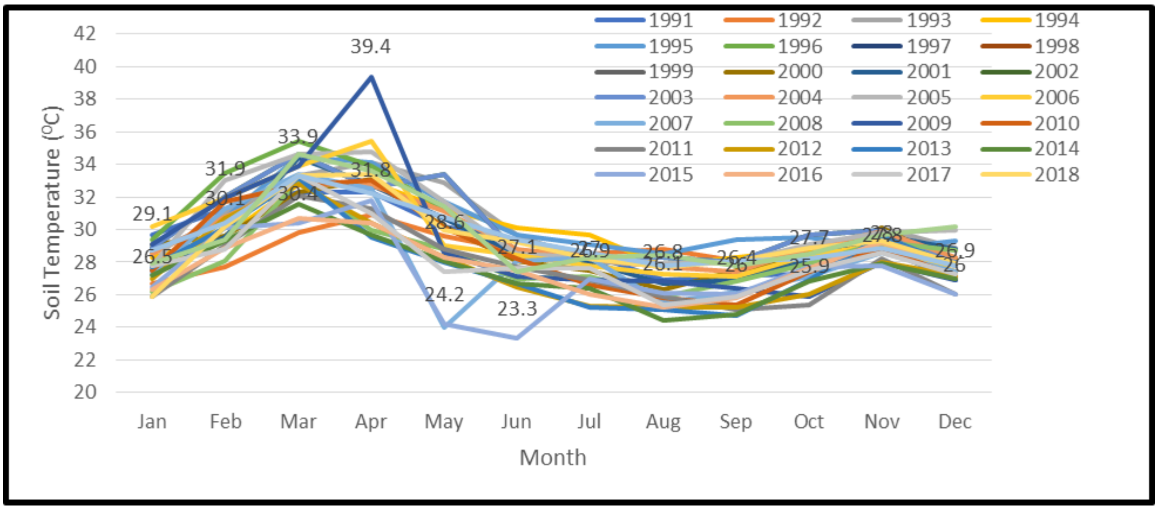

Figure 6: Variation in Monthly Soil Temperature at 30cm depth in Makurdi (1991-2020)

The result of variation in annual soil temperature at 30cm depth in the study area is presented in Figure 7 and Table 1. The result indicates a negative trend in the time series at an annual rate of 0.0628°C with R^2 and *r* of 0.2207 and 0.470. The trend is found to be significant at 0.05 confidence level, given that the calculated value of ‘t’ of 2.814 is greater than the critical value of ‘t’ of 1.70. This result suggests a general decline in soil temperature at 30cm depth in the study area during the study period. The result further shows that mean soil temperature at 30cm depth for the study period is 29.1°C with a standard deviation and coefficient of variation (CV) of 1.20 and 4.1% respectively. The low values of the standard deviation and coefficient of variation suggest that the soil temperatures during the study period have declined significantly in the last three decades, while the mean maximum air surface temperatures have increased significantly over the same time frame. The result further shows that highest mean annual soil temperature of 32.7°C at 30cm depth of was recorded in 1996, while the lowest temperature of 27.2% was recorded in 2015, which further provides evidence of declining mean annual soil temperature at 30cm depth.

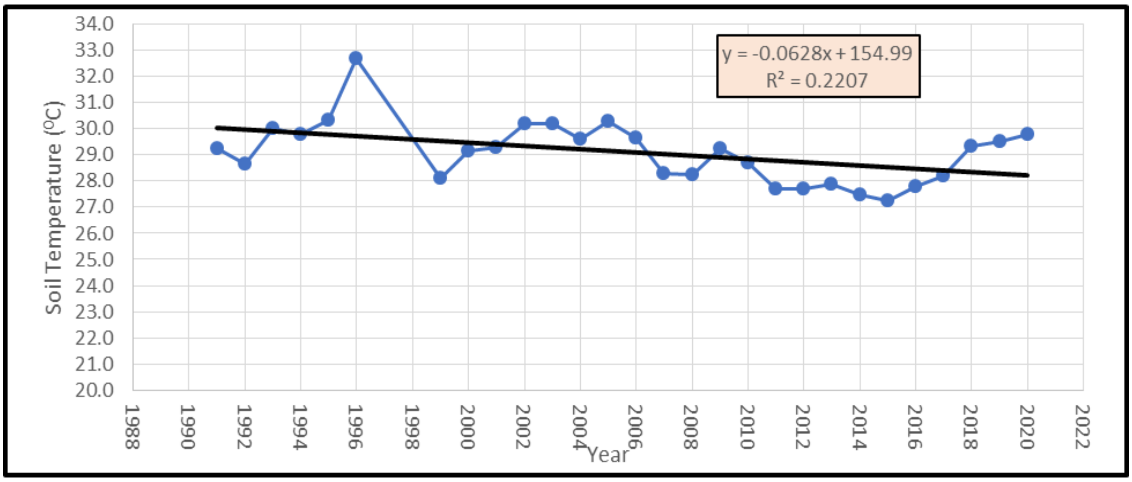

Figure 7: Variation in Annual soil Temperatures at 30cm depth in Makurdi.

The findings of Volodymyr, et al (2022) their study on dynamics of temperature variation in soil under fallow tillage at different depths is consistent with the present study. They reported that soil temperature oscillation amplitude decreases when the depth increases, and that the difference between the 0–5 cm layer and the adjacent 5–10 cm layer has the greatest value. They also reported a decrease in the frequency of the soil temperature oscillations which can result in the reduced level of its heating in different layers. Bourletsikas, Proutsos, Michopoulos, Argyrokastritis (2023) in their study on temporal variations in temperature and moisture soil profiles in a Mediterranean Maquis Forest in Greece reported that air temperature highly affects the upper 5 cm of the mineral soil. In general, it increases with depth in winter at an average rate of 0.036°C/cm and decreases in summer (0.035°C/cm), presenting higher values compared to air temperature from April to August and lower ones during the rest of the period. This finding is partly consistent with the finding of this present study due to differences in climate conditions of these two places. The findings of Oyewole, Olasupo, Akinpelu & Faboro (2018) in their prediction of soil temperature at various depths using a mathematical model at Osogbo, Osun State, Nigeria is consistent with that finding of this present study. They reported that annual levels at10cm and 30cm generally decrease, and are higher during the dry season than the wet season which perfectly agreed the findings of this present study. Similarly, Research on spatiotemporal variation of soil temperature in China from 1948 to 2018 by Zang, Geng, Zhang, Wu and Liang (2020) reported that soil temperature in most areas of northern China had an increasing trend, especially in the northeast China, which is at variance with the findings of this study. They however found that the soil temperature in most of the south China had a decreasing trend, which agreed with the findings of this presents study. The study by Cheng, Zhang, Jin & Ren (2022) on spatiotemporal variation characteristics of hourly soil temperature in different layers in the low-latitude plateau of China reported similarly findings with those of this present study. They reported that as soil depth increased, average soil temperature increased in autumn and winter, and decreased annually and in spring and summer.

Relationship between Air Surface Temperatures and Soil Temperatures at 30cm depth

The result of analysis of the relationship that exist between air surface temperatures and soil temperatures at 30cm depth is presented in Table 2. The result indicates a strong positive correlation between maximum air surface temperature and minimum air surface temperature with correlation coefficient of 0.588. The Correlation coefficient is significant at 0.05 (95%) confidence level, which Suggests that air surface maximum temperatures are good predictor of Air Surface minimum temperature the study area during the study period. Conversely, the result indicates a weak negative correlation between soil temperatures at 30 cm depth and air surface maximum temperatures with a correlation coefficient of -0.040 which is not significant at 0.05 (95%) level of confidence. This result suggests that, an increase in air surface maximum temperatures may lead to a decrease soil surface temperature in the study area. In the same vein, positive correlation was established between soil temperatures and air surface minimum temperatures in the study area with correlation coefficient of 0.013. This suggests that an increase surface temperature may lead to a slight increase in soil temperatures at 30 cm depth in the study area.

Table 2: Correlation Matrix for air surface and soil temperatures.

	Tmax	Tmin	S.Tempt
Tmax	1.000		
Tmin	0.588	1.000	
S.Tempt	-0.040	0.013	1.000

Source: Computed from raw data from NiMet Weather Station, Makurdi

TMax = Maximum Temperature; Tmin = Minimum Temperature; and S.Tempt = Soli Temperature

Khandaker, Anisuzzaman, and Tanaz (2015) found that a strong positive correlation up to 20 cm depth of soil with surface air temperatures, suggests there was no strong relationship at a depth greater than 20cm. Again, this finding is consistent the finding in this present study where weak correlation was found between soil temperature and air surface temperatures in Makurdi. Another study by Nuruddin and Lili (2005) found a linear relationship with R^2=0.57 between soil temperature of 1 cm depth which suggests that that the air temperature is the best variable to predict the soil temperature at a lower depth of less than 20cm. Furthermore, Farjana, Satya, Hamid & Reginald (2018) found that there is a noticeable difference between air and soil temperatures over temporal scales that range from diurnal to seasonal, which suggests that the ground-based upper layer soil temperature may be a better surrogate than the near-surface air temperature.

Implications of declining soil temperatures on crops.

Soil temperature plays a crucial role in determining the growth, development, and overall productivity of crops in tropical regions. While much attention has been given to the impacts of rising global temperatures on agriculture, the generally declining soil temperatures found in this study can also have significant implications for crop production. For instance, cooler soil temperatures can delay germination and slow down the early growth stages of crops. This can lead to extended timeframes for crop establishment and reduced overall yield potential. A study by Lobell, Schlenker & Costa-Roberts (2011) showed that certain tropical crops like maize and rice have optimal germination and growth within specific temperature ranges, and deviations from these ranges can result in reduced yields. In the same vein, soil temperature affects microbial activity and nutrient availability in the soil. Cooler temperatures can slow down microbial processes responsible for nutrient cycling, potentially leading to reduced nutrient availability for crops. This can impact the overall health and nutritional content of the harvested produce as demonstrated by (Blair, Faulkner & Till, 1991). In addition, soil temperature influences the activity of pests and pathogens in the soil. In tropical environment such as Makurdi, where many pests and diseases are already prevalent, declining soil temperatures may alter the timing and intensity of these biological interactions. In some cases, cooler temperatures might suppress certain pests, but they could also favour others, leading to shifts in pest and disease dynamics that farmers must manage (Madden, & Van den Bosch, 2004).

Soil temperature influences water movement and availability in the soil. Cooler soils might lead to slower evaporation rates and reduced water uptake by plants, potentially affecting their water stress tolerance and water-use efficiency (Hillel, 2004). Also, soil temperatures decline, the suitability of certain crops for specific regions may change. Tropical crops adapted to warmer conditions might face reduced yields or increased susceptibility to stressors in cooler soils. Conversely, crops that are better adapted to cooler conditions might become more suitable, potentially leading to shifts in crop choices and agricultural practices (Challinor, Watson, Lobell, Howden, Smith & Chhetri, 2014).

CONCLUSION

The study concludes that maximum and minimum air temperatures have significantly increased in Makurdi over the past 30 years, while soil temperatures at 30 cm depth have declined. A weak negative correlation exists between soil temperatures at 30 cm depth and air surface maximum temperatures, while a positive, though statistically insignificant, correlation was found with mean annual minimum air temperatures. To address these changes, several recommendations are suggested. Increasing green cover through tree planting is recommended to reduce the urban heat island effect by providing shade and cooling. Raising public awareness about the impact of rising temperatures can encourage practices that reduce emissions and waste. Farmers are encouraged to use cover cropping and mulching to conserve soil moisture and regulate temperature as well as planting of crops that can withstand heat stress. Enhancing soil organic matter through composting and green manure can improve soil stability and mitigate temperature fluctuations. Establishing windbreaks around fields can create warmer microclimates favorable to plant growth. Additionally, implementing proper irrigation practices, such as drip irrigation, can maintain stable soil temperatures. Lastly, selecting crop varieties suited to cooler soil temperatures and adjusting planting times is advised.

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