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RESEARCH ARTICLE

SPATIO-TEMPORAL MODELS OF MAXIMUM SURFACE TEMPERATURE IN CONTEXT OF HUMAN COMFORT IN IMO STATE ECOLOGICAL PROVINCES

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ABSTRACT

This study investigates the variability in maximum temperature across a century and its implications on human comfort and ecosystem in Imo State with a viewing to building capacity for adaptation. The study area was classified into three (Owerri, Orlu, and Okiwe) geographical provinces. Data on maximum temperature were extracted using CRU gridded data from the University of East Anglia for a century (1923 – 2023 climatic years). The descriptive analyses of data reveal that the climax mean monthly event of 32.5 ^{0}C is recorded consecutively in Owerri and Okigwe provinces during February. The comparative evaluations using linearized models give homogenous positive trends across the sampled locations, but with a highest model values of y = 0.005x + 30.823) in Okigwe province and a peak R^2 value of 0.232 recorded in Owerri province. This paper concludes that positive increase in Tmax anomalies converge fairly within human adaptive capacity and constitute minor threat to human comfort in Imo State. To boost resilient for the projected extreme events in the future, this paper recommends the immediate shift in emphasis from flower planting to that of fruits especially in open spaces, compounds, green belts, and selective afforestation to promote social gathering, human comfort and positive economic returns across towns and cities.

Keywords: Maximum temperature, heat island, thermal discomfort, human health, ecosystem.

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1.0. INTRODUCTION

There is upsurge recognition that climate change indicators (temperature) constitute one of the principal threats to global and local stability, with adverse impacts crosscutting environmental, socioeconomic, and health outcomes worldwide (Amnuaylojaroen, Parasin, & Limsakul, 2024). It is established that about half of the world's population lives in urban areas, and by 2030 is expected to go 60 percent (UN HABITAT, 2009). Similarly, extreme temperatures can lead directly to loss of life, while climate-instigated disturbances in ecological systems can indirectly impact the incidence of infectious diseases (Allen, et al., 2018; Kucaj & Gjoni, 2026).

Amidst the observed impacts and outcomes, how residents perceived and adapt to adverse thermal stressors for enhanced socio-economic and occupational productivities of the rural communities within the humid Tropics is either neglected in research or not well-known. The maxims of *thermal uniformity* had long been accorded to the Tropics (places located between Latitudes 23½ degrees North and South of the Equator), but there are indicators that the disparities in heating and cooling are functions of differential intervening (geographical) variables such as the nature relief, vegetation, cloud cover, atmospheric circulations, water bodies, land use, urbanization, industrialization, and ocean circulation.

Research evidences have shown that every increase in the surface temperature above 20 ^{0}C (Wet-Bulb Global Temperature (WBGT)) leads to a decrease in people's comfort and productivity by 2 – 3 percent. In context of health risks, research evidences have identified physiological strain and ills such as hyperthermia, abnormal kidney function, dehydration and neurological dysfunction (World Health organization and World Meteorological Organization 2025). Avoiding heat exposure or reducing physical activity may lower health risks, but this is not compatible with the ability to live healthy, interactive, and productive lives (World Health organization and World Meteorological Organization 2025).

There are obvious implications of extreme periodic oscillations in maximum temperature on the livelihood, health, social interaction, income, national economies and wellbeing of individual, groups, and the functionality of ecosystem through time. These impacts are highest for countries, industries and individuals directly dependent on manual work, but there are indirect and broader geographical and economic impacts on individual and groups, such as those relying on stable food prices and value chains affected by primary sector productivity (Duru, Umo, & Ojimma 2015).

In recent past, concerted attempts had been initiated to adapt and/ or avert the devastating effect of extreme thermal stressor can be mismatch based on event and time. The effectiveness of adaptation strategies varies significantly across studies, often depending on local socio-economic conditions, governance structures, and implementation capacity (Amnuaylojaroen & Parasin, 2024). In Burundi and Rwanda, Schmidt & Walz (2021) established that the used of drought-resistant crop varieties and improved irrigation techniques, have proven effective in enhancing food security and improving health outcomes through better nutrition and reduced poverty. In some highly urbanized and populated Nigerian cities such as Kano, Ikeja, Garki, Abuja, Owerri, Onitsha, and Aba.

It is observed that the relationship between the daily mortality rate and the average temperature will be stronger: if the air temperature will increase by 1 ^{0}C, then the daily mortality rate of days with an

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average daily temperature > 25° C will increase by 4.9 percent between 2021 and 2050 (Kucaj & Gjoni, 2026) in countries like China, USA and Britain. In cities within the Tropical Africa, increase in mismatch adaptive strategies such as use of air conditioning equipment, deforestation, anti-environmental engineering/ concrete works, bush burning, poor city planning/ housing, and poor waste management system constitute serious health and ecosystem concerns.

The average normal human body temperature is 37˚C (98.6˚F). To maintain this temperature without the aid of heating or cooling equipment, the ambient environment should be around 28˚C (82˚F). In the humid Tropics with extreme temperatures, the adverse health concerns of high surface temperature are not appropriately communicated through researches, especially in the rural communities. The central questions that are central to the analysis and discourse in this paper are: (i). Do maximum annual temperature patterns vary across the geologic formations in Imo State? (ii) Are there variations in linearized models of maximum temperature in the Imo State? (iii) What are the adverse health implications of extreme changes in maximum temperature on human comfort? The highlighted issues are chronologically elucidated in the course of this article to identify pattern in extreme maximum temperature in Imo State.

2.0. DESCRIPTION OF THE STUDY AREA

2.1. Location and Climate

Imo State is located at the center of Southeast Nigeria and is often called the Heartland. Geographically speaking, the state is located between Longitudes 6^0 7^1 and 7^0 28^1East of Greenwich Meridian and Latitudes 4^0 10^1 and 7^0 14^1 North of Equator as depicted in Figure 1. Relatively, the state share common boundaries with Abia, Anambra, Enugu, and Rivers States.

The climate of the study area is generally classified as *Af* climate based on Köppen's classification scheme. The dynamics in its weather and climates led to manifestation of four seasons, comprising long rainy, short rainy, long dry and short dry seasons (Umo, 2019; Umo, 2025). The mean annual rainfall is over 2500 mm and a mean temperature of approximately 26.9^0 Celsius (Umo and Ike 2020). The relative humidity varies within the range of between 72 percent for dry season and 92 percent for rainy seasons. Recently, there are remarkable evidences of rising temperature due to the effects global warming and climate change.

2.2. Geology

The geological formations of the Imo agro-ecological provinces presented in Figure 2 differ based on spatial spread. The Okigwe province is traverse by five distinct geological formations, comprising the False-bedded Rocks of Coal and Upper Measures, the Imo Shale, the Abeokuta formation, the Quaternary Alluvium, and the Coastal Plains Sands Deposits of Tertiary Times. The dominant formations composed of the Imo Shale, occupying major parts of the Northern flank especially Okigwe and Onuimo Local Government Areas.

The southern flank (Owerri) is a transitional province with alternate formations of comprising dominantly Quaternary Alluvium region and traces of the Coastal Plains Sand Deposits of Tertiary Times (Umo *et al.*, 2020; Umo & Enwereuzor, 2021). On the basis of Age stratification as indicator, Onwumerobi (2004) identified the existent of the Paleocene, Eocene, Pleistocene formations in the

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Okigwe ecological province. More so, the complexities in Geological formations coupled their complex sceneries (relief features).

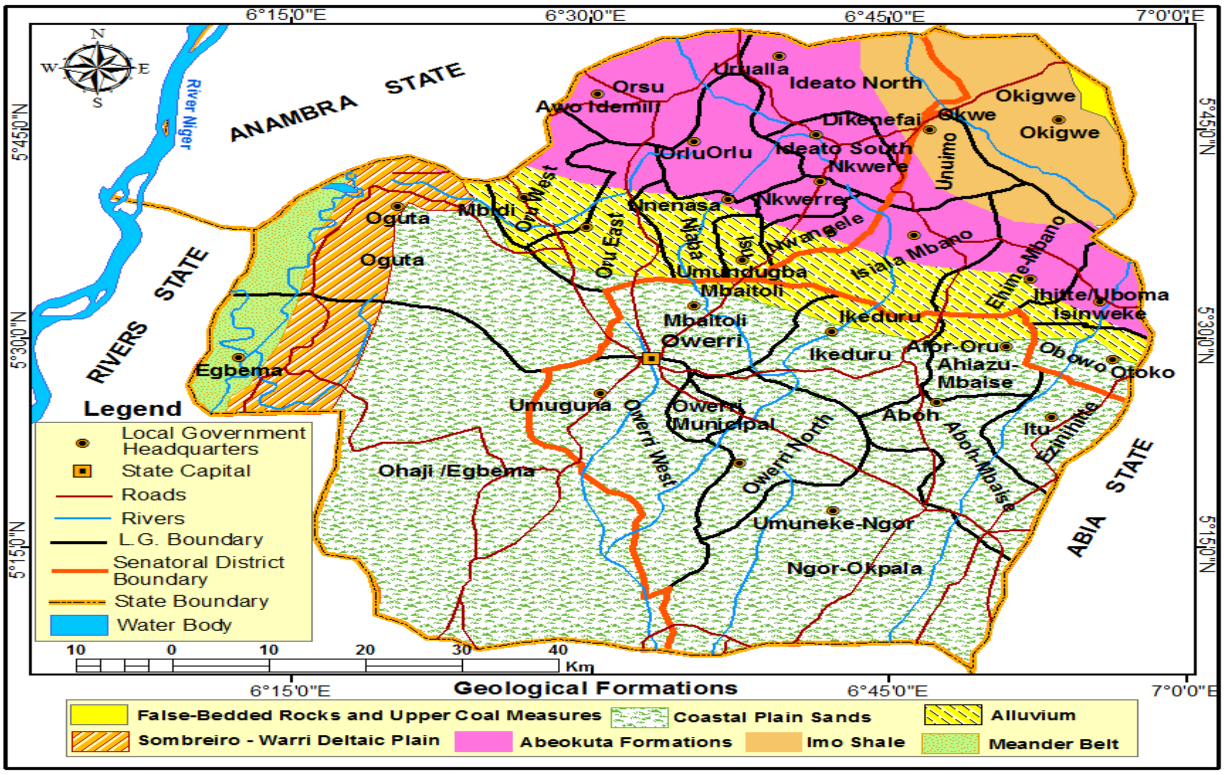

Figure 2: Imo State Showing the Geological Formations.
Source: Modified from the Nigeria Geological Survey Agency (2012).

The geological formations of the Western (Orlu) province presented in Figure 2 depict spatial dynamics, with shared attributes from the Okigwe and Orlu geological provinces. In addition, the existence of the unique Sombreiro, Meaner Belt, Coastal Alluvium, and the Coastal Plains Sand Deposits of Tertiary Times provide unique avenues for distinct agricultural production.

3.0. METHODOLOGY

3.1. Sampling and Data Extraction Methods

The study area was classified into three major geological provinces, comprising Okigwe, Orlu and Owerri as presented in Figure 1. In each province, a distinct geologic formation was purposively selected for maximum temperature data extraction and their coordinates recorded with the aid of using Germaine Global positioning System (GPS) and details summarized in Table 1. The rationale for the choices of locations for maximum temperature data extractions in each stratum (province) was to consider the areal differentiations (i.e. spatial spread).

The maximum temperature data for each province was extracted using from the University of East Anglia Climatic Research Unit (Harris, Jones, Osborn, & Lister, 2020), supported by CRU time series, version 4.05 of high resolution gridded data from January, 1923 to December 31st, 2023 (100) climatic years using gridded method. The gridded datasets were created with the grid cells'

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specifications of 0.5° × 0.5° in size to extract periodic Tmax at three distinct geological provinces in Imo State, comprising Coastal Plains Sand Deposits for Owerri Province, Imo Shale for Okigwe Province, and; False-bedded Rocks and Upper Coal Measures for Orlu Province respectively. The choice of CRU data series had gained high popularities and application in recent researches such as Okoro, Chen, Chineke & Nwofor, 2014; Chen, Tian, Yao, & Ou, 2016; and Omonigho (2022).

Table 1: Data Sources and Extraction Methods

Geological Provinces	Formation/ Data Site	Elevation	Durations
Owerri	Coastal Plains Sand Deposits	54.23 meters	7/1/1923 – 6/12/2023
Orlu	False-bedded Rocks	60.32 meters	7/1/1923 – 6/12/2023
Okigwe	Imo Shale Deposits	123.13 meters	7/1/1923 – 61/12/2023

Source: Authors' Compilation (2025).

3.3. Methods of Data Analysis

Data generated in the course of this study were analyzed using descriptive and inferential statistics. The descriptive statistics such as chart, graph, and mean were using for comparative purposes, while inferential statics such as linear regression, time series and analysis of variance were used predictive modellings and assessment of patterns in in each eco-geomorphological provinces in Imo State.

Specifically, time series with linear regression model were used in elucidating the annual trends, variances, and oscillations in maximum temperature for a century (1923 – 2023 climatic years), and compare the models between and among the eco-geomorphological provinces. On the basis of explainable variances and predictive power of variability in the mean annual maximum temperature, linear regression models were used.

4.0. PRESENTATION OF RESULTS AND DISCUSSIONS

The results generated in the course of this work are chronologically presented in Tables and Figures and discussed in what follow.

4.1. Descriptive Evaluations of Centurion Monthly Maximum Temperature (Tmax)

The descriptive evaluations of a century monthly patterns in surface maximum temperature is presents in Figure 2 the results reveal spatial and temporal disparities. In context of spatial differentiation, the Okigwe province depicts a generalized climax pattern, followed by Orlu province, while Owerri province portrayed a generalized least month pattern across the study periods.

A further exploration of monthly variance in maximum temperature using temporal dimension as index reveals that a highest mean monthly scenario reveal dominancy of the month February with a homogenous value of 33.8 ^{0}C recorded in Okigwe and Orlu temperature Provinces. The pattern is closely followed by the month of March where Okigwe province recorded a lethal monthly value of 33.4 ^{0}C, while the Orlu province counterpart established a comparatively lower value of 33.3 ^{0}C in the sequence. Contextually, the patterns in the results constitute serious concern to human comfort and health when compare with Lee *et al* (2017) report that short-term exposure to large diurnal temperature ranges has been associated with an increased burden of premature death, particularly from cardiovascular causes, among women and among elderly individual.

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A juxtaposition of the low pattern clearly indicated that a lowest monthly maximum temperature event of 28 ^{0}C is associated with the month of August for Owerri, followed by the month of July with a mean value of 28.2 ^{0}C. The patterns in the event reveal that Orlu province recorded a lowest value of 28.5 ^{0}C uniformly in the month of July and August respectively, whereas Okigwe province established a homogenous least monthly maximum temperature of value 28.6 ^{0}C during the July and August. The perspectives in the results of low events during the months of July followed by August regardless of spatial locations of sampled climatic points and years suggest the strong influence of rainfall and seasonal oscillation orchestrated by multiple geographic, atmospheric, anthropogenic factors in the studied provinces.

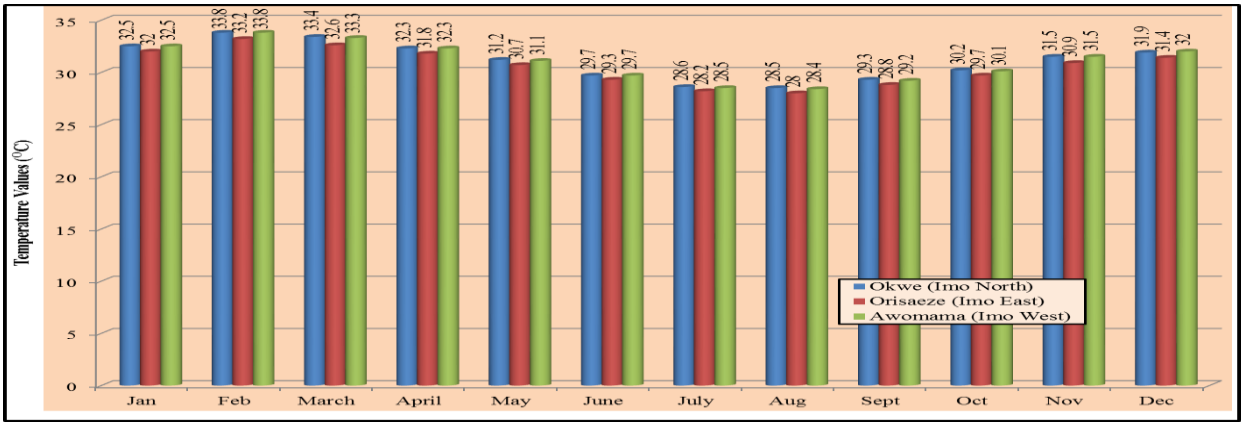

Figure 2: Descriptive Analysis of Monthly Temperature Pattern in Imo State.

4.2. Inferential Modellings of a Centurion Maximum Temperature (Tmax)

The linearized model of Tmax patterns in rural areas of Imo State are summarized in Figures 3, 4 & 5 respectively. The results presented in Figure 3 for Okwe in Okiwe province reveal temporal complexities. The case-bound evidences reveal that a mean highest event of 31.8 ^{0}C is recorded consecutively in the 1998 and 2016 climatic years, followed by a value of 31.7 ^{0}C for 2021 climatic year. Contrarily, a threshold value of 30.0 ^{0}C is associated with the 1976; followed by a 30.5 ^{0}C recorded homogenously during the 1975 and 1986 annual reports.

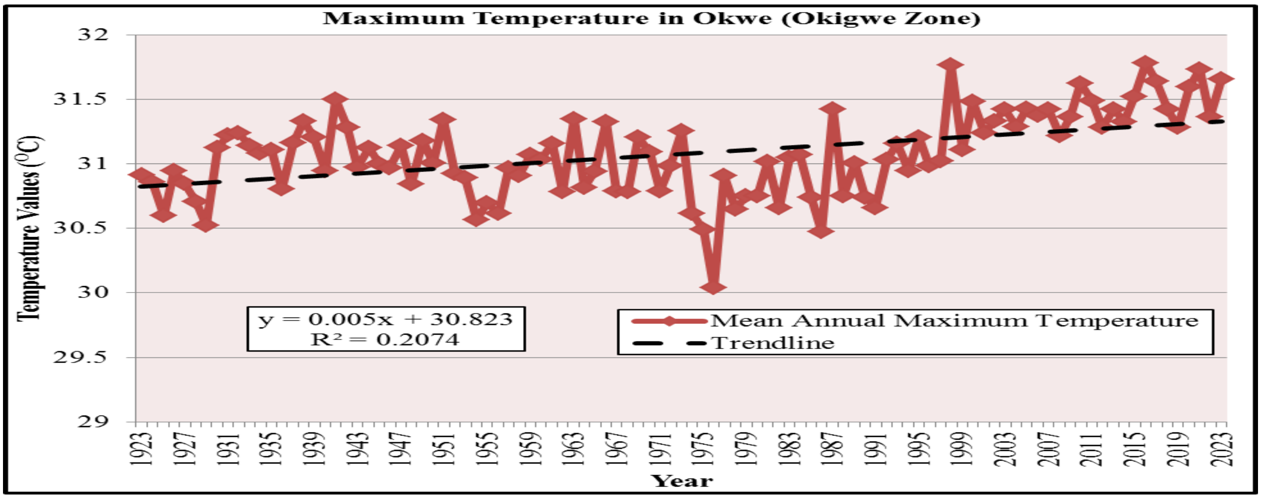

Figure 3: Temporal Trend of Maximum Temperature in Okwe, Okigwe Province.
Source: Authors' Analysis (2025).

On the dimension of convergences, the results in Figure 3 depict that a total of 52 climatic years recorded the mean Tmax values above the trend-line and a total of 43 climatic years recorded the mean values that converge below the regression line, while the residual of 5 climatic years recorded the mean Tmax values that converge on the regression (trend) line. The results validated (Gasparrini et al., 2026) observation that changes in a population's susceptibility to heat may also occur over longer timescales, such as within seasons, with substantially.

The linearized model of Tmax pattern in Awomama for Orlu Province is npresented in Figure 4 and the results temporal dynamics, with a historic climax value of 31.8 ^{0}C recorded uniformly during the 2016 and 2019 climatic years. The result is closely followed by a value of 31.7 ^{0}C recoded in 1998, while a least Tmax value of 30.0 ^{0}C is associated with the 1976, seconded by a value of 30.3 ^{0}C for 1975 in the sequence.

A further elucidation of the convergence pattern of Tmax values indicate that a total of 53 climatic years recorded annual events above the luinearized annual mean (trend line) and a total of 43 climatic years converge below the mean regression line, while the residual of 4 climatic years converge pon the average regression line.

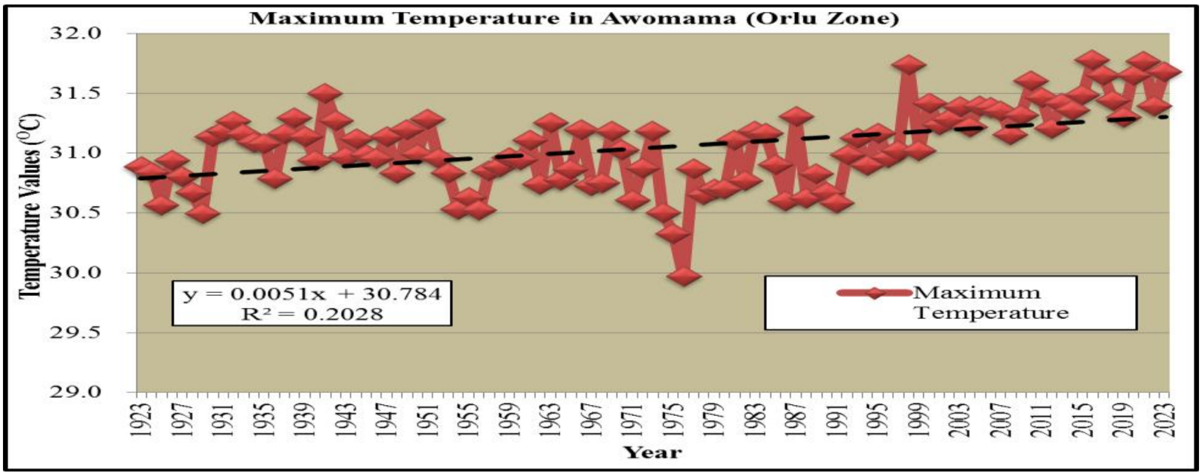

Figure 4: Temporal Trend of Maximum Temperature in Orlu Province.
Source: Authors' Analysis (2025).

On the dimension of Owerri Province, the linearized elucidation of oscillation pattern is summarized in Figure 5 and the results reveal attributes of homogeneities and heterogeneities. Empirically, the peaks mean value of 31.3 ^{0}C is recorded simultaneously during the 1998 and 2016 climatic years, followed by a value of 31.2 ^{0}C for 2021 climatic years. On the contrary, the lowest annual mean Tmax value of 29.5 ^{0}C recorded in 1976 climatic year, accompanied by a value of 29.9 ^{0}C for the 1975 climatic year in the sequence.

During work in hot conditions, the body's primary challenge is to provide enough blood flow to support both the muscles (for the metabolic processes involved in physical work) and skin circulation (for dissipating the heat generated in the muscles) as well as to ensure perfusion of essential internal organs and the brain. Comparatively, the notion show strong similarity with recent empirical reports

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that working in hot conditions compelled the body to provide enough blood flow to support both the muscles (for the metabolic) and skin circulation for dissipating the heat generated in the muscles (Nybo et al 2014). It also ensure perfusion of vital internal organs and the brain are better regulated (Nybo et al 2014; Sawka, 2011).

On the trending pattern, the results presented in Figure 5 clearly showed that a total of 49 climatic years recorded the annual Tmax values above regression line, and a total of 42 climatic years recorded the annual Tmax values that trended below the average line, while the residual of 9 climatic years established that the annual Tmax values converged on the line of best fit. The implication is that protracted exposure to the varying heating and warning temperature system constitute major health and thermal discomfort. The results validate Lee et al (2017) notion that diurnal temperature range (24-hour variations between maximum and minimum temperatures) is an important indicator for weather stability and global climate change, and has been linked with mortality and morbidity, particularly in Asia.

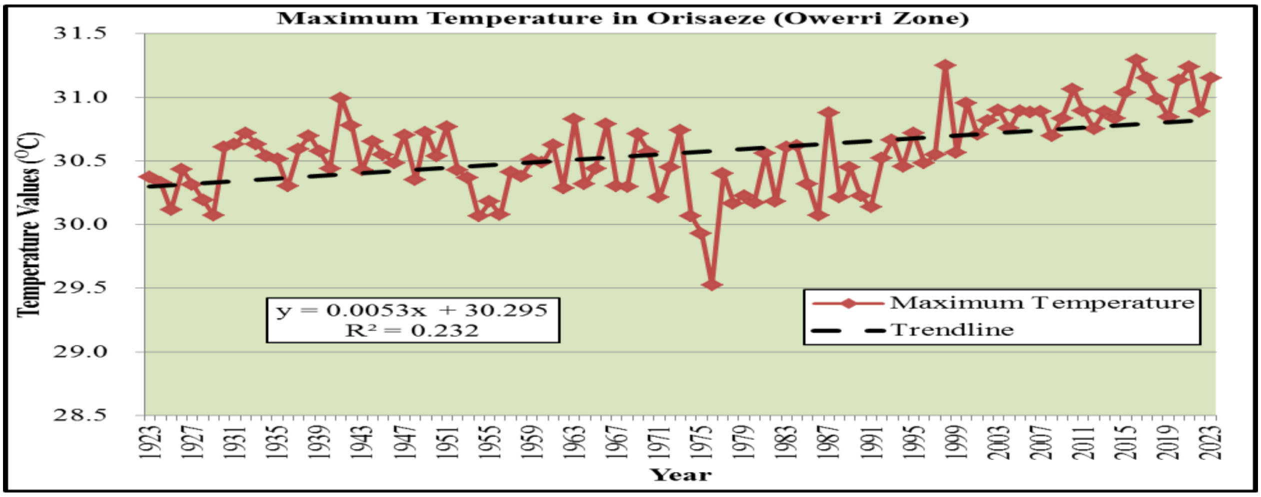

Figure 5: Temporal Trend of Maximum Temperature in Orisaeze, Owerri Province.
Source: Authors’ Analysis (2025).

4.3. Predictive Model of Spatial and Temporal Trend in Surface Temperature

The linearized models of annual fluxes in surface maximum temperature clearly showed the dominant convergences of mean annual events above the regression lines as well as generalized increasing trend in the three sampled geographical provinces of Imo State (Table 2). The increasing trends and high positive convergences suggest serious threat to human comfort, health status, and ecosystem.

Table 2: Spatiotemporal Trend of Annual Maximum Temperature in Imo State.

Ecological provinces	**Climatic Points**	**Regression Equation**	**Pattern of Trend**
Imo North	Okwe	$y = 0.005x + 30.82$; $R^2 = 0.207$	Increasing
Imo East	Orisaeze	$y = 0.005x + 30.29$; $R^2 = 0.232$	Increasing
Imo West	Awomama	$y = 0.005x + 30.78$; $R^2 = 0.202$	Increasing

Source: Authors’ Analysis (2025).

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Dimensionally, the results confirms a recent report that short-term exposure to large diurnal temperature ranges has been associated with an increased burden of premature death, particularly from cardiovascular causes, among women and among elderly individuals in some Asian countries (Lee et al 2017).

The relatively low predictive power and explainable variances are indicators of the locational influence coupled with the similarities of multiple geographical and anthropogenic factors controlling the temperature events. However, the similarities of the some key drivers notably the movement of Inter-Tropical Convergence Zone (ITCZ), ocean circulation leading to the dominance of the Topical Maritime Airmass (Am) collectively compel the established patterns, which partly upholds the Maxim of "thermal Uniformity". Spatial and temporal variations are clearly established in the course of this study, though not statically significance. The variations suggest clearly threat to human comforts, health, and ecosystem in the provinces, thereby necessitating for necessary interventions to promote adaptation and harmony in socio-economic and environmental interactions and resource management.

5.0. CONCLUSION AND RECOMMENDATIONS

The preceding results reveal that the distributions of surface maximum temperature vary in space and time. However, a comparative assessment of the historical records from the result showed that rural communities located within the Okigwe and Orlu ecological provinces of Imo State are dominantly under the influence of homogenous extremities in annual Tmax with the mean values that range between 30.0 and 31.8 ^{0}C respectively. The implication is that residents in Okigwe are more vulnerable to thermal heat stressor and a corresponding heat discomfort than the residents within the rural communities in Owerri Province, whose mean annual Tmax values range between 29.5 and 31.3 ^{0}C. However, there are predominance of urban heat island within Owerri province that their Okigwe and Orlu counterparts; due to the diversity in scenarios of anthropogenic parasitism.

Contextually, human comfort, commitments to work and allied socio-economic activities of the residents especially during the long dry season are most likely to undergo retrogression due to protracted positive increase in temperature within the study areas during the periods. In retrospection, the results partly affirmed Kjellstrom *et al.* 2009 and Ioannou *et al.* 2017 report that Changes in the weather within a day, from day-to-day, months, years, or between seasons can have significant impacts on work capacity and human health. Hourly increases in WBGT during the day are associated with lower work capacity and allied health risk in heat-exposed jobs, particularly for outdoor work.

This study therefor recommends for increase climate change education especially in the rural area to boost individuals and groups adapt strategies to extreme climate change stressors/ Also, the socio-cultural and ecological activities and practices that threaten human comforts (especially deforestation, poor waste management system, and burning) should be checkmate and appropriate precautionary actions taken to avert or mitigate the devastating impacts on atmospheric resources and human health.

Conflict of Interest

The authors declare that no conflict of interest exist in this manuscript.

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