Analysis of Thermal Comfort Trend of Kaduna Metropolis, Kaduna State, Nigeria

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Abstract

The aim of the study was to describe the Thermal Comfort of Kaduna Metrplis. The Thermo-hygrometric Index (THI), mean monthly Temperature and Relative Humidity values of Kaduna metropolis were sourced from Nigerian Meteorological Egency (Nimet) (2009 - 2023). THI values were derived, categorized, and used to determine the Thermal Comfort trend. The result revealed an increasing trend in THI throughout the study period, with the months of May and April having the hotter thermal comfort index (>25°C*) compared to other months of the year. The months of December and January recorded the less hot thermal comfort index (17-22* °C). *The year 2019, was the hottest year with mean annual THI of >24.5 °C. The study concluded that the thermal comfort of the study area was on the increase towards the discomfort level. Based on the findings, the study recommended green Kaduna initiative that would encourage tree planting, heat stress awareness and adaptation campaign and urban decongestion policies.*

Keywords: Thermal Comfort, Temperature, Relative Humidity and Thermo-hygrometric index

INTRODUCTION

Increased urban air temperature considerably affects the health, comfort and consequently the quality of life in urban spaces. Urban design and planning studies, therefore, face an increasing challenge as they aim to improve Outdoor Thermal Comfort (OTC) and microclimate conditions of urban environments (Reihaneh et al., 2022). People with different cultures and adaptation to different climates, may react differently to the same thermal conditions, indicating that the thermal and perceptive evaluation of a physical place can be influenced by psychological and sociocultural processes (Aghamolaei et al. 2021).

Over the past few decades, urban environments expanded at a remarkable rate. This vast and unplanned growth of urbanization reduced the environmental qualities and increased the energy consumption of buildings. The construction and operation of built environments are major contributors to the quality of life within urban places. Studies have revealed that the global mean surface temperatures in cities are likely to increase for between 1.4 and 4.8°C before the year 2100 (Intergovernmental Panel on Climate Change [IPCC] 2021). As a result, urban areas are prone to the effects of urbanization such as climate change, increased urban temperatures, and pollutant concentration (Aghamolaei et al., 2021). Moreover, increased urban air temperatures considerably intensify the energy consumption of buildings. These negative effects threaten the health and thermal comfort of urban residents in outdoor environments (IPCC, 2021). One of the key areas these changes have affected the urban environment is the establishment of Urban Canopy Heat Island (UCHI) scenario in most major cities of the world, resulting into discomfort conditions due to heat stress and associated cases (Ariko et al., 2018).

Thermal comfort is a state of satisfaction with the thermal environment, where individual feels neither too hot nor too cold. It is a complex combination of factors, including air temperature, humidity, air movement (wind speed), radiant temperature amongst other things (Ioannou et al., 2018). Thermal comfort has remained one of the critical environmental and health issues that has attracted most critical stakeholders over the globe (Steward and Oke, 2010). This is because the sudden change in global climate due to the incident of global warming has affected the comfort index of many urban settings. According to Yao et al. (2009), the major variables that affect thermal comfort are rate of urbanization, which is accompanied by construction of tall buildings, pavements and increased emission of greenhouse gases. The emission of greenhouse gases into the atmosphere affect the city centers with a distinct characteristic compared to their rural surroundings.

Linden et al. (2008), reported that majority of the cities in Sub-Saharan Africa (SSA) are associated with thermal comfort index that is above the comfort limit. They attributed this reality to high amount of insolation received, high relative humidity, emission of pollutants and improper urban planning. Similarly, Balogun et al. (2009), attributed variation of thermal comfort index between urban centers and their rural surrounding to urban surface structures and pollutant emission due to anthropogenic factors. Concentration of tall buildings and high population density has been observed by Gulyas et al. (2007), as the key factors responsible for the rapid changes in thermal comfort in most cities. Ali-Toudert and Mayer

(2007), attributed rising of thermal comfort index of most major cities of the world to narrow street canyons and absent of vegetation to serve as carbon sink.

In recent times, urban climatology and thermal comfort studies have attracted the attention of scholars globally. Mateeva (1996), investigated the thermal comfort of most cities in Bulgaria; Toy et al. (2007), took the lead in the studies of thermal comfort of major cities in Turkey; Gulyas and Unger (2007), championed similar studies in Hungary. Locally, the observed disparity in thermal comfort index has called the attention of the contemporary scholars in the field of climatology and meteorology. Balogun et al. (2009) conducted the thermal comfort studies in the Southwestern part of Nigeria by intensively investigating the variation between different Local Climatic Zones in Akure.

The peculiarity of the climate of Northern Nigeria has attracted Urban climatologists in the region to embarked on thermal comfort related researches in most of the major cities. Abdulhamed (2011), investigated the Urban Canopy Heat Island (UCHI) in Kano metropolitan city and found variations in heat concentration in the city compared to the rural surrounding areas. Usman (2012), studied the effects of sky view factors (SVF) on the micro climate of Kaduna metrpolis. The study reported a warmer urban Kaduna compared to the rural surrounding. Ariko et al. (2018), assessed the variability of bioclimatic conditions of Kaduna metropolis and found a warmer urban core compared to the rural surrounding. It is therefore an established fact that the urban centers are relatively hotter than their rural counterparts, thereby exposing the city dwellers with the potential risk of thermal stress and related effects. It is important to understand the trend of the thermal comfort index of Kaduna metropolis and to inform the relevant stakeholders on the pattern of thermal comfort toward providing a guide on proper urban planning strategies.

MATERIAL AND METHOD

The Study Area

Kaduna is the capital of Kaduna State. The state is in north-western Nigeria. The area is located between Latitudes 10°23' and 10° 43' North of the Equator and between Longitudes 7°17' and 7° 37' East of the Greenwich Meridian (See Figure 1). Kaduna metropolis comprises of Kaduna North Local Government Area (LGA), Kaduna South LGA, southern part of Igabi LGA, and the Northern part of Chikun LGA. Kaduna is 912km north of the Gulf of Guinea, about 390km from Nigeria's northern border and 180km from Abuja, the country's capital city. It has an area of about 35 square kilometers (Oguntoyinbo, 1983).

The city has tropical continental climate type characterized by wet and dry seasons. The tropical continental climate is more pronounced in the dry season particularly in December and January. The dry season is from October to April and is dominated by the north-east trade wind called Harmattan which prevails between November and February. The dry season is also rain-less from October to April. The wet season is dominated by the south-east winds which start between May/June to October (Ayoade, 1988). The natural vegetation of the study area is that of the Northern Guinea Savanna with grass dominating and scattered trees hardly higher than 15ft. Meanwhile, the seasonal character of rainfall in the study area has influenced the vegetation which turns evergreen during the wet season and pale brown in the dry season respectively (Oguntoyinbo, 1983).

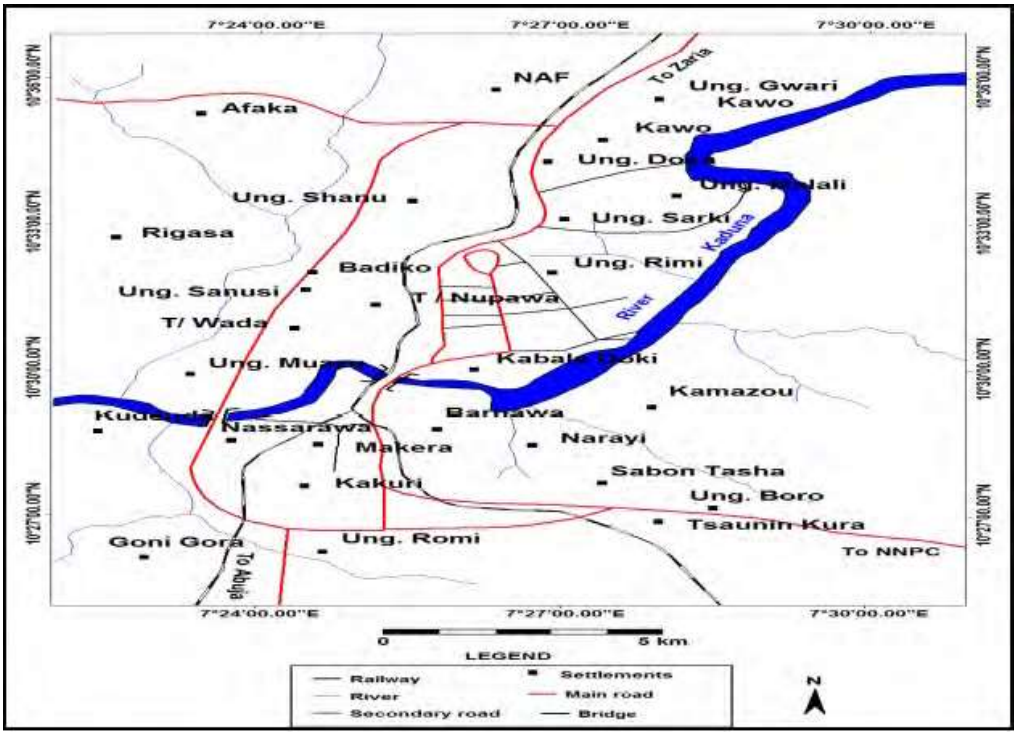

Figure 1: Map of the Study Area
Source: Adapted from the Administrative Map of Kaduna State

Methodology

Temperature and relative humidity were sourced from NiMets archives in Lagos. The thermal comfort index was derived based on Thermo-hygrometric index (THI). The Thermo-hygrometric indices (THI) were determine as given below:

THI = T- (0.55-0.0055RH) (T-14.5)
Where: THI= Themo-hygrometric index
RH= Relative Humidity
T= Temperature.
0.55, 0.0055 and 14.5 are constants.

This index has been used in many thermal comfort investigations (Matzarakis and Mayer, 1991; Toy and Yilmaz, 2007; Balogun et al., 2009). Simple line and bar graphs were used to present the thermal comfort trend of the study area. The comfort categories of thermo-hygrometric Index which include: Hyper-glacial (<-40°C), Glacial (-39.9 to -20°C), Extremely cold (-19.9 to -10°C), Very cold (-9.9 to -1.8°C), Cold (-1.7 to 12.9°C), Cool (13 to 14.9 °C), Comfortable (15 to19.9°C), Hot (20 to 26.4°C), Very hot (26.5 to 29.9°C), and Torrid (>30°C) were used to categorize the thermal comfort conditions of the study area.

RESULTS AND DISCUSSION

The mean monthly trends of thermal comfort index of Kaduna metropolis from 2009 – 2023 are presented in Figures 2, 3 and 4. As presented in Figure 2, the month of January was the only month that recorded a mean monthly THI that fell between the comfort limit (15 - 19.9°C) between the years 2009 - 2018 with exception of the years 2013 and 2017 when the THI of greater than 20°C were recorded. The months of February, March and April all recorded a hot category of THI (20 - 26.4°C) throughout the study period, with exception of the year 2017 when a mean monthly THI of less than 20°C was recorded in the month of February.

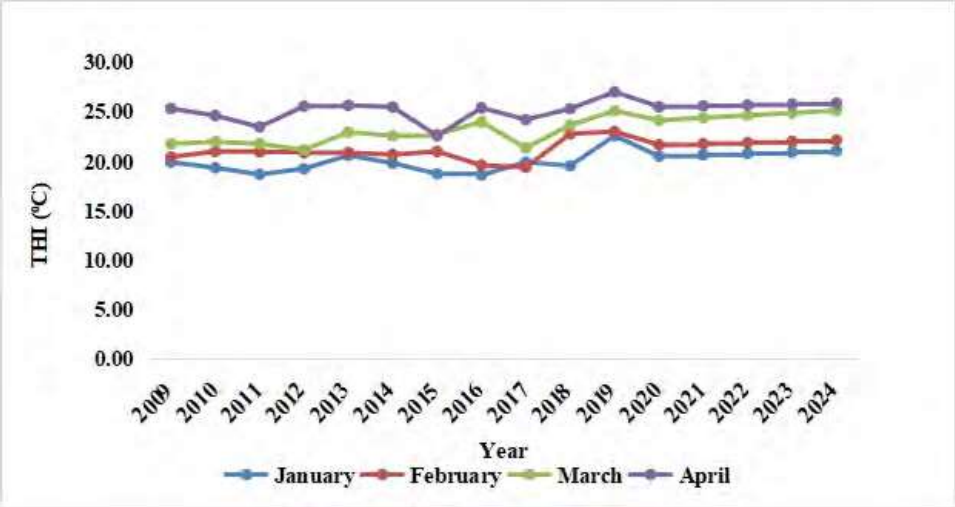

Figure 2: January, February, March and April Mean Thermal Comfort Trend of Kaduna Metropolis (2009-2024)

Results from Figure 3 show that, the month of April was warmer than all the months in the first quarter of each year under study. However, there seems to be a general increasing pattern of the thermal comfort index toward the less comfortable category across the first quarter. This may be due to global warming which is attributed to climate change (source) or the effect of urban heat island, that is, the resultant effect of urbanization and its vagaries (alteration of natural environment through construction of pavement, narrow streets, deforestation and increased emission of greenhouse gases)

The result in Figure 3 further shows that the months of May and June were relatively hotter compared to other months that made up the second quarter of the year. In other words, the THI recorded in July and August were relatively less hot than May and June. However, the month of May appeared to be the hottest month of the second quota of the year. The year 2019 appeared to be the hottest year throughout the study period. The trend revealed an increasing THI pattern in all the months of the second quarter of the year. However, no month recorded a THI that fell within the comfort category throughout the study period. This may be attributed to the geographical location of the study area and trend of global warming which is the concomitant effect of climate change and variability.

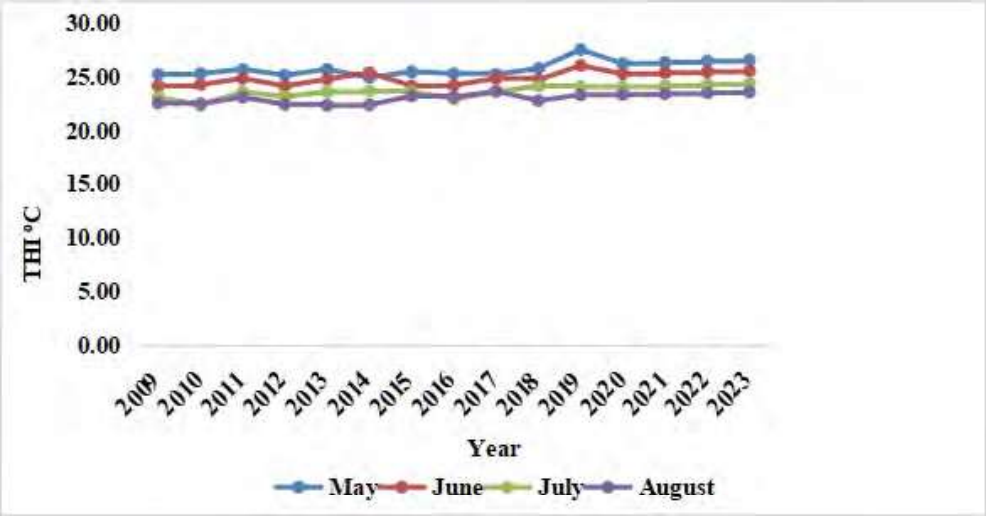

Figure 3: May, June, July and August Mean Thermal Comfort Trend of Kaduna Metropolis (2009-2023)

The mean monthly THI of the months of September, October, November and December are presented in Figure 4. The results indicate that December was the most relatively comfortable month compared to September, October and November. This is because, the month of December was characterized by a mean THI that falls between 17 - 19.9°C in the years 2009 - 2016. Thereafter, the years 2017 - 2023 witnessed an increased in the mean monthly THI that was slightly above 20°C in December. The month of November was slightly hotter than December with mean monthly THI that was slightly above 20°C throughout the study period. Of the months that constitute the last quarter of the year, October appeared to be the hottest month with mean monthly THI that was between 24 and 25°C from the years 2009 – 2018, and above 25°C between the years 2018 and 2023. The month of November was the second hottest month with mean monthly THI after October. No year recorded mean THI that was less than 24°C.

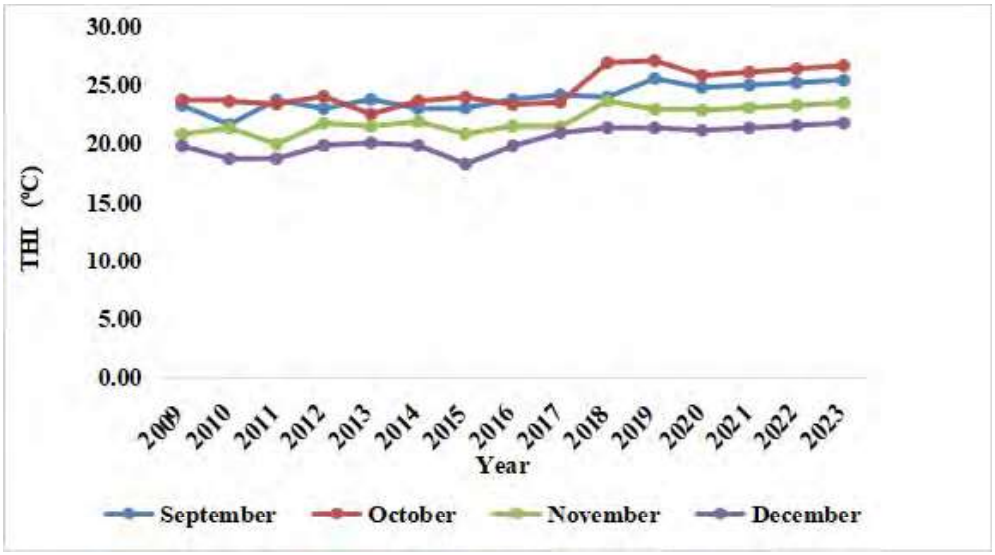

Figure 4: September, October, November and December Mean Thermal Comfort Trend of Kaduna Metropolis (2009-2023)

The mean monthly THI is presented in Figure 4. The result revealed that the month of May with a mean monthly THI of 25°C was the hottest month of the year. April and October were next to May with mean monthly THI of 25°C and 19°C respectively. January and December were less hot with THI that did not exceed 20°C; next to January and December was the month of February and November. It is observed that the months that are related to winter are relatively less hot compared to the summer months. However, the months of August and July were comparatively moderately hot compared to other summer months. This may be due to the moderative effect of rainfall experienced during these two months. However, no month recorded a mean monthly THI that falls within the comfortable category of the thermal comfort index of thermohygrometric categorization.

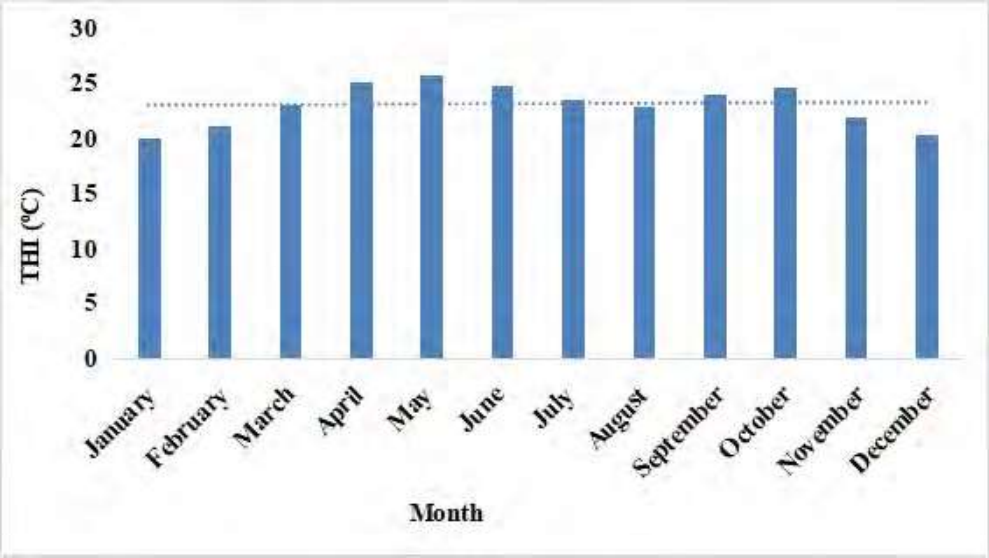

Figure 5: Mean Monthly Thermal Comfort of Kaduna Metropolis (2009-2023)

Figure 5 presents annual mean THI of the study area from the year 2009 - 2023. The results show that no year recorded a mean annual THI that fall within the Thermo-hygrometric categorization of comfortable level (15 - 19.9°C). The year 2019 was the hottest year with a mean annual THI of 24.5°C. The result shows that there was an increasing trend in annual mean THI in the study area with a general increase of about 1.5°C which was greater than the global rise in temperature of 1.1°C. This increase could result to heat stress and its resultant effect. The result validates Abdulhamed (2011), Sani (2012) and Ariko et al. (2014) assertions that most cities in the northern region of Nigeria were getting warmer over the years.

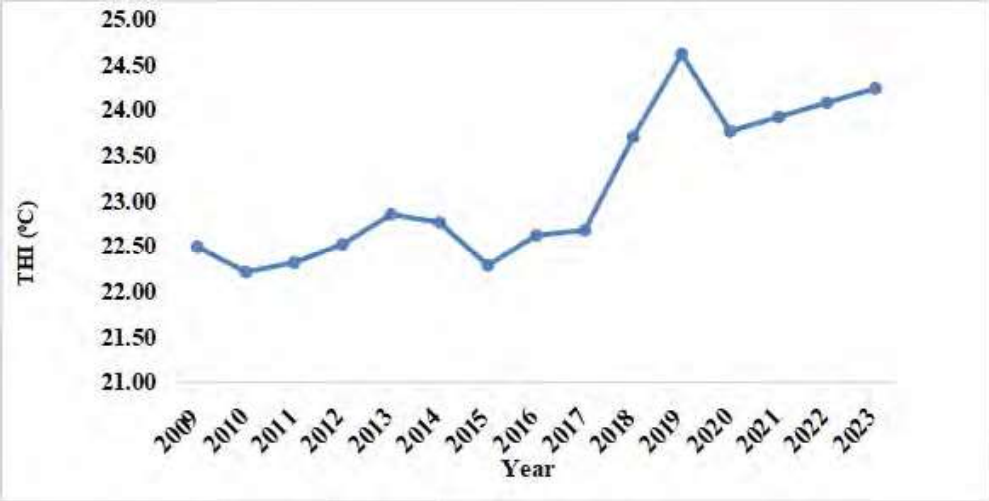

Figure 6: Mean Annual Thermal Comfort Trend of Kaduna Metropolis (2009-2023)

CONCLUSION

The study has analysed thermal comfort trend of Kaduna metropolis, Kaduna State, Nigeria. From the results obtained, there was no month of the year that had mean monkagthly thermal comfort index that fell within the comfortable category of THI. The thermal comfort of the study area showed an increasing trend towards the marginal level of hot as depicted by both the mean monthly index and mean annual index. The result implies the prevalence of discomfort condition with concomitant effects to city dwellers inhabiting the study area.

Based on the above findings, the study therefore came up with the following recommendations:

i. Policy makers in the state should encourage green Kaduna initiative, which will encourage planting of vegetation to modify the microclimate of metropolis.
ii. There is need for awareness campaign in the study area on mitigation procedure to reduce the negative effects of heat stress due to increasing trend of thermal comfort index.
iii. Urban planners should intensify their effort to reduce congestion of people in the city center by providing more layout at the country side with the aim of decongesting the center.
iv. There is the need to create awareness on THI and the need for public enlightenment on mitigation and adaptation strategies to urban discomfort and trend of thermal comfort.

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