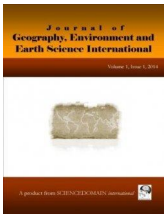

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Urban Warming in Port Harcourt Metropolis and Environs

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Authors' contributions

This work was carried out in collaboration between both authors. Author PN designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author VEW managed the analyses of the study. Both authors managed the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

The study examined urban warming in Port Harcourt Metropolis and Environs. The data used for this study were generated from field observation at fixed points on different land use types in the urban canopy between January to December 2017. Analysis of Variance was used to determine the differences in temperature across the various land use types. Thus, the temperature across different land use types from the city center to the rural fringes varied at the range of 4.8°C with a mean temperature value of 30.1°C. Urban warming was higher on the first three days of the week with a variation of 3.3°C and mean value of 5°C across the weekdays. However, urban warming increased at the rate of 0.1-0.2^{0}C per decade with 3.5% rise in population contributed by poor vegetation of the area. As a result, the city exceeded the recommended heat comfort threshold of 27°C temperature and +0.5°C-2.5°C urban warming value indicating that human comfort was compromised. Commercial and high residential areas had the highest urban heat effect across the different land use types. The result indicated that there was significant temperature variation across the different land use types. It was observed that increase in temperature does not imply a proportional increase

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in urban warming across different land use types. It is, therefore, recommended that policymakers, environmental practitioners as well as friends of the earth should adopt urban planning and management strategies using tree planting and general urban-greening approach in order to intervene urban warming in Port Harcourt Metropolis and Environs without further delay.

Keywords: Port Harcourt; urban warming; land use types; temperature; population.

1. INTRODUCTION

Urbanization in recent time has become a serious disaster in some of the cities across the globe. Over 50% of the world population is located in the cities [1]. Port Harcourt Metropolis and Environs have received intensive growth in its population and general urbanization process. However, urbanization has the capacity to modify the local climate of a city and its environs by producing the phenomenon of urban warming. As a result, urban warming has been unveiled to accompany urbanization due to a population explosion in various cities of the world [2]. Urban warming is known to occur when the temperature of the city is higher than that of the rural outskirts. It is also referred to as the increase of air temperature in the near-surface layer of the atmosphere within cities compared to their surrounding rural fringes [3]. The importance of undertaking urban warming studies is not to have knowledge of its effects when in excess but a a guide to practical implementation of town planning and creation of superb bioclimatic conditions [4].

Many factors have caused the effects of urban warming such as emission of greenhouse gas, increased pavement surfaces, loss of urban tree cover, urban morphology and low albedo of materials; others are thermal properties of materials, city size and generated anthropogenic heat [5]. When the city warming is compromised, there will be noticeably increased energy consumption, high emissions of air pollutants and greenhouse gases, compromised human health and comfort as well as impaired water quality [6]. In most Nigerian cities like Port Harcourt, surface areas have been altered with the changes from low-single storey buildings to multistorey buildings. Also, zinc and asbestos roofing are replaced with aluminium roofing sheets with resulting changes in radiation characteristics of the surfaces across different land use types [7]. The urban geometry and general structure such as the height of these buildings and their pattern affect the rate of escape of solar energy absorbed during the day by urban pavement materials. Therefore, understanding the population dynamics, anthropogenic activities and urban pavement materials in a city like Port Harcourt metropolis and environs will give a better insight in managing urban warming effects across the different land use types, weekdays and seasons of the year in cities across the world.

2. MATERIALS AND METHODS

2.1 Description of Study Location

Port Harcourt Metropolis and Environs is in the South-South zone and Niger Delta area of Nigeria located within Latitudes 4°05'30''N and 5°14'25''N and Longitudes 5°40'30''E and 7°11'01''E of the Greenwich Meridian (GM). The two principal local government areas are Obio/Akpor and Port Harcourt City. The metropolis and environs of Port Harcourt extend to the fringes of Etche, Okirika, Degema Ikwere, Eleme, Emohua and Oyibo LGAs respectively (Figs. 1 and 2). The area is located within the Niger Delta coastal zone made up of the sedimentary formation. As a coastal city, the equatorial monsoon climate influences its atmospheric characteristics due to its nearness to the Atlantic Ocean. Both the maritime and continental air masses control the rainfall and temperature pattern of the city [8]. Also, as a city located within the Inter-Tropical Convergence Zone (ITCZ) in the African continent, it is affected with the warm humid maritime tropical air mass with its south-western winds and the hot and dry continental air mass from the north-easterly winds. The moist south-west wind in the area generates heavy rainfall volumes ranging from 2000 mm to 2500 mm with the peak period from April to September and in some years extends to October [9]. From April, relative humidity increases, peaking in July to September and dropping steadily and continuously till March with the lowest trough in January [10]. In a year cycle, temperature peaks in January to March and relative humidity drops continuously within the months. The urban warming that affects human comfort is a function of air temperature during the dry season, relative humidity during the wet season and wind flow systems in the dry

Fig. 1. Port Harcourt metropolis and environs

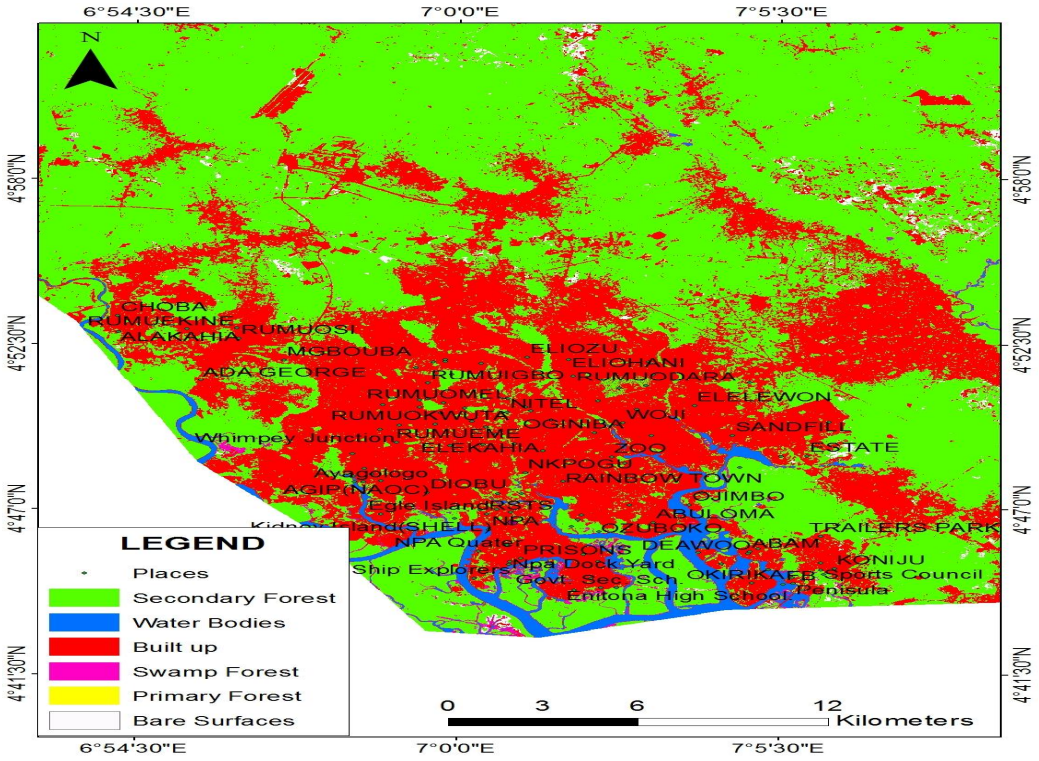


Fig. 2. Land cover of Port Harcourt metropolis and environs

season [11]. Average peak temperature is 32°C and the lowest 26°C are usually observed in January and July respectively [12]. The humidity is high with the mean annual figure at 85% with high and low peaks during the wet and dry seasons respectively [13]. Cloud cover pattern in the area is continuously improved with a monthly average of over 6 oktas [12] due to the massive water vapour that rises to the atmosphere as a result of adjacent water bodies. Cloud cover is highest during the wet season and lowest during the dry months respectively. The average daily sunshine was less than 3 hours as observed in July and about 4-5 hours in January and December respectively [14]. For the wind speed pattern, mean monthly range is between 0-3 m/s [15,16] with high and low trends observed during the nocturnal hours. Urban warming is influenced by these climatic parameters operating in Port Harcourt Metropolis and Environs, Rivers State, Nigeria.

2.2 Conceptual Issues and Methods of Data Collection

This study evolved by considering the urban warming framework which illustrates the temperature differences from the city center to the surrounding rural outskirts (Fig. 3). This concept has been adopted by many urban researchers in cities across the world [17,18,19]. The framework recognizes that in the process of urbanization, the city natural vegetation and other biophysical conditions are altered with urban manmade materials and other anthropogenic heat generators across the different land use types thereby increasing the city temperature above the rural fringes [20].

Data used for this study were collected from direct field observation and from the archives of Nigerian Meteorological Agency (NIMET), Port Harcourt International Airport covering a period of 12 months (January – December 2017). Direct field measurement of temperature was carried out during the 0600, 1200 and 1800 GMT hours. Port Harcourt Metropolis and Environs were stratified into 10 zones based on land use types, with the Tent zones serving as control (Table 1). The temperature data were collected simultaneously from the various land use types in Port Harcourt Metropolis and Environs as adopted by [21,22]. Temperature from ground observation and recording was carried out at the various land use types in pre-determined land use locations (35 points) across the weekdays (Sunday, Monday, Tuesday, Wednesday, Thursday, Friday and Saturday) in both wet and dry seasons [23,24]. The Multi-thermometers were HI/LO/AL UP model manufactured by MEXTECH. The thermometers had temperature resolution of 0.1°C with measuring range of -50°C to 300°C and -50°C to 200°C respectively. The temperature accuracy was ±1°C at the range of -50°C to 150°C. And the equipment was properly protected to avoid error reading.

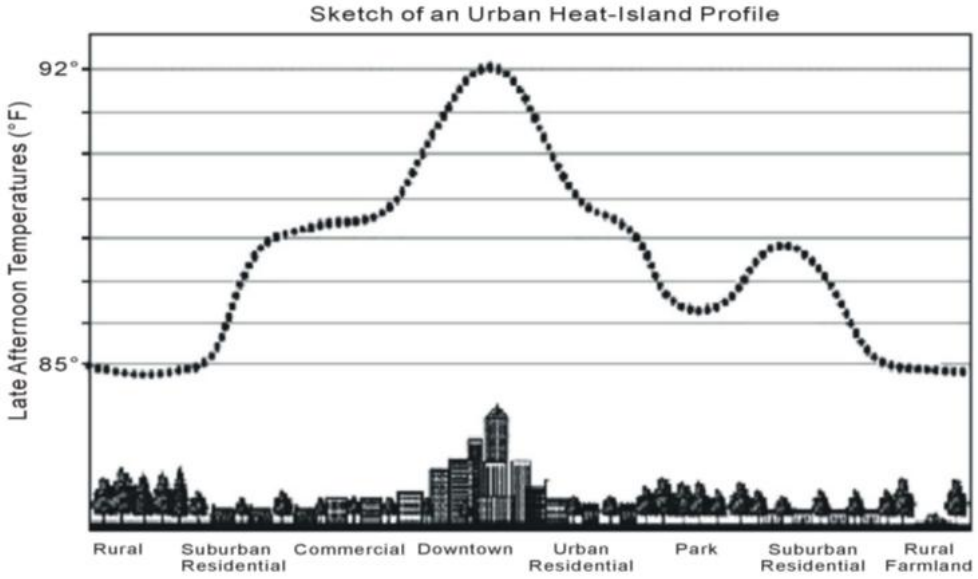


Fig. 3. Urban warming profile

This was carried out with the help of field assistants at various data sample points in Port Harcourt Metropolis and Environs. Temperature data from rural sites were collected from plots of land covered with low plants and grasses with the thermometer mounted on a wooden pole. Rural areas used were Elibrada, Obeta, Dankiri, Aleto and Omuagwa which acted as control points. Temperature data from urban area were collected from areas with low and high buildings, some with few or no trees collected 3 meters above head height in the canopy layer. The urban land cover was made up of stone, brick urban, pavement materials, concrete and other materials for construction.

Urban warming distribution across the weekdays (Sunday to Monday) was derived from hourly and daily temperature readings and converted to mean values in wet seasons of April, May and June (early wet season); July, August and September (late wet season) and dry season of October, November and December (early dry season) as well as January, February and March (late dry season). The wet season in Port Harcourt metropolis and environs begins from April - September and dry season from October – March [25,26]. Descriptive statistics of mean, range, tables, charts and plates were used to analyze the data generated. Also, satellite remote sensing imageries of Enhance Thematic Mapper (ETM+) of 2017 were adopted to detect changes and delineate land use types of Port Harcourt Metropolis and Environs. The Normalized Difference Vegetation Index (NDVI) was used to differentiate the greenness of the city area and the Normalized Difference Built-up Index was used to separate the built-up of the area in terms of infrastructure and urban pavement material variation (Fig. 4). The analysis of variance (ANOVA) was used to ascertain the variation in temperature across the different land use types in Port Harcourt Metropolis and Environs.

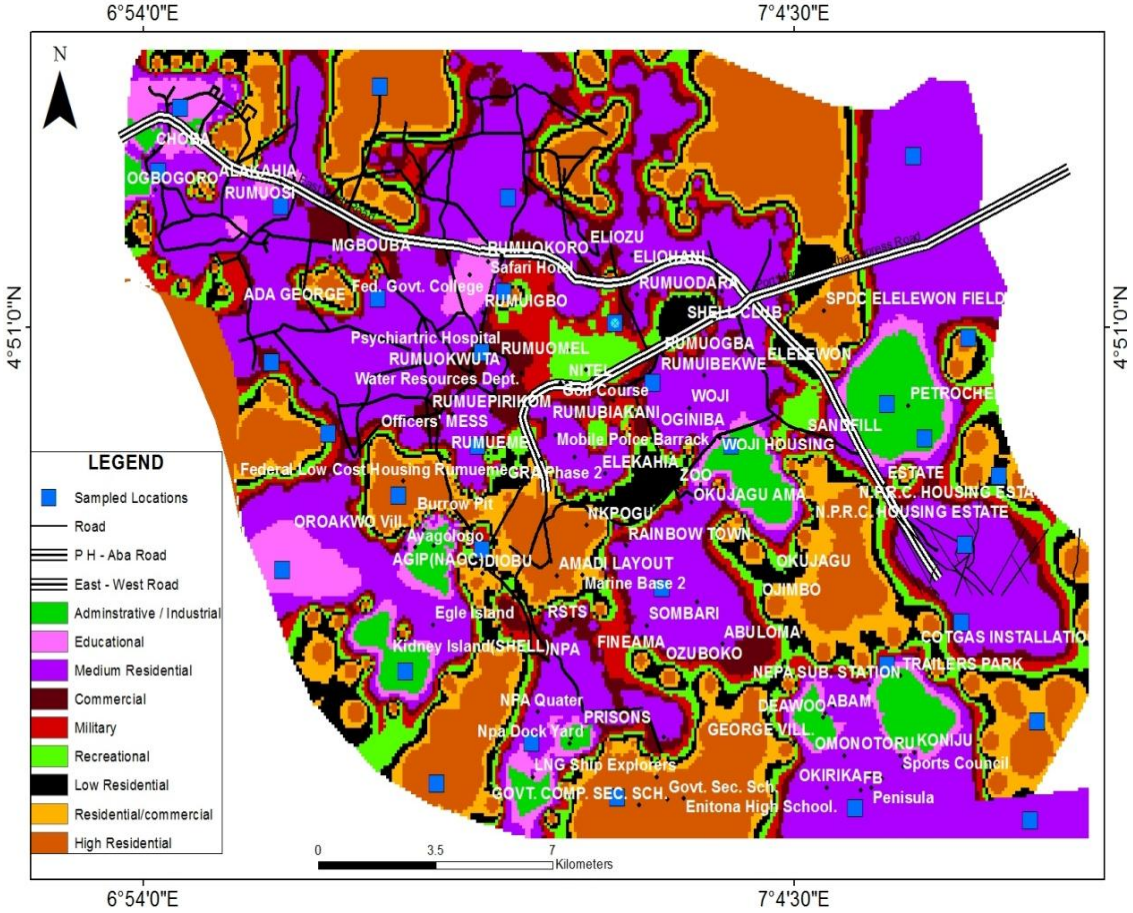


Fig. 4. Land use types and observation sites

Table 1. Zone, land use type and location

Zone	Land use type	Location
1	Low Residential	GRA, Shell estate, Total estate, Intel zone, Oyibo, Eleme, Igwuruta, Gbolokiri, Etche, Choba, Iwofe, Jetty, Elelenwo, Okirika, Eagle Island, Rumosi, Elekahia, Mgbuoba.
2	High Residential	Diobu, Enitona School Area, D-Line
3	Medium Residential	Ada-George, Abloma, Rumuigbo, Port Harcourt Township, Rumuola, Choba, Mgbuoba, Woji, Okirika, Rumuodara
4	Educational	University of Port Harcourt, University of Science and Technology, Port Harcourt Poly Technique, Ignatious Ajuru University
5	Commercial	Mile One market, Mile 3 Market, Rumuokoro Market, Slaughter, Oil Mill Market, Ikoku market
6	Military	Bori Camp, Airforce, Navy barracks
7	Recreational	Port Harcourt Tourist, Rainbow Zoo, Boro Park, Port Harcourt Pleasure Park, Woji Housing
8	Residential/Commercial	Rumuaghorlu, Rumuokwuta, Rumukrushi, Rumuodomaya, Rumuibekwe, Rukpoku, Orazi, Ogbunabali,
9	Admin/Industrial	Rivers State Secretariat, BMH, UPTH, Transamadi, Agip, Marine Base, NPA, Eleme Petrochemical area.
10	Rural	Elibrada, Aleto, Dankiri, Obeta, Omuagwa as control sites

3. RESULTS AND DISCUSSION

Temperature distribution and urban warming on various land use types and across weekdays during the year under examination were summarized in Table 2 and Figs 5-7. There was noticeable temperature rise at the city center compared with the rural fringes and recreation sites. Areas with mixed commercial and high residential buildings had relatively the highest temperature of 33.1°C, 30.5°C and 30.3°C (mean temperature of 31.3°C) in the city such as Mile One market, Mile 3 Market, Rumuokoro Market, Slaughter, Oil Mill Market, Ikoku market as well as Ogbunabali Rumuokwuta, Orazi, Rumuibekwe, Rumuaghorlu, Rukpoku, Rumuodomaya, Rumukrushi, etc. Rural and recreational sites had relatively lower temperature intensity of 29.4°C and 28.3°C respectively. These rural and recreation sites included Elibrada, Aleto, Dankiri, Obeta, Omuagwa as well as Port Harcourt Tourism Site, Rainbow Zoo, Boro Park, Port Harcourt Pleasure Park, Woji Housing respectively. Thus, temperature across different land use types varied at the range of 4.8°C with mean

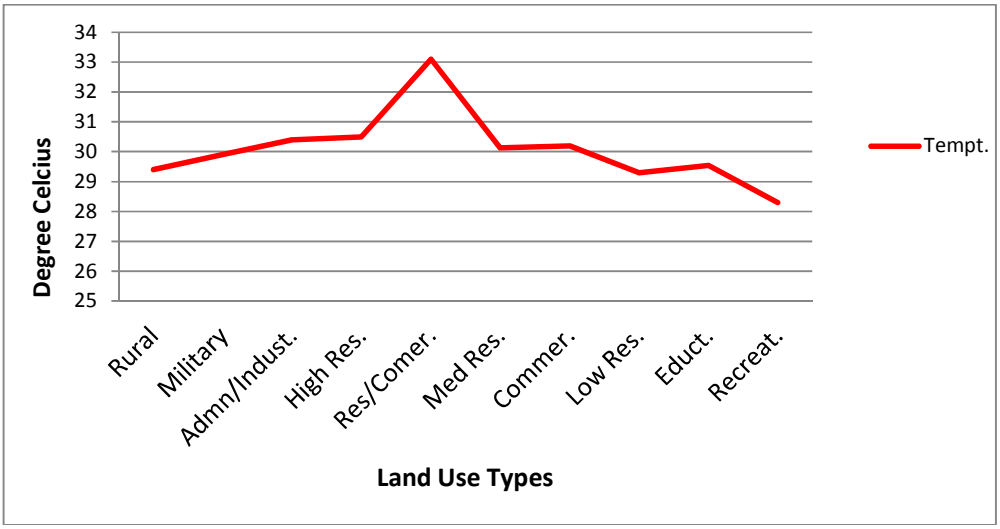
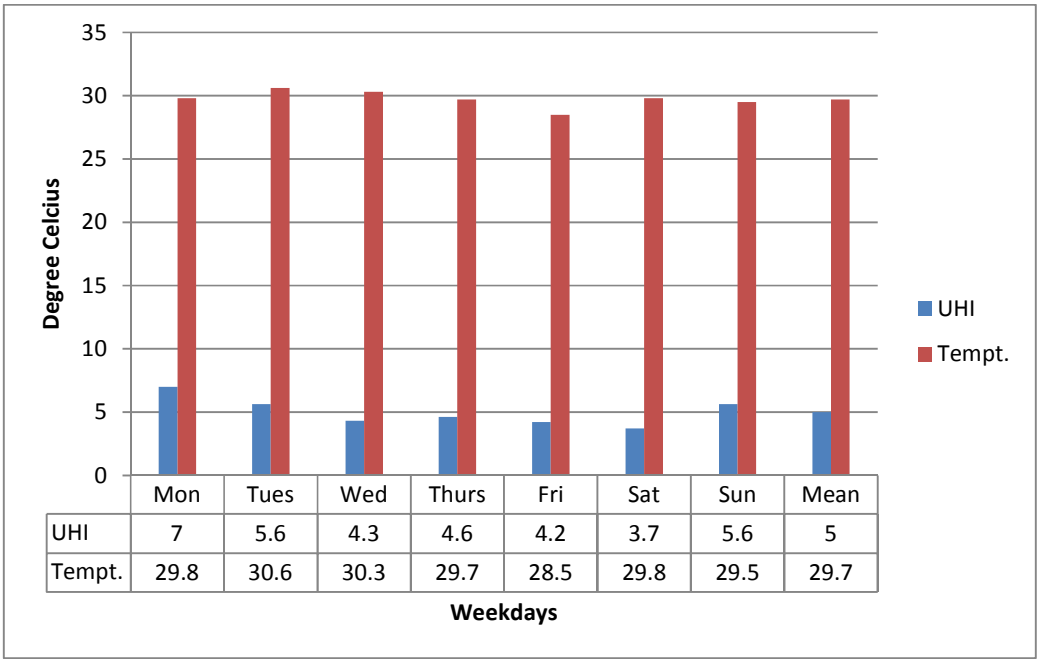


Fig. 5. Annual temperature spread across different land use types

Table 2. Annual temperature and urban warming across weekdays and land use types

	Mean temperature and URBAN WARMING in degree celcius										URBAN WARMING
Day	**Rural**	**Military**	**Admn/Indust**	**High Res.**	**Res/Comer.**	**Med Res.**	**Commer.**	**Low Res.**	**Educt.**	**Recreat.**	**= (ΔTu-r)**
Mon	29.1	29.3	30.6	29.4	34	30.6	30.1	30	28	27	7
Tues	29	31.5	31.6	31.3	33.5	31	31	29	30.4	27.9	5.6
Wed	29.1	28.7	31.8	31	33	30.2	30.4	29.2	30.7	29.2	4.3
Thurs	30	30.2	28.3	30	32.4	29.5	28.9	29	29	27.8	4.6
Fri	29.4	31.9	31.9	30.8	33.6	31.4	31.6	30	30.4	29.9	4.2
Sat	29.5	28.5	29.7	30.2	32.1	28.4	31.2	29.2	30.8	28.8	3.7
Sun	29.4	29.1	28.8	30.5	33.2	31	29.1	28.6	27.9	27.6	5.6
Mean	29.4	29.9	30.4	30.5	33.1	30.3	30.2	29.3	29.6	28.3	5



	Mon	Tues	Wed	Thurs	Fri	Sat	Sun	Mean
UHI	7	5.6	4.3	4.6	4.2	3.7	5.6	5
Tempt.	29.8	30.6	30.3	29.7	28.5	29.8	29.5	29.7

Fig. 6. Annual urban warming and temperature interaction across the weekdays

temperature value of 30.1°C. This finding is in tandem with the temperature threshold of [23] in smaller City of Benin in 2014 located in the same Niger Delta area of Nigeria which had annual mean temperature of 27°C across various land use types. Urban warming across the weekdays in the year under investigation indicated that the day with the least urban warming was Saturday (3.7°C) and Monday recorded the highest intensity of urban warming of 7.0°C. Sunday had urban warming of 5.6°C, Thursday was 4.6°C, Tuesday 5.6°C, Wednesday value was 4.3°C and Friday had urban warming value of 4.2°C. It was observed that urban warming varied with 3.3°C across the weekdays with mean warming value of 5°C. Thus, the city urban warming was higher in the early weekdays when compared with the low urban warming in the middle part of the weekdays. The interaction between temperature and urban warming (Fig. 6) indicated that increase in temperature is not directly proportional to increase in urban warming due to the variation in human activities and climatic parameters across the weekdays and land use types in Port Harcourt Metropolis and Environs.

Urban warming in Port Harcourt Metropolis and Environs has been induced by the rapid population growth. Therefore, population as a product of urbanization has induced concentration of people and manmade materials in a specific geographical space and also known as causative factor influencing urban warming in the cities. Thus, urban warming is one of the most noticeable climatological effects as a result of man's alteration of the biophysical environment. Population has been used to model the estimation of urban warming intensity in the cities as more than 50% of the world's population live in urban area and 70% was projected to live in the cities by 2050 [27].

Accordingly [28] generated a formula capturing rural and urban warming that is tied to population of the area. The researcher concluded that using generalization in population for warming bias of urban area can be used as prediction model. And such generalizations are possible and useful in climatic modeling, urban planning and weather forecasting. Therefore, the urban warming in Degree Celsius (°C) will increase with population according to the formula:

$$\text{URBAN WARMING} = 0.73 \log_{10} \text{Pop}$$

Where: Pop means population.

[29] tested the prediction model with a population of 10 persons and recorded warm bias of 1.46°C. [30] applied the population prediction model with a population of 10,000 persons and recorded

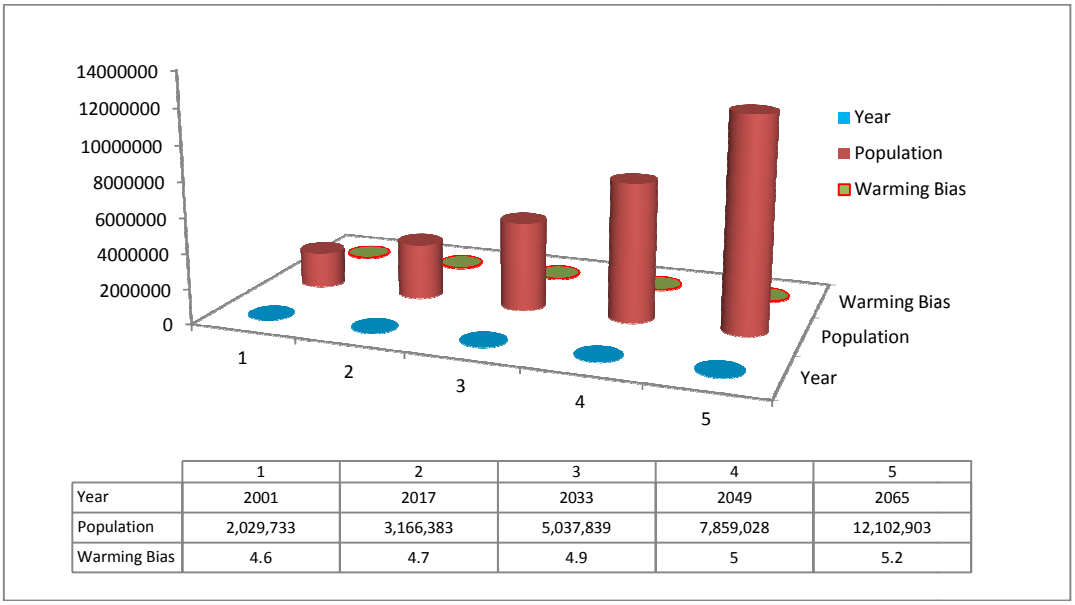
warming bias of 2.4°C. Using the population formula to understand the urban warming condition of Port Harcourt Metropolis and Environs with a population projection of 3.5% growth rate [31] in 2001 the city had 2,029,733 persons and warming bias of 4.6°C was established (Fig. 7).

Urban Warming = 0.73log 2,029,733 = 4.6°C

When the population was projected to 2017, the value was 3,229,384 persons with warming bias of 4.7°C. When the population was projected to 2033, 2049 and 2065 the warming biases were 4.9°C, 5.0°C and 5.2°C respectively. As a result, Port Harcourt Metropolis and Environs recorded 0.1°C to 0.2°C urban warming variation in sixteen years interval across its land use areas as projected in 48 years population growth. This is in tandem with [32] in a growth prediction report which concluded surface warming values ranging 0.09 to 0.27°C in an interval of one decade in a city. The Port Harcourt City and Obio/Akpor Local Government Areas (LGA) at the center of Port Harcourt Metropolis and Environs recorded projected population of 1,331,207 persons in 2017 with urban bias of 4.5°C respectively.

According to [33] that studied urban warming in Paris, it was evident that city people will be comfortable with urban warming threshold of +0.5°C-2.5°C. [34] suggested temperature comfort threshold of 27°C. [35] observed comfort threshold in the city of Kuala Lumpur, Malaysia with urban warming value of 1.5°C which falls within the acceptable range for human health and comfort. With the trend of population, temperature and urban warming in Port Harcourt Metropolis and Environs it is understandable that human comfort in the city has been compromised.

In order to establish if there is difference in urban temperature across different built-up areas in Port Harcourt Metropolis and Environs, the analysis of variance (ANOVA) was employed (Table 3). According to [36] when the calculated F-value is greater than the critical F-value, it means there is a significant variation.



	1	2	3	4	5
Year	2001	2017	2033	2049	2065
Population	2,029,733	3,166,383	5,037,839	7,859,028	12,102,903
Warming Bias	4.6	4.7	4.9	5	5.2

Fig. 7. Population and warming bias in Port Harcourt city area

Table 3. ANOVA test explaining the difference in temperature across different land use types

ANOVA						
Source of variation	**SS**	**df**	**MS**	**F-value**	**P-value**	**f-crit**
Rows	24.1898	5	4.83796	7.06052	8.19287E-05	2.44947
Columns	71.3248	8	8.9156	13.0114	5.2119E-09	2.18017
Error	27.4085	40	0.68521			
Total	122.923	53				

Temperature across the built-up areas has calculated F value of 13.0114 and the critical f-value of 2.18017 with 8 degrees of freedom for a two-tailed test at 0.05 significant levels. This showed that the calculated value (13.0114) is greater than the critical t value of 2.18017. This indicates that temperature across the built-up areas (military, administrative/industrial, high residential, medium residential, low residential, commercial, educational, recreational and rural) differ significantly. This supports the earlier view that temperature varied across different land use types such as residential/commercial had the warmest temperature of 33.1, high residential 30.5°C, educational 29.6°C and rural 29.4°C. This finding is in tandem with Olivia [37] in the city of Shippensburg, confirmed that urban temperatures are consistently higher at the city center and gradually drops toward the rural fringes. Also, [38] identified temperature difference of approximately 5°C between the city center and the rural sites in Brno, Czech Republic.

4. CONCLUSION

The warming of Port Harcourt Metropolis and Environs has been investigated and results revealed the condition and distribution of air temperature and urban warming on weekdays per annum as well as the influence of population on warming bias. Temperature was higher at the city center made up of relatively more commercial and residential buildings such as Mile One market, Mile 3 Market, Rumuokoro Market, Slaughter, Oil Mill Market, Ikoku market as well as Ogbunabali Rumuokwuta, Orazi, Rumuibekwe, Rumuaghorlu, Rukpoku, Rumuodomaya, Rumukrushi due to the presence of high manmade materials and economic activities taking place on these land use types. There was the relatively low temperature in recreation and rural sites such as Elibrada, Aleto, Dankiri, Obeta, Omuagwa as well as Port Harcourt Tourist, Rainbow Zoo, Boro Park, Port Harcourt Pleasure Park, Woji Housing due to the low concentration of urban pavement materials and less anthropogenic activities as well as high vegetal cover. As a result increase in temperature did not bring about a proportional increase in urban warming due to the influence of other human and climatic variables that propagate urban warming effects. Also, there was significant temperature variation across the different land use types in Port Harcourt Metropolis and Environs. Per annum, in Port Harcourt Metropolis and Environs the beginning first three days of the week (Sunday, Monday and Tuesday) were warmer which Monday was more uncomfortable due to intensive urban warming performance as a result of relatively high traffic flow and other human economic activities compared to other days of the week. High population index of people in Port Harcourt Metropolis and Environs had intensified urbanization resulting to serious alteration of the biophysical environment. However, urban warming increased at the rate of 0.1-0.2°C with 3.5% rise in population which seemed to be contributed by poor vegetation of the area. Thus, it is concluded that Port Harcourt Metropolis and Environs had exceeded the recommended urban warming and temperature comfort thresholds of +0.5-2,5°C and 27°C respectively. The excessive urban warming and temperature had the capacity to increase energy consumption, heat stress, change in pollution behaviour, greenhouse gas effect and general health failure of city dwellers. In view of these, it is recommended that policy makers, environmental practitioners as well as friends of the earth should adopt urban planning and management strategies using tree planting and general urban-greening approach in order to intervene the urban warming in Port Harcourt Metropolis and Environs without further delay.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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