Geospatial Analysis of Air Temperature Between Kaduna City and Its Rural Neighbours, Kaduna State, Nigeria

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Abstract

This study aimed at a geospatial analysis of Air Temperature between Kaduna City and its rural neighbours, Kaduna State, Nigeria. The study ascertained the prevalence of Urban Heat Island (UHI) within Kaduna City by comparing the temperature in the city to that in the neighbouring rural areas. Weather information from the Nigerian Meteorological Agency (NiMet), Geographic Information System (GIS) using Landsat imageries comprising Landsat 5 Thematic Mapper (Landsat TM), Landsat 7 Enhanced Thematic Mapper (7 ETM+) and Landsat 8 Operational Land Imager, descriptive and inferential statistics constituted the major analytical frameworks used in this study for evaluation. The spatial pattern of Land Surface Temperature (LST) exhibited a typical Urban Heat Island (UHI) pattern with increasing LST. LST is reported to decrease with increasing distance to the urban periphery and the hinterland. The Urban Heat Island (UHI) intensity was as low as 1.81^{O}C in 1990 and as high as 3.95^{O}C in 2001 with 2010 having a UHI intensity of 1.99^{O}C while 2020 recorded 3.77^{O}C. At a 95% confidence limit, the study found that there is a significant difference between the mean urban LST and the mean LST for the rural areas in Kaduna Metropolis. It is concluded that LST is rising in the city and elevated LST values have generally formed a cluster within the urban space. Also, there are higher LST/UHI pockets in the urban arena beyond the general high difference in LST between urban and rural spaces. With this discovery of UHI prevalence in Kaduna City on a decadal scale – 1990, 2001, 2010 and 2020, it is advised that a 2030 study be carried out to ascertain further trends and prevalence while deliberate mitigation efforts are being put in place to drive towards large scale urban greening, heating/greenhouse emission regulations and the enactment/enforcement of environmentally friendly policies.

Keywords**:** Land-use, land-cover, Urban Heat Island, land surface temperature, neighbours

Introduction

The world's urban space is rising progressively from 30% in1950 to 56% in 2020 (Meier Selhausen, et al., 2022). The World Bank (2023) also reported that 56% of the world population (4.4 billion) is urban. Nigeria is also experiencing urban growth with a significant population living in urban areas (Okpalike et al., 2022). One hundred and sixteen million, nine hundred and nineteen thousand, five hundred and forty-eight people (53.5 %) of the two hundred and eight million, five hundred and forty-one thousand, two hundred and twelve Nigeria population dwell in urban areas (Knoema, 2023).

There is a continuous alteration of the environment due to urbanization as hard, high heat-absorbing materials are used to replace the naturally existing vegetal cover to build the urban area and enhance livability, aesthetics and comfort. Technological advancements have led to the introduction of more structures which replace vegetation cover in the urban environment, thereby increasing impermeable surfaces and eventually increasing the heat storage capacity of the urban area (Xian & Crane, 2006; Kelbaugh, 2019). Land cover/land use amounting to a notable loss of canopy/vegetation cover resulting from urbanization is the major propeller of the Urban Heat Island (UHI) phenomenon (Zipperer et al., 2020).

Urban Heat Island can be said to have occurred when urban city temperature is higher in comparison to the surrounding rural or suburban areas which are predominated by vegetal/green areas (Livingstone, 2006; Voogt, 2004). Urban dwellers seem to be benefiting from exploiting the land for developmental purposes leading to structural polarization and eventual land use-environmental-conflicts (De Jong et al, 2021). The relationship between the exploitation of the natural environment for urban development is strongly linked to the prevalence of Urban Heat Island (Tanko et al., 2017). It was reported that land-use changes in Kaduna, among others, have led to the increasing intensity of UHI informed by the increase in population size leading to further growth and development of the urban area. This can result in security challenges and competition for the available employment opportunities. Those who get employed may also move to reside in urban areas for proximity to places of work and may also procure lands for construction of private/commercial houses. In some cases, lands can be reclaimed by the government for urban housing development, construction of roads, airports and industries (Daudu et al. , 2020).

This research employed Remote Sensing (RS) and Geographic Information System (GIS) to assess temperature changes that have occurred and are occurring in Kaduna urban environment and analysed the effect(s) of the observed growth on the development of UHI from 1990 to 2020 by comparing the city temperature with the surrounding rural temperature over a period of 30 years. The significant difference between the mean urban LST and the mean LST for the rural areas will also be tested.

Materials and Methods

Study Area

Kaduna State is situated between latitude 09º02' to 11º 32' and between longitude 06º15'to 08º38' with a total area of 70, 233sq.km.It is bounded by Abuja (FCT) and Niger State in the South-West, Katsina State, and Zamfara State in the North-West, Kano State and Bauchi State in the North-East, Plateau State and Nasarawa State in the South-East (Amusan et al., 2017). Kaduna metropolis forms the capital city of Kaduna State which is located in the northern Guinea savannah zone of Nigeria, lying between Latitudes 10° 24' 39"N and 10° 36' 40"N and Longitudes 7° 21' 26"E to 7° 30' 3"E at an altitude of 645m above sea level (Bununu et al., 2015; Daful et al., 2020).

Kaduna State has two seasons: wet/rainy season from May to October with heavy rainfall and high humidity and dry season from November to April with clear skies, low humidity, and comfortable temperatures (Abubakar et al., 2019). Rainfall in Kaduna State does not follow a pattern in amount and duration of heavier rainfall in the southern and eastern parts that decreases northwards towards Katsina and Westwards in the direction of Kontangora (Abajeand & Oladipo, 2019). Yearly rainfall peak is in August or September (Abaje et al., 2010). The rainy season is longer in the south and east where it begins in April and ends in October, with lower rainfall in the northern part of the state which lasts from mid-May to October (Omonijo, 2014). Kaduna State experiences a mean yearly rainfall of 1,272.5 mm with a yearly humidity of 56.64 percent. Two months, April and December account for the highest average temperature and lowest temperature of 28.9ºC and 22.9ºC respectively (Abaje et al., 2018).

Kaduna is underlain by basement complex and composed of metamorphosed gneiss with a base that is characterized by older granitic crystalline, metamorphic rocks of Precambrian to low Paleozoic epoch and gneisses with dotted plains of prolonged weathering; the soil is predominantly ferruginous (Oguntoyinbo, 1978; Mortimore, 1989).Rainfall influences the vegetation and soil following the same pattern of northern Guinea savannah and southern Guinea savannah (Al-Amin & Aliyu, 2014). Kaduna river impacts greatly on the microclimate of the Kaduna city through which its major tributaries are drained (Mande & Abashiya, 2020).

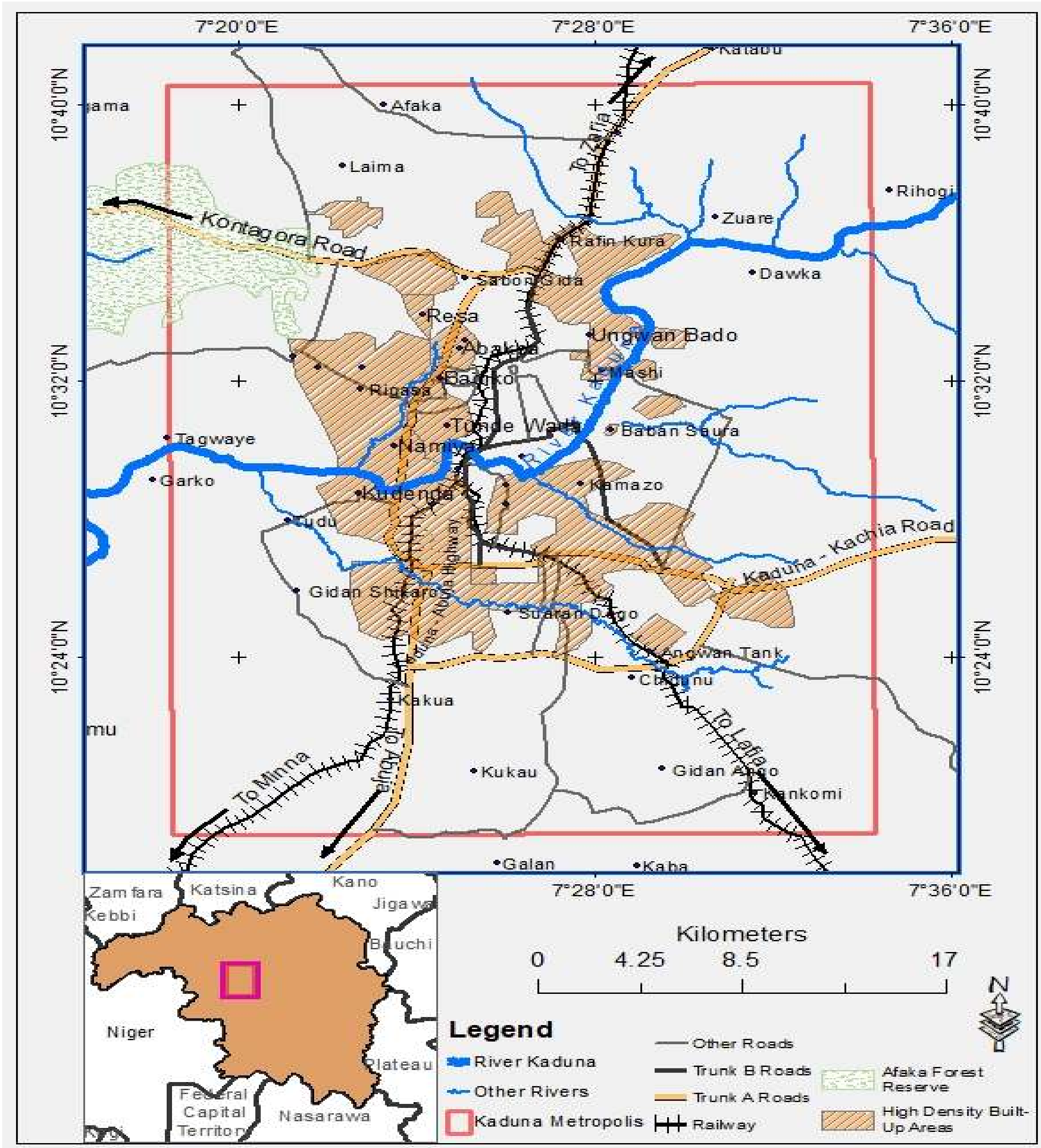

Figure 1: Kaduna Metropolis

Source: Compiled from ESRI Database (2012)

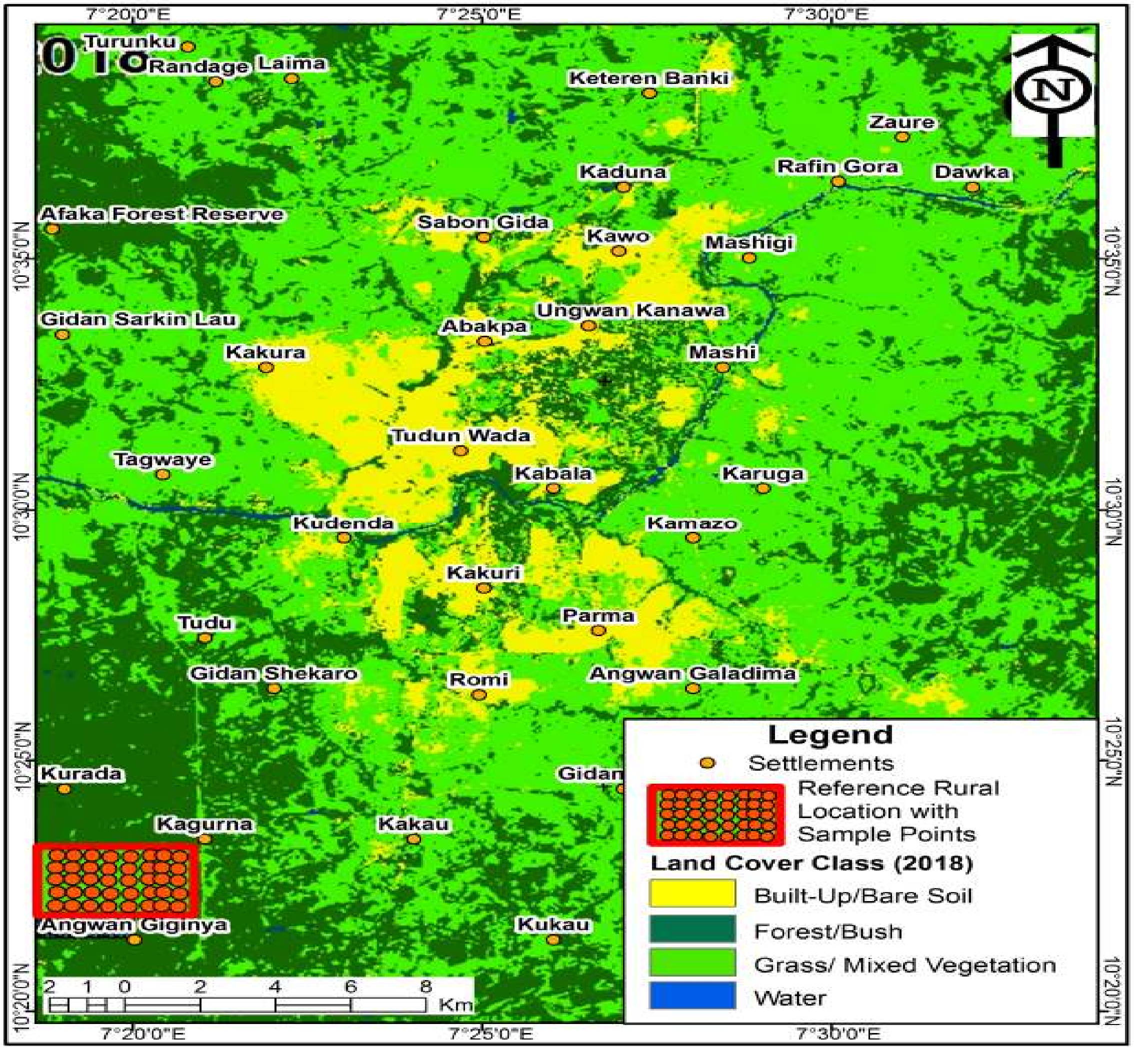

Figure 2: Land Cover of Kaduna Metropolis 2020 Showing Reference Rural Location for the Determination of the Urban Heat Island Intensity (Source: Data Analysis, 2020)

Research Design

Data Collection and Analytic Techniques

This research relied on the use of secondary data which was categorized into remotely sensed and non-remotely sensed. The remotely sensed dataset was Landsat imageries comprising Landsat 5 Thematic Mapper (Landsat TM), Landsat 7 Enhanced Thematic Mapper (7 ETM+) and Landsat 8 Operational Land Imager Thermal Infrared Sensor (OLI_TIRS) data for 1990, 2001, 2010 and 2020 sourced from the United States Geological Surveys (USGS) website (https://earthexplorer.usgs.gov/). The details of the Landsat data used in this study are presented in Table 1.

Table 1: Summed up characteristics of the utilized satellite images

Date	Type of image	Land-sat No	Month of acquisition	Spatial resolution	No of bands (°)	Sun elevation	Sun azimuth
1990	TM	5	December	28.5	7	45.18	127.40
2001	TM	5	December	28.5	7	53.41	138.82
2010	ETM	7	November	28.5	8	48.92	134.09
2020	OLI_TIRS	8	December	30	10	57.84	140.72

Source: Retrieved from Landsat Metadata Files (1990, 2001, 2010, 2020)

Air temperature from NiMet is used to analyse the temporal character of temperature in Kaduna metropolis. On the other hand, remotely sensed Landsat-derived land surface (skin) temperature was used for the analysis of the spatial pattern of thermal conditions in Kaduna urban areas. ArcGIS desktop versions (ArcGIS 10.7, ArcGIS Pro 2.5), XLSTAT and Minitab statistical software plus the Microsoft office 2016 (word and Excel) were used in the data extraction, analysis, and presentation in the present study. The area of interest (AOI) was carved out and layer stacking was done owing to the fact that each epoch (1990, 2001, 2010 and 2020) of the Landsat imageries used came in different bands, using Layer Stacking algorithm in Erdas Imagine 9.2 Software (Lupia, 2012).

Analysis of Variance

In order to analyse variability of temperature between rural and urban areas of Kaduna, one-way analysis of variance (ANOVA) was deployed. One-way ANOVA offers: group-level statistics for the dependent variable, a test of variance equality, and a plot of group means, range tests, pair wise multiple comparisons, and contrasts, to describe the nature of the group differences. An important first step in the analysis of variance is establishing the validity of assumptions. One assumption of ANOVA is that the variances of the groups are equivalent. The null hypothesis based on Hays (1981) is symbolically represented as:

$$H_O : \mu_1 = \mu_2 = \mu_3 \ . \ . \ . = \mu_k \qquad - \quad - \quad - \quad - \quad - \quad - \quad - \qquad (1)$$

Where: μ = group mean and; k = number of groups.

The mean squares are calculated by dividing each sum of squares by its degrees of freedom. The F ratios are the mean squares for each source divided by the within groups mean square. The significance level for the F is from the F distribution with the degrees of freedom for the numerator and denominator mean squares. If there is only one group, the ANOVA is not done; if there are fewer than three groups or the independent variable is a string variable, the test for linearity is not done (Hays, 1981).In testing the hypothesis, significance level of 0.05 percent was adopted. However, if ANOVA returns a statistically significant result, the alternative hypothesis (H_1), was discarded. This then implies that there are at least two group means that are statistically significantly different from each other.

GIS-based Zonal Statistics

The urban heat island phenomenon was quantified by the Urban Heat Island Intensity (UHII) which is a measure of the difference between the mean urban air temperature and the mean temperature of a nearby rural location (Oke, 1973). Based on Javier et al. (2015), UHII is usually stated in the form:

$$\Delta T_{u-r} = T_u - T_r, \qquad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - \quad - 2$$

Where: T_{u-r} is UHI intensity

T_u is urban temperature

T_r is rural temperature.

Until recently, studies on the UHI intensity have compared differences in urban versus rural air temperatures to establish the magnitude of the temperature difference between the urban and rural landscapes and settings using air temperature readings at urban and non-urban point locations. A time series air temperature data exists for urban point location in the Kaduna metropolis, as obtained from NiMet, but there is no such corresponding data for a nearby rural location to enable a comparison of the air temperature for a quantification of the UHI intensity. However, LST data is generally available at multi-temporal and near-global scale and is now frequently used in UHI studies. Research findings have shown that LST is closely related to the near-surface air temperature especially under specific weather conditions and hence is often used to estimate near-surface air temperature (Cresswell et al., 1999; Stisen et al., 2007).

In this regard, several studies have quantified the UHI intensity using LST data (Siu, 2011; Siu et al., 2013; Van Hove et al., 2011). Current study adopted the widely used GIS-based zonal statistical tools in extracting LST from the time-series Landsat imagery. The GIS-based zonal statistical tools allow us to perform analysis where the output is a result of computations performed on all cells that belong to each input zone. A zone can be defined as being one single area of a particular value, but it can also be composed of multiple disconnected elements, or regions, all having the same value. Zones can be defined by raster or feature datasets. Rasters must be of integer type, and features must have an integer or string attribute field. This analytical framework was deployed in assessing the differences in climatic elements between the inner city and rural neighbours with the view to determining urban heat island (UHI) intensity (1990-2020) in Kaduna Metropolis.

Choice of the reference rural location with which to compare the temperatures of the urban centre is very critical in a UHI intensity study. While it is fairly simple to estimate the temperature of an urban area with a view to establishing the UHI intensity between the urban and the rural/non-urban area, the choice of the rural area must meet certain conditions and assumptions for the result of the analysis to be reliable. These conditions are specifically related to the following: the distance of the reference rural location from the urban centre being compared, wind direction from the urban area in relation to the reference rural location, percentage of urban land cover in the reference rural area location, geographical size of the rural location versus the urban, etc. (Javier et al., 2015; Stewart & Oke 2009).

Following the scheme outlined in Javier et al. (2015), a suitable 1km^2 non-urban area, approximately 10.5 kilometers away from the Kaduna urban boundary was chosen. Care was exercised to ensure that the location had no significant urban form (less than 10% of urban landscape) to avoid a mixture of urban pixels which may distort UHI intensity results. A randomly chosen 1000 points were sampled for LST within the polygon identified as non-urban. The sampling protocol was maintained for all the epochs and the mean LST was calculated for each of the time period (1990, 2001, 2010 and 2020). Using zonal statistics tool where the classified LULC classes are the zones, the mean LST for the urban areas were calculated for all the epochs. The reference rural location polygon marked on the classified Landsat imagery of 2020 used in the study is presented in Figure 2.

Results and Discussion

Temporal Trends of Mean Temperature and Annual Precipitation in Kaduna(1950-1990)and (1990 -2020)

The pattern and trend of mean temperature in Kaduna Metropolis (1950-1990) is presented in Figure 3 while that of 1990-2020is shown in Figure 4. The linear trend lines in the two CPs exhibited a rising trend with an increment of +0.02^{O}C per annum (Figure 3) and +0.01^{O}C in the 1990-2020CP (Figure 4). Three mean temperature peaks were spotted with the first in 1972 (27.2^{O}C), while the second and third peaks amounting to 27.2^{O}C (each) were spotted in 1990 and 1992 (Figure 3) and two peaks 27.2^{O}C (each) were spotted in 1990 and 1992 (Figure 4). The lowest (24.31^{O}C) and (24.47^{O}C) were recorded in 1959 and 2015 respectively. This shows fluctuation, yet increasing temperature trend in both periods.

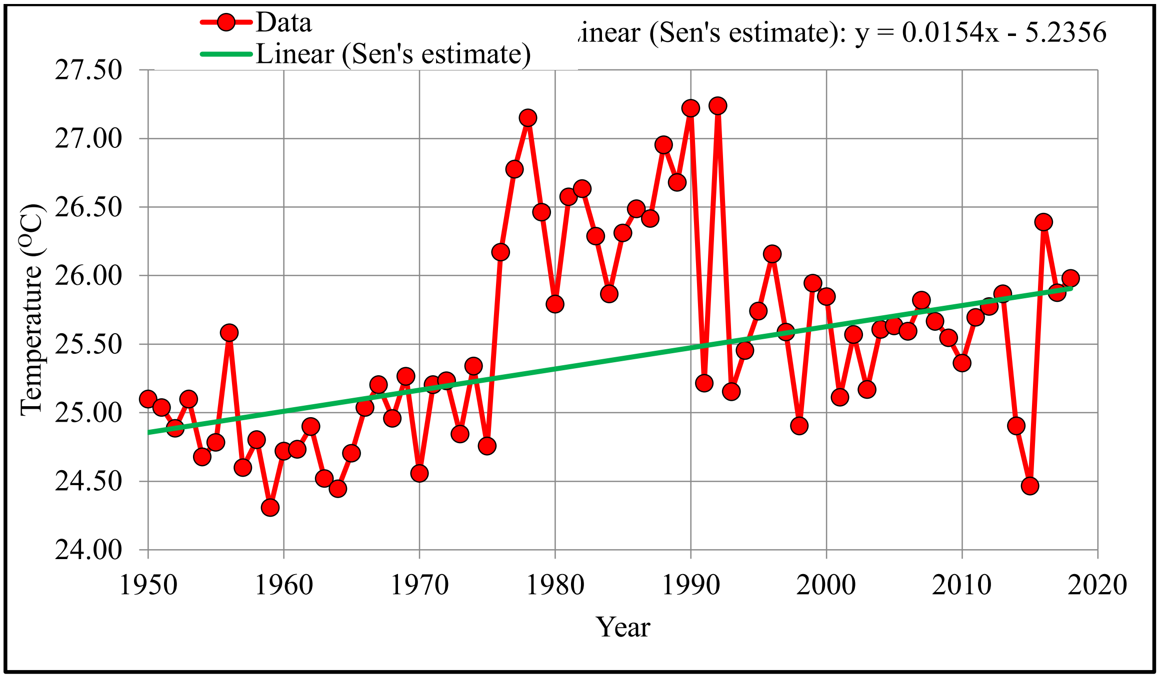

Figure 3: Mean Annual Temperature (1950 – 2020)

Source: Analyzed from NiMet Data (2020)

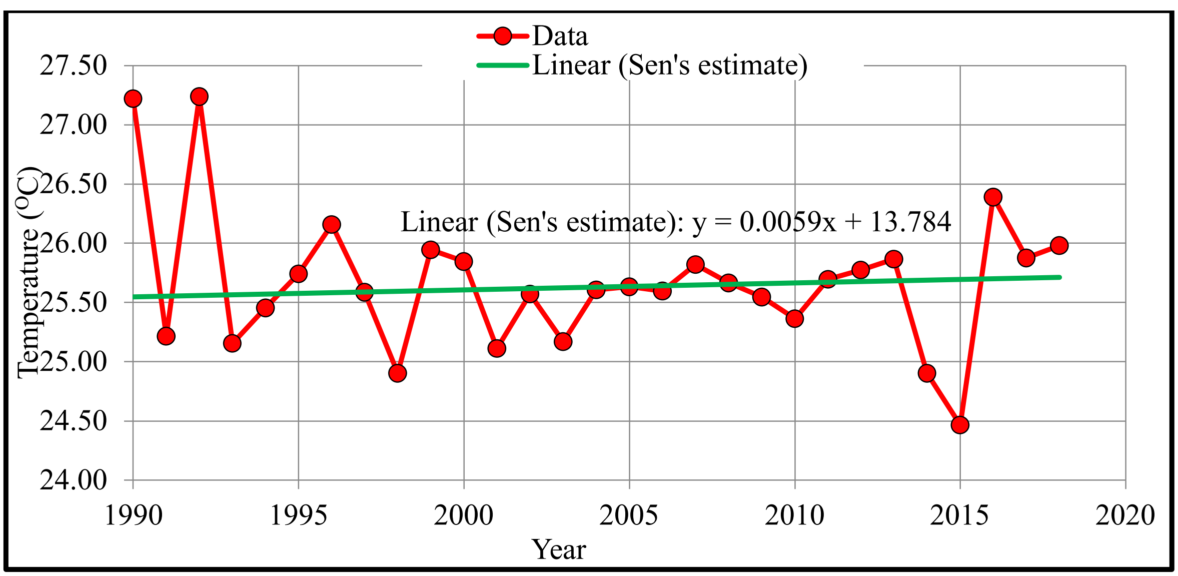

Figure 4: Mean Annual Temperature (1990 – 2018)
Source: Analyzed from NiMet Data (2020)
Differences in Temperature Between the Kaduna City and its Rural Neighbours in Kaduna

The intensity of the heat island is one of the oldest and most quantitative indicators of the thermal modification imposed by the city upon the territory in which it is situated and of its relative warming in relation to the surrounding rural environment especially at night time (Kim & Baik, 2002; Memon et al., 2009). In examining the differences in temperature between Kaduna city and its rural neighbours, the prevalence of a growing UHI was identified as detailed in the discourse below. The result of the LST between the Kaduna city and its rural neighbours in Kaduna Metropolis is presented in Table 2.

Table 2: Land Surface Temperature Differences Between Rural and Urban Pixel in Kaduna (1990-2020)

Year	Location		Difference (UHI Intensity)
	Rural	Urban	
1990	29.20^{O}C	31.01^{O}C	1.81^{O}C
2001	28.80^{O}C	32.75^{O}C	3.95^{O}C
2010	30.70^{O}C	32.69^{O}C	1.99^{O}C
2020	29.40^{O}C	33.17^{O}C	3.77^{O}C

Source: Researchers' Data Analysis (2020)

Table 2 indicated that, the pixel-based LST in 1990 was 29.20^{O}C in urban location and 31.01^{O}C in rural location. Also, in 2001, LST in rural area was 28.80^{O}C while that of urban was 32.75^{O}C. Also, the observed LST in rural area was 30.70^{O}C whereas the urban counterpart recorded 32.69^{O}C in 2010. Concerning LST in 2020, it is clear that the value of 29.40^{O}C was observed in nearby rural area while it was 33.17^{O}C in urban area. The UHI intensity was as low as 1.81^{O}C in 1990 and as high as 3.95^{O}C in 2001.

To appraise the significant difference between the mean urban LST and the mean LST for the rural areas, in Table 2 were exported to SPSS 22 Version and ANOVA test was deployed. The result as presented in Table 3 returned the Sum of Squares which reveals a between group of 16.589, within groups of 4.759 and F-value of 20.915. With the *p*-value of 0.004 which is actually less than 0.05, at 95% confidence limit, it was concluded that "there is significant difference between the mean urban LST and the mean LST for the rural areas in Kaduna Metropolis.

Table 3: ANOVA Result of Temperature between Urban and Rural Areas in Kaduna

Variable	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	16.589	1	16.589	20.915	0.004
Within Groups	4.759	6	0.793		
Total	21.348	7			

Source: Researchers' Data Analysis (2020)

Differences in Climatic Elements Between the Kaduna City and Rural Neighbours and Determination of Urban Heat Island Intensity (1990-2020)

One of the prime motivations for carrying out this research was to establish empirically the urban heat island intensity in different epochs (1990, 2001, 2010 and 2020) in Kaduna Metropolis. This was achieved through the evaluation of differences in climatic elements between the inner city and rural neighbours. Based on the unavailability of rainfall data in spatial context, this research relied more on temperature to ascertain the difference in climatic elements between the inner city and rural neighbour and the determination of UHI. Research findings have shown that LST is closely related to the near-surface air temperature especially under specific weather conditions and hence is often used to estimate near-surface air temperature (Cresswell et al., 1999; Prihodko & Goward, 1997; Stisen et al., 2007).

Although LST is not identical to UHI, it has been identified as the primary causal factor of temperature in the lower atmosphere (Oke, 2006). LST is the chief determinant of temperature at the lowest atmosphere and the primary factor of the UHI and urban warming. Voogt and Oke (2003) emphasize this association between elevated LST and the UHI by using the term "surface urban heat island," (SUHI). Thus, a cautious appraisal of LST in the urban and rural pixels in the study area for all the considered epochs (Table 3) indicated that the mean temperature (LST) of urban pixels was consistently higher than that of the non-urban areas for all the time steps.

The findings showed that while the LST was as low as 29.20^{O}C in 1990, the highest value was 30.70^{O}C in 2010 in non-urbanized locations. In contrast, 31.01^{O}C was the lowest observed mean temperature in rural areas in 1990 while it reached the peak of 33.17^{O}C in 2018 in highly urbanized portions of the study area. Analysis further showed that the UHI intensity within the period varied between 1.81^{O}C to 3.77^{O}C. The highest UHI intensity of 3.77^{O}C was recorded in 2018. The recorded UHI intensity depicted how much on average the urban core was warmer than the non-urban area in the study area. This indicated that, on the average, Kaduna metropolis was warmer than its surrounding rural area by at least 1.81^{O}C and at most 3.95^{O}C during the four epochs analysed.

Also, when these UHI intensity values were compared with the 0.4^{O}C annual trend from satellite-based LST and 0.2^{O}C annual trend from in-situ data, it is obvious that Kaduna Metropolis is experiencing the impact of climate change based on IPCC (2007) A1T, B1 and B2 climate change scenario. There is, therefore, *medium confidence* of possible trend of0.3^{O}C – 0.7^{O}C with *high confidence* of inability to differentiate anthropogenic-induced climate change from natural variability in the next two decades as well as up to 2.6^{O}C – 4.8^{O}C towards the last two decades of the 21st Century (Hayhoe et al., 2017).

The observed statistically significant clustering of high values of LST supports the observed UHI intensity in the study area. This finding was validated based onANOVA test and subsequent rejection of the hypothesized null hypothesis. Therefore, at 95% level of confidence (two-tailed test), the study established that significant difference actually existed between the mean urban LST and the mean LST for the rural areas in Kaduna Metropolis. This finding on UHI intensity corroborates that of Enete et al. (2012) and Balogun et al. (2012) and is in contradiction to that of Ojeh et al. (2016) and Adebayo et al. (2017).

For instance, Enete et al. (2012) documented UHI magnitude of 2^{O}C in the city of Enugu while Balogun et al. (2012) asserted that rural-urban heat flux ranges from 2^{O}C at midday in rainy season to 4^{O}C during night-time dry season. In contrast, Adebayo (1987) noted that although UHI intensity ranged from 1^{O}C–1.5^{O}C at the core of Ibadan city during the rainy season, it normally peaked at 8^{O}C during climax of dry season. Ojehet al (2016) also reported a one-year UHI intensity of 7^{O}C during the dry season from June 2014 and May 2015 NiMet dataset of Lagos. Besides, Adebayo et al (2017) reported that from 1990 to 2015 the core area of Ibadan on average was 5.32^{O}C warmer than the rural areas in terms of UHI intensity.

Conclusion

It is concluded that LST is rising in the city and elevated LST values have generally formed a cluster within the urban space. Also, there are higher LST/UHI pockets in the urban arena beyond the general high difference in LST between urban and rural spaces. With this discovery of UHI prevalence in Kaduna City on a decadal scale - 1990, 2001, 2010 and 2020, it is advised that a 2030 study be carried out to ascertain further trend and prevalence while deliberate mitigation efforts are being put in place to drive towards large scale urban greening, heating/green house emission regulations and the enactment/enforcement of environmentally friendly policies

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