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Assessing temperature warming and cooling rates using simple statistical analysis: The case study of Jalingo metropolis

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ABSTRACT

Urban climatologist particularly those interested in Urban Heat Island (UHI), require some form of explanations to UHI variations at both spatial and temporal scales in cities. Temperature cooling and warming rate can be use as a form of explanations for spatial and temporal variations for UHI intensity characteristics of an area. This study therefore, assessed variations in temperature warming and cooling rates in Jalingo. The study used temperature data collected at six locations representing six different thermal climate zones in the study area. Temperature data were collected for the period of 90 days thirty days in each of rainy season, dry season, and hamattan period. Simple statistical analysis was performed to determine the warming and cooling rates. The results indicate that temperature warm and cool differently in the study area. The results also revealed that general warming in the area within the study period begins at 8:00 h local time (GMT +1) with warming rate ranging from 0.94°C to 1.75°C across locations with a mean of 1.30°C. Cooling starts at 15:00 h ranging from -0.88°C to -1.84°C with an average of -1.48°C. It is recommended that environmental planners particularly the urban planners and Architectures should take into considerations the warming and cooling rates in their building design and also embrace appropriate landscaping to improve thermal comfort.

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1. Introduction

Sustainable urban planning faces two major challenges in this century; first, the impact of climate change and the necessity for adaptation measures to mitigate the consequences, and second, the challenges of urbanization and the necessity of balancing the various conflicting spatial demands. Climate change projections suggest that heat waves will become more frequent and severe during this century, consistent with the observed trend of the past decade (Fischer and Schär 2010). While urban areas will generally be exposed to the same change in regional climate as the surrounding area, the urban setting can exacerbate the impact of this exposure on a local scale. The presence of many buildings and artificial surfaces at the expense of open ground, open water and vegetation creates unique local climates altering temperature, moisture, wind patterns, and radiation. Consequently, micro climate characteristic especially temperature warming and cooling may vary considerably within cities.

Temperature cooling and warming rate as remarked by (Chow and Roth 2006; Nduka and Abdulhamed 2009; Makokha and Shisanya 2010) can be used as a form of explanations for spatial/temporal variations for UHI intensity characteristics of an area. Several studies have been conducted in recent times presenting various methodological approaches for studying the heat island effect and related urban planning activities. For instance, Dimitrov et al. (2021) adopted local climate zone (LCZ) approach in the mapping of surface urban heat island (UHI) in Sofia. The study used an unmanned aerial system (UAS) to conduct a thermal survey of the city, taking into account the influence of land use/land cover and urban morphology on the urban climate. The study identified 13 types of local climate zones in the study area and the results shows that UHI vary within Sofia in Bulgaria. Other studies include (Adebayo and Zemba 2003; Ibrahim et al. 2009; Aderoju et al. 2013; Milovanović et al. 2020; Berila and Isufi 2021; Nedkov et al. 2022). However, a significant issue (thermal comfort improvement strategy) which is considered importance to UHI studies was missing in these studies.

To ensure an effective and coherent development of adaptation strategies aimed at improvement of the urban thermal comfort, a better understanding of the variability in temperature warming and cooling rates within the urban environment thereon is needed. A study by Makokha and Shisanya (2010) in Nairobi Kenya revealed that temperature warm and cool differently in the city. The city center warmth up early compared to its peripheries while the low density areas with good landscaping with open spaces cool faster than high density areas. Another study in Onitsha southeast Nigeria by Nduka and Abdulhamed (2009) also supported the findings of Makokha and Shisanya (2010), however, Nduka (2010) used thermal climate zones to classify the study area unlike Makokha and Shisanya who used density to classify the study area. In all, the results show variations in temperature warming and cooling rates. Sunday Asa et al. (2023) conducted an experimental study of temperature characteristics in Jalingo metropolis where temperatures were found to vary spatially and temporally in the study area.

Therefore, in an effort to understand the microclimate variability (intra-urban variability) for sustainable thermal comfort planning, this study tend to assess temperature warming and cooling rates in Jalingo metropolis as a follow up of study by Sunday Asa et al. (2023). The aim is to assess temperature warming and cooling rates at different locations and time in the study area using simple statistical techniques, for the purpose of urban thermal comfort improvement and planning. The study also laid a foundation for urban canopy heat island assessment and evaluation in the study area.

2. Materials and methods

2.1 Study area

Jalingo is the capital of Taraba state in northeast Nigeria. Taraba State is situated between latitude 6°30’00”N and 9°36’00”N of the equator and longitude 9°10’00”E and 11°50’00”E of the Greenwich meridian. Jalingo metropolis on the other hand lies between latitude 8°52’00”N and 8°56’00”N of the equator while its longitudinal extent is between 11°19’00”E and 11°24’00”E east of the Greenwich meridian (Fig. 1). The metropolis consists of the whole of Jalingo local government area (LGA), as well as parts of Ardo-Kola LGA. The part of Ardo-Kola LGA that formed parts of the metropolis is Advanced Teachers College (ATC) now the Taraba State University (TSU) and its environ. Rainy season in Jalingo metropolis spans from April through October, with a mean annual precipitation amount between 750 mm to 880 mm (Adebayo 2001). Air temperatures in Jalingo vary between 29°C and 37°C, with an average mean of 32°C

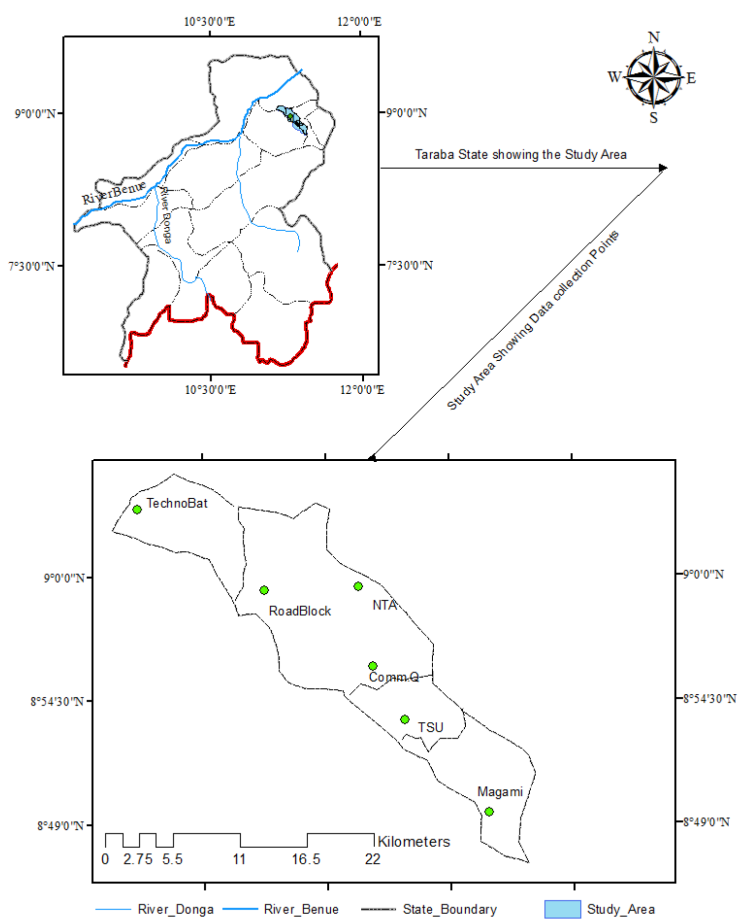

Figure 1. Location of the study area.

in the months of August and September. The coldest months are December and January, which is as a result of desiccated air (cold and dry wind) coming from the Sahara desert. The warmest months are April and May. The climate of Jalingo metropolis is influenced by two dominant trade winds, namely the Southwest trade wind and the Northeast trade wind.

The study area is situated on a gentle rolling slope to the great plains of Muri, lies between 196.9 m and 914 m above sea level. The highest peak in the area forms the watershed of the Lamurde River – the main river draining Jalingo metropolis, together with other streams which represent tributaries of the Benue River in that area (Zemba et al. 2019). Population of the area has increased over the years after the city was declared the state capital of Taraba state in 1991, resulting in an influx of people looking for employment opportunities provided by the new status of the city as such, population number in the city has increased by 35% (Zemba 2012). Consequently, there has been rapid urbanization.

Jalingo metropolis has been classified into thermal climate zones (TCZ) by Asa et al. (2017) adopting Stewart and Oke (2012) Landuse/landcover classification for urban climate study. Six TCZ were identified within Jalingo metropolis at different locations covering the entire city. The TCZ identified in the study area and their corresponding locations are: TCZ 9, at Taraba State University (TSU) and environ, TCZ 8 at Anguwan NTA and the market site (NTA), TCZ 7 at Technobat Estate and environ, TCZ 5, around Commissioners Quarters (Comm. Q) and environ, TCZ 3, around Magami area and environ and TCZ 2 at Road block (Jezco) and environ.

The major differences observed between the TCZs were their canyon geometry (H/W) ratio, building typologies, built-up density, thermal admittance and anthropogenic activities (Asa et al. 2017), all these features have the ability to modify microclimate of a place. Fig. 1 shows the locations of the study area and points at which temperature data collection sensor (thermochron Ibuttons) were mounted for temperature data collection, representing the various thermal climate zones classified by Asa et al. (2017).

2.2 Data collection

Temperature data was collected in-situ at an interval of ten minutes by thermochron Ibutton series DS1921. Thermochron ibutton is an automated digital temperature data logging sensor. The sensor was mounted over a network of six temperature data sampling stations in the study area. The sensor was calibrated by the researcher, the technical officer (T.O) and the chief meteorologist of Geography Department of the Modibbo Adama University, Yola. The results of the calibration indicates that the sensor work perfectly within the area and has the ability to accurately collect temperature data at a programmed time and at any climatic environment within the tropics. The sensors were mounted at a point within the TCZs in the area covering all different landuse typologies in the area. Hence, the sensors were mounted at; Taraba State University (TSU), TechnoBat Estate, Magami Estate, NTA, Jezco (Roadblock), and Commissioners Quarters (Comm. Q) covering the range of TCZ as found in Asa et al. (2017) and Sunday Asa et al. (2023).

Temperature data collection was done continuously and simultaneously in all locations for the period of 90 days in an improvised automated weather station (AWS). The improvised AWS was produced by the researcher in the form of a mini Stevenson screen with a small hole underneath that housed the ibutton. Six improvised AWS were produced and set up at a location within the six locations to collect temperature data after meeting up the guidelines set up by the World Meteorological Organization (WMO 2008). Fig. 2 shows thermochron ibutton and its accessories. Statistical analyses were carried out to assess the warming and cooling rates. Landsat 9 image of the study area Path (185) and Row (54) was downloaded from USGS (2023) to show spatial distributions of temperature collection sites and corresponding land surface temperature (LST).

Figure 2. Ibutton and its accessories (Embedded Data Systems). A - Ibuttons; B - USB; C - 1 wireconnectivity cable; D - 1 wire software.

2.3 Data analysis

In order to show spatial distribution of temperature collection points of the study area and temperature variation, LST algorithm was applied to retrieve LST of the study area from Landsat 9 image of the study area. Thermal infrared information from thermal infrared band (band 10) of Landsat 9 image that covered the study area acquired in December 2021 was used. ArcGIS 10.2 (ESRI) was used to retrieve the LST and also to analyze the spatial distribution of the retrieved LST.

The steps outlined by USGS (2016) for LST derivation was employed as presented below.

Step 1: Conversion of digital number (DN) values to radiance

The following equation is used to convert DN's to radiance units, expressed as:

$$L\lambda = ((LMAX\lambda - LMIN\lambda)/(QCALMAX-QCALMIN)) * (QCAL-QCALMIN) + LMIN\lambda \quad (1)$$

where:

Lλ = Spectral Radiance at the sensor's aperture in watts/(meter squared * ster * μm); QCAL = the quantized calibrated pixel value in DN; LMINλ = the spectral radiance that is scaled to QCALMIN in watts/(meter squared * ster * μm); LMAXλ = the spectral radiance that is scaled to QCALMAX in watts/(meter squared * ster * m); QCALMIN = the minimum quantized calibrated pixel value (corresponding to LMINλ) in DN; CALMAX = the maximum quantized calibrated pixel value (corresponding to LMAXλ) in DN= 255.

The LMINs and LMAXs are the spectral radiances for each band at digital numbers 0 or 1 and 255 (i.e. QCALMIN, QCALMAX), respectively.

LPGS used 1 for QCALMIN while NLAPS used 0 for QCALMIN for data products processed before April 5, 2004. NLAPS from that date to now use 1 for the QCALMIN value, in this study 1 was used for the value of QCALMIN.

Table 1. Details of Landsat datasets of the study area (USGS 2016).

Sensor	Space ID	Acquisition date	Time (GMT)	Thermal Conversion Constant K1	K2
LANDSAT_9	LC09_L1TP_187055_20211220_20220121_02_T1"	20 Dec 2021	12:01	774.8853 (band 10)	1321.0789 (band 10)

Step 2: Conversion from radiance to temperature in degree Kelvin

The formula below was use for conversion of radiance to temperatures in degree Kelvin is:

$$T = \frac{K2}{Ln\left(\frac{K1}{L\lambda} + 1\right)} \quad (2)$$

where:

T = effective at-satellite temperature in Kelvin; K2 = calibration constant 2; K1 = calibration constant 1 and Lλ = spectral radiance in watts/(meter squared * ster * μm).

Step 3: Conversion from degree Kelvin to degree Celsius

The derived temperature in degree Kelvin was then converted to degree Celsius using the formula: C=K-273.15. Table 1 presents the information of the Landsat image.

Temperature warming and cooling rates were computed using simple statistical analysis of the in-situ temperature data collected. The computation was done by subtracting the temperature value from the preceding time's value to get the warming or cooling rate for the subsequent time, and so on until reaching the temperature value at the starting time was reached. The negative results from the calculations indicate cooling while positive results indicate warming. For instance temperatures at time 07:00 h was subtracted from the temperature value at time 06:00 h to get the temperature warming or cooling rate at time 07:00 h to get warming or cooling rate at time 08:00 h, temperature values at 07:00 h was subtracted from values at 8:00 h this process continued until we reached the last hour.

The computation was done on an hourly basis, starting time was set at sunset, which is 18:00h local time or (17:00 h GMT) this is based on the results of previous studies such as Roth et al. (1989), Nduka and Abdulhamed (2009), and Makokha and Shisanya (2010). The result was standardized and re-arranges to read from 00.00 h local time. Temperature cooling and warming rates were later sampled at 08:00 h and 18:00 h local time as the sunrise and sunset respectively. The essence of this sampling was to examine the temperature cooling and warming rate at these periods. The reason for choosing the sunrise and sunset time was based on previous work such as Chow and Roth (2006), Nduka and Abdulhamed (2009), Makokha and Shisanya (2010) and Abdulhamid (2011) whose result shows that significant warming begins at 8:00 h local time and cooling begins at 18:00 h.

3. Results

3.1 Spatial distributions of temperature collection sites and corresponding LST

Fig. 3 shows the spatial distribution of the TCZ's and their corresponding LST as vary in the study area. The results presented in Fig. 3 shows that TCZ's where temperature data were collected for this study were spatially distributed across the study area given a complete coverage of the study area. From the LST derived and presented in Fig. 3, it is evident that temperature varies considerably within the study area and between TCZs. Roadblock and environ which correspond to TCZ 2 and TCZ 8 at NTA area has the highest temperature of 32°C distribution while TSU which correspond to TCZ 9 has the lowest temperature distributions 26°C while other locations; TCZ 7 at Technobat Estate and environ has temperature around 29°C, TCZ 3, around Magami area and environ has temperature of 31°C and TCZ 5, around Commissioners Quarters (Comm.Q) and environ has temperature of around 28°C. The results explained the fact that temperatures within the study area varies, as such it's warming and cooling will equally vary.

3.2 Mean hourly temperature trend

Temperature data collected using the Ibuttons over the network of six temperature data sampling stations chosen one each from the TCZ's identified were analyzed and standardized to mean hourly temperature, the result is presented in Fig. 4 below.

The result as presented in figure 4 revealed that temperatures in the locations follow the same pattern in most time of the study period, except for T.S.U and Comm.Q which deviates from the early morning hours between 2:00 h to 5:00 h local time before trailing after others at 6:00 h local time. These sites further deviate from others around mid-day at 12:00 h local time and trails after them at 18:00 h local time. Maximum temperature was attained NTA (35.66°C) at 14:00 h local time while lowest temperature was recorded at T.S.U (24.20°C). This result confirmed the findings of other studies elsewhere in Nigeria such as (Balogun et al. 2009; Nduka and Abdulhamed 2009; Ibrahim et al. 2011) that maximum temperatures were attained around 14:00 h.

Maximum temperature was recorded two hours after mid-day (12:00 noon) signifying the peak of warming period and the end of day time warming period while the lowest temperature was recorded an hour before sunrise signifying the peak period of cooling and end of night time cooling and the beginning of warming by the day. The differences observed in temperatures of these sites could be as a result of the differences in their surface, canyon geometry, surface cover and the level of anthropogenic activities within these sites (Oke 1987; Chow and Roth 2006).

3.3 Temperature warming and cooling rate

Mean hourly temperature warming and cooling were calculated and analyzed from the mean hourly temperature analyzed. The calculation was done on an hourly basis and starting time was set at sunset (19:00 h), this was later re-arranged to start at 00:00 h local time or (23:00 h GMT). Temperature cooling and warming were later sampled at 08:00 h and 18:00 h local time as the sunrise and sunset respectively. The result of temperature warming and cooling rates calculated is presented Table 2 while the statistical characteristics of the warming and cooling is presented in Table 3.

The results presented in Table 2 revealed that general temperature warming begins at 8:00 h. This because all the values at the time 8:00 h were positive indicating significant warming at all the locations with the exception of Road-block which started warming

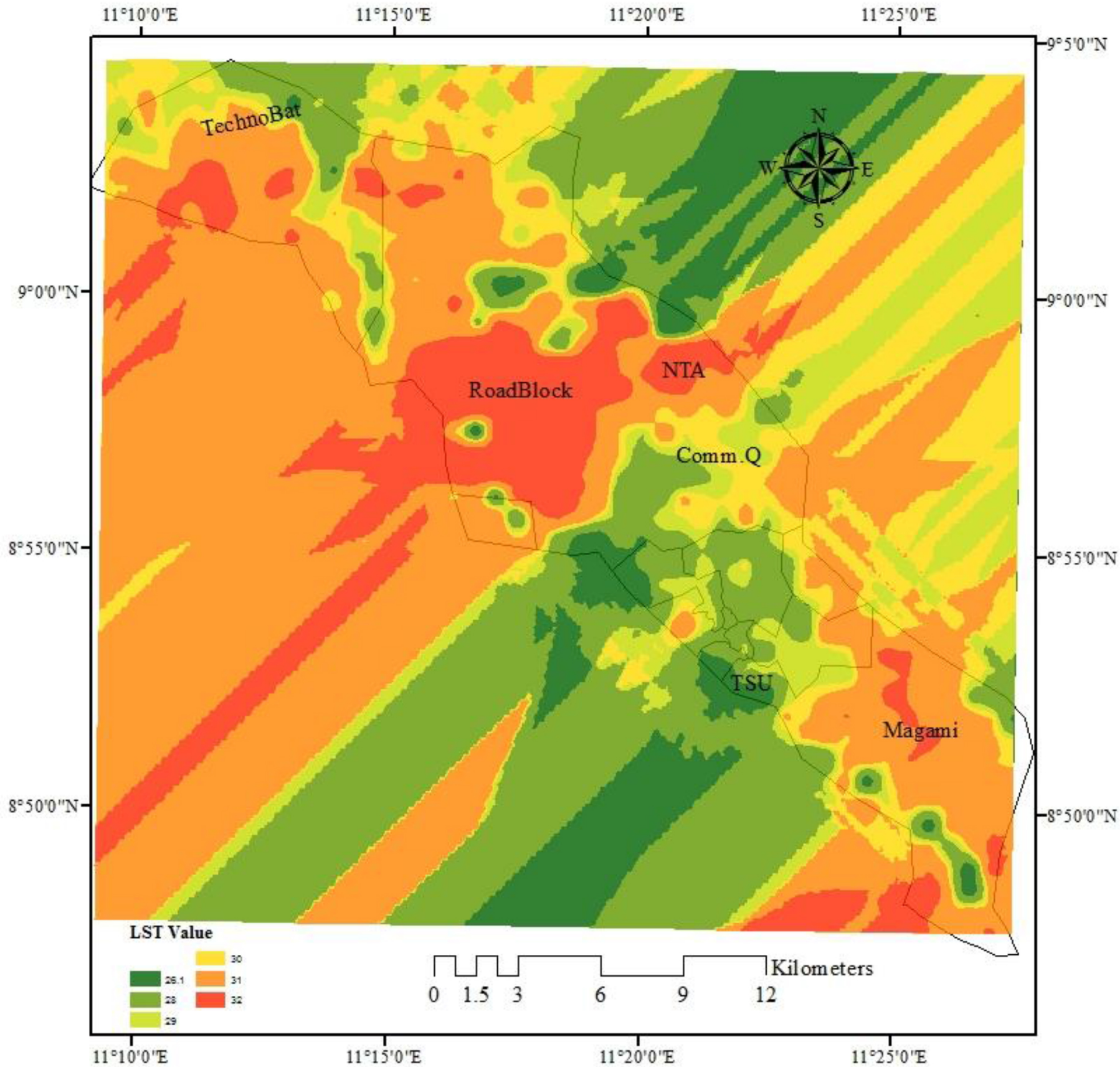

Figure 3. Spatial distribution of temperature collection points and corresponding LST.

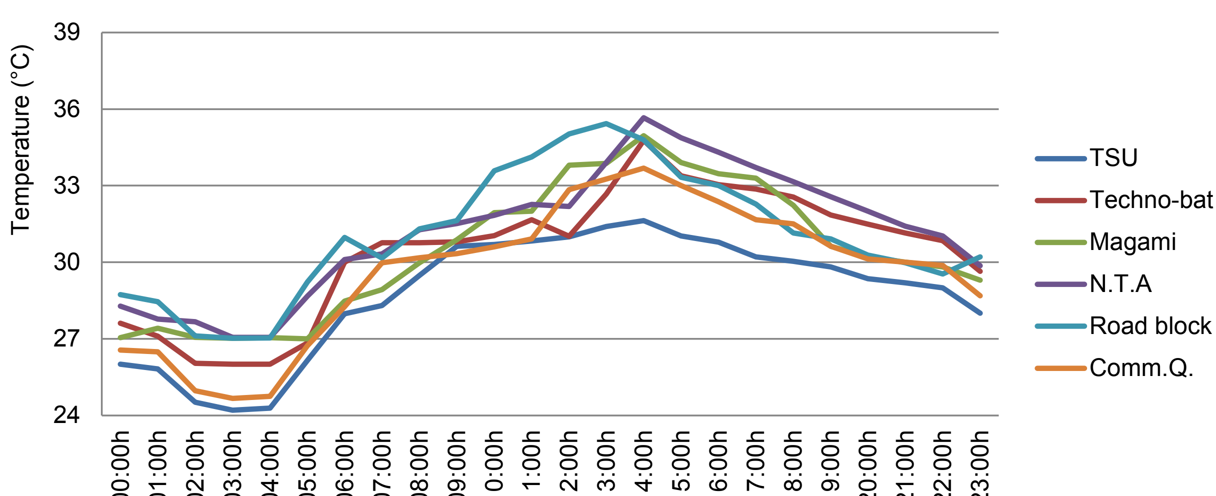

Figure 4. Mean hourly temperatures trends.

at 6:00 h two hours behind the sunrise set time. The reason for the early warming of the area can be attributed to high anthropogenic activities and the characteristics of the area as the area contains very busy streets with a major highway ("trunk A") which links Taraba State and South eastern parts of Nigeria and her neighbor, Adamawa State. The main motor park in Jalingo is situated at this site, thus making it the busiest in terms of vehicular traffic coupled with the presence of mechanic workshops, fuel stations and shopping malls. Anthropogenic heat generation is expected to be high here. The result is similar to finding of Nduka (2010) in Onitsha Nigeria. The results presented in Table 2 also shows that temperature cooling in the study begin by 14:00 h when three locations (Magami, NTA and Roadblock) representing 50% of the sites begins cooling down as their temperature value shows negative at that time but one hour later all the locations have started cooling as such it will be said generally by 15:00 h all the sites have started cooling down. Cooling reaches its peak at 00:00 h i.e 12:00 h before gradually winding down to terminate at 8:00 h at sunrise. The result shows that temperature cooling begins at sunset through the night and terminates at dawn and all the locations cooled and warmed up at different rates.

Table 2. Temperature warming and cooling rates.

Time	TSU	Technobat	Magami	NTA	Road-Block	Comm.Q
0:00	-1.25	-1.61	-0.78	-1.84	-1.48	-0.09
1:00	-1.15	-1.16	-0.58	-1.43	-1.28	-0.05
2:00	-1.15	-1.03	-0.53	-1.27	-1.14	-0.03
3:00	-1.18	-0.89	-0.46	-1.16	-0.19	-0.01
4:00	-0.91	-0.76	-0.5	-1.04	-0.09	-0.07
5:00	-0.72	-0.62	-0.35	-0.91	0.11	-0.03
6:00	-0.6	-0.58	-0.25	-0.49	1.16	-0.16
7:00	-0.53	-0.49	0.14	0.22	1.21	-0.5
8:00	0.39	0.21	0.9	0.25	1.4	0.14
9:00	0.28	0.62	1.05	0.41	1.54	1.26
10:00	0.16	0.64	1.06	0.67	0.55	1.31
11:00	0.3	0.68	1.1	0.94	0.1	0.53
12:00	0.49	0.96	1.16	1.72	0.2	0.82
13:00	0.77	1.01	1.2	1.75	0.37	1.43
14:00	0.94	1.21	-1.26	-0.79	-1.47	1.43
15:00	-1.16	-1.39	-1.18	-0.6	-1.14	-0.74
16:00	-1.6	-1.34	-1.06	-0.6	-0.72	-0.88
17:00	-0.58	-0.9	-0.61	-0.59	-0.33	-0.49
18:00	-0.47	-0.61	-0.6	-0.56	-0.23	-0.42
19:00	-0.24	-0.42	-0.58	-0.57	-0.27	-0.17
20:00	-0.2	-0.36	-0.43	-0.55	-0.3	-0.15
21:00	-0.17	-0.31	-0.39	-0.48	-0.44	-0.13
22:00	-0.13	-0.29	-0.31	-1.17	-0.67	-0.65
23:00	-0.06	-1.21	-1.51	-1.84	-1.48	-0.72

Table 3. Characteristics of mean temperature cooling and warming rate of the study area.

Locations	Range	Cooling rate	Warming rate	Mean	Std. Dev	Variance
TSU	2.54	-1.60	0.94	-0.4183	0.6531	0.660
TechnoBat	2.82	-1.61	1.21	-0.3688	0.8233	0.678
Magami	2.71	-1.51	1.20	-0.2104	0.8274	0.685
NTA	3.59	-1.84	1.75	-0.4321	0.9625	0.926
Roadblock	3.02	-1.48	1.54	-0.1992	0.9034	0.816
Comm.Q	2.31	-0.88	1.43	0.5621	0.7019	0.493

3.3.1 Sunrise temperature warming rates

Sunrise temperature was sampled at 8:00 h to assess temperature warming at that time. The result of the temperature warming at sunrise (8.00 h) local time is presented in Fig. 5 below. The results of temperature warming at sunrise (8.00 h) local time in Fig. 5, indicates that all the sites have warmth up by the set time. Jezco (Road Block) area had the highest temperature warming rate of 1.4°C/1h while the lowest was as site Comm.Q 0.14°C with a range of 1.26°C/1h and mean of 0.55°C/h. Two of the sites were above mean temperature warming rate, while the remaining sites were below the mean. This difference can be attributed to their height to width ratio (H/W) and surface cover as well as morphology of the area. Thus, TSU has higher H/W ratio which can increase the sky view and allow quick penetration of solar radiation while Techno-bat has lower H/W ratio which reduces the sky view thus inhibiting fast penetration of insulation and causing slow rate of warming (Asa et al. 2017). The findings were in line with Chen-Yi et al. (2009) who suggested that higher H/W ratio is responsible for slower warming of sites. Furthermore, the low temperature warming rate at Techno-bat can also be attributed to low anthropogenic activities in the site emanating from traffic, cooking, and diesel powered generators among others at that time in the area as reported by Asa et al. (2017). This result is confirmed the assertion by Balogun et al. (2009) that anthropogenic activities could be responsible for early temperature warming in areas.

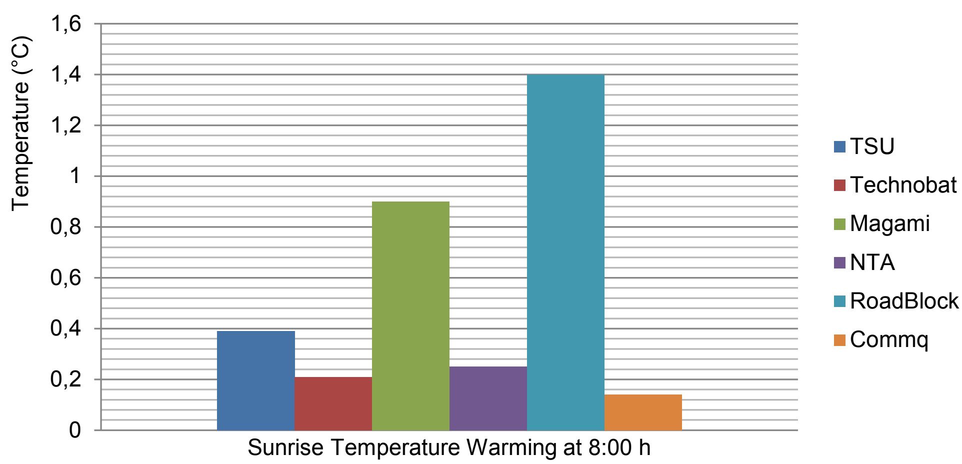

Figure 5. Characteristics of mean temperature warming rate of the study area at sunrise.

3.3.2 Sunset temperature cooling rates

Sunset temperature was taken at 19:00 h to show temperature cooling trend at sunset. The result is presented in Fig. 6.

The result presented in figure 6 above shows that all the locations have relatively cooling rate at the set time as they lie between -0.24 and -0.57°C/h. The maximum temperature cooling rate was recorded at Magami about 1.58°C/h while the minimum temperature cooling rate was at (TSU) with a record of -0.24°C/h, the study area has temperature cooling a range of -0.34°C/h and a mean of -0.39°C/h. Most of the locations have rates that clustered around the mean; which could be attributed to the low level of anthropogenic heat generation at this period which seems to be fairly distributed throughout the study area at this time. This result is similar to finding in Onitsha by Nduka and Abdulhamed (2009) who conducted a similar research but sampled his sunset time at 20:00 h, an hour after the sampled time for this research as well as work by Okpara (2002). Increasing temperatures decrease human comfort and raise mortality rates at temperatures outside an optimum range. When high temperatures are combined with low wind speeds and high humidity, the population may be put under severe thermal stress.

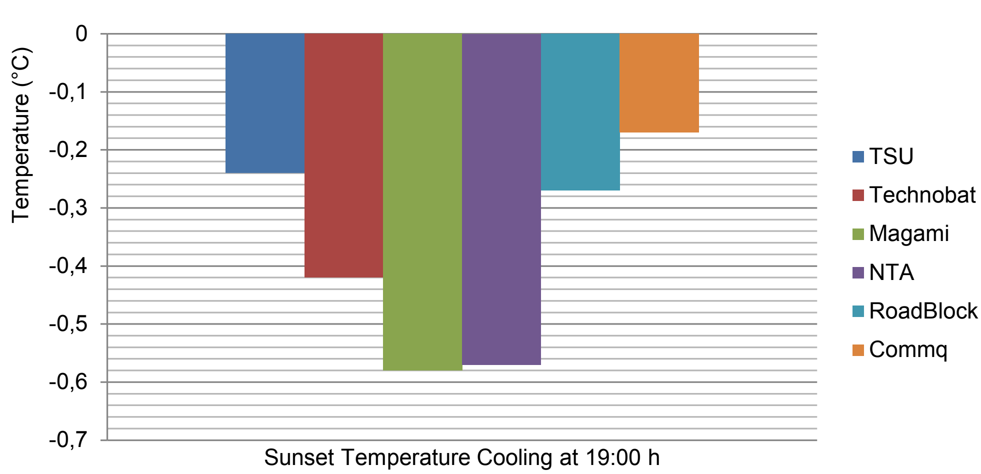

Figure 6. Characteristic of mean temperature cooling rate of the study area at sunset.

4. Discussion

The statistical descriptive characteristics results of temperature warming and cooling rates presented in Table 2 of this study revealed that, temperatures cooling rate in the study area range from -0.88°C to -1.84°C at Comm. Q and NTA respectively with a mean cooling rate of -1.48°C. Maximum temperature cooling rate was recorded by 00:00 h while the minimum temperature cooling rate was reached by time 4:00 h. Warming rate ranges from 0.94°C to 1.75°C with an average warming rate of 1.30°C. Table 2 also indicates that maximum temperature warming rate was reached at NTA area with a record of 1.75°C/h at time 6:00 h two hours behind our set sunrise time at 08:00 h, while the least was reached at TSU with a record of 0.94°C/h at time 10:00 h two hours after the set sunrise time.

Difference observed in the temperature warming and cooling rates of the study area could be attributed to urban geometry difference between the sites which is assumed to be one of the factors leading to the modification of urban climate. Specifically, urban geometry influences aspects such as increase heat storage due to greater thermal admittance of surface materials and decrease latent heat fluxes arising from the replacement of soils and vegetative surfaces by impervious materials it also leads to increase in solar radiation absorption due to lower level of urban material and reduced wind speed caused by aerodynamically rougher urban fabric. The differences can also be accentuated by the release of anthropogenic heat from domestic, commercial and transport energy sources.

The early temperature warming in the three sites (Magami, NTA and Roadblock) could be attributed to the high H/W ratio of the sites. The three sites that warmth up earlier than the set sunrise time were having H/W ratio above the mean H/W ratio of the study area (Asa et al. 2017). This result agreed with Chen-Yi et al. (2009) who suggested early temperature warming for areas with higher H/W and early temperature cooling for the same sites because of the level of solar radiation absorption capacity of the sites.

This study recommends an expanded study to cover a longer period and several Landsat images taken at temporal scale so as to have adequate information in order to make inferences about temperature changes in the study area over time.

5. Conclusion

From the findings of this research, the following conclusions were made:

- That temperature cooling in the study area begins at 15.00 h through the night and terminates at 07:00 h.
- Generally, temperature cooling in the study area begins at 15:00 h while temperature warming starts at 08:00 h.
- Temperature cooling rate in the area is between -0.24°C/h and -0.58°C/h.
- Maximum temperature cooling rate was recorded at Magami Estate while the minimum temperature cooling rate was at (TSU).
- It can also be concluded based on the results of the study that mean temperature cooling rate in the study area within the period of study is -0.39°C/h while the mean warming rate is of 0.55°C/h.

Although this work is novel, subsequent research on spatial and temporal research is advocated to augment this study. This is necessary because it will analyze sufficiently over a long period of observations, e.g., using images for at least a 10-20-year period for the different seasons, to make conclusions about the relationship between it and permanent urbanization and urban agglomerations in the study area. Such research could proffer invaluable perspectives on the temperature warming and cooling rates in the study area. This research also provides valuable insights into temperature warming and cooling in the study that underscores the necessity for effective thermal comfort management strategies that are sensitive to human thermal comfort. While the study provides valuable insights, it comes with the caveat of potential data inconsistencies, primarily due to irregular data recordings and malfunctioning instruments which formed the limitations to this study.

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Conflict of interest

The authors have declared that no competing interests exist. Both authors agreed with the findings and the research procedures.

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