RESEARCH PAPER

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SPATIOTEMPORAL TRENDS AND VARIABILITY ANALYSIS OF RAINFALL AND TEMPERATURE OVER BENIN METROPOLITAN REGION, EDO STATE, NIGERIA

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ABSTRACT. Rainfall and temperature are the two major climatic variables affecting humans and the environment. Hence, it is essential to study rainfall and temperature variability over urban areas. This study focused on analyzing the spatiotemporal trends and variability of rainfall and temperature over Benin metropolitan region, Nigeria. Time series analysis was used to determine temporal trends in rainfall as well as minimum and maximum atmospheric temperatures over a study period of 30 years (1990 to 2019). Analysis of variance was used to understand spatiotemporal variations of climatic elements among the spatial units (urban core, intermediate and peripheral areas). Land surface temperature (LST) and land use/land cover (LULC) classes of the study area were analyzed from Landsat TM Imagery of 2020. Results revealed a decreasing trend for rainfall and increasing trend for minimum and maximum atmospheric temperatures in all the spatial units. Rainfall distribution and temperature among the spatial units were statistically insignificant; however, significant temporal decadal variations were noticed for minimum and maximum air temperatures. This investigation provided valuable information for assessing changes in rainfall and temperature and concluded that the study area is becoming warmer; an indication of global warming and climate change.

KEYWORDS: Benin metropolitan region, climate change, rainfall, spatiotemporal, temperature, trend, variability

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INTRODUCTION

Climate change and variability is acknowledged today by a large part of the scientific community as a global phenomenon with diverse impacts on the environment, society and economy (Bayable et al. 2021; Wang et al. 2018; Birkmann & Mechler 2015; Tierney et al. 2013; IPCC 2007). Natural and anthropogenic factors are responsible for the devastating climate change through the emission of greenhouse gases. Infact, climate change is becoming a serious threat to sustainable development. Several studies (Niyongendak et al. 2020; Niang et al. 2014; IPCC 2014; IPCC 2007) have reported increases in the intensity and frequency of weather events. Globally, empirical data have shown that temperature has been on the rise since the late 19th century, with the last three decades been warmer than all previous decades (Hartmann et al. 2013). Per decade global temperature has been projected to increase by between 0.2 to 0.5°C, but rainfall variability differs from one region to another (IPCC 2007).

Trends in climate offer a general idea of noticeable changes within historical climatic data and throw up concerns regarding extreme weather events. The study of climate change focuses on the changes in climatic elements like rainfall and temperature, hence, the variability of these elements is of immense significance. Climatic variability across spatial and temporal dimensions are usually detected from the analysis of long-term observational data of specific climatic elements collected over an average period of not less than thirty years (Asfaw et al. 2018; Rahmstorf et al. 2017). The World Meteorological Organization (WMO 2016) considered the period 2011 to 2015 as the warmest on record since modern observations began in the late 1800s. Intergovernmental Panel on Climate Change (IPCC 2007) argued that the global climate has changed rapidly with approximately 0.7°C increase in mean temperature within the last century. But, the rate of climate change varies significantly among regions and this may be due to the varying land use/land cover types with different surface albedo, carbon cycle and evapotranspiration affecting the climate in different ways (Fatema & Chakrabart 2020; Snyder et al. 2004; Meissner et al. 2003). While temperature and rainfall may decrease over time in a given area, the trend at another locale may be the reverse (Adelekan 2011). This means that local climatic changes may not align with the overall regional or continental pattern of climate fluctuations. Consequently, the evidences and effects of climate change vary over space and time.

The effects of climate change are prominent in developing countries that are mainly dependent on climate driven economic sectors (Ongoma & Chen 2017).

Due to anthropogenic forcing, the 21st century warming will be strong in Africa (IPCC 2013). Urban spaces in developing societies are seen as hot spots to the effects of climate change due in part to the emerging industrial and commercial activities, high population density and infrastructures that are major emitters of greenhouse gases. Within this context, urban areas are expected to be significantly exposed to the impacts of climate change such as increased variability in temperature and rainfall (Dodman 2009). Additionally, IPCC (2013) stated that in most parts of sub-Sahara Africa, rainfall amount is expected to decline while rainfall variability is likely to increase. Specifically in Nigeria, the impacts of climate change will be felt in various climatic elements, especially rainfall and temperature. Therefore, it is anticipated that climate change may cause fluctuations in rainfall and temperature trends which can be intensified or weakened. Increase in temperature can cause incidents of heat waves, heat related sicknesses and even death in affected areas. Also, as the earth's temperature increases the rate of cloud formation and evapotranspiration increases and as a result, the rate of rainfall also increases (Ali-Rahmani et al. 2016). This could equally lead to a corresponding increase in the frequency of floods. Therefore, assessing the trends and variability of climatic indicators is a requirement for characterizing the features of climate change and adopting mitigation and adaptation strategies against the adverse impacts of climate change. Furthermore, there is the need to understand the past and current climatic trends in order to take up-to-date decisions in various planning processes such as producing renewable energy like solar and hydro energy as well as management of water resources. Therefore, studies for characterizing the fluctuations and trends of some climate factors are important and urgent.

There has been much recent scientific interest in climatic trends and variability. Several studies have been carried out at different spatiotemporal scales and in different parts of the world. For example, Ma (2021) studied the recent changes in temperature and precipitation of the summer and autumn seasons over Fujian Province, China and revealed an upward trend in both temperature and precipitation over a period of forty-eight years. Ekwueme & Agunwamba (2021) in examining trend analysis and variability of air temperature and rainfall in the regional river basins of southeastern Nigeria for the period 1922 to 2008 observed negative trend for rainfall in the study areas except for Owerri and Awka. For air temperature, they reported positive trend for all the study sites. Edokpa (2020) investigated variability in the long-term trends of rainfall and temperature over southern Nigeria and found no significant increasing/decreasing trend in monthly, seasonal and annual rainfall, with a decadal sequence of alternately increasing and decreasing rainfall trend. Niyongendako et al. (2020) examined trend and variability analysis of rainfall and extreme temperatures in Burundi and reported high monthly and inter-annual variability of rainfall and significant increasing trend for both minimum and maximum temperatures. Wani et al. (2017) carried out an assessment of trends and variability of rainfall and temperature for the district of Mandi in Himachal Pradesh, India and found that the annual minimum and maximum temperatures for the period of 30 years indicated an increasing trend but the amount of annual rainfall did not show any significant trend.

Other inquiries on climatic trends and variability include spatiotemporal variability and trends of rainfall and its association with Pacific Ocean sea surface temperature in west Harerge zone, eastern Ethiopia (Bayable et al. 2021); trends and variability of temperature and evaporation over the African continent: relationships with precipitation (Onyutha 2021); trends in climate variables (temperature and rainfall) and local perceptions of climate change in Lamu, Kenya (Yvonne et al. 2020); rainfall variability and trend analysis in Makurdi metropolis, Benue State, Nigeria (Aho et al. 2019); temporal and spatial variability of temperature and precipitation over East Africa from 1951 to 2010 (Ongoma & Chen 2017); descriptive analysis of rainfall and temperature trends over Akure, Nigeria (Ogunrayi et al. 2016); analysis of rainfall and temperature variability over Nigeria (Akinsanola & Ogunjobi 2014); climate variation assessment based on rainfall and temperature in Ibadan, southwestern, Nigeria (Egbinola & Amobichukwu 2013); changing rainfall and anthropogenic-induced flooding: impacts and adaptation strategies in Benin City, Nigeria (Atedhor et al. 2011) and others.

Therefore, our contribution in this study is to analyze the spatiotemporal trends and variability of rainfall and temperature from 1990 to 2019 over the Benin metropolitan region, as it is relatively the least studied area during the study period; creating a comparative dearth of current knowledge vis-a-vis other areas of the country and the world. Also, prior studies in the study area (Okhakhu 2016; Atedhor et al. 2011) did not show the trends and spatial variability of rainfall and temperature within and among the urban core, intermediate and peripheral areas respectively. Up till now, no investigation has revealed the land surface temperature and land use/land cover classes of the study area. This investigation centers on localized climate change assessment based on rainfall and temperature variations in order to understand the current climatic trends in the study area. This study will serve as a basis for current climate change mitigation and adaptation strategies in the study area. The outcome of this research will help to deepen the scientific and quantitative knowledge of climatic trends and variability and provide up-to-date empirical evidence on climate change, if any, in the study area. Thus, the specific objectives of the study were to (i) determine the temporal trends in rainfall and temperature in the spatial units, (ii) ascertain significant spatial variations in rainfall and temperature among the spatial units (iii) determine significant temporal variations in rainfall and temperature among the spatial units, and (iv) evaluate the current land surface temperature and land use/land cover classes of the study area.

MATERIALS AND METHODS

Study area

Benin metropolitan region which is made up of Oredo, Egor, Ikpoba-Okha and the urbanized parts of Ovia North-East and Uhunmwode Local Government Areas of Edo State (Balogun & Onokerhoraye 2017) is among the fastest growing ancient cities in Nigeria (Nkeki & Asikhia 2019). Benin metropolitan region is confined within Latitudes 6° 16′ and 6° 33′ N and Longitudes 5° 31′ and 5° 45′ E (Fig. 1). Its territorial coverage is approximately 1,318 km^2 with 166 km in the perimeter and situated on a fairly flat land, about 78 m above sea level (Asikhia & Nkeki 2013). Urbanization processes and other associated land use/land cover developments have partitioned the region into three major spatial units; the urban core, intermediate and peripheral areas (Nkeki & Asikhia 2019).

Benin metropolitan region is underlain by sedimentary formation of the Miocene-Pleistocene-age often referred to as the Benin formation (Odemerho 1988). It is located in the humid lowland tropical rainforest belt of Nigeria and experiences the typical rainforest zone climate of southern Nigeria which belongs to the Af category of Koppen's climatic classification scheme. The rainy season begins in March and ends in October. The area experiences a total average of 120 rainy days annually and could reach up to 140 rainy days in some years (Ugwa et al. 2016). Rainfalls are of high intensity and usually of double maxima with a little dry spell in August (Atedhor et al. 2011). The city is well drained by two major rivers; Ikpoba river, which drains the northeast of the city, and Ogba river, which drains the southwest of the city. The vegetation is predominantly the evergreen rainforest while urban developments have drastically reduced the vegetation.

Data collection and analyses

Monthly atmospheric temperature (minimum and maximum) and rainfall data for 30 years (1990 to 2019) over the urban core, intermediate and peripheral areas of the Benin metropolitan region were obtained from the Climatic Research Unit (CRU) Global Climate Dataset website. The climatic data points and locations of climatic data extraction points are shown in Figure 2 and Table 1 respectively. Land surface temperature (LST) map and land use/land cover classes data were analyzed from Landsat TM Imagery (2020) downloaded from the United State Geological Survey (USGS) website.

Data on rainfall and atmospheric temperature for 30 years (1990 to 2019) were analyzed for temporal trends using the time series analytical technique (Terence, 2006). Analysis of variance was used to understand the spatiotemporal variations of rainfall and temperature that exists among the urban core, intermediate and peripheral areas. Other statistical parameters like the mean, range and coefficient of variation of the climatic data were also computed. All statistical analyses were carried out using SPSS version 21 and Microsoft Excel. Results of the statistical analyses of temperature and rainfall were depicted using graphical and tabular methods.

RESULTS AND DISCUSSION

Trend analysis of rainfall

Rainfall and temperature are the foremost climatic variables that influence human well-being and crops production. (Ogunrayi et al. 2016). A 30 year time series analysis of the rainfall dataset as shown in Figures 3, 4 and 5 indicated an insignificant negative (decreasing) trend at $p > 0.05$ for rainfall amounts received in the urban core, intermediate and peripheral areas. The trend of rainfall was -3.458 mm per annum ($R^2 = 0.0435$) in the urban core, -3.3689 mm per annum ($R^2 = 0.0417$) in the intermediate and -3.4617 mm per annum ($R^2 = 0.0424$) in the periphery. This result suggests that rainfall has been on the decline over the study period.

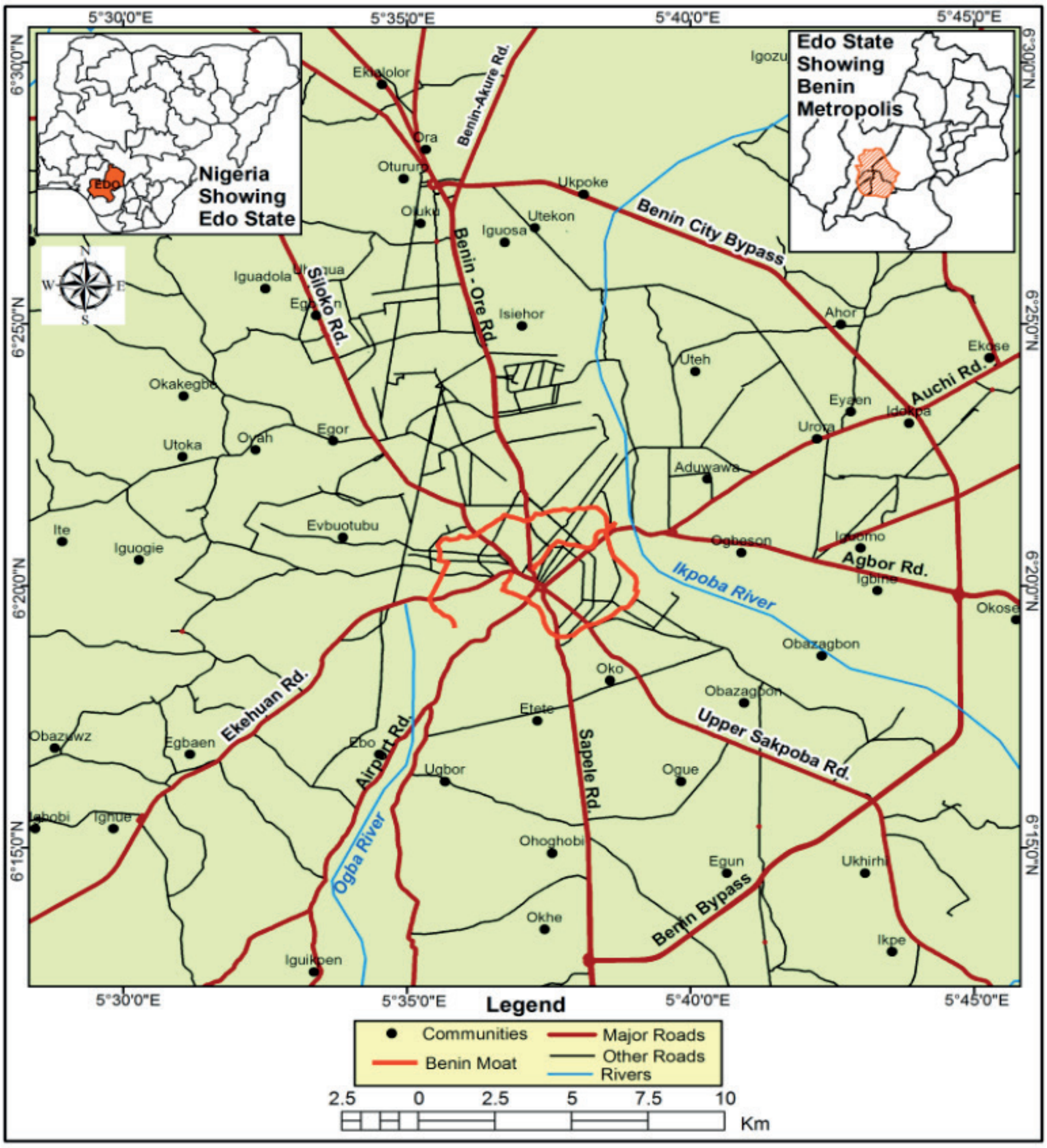


Fig. 1. Benin metropolitan region (Compiled using Google Earth Imagery, 2021)

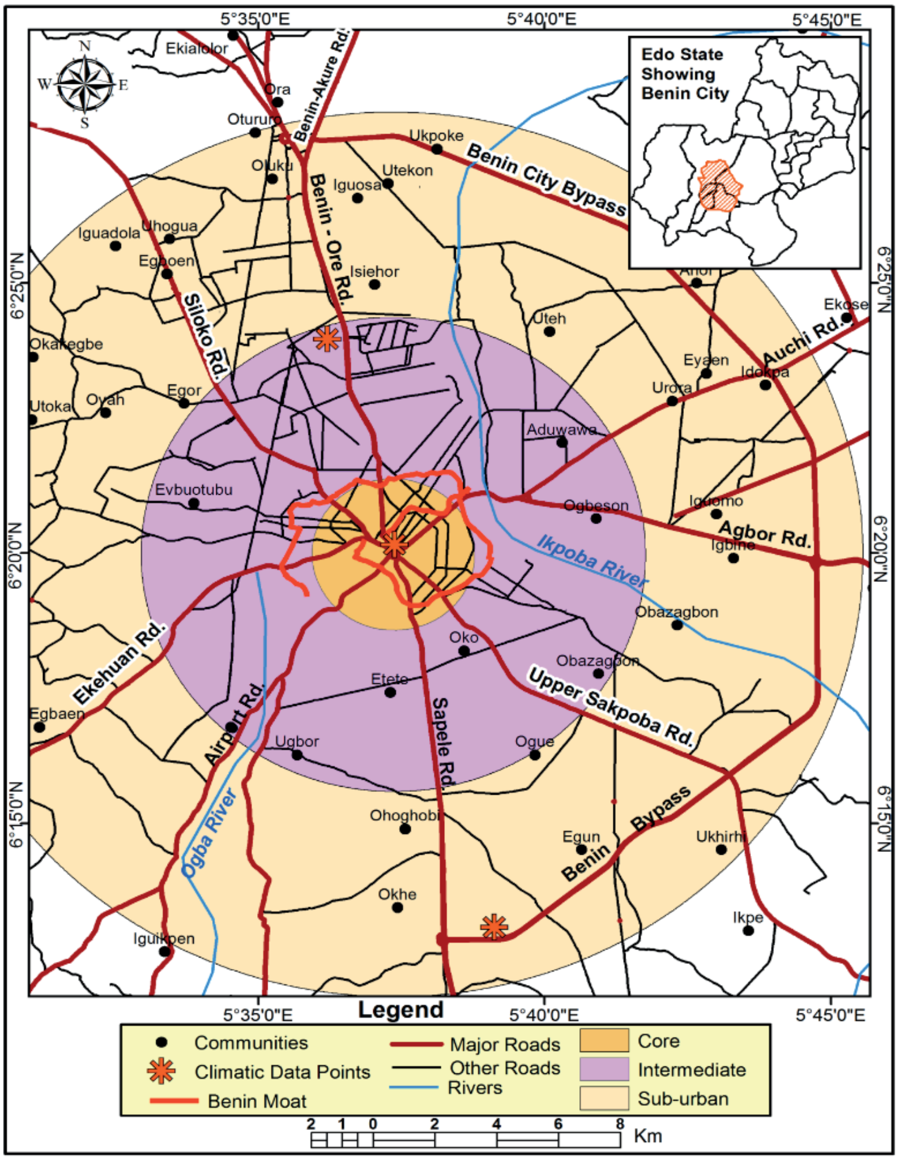


Fig. 2. Benin metropolitan region showing climatic data points (Compiled using open street map database, 2021)

Table 1. Geographical location of climatic data extraction points

S/No.	Description	Spatial unit	GPS coordinates
1	Paved surface near King's Square	Urban core	6° 20' 9.60" N, 5° 37' 22.80" E
2	Open field near Film House opposite Ekosodin road	Intermediate	6° 24' 18.00" N, 5° 35' 23.99" E
3	Bush fallow by Sapele road near Benin bye-pass	Periphery	6° 13' 4.79" N, 5° 39' 7.20" E

In the urban core, the highest rainfall amount (2338.00 mm) was recorded in 1991 and the lowest rainfall (1718.10 mm) was observed in 1993. Whereas in the intermediate area, the highest rainfall (2303.85 mm) was recorded in 1991 while the lowest rainfall (1681.2 mm) occurred in 1993. For the peripheral area, the highest rainfall (2386.3 mm) was experienced in 1991 and the lowest rainfall (1772.0 mm) occurred in 1993. From the results, the total rainfall amount during the study period was characterized by one distinct peak in 1991. This implies that 1991 was the wettest year during the period under study. Also the result shows that precipitation amounts were highest over the periphery (2386.3 mm) compared to the urban core and intermediate areas during the period under evaluation. The rainfall trend contradicts the work of Edokpa (2020) who detected no significant increasing/decreasing trend in monthly, seasonal and annual rainfall over the south-south region of Nigeria.

Trend analysis of atmospheric temperature

In analyzing the trend of minimum air temperature in the study area, Figures 6, 7 and 8 revealed an insignificant positive (increasing) trend for this climatic parameter ($p > 0.05$). In the urban core, intermediate and peripheral areas, minimum temperature was increasing at rates of 0.033°C ($R^2 = 0.588$), 0.033°C ($R^2 = 0.587$) and 0.033°C ($R^2 = 0.590$) per annum respectively. For changes in the maximum air temperature, Figures 9, 10 and 11 also indicated insignificant positive (increasing) trend at $p > 0.05$ in all the spatial units. Like minimum air temperature, maximum air temperature was increasing at rates of 0.027°C per annum ($R^2 = 0.043$) in the urban core, 0.028°C per annum ($R^2 = 0.547$) in the intermediate and 0.027°C per annum ($R^2 = 0.546$) in the periphery. This infers that the minimum and maximum air temperatures were increasing over the study period especially as there was decadal variability (Table 3). The annual average maximum temperature of the region was characterized by

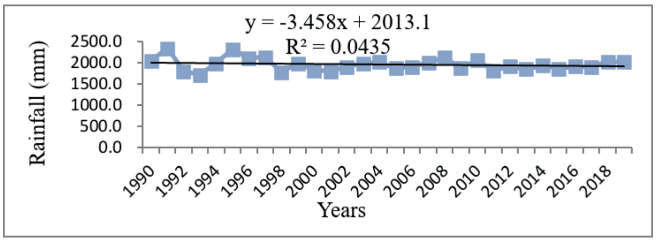


Fig. 3. Annual rainfall trend in urban core area (1990–2019)

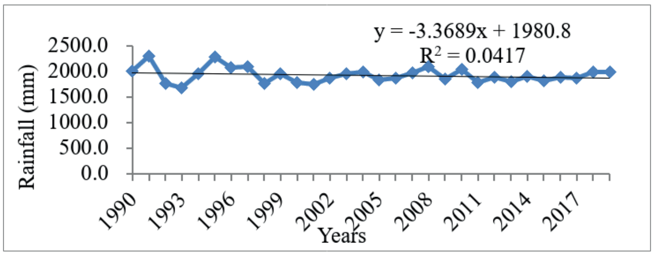


Fig. 4. Annual rainfall trend in intermediate area (1990–2019)

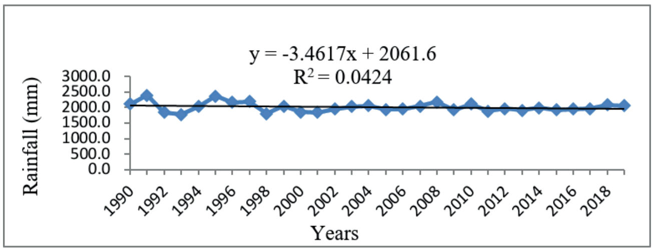


Fig. 5. Annual rainfall trend in peripheral area (1990–2019)

two distinct peaks across all spatial units (Fig. 9, 10 and 11); one in 2016 and the other in 2017. This shows that these years were the warmest years within the period under study. The overall increase in temperature may be due to the ongoing global warming, coupled with other factors such as land use and land cover changes. Generally, this connotes that there has been a surge in temperature in the study area, that is, the study area has become warmer. This warming may have negative implications on the physiological comfort and health of people in the area. The outcome on temperature trends across the study area is consistent with the findings of Ongoma & Chen (2017). Similarly, other studies (Ragatoa et al. 2018; Eresanya et al. 2018; Amadi et al. 2014) have shown a rising trend in air temperature across Nigeria.

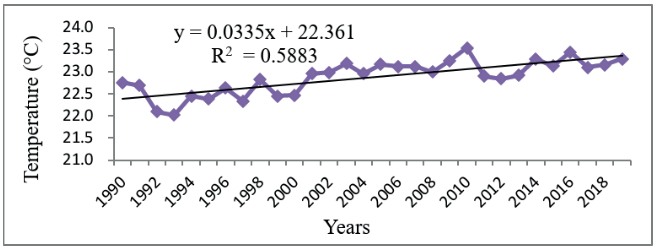


Fig. 6. Average minimum air temperature trend in urban core area (1990–2019)

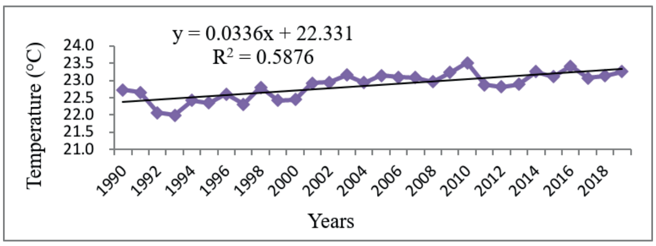


Fig. 7. Average minimum air temperature trend in intermediate area (1990–2019)

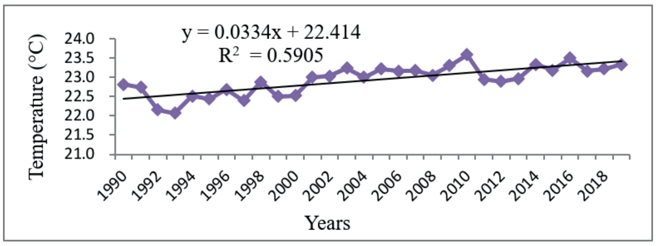


Fig. 8. Average minimum air temperature trend in peripheral area (1990–2019)

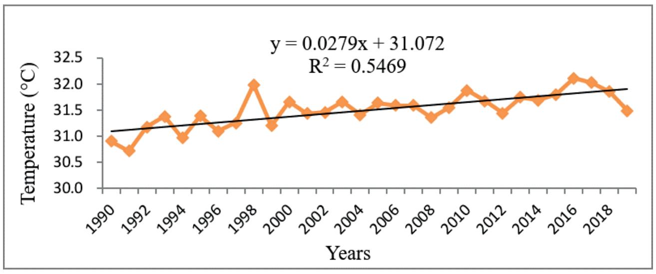


Fig. 9. Average maximum air temperature trend in urban core area (1990–2019)

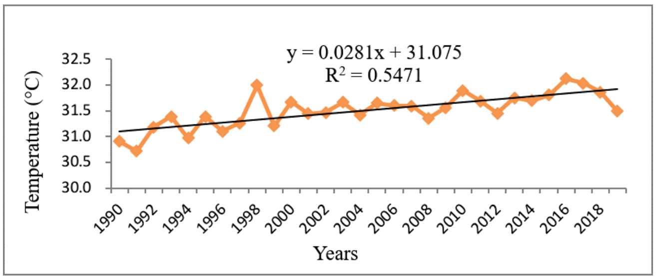


Fig. 10. Average maximum air temperature trend in intermediate area (1990–2019)

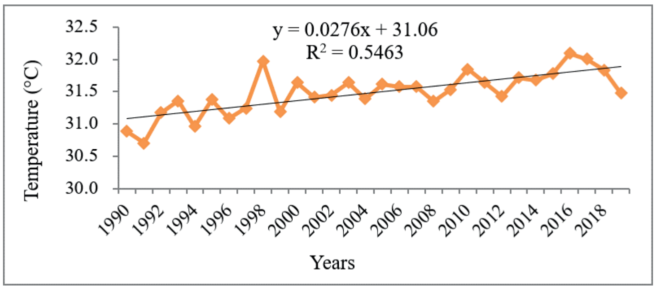


Fig. 11. Average maximum air temperature trend in peripheral area (1990–2019)

Spatiotemporal variability of rainfall and temperature

The distribution of total annual rainfall and atmospheric temperatures (minimum and maximum) of the different spatial units from 1990 to 2019 are presented in Table 2. Results indicated no marked variation of total rainfall among the urban core, intermediate and peripheral areas. This denotes that rainfall is fairly evenly distributed between the spatial units. However, the peripheral area received the greatest amount of rainfall during this period varying from 1772.03 to 2386.25 mm with mean value of 2007.97 mm over. This result differs from that of Egbinola & Amobichukwu (2013) who found that rainfall in Ibadan was highly variable. Although estimates of minimum air temperature was slightly higher in the peripheral area with values varying from 22.07 to 23.58 mm and mean value of 22.93°C, the values recorded for maximum air temperature were similar across the spatial units. The analysis of temperature data revealed non-significant variation ($p > 0.05$) among the spatial units. This implies that there were no marked changes in temperature across the spatial units that make up the Benin metropolitan region between 1990 and 2019.

Table 2. Spatial variations of climatic elements (1990–2019)

Urban core				Intermediate				Periphery				
Range	Mean	Std	CV (%)	Range	Mean	Std	CV (%)	Range	Mean	Std	CV (%)	p-value
Total annual rainfall (mm)												
1718.13 - 2337.95	1959.46	145.96	7.45	1681.19 - 2303.85	1928.53	145.20	7.53	1772.03 - 2386.25	2007.97	147.92	7.37	0.11
Annual average minimum air temperature (°C)												
22.02 - 23.53	22.88	0.38	1.68	21.99 - 23.51	22.85	0.38	1.69	22.07 - 23.58	22.93	0.38	1.67	0.71
Annual average maximum air temperature (°C)												
30.72 - 32.11	31.50	0.33	1.05	30.71 - 32.12	31.51	0.33	1.06	30.70 - 32.09	31.49	0.32	1.04	0.96

Temporal decadal variations of rainfall and temperature are presented in Table 3. The results show that there was non-significant ($p > 0.05$) decline in total rainfall amounts received in the urban core, intermediate and peripheral areas per decade. This connotes a consistent decrease in rainfall amount over the various spatial units during the period under investigation. Thus, it could be opined that the study area is becoming drier. This result is not surprising as minimum and maximum air temperatures have been on the increase over the same period (Table 3).

Atmospheric temperatures varied significantly with time for both the minimum and maximum air temperatures (Table 3). The result indicated a significant ($p < 0.05$) increase in minimum and maximum atmospheric temperatures per decade during the study period. This suggests that temperature over the study region is becoming warmer. Population boom and other associated land use/land cover changes may be attributed for the surge in minimum and maximum temperatures in the study area. The urban core area recorded decadal higher mean values for maximum air temperature compared to the intermediate and peripheral areas. Human activities and prevalence of hard, dry surfaces such as buildings, side-walks, roads, parking lots etc., in the urban core area which provide less shade and moisture than natural landscapes may have contributed to the observed higher temperatures. This finding indicates that the urban heat island phenomenon is in force in the study region as exemplified by the work of Efe & Eyefia (2014) and connotes clear evidences of global warming and climate change. This result aligns with the works of Oguntude et al. (2012), Atedhor et al. (2011) and Odjugo (2010) which reported separately clear indications of warming.

The urban heat island effect caused through urbanization processes such as reduced natural landscapes, increased industrial and commercial activities, urban material properties, metabolic heat as

Table 3. Temporal decadal variations of climatic elements from 1990–1999, 2000–2009 and 2010–2019 respectively

Climatic elements and spatial units	1990 - 1999				2000 - 2009				2010 - 2019				
	Range	Mean	Std	CV (%)	Range	Mean	Std	CV (%)	Range	Mean	Std	CV (%)	p-value
Total annual rainfall in urban core area (mm)	1718.13 - 2337.95	2020.36	213.88	10.59	1793.57 - 2121.63	1929.34	100.77	5.22	1819.49 - 2061.73	1928.68	81.04	4.20	0.27
Total annual rainfall in intermediate area (mm)	1681.19 - 2303.85	1988.44	210.54	10.59	1758.92 - 2087.37	1899.77	101.38	5.34	1784.59 - 2034.89	1897.38	85.72	4.52	0.28
Total annual rainfall in peripheral area (mm)	1772.03 - 2386.25	2069.31	218.80	10.57	1843.52 - 2178.01	1975.81	102.41	5.18	1874.36 - 2109.35	1978.80	76.63	3.87	0.28
Annual average minimum air temperature in urban core area (°C)	22.02 - 22.82	22.46	0.26	1.20	22.47 - 23.25	23.16	0.22	1.01	22.84 - 23.52	23.16	0.23	1.01	0.00*
Annual average minimum air temperature in intermediate area (°C)	21.99 - 22.79	22.43	0.26	1.20	22.44 - 23.22	22.99	0.22	0.96	22.80 - 23.51	23.13	0.23	1.01	0.00*
Annual average minimum air temperature in peripheral area (°C)	22.07 - 22.87	22.51	0.26	1.19	22.52 - 23.29	23.06	0.21	0.95	22.89 - 23.58	23.21	0.23	1.00	0.00*
Annual average maximum air temperature in urban core area (°C)	30.72 - 31.98	31.21	0.34	1.11	31.35 - 31.66	31.53	0.11	0.35	31.44 - 32.11	31.77	0.21	0.67	0.00*
Annual average maximum air temperature in intermediate area (°C)	30.72 - 31.99	31.20	0.34	1.11	31.35 - 31.66	31.53	0.11	0.36	31.44 - 32.12	31.77	0.21	0.67	0.00*
Annual average maximum air temperature in peripheral (°C)	30.70 - 31.97	31.19	0.34	1.10	31.35 - 31.64	31.52	0.10	0.35	31.42 - 32.09	31.75	0.21	0.66	0.00*

well as urban geometry have altered the urban energy balance in the Benin metropolitan region. Therefore, the thermal, hydrological and aerodynamic properties of the studied region have been altered resulting in higher local temperatures over time. Atmospheric temperatures (minimum and maximum) significantly increased per decade during the study period. This urban heat island effect has potential consequences for weather/climatic, human and environmental conditions. High atmospheric temperature may increase vulnerability to heat related morbidity and mortality (Luber & McGeehin 2008) and affect the energy demand and efficiency of the urban population. These temperature anomalies observed is an indication of warming over the study region.

Current land surface temperature and land use/land cover classes

The land surface temperature is a crucial climate variable for climate change assessment and is a tool for understanding energy balance over the earth surface (James & Mundia 2014). The current land surface temperature of Benin metropolitan region ranged from 23.02 to 33.00°C. The highest value of land surface temperature tends to concentrate along the development corridor from the urban core through the intermediate to the peripheral areas (Fig. 12). The driving factors of emerging commercial activities, high population density and increased built-up areas amongst others which are major emitters of greenhouse gases and alter the thermal, hydrological and aerodynamic properties along this corridor of development could be responsible for the high land surface temperature recorded. Thus, the development corridor can be seen as the zone of rapid urbanization. The undeveloped peripheral areas had lower land surface temperature as depicted by green and yellow shades (Fig. 12) as well as less built up areas (Fig. 13).

CONCLUSIONS

The spatiotemporal trends and variability analysis of rainfall and temperature (1990–2019) over Benin metropolitan region, Nigeria has been examined and provides valuable insights on the spatial and temporal trends of rainfall and temperature in the region. During this period, linear trend line revealed negative (decreasing) trend in total rainfall amounts in the study area and positive (increasing) trend in minimum and maximum

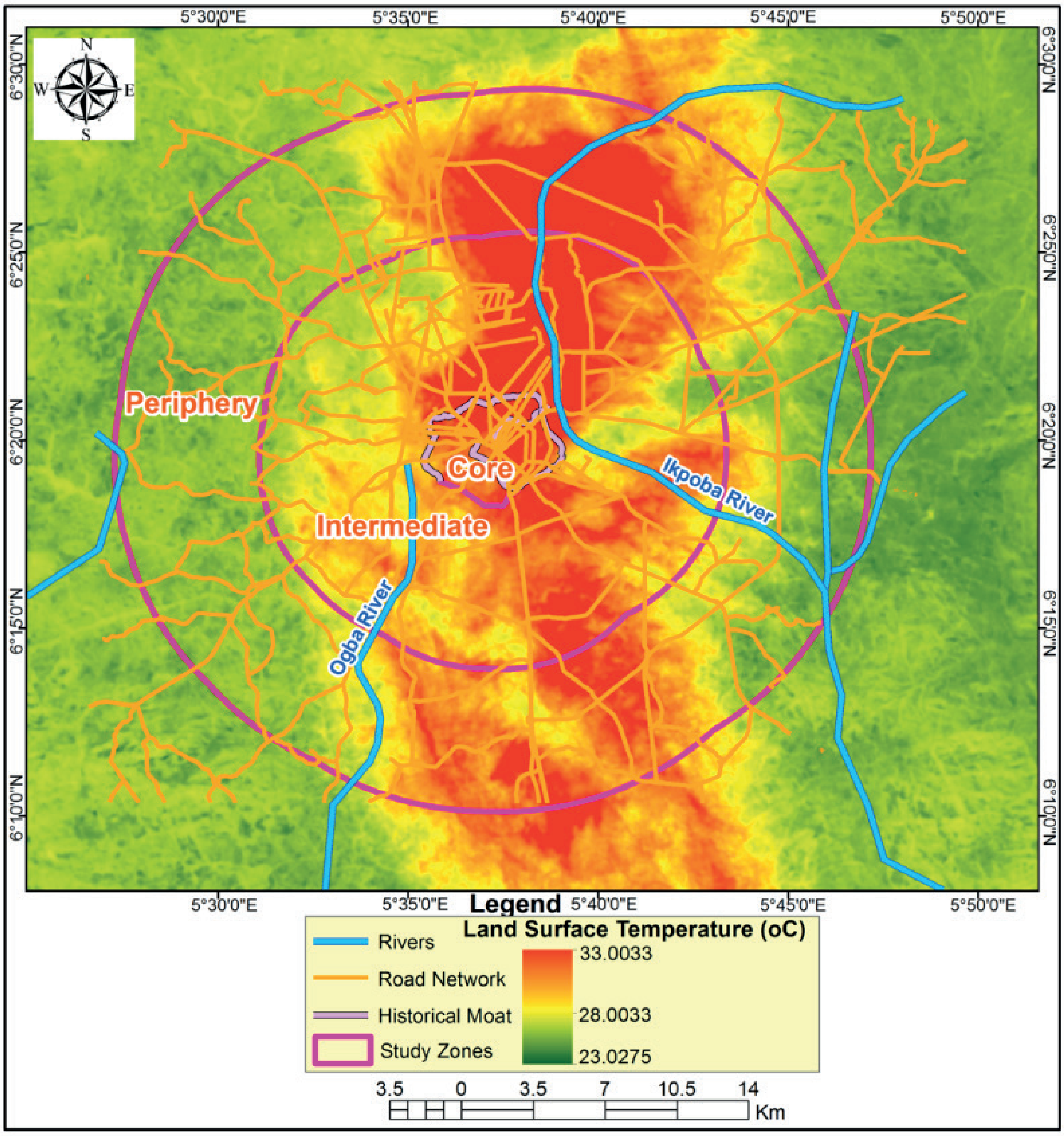
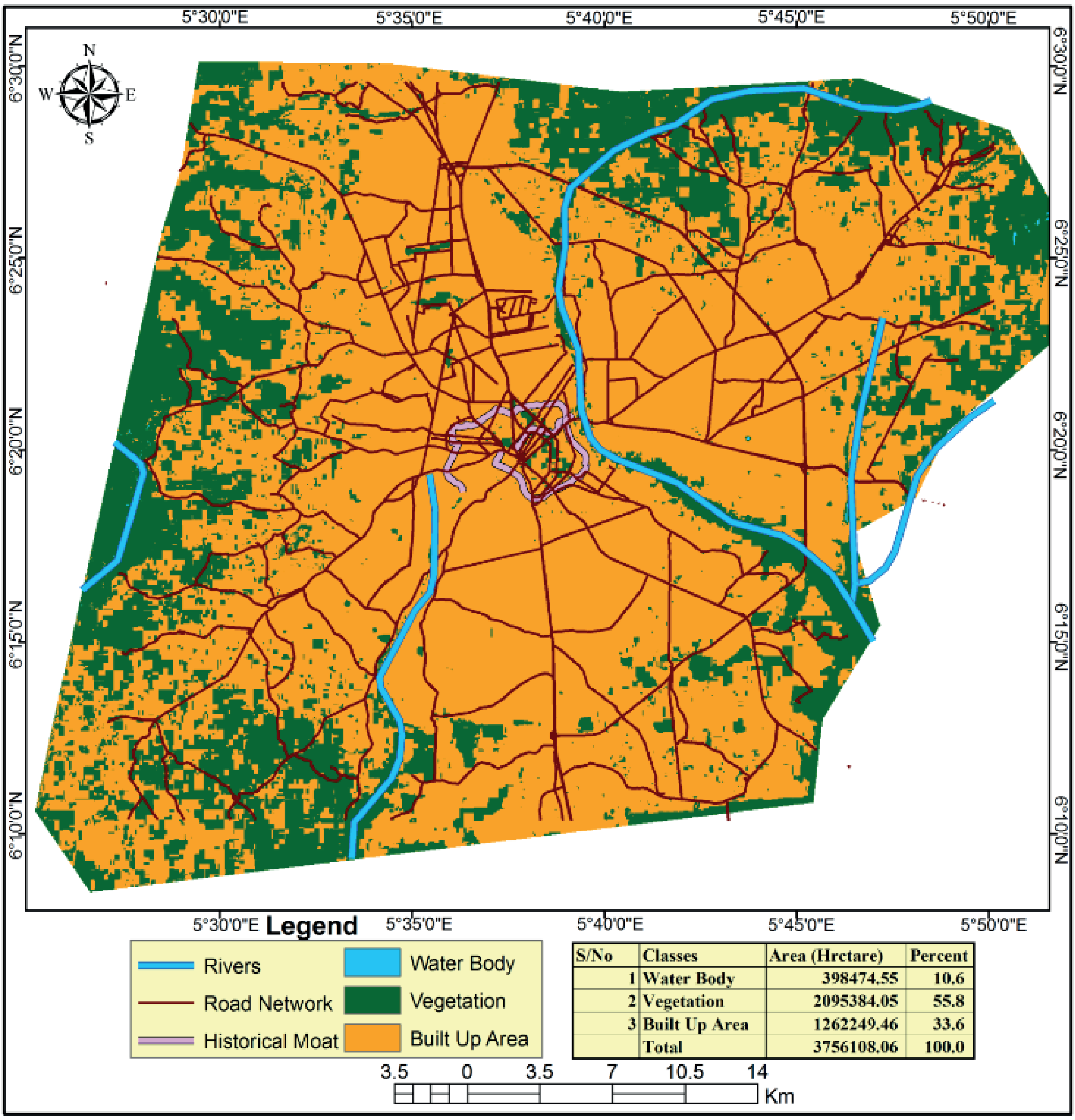


Fig. 12. Benin metropolitan region showing land surface temperature (January, 2020)
Source: Analyzed from Landsat TM Imagery, downloaded from the United State Geological Survey website



S/No	Classes	Area (Hrctare)	Percent
1	Water Body	398474.55	10.6
2	Vegetation	2095384.05	55.8
3	Built Up Area	1262249.46	33.6
	Total	3756108.06	100.0

Fig. 13. Benin metropolitan region showing land use/land cover classes (2020)
Source: Analyzed from Landsat TM Imagery, downloaded from the United State Geological Survey website

air temperatures indicating warming throughout the study period. Variability analysis showed that atmospheric temperatures significantly varied per decade across the three spatial units with a surge in mean atmospheric temperatures per decade indicating warming. Landsat TM imagery reported higher land surface temperature along the corridor of development. This indicated that global warming and climate change has occurred in the study area. Also, the significant rise in temperature could create shifts in the cropping season thereby reducing yield. It was recommended that qualitative climatic data should be made available and accessible especially from weather stations for easy analysis in order to improve climate change forecasting capacity in the study area.

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