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Spatio-Temporal Occurrence of Climate Change: Evidence from Rainfall and Temperature Records in the Agro-Ecological Zones of Ondo State, Nigeria

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ABSTRACT

This paper aimed to investigate the spatio-temporal occurrences of temperature and rainfall variation across agro-ecological zones in Ondo State, Nigeria, over the period of 39 years (1979 and 2018). Ground-based rainfall and temperature series data for Ondo State were sourced across two-stations each in the three agro-ecological zones (Guinea Savanna, Rainforest and Mangrove Swamp). The Mann Kendall slope methods was adopted to determine the trends in the rainfall and temperature data. kriging interpolation to show the spatial variation in both rainfall and temperature on a four-decade spread (1979– 1988, 1989–1998, 1999–2008, and 2009-2018) across the three agro-ecological zones. The result showed that in the agroecological zones of Ondo State, temperature and rainfall variation is more pronounced than envisaged at the rates of +0.4 °C to +1.5 °C and -0.5 °C to -0.8 °C, indicating increases and decreases in temperature across the stations, while rainfall showed consistent decline at the rate of -8.79 mm to -24.50 mm in the last four decades. The decline in rainfall is particularly worrisome for the rural agrarian communities in the agro-ecological zones due to their overdependence on rainfed agriculture. It is thus important that farmers in the respective agro-ecological zones look towards adopting drought-resilient seed and seedlings as well as high-yielding varieties of crop seedlings amidst the recent trend in shortage of rainfall.

***Keyword*:** Climate Change, Rainfall, Temperature, Agro-ecological Zone, Trend, Ondo

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1. INTRODUCTION

That there is an umbilical relationship between extremes of temperature and rainfall variation and the occurrence of climate change is not an understatement. This may have informed the assertion that changing temperature and precipitation regimes are the major manifestation of global climate change (Donat et al., 2013; Lin et al., 2017). Acknowledging the implication of rising temperature and rainfall uncertainties on climate change, the Inter-governmental Panel on Climate Change (IPCC) during the conference of Parties-27 warned that the global temperature rise must be kept below 2 °C above pre-industrial levels with efforts to limit the temperature increase even further to 1.5 °C. However, existing trends shows that the global temperature may rise above its current state of 0.3-1.7 °C (0.5- 3.1 F) to 2.6-4.8 °C (4.7-8.6 F) (IPCC, 2013). Evidence showed differential pattern of rising temperature and rainfall variables in both time and space (Q. Zhang et al., 2013). Accordingly, temperature (2.1-4.7 °C) and rainfall are on the increase in part of Europe (Andrews et. al., 2012), annual total precipitation is reportedly increasing at a rate of 4.76 mm/10a in relation to declining annual maximum consecutive dry days (–3.17) in Central Asia (M. Zhang et al., 2019), downward trends in rainfall (−100 mm), but significant increasing trends in maximum and minimum temperature at the rate of 1.9 °C and 1.2 °C have been reported across East Africa (Kenya, Ethiopia and Tanzania) between 1981–2016 (Gebrechorkos et al., 2019), reduction in late austral summer precipitation over Southern Africa (James and Washington, 2013) and a significant warming of 0.5 °C and 0.8 °C has been observed in the last three decades in West Africa (Collins 2011). Evidence of climate change manifested in the form of rising temperature and rainfall uncertainties is already glaring in Nigeria. Existing report showed that, the climatological average temperature of Nigeria is on the rise from 0.3 °C to 0.6 °C (Olawepo and Enu-iyin, 2014). Climatological records between 1949-2014 already showed that temperature is significantly on the rise ($p = 0.001$) in Northern Nigeria at range of 0.04 °C/decade to 0.09 °C/decade and a declining occurrence of annual rainfall at -0.02 to -0.04 mm/decade (Hassan et al., 2017). The variations in both rainfall and temperature over time over time, follows a spatial trend within certain arbitrary boundary with sharp increase in temperature up north (Odiana and Ibrahim, 2015), and increasing variability of rainfall characterized by downpour uncertainties from the north, north-central to the southern part of Nigeria (Abaje et. al., 2016).

Ondo State, located in Southwest Nigeria, has been experiencing climate change manifested in the form of temperature and rainfall variations (Eludoyin et al., 2017). This is particularly worrisome for the agrological communities which relied on rainfed agriculture. According to Salau et al., (2016), the cultivation of fruit and cash crops in Ondo State is already been affected by annual mean rainfall and temperature variations. Thus, this paper aimed to investigate the spatio-temporal occurrences of temperature and rainfall variation across agro-ecological zones in Ondo State, Nigeria, over the period of 39 years (1979 and 2018).

2. RESEARCH METHODOLOGY

2. 1. Study Area

Ondo State is located at the core of the rainforest ecological zone in the south-western part of Nigeria. It is geographically referenced at latitude 6° 00' N to 7° 30' N; and longitude 4° 30' E to 5° 30' E (Oyedotun and Obatoyinbo, 2012). With a landmass of approximately 15,500 km^2, Ondo State comprises eighteen Local Government Areas (LGAs) namely, Akoko North-East, Akoko North-West, Akoko South-East, Akoko South-West, Akure North, Akure South, Ese Odo, Idanre, Ifedore, Ilaje, Ile Oluji/Okeigbo, Irele, Odigbo, Okitipupa, Ondo East, Ondo West, Ose, and Owo (Figure 1).

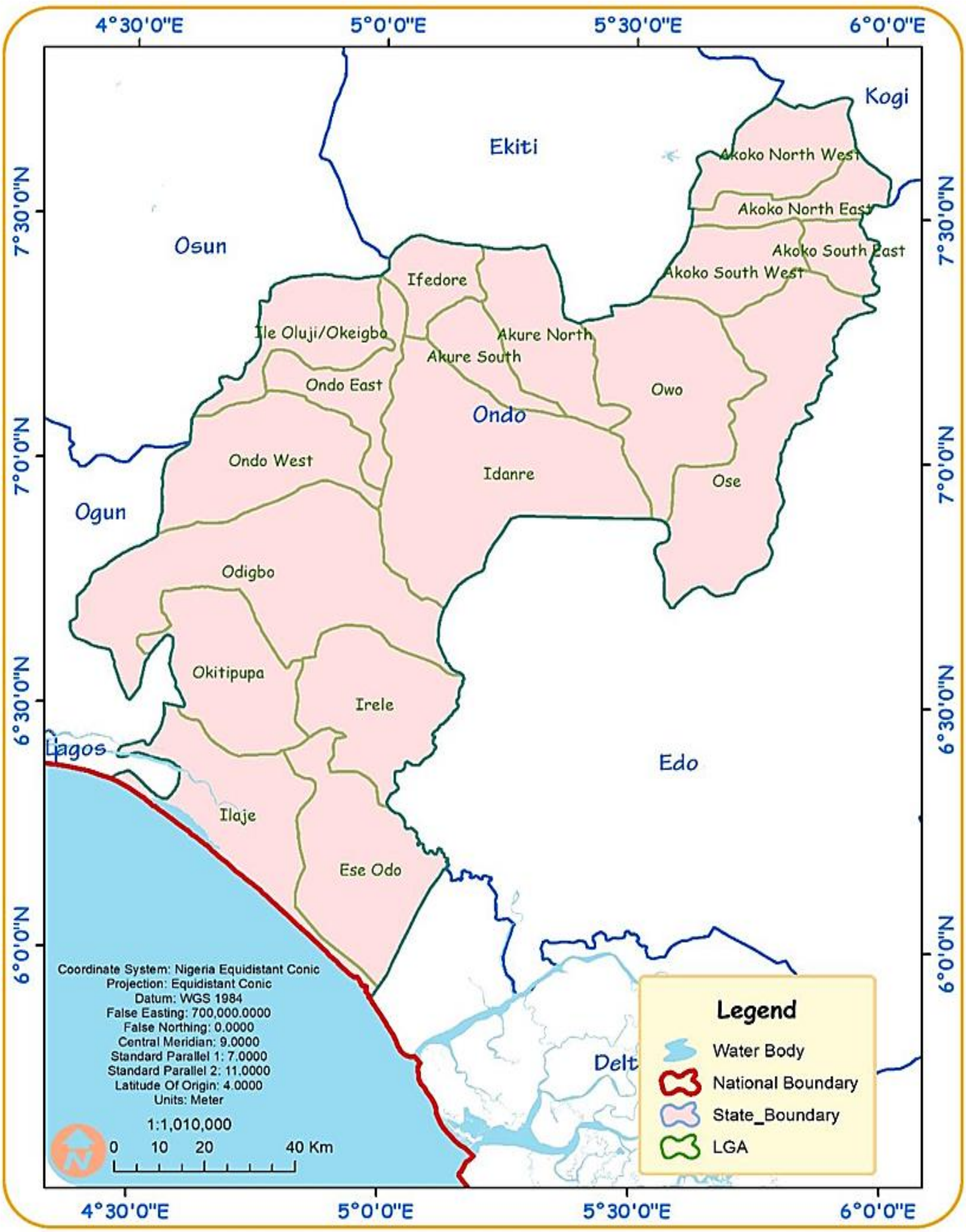


Figure 1. Map of Ondo State

The state lies within the tropical rainforest climate (Af) characterised by two distinct seasons (wet and dry), which are influenced by the tropical maritime (mT) air mass and the tropical continental (cT) air mass (Aribisala, Awopetu et al., 2015). Rainfall in the state is characterised by two peaks which are marked by heavy rainfall, with a mean annual rainfall of 1500–2000 mm. Mean, maximum, and minimum temperatures in Ondo State vary inversely with rainfall, as temperature values are higher in the dry season than the wet season. The temperature varies from 34 °C in the hottest month (February) to 26 °C in the coldest month (August) (Falola & Fakayode, 2014), while the mean annual temperature is 23-26 °C (Eludoyin et al., 2017).

The soils in the area are characterized by well-drained, loamy, sandy, and clayey soils with a medium-to-fine-grained texture that have developed predominantly from the weathering of the parent rocks, which are the basement complex rocks in the central and northern parts of Ondo State and sedimentary rock in the southern part. The state is subdivided into three ecological zones, which are coastal and mangrove swamp forest in the south, moist lowland tropical forest in the central and transitional guinea savanna in the north. The vegetation is dominated by *Melicia excelsa, Antaris africana, Terminalia superba, Lophira procera, Symphonia globulifera, Elaeis guineensis* (palm tree), and Wild Cola (*Cola gigantea*).

2. 2. Materials and Methods

Ground-based rainfall and temperature series data for Ondo State were sourced from secondary archives of the Nigeria Meteorological Agency (NIMET). The data spans the period of forty-two years between 1979 and 2018. The data were collated separately across the three different agro-ecological zones (Guniea Savanna, Rainforest and Mangrove Swamp) of Ondo State as shown in Table 1.

Table 1. The stations

S/No	Stations	LGAs	Zone
1	Isua Akoko	Akoko South-East	Guinea Savanna
2	Oka Akoko	Akoko South-West	
3	Iju-ta Ogbolu	Akure North	Rainforest Zone
4	Owena	Idanre LG	
5	Igbokoda	Ilaje	Mangrove Swamp
6	Okitipupa	Okitipupa	

The Mann Kendall slope method was adopted to determine the trends (increase or decrease) in both rainfall and temperature dataset in the study are. The Mann–Kendall statistic *S* of the series X is defined as:

$$S = \sum_{i-1}^{n-1} \sum_{j=i+1}^{n} sgn(xj - xi) \qquad \text{eq1}$$

where sgn is the signum function. The variation linked with S is computed as:

$$v(s)= \frac{n(n-1)(2n+5)-\sum_{k}^{m}=1t_k(t_k-1)(2t_{k+}5)}{18} \qquad \text{eq2}$$

where m refers to the number of tied groups and t_k refers to the number of data points in group k. In case where the sample size n > 10 as in this case (42 years), the test statistics Z(S) is computed as:

$$(S) = \begin{cases} \frac{S-1}{\sqrt{V(S)},ifS>0} \\ 0,\ ifS = 0 \\ \frac{S+1}{\sqrt{V(S)},ifS<0} \end{cases} \qquad \text{eq3}$$

Positive value of *Z(s)* indicates rising trends, whereas negative *Z(s)* value reflects declining trends. Trends are regarded remarkable if the absolute values-$|Z(s)|$ are higher than the standard normal deviate - $Z_{1-9/2}$ for the desired value of alpha ($\propto$) taken as 0.05 in this paper. The result form the Mann Kendall slope analysis was subjected to kriging interpolation to show the spatial variation in both rainfall and temperature on a four-decade spread (1979–1988, 1989–1998, 1999–2008, and 2009-2018) across the three agro-ecological zones Ondo State. This follows the principles of spatial resolution to a scale of 30m.

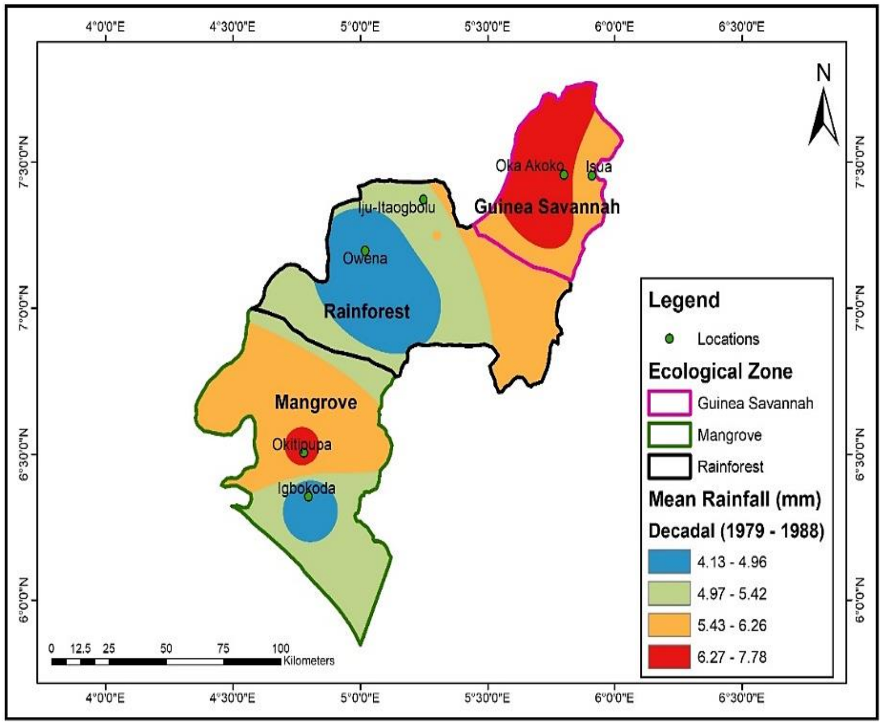
3. RESULT AND DISCUSSION

3. 1. Spatio-Temporal Trend of Rainfall

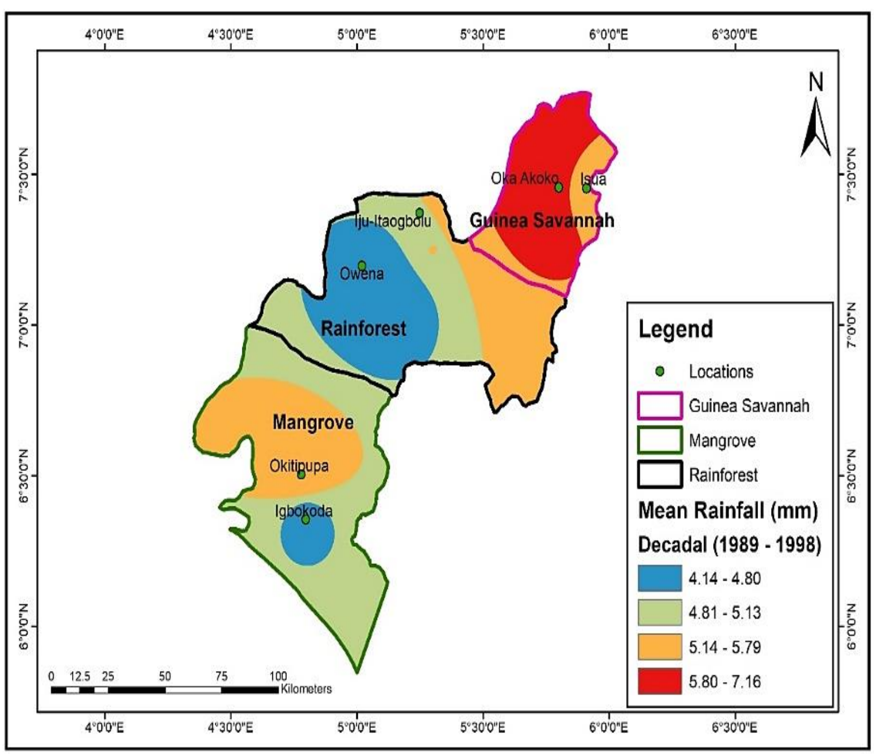
The average daily decadal rainfall occurrence in the three ecological zones varies, as shown in Figure 2. In the first decade (1979–1988), the Guinea Savanna Zone recorded high to very high average daily rainfall at the rate of 5.43–7.78 mm, while the Rainforest Zone experienced low to moderate average daily rainfall at the rate of 4.1–5.32. On the contrary, the average daily rainfall occurrence varied from low (4.13–4.96 mm) to very high (6.27–7.78 mm) in the Mangrove Swamp agro-ecological zone.

In the second decade (1989–1998), the Guinea Savanna Zone experienced a high to very high amount of average daily rainfall ranging between 5.14 and 7.16 mm, while low to moderate average daily rainfall was recorded in the Rainforest Zone. In the same vein, the mangrove swamp zone experienced low to high average daily rainfall in the range of 4.14-5.79 mm.

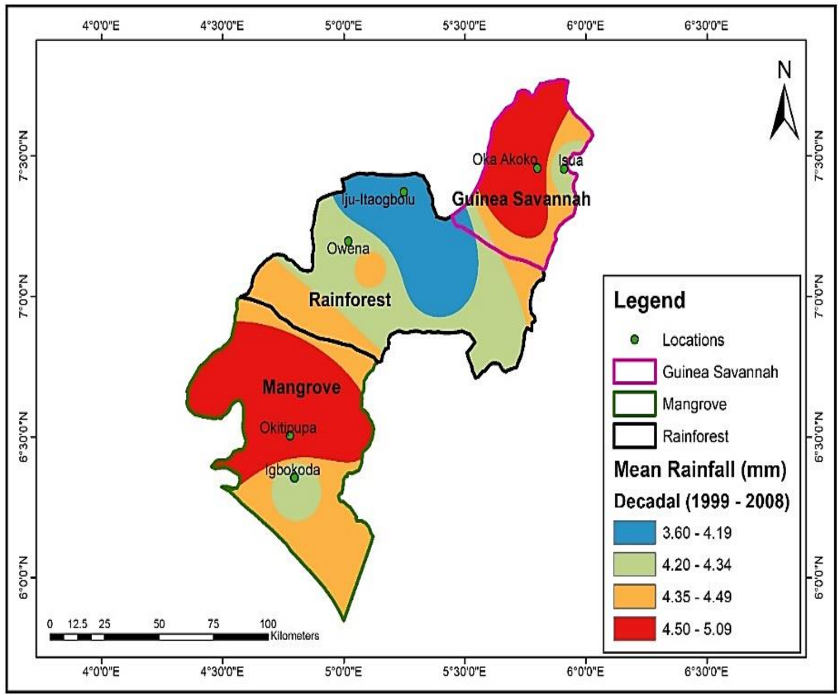
In the third decade, the Guinea Savanna Zone received a moderate to very high average daily rainfall total as opposed to the Rainforest Zone, which experienced low to moderate (3.60–4.34 mm) average daily rainfall. On the contrary, the Mangrove Swamp Zone experiences moderately high (4.20–4.49 mm) to very high (4.50–5.09 mm) average daily rainfall. The fourth decade showed much disparity in the average daily rainfall across the agro-ecological zones (Edet, 2019; Oyewole, 2019; Orabi, 2023).



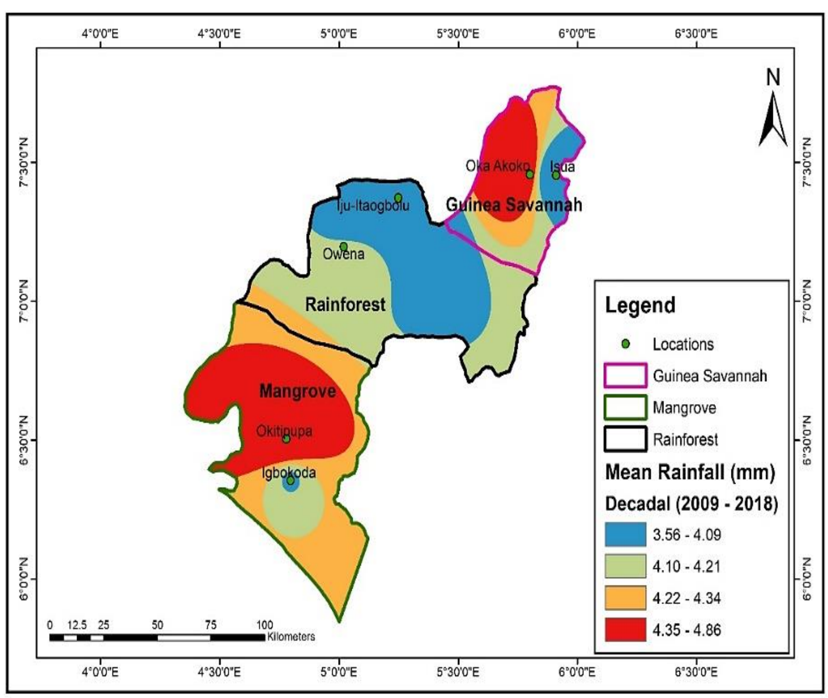
[A] First decadal average daily rainfall distribution (1979–1988)



[B] Second decadal average daily rainfall distribution (1989–1998)

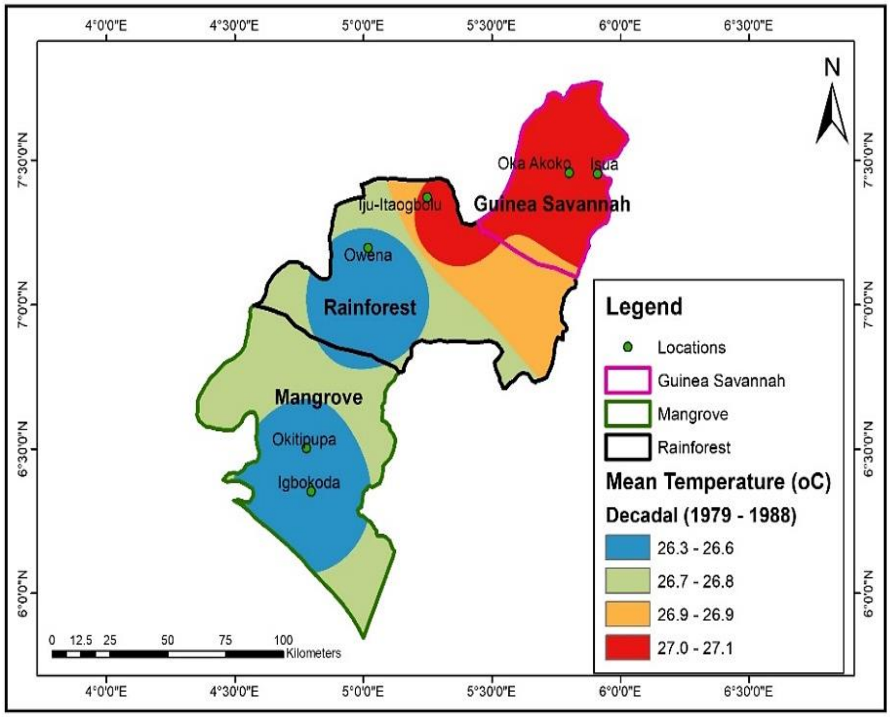


[C] Third decadal average daily rainfall distribution (1999–2008)

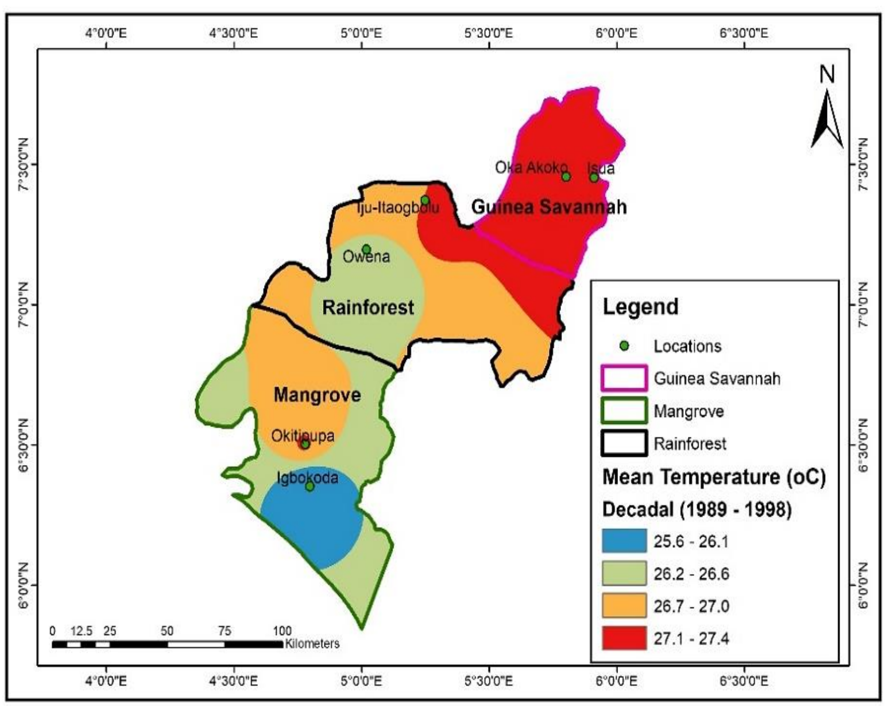


[D] Fourth decadal average daily rainfall distribution (2009-2018)

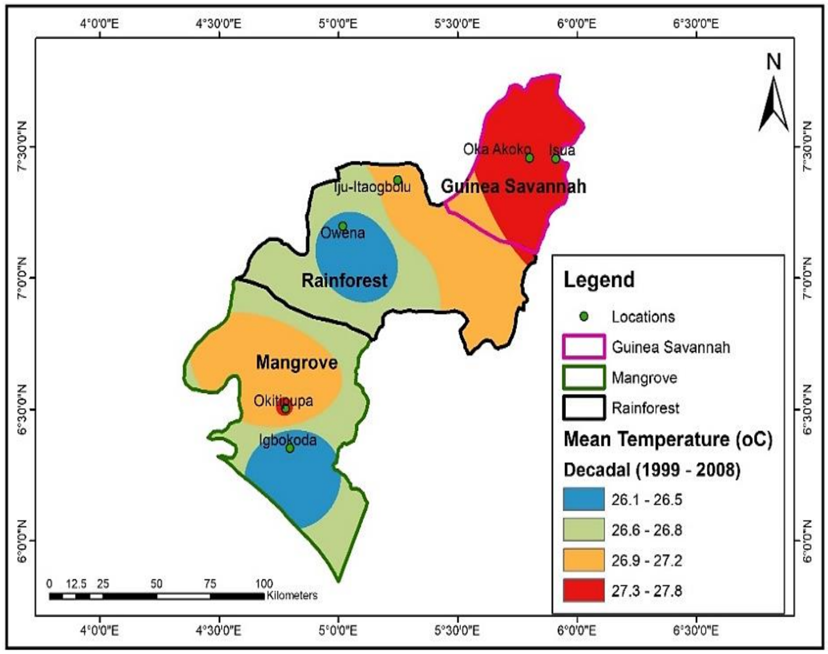
Figure 2(A,B,C,D). Spatio-temporal trend of average daily rainfall



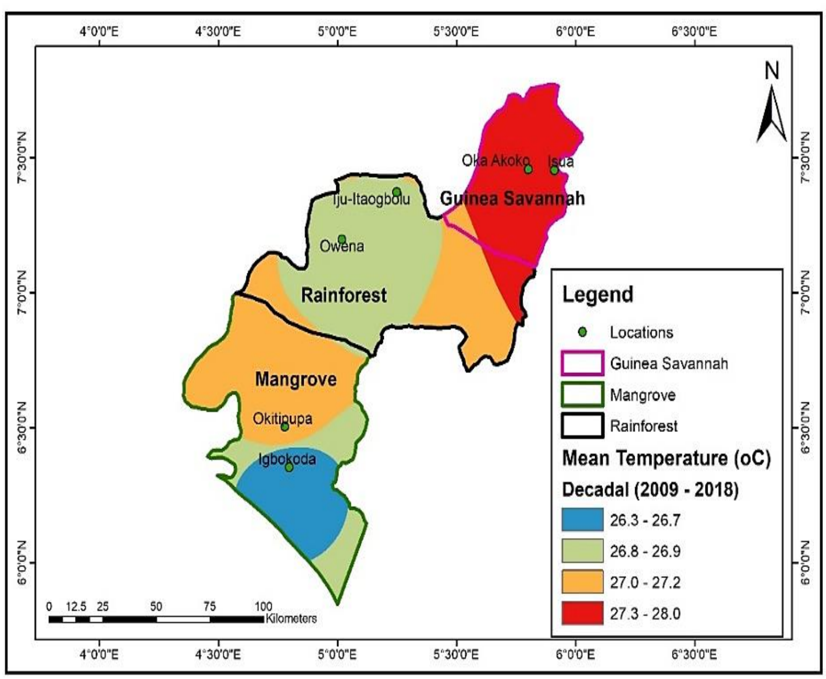
[A] First decadal average daily Temperature distribution (1979–1988)



[B] Second decadal average daily Temperature distribution (1989–1998)



[C] Third decadal average daily Temperature distribution (1999–2008)



[D] Fourth decadal average daily Temperature distribution (2009-2018)

Figure 3(A,B,C,D). Spatio-temporal trend of average daily temperature distribution

This is reflected in the result presented in Figure 2d. At one point in time, the Guinea Savanna and Mangrove Swamp Zone experienced low-moderate (3.56–4.21 mm) to high and very-high (4.22–4.86 mm) average daily rainfall, while the Rainforest Zone experiences moderate (4.10–4.21 mm) to high average (4.22–4.34 mm) daily rainfall.

The result showed that the average daily rainfall characteristics diminished temporarily from a 6.27–7.78 mm peak during the first decade to 5.80–7.16 mm, 4.50–5.09 mm, and 4.35–4.86 mm in the subsequent decades. The decrease in average daily rainfall trends is also reflected in the various agro-ecological zones. The result conforms to the assertion that rainfall events are more likely to show significant variation in both time and space (Wang, and Long, 2020).

3. 2. Spatio-Temporal Trend of Temperature

The average daily temperature recorded during the first decade varied from its peak (very high) at the range of 27–27.1 °C in the Guinea Savanna Zone to low (≤ 26.6 °C), moderate, and high (26.7–26.9 °C) in the Rainforest Zone (Figure 3). On the contrary, the Mangrove Swamp Zone experiences a low (≤ 26.6 °C) to moderate (26.7–26.8 °C) daily average temperature. Similarly, in the second decade, the average daily temperature distribution in the Guinea Savanna Zone was very high, at the range of 27.1–27.4 °C, while in the Rainforest Zone, the average daily temperature distribution varied from being moderate (26.2-26.6 °C) to high (26.7–27 °C) and very high (≥27.1 °C) in some instances. On the contrary, The Mangrove Swamp Zone recorded low (≤ 26.1 °C), moderate (26.2–26.6 °C), and high (≥27.1 °C) average daily rainfall distributions.

In the third decade, the average daily temperature distribution, the average daily temperature regime in the Guineas Savanna Zone is very high ((≥27.3 °C**)** as depicted in Figure 3c. On the contrary, the Rainforest Zone experiences a low (≤ 26.5 °C), moderate (26.6–26.8 °C) and high (27.3–27.8 °C) daily average temperature distribution. Similarly, the average daily temperature distribution in the Mangrove Swamp Zone was at the range of (≤ 26.5 °C), moderate (26.6–26.8 °C) and high (27.3–27.8 °C). Similar trend in the daily average temperature distribution in the third decade was observed in the fourth decade. The Guinea Savanna Zone experiences a very high average daily temperature distribution of ≥ 27.3 °C, while the Rainforest Zone received moderate (26.8–26.9 °C) to high (27–27.2 °C) average daily temperature distribution. On the contrary, the Mangrove Swamp Zone experiences three different daily average temperature distribution which are low (≤ 26.7 °C), moderate (26.8–26.9 °C) and high (27–27.2 °C).

The consistent variation in the decadal trends of temperature and rainfall distribution across the three agro-ecological zones showed evidence of climate change. In particular, the average daily temperature distribution in the Guinea Savanna Zone showed a significant increase during the period of investigation at a rate of +1 °C to +1.5 °C across the ground station, as depicted in Figure 4a. On the contrary, the average daily temperature distribution showed irregular variation in the Rainforest Zone with an appreciable increase of +0.4 °C in Owena Station and a decrease of -0.5 °C in Iju-Ita Ogbolu Station. A similar record was observed in the Mangrove Swamp where -0.8 °C of daily average temperature was recorded in Igbokoda Station as against 1.1 °C in Okitipupa Station (Figure 4a).

Contrary to rising temperatures recorded at some of the stations across the agro-ecological zones, average rainfall distribution was on the decline during the 39 years of investigation (Figure 4b). In the Guinea Savanna Zone, average rainfall distribution decreases in the range of

-23.44 to -24.50 mm, while in the Rainforest Zone, rainfall decreases in the range of -9.96 mm to -26.02 mm. In the mangrove Swamp Zone, significant decrease in average daily rainfall total was also observed in the range of -8.79 mm to -21.74 mm.

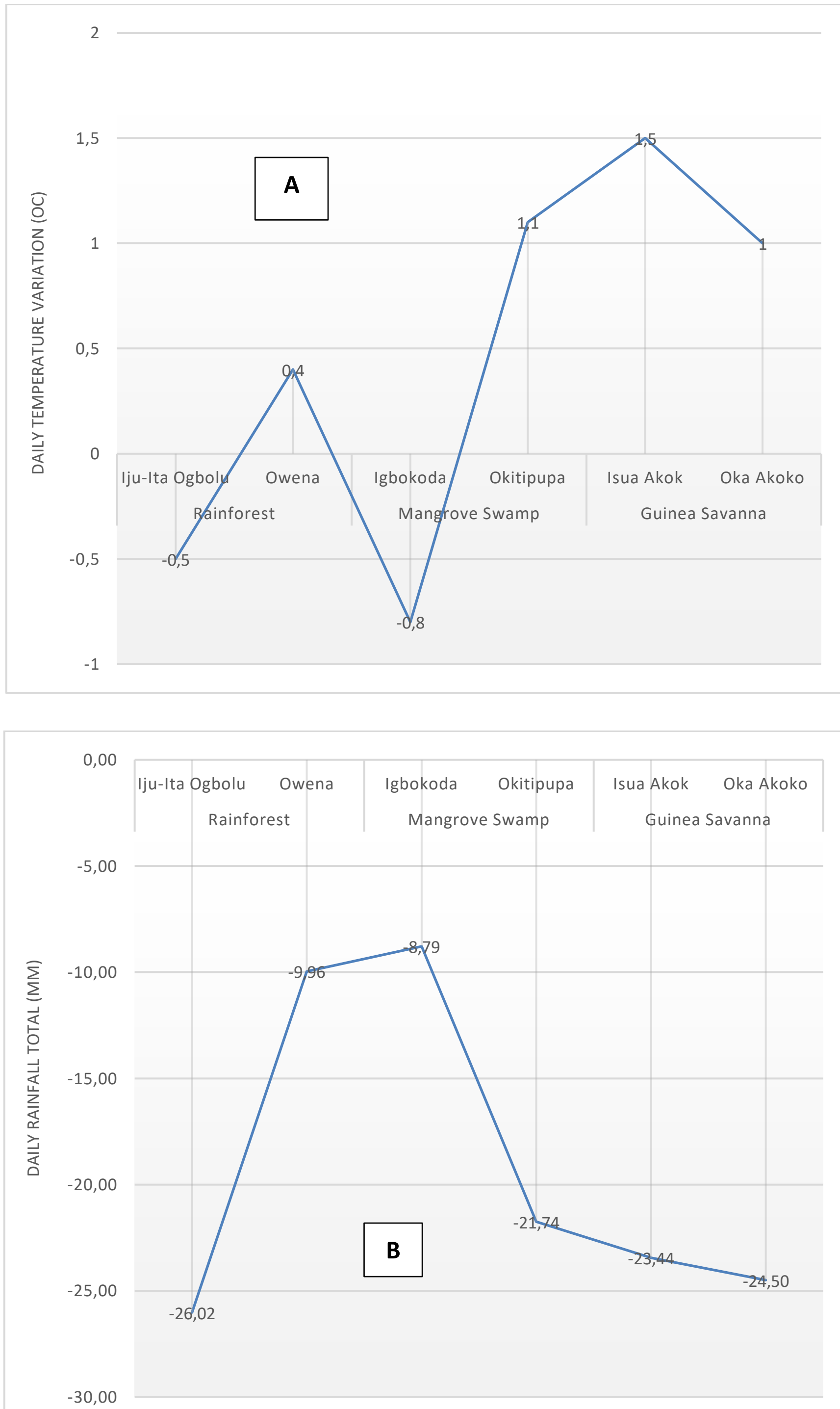


Figure 4(A,B). Changes of temperature and rainfall variation between 1979-2018.

4. CONCLUSION AND RECOMMENDATION

The result of this study consolidated the findings that climate change is evident in Nigeria and that its manifestations are in the form of changing temperatures and rainfall regimes. In the northern part of Nigeria, there is already evidence of increasing temperatures in the range of 0.04 °C/decade to 0.09 °C/decade and a declining occurrence of annual rainfall at -0.02 to -0.04 mm/decade (Hassan et al., 2017). This study has shown that in the agroecological zones of Ondo State, temperature and rainfall variation is more pronounced than envisaged at the rates of +0.4 °C to +1.5 °C and -0.5 °C to -0.8 °C, indicating increases and decreases in temperature across the stations, while rainfall showed consistent decline at the rate of -8.79 mm to -24.50 mm in the last four decades. The decline in rainfall is particularly worrisome for the rural agrarian communities in the agro-ecological zones due to their overdependence on rainfed agriculture. It is thus important that farmers in the respective agro-ecological zones look towards adopting drought-resilient seed and seedlings as well as high-yielding varieties of crop seedlings amidst the recent trend in shortage of rainfall.

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