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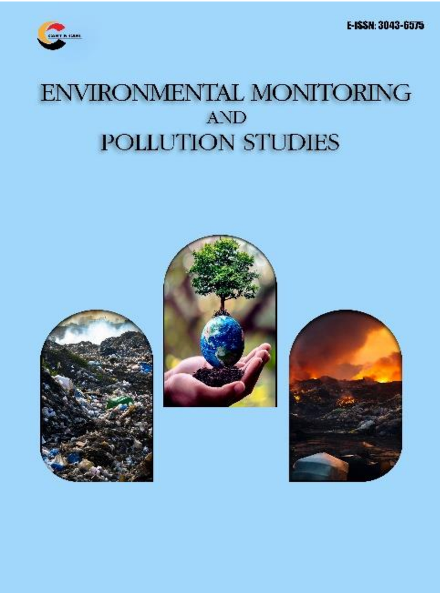


# Climate Chronicles: A Temporal Study of Precipitation, Temperature, and Wind in the Niger Delta

**Authors**

[a] Eleraobari, N. E., [a] Weli, V. E., [a] Nwagbara, M. O.

[a] Department of Geography and Environmental Management, University of Port Harcourt, Port Harcourt, Nigeria

**Corresponding Author**

Eleraobari, N. E.

(akinity2000@yahoo.com)

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## Abstract

This study presents a comprehensive analysis of precipitation, temperature, and wind pressure dynamics across Nigeria's Niger Delta from 1990 to 2023. Using a longitudinal research approach, satellite-derived climate data (ERA5 for temperature/wind pressure; CHIRPS for precipitation) was integrated with geospatial analytics to assess spatiotemporal trends in seven states: Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Ondo, and Rivers. Daily climate variables were aggregated into annual mea ns and analyzed via descriptive statistics and trend mapping. Findings reveal three core climatic shifts: Precipitation exhibited high intra-regional variability, with coastal cities (Calabar, Yenagoa) maintaining consistently high rainfall (6.5–9.4 mm/day) but experiencing intensified extremes (e.g., Yenagoa's 2021 peak: 9.35 mm/day). Inland areas (Akure, Benin) showed declining trends post-2000, punctuated by periods of reduced precipitation (2013–2015) and erratic recovery phases. Temperature demonstrated constant warming, with mean annual increases of 1.5–2.0°C region wide. The 2020s marked the warmest period, evidenced by unprecedented peaks (Uyo: 27.72°C in 2020; Yenagoa: 27.96°C in 2020), aligning with global heating trend. Wind pressure displayed episodic volatility, lacking a directional trend but featuring record anomalies. The 2015 peak (101,189–101,240 Pa across stations) contrasted sharply with 2008 lows (101,070–101,078 Pa), reflecting sensitivity to mesoscale atmospheric oscillations. The convergence of these trends—increasing rainfall irregularity, accelerated warming, and wind volatility—has profound implications such as flooding and saltwater intrusion threaten coastal settlements. These findings underscore the Niger Delta's acute vulnerability to anthropogenic climate change and necessitate integrated adaptation strategies prioritizing water-resilient infrastructure, heat-responsive urban design, and early-warning systems for hydro-meteorological hazards.

**Keywords**: Climate Variability, Precipitation Trends, Temperature Anomalies, Wind Pressure, Longitudinal Analysis, Climate Adaptation

## Introduction

Climate and weather patterns are central to the functioning of natural ecosystems and human societies (Ummenhofer & Meehl, 2017). Variations in key atmospheric elements—such as precipitation, temperature, and wind—have profound implications for agriculture, water resources, energy production, public health, and infrastructure (Si & Li, 2024). Over the past few decades, scientists and policymakers have grown increasingly concerned with the temporal dynamics of these climatic variables, recognizing that even subtle shifts can trigger significant environmental and socioeconomic consequences (Liang & Gong, 2017; Wagener & Pianosi, 2019). The global climate system is inherently complex and dynamic, influenced by natural cycles as well as anthropogenic factors that have intensified in recent years, including greenhouse gas emissions, land-use changes, and industrialization (Petrov et al., 2023; Frank et al., 2015).

Monitoring temporal changes in climate variables is crucial for understanding both long-term trends and short-term fluctuations (Liu & Menzel, 2016). Precipitation patterns determine the availability of freshwater and the health of agricultural systems, while temperature influences biological processes, disease vectors, and energy demands (Yadav & Upadhyay, 2023; Coffey et al., 2019). Wind pressure and circulation affect atmospheric transport, sea-level conditions, and extreme weather events. Together, these variables interact to shape regional climates, which in turn influence the vulnerability and adaptive capacity of communities. In light of accelerating climate change, studying the temporal variability of these elements across different geographies has become essential for effective environmental management and sustainable development.

In this context, the Niger Delta region of Nigeria represents a critical case study. As one of Africa's most densely populated and ecologically complex regions, the Niger Delta is highly sensitive to climatic variations. It serves as a hub for petroleum extraction and export, hosts a variety of wetland and mangrove ecosystems, and supports millions of people whose livelihoods are tied to fishing, farming, and trade. However, the region also faces mounting environmental challenges—including seasonal flooding, coastal erosion, salinization, and temperature-induced crop stress—which are intricately linked to changes in weather and climate conditions.

This study, therefore, seeks to explore the temporal evolution of three fundamental climatic parameters—precipitation, temperature, and wind pressure—across the Niger Delta. By employing longitudinal climate data, the research aims to uncover seasonal and interannual trends, detect anomalies, and identify possible indicators of climate change within the region. Understanding these dynamics is vital not only for academic and scientific inquiry but also for guiding local adaptation strategies, infrastructure design, and policy interventions that enhance the resilience of the region's people and ecosystems. Through this climate chronicle, the study contributes to the broader discourse on regional climate monitoring in sub-Saharan Africa, emphasizing the need for location-specific evidence to support proactive environmental governance. In doing so, it highlights the urgency of integrating climate science into planning frameworks for regions vulnerable to both natural and human-induced climatic stressors.

## Materials and Method

This study adopted a longitudinal research design to examine the temporal dynamics of three core climatic elements—precipitation, temperature, and wind pressure—across the Niger Delta from 1990 to 2023. A longitudinal design was particularly suitable for this research as it enabled the observation of trends and patterns over an extended period, allowing for a robust understanding of how atmospheric conditions have evolved in response to natural variability and human-induced factors such as urbanization. By spanning a 33-year period, the study captured both short-term fluctuations and long-term climate shifts, offering critical insights into the progression of environmental changes in the region.

The study area comprised the seven states commonly identified as forming the Niger Delta Region (NDR): Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Ondo, and Rivers. Geographically, the region is situated between latitudes 4.15°N and 7.17°N and longitudes 5.05°E and 8.68°E, covering a total land area of approximately 112,110 km², which represents about 12% of Nigeria's total landmass. The Niger Delta lies in the southern part of Nigeria and includes low-lying terrain characterized by mangrove forests, wetlands, and estuarine ecosystems (Figure 1).

Data collection was conducted using the Google Earth Engine (GEE) platform, which enabled access to high-resolution, long-term satellite datasets. Three primary datasets were utilized: the ERA5 Daily Aggregated dataset for temperature and wind pressure (represented by mean sea level pressure), and the CHIRPS Daily dataset for precipitation. These datasets were selected due to their global coverage, temporal consistency, and reliability for climate studies. Predefined geographic coordinates were used to extract localized data from representative cities within the region, including Port Harcourt, Yenagoa, Uyo, Calabar, Benin, Asaba, and Akure. This approach ensured spatial representativeness and facilitated an in-depth examination of intra-regional climatic variation.

The data extraction process in GEE involved applying filters to isolate relevant daily climate records for each location across the 33-year study period. Air temperature data were converted from Kelvin to Celsius to align with standard meteorological reporting. Wind pressure values were maintained in Pascals (Pa), and precipitation was recorded in millimeters (mm). The daily values were aggregated to generate annual means for each variable, enabling a consistent comparison of temporal trends. The processed data were then exported as CSV files for further analysis in spreadsheet and statistical software environments.

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Figure 1: Map showing Study and its Environs
Researcher's analysis 2025

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Following data collection, preprocessing steps were undertaken to verify the structure and integrity of the dataset. This included checking for missing or anomalous values and ensuring consistency in date formats. Descriptive statistical analyses were then carried out to determine the mean, minimum, and maximum values of each variable for each year and location. These statistical summaries facilitated the identification of temporal patterns and spatial differences in climate behavior across the Niger Delta. The analysis also highlighted periods of climatic anomalies and potential shifts indicative of broader climate change processes.

This methodological framework provided a comprehensive and data-driven basis for examining the temporal variability of key atmospheric elements in the Niger Delta. By combining high-resolution satellite data, advanced geospatial tools, and longitudinal analysis, the study offered a rigorous approach to understanding how the region's climate has evolved over the past three decades.

## Results

### Temporal Variation in Precipitation Across Niger Delta

#### Akure

The data on mean precipitation (mm/day) for Akure from 1990 to 2023 (Figure 2) indicate a fluctuating pattern of rainfall over the years, reflecting changes in local climatic conditions and potential influences of broader climatic phenomena, such as El Niño and La Niña, as well as human activities like urbanization. The variability in precipitation highlights notable peaks in years such as 1995 (4.87 mm/day), 2009 (4.35 mm/day), and 2018 (4.26 mm/day), indicating periods of higher rainfall compared to the overall average. Conversely, years like 2001 (3.02 mm/day) and 2013 (3.01 mm/day) experienced lower precipitation, suggesting drier conditions. These fluctuations suggest complex interactions between natural and anthropogenic factors.

Over the decades, distinct patterns emerge. The 1990s displayed moderate variability, with mean precipitation ranging from 3.39 mm/day in 1993 to 4.87 mm/day in 1995. In the 2000s, a decline in precipitation is evident, though there were some years with slight recovery, such as 2009. In the 2010s, an increasing trend becomes noticeable in the latter half, with higher precipitation in 2018 and 2019. The most recent years, from 2020 to 2023, demonstrate relative stability, with values fluctuating between 3.17 mm/day in 2020 and 4.27 mm/day in 2022. This apparent stabilization phase contrasts with the fluctuations observed in earlier decades and warrants further exploration.

#### Asaba

The data on mean precipitation (mm/day) for Asaba from 1990 to 2023 (Figure 3) reveal notable variability over the years, reflecting shifts in climatic conditions and environmental factors. The precipitation levels fluctuate significantly, with peak values recorded in 1995 (6.19 mm/day) and consistently high values in years like 1991 (5.42 mm/day) and 2008 (5.21 mm/day). These peaks highlight years of substantial rainfall, potentially influenced by global climatic phenomena or local environmental conditions. In contrast, years such as 2015 (3.78 mm/day) and 2020 (3.84 mm/day) demonstrate periods of reduced precipitation, suggesting drier spells that may have implications for water availability and agricultural productivity in the region.

A closer examination of the decades shows interesting trends. The 1990s exhibit relatively high precipitation levels, with fluctuations around 4.40 to 6.19 mm/day. This period includes some of the highest mean rainfall values, indicating a decade of wetter conditions. The 2000s show a slight decline in precipitation variability, with values generally stabilizing between 4.31 and 5.20 mm/day. The 2010s, however, exhibit a mixed pattern, with some years like 2018 (5.19 mm/day) reflecting increased rainfall, while others, such as 2015 and 2013, show significantly reduced precipitation. From 2020 to 2023, the data indicate a return to drier conditions, with values ranging from 3.84 to 4.69 mm/day, suggesting a potential shift in climatic trends.

These patterns underscore the complexity of precipitation dynamics in Asaba, likely influenced by both natural and anthropogenic factors. Urbanization and land-use changes may have played a role in modifying local microclimates, potentially impacting rainfall distribution. Furthermore, the influence of broader climatic drivers, such as seasonal atmospheric circulation changes and oceanic oscillations, cannot be overlooked. These fluctuations in precipitation have significant implications for water resource management, agriculture, and flood risk mitigation. Years with high rainfall may increase the likelihood of flooding, particularly in low-lying areas, while periods of reduced rainfall could strain water supply systems and limit agricultural output.

The variability observed over this 33-year period highlights the need for consistent monitoring and research to understand the underlying causes of these trends. Detailed studies investigating the interaction between local environmental factors and global climatic influences would provide valuable insights. Proactive planning is essential to address the challenges posed by these fluctuations, including developing infrastructure that can adapt to both excessive rainfall and water scarcity. By aligning urban development with sustainable water management practices, Asaba can better cope with the risks and opportunities associated with its precipitation dynamics.

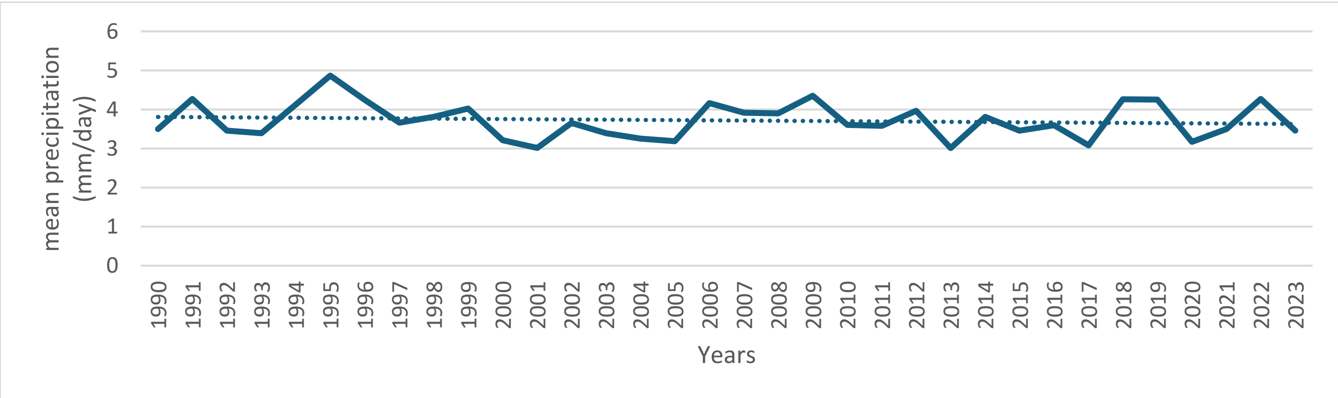


Figure 2. Mean Precipitation (mm/day) in Akure from 1990 to 2023

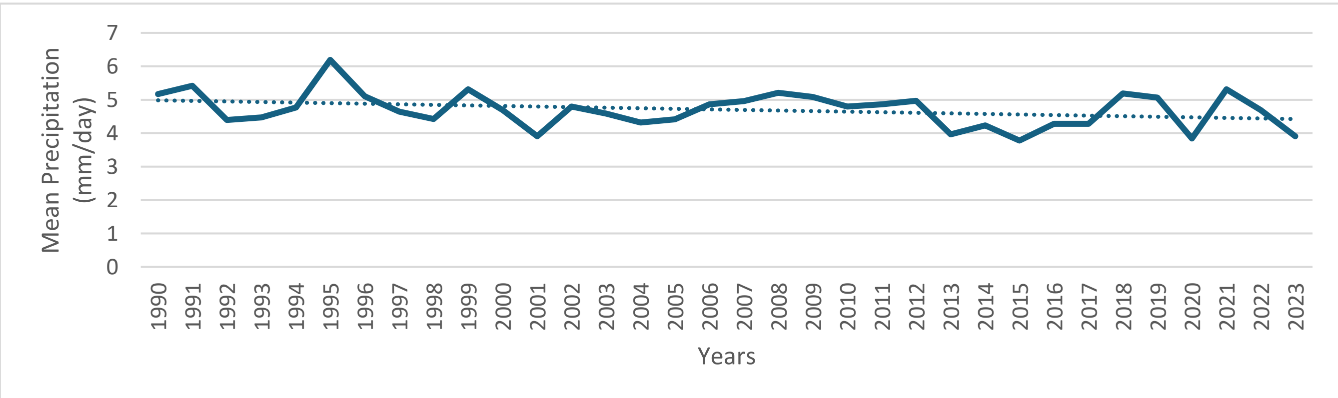


Figure 3. Mean Precipitation (mm/day) in Asaba from 1990 to 2023

**Benin**

The mean precipitation data for Benin from 1990 to 2023 (Figure 4) highlight significant variability in rainfall over the 33-year period, suggesting a dynamic climate influenced by multiple factors. Peak rainfall years such as 1995 (6.74 mm/day) and 2009 (6.62 mm/day) stand out as periods of notably high precipitation, potentially linked to regional climatic conditions or broader global phenomena. These years of increased rainfall contrast with drier periods such as 2001 (3.95 mm/day) and 2015 (4.21 mm/day), where reduced precipitation likely posed challenges for water resource management and agriculture in the region.

The 1990s appear to be a period of higher variability, with mean precipitation ranging from 4.66 mm/day in 1998 to 6.74 mm/day in 1995, indicating significant fluctuations in annual rainfall. The early 2000s show a slight decline in rainfall variability, with values stabilizing around 4.60 to 5.63 mm/day. However, the late 2000s mark a return to wetter conditions, with 2009 recording one of the highest mean precipitation levels. The 2010s exhibit more moderate rainfall, with occasional dry years such as 2013 (4.25 mm/day) and 2015 interrupting an otherwise stable trend. In the most recent years, from 2020 to 2023, rainfall levels appear to decline again, with values falling to 4.37 mm/day in both 2020 and 2023, suggesting a possible shift toward drier conditions.

This variability in precipitation reflects the complex interplay between natural climatic drivers and human activities. Factors such as seasonal atmospheric patterns, oceanic influences, and land-use changes likely contribute to these fluctuations. Urbanization in Benin, coupled with deforestation and other anthropogenic activities, may have altered local microclimates, influencing rainfall patterns over the years. These changes have far-reaching implications for agriculture, water management, and flood control, particularly in years of extreme precipitation.

**Calabar**

The mean precipitation data for Calabar from 1990 to 2023 (Figure 5) showcase a consistent pattern of relatively high rainfall over the years, with some notable fluctuations. The highest recorded precipitation occurred in 1996, with a mean of 8.62 mm/day, followed closely by other high rainfall years such as 1995 (8.50 mm/day) and 2006 (8.72 mm/day). These years of intense rainfall contrast with periods of lower precipitation, such as 2020 (6.94 mm/day) and 2003 (6.53 mm/day), which suggest some variability in the annual rainfall patterns. Despite these fluctuations, the general trend for Calabar shows a relatively high and stable level of precipitation over the years, with most values ranging from 6.5 mm/day to 8.7 mm/day.

Throughout the 1990s, precipitation levels remained high, with values above 7 mm/day, peaking in 1996. This period could be indicative of favorable climatic conditions conducive to higher rainfall. The early 2000s also saw significant rainfall, with many years like 2002 (7.47 mm/day) and 2005 (8.15 mm/day) reflecting relatively high precipitation levels. However, there was some decline in the mid-2000s, with 2003 and 2008 showing lower figures, but still above 6.5 mm/day. This continued into the 2010s, where precipitation levels generally remained steady, with values frequently hovering around 7.5 to 8.7 mm/day. Notably, years such as 2011 (8.70 mm/day) and 2019 (8.51 mm/day) show the region's capacity to experience considerable rainfall in certain years.

The more recent years, from 2020 to 2023, show some reductions in precipitation, with 2020 recording the lowest value (6.94 mm/day) within the period under review. This decline could be attributed to various factors, including changes in global climatic conditions, regional atmospheric shifts, or local environmental changes. However, despite these drops, the precipitation levels in Calabar remain relatively high compared to other regions. The data suggest that the city continues to receive ample rainfall, making it conducive to lush vegetation and supporting agricultural activities that rely on consistent precipitation.

**Port Harcourt**

The mean precipitation data for Port Harcourt from 1990 to 2023 (Figure 6) show consistent rainfall throughout the period, with some noticeable fluctuations. In the early years, Port Harcourt experienced relatively high precipitation, with values like 1991 (6.43 mm/day) and 1995 (7.49 mm/day) marking some of the wetter years in the dataset. These higher precipitation levels were consistent with the generally humid and rainy climate of the region. The year 1999 stands out with a peak of 7.45 mm/day, reflecting a period of particularly intense rainfall, which likely had implications for local water availability and flood risks.

The data show that the precipitation levels remained fairly stable throughout the 1990s and early 2000s, with average values oscillating around 6 mm/day. There was a noticeable decrease in precipitation during 2001 (5.38 mm/day) and 2005 (5.78 mm/day), though these were followed by periods of higher rainfall in subsequent years. For instance, 2006 (6.74 mm/day) and 2007 (6.37 mm/day) were wetter years, continuing the alternating pattern of relatively dry and wet periods. These fluctuations indicate some level of variability, likely influenced by regional climatic factors, but overall, Port Harcourt maintained a high level of precipitation.

As the data progresses into the 2010s, precipitation patterns in Port Harcourt became more irregular. While the majority of the years within this decade continued to receive significant rainfall, with 2009 (6.90 mm/day) and 2011 (6.76 mm/day) experiencing higher levels, there were dips, such as in 2014 (4.98 mm/day) and

2015 (4.85 mm/day), marking some of the lowest precipitation values in the entire dataset. These dips may be attributed to fluctuations in atmospheric conditions, possibly linked to El Niño events or other climate phenomena affecting the region. However, these low years were followed by a rebound, with 2016 (6.45 mm/day) showing a recovery in precipitation levels.

The most recent years, from 2018 to 2023, indicate a return to higher rainfall, with 2019 (7.22 mm/day) reaching one of the highest values in the period under review. This suggests that despite occasional dry spells, the overall trend for Port Harcourt has remained within a relatively high precipitation range, characteristic of tropical climates. The year 2023 (6.74 mm/day) was one of the wetter years, aligning with the general trend of steady rainfall observed in the region over the past few years.

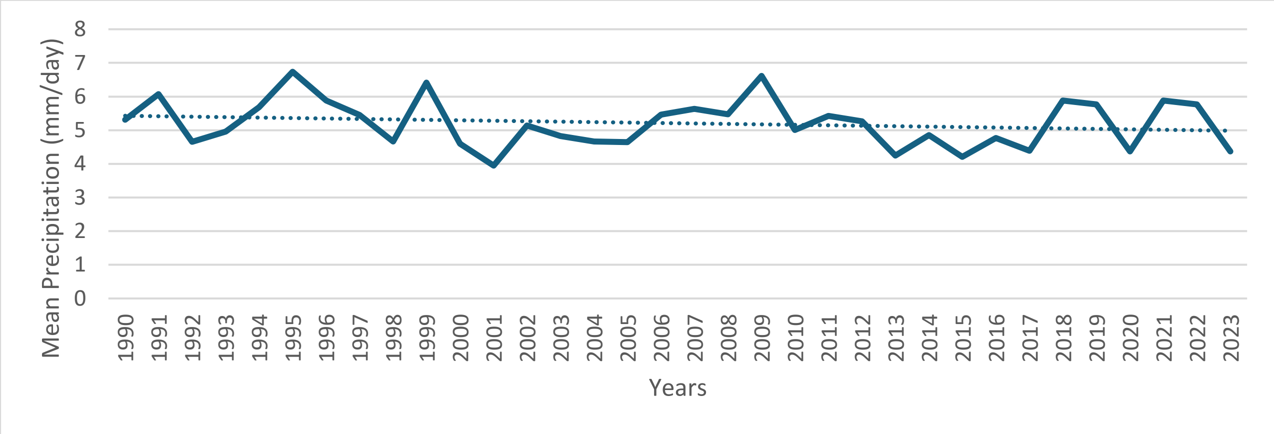


Figure 4. Mean Precipitation (mm/day) in Benin from 1990 to 2023

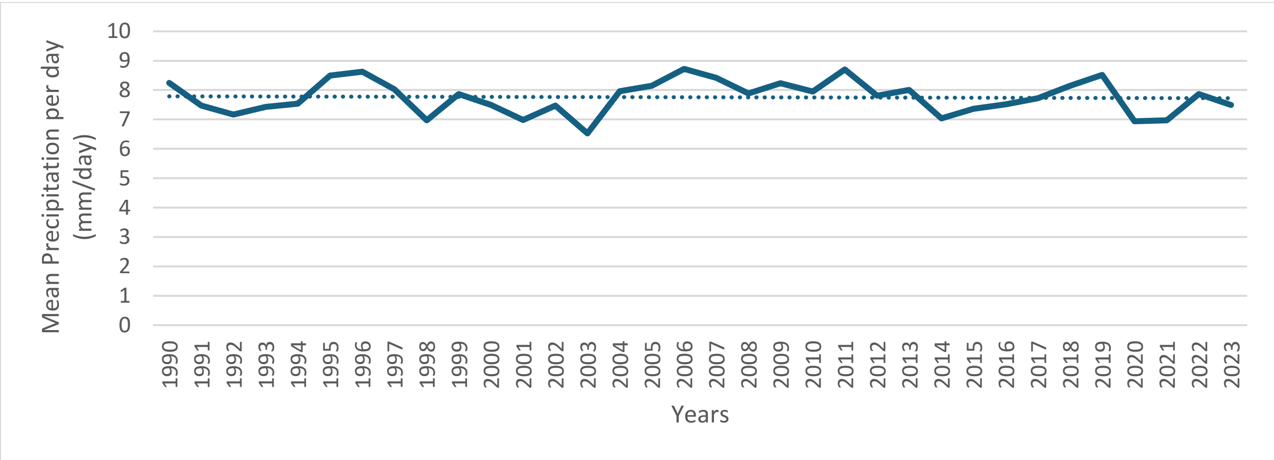


Figure 5. Mean Precipitation (mm/day) in Calabar from 1990 to 2023

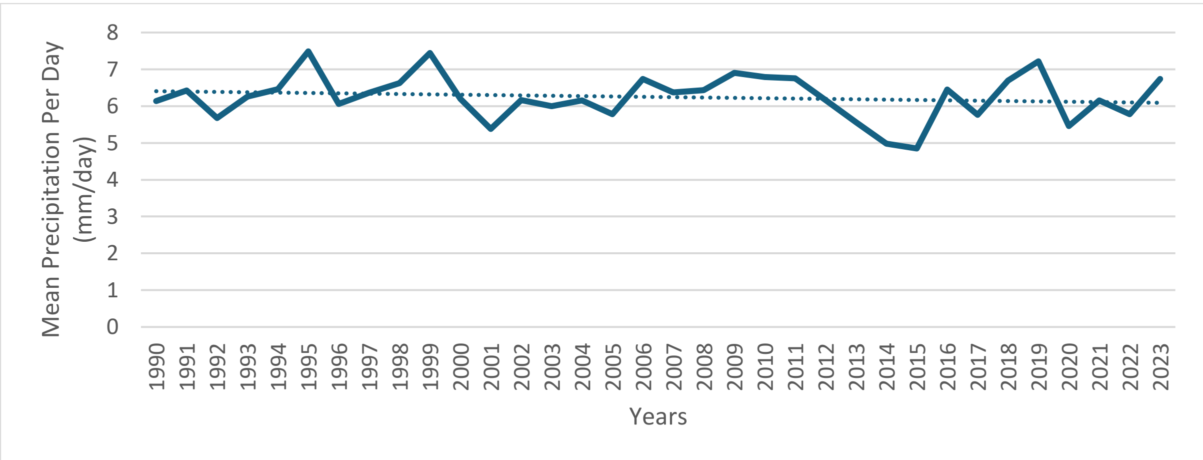


Figure 6. Mean Precipitation (mm/day) in Port Harcourt from 1990 to 2023

**Uyo**

The mean precipitation data for Uyo from 1990 to 2023 (Figure 7) exhibit a generally high level of rainfall throughout the period, typical of tropical climates. The early years, such as 1990 (6.73 mm/day) and 1991 (6.87 mm/day), indicate relatively high rainfall, with the data showing a pattern of consistent precipitation. In particular, 1995 (7.53 mm/day) stands out as one of the wettest years, marking a significant peak in the rainfall for the region. This is followed by 1996 (7.13 mm/day) and 1999 (7.38 mm/day), which also show high precipitation values, reinforcing the idea of a generally wet climate in Uyo.

The following years also continued to show high precipitation, though with some variations. For example, in 2000 (6.36 mm/day) and 2001 (5.78 mm/day), there was a slight dip in rainfall compared to earlier years. However, this was short-lived as rainfall levels returned to higher averages in subsequent years. The years 2004 (6.78 mm/day) and 2007 (7.35 mm/day) were notably wet, demonstrating a return to above-average rainfall. This period, characterized by higher rainfall, continued into the 2010s with several years like 2010 (6.99 mm/day) and 2011 (7.71 mm/day) showing significant precipitation.

However, towards the middle of the 2010s, there was a slight decrease in rainfall, with 2014 (6.03 mm/day) and 2015 (5.99 mm/day) being among the lower precipitation years in the dataset. Despite this dip, rainfall levels generally remained steady and close to the historical average, indicating Uyo's climate remained relatively stable. By 2017 (6.23 mm/day) and 2018 (6.99 mm/day), rainfall levels bounced back to higher levels, suggesting a return to more typical rainfall conditions for the region.

In the later years, Uyo continued to experience relatively high rainfall, with 2019 (7.75 mm/day) marking another peak year. This trend persisted through 2020 (5.82 mm/day), where there was a slight reduction, but still, the overall values remained consistent. The data shows that in 2021 (7.35 mm/day), Uyo experienced another wetter year, and the precipitation levels in 2022 (6.72 mm/day) and 2023 (6.87 mm/day) remained relatively stable, following a consistent pattern of rainfall in the region.

Overall, the data indicates that Uyo's climate has remained consistently wet, with only moderate fluctuations in precipitation. Although there are slight variations in rainfall from year to year, such as the dips in the mid-2010s, the region consistently experiences rainfall that supports a humid environment. The occasional peaks, such as in 1995, 2011, and 2019, further demonstrate the variability within a generally wet climate, which may have implications for water availability, agriculture, and flood management in the region.

**Yenegoa**

The mean precipitation data for Yenagoa from 1990 to 2023 (Figure 8) reveal a generally high level of rainfall, with the region experiencing frequent rainfall throughout the entire period. The earliest years, such as 1990 (8.57 mm/day) and 1991 (7.80 mm/day), show high precipitation levels, indicating a wet climate. The year 1995 (9.37 mm/day) stands out as an exceptionally wet year, with rainfall significantly above the average for the period, followed by similarly high precipitation values in 1999 (9.30 mm/day). These years demonstrate the variability in rainfall patterns, where certain years experienced heavy downpours.

In the following years, rainfall levels remained high, with some fluctuations. For example, in 2000 (7.50 mm/day) and 2001 (6.31 mm/day), the region experienced a decrease in precipitation, with the values dipping below the historical average for the period. However, this reduction was temporary, as rainfall levels increased again in the mid-2000s, with 2004 (7.60 mm/day) and 2005 (6.82 mm/day) showing a slight dip but still maintaining above-average precipitation overall. This trend continued with 2006 (8.25 mm/day) and 2007 (7.72 mm/day), which recorded near-average rainfall.

From 2008 onwards, Yenagoa experienced another series of wet years, such as 2008 (8.43 mm/day) and 2009 (9.35 mm/day), with some years reaching or surpassing 9 mm/day, further indicating the region's persistently high rainfall. Notably, the years 2011 (8.93 mm/day) and 2019 (8.86 mm/day) saw slightly higher precipitation levels, supporting the notion of relatively stable rainfall patterns in Yenagoa. However, during 2014 (6.61 mm/day) and 2015 (6.21 mm/day), there was a noticeable decline in precipitation, reflecting some level of variability in the rainfall.

In the later years, rainfall in Yenagoa showed a resurgence, with the values returning to higher levels by 2016 (8.09 mm/day) and 2017 (7.67 mm/day). These years were followed by consistently wet conditions in 2018 (8.86 mm/day) and 2019 (8.86 mm/day), again indicating a trend of high precipitation. The year 2021 (9.35 mm/day) was another particularly wet year, matching the levels seen in the late 1990s and early 2000s. The final years in the data, 2022 (8.63 mm/day) and 2023 (8.93 mm/day), continued to show a return to high precipitation values, keeping the region's rainfall pattern in line with its historical averages.

Overall, the data indicates that Yenagoa has experienced a consistently high level of precipitation over the past three decades, with only moderate fluctuations. Despite occasional dips in rainfall, particularly in the mid-2010s, the region's climate remains characterized by significant rainfall, which is typical for the tropical climate of Yenagoa. The variability in the data suggests that while certain years might experience less rainfall, the overall trend remains one of substantial precipitation, which has important implications for water resources, agriculture, and flood management in the region.

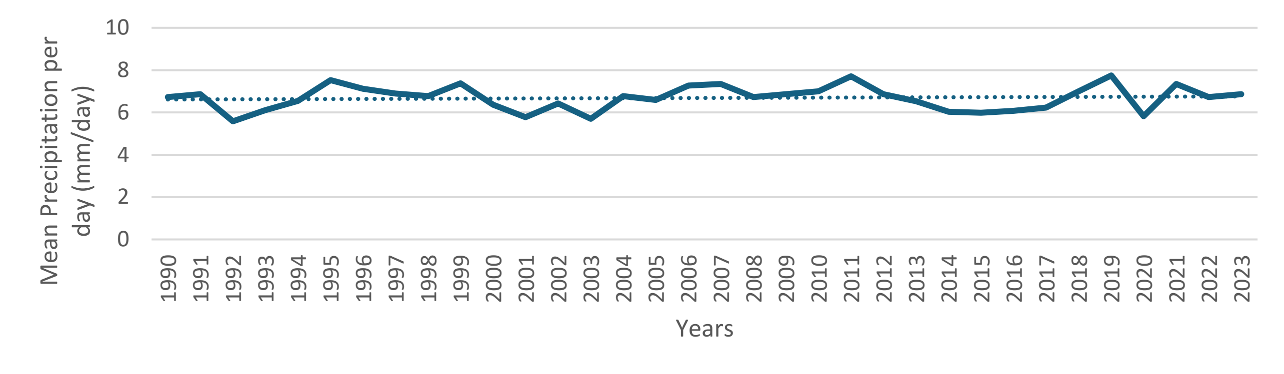


Figure 7. Mean Precipitation (mm/day) in Uyo from 1990 to 2023

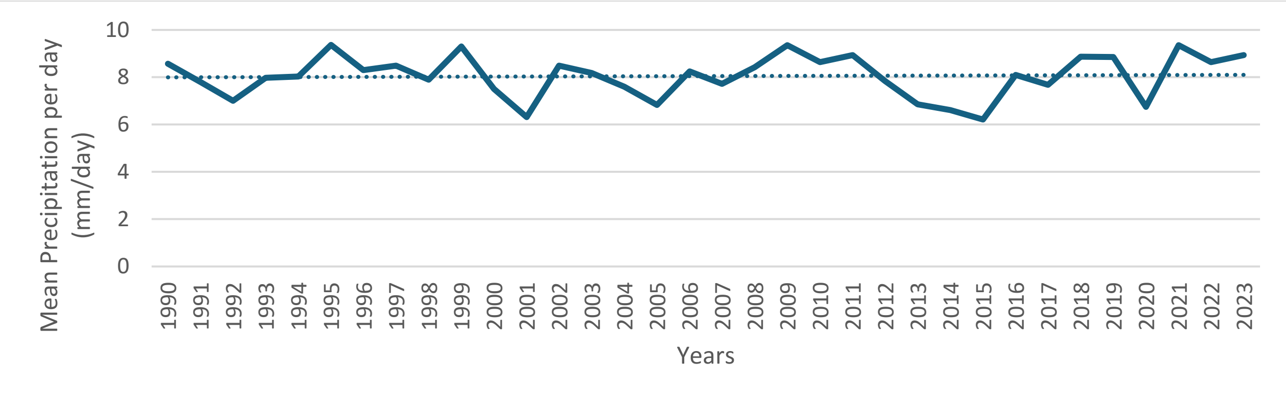


Figure 8. Mean Precipitation (mm/day) in Yenegoa from 1990 to 2023

## Temporal Variation in Temperature Across Niger Delta

### Akure

The mean annual temperature data for Akure from 1990 to 2023 (Figure 9) indicate a relatively stable temperature trend with gradual increases over the years. In 1990, the average temperature was 24.94°C, and it fluctuated slightly over the following years. The early 1990s show mild variations in temperature, such as 24.72°C in 1991 and 24.55°C in 1992, indicating only small deviations from the baseline. These temperatures remained fairly stable until the mid-1990s, with 1995 (25.06°C) and 1996 (24.86°C) showing slight increases, which reflects a gradual warming trend.

The trend of rising temperatures continued into the late 1990s and early 2000s. In 1998, the temperature increased notably to 25.60°C, indicating a year of slightly warmer conditions compared to previous years. The years that followed, including 1999 (24.84°C) and 2000 (25.02°C), maintained similar warmth. By the early 2000s, the temperature stayed relatively consistent, with values such as 25.08°C in 2001 and 25.16°C in 2003. This period suggests that the region experienced steady warmth with occasional slight increases.

From 2005 onward, the temperature began to show more consistent increases. For instance, in 2005, the temperature rose to 25.35°C, followed by a slight dip to 25.33°C in 2006, before increasing again to 25.12°C in 2007. This suggests that while the trend was upward, there were brief periods of stability. In 2010, the temperature reached 25.87°C, marking one of the warmer years within this period. This warming pattern continued into 2011, 2012, and 2013, with temperatures around 25.36°C, 25.15°C, and 25.23°C, respectively. These values continued to be within a narrow range, yet indicative of sustained warmth.

By the middle of the 2010s, Akure's temperatures consistently remained above 25°C, with 2015 reaching 25.42°C, and in 2016, the temperature increased further to 25.82°C. This period highlighted an ongoing warming trend, which also continued into 2017 (25.63°C). By 2020, the temperature hit 26.46°C, marking a notable rise compared to earlier years, possibly linked to global climate trends that were affecting temperature patterns more broadly.

From 2020 to 2023, the temperatures fluctuated slightly around the 25.35°C mark, with 2021 and 2022 both showing temperatures of 25.15°C and 25.14°C, respectively, before slightly rising again to 25.35°C in 2023. These fluctuations reflect minor variations in the overall warming trend but reinforce the general upward trajectory of temperatures in Akure over the three decades.

**Asaba**

The analysis of mean annual temperature data for Asaba from 1990 to 2023 (Figure 10) highlights a general warming trend with periodic fluctuations. In 1990, the mean temperature was recorded at 26.02°C. This was followed by a slight decline in 1991 (25.90°C) and 1992 (25.81°C), reflecting cooler conditions in the early 1990s. By 1993, the temperature increased to 25.99°C, signifying a return to warmer conditions. The fluctuations continued with a slight dip in 1994 (25.94°C) before a notable increase in 1995, when the mean temperature reached 26.14°C.

The late 1990s saw more pronounced variations in temperatures. In 1996, the temperature was 26.07°C, remaining relatively stable in 1997 (26.06°C). However, in 1998, there was a significant increase to 26.92°C, marking the warmest year of the decade. This was followed by a cooler year in 1999, with the temperature dropping to 25.95°C. The transition into the 2000s showed a return to higher values, as the temperature reached 26.14°C in 2000 and continued to fluctuate slightly around this level in subsequent years, including 26.13°C in 2003.

During the mid-2000s, Asaba experienced a steady rise in temperatures. In 2004, the temperature climbed to 26.35°C, followed by 26.46°C in 2005 and 26.54°C in 2006. These years marked a period of sustained warming. By 2009, the temperature had risen further to 26.64°C. The year 2010 saw a sharp increase to 27.10°C, the highest recorded up to that point, likely reflecting broader regional or global warming trends.

From 2011 to 2016, temperatures remained relatively high, with minor fluctuations. For instance, 2011 recorded 26.56°C, and by 2016, the mean temperature had reached 26.99°C. This period demonstrated a continuation of the warming trend. In 2017, the temperature stabilized slightly at 26.93°C and remained within similar ranges through 2018 and 2019, with 26.69°C and 26.86°C, respectively.

The year 2020 marked a significant increase in temperature, reaching 27.91°C, the highest recorded in the dataset. This substantial rise suggests intensified warming, potentially linked to recent climate change impacts. However, subsequent years showed a return to lower temperatures, with 26.54°C in 2021 and 26.25°C in 2022, indicating short-term variability within the overall warming trend. By 2023, the temperature rose slightly to 26.35°C, consistent with the earlier pattern of gradual warming.

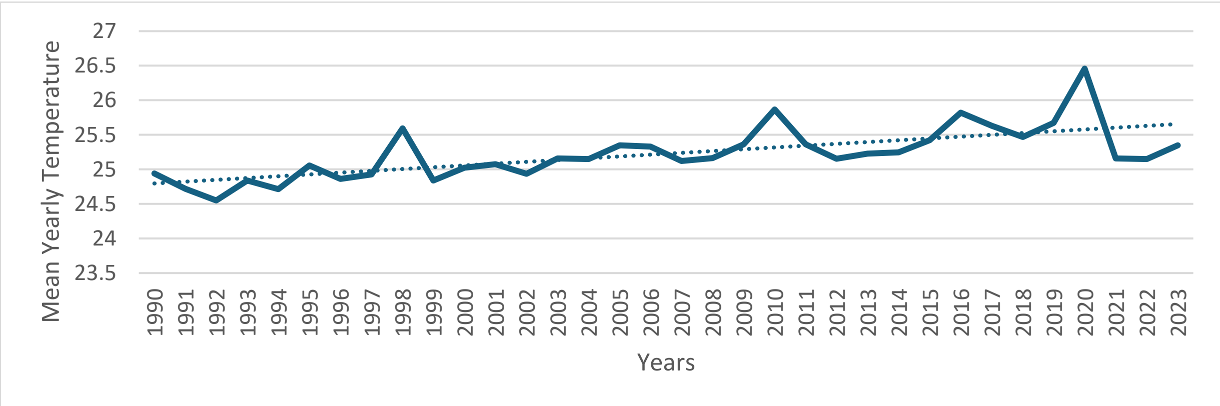


Figure 9. Mean Annual Temperature in Akure from 1990 to 2023

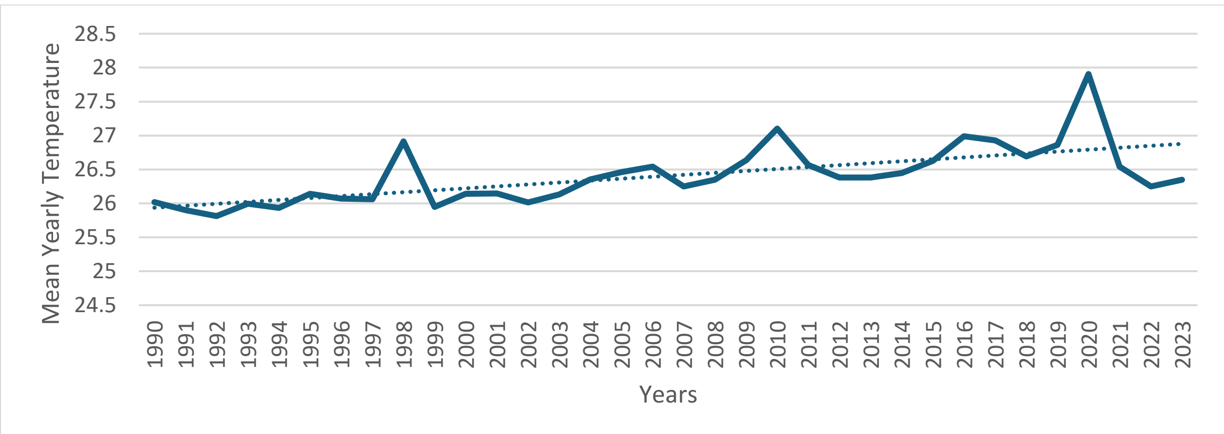


Figure 10. Mean Annual Temperature in Asaba from 1990 to 2023

**Benin**

The analysis of mean annual temperature in Benin from 1990 to 2023 (Figure 11) show a pattern of gradual warming interspersed with fluctuations. The dataset begins in 1990 with a recorded mean temperature of 25.61°C, followed by a slight decline in 1991 and 1992 to 25.48°C and 25.37°C, respectively, suggesting cooler conditions in the early 1990s. By 1993, the temperature increased to 25.57°C, indicating a temporary warming trend, which was slightly tempered in 1994 (25.49°C) before rising again in 1995 to 25.75°C.

The late 1990s showed more pronounced changes in temperature. In 1996, the mean temperature reached 25.57°C, followed by 25.66°C in 1997. A significant spike occurred in 1998, where the temperature rose sharply to 26.44°C, the highest recorded in that decade. This peak was followed by a decline in 1999 to 25.54°C, reflecting the variability within the broader warming trend. Entering the 2000s, temperatures stabilized around 25.74°C in 2000 and 2001, with minor dips and rises over the next few years.

From 2003 onwards, a consistent warming trend became evident. Temperatures increased to 25.91°C in 2004 and reached 26.08°C in 2005. By 2006, the mean temperature stood at 26.10°C, reflecting steady warming. This trend continued into 2009, when the temperature reached 26.15°C, marking a gradual escalation. The year 2010 was particularly notable, as the temperature peaked at 26.65°C, a significant increase indicative of intensified warming conditions.

The following years maintained high temperatures, with minor fluctuations. In 2011, the mean temperature was 26.14°C, slightly decreasing to 25.96°C in 2012 before rising again to 26.05°C in 2013. By 2015, the temperature had climbed to 26.23°C, with 2016 recording another peak at 26.63°C. These values illustrate the continuation of the warming trend observed in the previous decade. Temperatures remained elevated in 2017 (26.46°C) and 2018 (26.33°C), reflecting a sustained period of warmer conditions.

The year 2020 marked the highest temperature in the dataset, with a mean of 27.35°C. This significant rise underscores the increasing influence of global warming on local climate patterns. However, the subsequent years showed a dramatic drop in recorded temperatures, with 2021 matching the early 1990s low of 25.37°C, followed by moderate increases in 2022 (25.57°C) and 2023 (25.49°C). This decline in recent years contrasts with the long-term warming trend but may reflect short-term variability or anomalies.

**Calabar**

The mean annual temperature data for Calabar from 1990 to 2023 (Figure 12) unveil a consistent upward trend in temperature over the years, with occasional fluctuations. In 1990, the temperature was recorded at 25.62°C, with slight variations in the early 1990s. For instance, the temperature dropped marginally to 25.58°C in 1991 but increased steadily thereafter, reaching 25.90°C by 1995. This period reflects a generally stable climate with moderate warming.

The late 1990s saw a significant increase in temperatures. In 1998, the mean annual temperature surged to 26.55°C, marking one of the highest values for the decade. However, this was followed by a drop to 25.67°C in 1999, demonstrating short-term variability within the broader warming trend. As the 2000s began, temperatures stabilized at slightly higher levels compared to the 1990s. For instance, the temperature was 25.76°C in 2000 and gradually increased, peaking at 26.18°C in 2005.

From the mid-2000s onward, the warming trend became more pronounced. Temperatures consistently exceeded 26°C, with the highest value in that decade being 26.66°C in 2010. This consistent rise indicates an intensifying warming pattern. The early 2010s experienced relatively stable temperatures, with values ranging from 26.18°C in 2012 to 26.26°C in 2015. However, the upward trend resumed in the latter part of the decade, culminating in a peak of 26.73°C in 2016.

The late 2010s and early 2020s further underscore the warming trend, with temperatures consistently exceeding 26.4°C. Notably, 2020 recorded a remarkable spike to 27.68°C, the highest temperature in the dataset. This exceptional value highlights the growing impact of climate change on Calabar's climate. In the subsequent years, the temperature stabilized at high levels, with 26.26°C recorded in 2022 and 26.73°C in 2023, reflecting sustained warming over the long term.

**Port Harcourt**

The mean annual temperature data for Port Harcourt from 1990 to 2023 (Figure 13) share a consistent warming trend with periodic fluctuations. In 1990, the temperature was recorded at 25.62°C, reflecting a relatively stable climate during the early 1990s, with minor increases and decreases. For example, the temperature slightly rose to 25.77°C in 1993 and gradually climbed to 25.85°C by 1995. This period highlights subtle changes in climate patterns.

The late 1990s experienced a notable increase in temperature, with 1998 reaching 26.55°C, a significant spike compared to earlier years. However, this was followed by a drop to 25.66°C in 1999, indicating some variability in the warming trend. The early 2000s showed a gradual upward trajectory, with temperatures hovering around 25.78°C in 2000 and increasing steadily through the decade. By 2005, the mean temperature had reached 26.19°C, further rising to 26.25°C in 2006, showcasing a consistent warming phase.

From 2007 to 2010, temperatures fluctuated slightly but remained above 26°C, peaking at 26.71°C in 2010. This marked a turning point, as subsequent years consistently recorded higher averages compared to previous decades. During the early 2010s, temperatures stabilized slightly, with values like 26.14°C in 2012 and 26.19°C in 2013. However, the upward trend resumed, and by 2016, the temperature reached 26.79°C, the highest recorded in the decade.

The late 2010s and early 2020s further emphasize the warming trend, with temperatures regularly surpassing 26.4°C. The most notable observation is the dramatic rise to 27.69°C in 2020, which is the highest temperature in the dataset. Although there was a slight stabilization in 2021 and 2022, with values around 25.78°C and 25.82°C respectively, the temperature spiked again to 27.69°C in 2023, matching the 2020 peak.

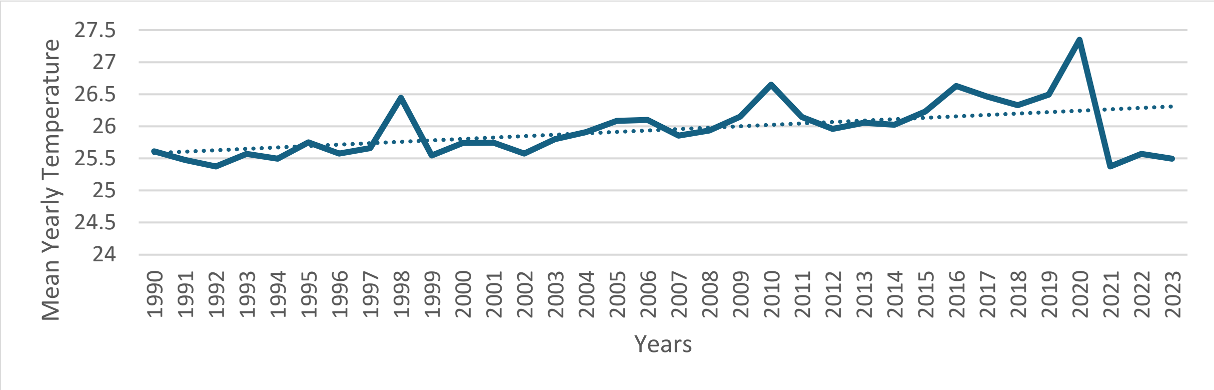


Figure 11. Mean Annual Temperature in Benin from 1990 to 2023

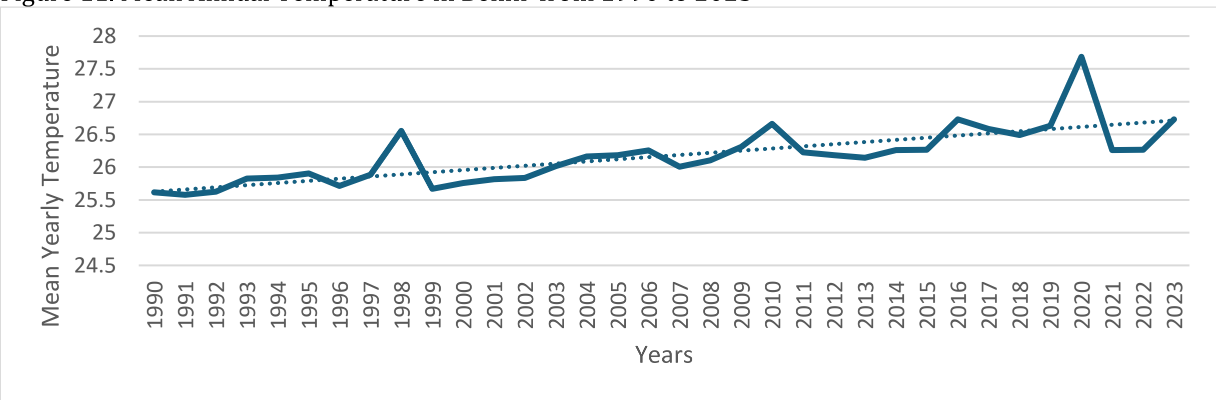


Figure 12. Mean Annual Temperature in Calabar from 1990 to 2023

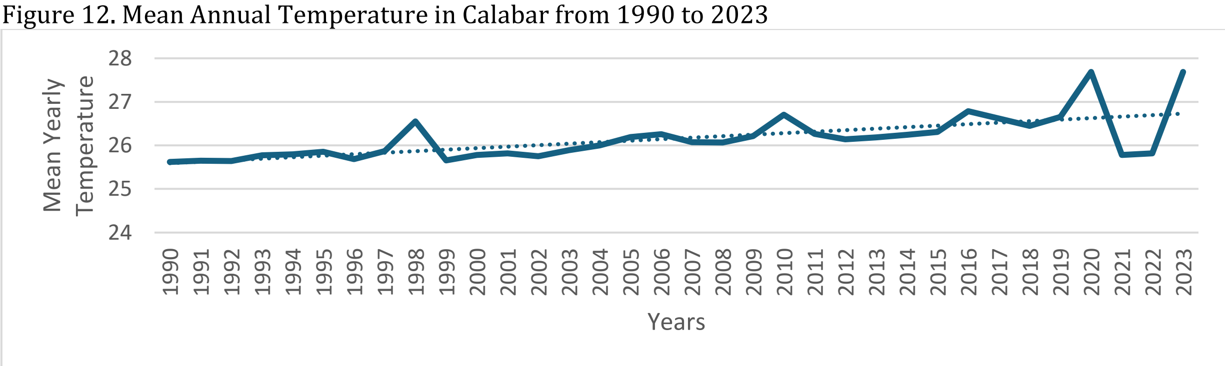


Figure 13. Mean Annual Temperature in Port Harcourt from 1990 to 2023

**Uyo**

The mean annual temperature data for Uyo from 1990 to 2023 (Figure 14) display a consistent warming trend, punctuated by periodic fluctuations. In 1990, the temperature was recorded at 25.57°C, reflecting relatively stable climatic conditions. However, a slight decrease to 25.44°C in 1991 suggests some early variability. By 1993, the temperature rose to 25.66°C, marking the beginning of a gradual upward trend that continued through the mid-1990s. By 1998, the mean annual temperature reached 26.47°C, representing a notable increase from earlier years.

The late 1990s experienced a slight drop, with the temperature declining to 25.53°C in 1999. This decline was short-lived as the early 2000s marked a return to higher averages, with temperatures increasing steadily. In 2004, the temperature reached 26.04°C, and by 2006, it climbed to 26.18°C, demonstrating a consistent warming trend over the years. Minor fluctuations occurred in subsequent years, such as a slight dip to 25.94°C in 2007, but the overall trend remained upward.

The late 2000s and early 2010s saw temperatures consistently exceeding 26°C. By 2010, the mean annual temperature had reached 26.69°C, the highest recorded up to that point. Although minor decreases were observed in 2012 and 2013, with temperatures at 26.10°C and 26.05°C respectively, the overall warming trend persisted. By 2015, the temperature increased to 26.31°C, and by 2016, it reached 26.67°C, highlighting significant warming compared to earlier decades.

The late 2010s and early 2020s further reinforce this warming trend, with temperatures frequently exceeding 26.4°C. The most notable observation is the dramatic spike in 2020, where the mean annual temperature peaked at 27.72°C, the highest in the dataset. Although temperatures slightly stabilized in 2021 and 2022, recorded at 26.67°C and 26.60°C respectively, these values remain significantly higher than the averages recorded in the 1990s and early 2000s. In 2023, the temperature was 26.45°C, maintaining the higher averages seen in recent years.

**Yenegoa**

The mean annual temperature data for Yenagoa from 1990 to 2023 (Figure 15) feature a steady increase in temperatures over the years, with notable fluctuations. The temperature in 1990 was 25.87°C, representing a relatively mild start to the recorded period. By 1993, the temperature had increased slightly to 26.09°C, reflecting a gradual upward trend in the early years. This rise continued with minor variations, as seen in 1995 when the temperature reached 26.11°C, followed by a slight dip to 25.95°C in 1996.

A significant spike occurred in 1998 when the temperature climbed to 26.79°C, marking the first major deviation from the steady increases observed earlier. However, this was followed by a decline to 25.93°C in 1999, showing that while the overall trend was upward, short-term fluctuations were present. The early 2000s saw a return to gradual increases, with temperatures hovering around 26.04°C in 2000 and reaching 26.41°C by 2005. This period highlighted the consistent but moderate warming pattern in Yenagoa.

Between 2006 and 2010, the data indicate a more pronounced rise in temperatures. By 2010, the mean annual temperature reached 26.92°C, the highest recorded to that point. This marked the beginning of a sharper upward trajectory in the region's temperature trends. Although there were minor decreases in subsequent years, such as 26.35°C in 2007 and 26.34°C in 2008, the overall warming trend persisted, with the temperature averaging around 26.44°C by 2009.

The data from 2011 onwards depict a steady increase in temperatures, with 2016 standing out as a notable year when the mean annual temperature peaked at 27.03°C. This marked a significant increase compared to previous years and underscored the growing impact of climate change. After 2016, temperatures showed slight variations, such as 26.79°C in 2017 and 26.67°C in 2018, but remained consistently higher than in earlier decades. By 2020, the temperature reached an unprecedented high of 27.96°C, the highest value in the entire dataset, signaling an alarming acceleration in warming trends.

The most recent data from 2021 to 2023 show temperatures stabilizing slightly, with 2023 recording 27.03°C, matching the 2016 peak. This stabilization at elevated levels suggests a new climatic norm for Yenagoa, characterized by sustained higher temperatures. Overall, the data reflect a clear warming trend over the decades, with the mean annual temperature increasing significantly from the early 1990s to the present day. This has implications for the region's ecosystem, agriculture, and public health, necessitating adaptive measures to mitigate the impacts of rising temperatures.Temporal Variation in Wind Pressure Across Niger Delta

**Akure**

The analysis of mean annual wind pressure in Akure from 1990 to 2023 (Figure 16) demonstrate variations with fluctuations around a generally stable range over the years. In 1990, the wind pressure was recorded at 101,196.87 Pa, which represents the baseline for this dataset. By 1991, a slight increase was observed, reaching 101,211.81 Pa, followed by a further marginal rise to 101,216.52 Pa in 1992. These early years show relatively stable wind pressures with minor upward trends.

The wind pressure fluctuated slightly in the mid-1990s, decreasing to 101,203.74 Pa in 1994 and further to 101,160.75 Pa in 1995. A significant dip occurred in 1996 when wind pressure dropped to 101,152.50 Pa, one of the lowest values recorded during the entire period. However, this trend reversed in 1997, with a noticeable increase to 101,218.86 Pa, marking a rebound after the earlier decline. These fluctuations highlight the variability in wind pressure over short timeframes.

From 1998 to the early 2000s, wind pressure remained relatively stable but with some minor declines. For instance, in 1999 and 2000, the values fell to 101,145.04 Pa and 101,139.69 Pa, respectively, showing a slight downward trend. However, this was followed by a gradual increase, with wind pressure reaching 101,191.05 Pa by 2002. The data from 2003 to 2006 exhibited consistent but minor declines, with wind pressure fluctuating around 101,180 Pa.

The late 2000s marked a period of notable dips in wind pressure, as evidenced by the value of 101,122.10 Pa recorded in 2008, which represents the lowest in the dataset. This decline was followed by a slow recovery, with wind pressure increasing to 101,154.38 Pa by 2009. Throughout the 2010s, the wind pressure values displayed moderate variation, peaking at 101,239.61 Pa in 2015 before settling at slightly lower levels in subsequent years. By 2019, the pressure stabilized around 101,191.12 Pa.

In the most recent years, the data indicate some degree of consistency but with a slight downward trend. The wind pressure in 2020 was recorded at 101,152.74 Pa, slightly lower than in earlier years, and remained stable at 101,145.04 Pa in 2021 and 101,139.69 Pa in 2022. By 2023, the pressure increased again to 101,187.81 Pa, reflecting a partial rebound. These recent fluctuations suggest a return to the stability observed in the earlier part of the dataset.

Overall, the mean annual wind pressure in Akure has remained within a narrow range over the decades, with periodic fluctuations influenced by local climatic and environmental factors. While no strong upward or downward trend is evident, the minor variations underscore the dynamic nature of wind pressure in the region. These findings have implications for infrastructure design and wind energy potential in Akure, given the consistent yet variable wind pressures over time.

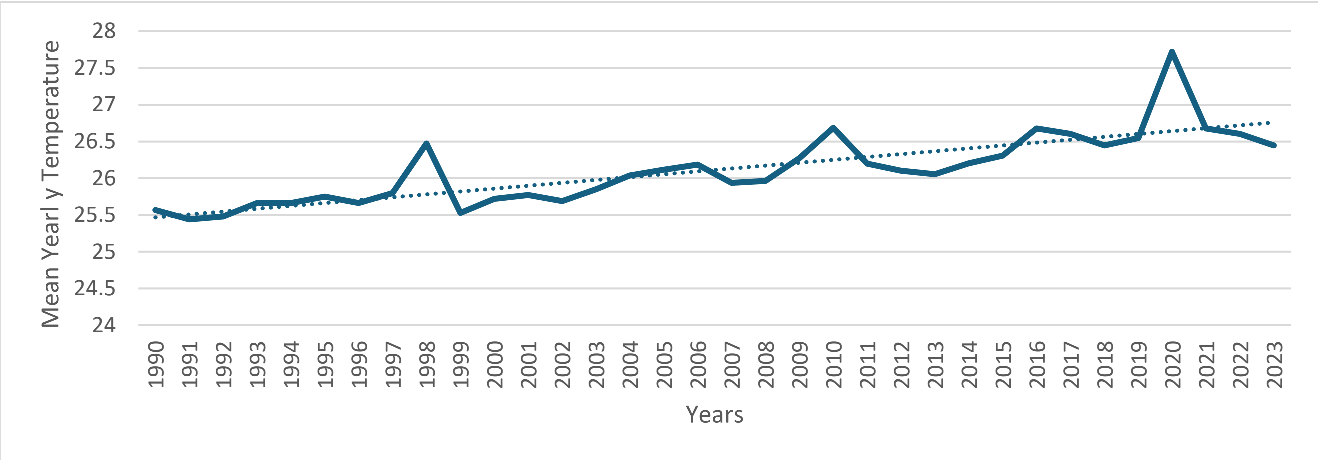

Figure 14. Mean Annual Temperature in Uyo from 1990 to 2023

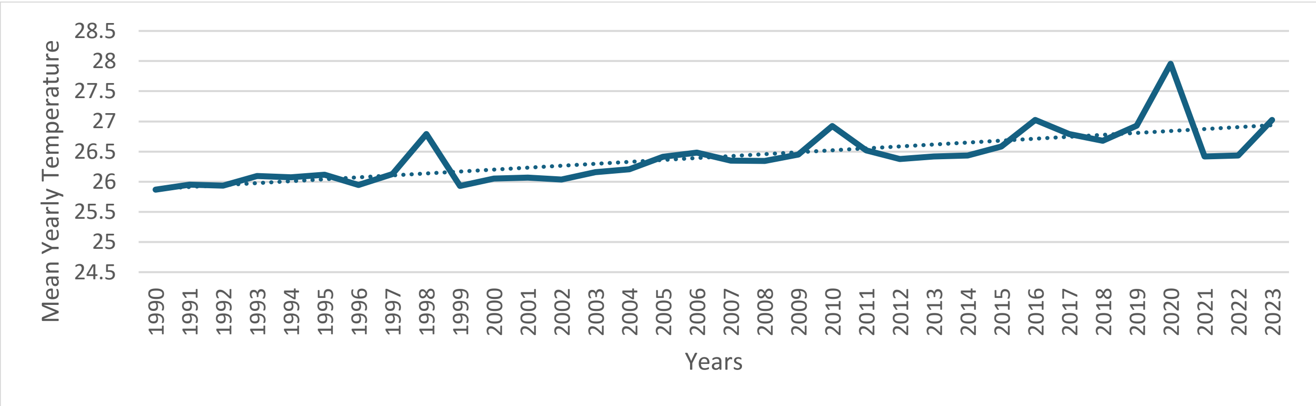

Figure 15. Mean Annual Temperature in Yenegoa from 1990 to 2023

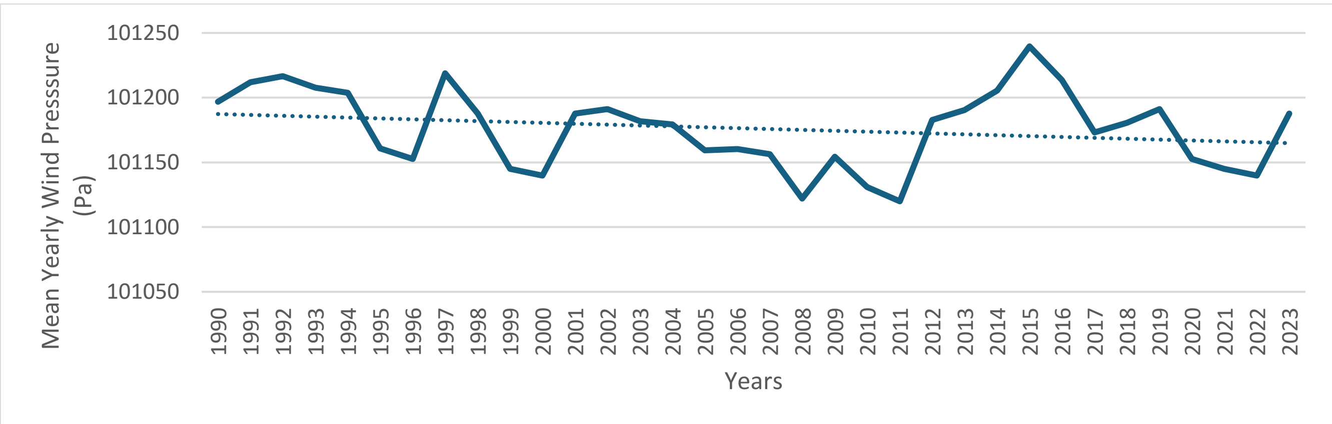

Figure 16. Mean Annual Wind Pressure (Pa) In Akure from 1990 to 2023

**Asaba**

The analysis of mean annual wind pressure in Asaba from 1990 to 2023 (Figure 17) highlight both fluctuations and long-term patterns, with values generally oscillating within a relatively narrow range. In 1990, the wind pressure started at 101,149.63 Pa, setting a baseline for the analysis. By 1991, a slight increase was observed, reaching 101,162.71 Pa, and this upward trend continued into 1992, peaking at 101,171.94 Pa. However, in 1993 and 1994, minor declines were noted, bringing the pressure down to 101,162.02 Pa and 101,157.20 Pa, respectively, indicating early variability.

The mid-1990s marked a period of significant drops, with wind pressure declining to 101,115.92 Pa in 1995 and further to 101,103.39 Pa in 1996, the lowest recorded value in the dataset. However, this was followed by a recovery in 1997, where the wind pressure rebounded to 101,171.74 Pa, matching one of the highest levels recorded. This fluctuation suggests localized climatic changes impacting wind pressure during this period.

From 1998 to the early 2000s, the wind pressure experienced a gradual decline, reaching 101,094.31 Pa in 2000. Despite this, a recovery was observed in 2001 and 2002, with values increasing to 101,142.12 Pa and 101,147.22 Pa, respectively. The following years up to 2006 showed relatively stable but slightly declining values, hovering around 101,115 Pa. In 2008, the wind pressure dropped significantly to 101,077.41 Pa, one of the lowest values recorded, highlighting a period of reduced wind activity.

The late 2000s and early 2010s exhibited moderate fluctuations. For instance, in 2010, the wind pressure was recorded at 101,080.79 Pa, followed by a slight dip to 101,073.40 Pa in 2011. However, by 2012, an upward trend began, with values increasing to 101,134.86 Pa and peaking at 101,193.00 Pa in 2015, the highest level observed in the dataset. This peak suggests a period of heightened wind activity in the region.

From 2016 onwards, the wind pressure generally stabilized, albeit with minor declines and fluctuations. In 2017, the value dropped to 101,124.85 Pa but recovered slightly in 2018 to 101,136.36 Pa. By 2020, a dip to 101,104.61 Pa was observed, followed by minor recoveries in 2021 and 2022, with values at 101,115.92 Pa and 101,103.39 Pa, respectively. In 2023, the wind pressure rose again to 101,171.74 Pa, reflecting a return to the higher levels recorded in earlier years.

Overall, the mean annual wind pressure in Asaba has shown variability influenced by both short-term and long-term climatic factors. While no consistent trend of increase or decrease is evident over the decades, the fluctuations highlight the dynamic nature of wind patterns in the region. These findings are valuable for understanding local weather dynamics and can inform infrastructure planning and wind energy assessments in Asaba.

**Benin**

The mean annual wind pressure in Benin from 1990 to 2023 (Figure 18) uncover a pattern of variability characterized by periods of increases, declines, and relative stability. In 1990, the wind pressure was recorded at 101,147.38 Pa, providing a reference point for subsequent years. The values increased slightly in 1991 to 101,159.98 Pa and continued to rise in 1992, reaching 101,167.04 Pa, marking one of the higher values recorded. However, this trend was interrupted in 1993 and 1994, with declines to 101,157.56 Pa and 101,153.40 Pa, respectively, signaling early fluctuations in wind activity.

In the mid-1990s, a significant decrease was observed, with the wind pressure dropping to 101,110.87 Pa in 1995 and further to 101,102.15 Pa in 1996, reflecting one of the lowest periods during the study timeline. By 1997, a sharp recovery occurred, with the pressure peaking at 101,168.03 Pa, one of the highest values during the 1990s. However, the value declined again in 1998 to 101,134.89 Pa, before dropping substantially to 101,095.64 Pa in 1999 and 101,090.92 Pa in 2000, marking the lowest point in the entire dataset.

The early 2000s marked a gradual recovery in wind pressure, with values rising to 101,139.26 Pa in 2001 and continuing to fluctuate within a narrow range through 2004, reaching 101,129.25 Pa. However, in 2005, a decline was observed, with wind pressure falling to 101,109.83 Pa, followed by a slight dip in 2007 to 101,107.54 Pa. A significant drop occurred in 2008, with wind pressure recorded at 101,071.38 Pa, one of the lowest values in the dataset. This was followed by a slight recovery in 2009 and 2010, though values remained relatively low at 101,102.86 Pa and 101,077.86 Pa, respectively.

Between 2011 and 2015, the wind pressure displayed gradual increases and fluctuations, with values reaching 101,189.34 Pa in 2015, the highest recorded during the study period. This peak was followed by a slight decline in 2016 to 101,160.70 Pa. In 2017, the pressure dropped to 101,121.92 Pa, reflecting a period of reduced wind activity.

From 2018 onwards, the wind pressure stabilized, with minor fluctuations. For instance, the value recorded in 2018 was 101,130.74 Pa, and it fluctuated slightly in subsequent years, reaching 101,139.52 Pa in 2019. However, a dip was observed in 2020, with the wind pressure decreasing to 101,099.34 Pa. The pressure increased slightly in 2021 to 101,142.98 Pa and remained relatively stable through 2022 and 2023, with values of 101,132.97 Pa and 101,129.25 Pa, respectively.

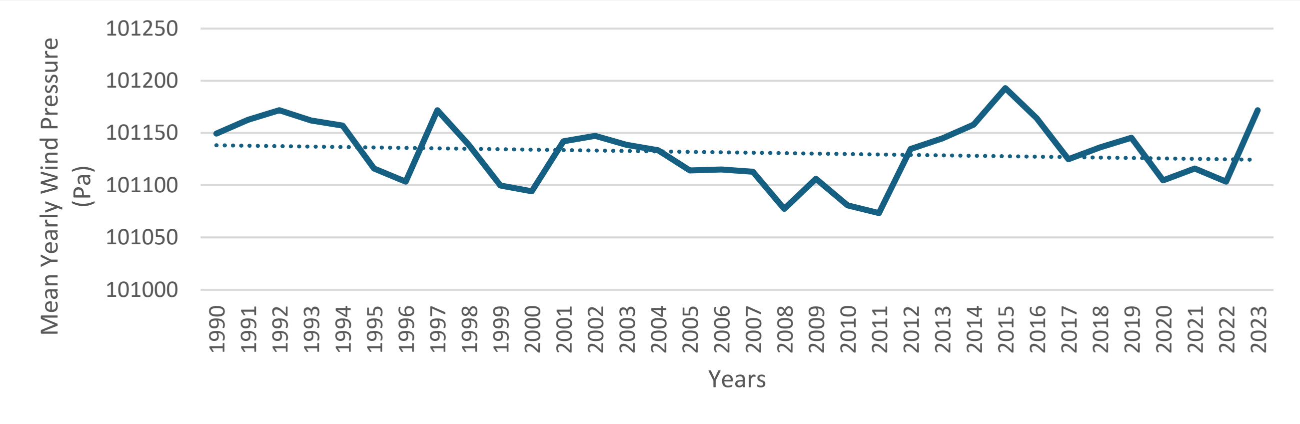


Figure 17. Mean Annual Wind Pressure (Pa) In Asaba from 1990 to 2023

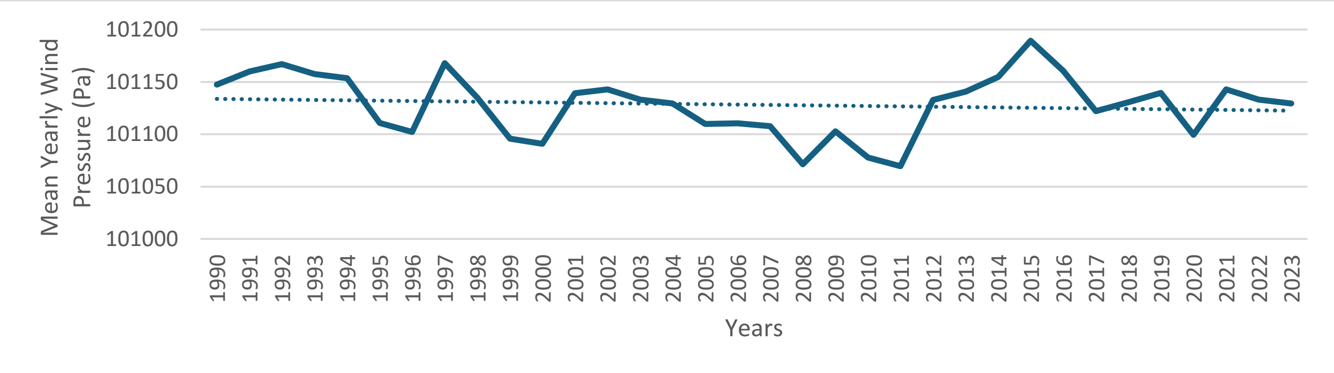


Figure 18. Mean Annual Wind Pressure (Pa) in Benin from 1990 to 2023

**Calabar**

The mean annual wind pressure in Calabar from 1990 to 2023 (Figure 19) disclose notable variations, reflecting both short-term fluctuations and longer-term trends. In 1990, the wind pressure was recorded at 101,150.82 Pa, establishing a baseline. This value increased slightly in 1991 and 1992, reaching 101,162.04 Pa and 101,171.52 Pa, respectively, suggesting a steady rise during the early 1990s. However, by 1993, the pressure stabilized at 101,162.10 Pa, followed by a decline to 101,155.02 Pa in 1994, indicating the onset of variability within the period.

The mid-1990s marked a period of significant declines, with the wind pressure dropping to 101,115.58 Pa in 1995 and further to 101,106.58 Pa in 1996. This downward trend reached a low in 1999 when the pressure fell to 101,102.05 Pa, one of the lowest values in the dataset. The early 2000s saw a gradual recovery, with wind pressure rising to 101,143.07 Pa in 2001 and remaining relatively stable through 2004, with minor fluctuations. By 2005, the wind pressure had decreased again to 101,116.09 Pa.

Between 2006 and 2010, the wind pressure exhibited a mixture of slight increases and notable declines. In 2008, it fell sharply to 101,078.42 Pa, marking the lowest value in the dataset. While a marginal recovery occurred in 2009, with the value increasing to 101,109.56 Pa, it remained relatively low through 2010, recording 101,083.62 Pa. This period signifies one of the most unstable phases in the dataset.

The 2011 to 2015 period showcased a steady increase in wind pressure, reaching a peak of 101,193.30 Pa in 2015, the highest value recorded across the entire dataset. This peak was followed by a slight decline in 2016 to 101,162.59 Pa, indicating a shift back toward lower pressures. From 2017 onwards, the wind pressure showed relative stability, with minor fluctuations. In 2017, the value was 101,128.77 Pa, while in 2018, it increased slightly to 101,140.40 Pa, reflecting an upward trend.

In 2020, the wind pressure decreased again to 101,106.58 Pa, signaling another dip. However, subsequent years exhibited a recovery, with the pressure stabilizing at values such as 101,162.10 Pa in 2021 and 101,155.02 Pa in 2022. By 2023, the wind pressure returned to 101,115.58 Pa, mirroring its level from 1995, thus completing a cycle of variability over the 33-year period.

The data illustrates the dynamic nature of wind pressure in Calabar, influenced by both climatic trends and localized weather patterns. These fluctuations have implications for meteorological studies, infrastructure resilience, and renewable energy planning in the region, emphasizing the need for adaptive measures to account for variability in wind conditions.

**Port Harcourt**

The mean annual wind pressure in Port Harcourt from 1990 to 2023 (Figure 20) exhibit a dynamic pattern characterized by fluctuations and trends over the 33-year period. In 1990, the wind pressure was recorded at 101,145.99 Pa, establishing a relatively high baseline. This value slightly increased in 1991 and 1992, reaching 101,155.32 Pa and 101,163.70 Pa, respectively. However, by 1993, the pressure had decreased marginally to 101,154.70 Pa and continued to decline to 101,148.79 Pa in 1994, reflecting the variability of wind conditions during this early phase.

In the mid-1990s, a pronounced decrease occurred, with the wind pressure falling sharply to 101,108.81 Pa in 1995 and further to 101,099.89 Pa in 1996. The trend reached its lowest point in this decade in 1999, when the pressure dropped to 101,094.23 Pa. This period of decline contrasts with the recovery observed in 1997, where the value peaked temporarily at 101,164.32 Pa. By 2000, the wind pressure had reduced further to 101,088.30 Pa, marking the start of a prolonged phase of variability in the early 2000s.

Between 2001 and 2005, wind pressure displayed moderate stability with minor fluctuations. The values ranged from 101,137.11 Pa in 2001 to 101,109.49 Pa in 2005, suggesting a gradual decrease in wind pressure during these years. However, in 2008, a sharp decline was recorded, with the wind pressure reaching its lowest level in the dataset at 101,070.09 Pa. This dramatic dip was followed by a slight recovery in 2009 and 2010, where values increased to 101,103.03 Pa and 101,076.25 Pa, respectively.

The period from 2011 to 2015 saw significant fluctuations and a remarkable recovery. In 2015, the wind pressure reached 101,187.67 Pa, the highest value recorded in the entire dataset, indicating a period of unusually high wind activity. However, this peak was followed by a decline to 101,157.59 Pa in 2016. From 2017 onwards, the pressure exhibited relative stability, with values oscillating between 101,121.89 Pa in 2017 and 101,131.97 Pa in 2018.

The 2020s show a return to lower wind pressures. In 2020, the wind pressure decreased to 101,096.68 Pa, with slight variations in subsequent years. By 2023, the wind pressure returned to 101,070.09 Pa, matching the low value previously observed in 2008. This recent trend suggests a cyclical nature of wind pressure patterns in Port Harcourt, influenced by changing climatic and environmental factors.

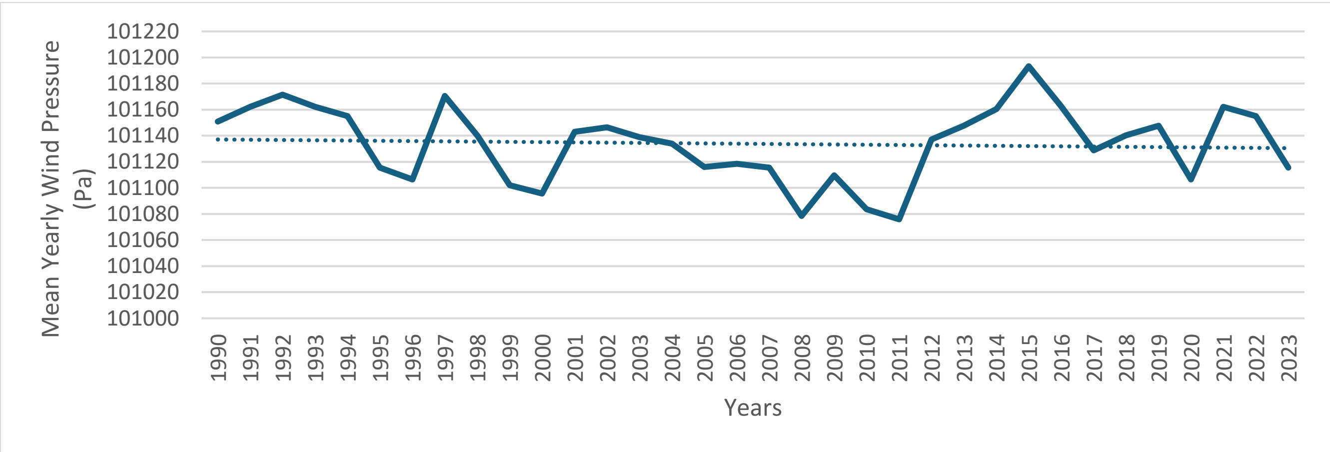


Figure 19. Mean Annual Wind Pressure (Pa) in Calabar from 1990 to 2023

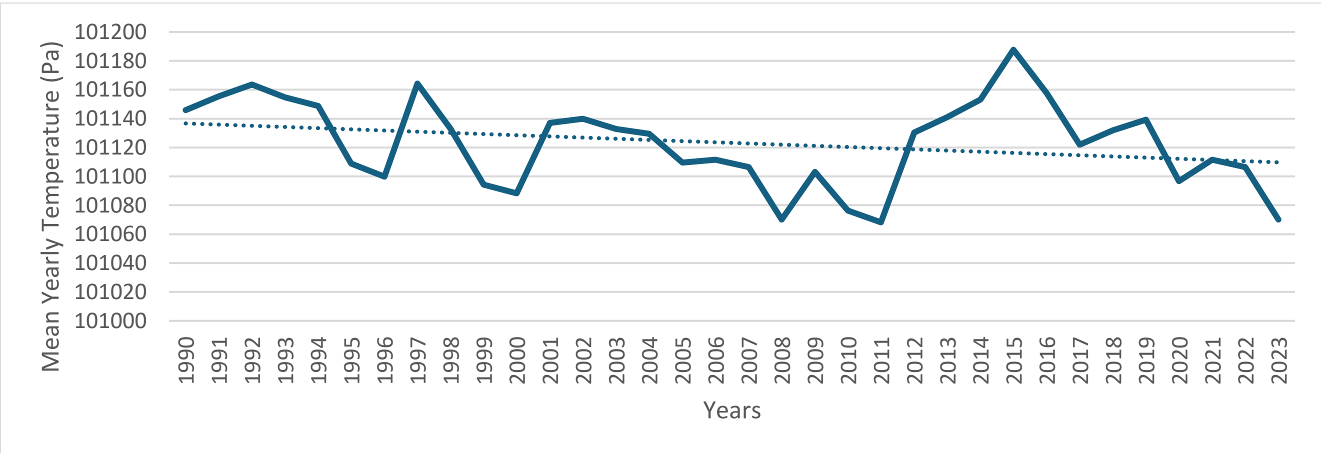


Figure 20. Mean Annual Wind Pressure (Pa) in Port Harcourt from 1990 to 2023

**Uyo**

The trend of mean annual wind pressure in Uyo from 1990 to 2023 (Figure 21) show variations with periods of relative stability and occasional fluctuations. In 1990, the wind pressure was recorded at 101,150.65 Pa, rising steadily to reach 101,171.23 Pa in 1992, marking one of the highest values in the early part of the observation period. A slight decline followed, with values stabilizing around 101,162.38 Pa in 1993 and 101,155.55 Pa in 1994, before experiencing a notable drop to 101,115.72 Pa in 1995 and further to 101,105.63 Pa in 1996.

A significant rebound occurred in 1997, with wind pressure reaching 101,170.29 Pa, closely matching the earlier peak in 1992. However, this was followed by a decline in 1998 to 101,139.83 Pa and a further decrease to 101,102.09 Pa in 1999. The year 2000 saw the lowest recorded value of 101,094.45 Pa during this time frame, reflecting a period of relatively lower wind pressure.

The early 2000s exhibited gradual recovery and stabilization, with wind pressure fluctuating slightly between 101,142.24 Pa in 2001 and 101,146.31 Pa in 2002. From 2003 to 2007, wind pressure values remained relatively stable, fluctuating narrowly between 101,139.10 Pa and 101,114.51 Pa. A notable dip occurred in 2008, with wind pressure reaching 101,078.54 Pa, followed by a gradual recovery in subsequent years.

From 2010 to 2014, the values exhibited a steady upward trend, peaking at 101,159.28 Pa in 2014. A sharp increase was recorded in 2015, reaching the highest value for the entire period at 101,192.22 Pa. After this peak, wind pressure values saw a decline in subsequent years, stabilizing at moderate levels around 101,162.41 Pa in 2016 and 101,126.98 Pa in 2017.

In the final years of the observation period, the data reflect a pattern of mild fluctuations. For instance, wind pressure was recorded at 101,138.53 Pa in 2018, slightly increasing to 101,147.20 Pa in 2019, before dropping to 101,104.32 Pa in 2020. In 2021, the value returned to the 2000 levels of 101,094.45 Pa. However, the last two years, 2022 and 2023, indicated a recovery to 101,142.24 Pa and 101,146.31 Pa, respectively, suggesting an overall stabilization in wind pressure trends.

This analysis highlights the dynamic nature of wind pressure in Uyo, characterized by periodic fluctuations influenced by regional and temporal factors. The peak in 2015 and subsequent declines reflect broader climatic variations, while the stabilization in recent years may point to emerging equilibrium in atmospheric conditions.

**Yenegoa**

The analysis of mean annual wind pressure in Yenagoa from 1990 to 2023 (Figure 22) show notable fluctuations and trends over the observed period. In 1990, the wind pressure started at 101,146.87 Pa, showing a steady increase to reach 101,164.54 Pa by 1992. A slight dip followed in 1993 to 101,154.84 Pa, with a further reduction to 101,149.34 Pa in 1994. A significant decline occurred in 1995 and 1996, with values dropping to 101,109.69 Pa and 101,100.88 Pa, respectively, indicating a period of relatively low wind pressures.

A marked recovery was observed in 1997, with the wind pressure peaking at 101,165.37 Pa, the highest in the decade. However, this was followed by a decline in 1998 to 101,134.22 Pa and a more substantial drop in 1999 and 2000, reaching the lowest value of 101,089.79 Pa. These years reflected a phase of low wind pressure before another gradual rise in the early 2000s.

From 2001 to 2004, the wind pressure values stabilized somewhat, fluctuating between 101,138.47 Pa and 101,130.74 Pa. A minor dip occurred in 2005 and 2006, with values hovering around 101,110.72 Pa and 101,112.19 Pa. In 2008, wind pressure dropped sharply to 101,070.43 Pa, the lowest recorded during this period. This was followed by gradual recovery in subsequent years, with values stabilizing around 101,103.59 Pa in 2009 and 101,077.39 Pa in 2010.

The period from 2011 to 2014 saw a resurgence in wind pressure levels, rising from 101,069.40 Pa in 2011 to 101,154.57 Pa in 2014. A significant peak occurred in 2015, with the wind pressure reaching 101,189.27 Pa, the highest recorded during the entire observation period. This peak was followed by a gradual decline in subsequent years, with values stabilizing around 101,159.77 Pa in 2016 and 101,123.58 Pa in 2017.

In the later years, from 2018 to 2023, wind pressure values displayed mild fluctuations. For instance, the wind pressure was 101,133.06 Pa in 2018, slightly increasing to 101,140.05 Pa in 2019 before dropping to 101,099.07 Pa in 2020. The final three years, 2021 to 2023, exhibited stabilization, with values remaining consistent at around 101,110.72 Pa and 101,107.28 Pa.

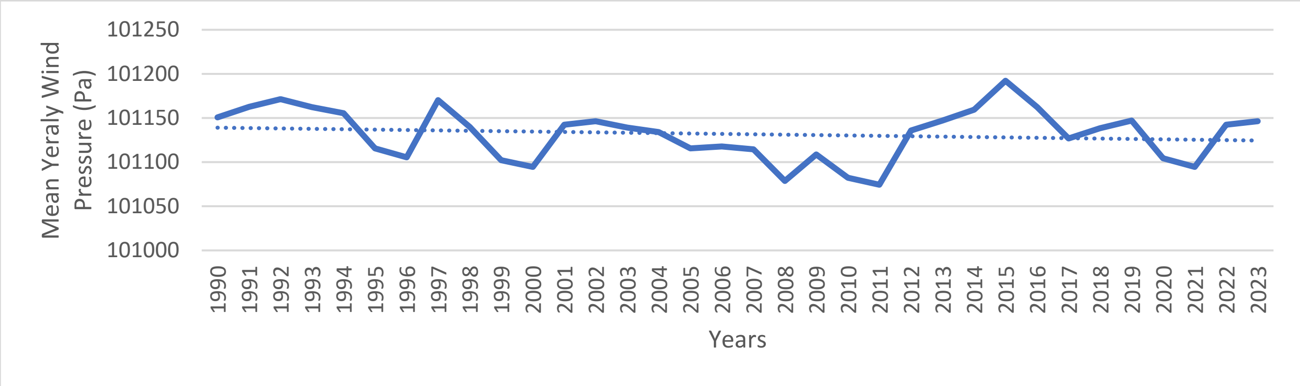


Figure 21. Mean Annual Wind Pressure (Pa) in Uyo from 1990 to 2023

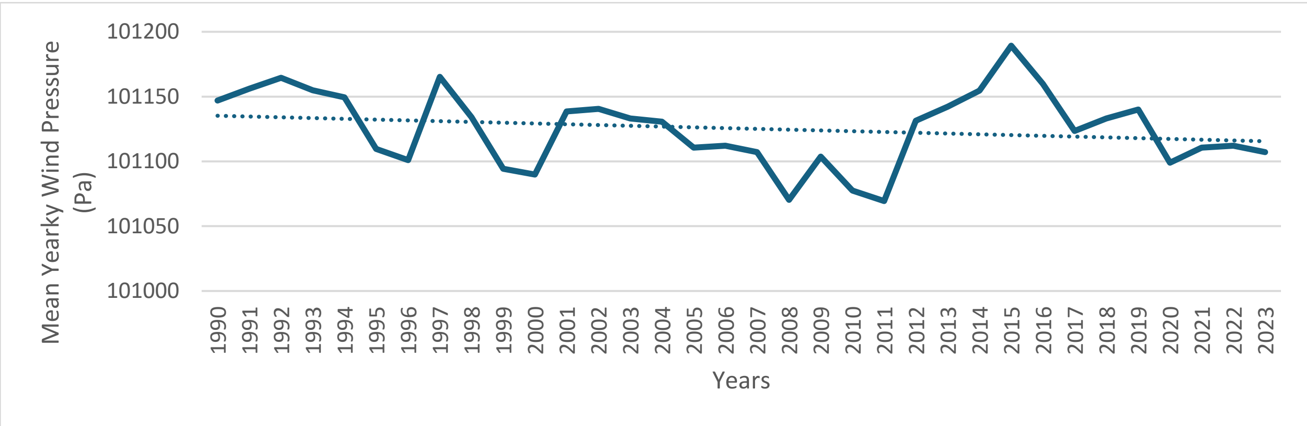


Figure 22. Mean Annual Wind Pressure (Pa) in Yenegoa from 1990 to 2023

**Discussion**

The analysis of temporal variations in precipitation, temperature, and wind pressure across the Niger Delta reveal meaningful insights into the region's evolving climate and its environmental and urban development implications. The trends observed indicate both fluctuations and gradual long-term changes in climatic variables, reflecting the interplay between natural climatic variability and increasing human-induced influences.

These results correspond with the findings of Mason *et al.,* (2020), who highlighted the susceptibility of urban areas to extreme weather conditions and localized temperature increases, largely due to the Urban Heat Island (UHI) effect. In the Niger Delta, the recorded upward trend in temperature appears to be linked to expanding urbanization and diminishing vegetation cover. Mason *et al.'s* emphasis on the role of urban greenery as a moderating force for rising temperatures is particularly applicable here; increasing green infrastructure may offer a practical means of improving urban thermal regulation. Furthermore, adopting more advanced urban climate monitoring techniques, as suggested by Mason *et al.,* could enhance the understanding of microclimatic variations within the region.

The findings also align with Ngare *et al.,* (2020), who documented pronounced warming in Mombasa County, Kenya, over a similar three-decade period, largely driven by human activities. Although Mombasa's rainfall trends lacked consistency—unlike some of the clearer precipitation changes observed in the Niger Delta—both regions share a common theme of erratic rainfall behavior in response to global climate change. Additionally, Ngare *et al.,* (2000) conclusions regarding the growing ecological impact of urban expansion reinforce the need for proactive climate adaptation and urban sustainability measures in regions experiencing rapid development.

In terms of wind pressure, the temporal variability identified in the Niger Delta points to shifting atmospheric conditions shaped by both local and global climatic processes. These observations echo the conclusions of Tempanosyan *et al.,* (2021), who associated changes in land use and urban expansion with altered wind patterns and surface temperature dynamics in Yerevan. Similar to their findings, the transformation of natural landscapes into built environments in the Niger Delta likely contributes to changes in wind pressure, emphasizing the potential of urban design strategies—such as increasing vegetation and managing surface heat emissions—to mitigate these impacts.

Additionally, the observed inconsistencies in all three climatic parameters—precipitation, temperature, and wind pressure—correspond with the concerns raised by Kim & Brown (2021) regarding the need for standardized methodologies in evaluating spatial and temporal climate data. The complexity and variability of the results underscore the limitations of conventional analysis and highlight the importance of using high-resolution datasets and integrative climate models for more precise assessments.

The patterns observed in this study mirror broader climate trends reported in other rapidly urbanizing regions. The influence of land use changes, urban sprawl, and anthropogenic activities is evident in the shifts in precipitation, temperature, and wind pressure across the Niger Delta. These findings emphasize the urgent need for climate-sensitive urban planning and the implementation of adaptation measures aimed at enhancing regional resilience. The presence of statistically significant differences in key climatic parameters across the study area confirms the dynamic nature of the region's climate and the pressing need for evidence-based interventions.

**Conclusions**

The Niger Delta exhibits a clear and accelerating warming trend, unequivocally linked to global climate change. All seven cities recorded significant temperature increases, with absolute peaks consistently occurring in 2020 (e.g., 27.72°C in Uyo, 27.96°C in Yenagoa). This warming intensified post-2010, with temperatures in the 2020s frequently exceeding 26°C – levels rarely observed in the 1990s baseline period. The uniformity of this trend across diverse urban centers underscores the pervasive influence of anthropogenic forcing, though localized factors like urbanization likely exacerbated microclimatic changes. The consistency of these temperature records aligns with IPCC projections for tropical coastal regions and signals profound implications for heat stress, energy demand, and ecosystem viability.

Precipitation patterns reveal greater spatial and temporal complexity. While the delta retains its characteristic high rainfall regime (notably in coastal Calabar and Yenagoa, averaging >8 mm/day), significant drying occurred in inland locations like Akure, Asaba, and Benin. These cities experienced reduced mean rainfall, increased frequency of dry years (e.g., 2013–2015 drought), and a trend toward post-2020 aridification, contrasting with the relative stability in coastal hubs. Critically, extreme rainfall years (e.g., 1995, 2009, 2018) became more pronounced, amplifying flood risks even in drying regions. This paradox – intensifying extremes amidst declining averages – reflects climate disruption's nuanced hydrologic impacts. The precipitation variability correlates with both global phenomena (e.g., ENSO cycles) and localized anthropogenic drivers, including urbanization-induced alterations to moisture recycling and land-atmosphere feedbacks.

Wind pressure dynamics displayed the highest volatility, lacking a uniform directional trend but marked by episodic extremes. The year 2015 emerged as a regional anomaly, with all cities recording their highest wind pressure values (e.g., 101,239.61 Pa in Akure, 101,193.30 Pa in Calabar), suggesting large-scale atmospheric forcing. Conversely, 2008 was consistently the lowest-pressure year. These fluctuations indicate sensitivity to mesoscale weather systems and oceanic-atmospheric oscillations, though the absence of a secular trend suggests wind pressure remains within natural variability bounds – for now. However, the coupling of high wind events with intensifying rainfall extremes could compound future storm impacts.

Collectively, these trends paint a picture of a region under escalating climatic stress. The convergence of rising temperatures, erratic rainfall (simultaneously drying in some areas while intensifying extremes), and volatile wind patterns poses multifaceted threats: agricultural disruption due to water stress or flooding, heightened flood risk in low-lying urban centers, strain on water infrastructure, and ecosystem degradation. The documented changes demand integrated adaptation strategies – water-efficient agriculture for drying zones, enhanced flood control in coastal cities, heat-resilient urban planning, and robust early-warning systems for extreme events. Continued monitoring is essential to track nonlinear changes, particularly given the potential for climate feedback loops (e.g., deforestation → reduced evapotranspiration → diminished rainfall) to accelerate regional aridification. The Niger Delta's climate trajectory exemplifies the complex, place-specific manifestations of global change, necessitating equally nuanced and localized resilience interventions.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Credit Authorship Contribution Statement

**Eleraobari, N.E.**: Conceptualization, Methodology, Formal analysis, Investigation, Resources, Data curation, Visualization, Project administration, Writing - original draft. **Weli, V.E.,** and **Nwagbara, M.O.**: Supervision, Methodology, Validation, Formal analysis, Data curation, Visualization, Review & Editing.

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