Analysis Of Spatiotemporal Trends in Rainfall, Air Temperature,And PM2.5 Concentration in Nigeria

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Abstract-This study analyzes the spatiotemporal patterns of rainfall, air temperature, and $PM_{2.5}$ concentrations across selected Nigerian cities from 1980 to 2023, integrating meteorological and environmental datasets to explore correlations, anomalies, and possible causal interactions in the context of climate variability and air quality. Rainfall trends vary regionally, with mild increases in Enugu and Abuja enhancing agricultural potential but raising flood risks, more pronounced increases in Uyo and Port Harcourt exacerbating flood vulnerability, and significant declines in Sokoto, Gombe, and Kano indicating progressive aridification and water stress, while Ilorin remains stable as a climatic buffer. Air temperature trends show widespread warming, most intense in southern and coastal cities (Uyo, Port Harcourt, Ikeja, Owerri, Enugu) due to urbanization, deforestation, and oceanic influences; moderate warming in the central belt (Abuja, Ilorin, Gombe) linked to seasonal and land-use changes; and slower warming in the north (Sokoto, Kano) possibly moderated by arid climate conditions. $PM_{2.5}$ concentrations reveal strong spatial disparities: persistently high in Port Harcourt and Kano from industrial activity, oil refining, and open burning; moderate-to-high in Ikeja from traffic and industry; moderate and fluctuating in Abuja, Enugu, and Owerri; relatively low but seasonally peaked in Ilorin and Gombe; consistently lowest in Uyo due to minimal emissions; and fluctuating in Sokoto with peaks from desert dust intrusions. These results highlight the intricate linkages between climatic and atmospheric variables in Nigeria, underscoring region-specific vulnerabilities and providing an evidence base for targeted adaptation strategies, sustainable urban development, and integrated environmental management to mitigate the impacts of climate change and air pollution.

Index Terms : Rainfall trend, Air temperature, $PM_{2.5}$ concentration, Spatiotemporal variability, Climate change, Nigeria.

I. INTRODUCTION

In recent decades, the dynamics of Earth's climate and atmospheric composition have attracted growing scientific, political, and public attention (Weber and Stern 2011). Among the various indicators of environmental change, rainfall patterns, surface air temperatures, and atmospheric particulate matter particularly $PM_{2.5}$ (particulate matter with a diameter of less than 2.5 micrometers) serve as critical metrics for assessing the state of both the climate system and public health (Omokpariola et al., 2025). These variables are not only interdependent but also exhibit strong spatiotemporal variability influenced by natural processes and anthropogenic activities (Huang et al., 2013). Understanding their long-term trends and regional variations is vital for informing climate adaptation, air quality management, and sustainable development policies (Zheng et al., 2023).

Rainfall and temperature patterns are central components of the Earth's hydrological and energy cycles (Yang et al., 2021). Variations in these elements whether seasonal, interannual, or long-term can lead to significant impacts on agriculture, water availability, ecosystem dynamics, and human livelihoods (Talukdar et al., 2023). Global climate change has intensified concern over shifting precipitation regimes, with some regions experiencing increased rainfall and flooding, while others face prolonged droughts and desertification (Jain et al., 2024). Concurrently, rising air temperatures are altering evapotranspiration rates, snowmelt timing, and atmospheric circulation patterns, all of which feed back into the distribution and intensity of precipitation events (Liu et al., 2020). In many regions, these climatic changes are no longer hypothetical projections but observable realities that demand quantitative assessment (Collins et al., 2012).

$PM_{2.5}$ concentrations, on the other hand, primarily reflect air quality conditions and pose severe health risks due to their ability to penetrate deep into the human respiratory system(Kumar et al., 2025). These fine particles originate from various sources, including fossil fuel combustion, industrial activities, biomass burning, and natural sources such as dust and sea salt (Kelly and Fussell 2020). Epidemiological studies have consistently linked prolonged exposure to elevated $PM_{2.5}$ levels with respiratory illnesses, cardiovascular diseases, and premature mortality(Rücker et al., 2011). Beyond health impacts, $PM_{2.5}$ also plays a significant role in atmospheric chemistry and radiative forcing, thereby influencing regional climate patterns(Nibagwire et al., 2025). For example, aerosol-cloud interactions can suppress or enhance rainfall, and aerosol absorption can warm the atmosphere while cooling the surface. These dual roles make $PM_{2.5}$ both a consequence and a driver of climate variability (Nibagwire et al., 2025).

Recent research has emphasized the importance of integrated analyses that explore the co-variability and interactions between meteorological parameters (rainfall and temperature) and $PM_{2.5}$ concentrations. Such studies are essential because meteorological conditions strongly influence the dispersion, chemical transformation, and removal of airborne particles (Myung and Joung 2024). Rainfall, for instance, is known to reduce $PM_{2.5}$ levels through wet deposition, while wind and temperature modulate atmospheric mixing and pollutant transport (Alam et al., 2025). However, these interactions are complex and often vary across geographic regions and temporal scales. For example, while high temperatures may enhance atmospheric dispersion in some areas, they may promote photochemical reactions and secondary aerosol formation in others, thereby increasing $PM_{2.5}$ levels (Bui et al., 2025)

From a spatiotemporal perspective, global and regional assessments have revealed heterogeneous patterns in all three variables (Shekhar et al., 2015). In arid and semi-arid regions, long-term declines in rainfall coupled with rising temperatures have exacerbated drought conditions, while $PM_{2.5}$ concentrations remain high due to both dust mobilization and human-induced emissions. (Anastasia and Nabilla 2015). In contrast, tropical and monsoon-influenced areas may exhibit increases in rainfall intensity and seasonal concentration, alongside sharp diurnal and seasonal variations in air pollution levels (Khandeparker et al., 2015). In urban centers, the interaction between urban heat island effects and local emission sources creates microclimates that further distort expected pollutant-meteorology relationships. These disparities underscore the need for localized and data-driven assessments that can capture the nuances of regional climate and air quality dynamics (Koldasbayeva et al., 2024).

Advancements in satellite remote sensing, ground-based monitoring networks, and atmospheric reanalysis data have made it increasingly feasible to conduct high-resolution spatiotemporal analyses of rainfall, temperature, and $PM_{2.5}$. Statistical methods such as trend analysis (e.g., Mann–Kendall test), correlation studies, and spatial interpolation techniques (e.g., kriging or inverse distance weighting) are commonly employed to discern patterns and identify drivers of change. Additionally, machine learning approaches are emerging as valuable tools for predicting air quality under varying meteorological conditions and projecting future trends based on historical data (Siddiqui et al., 2024).

This study aims to analyze the spatiotemporal trends in rainfall, air temperature, and $PM_{2.5}$ concentrations over selected regions and time periods, with an emphasis on identifying correlations, anomalies, and potential causal interactions among the variables.

II. MATERIALS AND METHODS

Nigeria, located in West Africa, has a population of approximately 229.5 million according to the 2024 census. The country lies between latitudes 4°N and

14°N and longitudes 3°E and 14°E, bordered by Niger to the north, Chad and Cameroon to the east, the Gulf of Guinea to the south, and Benin to the west. Covering an area of approximately 923,769 square kilometers, Nigeria is the most populous country in Africa and the sixth most populous in the world. The nation exhibits diverse geography and climate, ranging from arid regions in the north to humid equatorial climates in the south. Nigeria is endowed with abundant natural resources, including significant petroleum and natural gas reserves.

The climate in Nigeria is predominantly tropical, characterized by distinct rainy and dry seasons that vary by location. The southern region is the most economically developed, with extensive exploitation of forest resources. This region also hosts the majority of Nigeria's major industrial activities, oil fields, and seaports (Omaliko et al., 2025). The northern regions, particularly Sokoto and Kano, are among the most densely populated areas (Koko et al., 2023). Lagos, a cosmopolitan city consisting of islands and mainland, has experienced remarkable economic and population growth in recent decades. Approximately one-fifth of Nigerians derive their livelihood from agriculture (Koko & Bello, 2023).

For this study, ten locations were selected across Nigeria based on their distinct geographical and economic characteristics: Ilorin, Ikeja, Sokoto, Uyo, Kano, Owerri, Enugu, Abuja, Port Harcourt, and Gombe (see Figure 1). These cities represent diverse climatic zones and urbanization levels, which are important for analyzing spatial variability in climate and air quality parameters (Reddingy, 2008). The locations were plotted using QGIS software (version X.X) to visualize their spatial distribution.

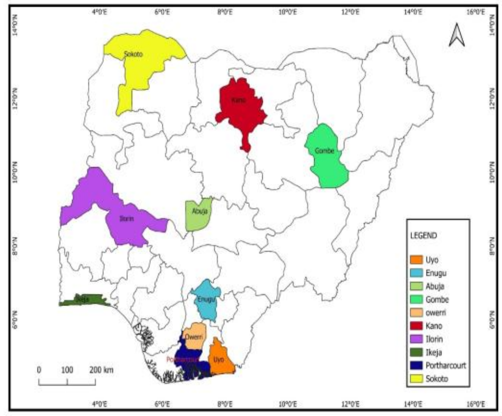

Figure 1: Map of Nigeria showing the selected study locations.

Data Analysis

Descriptive statistical methods were used to analyze the datasets, including calculations of mean and standard deviation, as well as the generation of scatter plots to visualize trends., whose analysis often involves linear regression, where the trend line is represented by the equation:

$$y = \beta_0 + \beta_1 x + \varepsilon \quad (1)$$

Where; y is the dependent variable, x is the independent variable, β_0 is the intercept, β_1 is the slope (representing the trend), ε is the error term.

Atmospheric Parameters Analyzed

The datasets used in this study were obtained primarily from satellite retrievals and meteorological records for the selected cities:

i) Particulate Matter (PM2.5) concentrations from NASA Giovanni (1980–2024).
ii) Air temperature data from NASA Giovanni (1980–2024).
iii) Rainfall data obtained from the Nigerian Meteorological Agency (NiMet) (1980–2024).

The QGIS software was utilized for spatial mapping and calculation of trend across the locations.

QGIS (Quantum Geographic Information System) is a free, open-source software that allows users to create, edit, visualize, analyse, and publish geospatial information.

III. RESULTS AND DISCUSSION

Analysis of spatiotemporal trends in rainfall, air temperature, and PM2.5 concentrations revealed provide insight into regional environmental stability and potential vulnerabilities.

3.1 Rainfall Variability Across Nigerian Cities

Figure 2 illustrate Rainfall trend plots, changes in average annual rainfall over time, with upward trends indicating increasing rainfall, downward trends suggesting potential drying or desertification, and flat or fluctuating trends reflecting irregular patterns without significant change. In Enugu, a slightly increasing trend suggests improved agricultural productivity, although this may raise the risk of seasonal flooding. Owerri shows a slight decline or fluctuating downward trend, indicating reduced rainfall that could impact rain-fed agriculture, potentially due to urban expansion or climate shifts. Abuja displays a mild upward trend, which could present benefits but also flood risks associated with poor drainage. Ikeja's trend appears stable or slightly increasing, likely influenced by urbanization and the urban heat island effect, leading to localized intense rains. In Sokoto, a clear declining trend reflects climate change impacts, threatening agriculture and water availability.

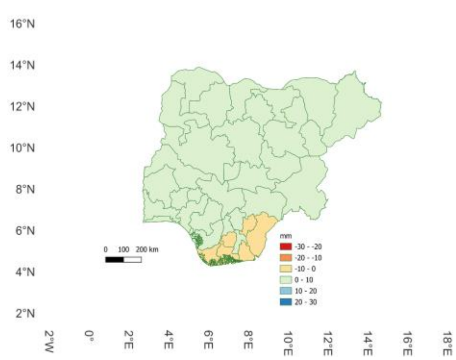

Figure 2: Spatial variability of rainfall trends in Nigeria from 1980-2023

Gombe also shows a notable downward trend, indicating a broader drying pattern in northeastern Nigeria, suggesting the need for adaptive strategies like irrigation. Kano experiences a similar decline, which, compounded by population growth, may increase water stress and emphasize the importance of long-term resource management. Port Harcourt exhibits a mildly increasing trend, raising concerns about flooding in an already high rainfall region, while Ilorin displays stable rainfall conditions, potentially serving as a buffer between the arid north and the wet south. Uyo shows a steady increasing trend, enhancing water availability and agricultural potential but also raising infrastructure flood risks.

3.2 Air Temperature trend Across Nigerian Cities

Figure 3 analyzes the trends in air temperature across various regions of Nigeria, revealing significant disparities influenced by urbanization, land use, and climatic conditions. Southern and coastal cities, such as Uyo, Port Harcourt, Ikeja, Owerri, and Enugu, exhibit the highest warming trends, with steadily rising temperatures likely linked to factors such as urbanization, deforestation, and oceanic influences that exacerbate heat retention. In contrast, the central belt, encompassing Abuja, Ilorin, and Gombe, experiences moderate warming, attributable to changing seasonal cycles and shifts in land use, as these areas lie within transitional zones impacted by both humid and dry air masses.

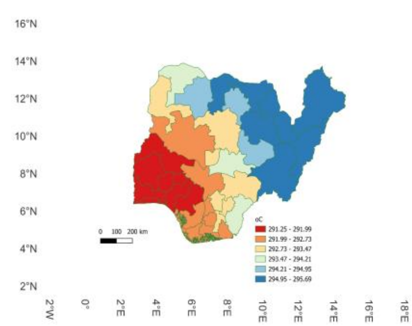

Figure 3: Spatial variability of air temperature trends in Nigeria from 1980-2023

The northern Nigeria cities, including Sokoto and Kano, display a slower overall warming trend, characterized by less dramatic temperature changes despite their reputation for heat. This muted rate of change may be attributed to the predominance of arid, dry air, which inherently maintains high thermal amplitude. Understanding these diverse temperature trends is crucial for developing effective climate adaptation strategies and policies in Nigeria.

3.3 PM2.5 trend Across Nigerian Cities

Figure 4 provides a detailed analysis of PM2.5 concentration trends across various Nigerian cities, revealing distinct patterns influenced by urban development, industrial activity, and environmental factors. Port Harcourt consistently exhibits very high PM2.5 levels, primarily due to intensive oil refining, gas flaring, and industrial operations, indicating a significant public health concern. Kano also demonstrates high PM2.5 concentrations, though slightly below those of Port Harcourt, with sources including industrial emissions, traffic, and open burning; despite a potential slight decrease in trend, levels remain elevated. Ikeja (Lagos) presents moderate to high PM2.5 values, heavily influenced by urban traffic and industrial activities, exhibiting seasonal fluctuations likely associated with dry and harmattan seasons.

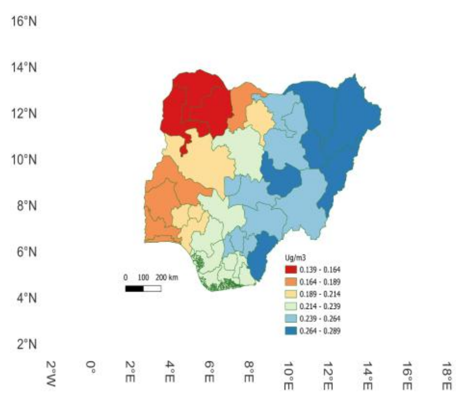

Figure 4: Spatial variability of PM2.5 trends concentration in Nigeria from 1980-2023

Abuja reflects moderate PM2.5 levels, where urban development and traffic contribute, although industrial activity is less pronounced compared to Port Harcourt and Kano. Both Owerri and Enugu show moderate and fluctuating trends, influenced by biomass burning, vehicle emissions, and some industrial impact. In contrast, Ilorin generally maintains lower PM2.5 levels relative to Kano and Port Harcourt, with fluctuations associated with seasonal dust and agricultural practices. Gombe reveals relatively lower but rising PM2.5 levels, potentially linked to urban expansion or transboundary dust from the Sahara. Uyo stands out with consistently low PM2.5 concentrations, attributed to minimal industrial and vehicular emissions. Finally, Sokoto exhibits a fluctuating trend with noticeable peaks, likely due to desert dust during dry seasons. Understanding these trends is crucial for addressing air quality management and public health strategies across Nigeria.

CONCLUSION

The analysis of rainfall, air temperature, and $PM_{2.5}$ concentrations across Nigerian cities from 1980 to 2023 reveals distinct spatial and temporal patterns shaped by climatic variability, urbanization, and anthropogenic activities. Rainfall trends indicate both opportunities and risks, with increasing precipitation in some regions improving water availability but heightening flood hazards, while declining trends in others signal growing aridification and water stress. Temperature patterns show a general warming trend nationwide, with the most rapid increases in southern and coastal cities, moderate warming in the central belt, and slower rates in the north, reflecting differences in land use, climatic zones, and atmospheric dynamics. $PM_{2.5}$ concentrations exhibit pronounced disparities, with industrialized and densely populated areas facing persistently high levels, while less urbanized regions record lower values but remain susceptible to seasonal dust transport. These findings highlight the complex interplay between climate change and air quality, emphasizing the need for region-specific adaptation measures, sustainable urban planning, and strict environmental regulations. Strengthening monitoring networks, promoting clean energy, improving waste management, and enhancing climate resilience strategies are essential to safeguard public health, protect ecosystems, and ensure sustainable socio-economic development in Nigeria.

The intricate interactions between multiple factors must be taken into account when examining spatiotemporal trends in temperature, rainfall, and PM2.5 (Ayanlade, Atai, and Jegede, 2019; Musa & Ogbe, 2025). Comprehending these interplays is essential for managing air quality and implementing public health initiatives. To create effective mitigation strategies and protect public health in the face of rising dust pollution and other climatic variations in West Africa, where rainfed agriculture is a major source of income for the populace, regional cooperation and investment in air quality monitoring infrastructure are crucial.

ACKNOWLEDGMENT

We are grateful to The Earth Science Data Systems (ESDS) and Nigerian Meteorological Agency (NiMet), which provides accessible and comprehensive satellite data for atmospheric research.

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