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Seasonal and Interannual Variability of Precipitation in Nigeria

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Abstract
This study examines the seasonal and interannual variability of precipitation in Nigeria, focusing on the relationship between precipitation patterns and atmospheric circulation. Nigeria, as the most populous country in Africa, heavily relies on agriculture, making understanding precipitation variability crucial for food security, water resources management, and socio-economic stability. The research utilizes the ECMWF ERA5 reanalysis dataset from 1980 to 2020, analysing total precipitation, 10-meter wind components, and mean sea-level pressure across various regions in Nigeria. The study reveals significant spatial and temporal variability in precipitation, with southern regions experiencing higher and more consistent rainfall due to the influence of the Intertropical Convergence Zone (ITCZ) and moist maritime air masses. In contrast, northern regions exhibit lower rainfall and higher interannual variability, influenced by dry, continental air masses and the brief incursion of the ITCZ during the wet season. Statistical and empirical orthogonal function (EOF) analyses highlight the complex relationships between precipitation and atmospheric variables. The results indicate region-specific relationships, emphasizing the importance of local climatic conditions in shaping precipitation patterns. The EOF analysis identifies dominant modes of variability, with the first two EOFs explaining approximately 75% of the total variance, underscoring the role of large-scale atmospheric processes like the ITCZ. This study contributes to a better understanding of the climatic dynamics affecting Nigeria's precipitation. The findings are critical for agricultural planning, disaster preparedness, and long-term climate adaptation strategies in Nigeria.

Keywords: Precipitation, Variability, Seasonal, Interannual, Atmospheric Circulation Patterns, ITCZ, Wind Speed and Direction, MSLP, Regional, EOF, OLS, Nigeria.

Introduction

Background:

Understanding precipitation variability in Nigeria is crucial for several reasons. As the most populous country in Africa, Nigeria relies heavily on agriculture, with a significant portion of its population engaged in farming activities (Adebayo, 2021). The variability of rainfall has profound implications for food security, water resources management, and overall socio-

economic stability. As Nigeria experiences fluctuations in precipitation patterns, the impacts are felt across various sectors, particularly agriculture, which is heavily dependent on seasonal rainfall (Ojo & Fadare, 2020). Changes in rainfall can lead to droughts or floods, affecting crop yields, water availability, and the livelihoods of millions of people (Adenodi, 2018). Studying precipitation variability is vital for agricultural planning, water resource management, and disaster preparedness. Variations in rainfall patterns can lead to water scarcity, affect crop yields, and increase flooding risks, affecting food security and livelihoods (Adefisan et al., 2019).

Moreover, precipitation variability is closely linked to atmospheric circulation patterns and broader climate change phenomena. Changes in atmospheric circulation, such as the West African Monsoon, can alter the distribution and intensity of rainfall across Nigeria (Okonkwo & Demoz, 2022). Atmospheric circulation influences the distribution and intensity of rainfall across Nigeria, with phenomena such as the Intertropical Convergence Zone (ITCZ) and sea surface temperature anomalies playing significant roles (Animashaun et al., 2020). Understanding these patterns is essential for predicting future climate scenarios and developing effective adaptation strategies.

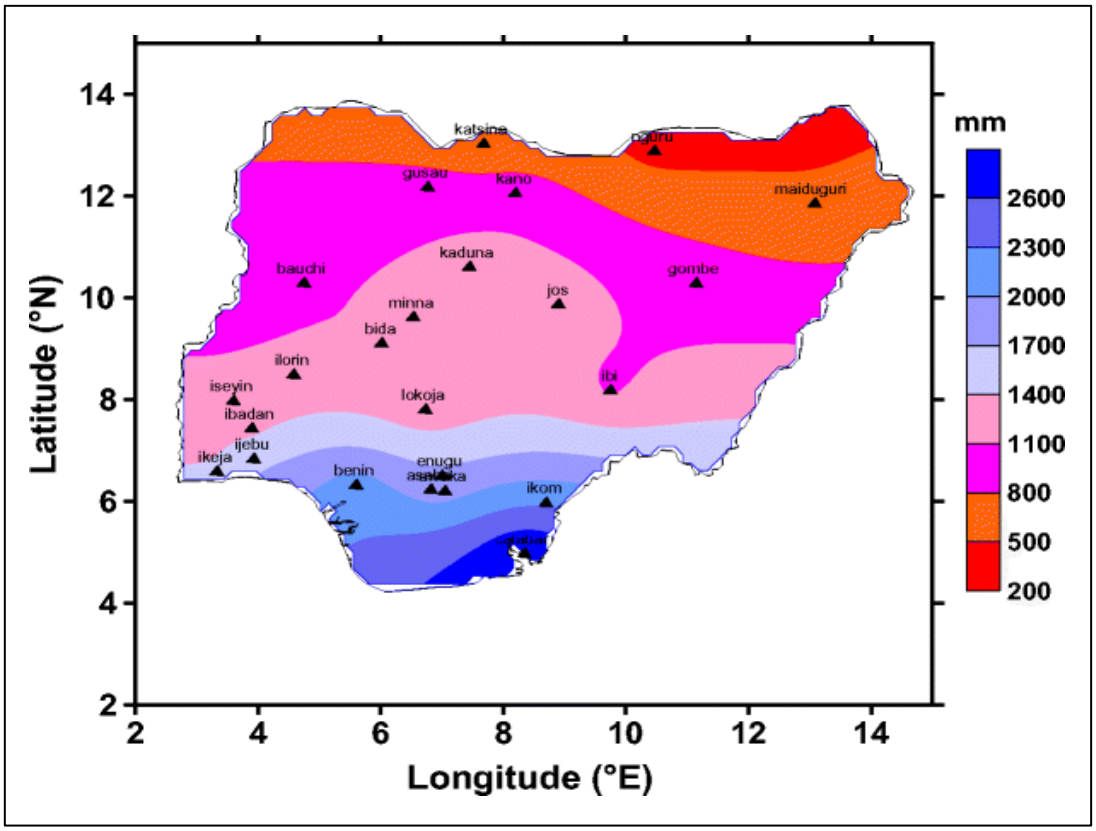


Figure 1: Spatial pattern of annual rainfall in Nigeria (Akinsanola et., al. 2017)

Previous Studies Review: A considerable body of research has focused on analysing precipitation patterns across Nigeria and broader West Africa, with a particular emphasis on

seasonal and interannual variability. These studies have provided significant insights into the drivers and characteristics of rainfall variability, often highlighting the critical role of large-scale atmospheric phenomena.

a) **Seasonal Variability:** Many researchers have explored the seasonal distribution of rainfall in Nigeria. For instance, Ayoade (2019) highlighted the significant seasonal variation in precipitation, largely influenced by the northward and southward movements of the Inter-Tropical Convergence Zone (ITCZ). Similarly, Akinsanola and Ogunjobi (2017) examined the onset and cessation of the rainy season across Nigeria, noting substantial regional differences. Also, Nicholson (2013) provided an extensive review of the rainfall regime in the West African Sahel, which includes northern Nigeria, emphasizing the region's sensitivity to shifts in the West African Monsoon (WAM) and the Intertropical Convergence Zone (ITCZ). All this study emphasized the critical role of the West African Monsoon in shaping the seasonal rainfall patterns.
b) **Interannual Variability:** On the interannual scale, studies have shown that precipitation in Nigeria is affected by large-scale atmospheric and oceanic phenomena. Odekunle et al. (2020) found that the El Niño-Southern Oscillation (ENSO) significantly impacts rainfall variability, with El Niño events generally leading to reduced rainfall in Nigeria. This was corroborated by Nwokoro et al. (2018), who analyzed historical rainfall data and reported a strong correlation between ENSO phases and precipitation anomalies in the region.
c) **Atmospheric Circulation and Climate Change:** The relationship between atmospheric circulation patterns and precipitation has also been a subject of extensive research. Oguntunde et al. (2019) investigated the impact of climate change on rainfall variability, concluding that shifts in atmospheric circulation patterns, such as the strengthening of the Harmattan winds, have led to changes in the timing and amount of precipitation. Additionally, their findings suggested an increasing trend in the frequency of extreme weather events, such as heavy rainfall and prolonged droughts.

Knowledge Gaps: Despite the wealth of information from previous studies, several gaps remain in our understanding of precipitation variability in Nigeria:

a. **Regional Differences:** While many studies have focused on Nigeria as a whole, there is a need for more detailed analyses at the state or regional level to capture local variations in precipitation patterns.
b. **Temporal Resolution:** Most studies have emphasized seasonal and annual averages, often overlooking shorter-term variations such as monthly or weekly changes in precipitation, which are crucial for agricultural planning and disaster management.
c. **Integration of Variables:** Few studies have comprehensively integrated multiple atmospheric variables, such as wind components and sea-level pressure, to analyse their combined effects on precipitation variability.
d. **Climate Change Projections:** There is a lack of studies projecting future precipitation trends under different climate change scenarios, which is vital for long-term planning and adaptation strategies.

This study will contribute to this area by providing a comprehensive analysis that integrates climate change projections with observed precipitation trends.

Objective: The objective of this study is to examine the seasonal and interannual variability of precipitation in Nigeria and to understand its relationship with atmospheric circulation patterns. The analysis will focus on key data variables, including total precipitation (TP), 10-meter wind components (U10, V10), and mean sea-level pressure (MSL).

To achieve this, the study will utilize data from the ECMWF ERA5 reanalysis dataset, focusing on the following variables:

- **Total Precipitation (TP):** To measure the amount of rainfall over different regions and seasons.
- **10-meter Wind Components (U10, V10):** To assess wind patterns that influence moisture transport and precipitation distribution.
- **Mean Sea-Level Pressure (MSL):** To evaluate the influence of atmospheric pressure systems on precipitation variability.

By investigating these variables, this study aims to contribute to a better understanding of the climatic dynamics affecting Nigeria's precipitation and to inform strategies for managing water resources and agricultural practices in the face of changing climate conditions (Sidi, 2022).

DATA AND METHODS

Data Source: For this study, we will utilize the ECMWF ERA5 reanalysis data, which provides comprehensive and high-resolution atmospheric, land, and oceanic climate variables. The ERA5 dataset is produced by the Copernicus Climate Change Service (C3S) and covers the period from January 1940 to the present. It offers hourly estimates on a 31 km grid, resolving the atmosphere using 137 vertical levels up to 80 km. This extensive dataset is particularly suitable for our study as it integrates vast amounts of historical observations into global estimates using advanced modelling and data assimilation techniques, thereby providing reliable and consistent data for analysing precipitation variability in Nigeria (ECMWF, 2023)

Variables: The following variables from the ERA5 dataset are used in this study:

a) **Total Precipitation (TP):** These variable measures the accumulated precipitation over a specific period, providing insights into rainfall distribution and intensity across Nigeria.
b) **10-meter Wind Components (U10, V10):** These variables represent the eastward (U10) and northward (V10) wind components at a height of 10 meters above the surface. They are used to assess wind patterns that influence moisture transport and precipitation distribution.
c) **Mean Sea-Level Pressure (MSL):** This variable represents the atmospheric pressure at sea level, which is crucial for understanding the influence of atmospheric pressure systems on precipitation variability.

Study Period and Data Resolution: For a study focusing on seasonal and interannual variability, a study period of 40 years (from 1980 to 2020) is suitable to capture a wide range of climatic conditions and allow for robust statistical analysis. Using monthly averaged data

is most appropriate as it provides a good balance between temporal resolution and the ability to analyse longer-term trends. This period and data frequency cover multiple phases of important climate phenomena, such as El Niño and La Niña, which are highly relevant to the study.

Study Location: The selected regions cover a broad spectrum of climatic conditions, from semi-arid in the north to humid tropical in the south. This allows for a comprehensive analysis of precipitation patterns and their variability across different climatic zones.

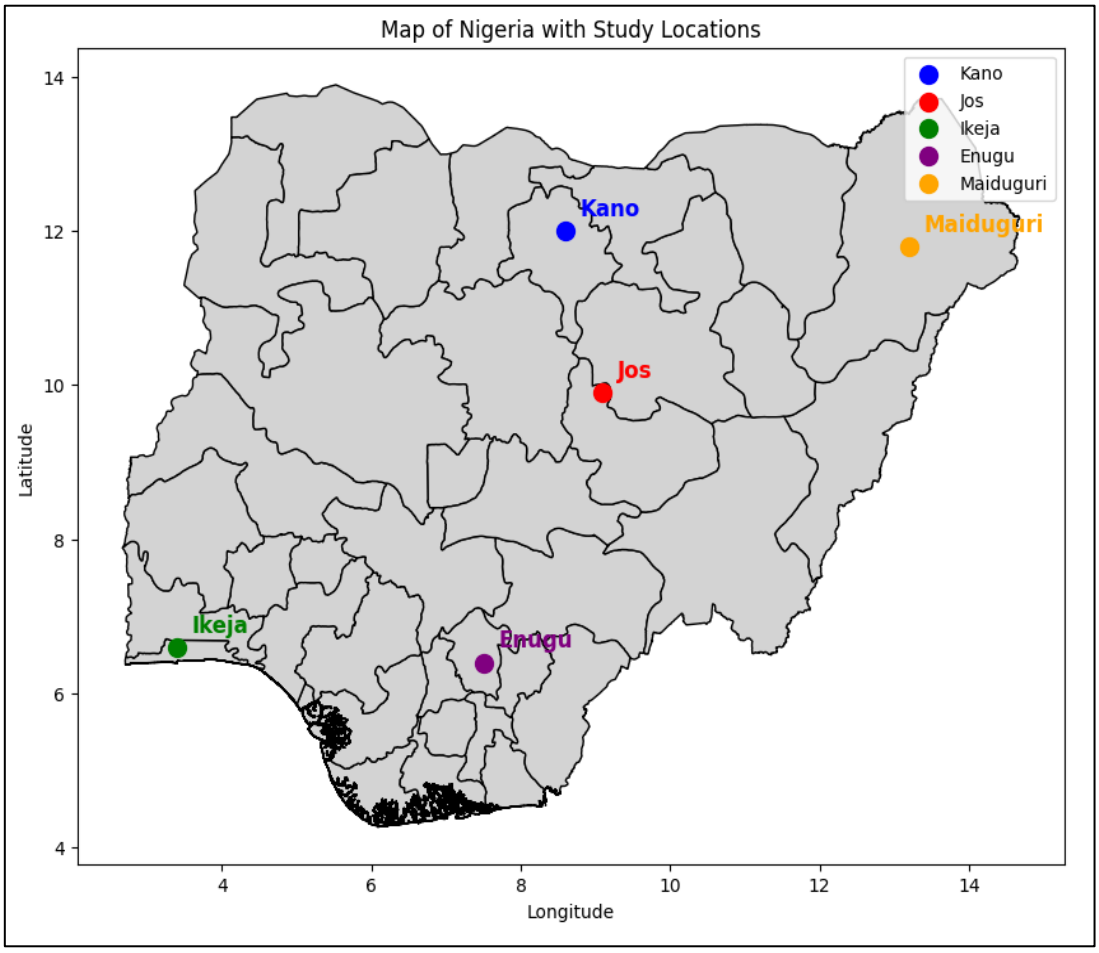


Figure 2: Map of Nigeria showing the study locations

a) **Kano (Northern Nigeria):** This region experiences a semi-arid climate and is significantly affected by interannual variability in rainfall, making it an important area for studying drought and agricultural impacts.
b) **Jos (Central Nigeria):** The central region has a mix of climatic conditions and is crucial for understanding the transition between the northern and southern climatic zones, as well as the influence of the ITCZ.
c) **Ikeja (Southern Nigeria):** This region experiences a tropical climate with heavy rainfall, making it essential for studying the impacts of seasonal rainfall patterns and flooding.

d) **Enugu (Southeast Nigeria):** Similar to the southern regions, this area has significant rainfall and is also influenced by the Atlantic Ocean.
e) **Maiduguri (Northeast Nigeria)**: This area is prone to drier conditions and is influenced by the Harmattan winds during the dry season.

Methodology: The following methods will be employed to analyse the data:
a. **Exploratory Data Analysis (EDA):** Initial analysis will be conducted to visualize and understand the general trends, patterns, and anomalies in the dataset. This will include plotting time series and spatial distribution of the variables.
b. **Statistical Analysis:** Statistical techniques will be used to identify trends and variability in the precipitation data. This will include calculating seasonal and annual averages, standard deviations, and anomalies.
c. **Empirical Orthogonal Function (EOF) Analysis:** EOF analysis will be used to identify the dominant modes of variability in the precipitation and atmospheric circulation data. This technique helps in decomposing the data into orthogonal modes that explain the variance in the dataset.
d. **Correlation and Regression Analysis:** Correlation and regression techniques will be applied to explore the relationships between precipitation and atmospheric circulation patterns. This will include analysing the correlation between TP and the wind components (weed speed & wind direction) as well as MSL.

By employing these methods, the study aims to provide a detailed understanding of the seasonal and interannual variability of precipitation in Nigeria and its relationship with atmospheric circulation patterns.

RESULT AND DISCUSSION

1. **Exploratory Data Analysis (EDA):** The exploratory data analysis (EDA) provided critical insights into the spatial and temporal variability of precipitation and associated atmospheric variables across key regions in Nigeria, namely Kano, Jos, Ikeja, Enugu, and Maiduguri. The analysis included the examination of seasonal patterns, interannual variability, and the relationship between precipitation and other meteorological factors such as wind speed, wind direction, and mean sea-level pressure (MSLP).

a. **Mean Precipitation Values:** The EDA as depicted in figure 3 revealed substantial spatial variability in mean precipitation across Nigeria, with southern regions such as Ikeja and Enugu experiencing significantly higher precipitation levels compared to northern regions like Kano and Maiduguri. This pattern aligns with the established climatology of Nigeria, where southern regions, closer to the equator and the Atlantic Ocean, benefit from the influence of the Intertropical Convergence Zone (ITCZ) and moist maritime air masses, leading to a more humid tropical climate with consistent rainfall throughout the year (Udo & Okujagu, 2014). In contrast, the northern regions, characterized by a semi-arid to arid climate, experience limited rainfall, particularly during the dry season when the ITCZ retreats southward.

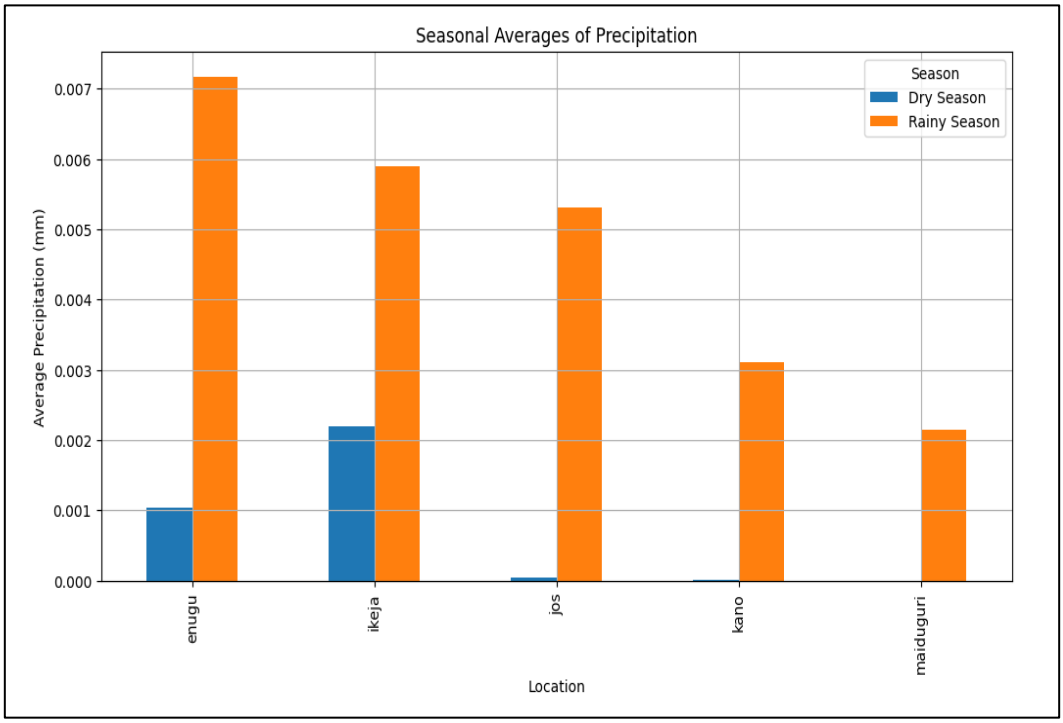


Figure 3: Seasonal Averages of Precipitation for dry and wet seasons in each location

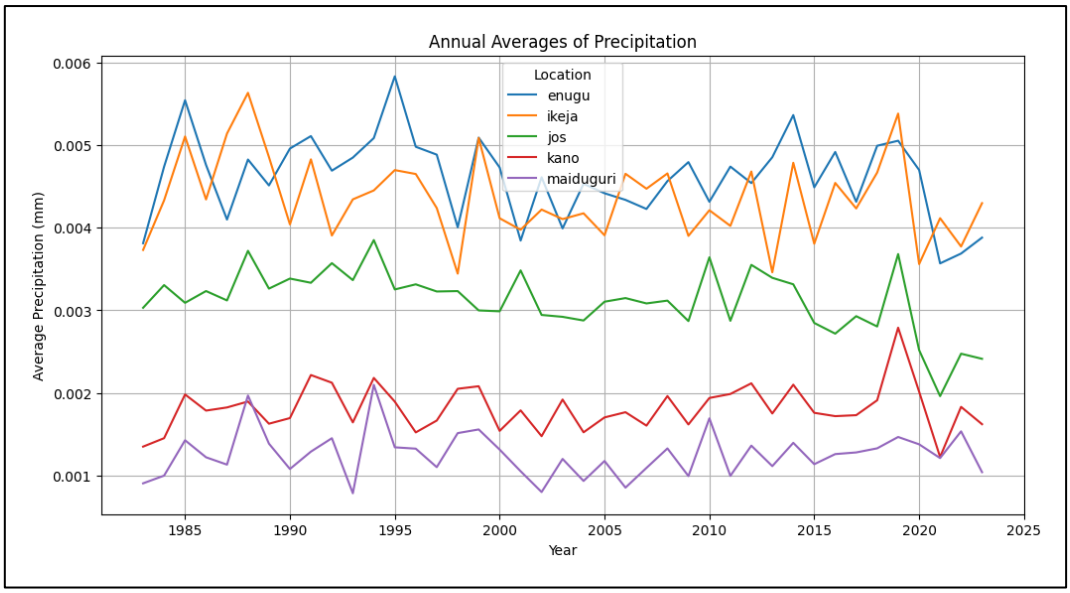


Figure 4: Annual Averages of Precipitation for each location

b. **Seasonal Trends:** Seasonal trends can be seen in figure 3, where precipitation further underscore the climatic dichotomy between Nigeria's southern and northern regions. In the south, regions like Enugu and Ikeja show a clear peak in precipitation during the middle months of the year as seen in figure 5, corresponding with the northward shift of the ITCZ (Olaniran & Sumner, 1989). Northern regions such as Kano and Maiduguri, however, exhibit

a shorter and delayed rainy season, reflecting their distance from the equatorial moisture source and the brief incursion of the ITCZ during the wet season.

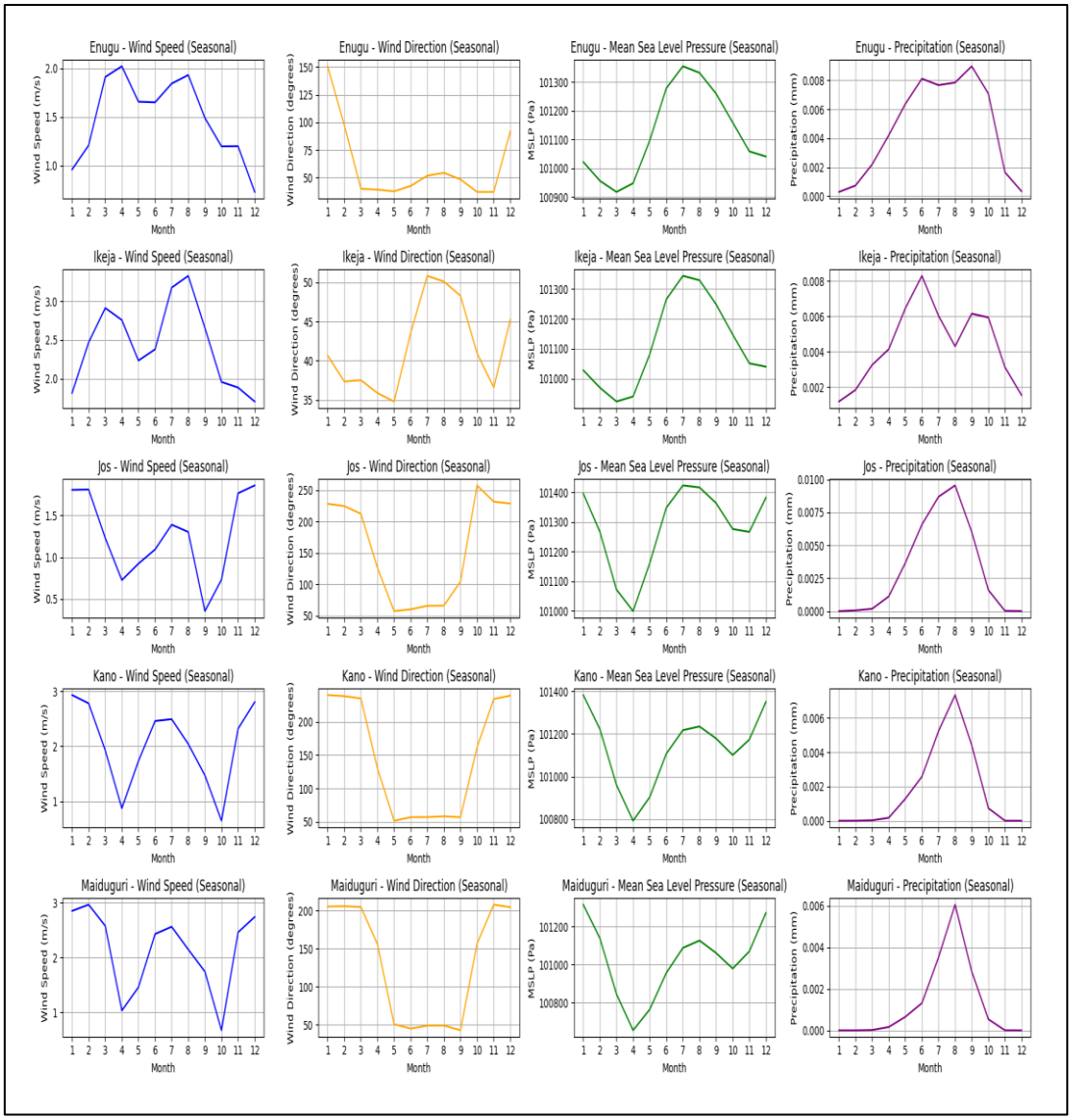


Figure 5: Time Series Analysis for precipitation and other meteorological factors for different locations

c. **Wind Direction and Precipitation Patterns:** From the wind vane depicted in figure 6 the seasonal wind direction analysis highlights its critical role in shaping regional precipitation patterns. In southern Nigeria, the dominance of south-westerly monsoon winds during the rainy season facilitates the inland movement of moist air from the Atlantic, resulting in heavy rainfall. In contrast, the northern regions predominantly experience northeasterly winds for most of the year, which are dry and contribute to the arid conditions typical of these areas. The brief rainy season in the north is associated with a temporary shift to southerly winds, but the duration and intensity of these winds are insufficient to bring substantial rainfall (Sawa, 2010; Omotosho & Abiodun, 2007).

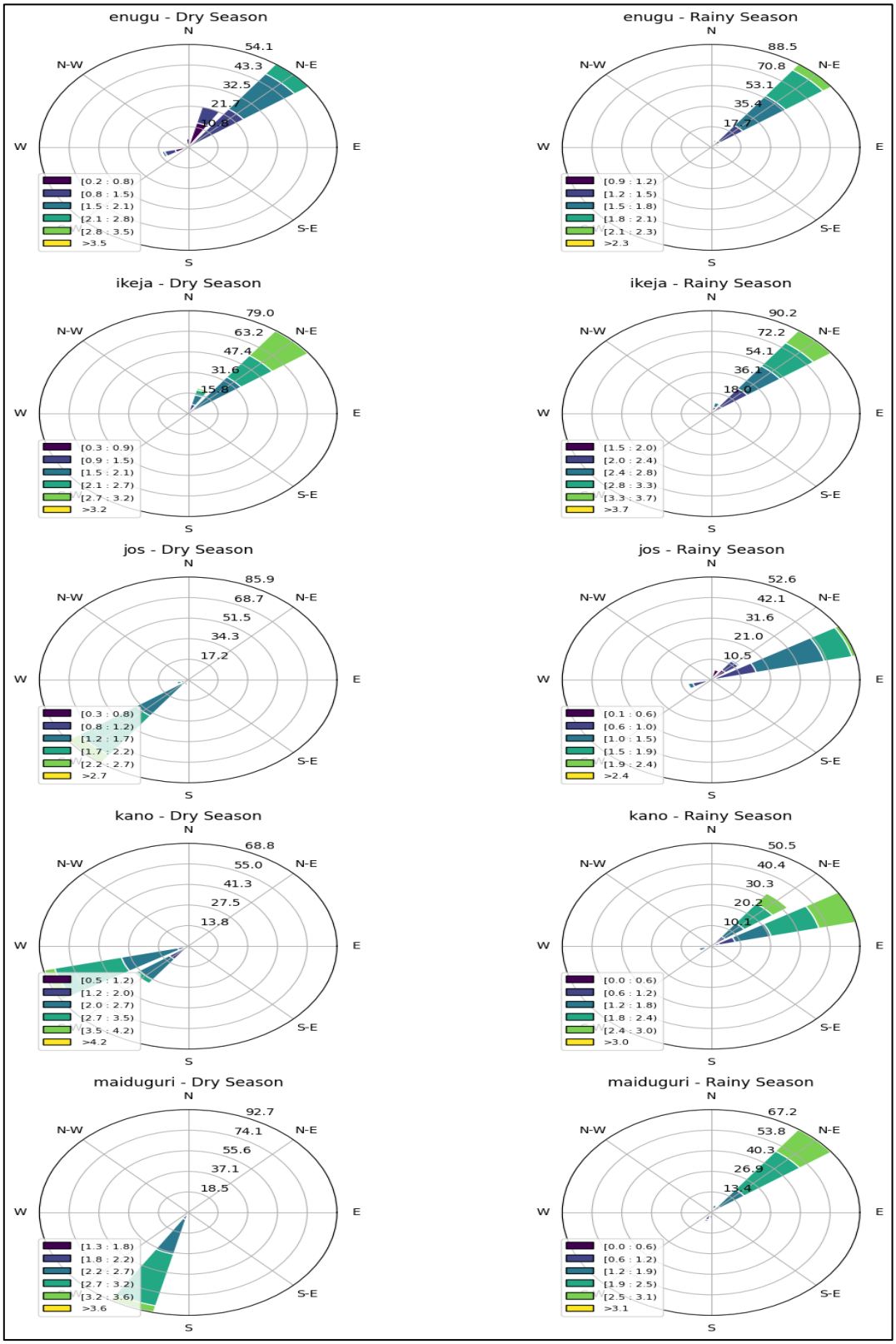


Figure 6: Showing direction using wind roses for each season and location

d. **Variability and Standard Deviations in Precipitation:**

The northern regions, such as Kano and Maiduguri, exhibit higher interannual variability compared to the southern regions, despite their lower standard deviations during both dry and rainy seasons. This is evident from the significantly lower standard deviations in the dry season for Kano and Maiduguri (Table 1).

Table 1: Seasonal Standard Deviations and Anomalies

	STD		**Anomalies**	
location	Dry Season	Rainy Season	Dry Season	Rainy Season
enugu	0.001079	0.002196	-0.00357	0.002553
ikeja	0.001333	0.00211	-0.00216	0.001545
jos	0.000199	0.003322	-0.00307	0.002192
kano	3.59E-05	0.002715	-0.00181	0.001292
maiduguri	3.11E-05	0.002245	-0.00125	0.000895

However, the overall variability in these regions is more pronounced due to the extreme fluctuations between dry and wet conditions, which can lead to periods of both drought and excessive rainfall (Adelekan, 2023). This erratic nature of rainfall poses substantial challenges for agricultural activities and water resource management in the north. In contrast as depicted in the box plot in figure 7, the southern regions like Enugu and Ikeja display more consistent precipitation patterns with lower standard deviations, indicating a more stable climate. This stability is crucial for sustaining agricultural productivity and managing water resources effectively.

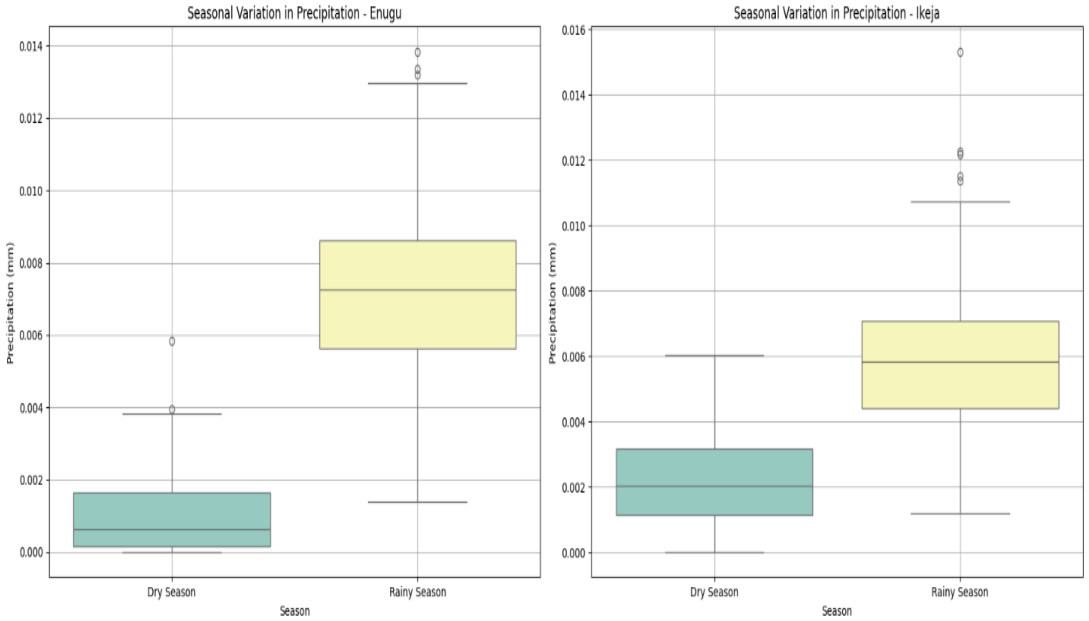
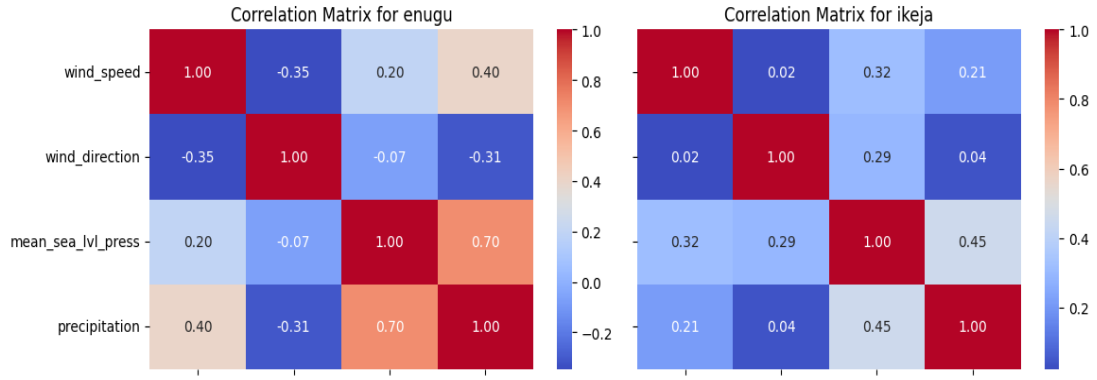




Figure 7: Box Plot Showing Variability for each season and locations

e. **Atmospheric Variables and Their Influence:** The relationship between precipitation and other atmospheric variables, such as wind speed, wind direction, and MSLP, was evident in the heat map of figure 8 and as clearly seen in the seasonal plots. The southern regions, with their lower wind speeds and more variable wind directions, showed a clear correlation with increased precipitation during the rainy season, driven by the ITCZ. In the northern regions, the higher and more consistent MSLP, coupled with lower precipitation, reflected the dominance of dry, continental air masses, which suppress rainfall for most of the year (Ayoade, 2004; Oguntunde et al., 2011).



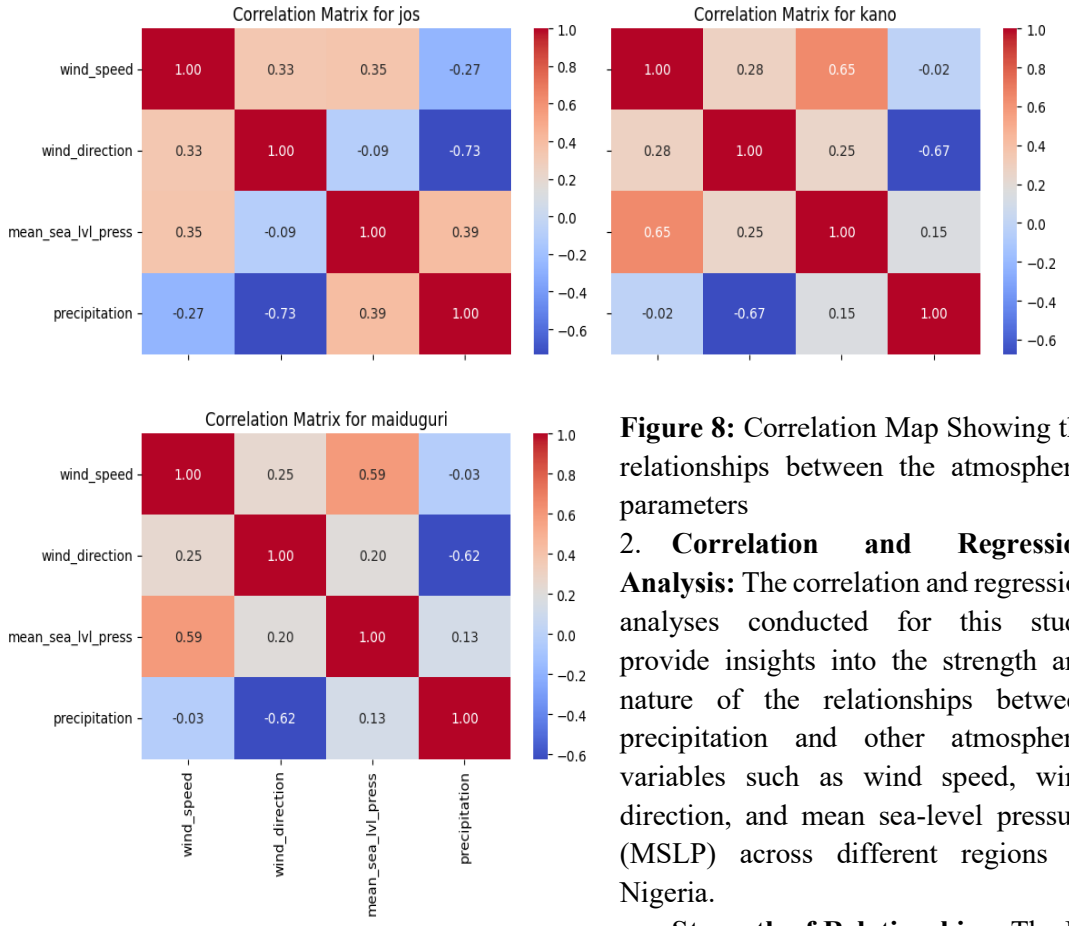


Figure 8: Correlation Map Showing the relationships between the atmospheric parameters

2. **Correlation and Regression Analysis:** The correlation and regression analyses conducted for this study provide insights into the strength and nature of the relationships between precipitation and other atmospheric variables such as wind speed, wind direction, and mean sea-level pressure (MSLP) across different regions in Nigeria.

a. **Strength of Relationships:** The R-squared values from the OLS regression results indicate the strength of the relationships between the variables as shown in the table below.

Table 2: OLS regression results for each location

Location	R-squared	Relationship Strength
Enugu	0.598	Moderate to Strong
Ikeja	0.22	Weak
Jos	0.675	Strong
Kano	0.564	Moderate
Maiduguri	0.454	Moderate

These R-squared values help evaluate the explanatory power of the regression models. For instance, the high R-squared values for Enugu and Jos suggest that the models effectively capture the variability in precipitation in these regions, while the lower R-squared values for Ikeja indicate a weaker relationship. This further demonstrated in figure 9, which shows the "Scatter and residual Plot (differences between observed and predicted values) of Observed vs. Predicted Values". Where the red dashed line is plotted for reference. The closer the scatter points are to this line, the better the model's predictions. While the residuals plot ideally,

should be randomly scattered around zero, indicating no systematic errors in the predictions. Patterns in the residuals may suggest model inadequacies.

Table 3: Relationships between precipitation and other atmospheric variables based on the OLS regression results

Location	***Wind Speed Coefficient***	***Wind Direction Coefficient***	***Mean Sea-Level Pressure Coefficient***	***R-squared***
Enugu	0.0014	-1.06E-05	1.44E-05	0.598
Ikeja	0.0003	-1.37E-05	7.72E-06	0.22
Jos	-0.0013	-2.57E-05	9.43E-06	0.675
Kano	-0.0001	-2.13E-05	4.79E-06	0.564
Maiduguri	-5.70E-05	-1.69E-05	2.58E-06	0.454

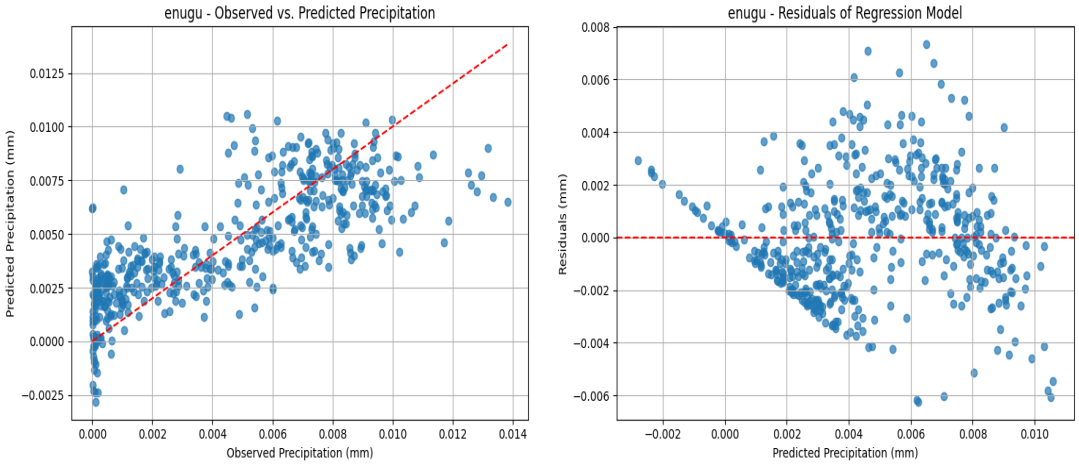
b. **Nature of Relationships:** The coefficients from the OLS regression results as shown in table provide insights into the nature of these relationships:

i. **Wind Speed:** The coefficients for wind speed vary across regions. For example, in Enugu, the coefficient is 0.0014, indicating a positive relationship between wind speed and precipitation. In contrast, Jos shows a negative coefficient (-0.0013), suggesting that higher wind speeds are associated with lower precipitation.

ii. **Wind Direction:** The coefficients for wind direction are consistently negative across all regions, indicating that changes in wind direction are inversely related to precipitation. For instance, in Enugu, the coefficient is -1.057e-05, and in Kano, it is -2.134e-05.

iii. **Mean Sea-Level Pressure (MSLP):** The coefficients for MSLP are positive across all regions, indicating that higher MSLP values are associated with higher precipitation. For example, in Enugu, the coefficient is 1.437e-05, and in Jos, it is 9.426e-06.

These findings suggest that the relationships between precipitation and atmospheric variables are complex and region-specific, highlighting the importance of considering local climatic conditions when analysing precipitation patterns.



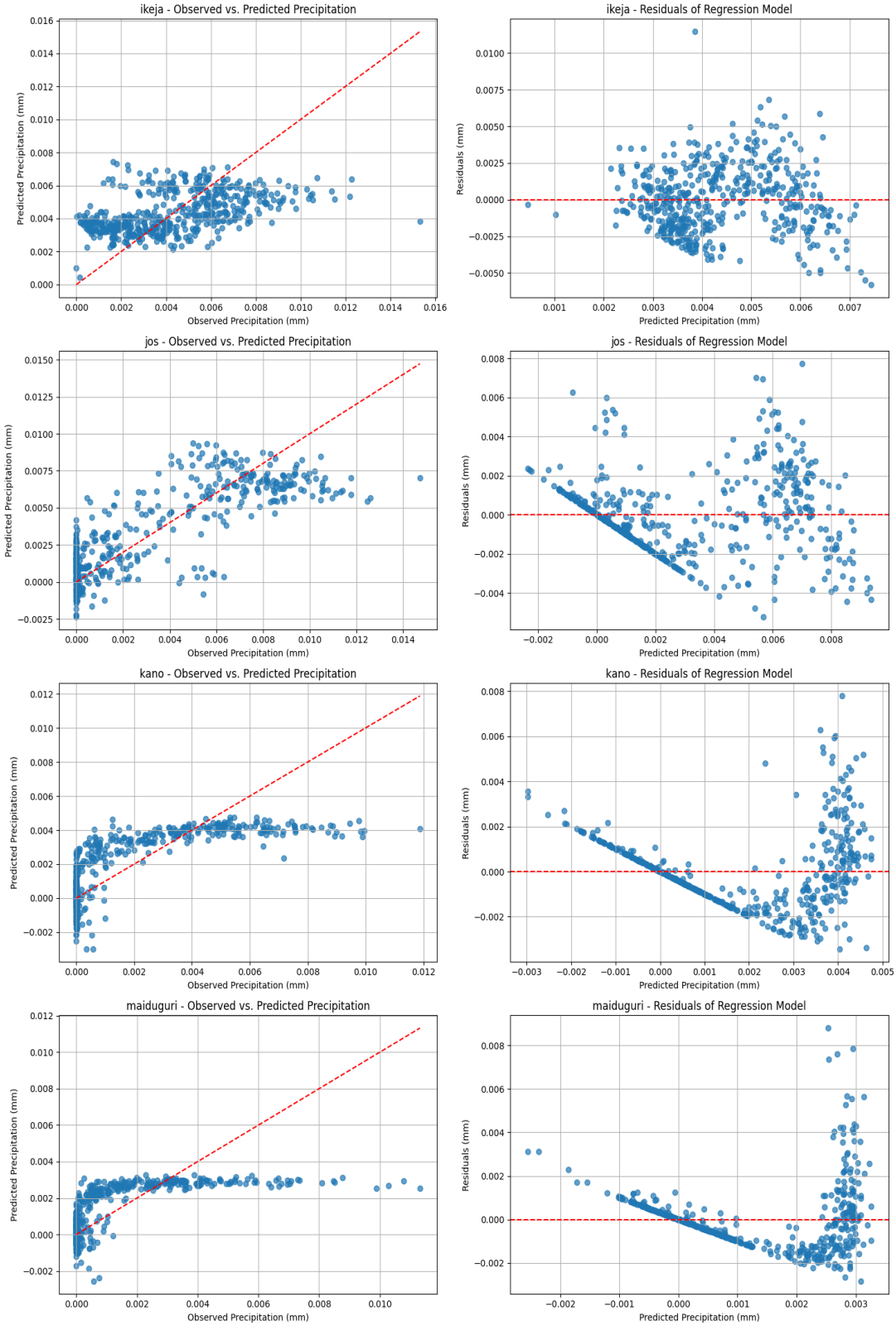


Figure 9: Scatter and residual Plot for precipitation for each location

3. **Empirical Orthogonal Function (EOF) Analysis:** In the context of this study, EOF analysis was applied to explore the spatiotemporal patterns of precipitation and other related atmospheric variables across selected locations in Nigeria, which include Kano, Jos, Ikeja, Enugu, and Maiduguri.

The results of the EOF analysis underscore the complex spatial variability in precipitation and associated atmospheric conditions across Nigeria. The first EOF's dominance highlights the importance of large-scale atmospheric processes, such as the ITCZ and related climatic features, in shaping regional precipitation patterns. The second EOF further reveals the significance of regional-scale processes, particularly in central Nigeria, where local topography and possibly mid-latitude interactions play a crucial role.

a. Explained Variance by Each EOF: The EOF analysis performed in this study produced three significant modes, each explaining a portion of the total variance in the dataset. The explained variances for the first three EOFs are as shown in table 4:

Table 4: Explained Variance by each EOF:

i.	**EOF 1: 41.03%**
ii.	EOF 2: 34.12%
iii.	EOF 3: 11.01%

These percentages indicate that the first EOF captures the largest share of the variance, highlighting a dominant mode of variability that is most representative of the overall dataset. Together, the first two EOFs account for approximately 75.14% of the total variance, suggesting that these modes are particularly significant in explaining the main patterns of variability in precipitation and associated variables across the regions studied.

b. First EOF (Spatial Pattern): The spatial pattern associated with the first EOF reveals the dominant mode of variability across the different locations in Nigeria. This mode is characterized by positive loadings over most of the locations, particularly in southern regions like Ikeja and Enugu, which are associated with higher average precipitation. The negative loadings observed in the northern regions such as Kano and Maiduguri reflect the reduced precipitation typical of these areas. The first EOF, therefore, likely captures the broad contrast between the wet southern regions and the dry northern regions, a fundamental climatic gradient influenced by the Intertropical Convergence Zone (ITCZ) and other large-scale atmospheric circulations (Nicholson, 2009). The significance of the first EOF in explaining the majority of the variance suggests that the most dominant pattern of variability across the study area is related to this north-south climatic gradient. This finding is consistent with previous research, which has documented the stark differences in precipitation patterns across Nigeria's latitudinal zones (Adejuwon, 2012; Odekunle, 2006).

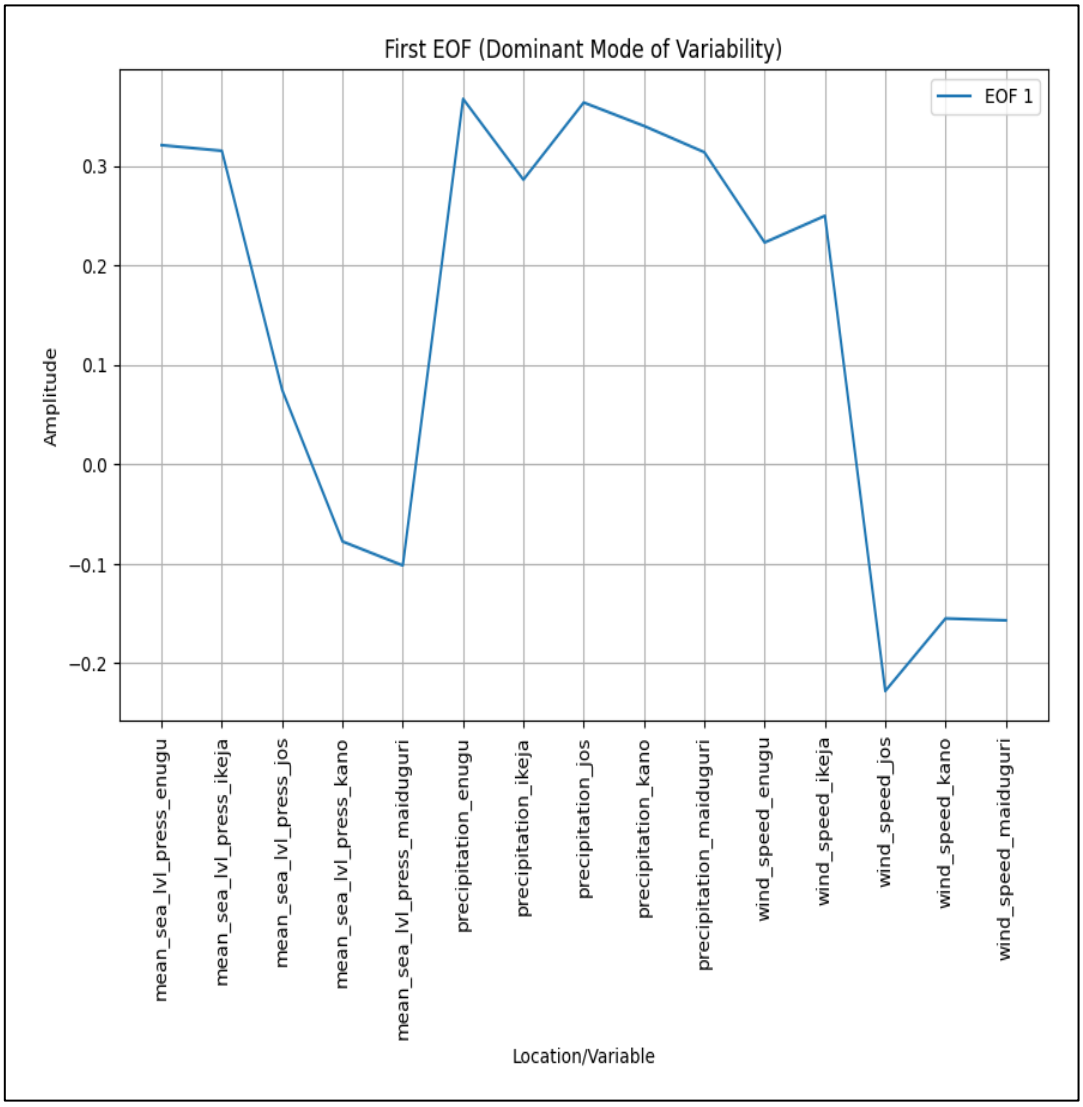


Figure 6: First EOF (Dominant Mode of Variability)

c. Second EOF (Spatial Pattern): The second EOF captures a different mode of variability, which explains 34.12% of the total variance as shown in figure 7. The spatial pattern of this EOF is characterized by strong positive loadings over Jos and surrounding central regions. This suggests a regional mode of variability that is distinct from the north-south gradient captured by the first EOF. The strong positive loadings over Jos may be indicative of the region's unique topography and its influence on local climate patterns, including orographic effects that can enhance precipitation. The second EOF might also capture variability associated with mid-latitude influences or variations in the strength and position of the ITCZ, which could differentially impact central Nigeria compared to the more northerly and southerly regions. This finding aligns with studies that have noted significant interannual and decadal variability in central Nigeria's climate, influenced by both tropical and extratropical systems (Oguntunde et al., 2011; Sawa, 2010).

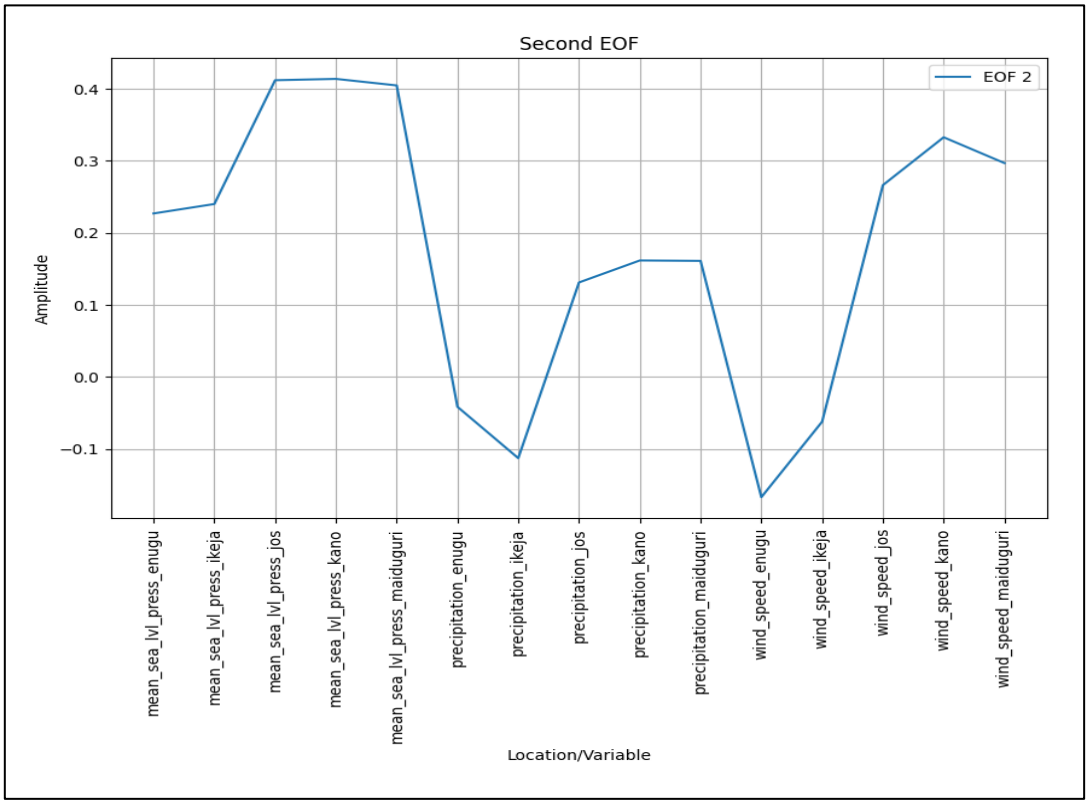


Figure 8: Second EOF (Variability)

Understanding these EOF patterns is critical for improving seasonal climate predictions and developing more effective strategies for managing water resources and agricultural planning in Nigeria. By identifying the dominant modes of variability, policymakers and scientists can better anticipate the impacts of climate variability on different regions, thereby enhancing resilience to climate-related risks.

CONCLUSION

The study on the seasonal and interannual variability of precipitation in Nigeria has provided comprehensive insights into the complex relationships between precipitation and atmospheric circulation patterns across different regions. Here are the key findings and their implications:

- **Spatial Variability in Precipitation:** The analysis revealed significant spatial differences in mean precipitation values, with southern regions (e.g., Ikeja and Enugu) experiencing higher precipitation levels compared to northern regions (e.g., Kano and Maiduguri). This pattern is consistent with the influence of the Intertropical Convergence Zone (ITCZ) and moist maritime air masses in the south, and the semi-arid to arid climate in the north.
- **Seasonal Trends:** Seasonal trends highlighted a clear distinction between the southern and northern regions. Southern regions show a peak in precipitation during the middle months of the year, corresponding with the northward shift of the ITCZ, while northern regions exhibit a shorter and delayed rainy season.

- Wind Direction and Precipitation Patterns: The dominance of south-westerly monsoon winds in southern Nigeria facilitates heavy rainfall, whereas northeasterly winds in the north contribute to arid conditions. The brief rainy season in the north is associated with a temporary shift to southerly winds, but the duration and intensity are insufficient to bring substantial rainfall.
- **Variability and Standard Deviations:** Northern regions experience higher interannual variability, posing significant challenges for agricultural activities and water resource management. In contrast, southern regions display more consistent precipitation patterns, indicating a more stable climate.
- **Relationships with Atmospheric Variables:** The study found that precipitation is positively correlated with mean sea-level pressure (MSLP) and inversely related to wind direction changes. Wind speed showed varying relationships across regions, highlighting the complexity of these interactions.
- **Empirical Orthogonal Function (EOF) Analysis:** The EOF analysis revealed that the first two modes capture approximately 75.14% of the total variance, indicating that large-scale atmospheric processes and regional-scale features are crucial in shaping precipitation patterns.
- **Implications and Recommendations:**
- **Agricultural Planning and Water Resource Management:** The study emphasizes the need for region-specific agricultural planning and water resource management strategies. Southern regions benefit from consistent rainfall, while northern regions require adaptive measures for erratic rainfall.
- **Climate Change Adaptation:** Understanding precipitation and atmospheric circulation patterns is crucial for predicting climate scenarios and preparing for extreme weather, aiding in effective climate change adaptation.
- **Regional Studies:** Detailed regional analyses are essential for capturing local precipitation variations, enabling the development of targeted policies to address specific climatic challenges.

In conclusion, this study contributes significantly to the understanding of precipitation variability in Nigeria, emphasizing the critical role of atmospheric circulation patterns and the need for region-specific strategies to manage water resources and agricultural activities. The findings of this study can inform policy decisions and adaptation strategies, ultimately enhancing the resilience of communities to climate-related challenges.

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