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The Nigerian Climate Classification: A Multivariate Analysis

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Abstract

Many of the climate classification schemes in Nigeria have been questioned for their complexity and inconsistencies, which restrict their application in environmental, agricultural, and water resource management problems. Nigeria is blessed with diverse climate regions, including semi-arid, savannah, and tropical rainforest, which are found throughout the country. However, little is known about the historical trends of climate variations over time and space. Thus, this research attempted to use a multivariate analysis in the climate classification of Nigeria. Data used for the classification and regionalisation of climatic areas in Nigeria were extracted from the Climatic Research Unit (CRU) Time-Series (TS) version 4.07 (TS4.07). The data for the study were analysed using principal component analysis (PCA) and K-means clustering analysis (KMCA). The results of the PCA showed that rainfall and DTR had four homogeneous climate regions, and temperature and vapour pressure had three homogeneous regions respectively, which explain over 91% of the total change. The results of the study show there is a gradient from south to north, with rises in diurnal temperature range, and a decrease in rainfall and vapour pressure towards the north. The results of the K-means clustering divide rainfall, DTR, temperature, and vapour pressure into six clusters, which helped define regional changes and spot transition zones. In general, PCA results gave a clear idea of Nigeria's climate structure, while K-means clustering complements these findings by enhancing spatial differences and confirming regional patterns. The findings of this study give a better statistical framework to classify Nigeria's climate, which is helpful for adapting to climate change and managing numerous natural resources in the country.

Keywords: Climate Classification, Regionalization, Multivariate Analysis, Climate Regions

1. Introduction

The climate of a region is defined by its weather patterns over 30 years, encompassing elements such as diurnal temperature range (DTR), vapour pressure (VAP), rainfall (RF), relative humidity (RH), cloud cover (CC), temperature (Temp), wind speed (WS), wind directions (WD), and sunshine (SS). Arnfield (2016) averred that climate is intricate and expansive, integrating information from various aspects of the Earth's environment. Studies have demonstrated that climatic factors, whether biological or physical, have impacted different regions of the Earth in varied ways (Griffiths, 1983; Arnfield, 2016).

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While classification may have different meanings, it is generally recognised as the organisation of items or events into categories based on shared characteristics or attributes (Oliver, 2005). Khlebnikova (2009) described climate classification as a structured method for organising vast quantities of meteorological data concerning global weather patterns. There are three primary systems used in climate classification. The first is empirical classification, which relies on quantifiable climate parameters. For instance, the Köppen classification is based on temperature and rainfall statistics (Ritter, 2003). Ritter (2003) notes that temperature and rainfall are among the easiest climate variables to record, possessing some of the most extensive historical data availability.

The second system involves generic classification, which is based on fundamental elements that influence climate. Ritter (2003) asserts that this approach requires an understanding of various climate factors, such as air masses, pressure systems, and solar radiation. Due to the numerous variables involved, generic classification is considered one of the most challenging to develop and apply.

The third is applied classification systems, which are derived from specific climate-related issues. The Thornthwaite climate classification system is a good example, which categorises climates according to potential evapotranspiration, thereby grouping them based on their water needs. Research carried out by Thornthwaite and his team aimed to create a water budget method that evaluated water demand across various environmental contexts. His classification system emerged from the challenge of forecasting water supply and demand in different climatic areas (Ritter, 2025).

Since 1880, over 418 climate classification systems have been introduced, resulting in 36,334 citations. Gentilli (1958) reported that more than 78 climatic classification methods had been documented, while Terjung and Louie (1972) indicated that approximately 148 classification systems have been developed and published since 1880. Olaniran (1986) and Wuam et al. (2020) emphasised the necessity for a variety of schemes, as any single classification system can only serve a limited range of objectives.

Over the years, several investigations into climate classification have been conducted in different countries worldwide. For instance, around 500 BC, Parmenides classified the Earth's climate into three regions using temperature data. Ptolemy (90-168 AD) classified climates into seven regions using daylight duration as a means of classification. Hind (1842) proposed a climate classification that centred on moisture characteristics and temperature, by identifying three principal climatic features. Köppen and Geiger (1928) defined the Earth's climate using temperature and rainfall data, resulting in five significant climatic classifications. Köppen (1931, 1936) employed an alphabet to categorise the Earth's climate into five segments. Thornthwaite (1931, 1948) classified the Earth's climate based on heat and moisture. While Scaetta (1939) offered one of the first accounts of Nigeria's climate classification from a bioclimatic standpoint, highlighting rainfall and temperature as essential factors that shape ecological and vegetation patterns. Gorczynski (1941) classified climatic regions with the help of a bioclimatic perspective that focused on temperature and humidity, which focuses on human thermal comfort, offering a human-centred view of climate instead of just a physical classification. The climate classification proposed by Flohn (1950) is founded on a synthesis of large-scale atmospheric circulation and air-mass dynamics.

However, Barry and Chorley (1971), Hare (1973), and Olaniran (1986) have observed that most of the previous classification schemes did not significantly contribute to research on climate's effects on human health or the understanding of local climate components. Rather, they primarily offer a formal structure for evaluating the agricultural potential of different regions.

It has been revealed in the literature that it is only a few researchers who employed rainfall and temperature in their climate classification scheme exclusively, while others depend solely on maps of the entire continent in their climate classification. It has been advised that for any climate classification scheme to be effective and coherent, the researcher should incorporate multiple climatic factors, since climate is a multidimensional and complex phenomenon which comprises various weather parameters (Ayoade, 1977; Anyadike, 1987). Over the past 46 years, numerous climate classification schemes have been implemented using multivariate techniques alongside meteorological parameters.

Mohammed et al. (2021) employed principal component analysis (PCA) and hierarchical cluster analysis (HCA) in transforming rainfall data and reducing long-term rainfall datasets into a smaller dataset suitable for data analysis. The results of the HCA analysis identified four distinct climate regions across Nigeria. Wang et al. (2020) employed cluster analysis and PCA to classify urban areas into different groups based on their similarities. The results of the study revealed that this technique is more effective when analysing large climatic parameters with numerous variables. Their study further revealed that this method gives room for each city to maintain its uniqueness while adapting to varying environmental conditions. Darand and Daneshvar (2014) investigated rainfall patterns in Iran using daily gridded rainfall data from 1951 to 2007, obtained from the APHRODITE database. They applied PCA and HCA to a seasonal correlation matrix consisting of eight variables to regionalise rainfall mechanisms.

Almonacid et al. (2023) utilised non-hierarchical K-means clustering in climate classification in Santa Cruz province, employing monthly mean temperature and total rainfall amount to identify 11 distinct climatic regions. Their study further revealed that the driest parts of the country are the central and northeastern regions; on the other hand, the wettest and coldest parts are the southwestern and southern regions. Almazroui et al. (2014) used rainfall and air temperature datasets over long-term periods; their study was able to classify the climate of Saudi Arabia into five homogeneous groupings. They further classified the country into Northern, Red Sea Coastal, Interior, Highland, and Southern groups with the help of PCA and correlation analysis. According to the findings, these climatic classifications exhibit a notable characteristic, particularly regarding seasonality and interannual variability.

Anyadike (1987) explored the climate of West Africa using multivariate methods such as cluster and factor analysis. In contrast to earlier classifications, the study revealed that the regions are well-defined based on climate. Ayoade (1977) implemented three statistical methods involving various variables to characterise climates in Nigeria and examined the challenges associated with climate classification.

In contrast, Olaniran (1986) used 24 climatic variables to assess different aspects of the physical controls and climate characteristics within Nigeria's climatological regions. He subsequently performed factor analysis on each of these variables. The results indicated that three main characteristics could account for the regional climatology of the country: air mass residential time, wind patterns, and rainfall characteristics (including volume, average intensity, and duration of the rainy season). Mobolade and Pourvahidi (2020) developed a bioclimatic architectural strategy for Nigeria. The study revealed that Nigeria can be classified into five different climatic regions, such as hot-dry, hot-humid, temperate-humid, temperate-dry, and temperate-dry with a cool climate.

A multitude of studies conducted in Nigeria suggest that many of these investigations overlook other climatic conditions that directly affect individuals. For example, Ayoade (1977) employed four climatic parameters such as temperature, rainfall, relative humidity, and sunshine; Olaniran (1986) utilised three climatic parameters such as temperature, relative humidity, and rainfall; while Efe (2006) employed only two climatic variables such as rainfall and rainy days data in classifying the climate of Nigeria; similarly, Eludoyin et al. (2013) employed relative humidity and temperature data in their classification of the climate of Nigeria; and Mobolade and Pourvahidi (2020) classified the climate of Nigeria adapting to a new bioclimatic methodology. However, research experts around the world, in their separate studies, have advised researchers that other climatic parameters like vapour pressure and diurnal temperature range (DTR) should be incorporated in their study of climate classification. Therefore, utilising these criticisms and other problems associated with climate classification in Nigeria, this study aims to classify Nigeria's climate using DTR, rainfall, vapour pressure, and temperature data with the help of PCA and KMCA analyses.

2. Materials and Methods

2.1. *Study Area*

Nigeria, as a country, is located in West Africa and is part of the African continent. It lies between latitudes 4°N and 14°N and longitudes 3°E and 15°E. Nigeria's land area covers about 923,768 square kilometres and is surrounded by four French-speaking countries (the Republic of Benin to the west, the Niger Republic to the north, Cameroon and the Republic of Chad to the east) and the Gulf of Guinea to the south, while Lake Chad to the northeastern part of Nigeria. The World Bank Group (2021) has shown that the southern parts of Nigeria are associated with distinct rainfall patterns, which make these parts of the country receive heavy amounts of rainfall during the rainy season (March to October). Annual rainfall in these parts of the country ranges between 2000 mm to 4,000 mm in the Niger Delta region. While the central parts of the country are affected by one clear rainy season (April to September) and a dry season (December to March). In the same vein, Nigeria experienced the Harmattan Season from November to March. The Harmattan brings dry and dusty wind, which originates from the Sahara Desert; this dry and dusty wind is the primary cause of the Harmattan season in Nigeria. The coastal part of Nigeria is associated with a very short dry season, while March to October are wet months (The World Bank Group, 2021).

2.2 Data Collection

The four climatic parameters for this study namely Temperature, Diurnal Temperature Range, Rainfall, and Vapour Pressure, are collected from the archival records of the Climatic Research Unit (CRU) Time-Series (TS) version 4.07 (TS4.07) on a spatial resolution of 0.5º x 0.5º developed by the University of East Anglia for the 36 states of Nigeria, including the Federal Capital Territory (FCT), Abuja, and the data span the period from January 1901 to December 2022 (Harris et al., 2020; University of East Anglia Climatic Research Unit et al., 2023). The data were retrieved from the CRU database with the help of Google Earth Pro. Over the years, the CRU data have been applied in various climatological research (Horn et al., 2018; Harris et al., 2020; University of East Anglia Climatic Research Unit et al., 2023; Eyefia et al., 2023; Eyefia, 2023; Eyefia, 2024; Eyefia, 2025).

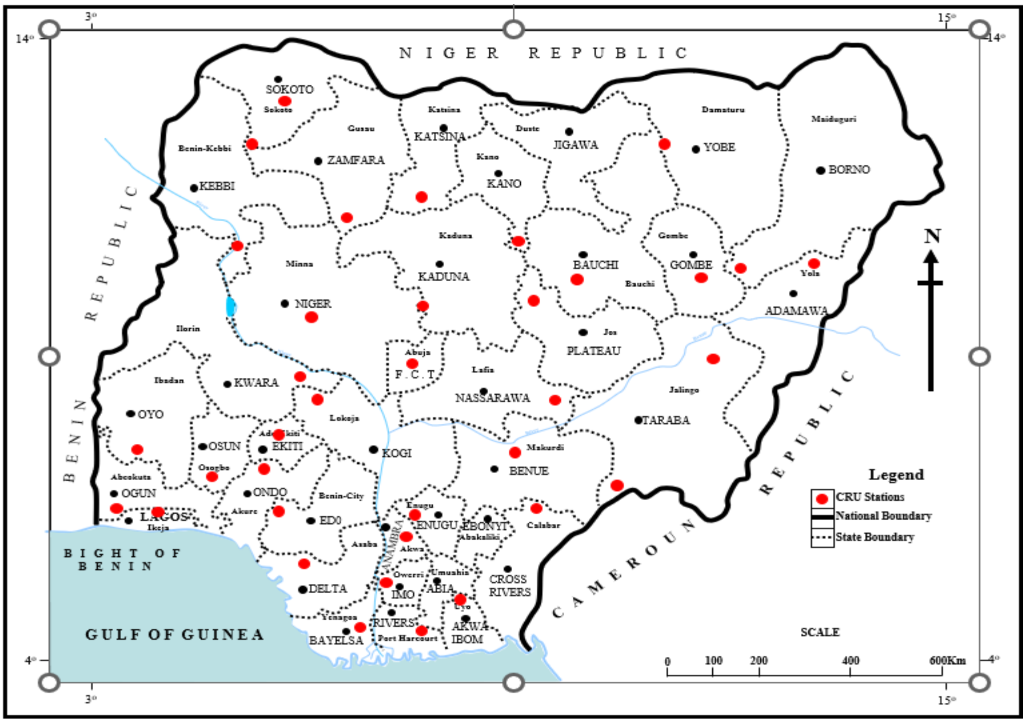

Figure 1: The 37 CRU Stations Used For the Study

2.3 Data Analysis

The data for the study were analysed using IBM SPSS Statistics Version 23. The study employed spatial data visualisation tools and inferential statistical techniques in the data analysis. The spatial data visualisation tools, specifically the thematic mapping (Figures 2 - 9), were employed to examine the spatial distribution and patterns of weather variables across Nigeria's 37 climate reporting units. Specifically, the mapped climate reporting units helped support and show the climate classification results from the PCA and K-means cluster analysis. Inferential statistics such as principal component analysis (PCA) and K-means cluster analysis (KMCA) were used to classify Nigeria into different climatic regions with the help of components and clusters.

Spatial Data visualisation (SDV) is the technique of efficiently communicating relationships, trends, and ideas through visual illustrations of spatial data and geographic information. It includes the conceptualisation and production of graphical presentations and mappings aimed at rendering geographical data comprehensible and visible (PlaceTrends 2025).

PCA is a popular dimensionality-reduction technique that reduces the number of variables in large datasets while keeping the majority of the original information (Jaadi, 2024). Similarly, Everitt and Dunn (1991) described PCA as a multivariate analysis method that operates without supervision, aimed at converting a collection of observed variables into a new group of mutually uncorrelated variables. In PCA, a component denotes a new variable that has been transformed and is expressed as a linear combination of the initial variables. In this study, these components revealed the predominant patterns of climate variations across Nigeria. Every component sums up a certain combination of temperature and rainfall features that explain climate differences in different reporting units.

K-Means Clustering analysis is a statistical technique used in multivariate analysis to create groups or clusters of products so that products in the same cluster are similar but not the same as variables in another cluster (Wilks, 2020; Bortolozo et al., 2023; Moraes et al., 2023; Pampuch et al., 2023). While Reutterer and Dan (2022) defined K-Means cluster analysis as an exploratory technique for grouping data points or reducing datasets into fewer unique categories. In this study, clusters were used to sort climate reporting units into different climatic clusters, and each cluster is a climatic region that shares similar climatic features but differs from other clusters. Research has shown that both strategies make it easier to identify major regional variations and climate patterns (Wilks, 2020; Bortolozo et al., 2023)

3. Results and Discussion

This section presents the results of Principal Component Analysis and K-Means Clustering Analysis for Diurnal Temperature Range, Rainfall, Temperature, and Vapour Pressure in Tables 1- 8 and Figures 2 – 9 below.

3.1 Principal Component Analysis (PCA)

3.1.1 Diurnal Temperature Range

The Diurnal Temperature Range (DTR) refers to the difference between the maximum and minimum temperatures recorded during a given day (Eyefia et al., 2023; Britannica, 2023; Echebima & Obafemi, 2023; Dike et al., 2019). DTR, which is a measure of daily temperature variability, is often utilised to assess the consistency of weather conditions in a specific area (Ding et al., 2012; Yang et al., 2013). Table 1 illustrates the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy for DTR in Nigeria. According to Table 1, the KMO value recorded is 0.918, confirming it exceeds the threshold of 0.70 set by Kaiser (1974). Bartlett's Test of Sphericity has a significance level of .000, which is lower than 0.05, as suggested by Bartlett (1951). It is recommended that if the p-value is above 0.05, principal component analysis (PCA) should not be conducted. The findings from the PCA result, generated by the IBM SPSS statistical software, indicate that the correlation matrix determinant for diurnal temperature range (DTR) is 2.70, suggesting a strong relationship. This also means the correlation matrix is not an identity matrix.

Table 1: KMO and Bartlett's Test for Diurnal Temperature Range (DTR) in Nigeria

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.918
Bartlett's Test of Sphericity	Approx. Chi-Square	13797.636
	Df	666
	Sig.	.000

The results presented in Table 2 display the total variance explained by each component in the PCA of Nigeria's Diurnal Temperature Range (DTR). The total variance explained helps in identifying the most significant variables for the study and classification by showing the proportion of total data variability accounted for by each principal component. Zwick and Velicer (1986) recommend retaining factors with eigenvalues exceeding 1.0. Thus, the researcher decided to retain six components, as shown in Table 2, which revealed that the eigenvalues of the first four factors were above one. The four components account for 93.46% of the data variation. These results indicate meaningful classifications of states and support the structure of four components depicted in Figure 2.

Table 2: Total Variance Explained for DTR in Nigeria

	Initial Eigenvalues			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	17.557	47.451	47.451	13.685	36.987	36.987
2	9.433	25.494	72.945	9.305	25.148	62.135
3	5.175	13.987	86.932	8.474	22.904	85.039
4	2.416	6.530	93.462	3.117	8.423	93.462
5	.686	1.855	95.317			
6	.566	1.531	96.848			
Extraction Method: Principal Component Analysis.						

Table 2 shows that PCA analysis results divided DTR into four groups. The results of the PCA in Figure 2 show that Component 1 encompasses 16 states from the Niger Delta, Southeastern, and Southwestern regions, with DTR varying from 7.6°C (Lagos State) to 9.9°C (Ekiti State). Component 2 includes nine states from the Northeast and North-Central regions, where the DTR ranges from 10.6°C (Benue State) to 14.7°C (Borno State). Component 3 comprises ten states situated in the North-Central, North-Western, and South-Western regions, with DTR values from 10.6°C (Oyo State) in a Tropical Savannah Climate (Aw) to 14.3°C (Jigawa State).

Component 4 consists of just two states within the North-Central region, with DTRs ranging from 11.0°C (Federal Capital Territory [FCT], Abuja) to 18.9°C (Kogi State) (Figure 2). Overall, Figure 2 illustrates that DTR increases from the southern part to the northern part of the country. The increase in south–north diurnal temperature range is in accordance with earlier findings of Ayoade 1977, Olaniran, 1986; Dike et al., 2019; Echebima and Obafemi, 2013, who have reported lower DTR values in humid coastal and rainforest regions of Nigeria owing to the effects of high cloud cover and atmospheric moisture, and higher DTR values in the arid northern regions as a result of low humidity and strong nocturnal radiative cooling. The DTR is seen to decrease from the south in the Tropical Monsoon climate (Am) to the north in the Sahelian hot and semi-arid climate. The DTR data collected from the 37 climate reporting units across Nigeria indicate that DTR ranges from 7.6°C to 18.9°C, with an average of 11.3°C over the 122-year study period.

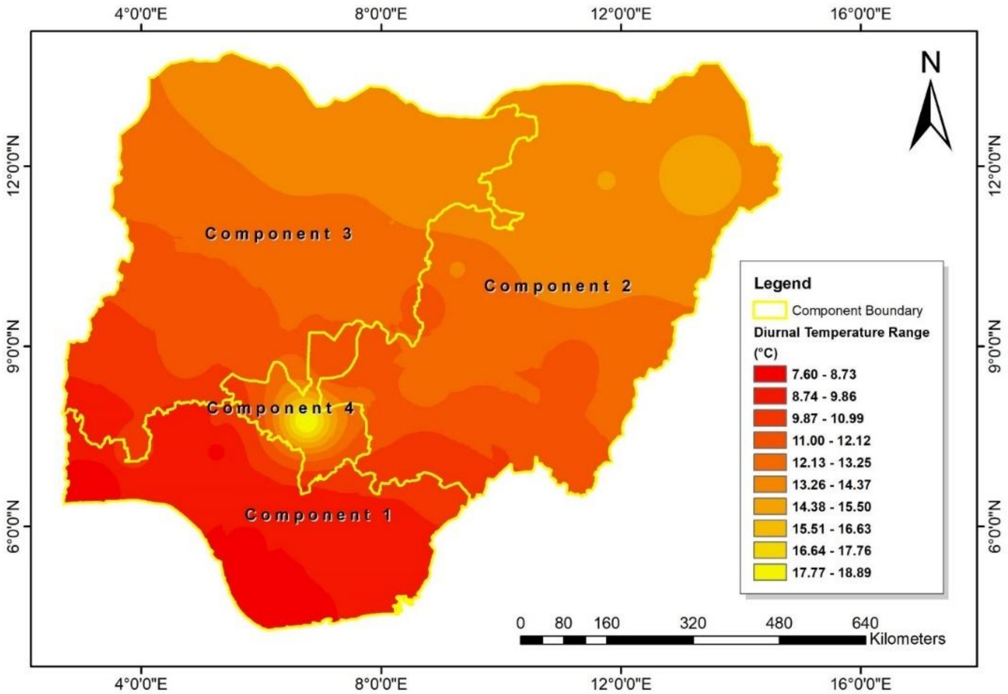

Figure 2: The Four Components of DTR in Nigeria

3.1.2 Rainfall

The findings from PCA using IBM SPSS statistical software indicated that the determinant of the correlation matrix for rainfall (Rf) was 7.33, demonstrating a strong relationship among the 37 climate reporting units.

Table 3: KMO and Bartlett's Test for Rainfall in Nigeria

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.888
Bartlett's Test of Sphericity	Approx. Chi-Square	13193.130
	Df	666
	Sig.	.000

Table 3 reveals that the Kaiser-Meyer-Olkin Measure of Sampling Adequacy stands at 0.888, which is above the 70 threshold. Additionally, Bartlett's Test of Sphericity is significant at .000, falling below the 05-threshold suggested by Bartlett (1951). Over 122 years, data on rainfall in Nigeria showed an average rainfall of 1214.4mm, with amounts ranging from 52.4mm to 216.8mm.

Table 4: Total Variance Explained for Rainfall in Nigeria

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	22.219	60.052	60.052	9.962	26.926	26.926
2	6.494	17.552	77.604	9.211	24.895	51.821
3	3.376	9.123	86.728	8.005	21.636	73.457
4	1.666	4.502	91.229	6.576	17.772	91.229
5	.801	2.164	93.393			
6	.621	1.678	95.072			

In Table 4, the eigenvalues of the first four factors exceeded 1.0, leading the researcher to retain six components. Out of thirty-seven variables, the four rainfall (RF) region components can explain 91.229% of the data analysed in the study. The results of PCA for rainfall in Figure 3 indicate that Component 1 predominantly includes the south-south, southeastern, and north-central states with substantial rainfall, comprising 11 states with rainfall ranging from 115.2mm (Kogi State) to 216.8mm (Rivers State). Findings from this study highlight a strong positive correlation, suggesting that tropical wet rainforests are expected to receive significant rainfall for extended periods. Component 2 encompasses southwestern, south-south, and north-central states with moderate rainfall, which comprises nine states with rainfall amounts ranging from 98.3mm (Kwara State) to 194.0mm (Delta State). The research indicates that rainfall in these areas is not only consistent but also adequate. Component 3 is largely characterised by northern and north-central states with minimal rainfall, including nine states with rainfall between 52.4mm (Borno State) and 79.4mm (Plateau State).

Component 4 is composed of eight states, which were located in the north-central and northeastern states of Nigeria's transitional rainfall zone, with rainfall that ranges between 78.5mm (Gombe State) to 113.6mm (Taraba State). The results of the study indicate that rainfall is not regular and is decreasing in these regions, which delineate a clear border between the wet southern and dry northern states. The results show that rainfall in the Sahel and the Sudan savannah remains sparse and seasonal. The PCA results generally categorised Nigeria's climate into four distinct rainfall components, and these classifications closely correspond with Nigeria's climatic zones, such as Rainforest, Guinea Savannah, Sudan Savannah, and Sahel, as revealed by the earlier findings of Ayoade (1977), Anyadike (1987), and Efe (2006). The findings of this study regarding the transitional rainfall zones in the north-central states further support the view that the Middle Belt represents a zone of climatic overlap influenced by both humid maritime and dry continental air masses.

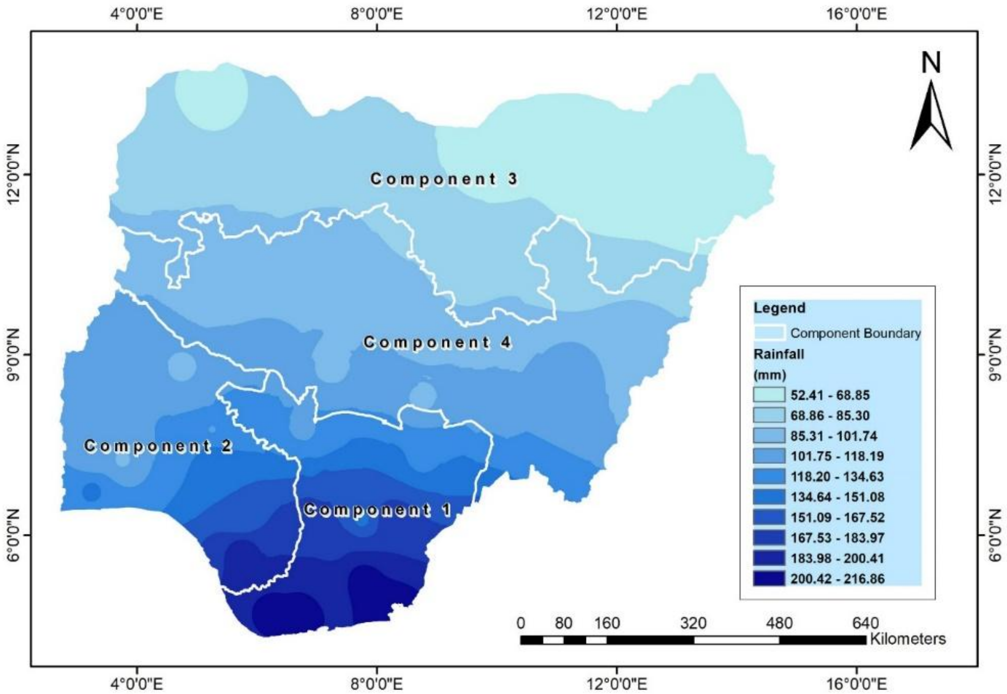

Figure 3: The Four Components of Rainfall in Nigeria

3.1.3 Temperature

According to the KMO and Bartlett's test results shown in Table 5, factor analysis is suitable for the dataset. A KMO value of 0.968 indicates that the variables share information effectively, and the null hypothesis of an identity matrix can be rejected due to the significant result of Bartlett's Test of Sphericity ($p = 0.000$). This reveals a strong correlation among the 37 factors. The temperature records collected over 122 years indicated an overall mean temperature of 26.8°C in Nigeria. The PCA results provided by the IBM SPSS statistical software revealed that the correlation matrix determinant for temperature was 8.12.

Table 5: KMO and Bartlett's Test for Temperature in Nigeria

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.968
Bartlett's Test of Sphericity	Approx. Chi-Square	16410.013
	Df	666
	Sig.	.000

Table 6: Total Variance Explained for Temperature in Nigeria

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	30.904	83.525	83.525	15.958	43.130	43.130
2	3.287	8.883	92.408	12.412	33.545	76.675
3	1.528	4.131	96.539	7.350	19.864	96.539
4	.513	1.386	97.925			

Table 6 presents the total variance explained for temperature in Nigeria. In the analysis, the researcher chose to retain four components because of the initial three of the five factors that possessed eigenvalues above 1.0 (Table 6). These three temperature region components account for 96.539% of the total data from the thirty-seven variables used in this analysis.

The results of the PCA in Figure 4 revealed that component 1 is made up of 19 states that are located in the south-east, south-west, coastal and north-central Nigeria, which are characterised by moderate temperatures. Also, it was observed that temperatures range between 25.6°C (Rivers State) to 27.3°C (Kwara State) in these regions. The moderate temperature observed in these regions is as results of the humidity factor that regulate the temperature in these 19 states owing to the influence of the coastal and rainforest zones of the region. Component 2 comprises 13 north-central, north-east, and north-west states that range between 25.7°C (Kaduna State) to 28.8°C (Sokoto State) with temperature variations, suggesting that hot and arid conditions are experienced in the Sudan and Sahel savannah regions of Nigeria.

Component 3 is made up of five states that are situated in the north-central and north-east regions of Nigeria, with temperatures that range between 25.2°C (Plateau) to 27°C (Adamawa and Gombe States), respectively, which shows variations of temperature across the five states. These regions revealed a climatic transition from the humid south to the arid north, indicating a sharp temperature variation across the regions. The results of the study revealed that Plateau state had a cooler temperature of 25.2°C as a result of its location close to the highland and the cooling effects of elevation. While Sokoto state received the highest temperature of 28.8°C, that is synonymous with Nigeria's temperature gradient. On the other hand, some states, like the Niger, Kogi, Federal Capital Territory, and Kwara, display climate transition zones characteristics. While Adamawa and Taraba States indicate diverse climatic patterns, likely due to topographic differences in these two states.

In Nigeria, there are three primary temperature zones, which comprise the coastal and southern (moderate and humid), northern (hot and arid), and the middle belt and highlands (temperature variations). The results of PCA classification results align with Nigeria's geographical and climatic divisions. Figure 4 shows that the primary temperature differences in Nigeria exist between the hinterland and coastal regions, as well as between the lowlands and the highlands (Plateau) region. This temperature-based regional pattern agrees with earlier research findings of Ayoade (1977), Olaniran (1986), Mobolade and Pourvahidi (2020), which highlighted the significance of controlling the impact of altitude in the highland region of Plateau State and the greater influence of hot conditions in the Sudan and Sahel savannah regions. The lower temperatures observed in Plateau State further confirm the role of elevation in reducing ambient temperature across Nigeria. As shown in Figure 4, the annual mean temperature ranges from 21°C to 27°C in the Plateau but may reach 27°C in the interior lowlands. The findings of this study show that the mean temperature in coastal areas surpasses that of interior lowlands in Nigeria.

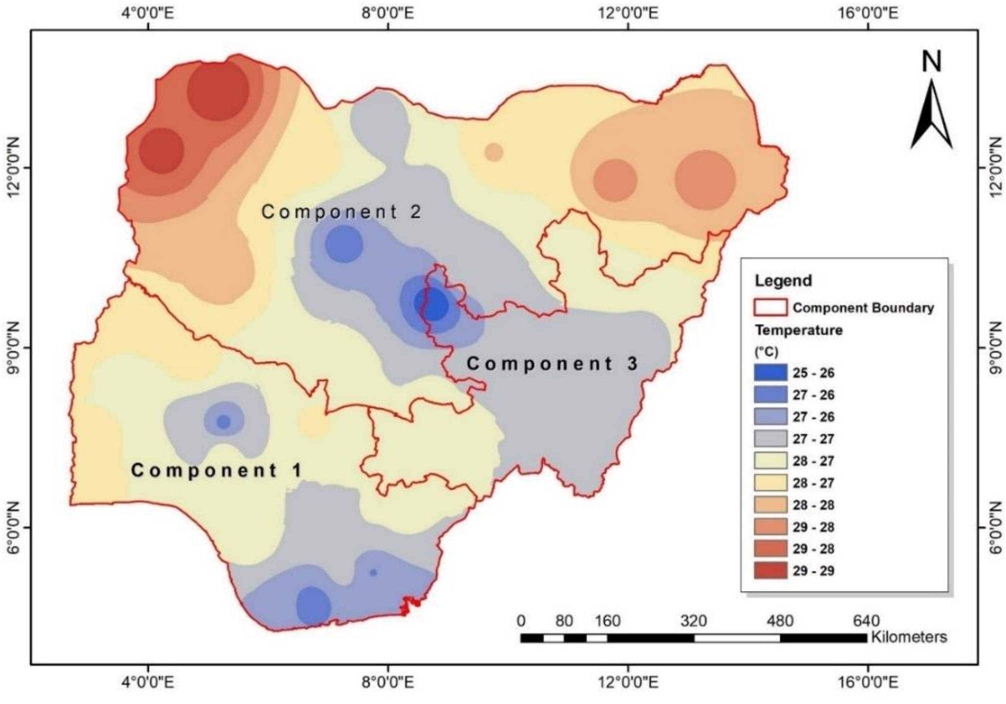

Figure 4: The Three Components of Temperature in Nigeria

3.1.4 Vapour Pressure

Vapour pressure is the pressure at which a liquid and its vapour reach equilibrium at a given temperature. The findings of the present study revealed that vapour pressure in Nigeria ranges between 16.3 hPa to 29.4 hPa, with a mean of 23.1 hPa for the periods of the study. The findings of PCA analysis results output from the IBM SPSS statistical software indicate a correlation matrix determinant of 5.82 for vapour pressure, which revealed a strong relationship between the 37 climate reporting units.

Table 7: KMO and Bartlett's Test for Vapour Pressure in Nigeria

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.959
Bartlett's Test of Sphericity	Approx. Chi-Square	18184.012
	Df	666
	Sig.	.000

Table 7 presents the results of the Kaiser-Meyer-Olkin Measure of Sampling Adequacy. The table reveals that KMO had a value of 0.959, which exceeds the 0.70 threshold, while the Bartlett's Test of Sphericity had a significant level of .000.

Table 8: Total Variance Explained for Vapour Pressure in Nigeria

Component	Initial Eigenvalues			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	29.554	79.875	79.875	13.572	36.680	36.680
2	3.700	10.001	89.876	12.333	33.331	70.012
3	2.287	6.182	96.058	9.637	26.046	96.058
4	.740	1.999	98.056			
5	.334	.901	98.958			
Extraction Method: Principal Component Analysis.						

As shown in Table 8, the initial three factors indicate eigenvalues exceeding 1.0, leading the researcher to retain five components. These three vapour pressure regions account for 96.058% of the data from the thirty-seven variables examined in the study.

Figure 5 presents the Principal Component Analysis (PCA) results based on vapour pressure patterns. Component 1 contains 13 states, all located in the north-central, north-east, north-west, and south-east regions of Nigeria, which experience higher vapour pressure. The findings of the study revealed that Bauchi State had the highest vapour pressure of 17.3 hPa, while Enugu State had the lowest vapour pressure of 26.2 hPa. The findings of the study revealed that states within the highland regions experience constant rainfall and water retention. The higher vapour pressure observed in these regions is characterised by increased humidity and elevational impact. Component 2 is made up of states that are situated in the south-east, south-south, and south-west regions of Nigeria, which comprises 16 states with vapour pressure that range between 24.2 hPa (Ekiti State) to 29.4 hPa (Lagos State), which exhibits extremely high vapour pressure.

The study revealed that Delta and Lagos States exhibit strong characteristics, showing varied climatic conditions as a result of their location in the coastal and rainforest regions of Nigeria. The very high vapour pressure recorded in these regions is the result of the high regional moisture content and moderate temperatures associated with the region. While states in the highland regions, such as Taraba, Plateau, and Adamawa States, moisture retention is more commonly observed in these regions. The results of the study identify three main vapour pressure regions in Nigeria, namely the rainforest and the southern coastal region with high vapour pressure, the northern arid regions with low vapour pressure, and the highland and the north-central regions exhibiting moderate vapour pressure.

Component 3 is composed of 8 states, with Katsina state having the highest vapour pressure of 16.3 hPa, and Kebbi state having the lowest of 20.2 hPa. These states are found in the northern arid regions of Nigeria, which record low vapour pressure readings. The northern states that are situated within the northern dry zone are characterised by arid conditions of the Sahel and low vapour pressure, resulting in substantial moisture loss and low humidity. The small variations observed in Jigawa, Kano, and Kebbi states suggest a slight change in atmospheric water content.

The results suggest that vapour pressure in Nigeria aligns with rainfall patterns. From the southern to northern states, vapour pressure decreases, and the state with the highest vapour pressure reflects the highest amount of atmospheric water content; the opposite was observed in the northern regions of the country. The results of the study indicate a significant relationship between Kebbi, Delta, and Lagos states, suggesting mixed climatic influence, which has contributed to the regional shifts in vapour pressure. The results of the study show that average vapour pressure was observed in Enugu, Kwara, and Kogi, reflecting a transition between warmer and more humid regions. The PCA results are successful in classifying states into humidity zones corresponding to Nigeria's geography and climate, which indicates overlapping climatic influences in some states. The revealed decrease in vapour pressure from southern to northern Nigeria reflects the country’s rainfall and humidity gradients, emphasising the close relationship between atmospheric moisture content and rainfall regimes (Eludoyin et al., 2013; Eyefia et al., 2023). Also, similar patterns have been documented in previous multivariate climate studies that were carried out by Anyadike (1987) and Olaniran (1986), which recognised southern Nigeria as consistently humid and the northern regions as moisture-deficient.

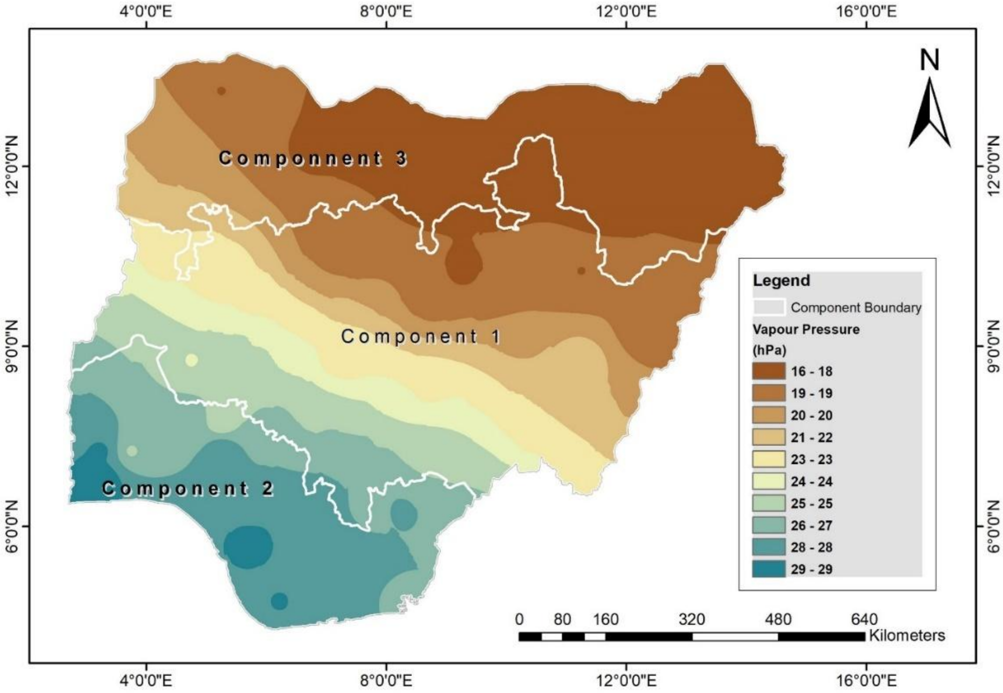

Figure 5: The Three Components of Vapour Pressure in Nigeria

3.2 K-Means Cluster Analysis

K-Means Clustering analysis is employed to assign the states into different clusters based on their climate characteristics, placing states with similar climate characteristics together.

3.2.3 Diurnal Temperature Range

Figure 6 shows the Diurnal Temperature Range (DTR) for Nigerian states across six clusters, meaning Nigerian states display six DTR distinct patterns. Cluster 1 is composed of 11 southern rainforest and coastal states, with temperature that ranges from 8.8°C (Akwa Ibom and Ogun State) to 9.9°C (Ekiti State). The zones recorded the lowest DTR, from 8.8 to 9.9°C. The lowest DTR recorded in this region is attributed to high humidity, which reduces temperature fluctuations. This can be explained by the region's coastline and rainforest qualities, which retain heat during the day and release it at night.

The results of the study show that Cluster 2 had only Kogi State, with a relatively high DTR of 18.9°C, making it the state with the highest mean DTR in Nigeria from 1901 to 2022. The results of this study suggest that this region's local climate distinctions, most likely caused by influences from the savannah and plateau regions. Cluster 3 has north-central and south-west states with moderate DTR, which includes six states with DTR ranging from 10.6°C (Benue and Oyo) to 11.7°C (Taraba State). These zones are transitions between the humid south and the dry north, with minor temperature variances. Cluster 4 comprises eight states that are located within the northern dry and semi-arid states with high DTR that range between 13.6°C (Sokoto State) to 14.7°C (Borno). The high DTR observed in these regions can be attributed to the low level of humidity recorded and heavy sun radiation. These states fall within the Sahel and Sudan Savannah climate of Nigeria, where clear skies enable heat to escape fast at night.

Cluster 5 is made up of six states that are located in the north-west, north-east, and north-central states of Nigeria, which are characterised by high DTR values, with DTR values that range between 12.1°C (Niger State) to 13.3°C (Bauchi State). The integration of the savannah and semi-arid climate forces shape the climate of these states. Cluster 6 has five states, which are located in the coastal and southwestern states of Nigeria, with DTR that ranges between 7.6°C (Lagos State) to 8.5°C (Ondo State). The DTR recorded in these states is fairly low (approx. 7.6-8.5°C), the low DTR recorded in these states area as a result of its closeness to water bodies, which balances temperature shifts. On the other hand, Kogi State had a DTR of 18.9°C as a result of its microclimate, which remains distinct. The result of the study has shown that the ocean and the humid tropical weather in this region have a great effect on DTR as a result, DTR reading is low in the southern coastline states of Nigeria (Clusters 1 and 6). This result is in consonance with previous findings that revealed that Nigeria typically has five to six major DTR regions, which depend on climate and location characteristics. High DTR trends are evident in northern arid regions, and low DTR trends in the coastal regions of Nigeria.

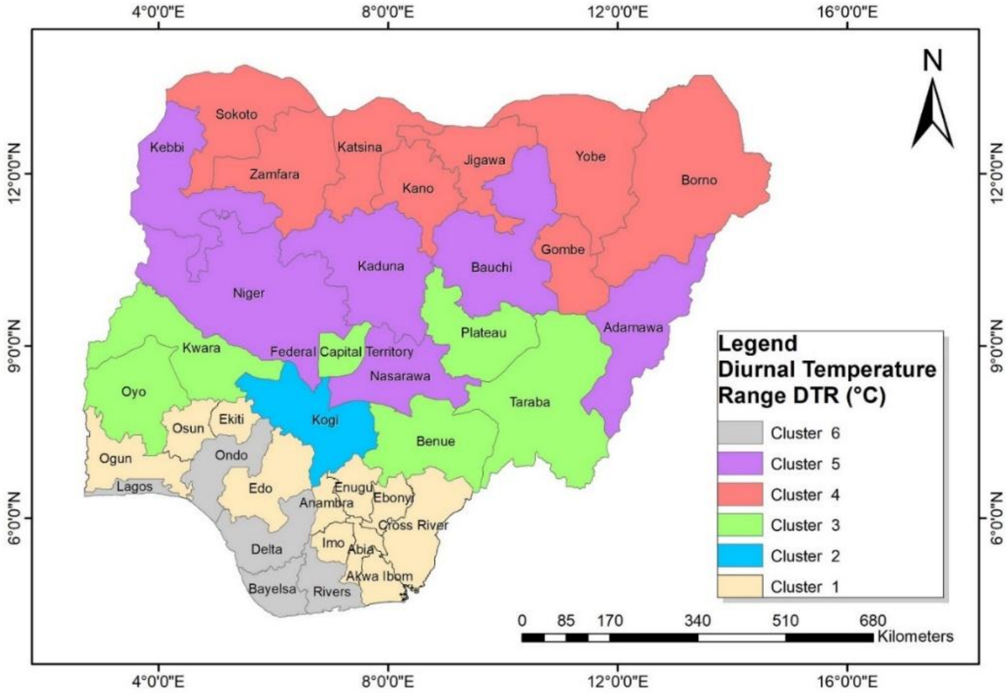

Figure 6: The Six Clusters for Diurnal Temperature Range in Nigeria

3.2.2 Rainfall

Figure 7 depicts the cluster membership of Nigerian states according to rainfall trends. Cluster 1 consists of two states only, with Delta State having the highest rainfall (194.0 mm) and Abia State having the lowest rainfall (191.2 mm). The results of this study show that rain falls regularly in the humid rainforest of Nigeria. Cluster 2 is made up of 12 states, with Nasarawa State having the highest rainfall (99.0 mm), and with Oyo State, Bauchi State, and the Federal Capital Territory, Abuja (77.3 mm) receiving the least amounts of rainfall in the northern Guinea Savannah and North Central parts of Nigeria, respectively. Cluster 3 is composed of four states with very high rainfall, which ranges between 206.0 mm (Bayelsa State) to 216.8 mm (Cross River State), with annual rainfall exceeding 200 mm. As a result of the location of these states in coastal rainforests, these states produce reliable rainfall throughout the year.

Cluster 4 is composed of four states, with Imo State having the highest rainfall (179.9 mm) and Edo State having the lowest rainfall (152.6 mm). The location of these states in the savannah and southern rainforest regions made these regions receive higher rainfall, but the rainfall amounts received in these regions are lower compared to the rainfall received in cluster 3. Cluster 5 includes six states, with the highest being recorded in Katsina State (71.9 mm) and the lowest being recorded in Borno State (52.4 mm). These states have a history of low rainfall since they are in the dry Sahel Savannah. Cluster 6 has nine states, with Ondo State receiving the highest rainfall (147.1 mm) and Ogun State recording the lowest (109.6 mm). This region experiences rainfall that ranges from moderate to heavy rainfall, which suggests a change between Nigeria's savannah and rainforest areas.

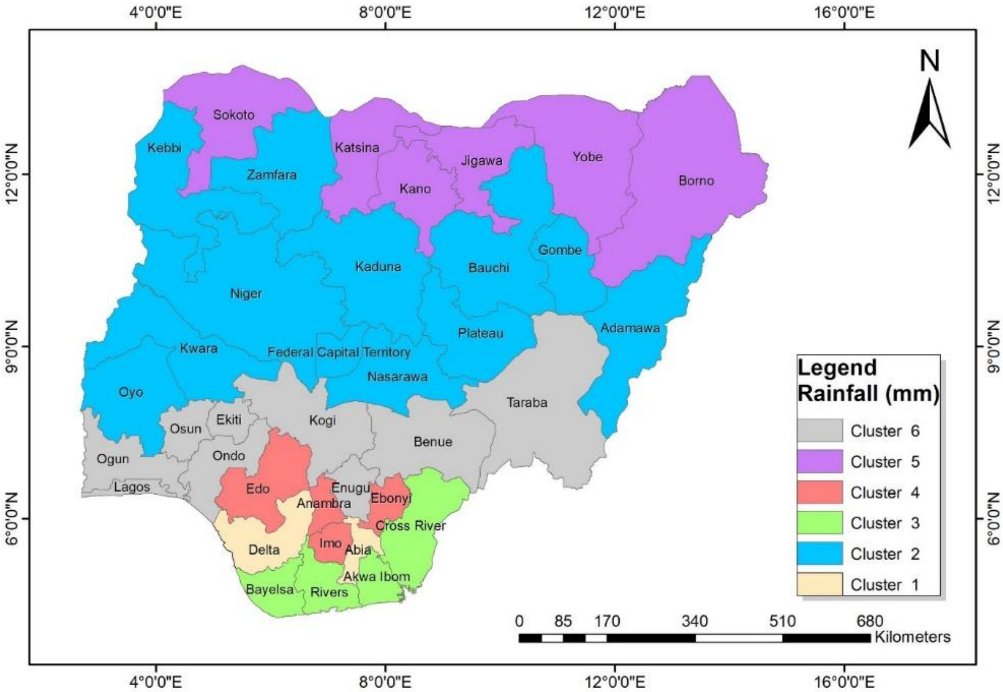

Figure 7: The Six Clusters for Rainfall in Nigeria

3.2.3 Temperature

Figure 8 presents the results of K-means clusters for Nigerian states based on temperature characteristics. The results of the study revealed that Cluster 1 is made up of 12 states, which are located in the southwestern, northeastern, northcentral and southeastern regions of Nigeria, with moderate temperatures; the temperature in these regions ranges between 26.3°C (Osun and Taraba States) to 26.7°C (Enugu, Gombe, and Nasarawa States). Cluster 2 is composed of two states with very high temperatures, which range between 28.6°C (Kebbi State) to 28.8°C (Sokoto State); these states are located very close to the Sahel Desert. Cluster 3 had six states with temperature that ranges between 25.6°C (Rivers State) to 26.0°C (Bayelsa and Cross River States). Major bodies of water and forests of Nigeria are situated in these regions, where the temperature remains low due to the heavy abundance of moisture in the air.

Cluster 4 represents three states having hot weather conditions. The temperatures in these states vary from Niger State, with temperatures as low as

27.7°C (which possesses a tropical savannah climate), to Borno and Yobe States (hot semi-arid climate), which have the highest temperatures of 27.9°C due to their location in the semi-arid region. Cluster 5 contained only Plateau State, with a minimum temperature of 25.2°C. The low temperature is observed as a result of its nearness to the high altitudes, which is why it is Nigeria's coldest state. Cluster 6 had 13 states that are located in the southern, central and western parts of Nigeria, with temperatures varying from 26.8°C in Ondo State to 27.4°C in Jigawa State.

The temperature clusters results revealed in this study are consistent with Nigeria's identified climatic regions, with the Sahelian and Sudan savannah regions having high temperature concentration and coastal, rainforest, and highland regions having lower temperatures. Similar spatial patterns have been documented by Ayoade (1977) and Olaniran (1986), confirming that temperature distribution in Nigeria is strongly controlled by latitude, altitude, and moisture availability.

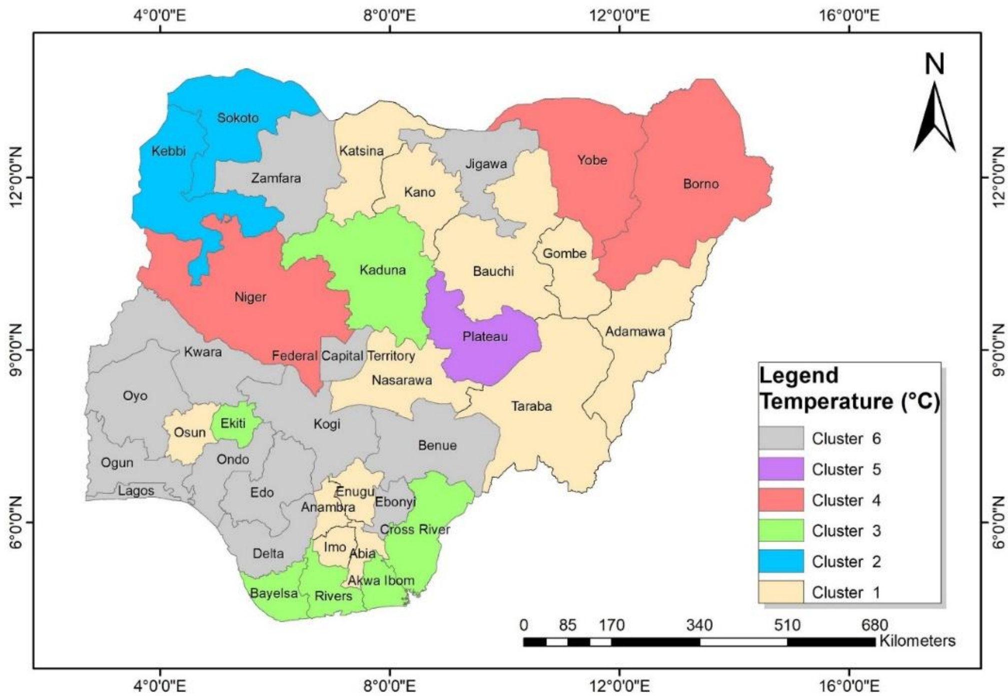

Figure 8: The Six Clusters for Temperature in Nigeria

3.2.4 Vapour Pressure

Figure 9 presents the cluster analysis of vapour pressure across states in Nigeria. The result of the study revealed that each state is assigned to a cluster (1-6) based on its vapour pressure values. As it is shown in Figure 9, cluster 1 contained two states that are located in the north-east and north-west regions of

Nigeria, with vapour pressures ranging from 20.2 hPa (Kebbi State) to 21.1 hPa (Taraba State). The findings of this study revealed the presence of dry and wet seasons, which shows that there is an intermediate climatic condition. Cluster 2 had six states, which are located in the north-west, north-east, and north-central regions of Nigeria, with vapour pressures that range from 17.4 hPa (Zamfara State) to 18.4 hPa (Plateau State). The findings of this study show that the low vapour pressure observed in these regions is caused by the arid conditions of these states.

Cluster 3 has 10 states, which are located in the south-south, south-west, south-east, and north-central regions of Nigeria, with a vapour pressure that ranges between 25.3 hPa (Oyo State) to 27.4 hPa (Anambra and Imo States), respectively. The moderate vapour pressure observed in Oyo State is a result of inland tropical savannah climate conditions while Anambra and Imo States show higher vapour pressure as a result of the high humidity conditions in the region, with a lot of rainfall, and continuous atmospheric moisture from the tropical rainforest climate. Cluster 4 contains six states, with vapour pressure ranging from 22.2 hPa (Niger State) to 24.8 hPa (Benue State). Cluster 5 is composed of six states located in northern regions of Nigeria with vapour pressure ranging from 17.3 hPa (Bauchi State) to 16.3 hPa (Katsina State). The results of the study revealed that these states record the lowest vapour pressure. This value recorded is consistent with the arid weather conditions of this region. Cluster 6 consists of seven states with vapour pressure that range between 26.2 hPa (Osun State) to 29.4 hPa (Lagos State), which are located in the coastal and rainforest states. As a result of the warm and humid temperature in these regions, these regions observed high vapour pressure records, with Lagos state recording the highest vapour pressure (29.4 hPa) and Delta State recording the lowest vapour pressure (28.8 hPa). These present results correspond with previous findings, which indicate that coastal and rainforest regions of Nigeria received higher vapour pressure owing to consistent moisture availability and reduced evaporation stress, while the lowest values occur in the semi-arid northern states (Anyadike, 1987; Eludoyin et al., 2013). The intermediate vapour pressure values observed in north-central states further highlight their transitional climatic nature.

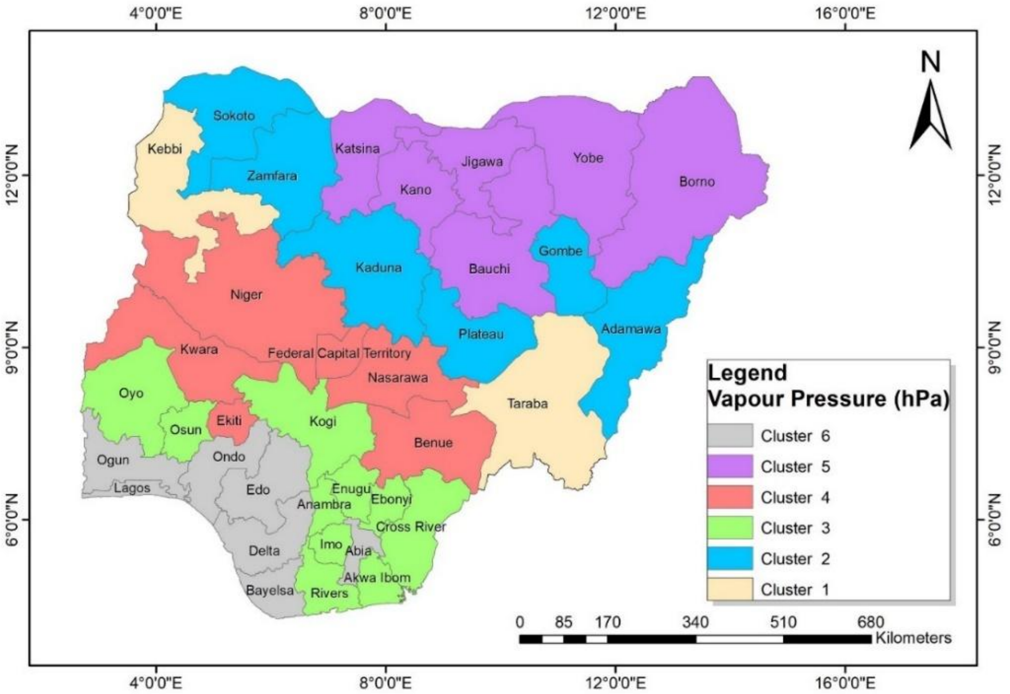

Figure 9: The Six Clusters for Vapour Pressure in Nigeria

4. Conclusions

This study employed principal component analysis (PCA) and k-means cluster analysis (KMCA) to investigate temperature, rainfall, diurnal temperature range (DTR), and vapour pressure in Nigeria for the period of 122 years. The research has revealed that the highest temperature variations in Nigeria are between the coastal and the hinterland areas and between the lowlands and the plateau regions. The study found that Nigeria has three major temperature zones, namely coastal and southern (mild and humid), northern (hot and dry), and the central belt and highlands (varying temperatures). These classifications correspond well to Nigeria's climatic and topographical divisions.

According to the study, Nigeria has three major vapour pressure zones, namely rainforest regions and the southern coastal region with very high vapour pressure, the northern dry zone with low vapour pressure, and the highland parts and north-central region with moderate vapour pressure. Rainfall analysis divided the Nigerian climate into four separate components that correlate closely to the country's climatic zones (rainforest with high rainfall, Guinea Savannah with moderate rainfall, Sudan Savannah with low rainfall, and Sahel with transitional rainfall).

The study found that DTR increases from the south to the north of the country. The study found that vapour pressure decreased from the southern to the northern states. The analysis found that clustering tendencies are strongest in arid northern states with high DTR, and the opposite in coastal regions with low DTR.

In this study, k-means cluster analysis and Principal Component Analysis (PCA) were used to identify Nigeria's climatic characteristics, although the results had distinct analytical strengths. PCA not only divided states into important climatic areas, but it also provided measurements of the proportion of variance explained by each of the principal components, allowing us to identify the dominant climatic variables that underpin such groups. For example, PCA integrated DTR, rainfall, temperature, and vapour pressure into 3-4 components with explained variances of more than 91%, which closely matched Nigeria's climatic zones.

In contrast, k-means clustering produced six descriptive groupings per variable based only on value similarities, without considering the hierarchical relevance of variables or the percentage variance collected. Consequently, while k-means has the characteristic of classifying the different states, PCA still has the explanatory advantage of identifying not only the spatial pattern but also the dormant climatic processes that regulate Nigeria's climate. Generally, the results of this study are consistent with present climate classifications of Nigeria; also, the study revealed that multivariate techniques such as PCA and k-means clustering are effective in capturing both dominant climatic zones and transitional climatic processes.

5. Recommendations

It is suggested that all the state governors in the northern region use vapour pressure data as an input to their climate resilience programs since the study revealed that the atmosphere in the area has very low moisture levels, which can lead to drought-related problems.

Moreover, the various northern areas must concentrate on irrigation as a means of overcoming the negative effects of dry weather on agricultural yields. Cross River, Bayelsa, and Delta are not only coastal states, but areas severely affected by flooding; therefore, reforestation and drainage systems should be considered as their main flood mitigation measures to keep their territories safe from floods.

To make up for the lack of rainfall, the northern states of Borno, Sokoto, and Katsina can use any of the following three methods: reforestation, irrigation agriculture, and rainwater harvesting. There is a need to construct water storage schemes and dams not only for dealing with the fluctuating rainfall but also for water collection during the dry season in the middle belt states such as Kwara, Kogi, and Nasarawa.

Climatologists, urban planners, and architects in the northern states are required to use building materials that have the necessary thermal insulation for their buildings if they want buildings in high-DTR areas to have the same temperature throughout the day and at night.

Farmers in places with high DTR, like Kogi, Borno, and Sokoto, should cultivate crops that can withstand rapid temperature changes.

These three northern states of Borno, Kebbi, and Sokoto need a major supply of cool air, and this need should be given priority over the rest.

The impact of heatwaves could be alleviated partially through the increase of green spaces and the application of urban cooling systems. The local government of the Middle Belt and Plateau State should pass environmental conservation laws to preserve the unique nature of the landscapes in these areas.

If the temperature of the southern region is to be stabilised, it is highly advised that the coastal rainforests and the mangroves in the south be safeguarded against destruction. Nigeria, by adopting such measures, can not only become climate resilient but also achieve the efficient use of the resources and the removal of regulations that would lessen the impact of air moisture variations on different businesses.

References

Almazroui, M., Dambul, R., Islam, M. N., & Jones, P. D. (2015). Principal components-based regionalisation of the Saudi Arabian climate. International Journal of Climatology, 35(9), 2555-2573. https://doi.org/10.1002/joc.4139.

Almonacid, L., Pessacg, N., Díaz, B., & Peri, P.L. (2023). Climate regionalisation of Santa Cruz province, Argentina. *Atmósfera* 37, 245-258. https://doi.org/10.20937/ATM.53166

Anyadike, R. N. C. (1987). A multivariate classification and regionalisation of West African climates. *International Journal of Climatology* (John Wiley & Sons, Ltd.). Vol. 7, (2), pp 157-164.

Arnfield, A. J. (2016, March 17). *climate classification*. *Encyclopaedia Britannica*. https://www.britannica.com/topic/classification-1703397.

Ayoade, J. O. (1977). On the Use of Multivariate Techniques in Climatic Classification and Regionalisation. *Arch. Met. Geoph. Biokl.,* Set. B, 24, 257-267.

Barry, R. G., & Chorley, R.J. (1971). *Atmosphere, Weather and Climate*. Methuen, London.

Bartlett, M. S. (1951). A further note on tests of significance in factor analysis. *British Journal of Psychology*, 4, 1–2.

Bortolozo, C., Pampuch, L., Andrade, M., Metodiev, D., Carvalho, A., Mendes, T., Pryer, T., Egas, H., Mendes, R., Sousa, I., & Power, J. (2024) ARHCS (Automatic Rainfall Half-Life Cluster System): A Landslides Early Warning System (LEWS) Using Cluster Analysis and Automatic Threshold Definition. *International Journal of Geosciences*, 15, 54-69. Doi: 10.4236/ijg.2024.151005.

Britannica (2023). *Temperature*.https://www.britannica.com/science/climate-meteorology/Temperature#ref149502.

Darand, M., & Mansouri Daneshvar, M.R. (2014). Regionalisation of Precipitation Regimes in Iran Using Principal Component Analysis and Hierarchical Clustering Analysis. *Environ. Process*. 1, 517–532. https://doi.org/10.1007/s40710-014-0039-1.

de Camargo, A. P. (1991). Climatic classification for zoning of agroclimatic aptitude. Brazilian *Journal of Agrometeorology* 8, 126–131

Dike, V.N., Lin, Z.H., Wang, Y., & Nnamchi, H. (2019). Observed Trends in Diurnal Temperature Range over Nigeria. *Atmospheric and Oceanic Science Letters*, 12, 131-139. https://doi.org/10.1080/16742834.2019.1570688.

Ding, Z., Guo, P., Xie, F., Chu, H., Li, K., Pu, J., Pang, S., Dong, H., Liu, Y., Pi, F., & Zhang, Q.Y. (2015). Impact of Diurnal Temperature Range on Mortality in a High Plateau Area in Southwest China: A Time Series Analysis. *Science of The Total Environment*, 526, 358-365. https://doi.org/10.1016/j.scitotenv.2015.05.012.

Echebima, S., & Obafemi, A. (2023). The Influence of Local Rainy and Dry Seasons on the Diurnal Temperature Range in Nigeria. *Atmospheric and Climate Sciences*, 13, 314-332. Doi: 10.4236/acs.2023.132017.

Efe, S.I. (2006). Regionalisation of Nigerian Climate: A Recent Approach. *The Nigerian Academic Forum*, 11, 32-39.

Eludoyin, O. M., Adelekan, I. O., Webster, R., & Eludoyin, A. O. (2013). Air temperature, relative humidity, climate regionalisation and thermal comfort of Nigeria, 34 (6), pp. 2000-2018. https://doi.org/10.1002/joc.3817.

Everitt, B. S., & Dunn, G. (2001). *Applied Multivariate Data Analysis*. Wiley & Sons, Ltd. DOI:10.1002/9781118887486.

Eyefia, A. O. (2023). Spatial and Trend Anomaly Assessment of Rainfall and

Temperature in Africa. Environs Echo: *A Journal of Issues Shaping, Re-Ordering and Articulating the Built Environment*, 2 (1), 56-68.

Eyefia, O. A. (2024). The Nexus Between Climatic Variables and Diarrhoea, Tuberculosis (TB), and Typhoid in Selected South-South States, Nigeria. *World News of Natural Sciences, an International Scientific Journal* 57, 283-299

Eyefia, O. A. (2025). The effects of climate-related factors on the incidence of malaria cases in the Braced States, Nigeria. *Journal of Colombo Geographer*, 3, (I), 48-70.

Eyefia, O. A., Efe, S.I., & Atuma, I. M. (2023). Urban-Rural Temperature and Diurnal Temperature Range (DTR) in Delta State, Nigeria. *World News of Natural Sciences An International Scientific Journa*l, 50, 130-146. Available online at www.worldnewsnaturalsciences.com.

Flohn, H. (1950). Neue Anschauungen über die allgemeine Zirkulation der Atmosphäre und ihre Klimatische Bedeutung. *Erdkunde*, 4, p. 141–162.

Gentilli, J. (1958). *A Geography of Climate*. Perth: University of Western Australia Press.

Gorczynski, W. (1941). Decimal scheme of World Climates. *Scripps Inst. of Oceanogr*.

Griffiths, J. F. (1983). Climatic classification, *International Journal of Environmental Studies*, 20:2, 115-125.

Hare, F. K. (1973). Climatic classification. In: McBoyle, G., ed: *Climate in Review*. Houghton Mifflin, Boston, 314 p.

Harris I, Osborn TJ, Jones P and Lister D (2020) Version 4 of the CRU TS Monthly High-Resolution Gridded Multivariate Climate Dataset. *Sci Data* 7, 109 (2020). https://doi.org/10.1038/s41597-020-0453-3.

Holdridge, L. R. (1967). *Life Zone Ecology*. San Jose, Costa Rica: Tropical Science Centre, 266 p. 1967

Horn, L. M., Hajat, A., Sheppard, L., Quinn, C., Colborn, J., Zermoglio, M. F., Gudo, E. S., Marrufo, T., & Ebi, K. L. (2018). Association between Precipitation and Diarrheal Disease in Mozambique. *International Journal of Environmental Research and Public Health*, 15(4). https://doi.org/10.3390/ijerph15040709.

Jaadi, Z. (2024). Principal Component Analysis (PCA): A Step-by-Step Explanation. Learn how to use a PCA when working with large data sets. https://builtin.com/data-science/step-step-explanation-principal-component-analysis.

Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika* 39 (1): 31–36.

Khlebnikova, E. I. (2009). Classification of the climate of the Earth. In: Gruza GV(ed) Environmental structure and function: climate system, vol 1. *EOLSS*, pp 229–245.

Koppen, W. (1931). *Grundriss der Klimakunde: outline of climate science* (p. 388). Berlin: Walter de Gruyter.

Koppen, W. (1936). Das geographische system der klimat. *Handbuch der klimatologie*, 46.

Köppen, W., & Geiger, R. (1928). *Klimate der Erde*. *Gotha: Verlag Justus Perthes*.

Mobolade, D. T., & Pourvahidi, P. (2020). Bioclimatic Approach for Climate Classification of Nigeria. *Sustainability*, 12, 4192. https://doi.org/10.3390/su12104192.

Mohammed, B., Hasan, S., & Mohsin, A. A. (2021). A Review of Principal Component Analysis Algorithm for Dimensionality Reduction. Journal of Soft Computing and Data Mining, 2(1), 20–30. https://doi.org/10.30880/jscdm.2021.02.01.003.

Moraes, M.V., Pampuch, L.A., Bortolozo, C.A., Mendes, T.S., Andrade, M.R.M., & Metodiev, D. (2023). Thresholds of Instability: Precipitation, Landslides, and Early Warning Systems in Brazil. *International Journal of Geosciences*, 14, 895-912. https://doi.org/10.4236/ijg.2023.1410048

Olaniran, O. J. (1986). On the Classification of Tropical Climates for the Study of Regional Climatology: Nigeria as a Case Study. *Geografiska Annaler: Series A, Physical Geography*, 68(4), 233–244. https://doi.org/10.1080/04353676.1986.11880178.

Oliver, J. E. (2005). Climate Classification. In: Oliver, J.E. (eds) Encyclopaedia of World Climatology. *Encyclopaedia of Earth Sciences Series. Springer*, *Dordrecht*. https://doi.org/10.1007/1-4020-3266-8_43.

Pampuch, L.A., Negri, R.G., Loikith, P.C., & Bortolozo, C.A. (2023). A Review on Clustering Methods for Climatology Analysis and Its Application over South America. *International Journal of Geosciences*, 14, 877-894. https://doi.org/10.4236/ijg.2023.149047.

Placetrends (2025). *Spatial Visualisation: Spatial Analysis Term Definition and Applications*. https://placetrends.com/glossary/Spatial_Visualization.html.

Reutterer, T., & Dan, D. (2022). Cluster analysis in marketing research. In: Homburg, C., Klarmann, M., Vomberg, A. (eds) *Handbook of Market Research. Springer, Cham*. https://doi.org/10.1007/978-3-319-57413-4_11.

Ritter, M. E. (2003). *The Physical Environment: An Introduction to Physical Geography*. Available at https://www.thephysicalenvironment.com/.

Ritter, M. E. (2025). The physical environment: Climate classification. https://geo.libretexts.org/Bookshelves/Geography_(Physical)/The_Physical_Environment_(Ritter)/09%3A_Climate_Systems/9.03%3A_Climate_Classification.

Scaetta, H. (1939). Les types climatiques de l ' A O F. Leur rapport avec l'évolution du sol tropical. *La météorologie*, 3e série, no. 19, p. 39-48.

Terjung, W. H., & Louie, S. (1972). Energy input-output climates of the world: a preliminary attempt. *Arch. Met. Geoph. Biokl*. Series B, 20, 129-166.

Thornthwaite, C. W. (1931). The climates of North America according to a new classification. *Geographical Review*, 21, 633-655.

Thornthwaite, C. W. (1948). An approach toward a Rational Classification of Climate, *Geog. Review*, 38, p. 55–94.

Trewartha, G. T. (1954). *An introduction to climate*. New York: McGraw-Hill. 402p. 1954

University of East Anglia Climatic Research Unit; Harris, I.C.; Jones, P.D.; Osborn, T. (2023): CRU TS4.07: Climatic Research Unit (CRU) Time-Series (TS) version 4.07 of high-resolution gridded data of month-by-month variation in climate (Jan. 1901- Dec. 2022). NERC EDS Centre for Environmental Data Analysis. https://catalogue.ceda.ac.uk/uuid/5fda109ab71947b6b7724077bf7eb753/.

Wang, J., Zhang, L., Zhang, D., Zhao, F., & Yang, X. (2020). The application of principal component cluster analysis in environmental classification for Chinese cities. The Third International Workshop on Environment and Geoscience, IOP *Conf. Series: Earth and Environmental Science* 569, pp 1-8. doi:10.1088/1755-1315/569/1/012040.

Wilks, D.S. (2020). Statistical Methods in the Atmospheric Sciences. International Geophysics Series, 4th Edition, *Elsevier*, Amsterdam.

Wuam, P. W., Ubayo, N., & Dauda, I. (2020). Implication of Koppen's climate classification on agriculture in Nigeria, Mediterranean Publication and Research International (MPRI-JHSS) *International Journal of Humanities & Social Science*, vol. 11, no.6, Jun 2020, 282 – 290.

Yang, J., Liu, H. Z., Ou, C. Q., Lin, G. Z., Zhou, Q., Shen, G. C., Chen, P. Y., & Guo, Y. (2013). Global climate change: Impact of diurnal temperature range on mortality in Guangzhou, China. *Environmental Pollution*, 175, 131-136. https://doi.org/10.1016/j.envpol.2012.12.021.

Zwick, W. R., & Wayne, F. V. (1986). Comparison of five rules for determining the number of components to retain." *Psychological Bulletin* 99 (3), 432.

Oja, P., Titze, S., Bauman, A., de Geus, B., Reger-Nash, B., & Kohlberger, T. (2011). *Health benefits of cycling: A systematic review*. Scandinavian Journal of Medicine & Science in Sports, 21(4), 496-509. https://doi.org/10.1111/j.1600-0838.2010.01112.x

Pucher, J., & Buehler, R. (2017). *Cycling towards a more sustainable transport system: A global review*. Transport Reviews, 37(4), 501-519. https://doi.org/10.1080/01441647.2017.1329844

Pucher, J., & Dijkstra, L. (2010). *Promoting safe walking and cycling to improve public health: Lessons from the Netherlands and Germany*. American Journal of Public Health, 100(6), 991-997. https://doi.org/10.2105/AJPH.2009.189324

Rietveld, P. (2001). Biking and Walking: The Position of Non-Motorized Transport Modes in Transport Systems, Tinbergen Institute Discussion Papers 01-111/3, Tinbergen Institute.

Safiz, A., Rahman, A., & Abdullah, M. (2021). *Non-motorized transportation: A review of its benefits and challenges*. Transportation Research Journal, 35(4), 255-268. https://doi.org/10.1016/j.traj.2021.01.004

United Nations. (2014). *World urbanization prospects: The 2014 revision*. United Nations Department of Economic and Social Affairs, Population Division. Retrieved from https://www.un.org/en/development/desa/population/publications/pdf/urbanization/WUP2014-Report.pdf

Zafiz, A., Rahman, A., & Abdullah, M. (2021). *The role of non-motorized transportation in improving air quality, reducing global warming, and enhancing public welfare in developed countries*. Environmental Sustainability Journal, 28(3), 134-148. https://doi.org/10.1016/j.esj.2021.02.007