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Re-defining the Climatic Zones over Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author IOA designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors SIA and EJE managed the analyses of the study. Authors IOA and SIA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study aimed at identifying climatic zones over Nigeria.
Duration of Study: Daily air temperature data for the 36 states and FCT in Nigeria were obtained from National Aeronautic and Space Administration (NASA) for the period of thirty-seven (37) years (1984-2020).
Method: Several hierarchical clustering procedures–single linkages, complete linkage, average distance within clusters, average distance between clusters, centroid clustering, median linkage and Ward's method were used in this study.
Results: Based on the findings, median linkage, complete linkage and Ward's clustering method solutions seems more realistic. The application of cluster analysis, revealed five climate zones (cluster) over Nigeria. Cluster 1 covers Plateau state only while cluster 2 covers three south-west states and one north-west state (Kaduna). Cluster 3 covers all the states in south-east, south-south (except Cross River), North-central (except Kogi and Kwara), Bauchi in North-west and ogun and Oyo in South-west. Cluster 4 covers one state in south-south (Cross River), South-south (Lagos), two states in North-central (Kogi and Kwara), three states in North-east (Adamawa, Gombe and Taraba) and four states in North-west (Jigawa, Kano, Kastina and Zamfara). Lastly cluster 5 covers two states in North-east (Borno and Yobe) and North-west (Kebbi and Sokoto).

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Conclusion: Our findings clearly show that cluster analysis can be applied to identify similar weather/climate state from air temperature data.

Keywords: Clustering techniques; climate zones; temperature; hierarchical cluster analysis.

1. INTRODUCTION

Surface air temperature is one of the major indicators of climate change in the world. Climate change over a province has a major impact on water resources management, agricultural production and the overall economy of the country. According to [1], long term changes in climate can directly or indirectly affect many aspects of society such as increase in precipitation patterns and surface air temperature, size and number of forest fires, and so on. Increase in air temperatures could increase air conditioning costs and affect the spread of diseases like Lyme disease, but could also improve conditions for growing some crops. As the Earth's air temperature increases, heat waves are expected to become more frequent, longer, and more intense [2]. Temperature increases of approximately 0.2 to 0.3°C per decade have been observed in the various ecological zones in Nigeria [3]. The four climate zones over Nigeria accepted by climatologists are [4]:

(i) The Tropical Rainforest Climate or The Equatorial Monsoon
(ii) Tropical Savanna Climate or Tropical Wet and Dry Climate
(iii) The Sahel Climate or Tropical Dry Climate or Warm Desert Climate
(iv) Alpine Climate or Highland Climate or Warm Semi-Arid Climate

In this research, these zones have been questioned using cluster analysis methodology. Cluster analysis applied to climatological variables is an appropriate approach for redefining the climate divisions, and its use is becoming increasingly more common in atmospheric research [5-7]. Several studies have evaluated the increasing trend in air temperature in Nigeria using different methods [8-11]. Also, studies have shown that the impacts of climate change on Nigeria is arising from increases in temperature [12-14]. Many studies have used precipitation data and different methods to define climatic types and zones of similar climate. The most famous methods are the Koppen and Thornthwaite classifications. One advantage of these approaches is that they directly and quantitatively spell out the climate types, while the disadvantage is that the classification rules are subjectively formulated [7]. In this study, the cluster analysis methodology has been used in zoning the climate of the 36 states and FCT in Nigeria using air temperature data.

2. METHODOLOGY

2.1 Study Area, Data and Methods

Nigeria lies between 4^0 and 14^0N latitude and longitude 4^0 to 14^0E. It is bounded on the north by the Republic of Niger, east by Cameroon and west by Benin Republic while the southern boundary is Gulf of Guinea which is an arm of the Atlantic Ocean (Fig. 1). Nigeria is composed of various ecotypes and climatic zones. The Nigerian climate is characterized mainly by the dry north-easterly and the moist south-westerly winds. The main ecological zones are the tropical rainforest along the coast, savannah in the middle belt and semi-arid zones in the northern fringes. The daily air temperature data was obtained from National Aeronautic and Space Administration (NASA) (Modern Era Retrospective Analysis Version 2 (MERRA-2)) for the period of thirty-seven (37) years (1984-2020).

2.2 Cluster Analysis

Several clustering techniques begin not with the raw data but with a matrix of inter-individual measures of distance or similarity calculated from the raw data. Similarity signifies the degree of correspondence among objects across all of the uniqueness used in the analysis. It is a set of rules that serve as criteria for separating or grouping items. The distance measure is often used as a measure of similarity, with higher values representing greater dissimilarity (distance between cases), not similarity instead of the Correlation measure. Several distance measures are available, each with specific characteristics. The most commonly distance function is the Euclidean distance between two vectors $X = (\mathrm{x}_1, \mathrm{x}_2, \ldots\ldots, \mathrm{x}_\mathrm{p})^{/}$ and $Y = (\mathrm{y}_1, \mathrm{y}_2, \ldots\ldots, \mathrm{y}_\mathrm{p})^{/}$ defined as:

$$d(x,y) = \sqrt{(x-y)^{/}(x-y)} = \sqrt{\sum_{j=1}^{p}(x_j - y_j)^2} \quad (1)$$

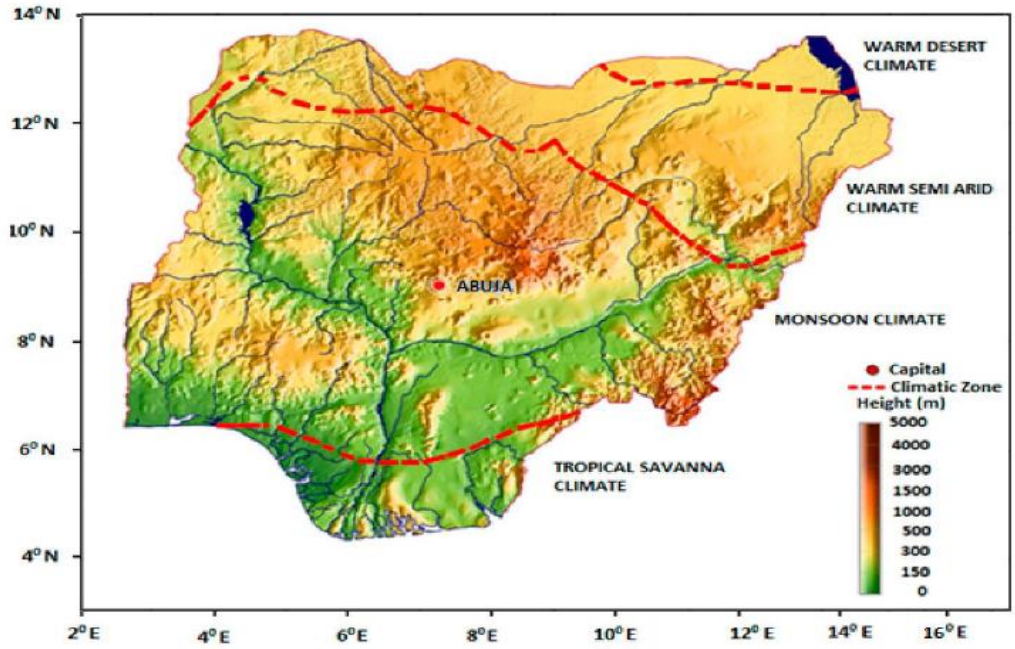

Fig. 1. Map of Nigeria

To adjust for differing variances and covariances among the *p* variables, the statistical distance can be used, which is given as:

$$d(x,y) = \sqrt{(x-y)/S^{-1}(x-y)} \quad (2)$$

where **S** is the sample covariance matrix [15].

Other distance measures include:

(i) Squared Euclidean distance: The sum of the squared differences without taking the square root. Mathematically:

$$d^2(x,y) = \sum_{j=1}^{p}(x_j - y_j)^2 \quad (3)$$

(ii) City- block (Manhattan) distance: Uses the sum of the variables' absolute differences.
(iii) Chebychev distance: Is the maximum of the absolute difference in the clustering variables' values. Frequently used when working with metric (or ordinal) data.
(iv) Mahalanobis distance: Is a generalized distance measure that accounts for the correlations among variables in a way that weights each variable equally.

There are three different procedures that can be used to cluster data: hierarchical cluster analysis, *k*-means cluster, and two-step cluster. The choice of a method depends on, among other things, the size of the data file. The two-step procedure can be used If the data file is large (even 1,000 cases is large for clustering) or a mixture of continuous and categorical variables. If the data file is small, the hierarchical clustering method can be used and it enables one to easily examine solutions with increasing numbers of clusters. The *k*-means clustering method produces a partition of the data into a particular number of groups set by the investigator and the data file is moderately sized. A combination approach using a hierarchical approach followed by a non-hierarchical approach (K-means) is often advisable. A hierarchical technique is used to select the number of clusters and profile clusters centers that serve as initial cluster seeds in the nonhierarchical procedure. While a non-hierarchical method (K-means) then clusters all observations using the seed points to provide more accurate cluster memberships. In this way, the advantages of hierarchical methods are complemented by the ability of the nonhierarchical methods to refine the results by allowing the switching of cluster membership [15]. In this study, several hierarchical clustering methods were performed using the Euclidean distance between two vectors.

2.3 Hierarchical Clustering

Hierarchical methods and other clustering algorithms represent an attempt to find "good" clusters in the data using a computationally efficient technique. The number of ways of

partitioning a set of *n* items into *g* clusters is given by:

$$N(n,g) = \frac{1}{g!}\sum_{k=1}^{g}\binom{g}{k}(-1)^{g-k}k^{n} \quad (4)$$

The hierarchical clustering method is also called the agglomerative hierarchical methods. Agglomerative hierarchical clustering methods begin by placing each observation into a separate cluster. Clusters are then joined, two at a time, until the number of clusters is reduced to the desired target. Agglomerative techniques are [15]:

(i) Single linkage (Nearest neighbor): the distance between two clusters A and B is defined as the minimum distance between a point in A and a point in B:

$$\mathrm{D(A,B)} = \min\{\mathrm{d}(\mathrm{y_i},\mathrm{y_j}) \text{ for } \mathrm{y_i} \text{ in A and } \mathrm{y_j} \text{ in B}\} \quad (5)$$

where $\mathrm{d}(\mathrm{y_i},\mathrm{y_j})$ is the Euclidean distance

(ii) Complete linkage (Furthest neighbor): the distance between two clusters A and B is defined as the maximum distance between a point in A and a point in B:

$$\mathrm{D(A,B)} = \max\{\mathrm{d}(\mathrm{y_i},\mathrm{y_j}) \text{ for } \mathrm{y_i} \text{ in A and } \mathrm{y_j} \text{ in B}\} \quad (6)$$

(iii) Centroid: In the centroid method, the distance between two clusters A and B is defined as the Euclidean distance between the mean vectors (often called centroids) of the two clusters:

$$\mathrm{D(A,B)} = \mathrm{d}(\overline{\mathrm{y_A}},\overline{\mathrm{y_B}}) \quad (7)$$

$$\text{where } \overline{\mathrm{y_A}} = \sum_{\mathrm{i=1}}^{\mathrm{n_A}}\frac{\mathrm{y_i}}{\mathrm{n_A}} \quad (8)$$

After two clusters A and B are joined, the centroid of the new cluster AB is given by the weighted average:

$$\overline{\mathrm{y_{AB}}} = \frac{\mathrm{n_A}\overline{\mathrm{y_A}}+\mathrm{n_B}\overline{\mathrm{y_B}}}{\mathrm{n_A}+\mathrm{n_B}} \quad (9)$$

(iv) Median linkage: defines the distance between 2 clusters as the distance between the medians of each cluster, where the median is located at the median values of each variable over all members of the cluster. The two clusters with the smallest distance between medians are merged at each step given as:

$$\mathrm{m_{AB}} = \frac{1}{2}(\overline{\mathrm{y_A}} + \overline{\mathrm{y_B}}) \quad (10)$$

The median in equation (10) is not the ordinary median in the statistical sense. The terminology arises from a median of a triangle, namely, the line from a vertex to the midpoint of the opposite side.

(v) Average linkage: the distance between two clusters A and B is defined as the average of the $\mathrm{n_A n_B}$ distances between the $\mathrm{n_A}$ points in A and the $\mathrm{n_B}$ points in B:

$$\mathrm{D(A,B)} = \frac{1}{\mathrm{n_A n_B}}\sum_{\mathrm{i=1}}^{\mathrm{n_A}}\sum_{\mathrm{j=1}}^{\mathrm{n_B}}\mathrm{d}(\mathrm{y_i},\mathrm{y_j}) \quad (11)$$

where the sum is over all $\boldsymbol{y}_i$ in A and all $\boldsymbol{y}_j$ in B.

(vi) Ward's method: defines the distance between 2 clusters in terms of the increase in the sum of squared deviations around the cluster means that would occur if the two clusters were joined. If AB is the cluster obtained by combining clusters A and B, then the sum of within-cluster distances (of the items from the cluster mean vectors) are:

$$\mathrm{SSE_A} = \sum_{\mathrm{i=1}}^{\mathrm{n_A}}(\mathrm{y_i}-\overline{\mathrm{y_A}})'(\mathrm{y_i}-\overline{\mathrm{y_A}}) \quad (12)$$

$$\mathrm{SSE_B} = \sum_{\mathrm{i=1}}^{\mathrm{n_B}}(\mathrm{y_i}-\overline{\mathrm{y_B}})'(\mathrm{y_i}-\overline{\mathrm{y_B}}) \quad (13)$$

$$\mathrm{SSE_{AB}} = \sum_{\mathrm{i=1}}^{\mathrm{n_{AB}}}(\mathrm{y_i}-\overline{\mathrm{y_{AB}}})'(\mathrm{y_i}-\overline{\mathrm{y_{AB}}}) \quad (14)$$

where $\overline{\mathrm{y_{AB}}} = \frac{\mathrm{n_A}\overline{\mathrm{y_A}}+\mathrm{n_B}\overline{\mathrm{y_B}}}{\mathrm{n_A}+\mathrm{n_B}}$ and $\mathrm{n_A}$, $\mathrm{n_B}$, and $\mathrm{n_{AB}} = \mathrm{n_A}+\mathrm{n_B}$ are the numbers of points in A, B, and AB, respectively.

Ward's method joins the two clusters A and B that minimize the increase in SSE, defined as:

$$\mathrm{I_{AB}} = \mathrm{SSE_{AB}} - (\mathrm{SSE_A} + \mathrm{SSE_B}) \quad (15)$$

Ward's method is more likely to join smaller clusters or clusters of equal size.

All the hierarchical methods follow the basic four-step routine below to find those subsets that are both homogeneous and well separated, so that objects within the same cluster should resemble each other and objects in different clusters should differ from one another [7]:

1. The specified distance measure between all entries (climate stations) is calculated.
2. The two closest entries are merged to form a new cluster based on a defined criterion.
3. The distance between all entries is recalculated.
4. Steps 2 and 3 are repeated until all entries are merged into one cluster.

3. RESULTS AND DISCUSSION

Fig. 2 shows the average yearly air temperature across the 36 states and FCT in Nigeria. Minimum air temperature occurs in Plateau state while maximum air temperature occurs in Borno, Nigeria. Air temperature is also high in Sokoto, Kebbi, Yobe, Kastina and Yola state (Fig. 2). This finding is in agreement with the work of [16] which reported that temperature variation is higher over northern part of the country than over the southern part [17] attributed the temperature variation to the equator ward incursion of mid latitude systems (with alternating cool and warm air masses) which has greater influence on temperature variation over the northern part than over the southern part of Nigeria.

In this study, several hierarchical clustering procedures–single linkages, complete linkage, average distance within clusters, average distance between clusters, centroid clustering, median linkage and Ward's method were performed, and compared to define the most suitable clustering method for defining air temperature zone over Nigeria. Sample of the first 10 stages of agglomeration schedule for air temperature data using different methods is presented in Table 2 and 3. State 6 (Taraba) is joined with state 20 (Cross River) in stage 1 since the Euclidean distance between these two states is smaller than the distance between any other pair of states across all the methods (Table 2 and 3). The distance is shown in the column labeled "Coefficients". The columns under the heading "Stage Cluster First Appears" show the stage at which a cluster or state being joined first occurred in its current form. The "Next Stage" column shows when a cluster constructed at the current stage will be involved in another joining. Thus, cluster 6 as constructed in stage 10 (states 6, 20, and 15) will not be used until stage 22 (single linkage), 23 (average within groups linkage), 24 (average between groups linkage and centroid clustering) and 25 (median clustering and ward's method). It is a lot easier to follow how groups and individual states join together in this process in a dendrogram (Figs. 3-9), which shows all the steps in the hierarchical procedure, including the distances at which clusters are merged.

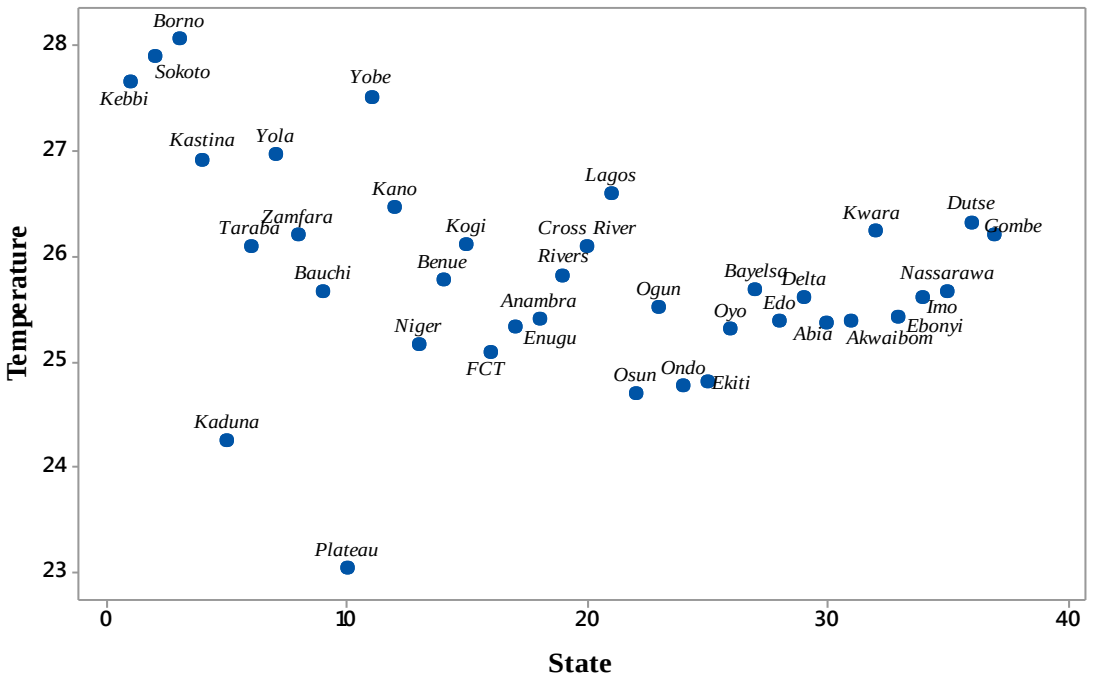

Fig. 2. Average yearly air temperature across states in Nigeria

Table 1. Agglomeration Schedule for Air temperature data using different methods

	Cluster Combined				Stage Cluster First Appears		
Methods	**Stage**	**Cluster 1**	**Cluster 2**	**Coefficients**	**Cluster 1**	**Cluster 2**	**Next Stage**
Average (Between groups) linkage	1	6	20	0.000	0	0	10
	2	29	34	0.000	0	0	17
	3	9	35	0.000	0	0	8
	4	8	37	0.000	0	0	11
	5	28	30	0.000	0	0	9
	6	18	31	0.000	0	0	9
	7	17	26	0.000	0	0	18
	8	9	27	0.000	3	0	17
	9	18	28	0.000	6	5	15
	10	6	15	0.001	1	0	24
Average (within groups) linkage	1	6	20	0.000	0	0	10
	2	29	34	0.000	0	0	17
	3	9	35	0.000	0	0	7
	4	8	37	0.000	0	0	11
	5	28	30	0.000	0	0	9
	6	18	31	0.000	0	0	9
	7	9	27	0.000	3	0	17
	8	17	26	0.000	0	0	16
	9	18	28	0.000	6	5	12
	10	6	15	0.000	1	0	23
Single linkage	1	6	20	0.000	0	0	10
	2	29	34	0.000	0	0	17
	3	9	35	0.000	0	0	8
	4	8	37	0.000	0	0	12
	5	28	30	0.000	0	0	7
	6	18	31	0.000	0	0	7
	7	18	28	0.000	6	5	11
	8	9	27	0.000	3	0	17
	9	17	26	0.000	0	0	13
	10	6	15	0.001	1	0	22

	Cluster Combined				Stage Cluster First Appears		
Methods	**Stage**	**Cluster 1**	**Cluster 2**	**Coefficients**	**Cluster 1**	**Cluster 2**	**Next Stage**
Complete linkage	1	6	20	0.000	0	0	9
	2	29	34	0.000	0	0	17
	3	9	35	0.000	0	0	8
	4	8	37	0.000	0	0	11
	5	28	30	0.000	0	0	10
	6	18	31	0.000	0	0	10
	7	17	26	0.000	0	0	18
	8	9	27	0.001	3	0	17
	9	6	15	0.001	1	0	25
	10	18	28	0.001	6	5	15

Table 2. Agglomeration Schedule for Air temperature data using different methods

		Cluster Combined			Stage Cluster First Appears		
Methods	**Stage**	**Cluster 1**	**Cluster 2**	**Coefficients**	**Cluster 1**	**Cluster 2**	**Next Stage**
Centroid linkage	1	6	20	0.000	0	0	10
	2	29	34	0.000	0	0	18
	3	9	35	0.000	0	0	8
	4	8	37	0.000	0	0	11
	5	28	30	0.000	0	0	9
	6	18	31	0.000	0	0	9
	7	17	26	0.000	0	0	17
	8	9	27	0.000	3	0	18
	9	18	28	0.000	6	5	15
	10	6	15	0.001	1	0	24
Median linkage	1	6	20	0.000	0	0	10
	2	29	34	0.000	0	0	17
	3	9	35	0.000	0	0	8
	4	8	37	0.000	0	0	11
	5	28	30	0.000	0	0	9
	6	18	31	0.000	0	0	9
	7	17	26	0.000	0	0	18
	8	9	27	0.000	3	0	17

	9	18	28	0.000	6	5	15
	10	6	15	0.001	1	0	25
Ward's methods	1	6	20	0.000	0	0	9
	2	29	34	0.000	0	0	18
	3	9	35	0.000	0	0	8
	4	8	37	0.000	0	0	12
	5	28	30	0.000	0	0	10
	6	18	31	0.000	0	0	10
	7	17	26	0.000	0	0	19
	8	9	27	0.001	3	0	24
	9	6	15	0.001	1	0	25
	10	18	28	0.002	6	5	15

The dendogram (Figs. 3-9) shows the result of clustering the 36 states and FCT in Nigeria using the Euclidian distance method. At the start, 6, 9, 7, 5, 6, 5 and 5 major clusters were formed using the average distance between clusters, average distance within clusters, single linkages, complete linkage, centroid clustering, median linkage and Ward's method respectively. A new cluster is formed when the first cluster (1) joined with the second cluster (2) and this process continued until a single cluster was formed. Thus:

(i) **Average distance between clusters combines**: Taraba, Cross River, Kogi, Zamfara, Gombe, Kwara, Dutse, Kano, and Lagos in cluster 1; Kastina and Yola in cluster 2; Benue, Rivers, Edo, Abia, Delta, Anambra, Ebonyi, Enugu, Nassarawa, Ogun, Niger, FCT, Bauchi, Akwaibom, Imo, Bayelsa and Oyo in cluster 3; Ondo, Ekiti, Osun and Kaduna in cluster 4; Kebbi, Yobe, Sokoto and Borno in cluster 5; lastly, Plateau in cluster 6 (Fig. 3).

(ii) **Average distance within clusters combines:** Taraba, Cross River, Kogi, Zamfara, Gombe, Kwara, Dutse, Kano, and Lagos in cluster 1; Kastina and Yola in cluster 2; Kebbi, Yobe in cluster 3; Sokoto and Borno in cluster 4; Benue, Rivers, Delta, Bayelsa, Imo, Nassarawa and Bauchi in cluster 5; Ogun, Niger, FCT, Edo, Anambra, Ebonyi, Enugu, Abia, Akwaibom, and Oyo in cluster 6; Ondo and Ekiti in cluster 7; Osun and Kaduna in cluster 8; lastly, Plateau in cluster 9 (Fig.4).

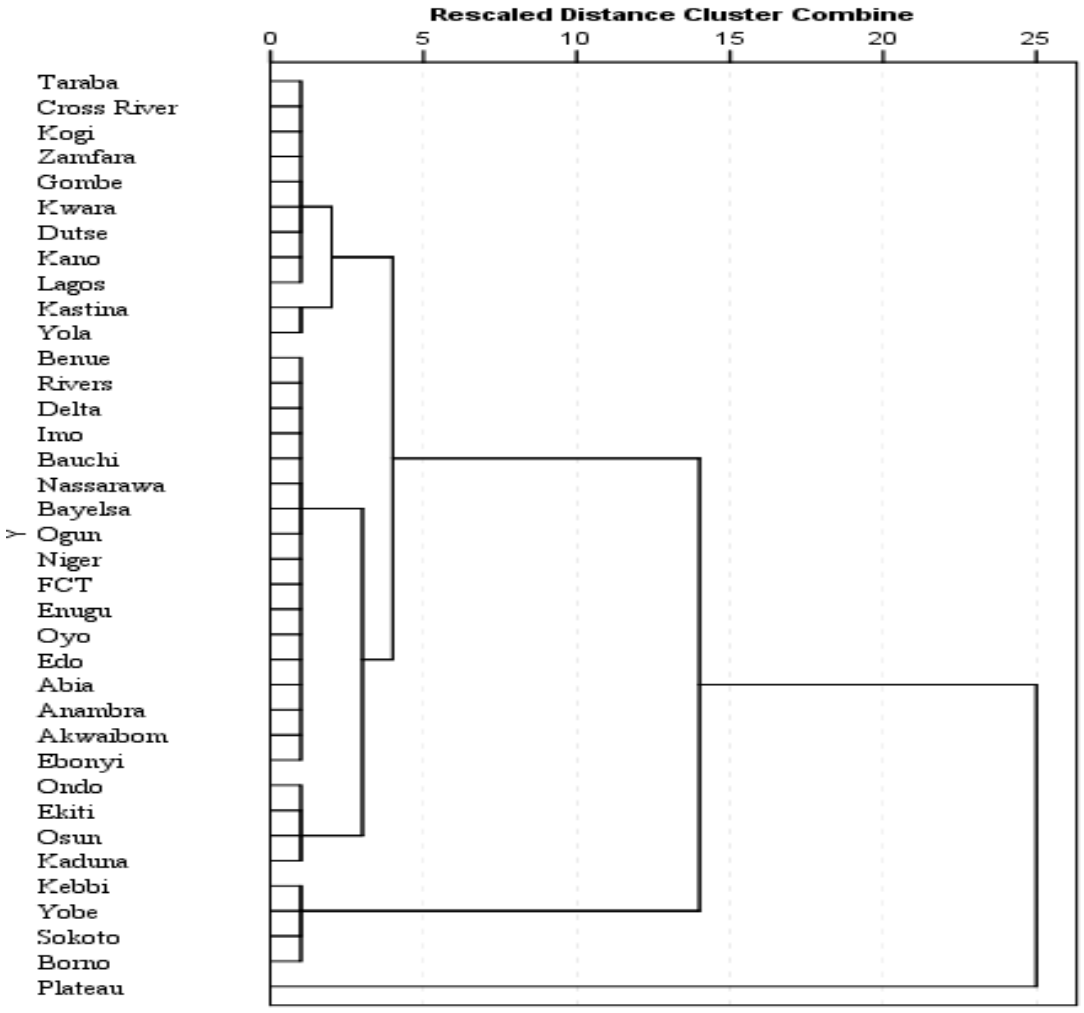

Fig. 3. Dendrogram for average (between groups) linkage clustering method

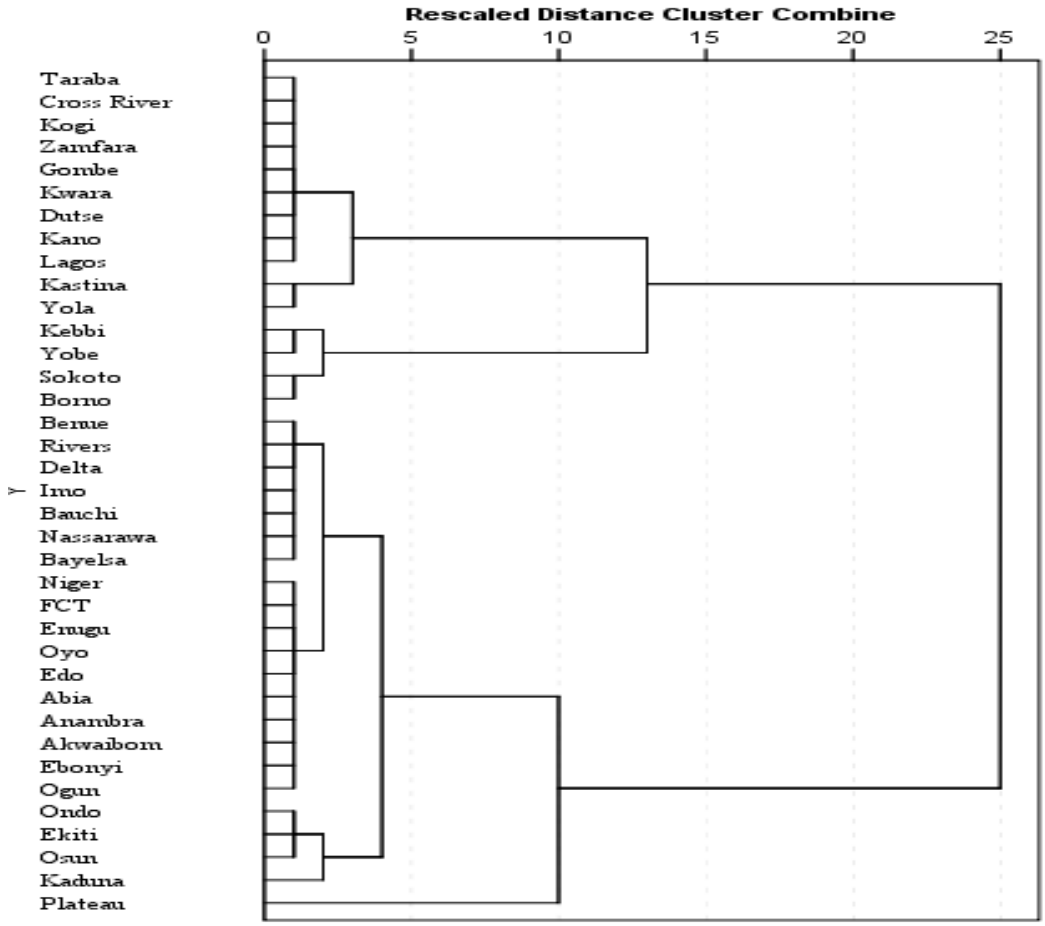

Fig. 4. Dendrogram for average (within-groups) linkage clustering method

(iii) **Single linkages combine**: Taraba, Cross River, Kogi, Zamfara, Gombe, Kwara, Dutse, Kano, and Lagos in cluster 1; Benue, Rivers, Edo, Abia, Delta, Anambra, Ebonyi, Enugu, Nassarawa, Ogun, Niger, FCT, Bauchi, Akwaibom, Imo, Bayelsa and Oyo in cluster 2; Ondo, Ekiti and Osun in cluster 3; Kastina and Yola in cluster 4; Kaduna in cluster 5; Kebbi, Yobe, Sokoto and Borno in cluster 6; lastly, Plateau in cluster 7 (Fig. 5).

(iv) **Complete linkage combines:** Taraba, Cross River, Kogi, Zamfara, Gombe, Kwara, Dutse, Kano, Kastina, Yola and Lagos in cluster 1; Kebbi, Yobe, Sokoto and Borno in cluster 2; Ondo, Ekiti, Osun and Kaduna in cluster 3; Benue, Rivers, Delta, Bayelsa, Imo, Nassarawa, Ogun, Niger, FCT, Bauchi, Edo, Anambra, Ebonyi, Enugu, Abia, Akwaibom, and Oyo in cluster 4; lastly, Plateau in cluster 5 (Fig. 6).

(v) **Centroid clustering combines**: Taraba, Cross River, Kogi, Zamfara, Gombe, Kwara, Dutse, Kano, and Lagos in cluster 1; Kastina and Yola in cluster 2; Benue, Rivers, Delta, Bayelsa, Imo, Nassarawa, Bauchi, Ogun, Niger, FCT, Edo, Anambra, Ebonyi, Enugu, Abia, Akwaibom, and Oyo in cluster 3; Ondo, Ekiti, Osun and Kaduna in cluster 4; Kebbi, Yobe, Sokoto and Borno in cluster 5; lastly, Plateau in cluster 6 (Fig. 7).

(vi) **Median linkage combines**: Taraba, Cross River, Kogi, Zamfara, Gombe, Kwara, Dutse, Kano, Kastina, Yola and Lagos in cluster 1; Benue, Rivers, Delta, Bayelsa, Imo, Nassarawa, Ogun, Bauchi, Edo, Anambra, Ebonyi, Enugu, Abia, Akwaibom, and Oyo in cluster 2; Ondo, Ekiti, Osun, Niger, FCT and Kaduna in cluster 3; Plateau in cluster 4; lastly, Kebbi, Yobe, Sokoto and Borno in cluster 5 (Fig. 8).

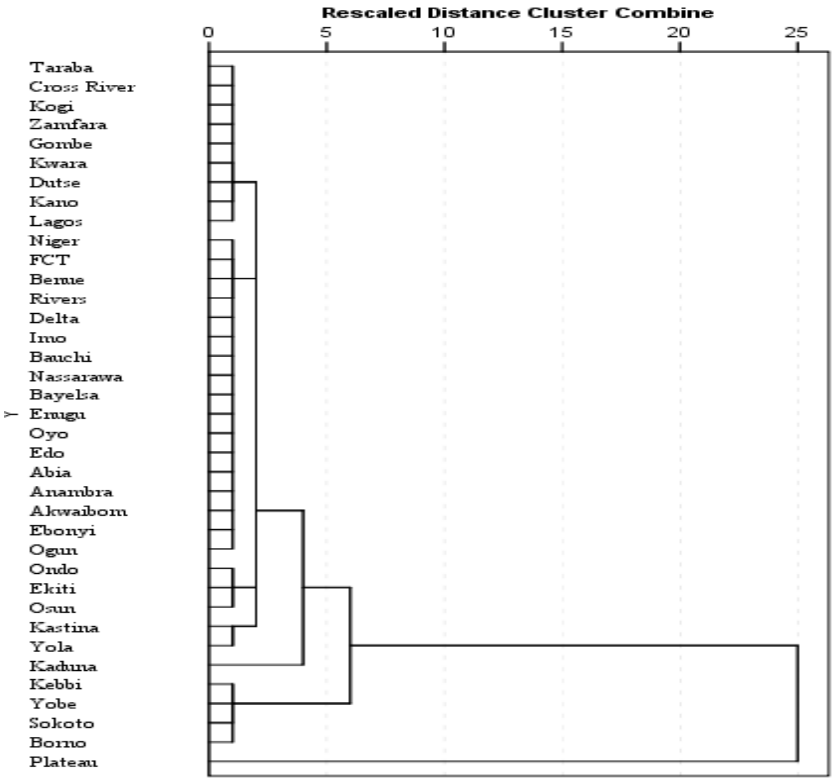

Fig. 5. Dendrogram for single (Nearest neighbor) linkage clustering method

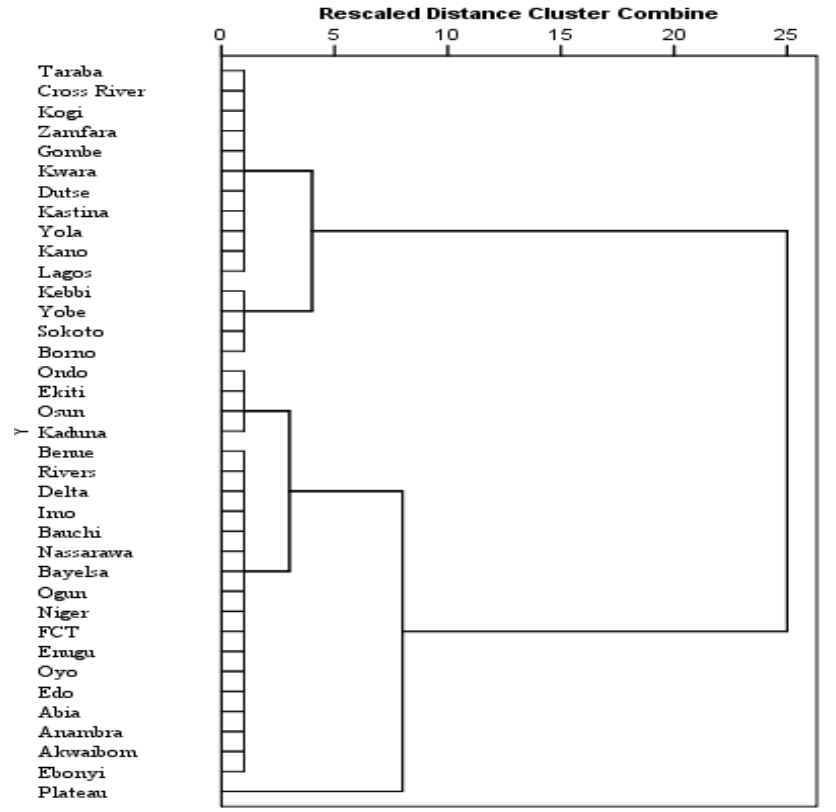

Fig. 6. Dendrogram for complete (Farthest neighbor) linkage clustering method

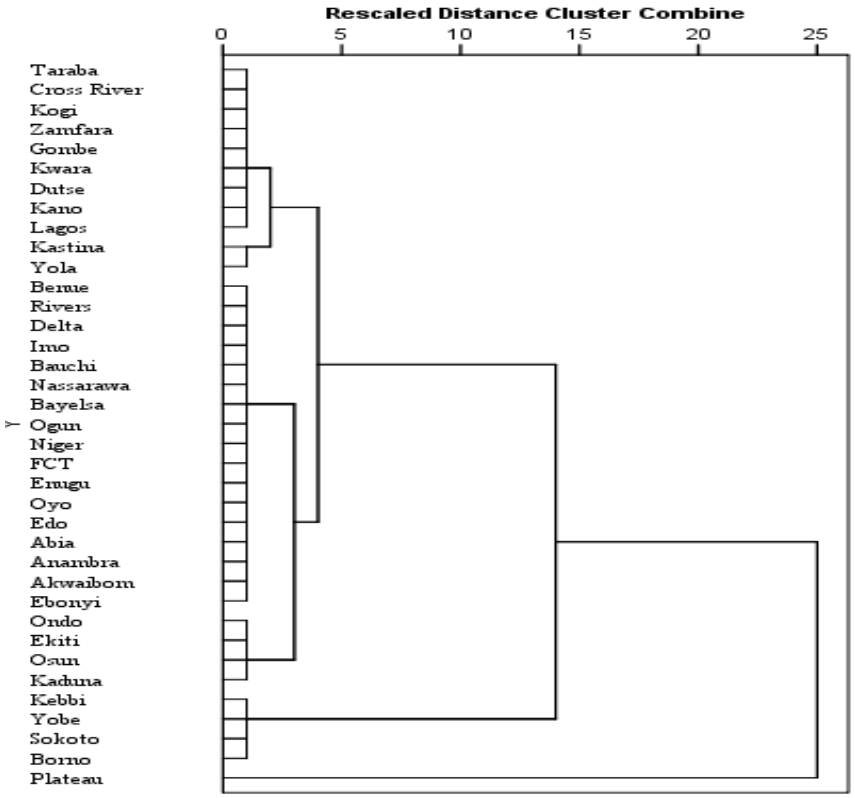

Fig. 7. Dendrogram for centroid clustering method

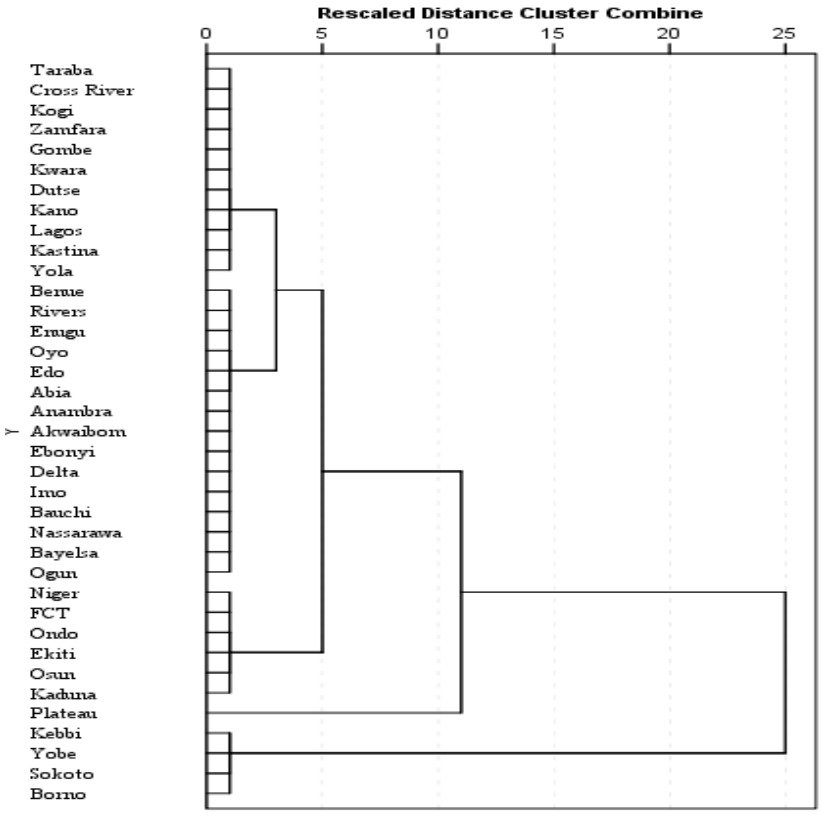

Fig. 8. Dendrogram for median clustering method

(vii) **Ward's method combines**: Taraba, Cross River, Kogi, Zamfara, Gombe, Kwara, Dutse, Kano, Kastina, Yola and Lagos in cluster 1; Kebbi, Yobe, Sokoto and Borno in cluster 2; Benue, Rivers, Delta, Bayelsa, Imo, Nassarawa, Ogun, Niger, FCT, Bauchi, Edo, Anambra, Ebonyi, Enugu, Abia, Akwaibom, and Oyo in cluster 3; Ondo, Ekiti, Osun, and Kaduna in cluster 4; lastly, Plateau in cluster 5 (Fig. 9).

The general shape of the dendogram suggests grouping the 36 states and FCT into two groups. Fig. 10 – 16 represents air temperature cluster groups across states in Nigeria for the different clustering method consider in this study.

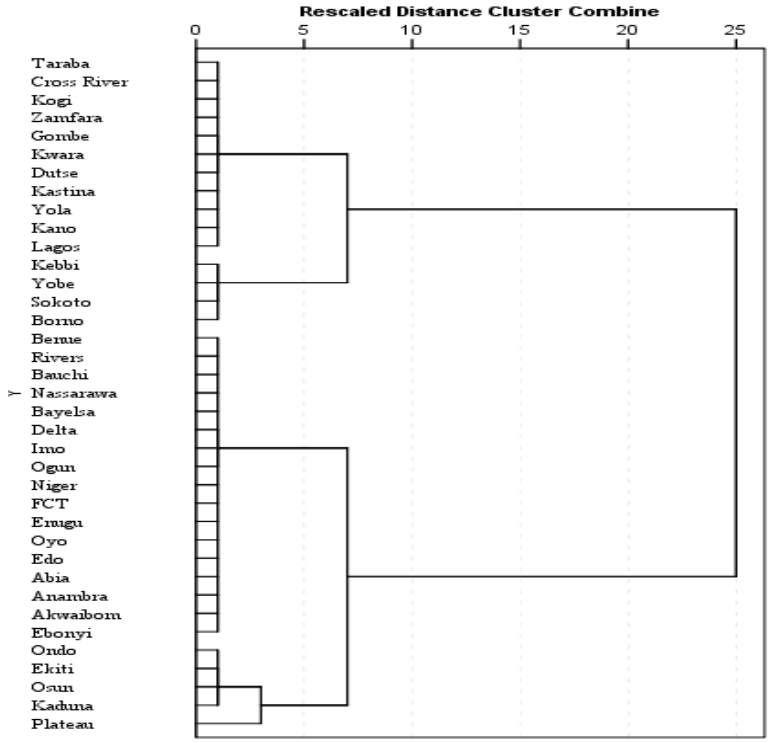

Fig. 9. Dendrogram for Ward's clustering method

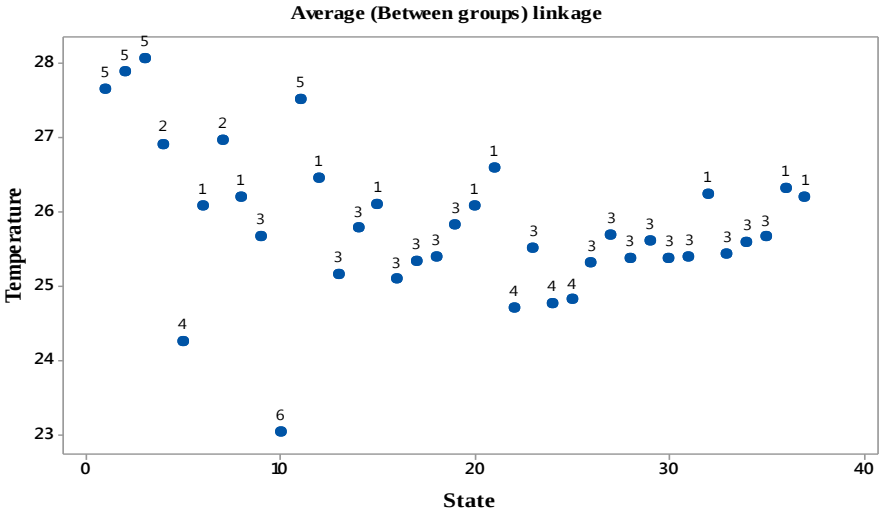

Fig. 10. Air temperature Cluster groups across states in Nigeria for average (Between groups) linkage method

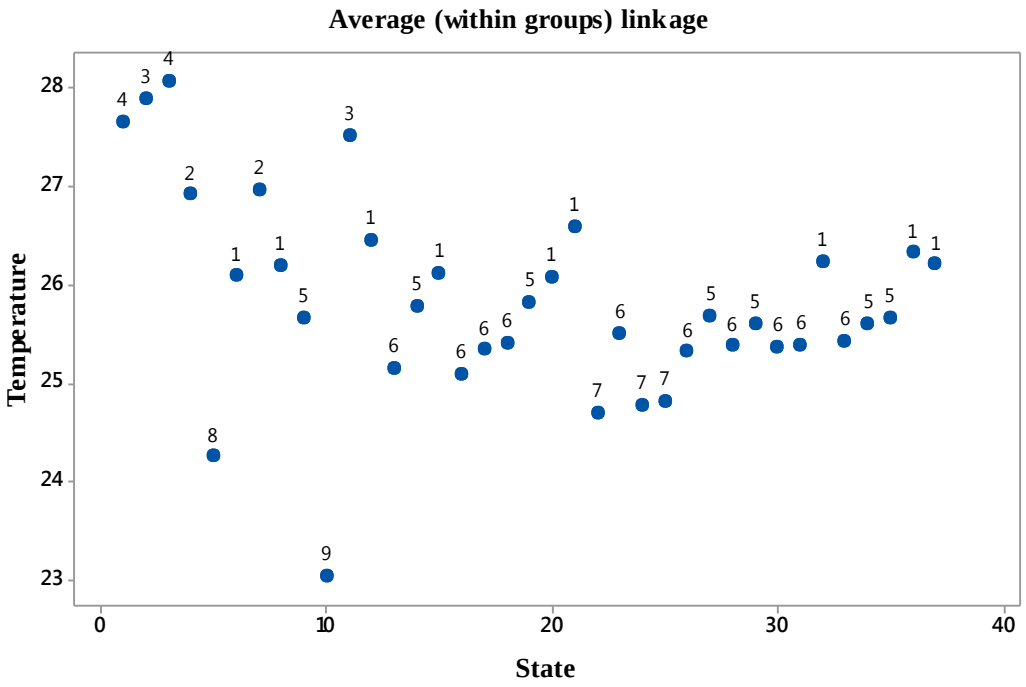

Fig. 11. Air temperature Cluster groups across states in Nigeria for average (within group) linkage method

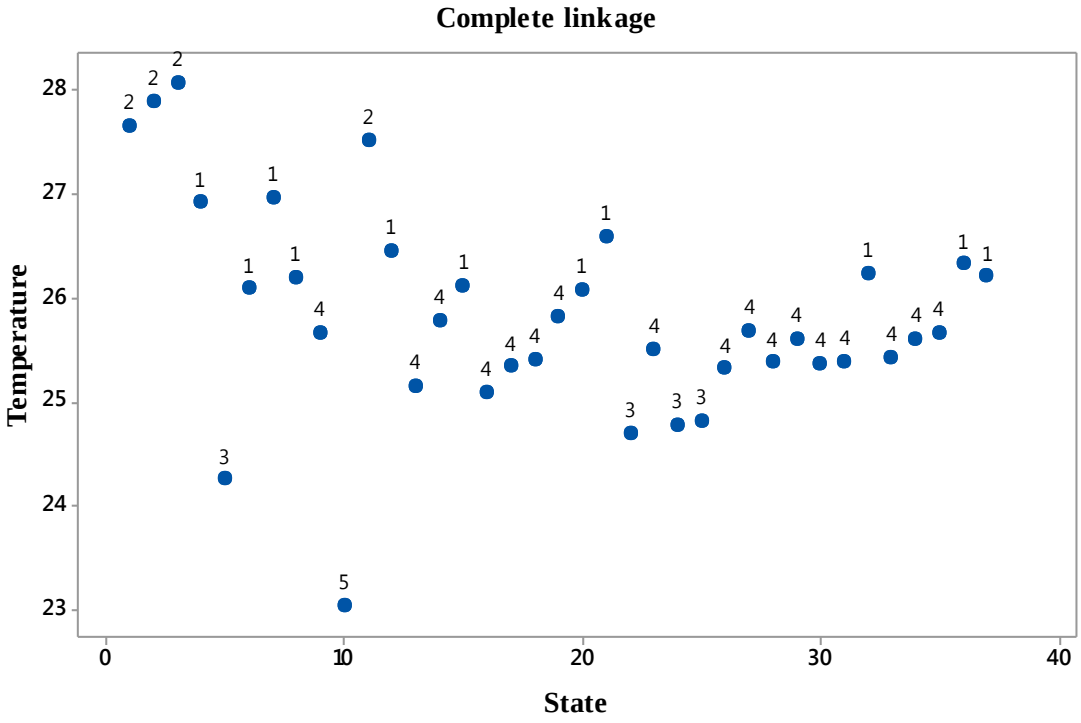

Fig. 12. Air temperature Cluster groups across states in Nigeria for Complete linkage method

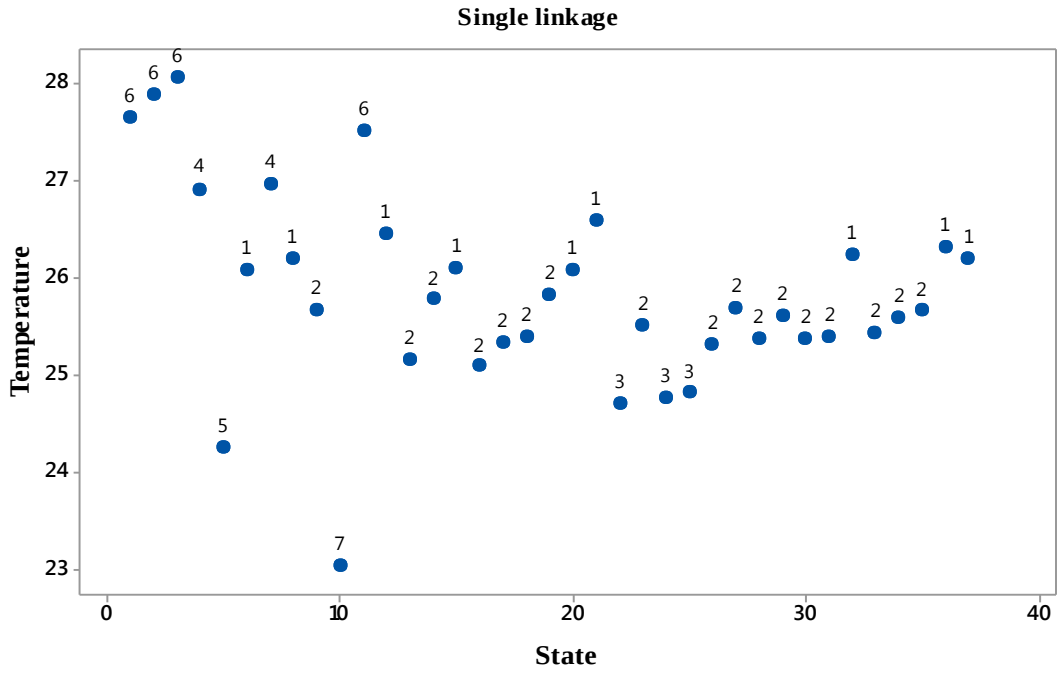

Fig. 13. Air temperature Cluster groups across states in Nigeria for Single linkage method.

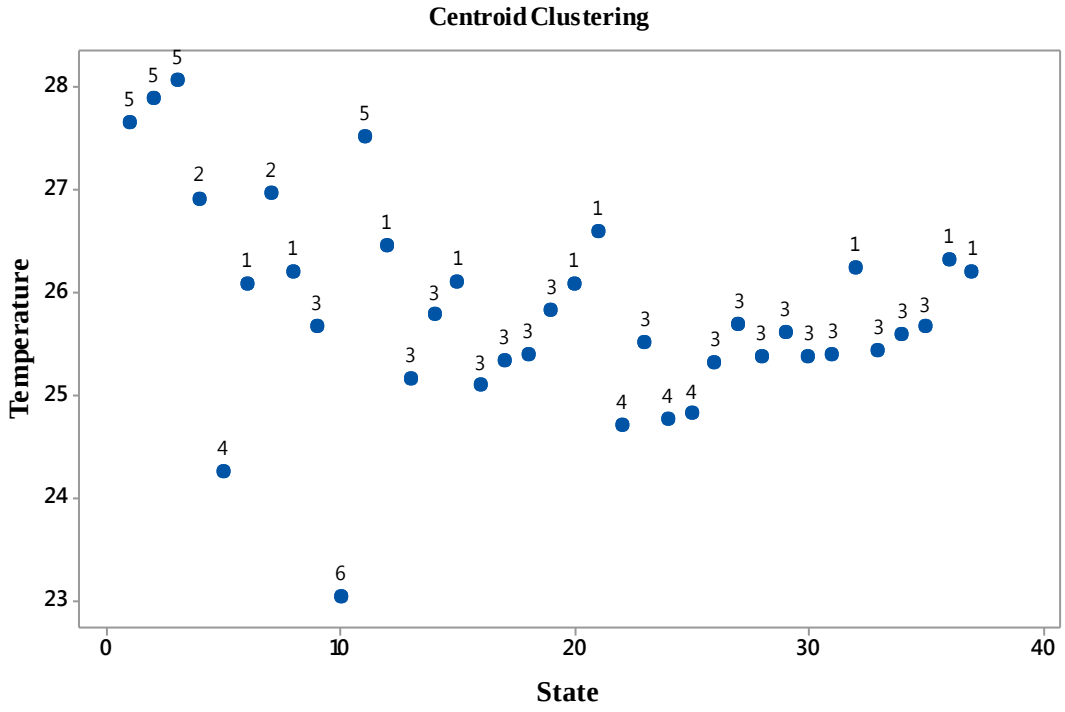

Fig. 14. Air temperature Cluster groups across states in Nigeria for Centroid clustering method

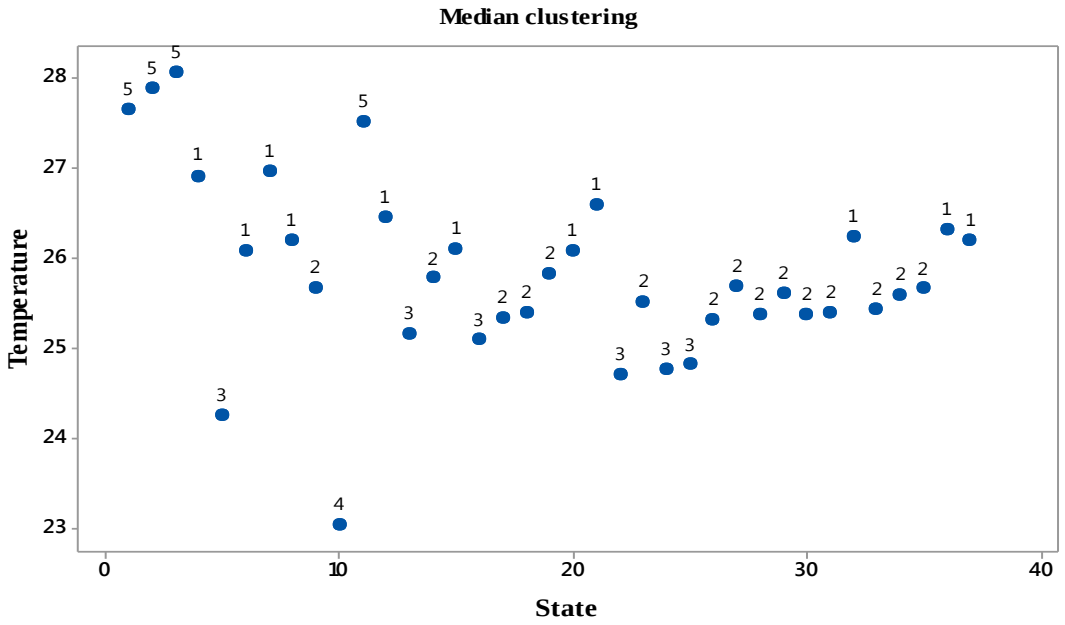

Fig. 15. Air temperature Cluster groups across states in Nigeria for median clustering method

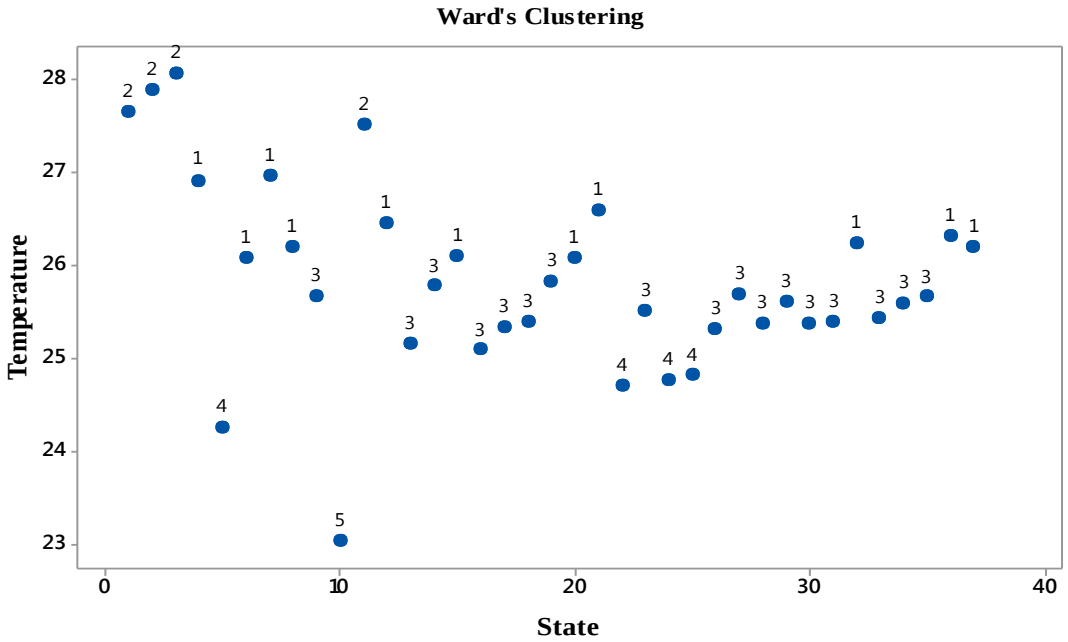

Fig. 16. Air temperature Cluster groups across states in Nigeria for Ward's clustering method.

The limitations and strengths of clustering methods must be understood to make an informed decision on which technique is most appropriate for a particular location. It is clear that the average within group linkage distributes the states more evenly across the clusters, while the rest technique assigns most of the states into one or two cluster. Comparison of the annual temperature variation of these states (Fig. 17) with Figs. 3-9 reveals that median linkage, complete linkage and Ward's clustering method solutions seems more realistic.

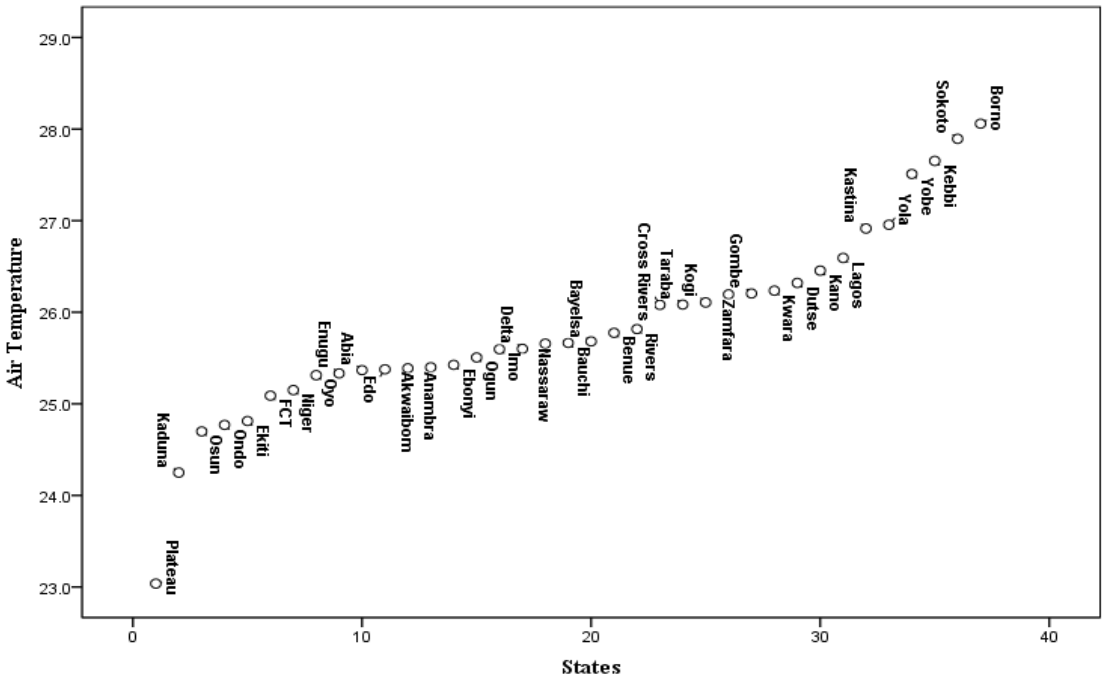

Fig. 17. Increasing average yearly trend of air temperature across the 36 states and FCT in Nigeria

It has been established in literature that there are four accepted climate zones over Nigeria. In this research, these zones have been questioned using cluster analysis methodology. As is so often found in climatological research, the Ward's method is the most acceptable method [7]. The Ward's method reveals that the climate over Nigeria can be grouped into five (5) zones based on increasing trend of air temperature data (Table 3).

Table 3. Cluster distribution of air temperature zones across the 36 states and FCT in Nigeria

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
T<24^{o}C	24≤ T <25 ^{o}C	25≤ T <26 ^{o}C	26≤ T <27 ^{o}C	T ≥ 27 ^{o}C
Plateau	Kaduna	F.C.T.	Cross River	Yobe
	Osun	Niger	Taraba	Kebbi
	Ondo	Oyo	Kogi	Sokoto
	Ekiti	Enugu	Zamfara	Borno
		Abia	Gombe	
		Edo	Kwara	
		Akwaibom	Dutse	
		Anambra	Kano	
		Ebonyi	Lagos	
		Ogun	Kastina	
		Imo	Yola	
		Delta		
		Nassarawa		
		Bauchi		
		Bayelsa		
		Benue		
		Rivers		

According to [18], Nigeria climate was classified into five zones: coastal, forest, Guinea, southern and northern Sudan climatic zones. Theses climatic zones differ from [4] classification of Nigeria climate. These classifications were done based on temperature and rainfall data. From this work, Plateau state is grouped separately (cluster 1) because of its unique characteristic type of climate. The Jos Plateau is separated from the other states around it by very steep slopes called Escarpments and it's over 1200m above sea level. Because of the height above sea level, this upland plain is famous for its cool weather (below 27^0C) and is suitable for arable agriculture.

Cluster 2 covers three south-west states and one north-west state (Kaduna). Cluster 3 covers all the states in south-east, south-south (except Cross River), North-central (except Kogi and Kwara), Bauchi in North-west and ogun and Oyo in South-west. Cluster 4 covers one state in south-south (Cross River), South-south (Lagos), two states in North-central (Kogi and Kwara), three states in North-east (Adamawa, Gombe and Taraba) and four states in North-west (Jigawa, Kano, Kastina and Zamfara). Lastly cluster 5 covers two states in North-east (Borno and Yobe) and North-west (Kebbi and Sokoto). Nigeria lies in West Africa and experiences a diverse climate that ranges from arid in the north to tropical in the majority of the rest of the country. It is located close to the equator where the sun is high in the sky at mid-day throughout the year. Hence, air temperatures are high throughout the year in Nigeria. In the upland areas, mean annual temperatures vary from 21^0C to 27^0C (Cluster 1). On the lowlands, means annual temperatures are higher than 27^0C (Cluster 2-4). According to [4], the northeast of Nigeria is likely to experience an increase in air temperature, 4.5°C from present day climate by 2081-2100. The coastal regions in the southwest are projected to warm less than the interior regions.

4. CONCLUSIONS

In previous studies, the precipitation and air temperature data were used to define the different climatic zones in Nigeria. On the contrary, in this study, air temperature data was used only because it's one of the major indicators of climate change in Nigeria. The application of cluster analysis resulted into five clusters from the 36 states and FCT, Nigeria. Based on the findings of this study, the median linkage, complete linkage and Ward's clustering method solutions seems more realistic. Only Plateau state is group under Cluster 1 and has the lowest air temperature. Cluster 2 covers three south-west states and one north-west state (Kaduna). Cluster 3 covers all the states in south-east, south-south (except Cross River), North-central (except Kogi and Kwara), Bauchi in North-west and Ogun and Oyo in South-west. Cluster 4 covers one state in south-south (Cross River), South-south (Lagos), two states in North-central (Kogi and Kwara), three states in North-east (Adamawa, Gombe and Taraba) and four states in North-west (Jigawa, Kano, Kastina and Zamfara). Lastly cluster 5 covers two states in North-east (Borno and Yobe) and North-west (Kebbi and Sokoto). It is known that there are four accepted climate zones over Nigeria based on precipitation and air temperature data. In this research, five climatic zones were discovered based on air temperature data using cluster analysis methodology.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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