

Computational Analysis of Meteorological Data of Ikeja Lagos State Using the EOF Analysis

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Abstract

In this work, empirical orthogonal transformation (EOF) is used to analyse the meteorological data of Ikeja Lagos State. The meteorological data, when comparison was made on the wet seasons of all components, with minimal rainfall, high windspeed, zero SSH, and zero Tmax shows that the air is humid at all the three components. For the dry season, it could be observed that the highest month realized is at the first component while the month in component 5 is minimal. Also high and minimal amount of Tmax, Solar Radiation, and SSH were seen on the first and fifth component respectively which, shows that the dry season is very hot at component one and cold at component five. When rotation was performed on the data a comparison was also performed on all components (wet season) and this shows that the months realized on each are same (1.1) other features in common are Tmax, rainfall, which shows that the wet season is cold. parameters utilized were monthly Solar radiations, sunshine hours, wind speed, maximum and minimum temperatures, rainfall, cloud cover, and relative humidity, with a data spanning forty-three (43) years (1980 to 2023). The data was analysed using unrotated data and three orthogonal transformations (Varimax, Quatimax, and Equamax) where seven components were extracted. From component matrices, it was discovered that there are two distinct seasons: A rainy or wet and dry. The period of wet determined to be around 7.2 months and for the dry season, as 4.9 months. These values determined are consistent with what is observed in real-time of 7.0 months of wet season and 5.0 months of dry season. This shows that EOF describe the two seasons quantitatively.

Keywords: Empirical orthogonal transformations, Meteorological data, Regression analysis, Ikeja, Nigeria.

1. Introduction

Climate change is a global issue that impacts on every living being in the world. It refers to any significant change in the measures of weather elements such as temperature, rainfall, wind pattern etc. and lasting for an extended period of time (Nigerian Meteorological Agency (NiMet, 2017). The earth climate is dynamic and naturally varies on seasonal, decadal, Centennial and longer timescale. Each “up and down” fluctuation can lead to conditions which are warmer or colder, wetter or drier, more stormy or quiescent (Gocic and Trajkovic 2013; NOAA, 2007). Hannachi et al. (2022) provide a description of the mathematics behind common EOFs which also is relevant for our analysis, but here we present a slightly different approach for applying them for the purpose of climate model evaluation and for assessing different model ensembles. On a joint data matrix rather than the step-wise algorithm for a set of covariance matrices described by Hannachi et al. (2022). The climate of Ikeja and Nigeria at large has shown considerable temporal and spatial shifts in its variability and change since the late 1960s and early 1970s through a careful study of meteorological data (FRN, 2003; NiMet, 2012).

Empirical Orthogonal Function (EOF) analysis, also called principal component analysis (PCA) (Fukuoka, 1951; Lorenz, 1956), is among the most widely and extensively used methods in dimensionality reduction and patterns

extraction in atmospheric science. Both names are commonly used and refer to the same set of procedures. Typically, the EOFs are found by computing the eigen values and eigenvectors of a spatially weighted anomaly covariance matrix of a field. The derived eigen values provide a measure of the percentage variance explained by each mode. EOF analysis and PCA have become the standard statistical techniques in the geophysical sciences of meteorology, climatology and oceanography (Preisendorfer, 1988; Emery and Thomson, 1997), particularly in the area of climate research (Peixoto and Oort, 1992; Von Storch and Zwiers, 1999).

The aim of this paper is to analyse the meteorological data of Ikeja, Lagos State using the statistical analysis of Empirical orthogonal transformations. The purpose of the analysis is to determine the durations and the characteristics of the seasons.

2.0 Theory

2.1 Empirical Orthogonal Transformations

Empirical Orthogonal Function (EOF) analysis seeks structures that explain the maximum amount of variance in a two-dimensional data set. In climate studies, EOF analysis is often used to study possible spatial modes (i.e., patterns) of variability and how they change with time. In statistics, EOF analysis is known as Principal Component Analysis (PCA). As such, EOF analysis is sometimes classified as a multivariate statistical technique. The data to be used for the EOF analysis are transformed into a two-dimensional data matrix by the software, X (say) as follows:

$$X = M \times N [X_{i,j}], \quad \text{where } i = 1, \dots, M; j = 1, \dots, N. \quad (1)$$

M and N are the dimensions of the data matrix enclosed by the square brackets, and subscript notation $X_{i,j}$ to indicate the same matrix. The transpose of the matrix is obtained by reversing the order of the indices to make it an $M \times N$ matrix.

$$X^T = N \times M [X_{j,i}], \quad \text{where } i = 1, \dots, M; i = 1, \dots, N. \quad (2)$$

In multiplying a matrix time itself we generally need to transpose it once to form an inner product, which results in two possible “dispersion” matrices. In this case are called correlation/covariance matrix

$$C = XX^T = X_{i,j}X_{j,i} = X_{i,i}. \quad (3)$$

The other dispersion matrix in which the roles of the structure and the sampling variables are reversed is:

$$C = X^T X = X_{j,i}X_{i,j} = X_{j,j}. \quad (4)$$

In this projection of a matrix onto itself, one of the dimensions gets removed and we are left with a measure of the dispersion of the structure with itself across the removed dimension (or the sampling dimension). If the sampling dimension is time, then the resulting dispersion matrix is the matrix of the covariance of the spatial locations with each other, as determined by their variations in time. These dispersion matrices are in fact covariance/correlation matrices. In the second case the covariance at different times is obtained by projecting on the sample of different spatial points. Either of these dispersion matrices may be scientifically meaningful depending on the problem under consideration. These matrices generated can be either positive definite or positive semi-definite covariance/correlation matrices and are usually symmetrical. EOF (or PCA) analysis consists of an eigenvalue analysis of any one of these dispersion matrices. Any symmetric matrix C can be decomposed through a diagonalization, or eigen analysis using the followings:

$$C e_i = \lambda_i e_i, \quad (5)$$

$$CE = E\Lambda, \quad (6)$$

where E is the matrix with the eigenvectors e_i as its columns and Λ is the matrix with the eigenvalues λ_i , along its diagonal and zeros elsewhere. The eigen functions of the Hermitian matrix C form an orthonormal basis to represent C and hence called empirical functions or empirical modes. The eigenvalue λ_i is a measure of the percentage variability represented by i^{th} EOF. The set of eigenvectors, e_i , and associated eigenvalues, λ_i , represent a coordinate transformation into a coordinate space where the matrix C becomes diagonal. Because the covariance /correlation matrix is diagonal in this new coordinate space, the variations in these new directions are uncorrelated with each other, at least for the sample that has been used to construct the original covariance/correlation matrix. The eigenvectors define directions in the initial coordinate space along which the maximum possible variance can be explained, and in which variance in one direction is orthogonal to the variance explained by other directions defined by the other eigenvectors. The eigenvalues indicate how much variance is explained by each eigenvector. If you arrange the eigenvector/eigenvalue pairs with the biggest eigenvalues first, then you may be able to explain a large amount of the variance in the original data set with relative few coordinate directions, or characteristic structures in the original structure space.

3.0 Materials and Method

3.1 Data and Study Area

The study utilizes monthly meteorological data from Ikeja covering the years from 1980 to 2023 obtained from the Nigerian Meteorological Agency archives. Ikeja is located at Latitude $6^{\circ}35'39''$ N, Longitude $3^{\circ}20'14''$ E at an elevation of 41 m above sea level. (Torrence and Combo 1998). The region experiences two seasons: a rainy season from April to October and a dry season from November to March (Fasona et al., 2005; Ojeh et al., 2016; Nwilo et al., 2020). The wet seasons is characterised by heavy rainfall, and the dry seasons characterised by little or no rainfall. (Sallau et al., 2016; Akpootu et al., 2017). Being a state of tropical wet and dry climate, the rainy seasons; is characterised with two distinct seasons the more intense one occurs between April and July, with a milder one from October to November. The wetter seasons lasts for 6.6 months, from April to 8, to October 29. The month with the wet days in Ikeja is September. The drier seasons lasts for 5.3 months. from October 29 to April 18. The month with the fewest rainy days in Ikeja is January (Akpoota et al., 2017).

3.2 Data Analysis

To analyse the data using EOF, SPSS software version 20 was used. The EOF results were obtained for non-rotated and three orthogonal rotations. The three types of rotation are, Varimax, Quatimax, and Equamax.

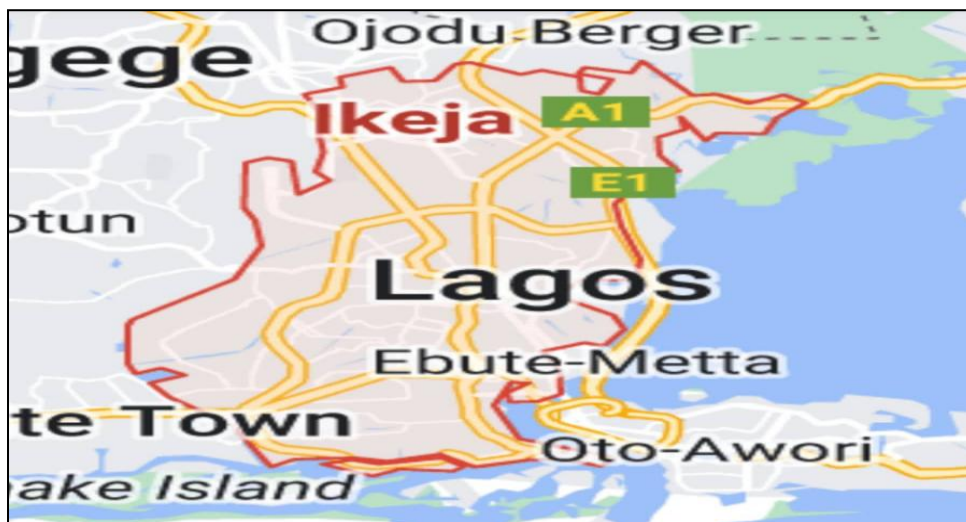


Figure 1: Map of Ikeja Lagos State with LGA Boundaries (Akpoota et al, 2017).

4.0 Results and Discussions

Table 1 shows the KMO which is used to determine the sampling adequacy of the data. From the table 1, it can be seen that the value is 0.75, which is greater than 0.5. This shows that meaningful information can be obtained. The value of the significance parameter shows that the data are also statistically significant.

Table 1. Kaiser-Meyer-Olkin Measure of Sampling Adequacy

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	0.7591
Sig.	0.0000

Keys: KMO (Kaiser-Meyer-Olkin Measure of Sampling Adequacy).

From Table 2, the communalities show the percentages of the information in the individual Parameters that are being extracted and captured by the software for the statistical analysis. From the column of the extracted information captured, it shows that most of the extracted Information amount to 80% and above.

Table 2. Communalities

Measurements	Initial	Extraction
Solar Rad	1.0000	0.9949
SSH	1.0000	0.9872
Windspeed	1.0000	0.9969
Tmax	1.0000	0.8084
Tmin	1.0000	0.9772
Rainfall	1.0000	0.9902
CC	1.0000	0.9995
RH	1.0000	0.9775

Keys: Solar Rad (Solar Radiation), SSH (Sunshine Hours), Tmax (Maximum Temperature), Tmin (Minimum Temperature), CC (Cloud Cover) and RH (Relative Humidity).

Table 3 shows the component matrix and the total variance explained by each component and the number of months each component represents, with the corresponding appropriate names. Component 1 is a dry season because both coefficients of solar radiation, sunshine hours, and minimum temperature are high. The coefficients of rainfall and cloud cover are negative which shows the absence of rainfall and cloud. This may probably be the four more intense season which occurs between (April and July) as the number of months lasted for about four months (Ileoja 1981). The second component is a wet season because the coefficients of rainfall is positive, and there is no sunshine hours as the coefficient of sunshine hours is negative, there is high coefficient of windspeed and maximum temperature is negative. It can be seen that it lasts for 1.8 months. This may represent the months of October and November as the two months have a milder rainfall. Component 3 is also wet season this is because the coefficients of maximum temperatures is high and the coefficient of rainfall is positive. This shows that the weather is completely wet and cloud cover is also negative and it lasts for 1.5 months. This may also likely be milder rainy period in Ikeja as cited by Ileoja (1981). Component 4 is also a wet season as the coefficient of maximum temperature is negative and high value of the coefficient of rainfall. This lasted for about 1.4 months. Component 5 is a dry season because the coefficient of rainfall is negative, a small cloud cover, and moderate relative humidity this may likely be the beginning of the dry season as the number of days lasted for only 0.83. Component 6 is a wet season because the coefficient of maximum temperature is negative, no relative humidity as the coefficient is negative, the coefficient of rainfall is very small which lasted for 0.52 days. This may likely be the end of rainy season. Component 7 is also a wet season with a little amount of rainfall which also implies the coldness and covers 0.30 days. Also comparing the two wet seasons on component 2, 3 and 4. It could be said that the highest months observed was at the second

component even though with a medium amount of rainfall, high windspeed, zero SSH, and zero Tmax at all the components this shows that the air is humid in all the three components as cited by Akpoota et al. (2007).

Another comparison is on the two components (6 and 7) of wet seasons which shows that the amount of rainfall realized on the two components are very negligible which may be attributed to being the beginning and the end of dry season (Aliyu et al., 2020). On the dry season, when components 1 and 5 were compared. It could be observed that the highest month realized is at the first component while the month in component 5 is minimal. Also, high and minimal amount of Tmax, solar radiation, and SSH were seen on the first and fifth component, respectively. This shows that the dry season is very hot at component one and cold at component five. Thus, from the overall result, it can be said that the wet season covers 5.4 months and dry season covers 5.5 months.

Table 3. Component matrix and percentage variance with no rotation

Model Parameters	Component						
	1	2	3	4	5	6	7
Tmax	0.89022	-0.04828	-0.04152	-0.01763	0.03649	-0.08335	0.05677
SolarRad	0.78267	0.21739	0.01798	0.22666	-0.01752	0.20835	-0.48951
SSH	0.72611	-0.07070	0.26868	0.31625	0.32272	0.27453	0.32130
RH	-0.63767	0.27293	0.46812	0.07830	0.48086	-0.12100	-0.15883
Rainfall	-0.53979	0.35373	0.32537	0.51011	-0.41370	0.16666	0.09334
Windspeed	-0.09749	0.78671	-0.38262	-0.34321	0.10442	0.28690	0.10504
Tmin	0.60115	0.60420	0.10740	0.07909	-0.06697	-0.46775	0.09862
CC	-0.28790	-0.00913	-0.69495	0.61983	0.18888	-0.11722	0.00229
Initial Eigenvalues	3.08407	1.23826	1.04013	0.92629	0.55923	0.48298	0.40078
% of Variance	38.55087	15.47821	13.00167	11.57859	6.99040	4.37058	2.50975
Cumulative %	38.55087	54.02908	67.03074	78.60933	85.59973	89.9703	92.48003
Number of Months	4.626104	1.75739	1.4601999	1.389431	0.838848	0.52447	0.30117
Descriptions	Dry	Wet	Wet	Wet	Dry	Wet	Wet

Table 4 shows the component matrix and the total variance explained by each component and the number of months that each component represents with their corresponding appropriate names. Component 1 is dry season because of the presence of both high maximum temperature, solar radiation and sunshine hours. The coefficient of the rainfall is negative and relative humidity also negative (which shows, the complete dryness of the weather). It usually lasts for 2.8 months. Component 2 is a wet season because the coefficient of rainfall is positive and moderate, and the coefficient of minimum temperature is high. It can be seen that it lasts for 1.6 months. Component 3 is also a wet season because the coefficients of rainfall and minimum temperature are high. It can be seen that it lasts for 1.5 months. Component 4 is also a wet season. Here the coefficients of both minimum and maximum temperatures are low and no rainfall but the coefficient of wind speed is high which lasts for about 1.5 months. Component 5 is a dry season. Here the coefficient of rainfall is high, maximum temperature is positive and moderate, it lasted for about 1.9 months. Component 6 is a wet and cold season due to the presence of negative maximum and minimum temperature, no relative humidity and this lasted for about 1.33 months. Component 7 is a wet season and lasted for about 1.2 months. Comparing components 2, 3, 4, 6 and 7 (wet season) shows that the months realized on each are the same (1.1). Other features in common are Tmax and rainfall, which shows that the wet season is cold. Finally, this result shows that the wet season covers 7.2 months, and the dry season covers 4.8 months.

Table 4. Component matrix and percentage variance with varimax rotation

Model Parameters	Component						
	1	2	3	4	5	6	7
Tmax	0.8902	-0.0483	-0.0415	0.0176	-0.0365	-0.0834	0.0568
SolarRad	0.7827	0.2174	0.0180	0.2267	-0.0175	0.2084	-0.4895
SSH	0.7261	-0.0707	0.2687	0.3162	0.3227	0.2745	0.3213
RH	-0.6377	0.2729	0.4681	0.0783	0.4809	-0.1210	-0.1588
Rainfall	-0.5398	0.3537	0.3254	0.5101	-0.4137	0.1667	0.0933
Windspeed	-0.0975	0.7867	-0.3826	-0.3432	0.1044	0.2869	0.1050
Tmin	0.6012	0.6042	0.1074	0.0791	-0.0670	-0.4677	0.0986
CC	-0.2879	-0.0091	-0.6950	0.6198	0.1889	-0.1172	0.0023
Eigen Values	1.2156	1.1653	1.1589	1.0951	1.0623	1.0201	1.0145
% of Variance	23.5283	13.7333	12.8819	12.8558	16.1166	11.0842	10.1816
Cumulative %	23.5283	37.2616	50.0807	62.9365	79.0532	90.1374	99.6467
Number of Months	2.8234	1.6480	1.5383	1.5427	1.934	1.3301	1.2218
Descriptions	Dry	Wet	Wet	Wet	Dry	Wet	Wet

Table 5. Component matrix and percentage variance with quatimax rotation

Model Parameters	Component						
	1	2	3	4	5	6	7
Tmax	0.8902	-0.0483	-0.0415	0.0176	-0.0365	-0.0834	0.0568
SolarRad	0.7827	0.2174	0.0180	0.2267	-0.0175	0.2084	-0.4895
SSH	0.7261	-0.0707	0.2687	0.3162	0.3227	0.2745	0.3213
RH	-0.6377	0.2729	0.4681	0.0783	0.4809	-0.1210	-0.1588
Rainfall	-0.5398	0.3537	0.3254	0.5101	-0.4137	0.1667	0.0933
Windspeed	-0.0975	0.7867	-0.3826	-0.3432	0.1044	0.2869	0.1050
Tmin	0.6012	0.6042	0.1074	0.0791	-0.0670	-0.4677	0.0986
CC	-0.2879	-0.0091	-0.6950	0.6198	0.1889	-0.1172	0.0023
Eigen Values	1.2545	1.1894	1.1871	1.0790	1.0158	1.0113	0.9946
% of Variance	32.348	14.8675	13.1725	12.655	16.0308	10.9741	11.51
Cumulative %	32.348	47.2155	60.388	73.043	89.0738	92.974	98.6467
Number of Months	3.8818	1.7841	1.5807	1.5186	1.9237	1.3169	1.3919
Descriptions	Dry	Wet	Wet	Wet	Dry	Wet	Wet

Component matrix and percentage variance with quatimax rotation are presented in Table 5. Component 1 is Dry season because the coefficient of the maximum temperature is high and the coefficients of rainfall and Relative humidity are negative, which shows the complete dryness of the weather and it lasts for 3.8 months. Component 2 is a wet season because of the presence of rainfall, negative cloud cover which indicates coldness; it lasted for about 1.8 months. Component 3 is a wet season because of the coefficient of maximum temperature is negative) which lasts for 1.6 months. Component 4 is also a wet season because the coefficient of rainfall is moderate and maximum temperature is low which indicate coldness this lasts for 1.5 months. Component 5 is a dry season because the coefficients of both maximum and minimum temperatures are low and negative, there is no rain. It last for almost 1.9 months. Component 6 is a wet season. This is because of the presence of rainfall; it lasted for about 1.3 month. The last component is also a wet season because the coefficient of rainfall is very small and negative solar radiation is negative it last for 1.4 months. From this result, it can be said that the wet season covers 7.5 months while the dry season covers 5.3 months.

Table 6. Component matrix and percentage variance with equamax rotation

Model Parameters	Component						
	1	2	3	4	5	6	7
Tmax	0.8902	-0.0483	-0.0415	0.0176	-0.0365	-0.0834	0.0568
Solar Rad	0.7827	0.2174	0.0180	0.2267	-0.0175	0.2084	-0.4895
SSH	0.7261	-0.0707	0.2687	0.3162	0.3227	0.2745	0.3213
RH	-0.6377	0.2729	0.4681	0.0783	0.4809	-0.1210	-0.1588
Rainfall	-0.5398	0.3537	0.3254	0.5101	-0.4137	0.1667	0.0933
Windspeed	-0.0975	0.7867	-0.3826	-0.3432	0.1044	0.2869	0.1050
Tmin	0.6012	0.6042	0.1074	0.0791	-0.0670	-0.4677	0.0986
CC	-0.2879	-0.0091	-0.6950	0.6198	0.1889	-0.1172	0.0023
Eigen Values	1.1767	1.1445	1.1410	1.1119	1.1083	1.0272	1.0222
% of Variance	14.7091	14.3066	14.2623	13.8989	13.8531	12.8397	12.7770
Cumulative %	14.7091	29.0157	43.2780	57.1769	71.0301	83.8698	96.6467
Number of Months	1.7651	1.7168	1.7115	1.6679	1.6624	1.5408	1.5332
Descriptions	Dry	Wet	Wet	Wet	Dry	Wet	Wet

Table 6 presents the component matrix and percentage variance with equamax rotation. Component 1 is a dry season because the coefficient of the maximum temperature is high and the coefficients of rainfall and Relative humidity are negative (which shows, the complete dryness of the weather). It lasts for 1.7 months. Component 2 is wet season because of the presence of rainfall and high coefficient of minimum temperature (this indicate coldness). It lasted for about 1,7 months. Component 3 also a wet season because of the coefficient maximum temperature is negative. Cloud cover also negative this last for 1.7 months. Component 4 is also a wet season Here the coefficient of rainfall is high no windspeed which lasted for almost 1.7 months. Component 5 is a dry season, because the coefficients of both maximum and minimum temperatures are negative and this lasts for 1.7 month. Component 6 is a wet season both maximum and minimum temperatures are negative, relative humidity also negative, the coefficient of rainfall is moderate It lasted for about 1.5 month. Component 7 is also a wet season. Here rainfall is also moderate, negative solar radiation and this last for 1.5 months. From this result, it can be said that When rotation was performed on the data the wet season covers 8.2 months and the dry season covers 3.4 months.

5. Conclusion

From the analysis of the result, it can be seen that the application of empirical orthogonal function determined the two seasons as wet and dry. The period of wet is around 7.2 months, and the dry is 4.9 months, consistent with what was observed in real time of 7 months for wet and 5 months for dry in Ikeja Lagos State. From the analysis it shows the best rotations among the three is varimax as the months realizes the highest months of 7.2 for the wet, and 4.7 months for the dry. Comparison on the wet season when there is no rotation shows that the air is humid at all components Also high and minimal amount of Tmax, Solar Radiation, and SSH were seen on the first and fifths components, respectively, which shows that the dry season is very hot at component one and cold at component five Comparison was also performed on all components (wet season) and this shows that the months realizes on each are same (1.1). Other futures in common are Tmax, and rainfall, which shows that the wet season is cold. The analysis of the wet season shows that season is concentrated within seven months (April to October) and a dry season from November to March. Hence it can be said that based on this analysis, EOF now describes the two seasons quantitatively.

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