Available online at www.worldnewsnaturalsciences.com

World News of Natural Sciences

An International Scientific Journal

WNOFNS 59 (2025) 1-13 EISSN 2543-5426

Assessment of climate parameters and their relationship with aerosol optical depth over Katsina city, Nigeria

Cynthia Chioma Anosike

Department of Physics, Faculty of Physical Sciences, Imo State University, Owerri, Nigeria

Center for Atmosphere and Environmental Research, Imo State University, Owerri, Nigeria

E-mail address: anosikechioma93@gmail.com

ABSTRACT

Climate variability, characterized by fluctuations in weather patterns over time, significantly influences regional ecosystems and human societies. Tiny particles suspended in the atmosphere, aerosol, play a crucial role in climate variability by interacting with solar radiation and affecting cloud formation and precipitation. This study investigates the relationship between climatic parameters (rainfall and precipitation) and aerosol optical depth and their temporal variability in Katsina City, Katsina Nigeria, from 2002 to 2022. AOD exhibited pronounced seasonal variations, with a high value trend during the dry season. AOD was at its highest peak in 2008 and lowest trend in 2018. For the seasonal variation, AOD was observed least in the month of August during the study. Rainfall patterns displayed distinct seasonal trend, concentrated between April and October, while temperature at the study location during the study period was hot year through. In this study, a significant negative correlation was found between AOD and rainfall, suggesting that increased aerosol loading may inhibit precipitation. This finding aligns with the understanding that aerosols can modify cloud microphysics, potentially leading to less efficient rain formation. However, the relationship between AOD and temperature was found to be weak, indicating that other factors likely exert a stronger influence on temperature variations in the study area. Understanding the complex interplay between aerosols, rainfall, and temperature is crucial for assessing the impacts of climate variability and developing effective adaptation strategies. Further research is needed to investigate the specific mechanisms driving these interactions and to assess the potential impacts of these findings on regional climate and air quality management.

***Keywords*:** Aerosol, AOD, Rainfall, Temperature, Climate Variability, Katsina City, Nigeria

(Received 27 November 2024; Accepted 28 December 2024; Date of Publication 29 December 2024)

1. INTRODUCTION

Aerosol plays a crucial role in impacting precipitation and weather, acting as both cooling and warming agent[1]. Aerosols are tiny droplet of liquid or solid substances suspended in air[2]. Studies have highlighted their influence on regional and global climate variability, with anthropogenic aerosols often suppressing precipitation while altering cloud properties[1, 3]. Aerosol optical depth impacts climate variability by influencing temperature and precipitation patterns[4] and also influences the radiative budget by affecting atmospheric radiation, which can lead to climate variability[5]. Increased aerosol levels, particularly from wildfires, can exacerbate climate change effects, posing risks to human well-being and increasing the frequency of fire outbreaks[6, 7]. Studies have raised concerns about the uncertainty of aerosol's effect on cloud and precipitation.

Climate variability in Nigeria presents significant challenges, particularly affecting agricultural productivity and socio-economic stability[8]. Average annual temperatures in Nigeria have shown a consistent upward trend, especially in northern regions, with significant warming observed in the Sahelian zone[9]. Rainfall is a crucial component of the water cycle and global water components, significantly influencing climate conditions[10].

In Nigeria, rainfall is a significant source of water, especially in the southern part of the country[11]. Aerosol optical depth (AOD) in Nigeria, particularly in the Guinea Coast region, exhibits significant seasonal and spatial variability influenced by meteorological conditions and anthropogenic activities. Studies indicate that AOD levels peak during the harmattan season, with values exceeding 0.8, while lower values are recorded during the monsoon season[12]. A study of the variability of aerosol and its relationship with climate parameters in West Africa presents strong correlations between aerosol, reduced precipitation, and temperature change[13].

This paper aims at finding a relationship between aerosol optical depth (AOD) and climatic parameters (rainfall and temperature) for 21 years (2002-2022) in Katsina City, Nigeria. The paper also observed the trend of AOD, rainfall, and temperature during the study period. The data used for analysis were collected from NASA MODIS for AOD and climate research unit for rainfall and temperature.

2. METHODS

2. 1. Location of Study

The location of this study is situated in Nigeria. Nigeria is located in Western coast of Africa with a population of over 160 million people according to 2006 census. It is bordered to the north by Niger, to the east by Chad and Cameroon, to the south by the Gulf of Guinea of the Atlantic Ocean, and the west by Benin. It covers an area of 923,769 square kilometers. Nigeria possesses a varied geography, ranging from arid to humid equatorial climates. The location of this study is the capital city of Katsina State, Nigeria.

Katsina State is located in Northwestern geopolitical zone of Nigeria. Katsina lies within latitudes 11°N and 13°N and Longitudes 6°E and 9°E. It is situated on a plateau, with an average elevation or around 400 meters above sea level. Covering an area of approximately 23,938 square kilometers, Katsina population is estimated at over 6 million as at 2022. Katsina State has a tropical steppe climate, bordering on a tropical savanna climate. The rainy season typically lasts from May to September, while the dry season extends from October to April. The state receives an average annual rainfall of around 791.61 millimeters. The temperature ranges from 21 °C to 30 °C throughout the year. Agriculture is the mainstay of the economy, with crops like millet, sorghum, groundnuts, and cotton being major products. The state also has significant livestock resources. Figure 1 shows the map of Katsina State, Nigeria.

Figure 1. Map of Nigeria showing Katsina State, Nigeria.

2. 2. Choice of Location

The location were selected based on its characteristics (e.g. climate, geography, pollution levels and level of urbanization) to highlight the patterns of aerosol, temperature, and rainfall.

2. 3. Data Collection

The study data can be regarded as a secondary data since it was collected from an already processed database. The satellite data for aerosol was assessed from the National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) platform. The climate data for rainfall and temperature was assessed from the Climate Research Unit (University of Anglia).

2. 4. Data Analysis

All data were subjected to statistical analysis such as descriptive statistics, correlation analysis, trend analysis, and regression analysis. The statistical correlations were determined and compared with results from other studies. The analysis tools used for cleaning, data analysis, and data visualization are MS Excel and Python programming language.

3. RESULTS AND DISCUSSION

3. 1. Analysis of Aerosol Optical depth

Air quality over the study period at Katsina City, Katsina State Nigeria, has experienced an enormous decline during the study period. The sources of pollution at this study area are the Sahara dust and anthropogenic activities[14].

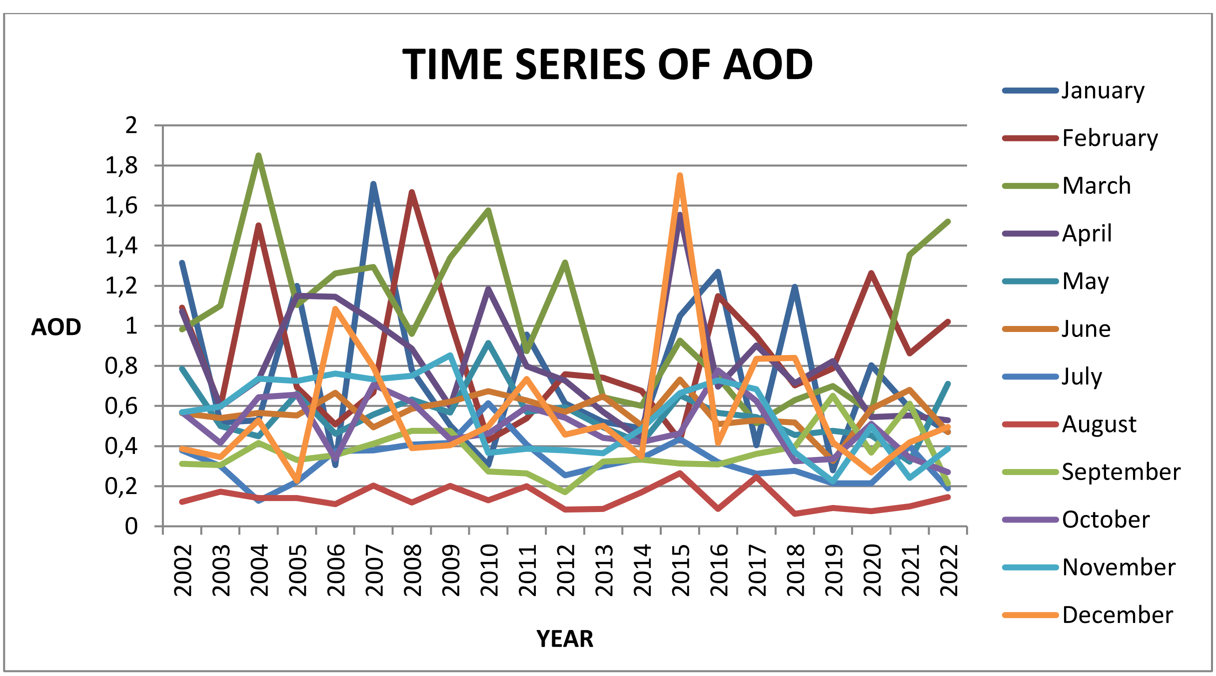

Figure 2. Time Series of Aerosol Optical Depth (2002-2022).

From Figure 2, it can be observed that aerosol optical depth (AOD) recorded its highest value on March 2008 with 1.85, while the lowest value was recorded on August 2018 with a value of 0.062. It can also be observed from Figure 2 that AOD was experienced mostly in the year 2008 and the lowest in the year 2018. 2018 recorded the lowest AOD value and this might be attributed to the worldwide pandemic, which further proves that anthropogenic activities might affect air quality in Katsina City.

In the study, the concentration profile of AOD of Katsina City, Nigeria is presented in Table 1. The month of August has reported to experience the least pollution throughout the study period, while the month of February experienced it most, with February, March, April and December also having high values. This pollution can be attributed to the harmattan season that is accompanied with dust coming from the Sahel region of Africa. Alongside dust from the Sahel region, Katsina is a major city that is characterized with a lot of anthropogenic pollutions.

Figure 3 and 4 shows the mean monthly and inter-annual variation of aerosol optical depth for the period of the study. From Figure 3 and 4, we can observe the mean monthly trend of AOD and also its mean inter annual variation. From Figure 3, we can observe that AOD was prominent in the dry months and deep at the rainy months and peak again at the harmattan months.

Table 1. AOD Statistics over Katsina City, Nigeria.

Statistics	Mean	Variance	Standard Deviation	Skew	Kurtosis
2002	0.6785	0.135524	0.368135	0.301665	-0.98483
2003	0.498917	0.055251	0.235056	1.402309	3.537597
2004	0.68475	0.257128	0.507078	1.464256	1.880897
2005	0.638583	0.136025	0.368816	0.253562	-1.10949
2006	0.614333	0.139182	0.37307	0.657127	-0.84618
2007	0.747333	0.177478	0.421281	1.162996	1.322698
2008	0.689667	0.14908	0.386109	1.35368	3.360044
2009	0.62	0.097365	0.312034	1.251812	1.511555
2010	0.61875	0.174544	0.417785	1.295021	1.323099
2011	0.57925	0.055922	0.236478	-0.04367	-0.8375
2012	0.5385	0.104826	0.323768	1.008787	2.21786
2013	0.4695	0.032669	0.180745	-0.61509	0.471629
2014	0.434583	0.017577	0.132579	-0.09293	0.706473
2015	0.7695	0.226582	0.476006	1.134802	0.437805
2016	0.631	0.116967	0.342004	0.457115	-0.0066
2017	0.57125	0.055987	0.236615	0.258235	-1.00642
2018	0.540167	0.089625	0.299375	0.697379	0.954888
2019	0.443917	0.059246	0.243406	0.356865	-1.21648
2020	0.512917	0.09286	0.30473	1.228121	2.772165
2021	0.539417	0.10899	0.330136	1.344691	2.619084
2022	0.535167	0.155758	0.394662	1.629185	2.790313

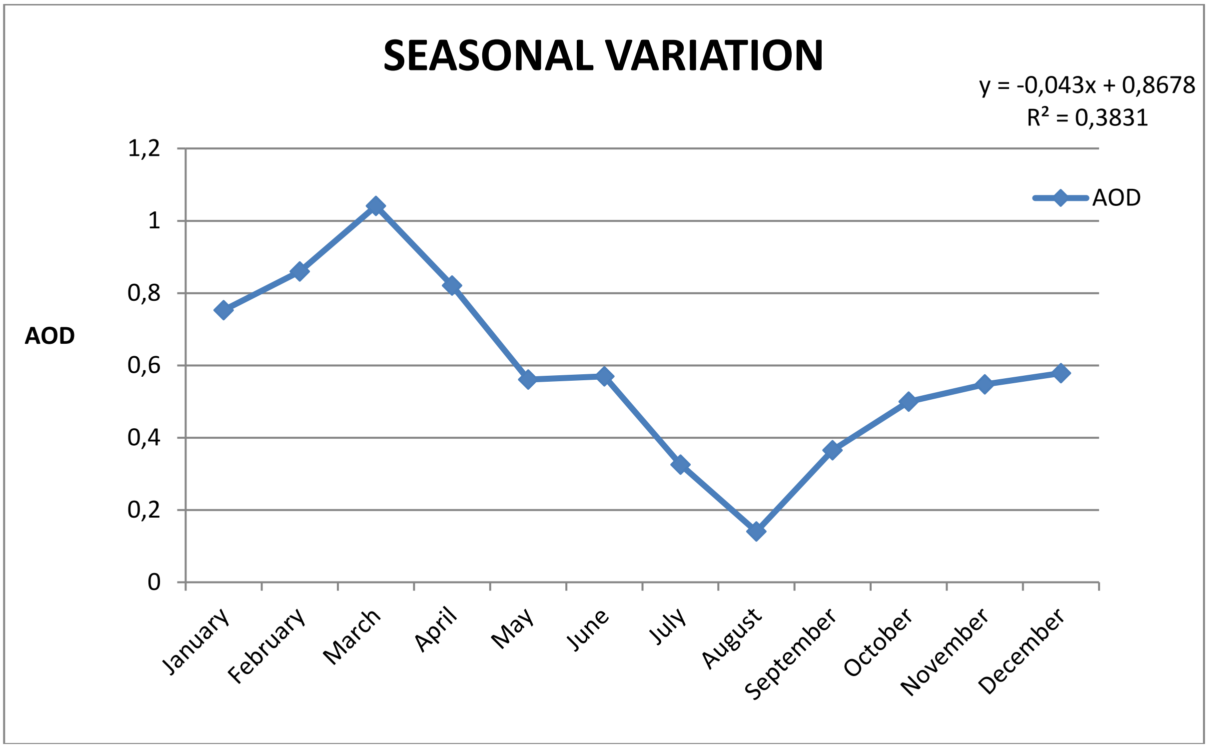

Figure 3. Seasonal Variation of AOD.

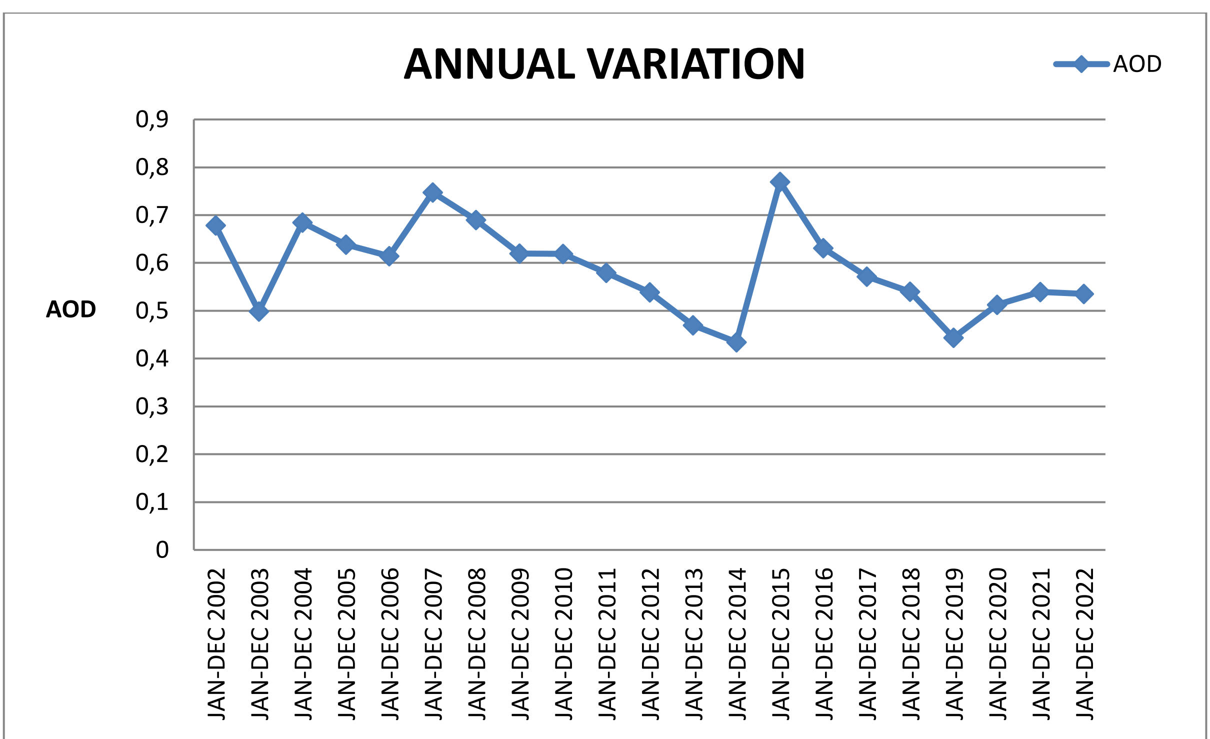

Figure 4. Annual Variation of AOD.

3. 2. Analysis of Rainfall

Rainfall variability in Nigeria is characterized by significant regional differences and trends influenced by climatic factors[15, 16]. This study indicates that for the study location, December to February experienced no rainfall, while March and November experienced very little rainfall.

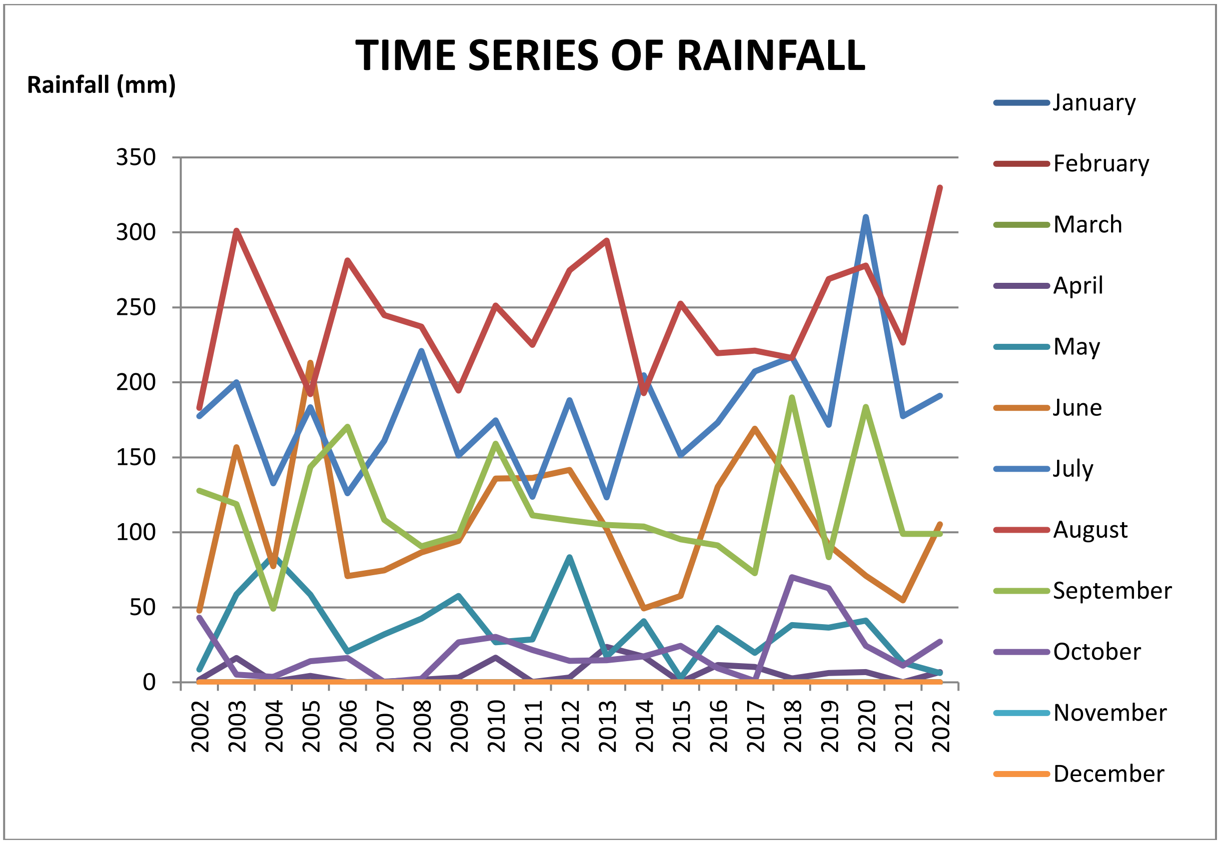

Figure 5. Rainfall Time Series (2002-2022).

It is observed that during the study period, Katsina city has experienced rainfall from April-October. Whereas the rainfall pattern in the month of April for all study year has being minimal, it can be observed that rainfall were at its most in the month of August whereas other months experienced heavy rainfall as well. It has also being studied that rainfall patterns are affected by global sea surface temperature anomalies and oscillations that have affected Northern Nigeria, where the study location is located.

The study also reported that Katsina has experienced an annual rainfall of above 500 mm over the study period, with year 2021 experiencing the least annual rainfall with 581.9 mm and the year 2020 experiencing the most rainfall with 915.6 mm.

It can be observed from Figure 4 that 2020 (pandemic year) experienced the least pollution and also we can also observed a pattern as rainfall was experienced most in 2020 (Figure 7). Figure 6 and Figure 7 shows the monthly variation and annual variation of rainfall patterns over the study location.

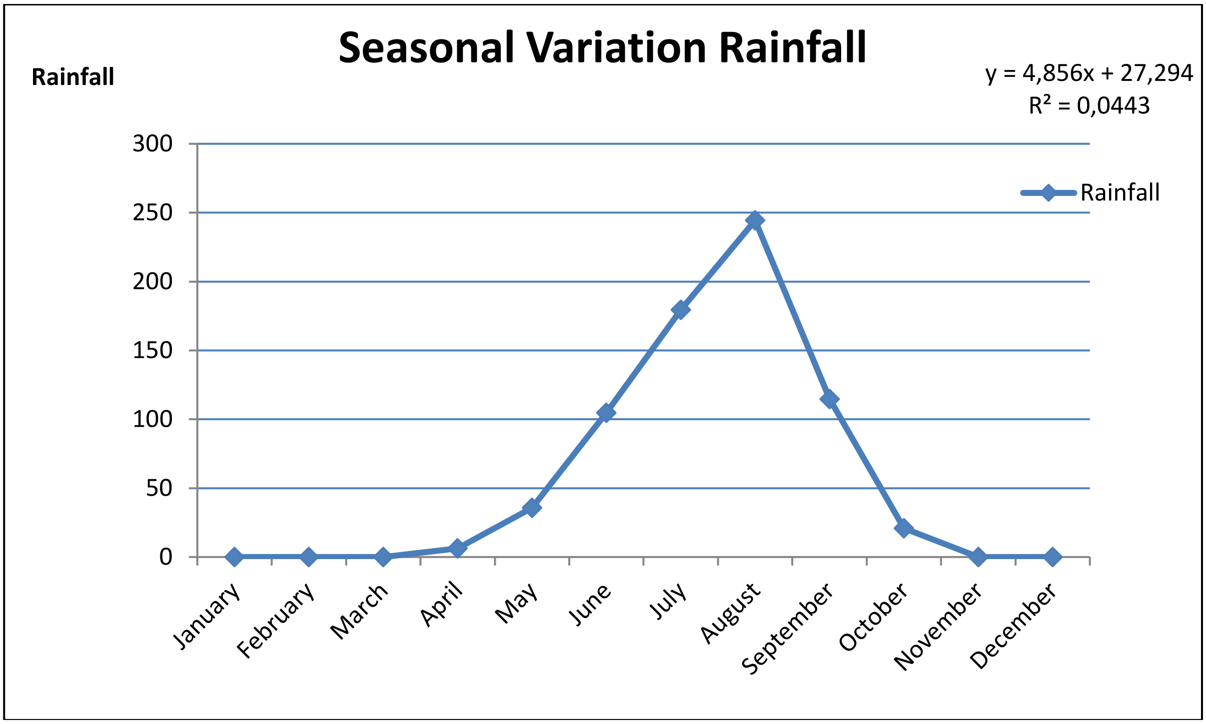

Figure 6. Monthly Distribution of Rainfall (2002-2022).

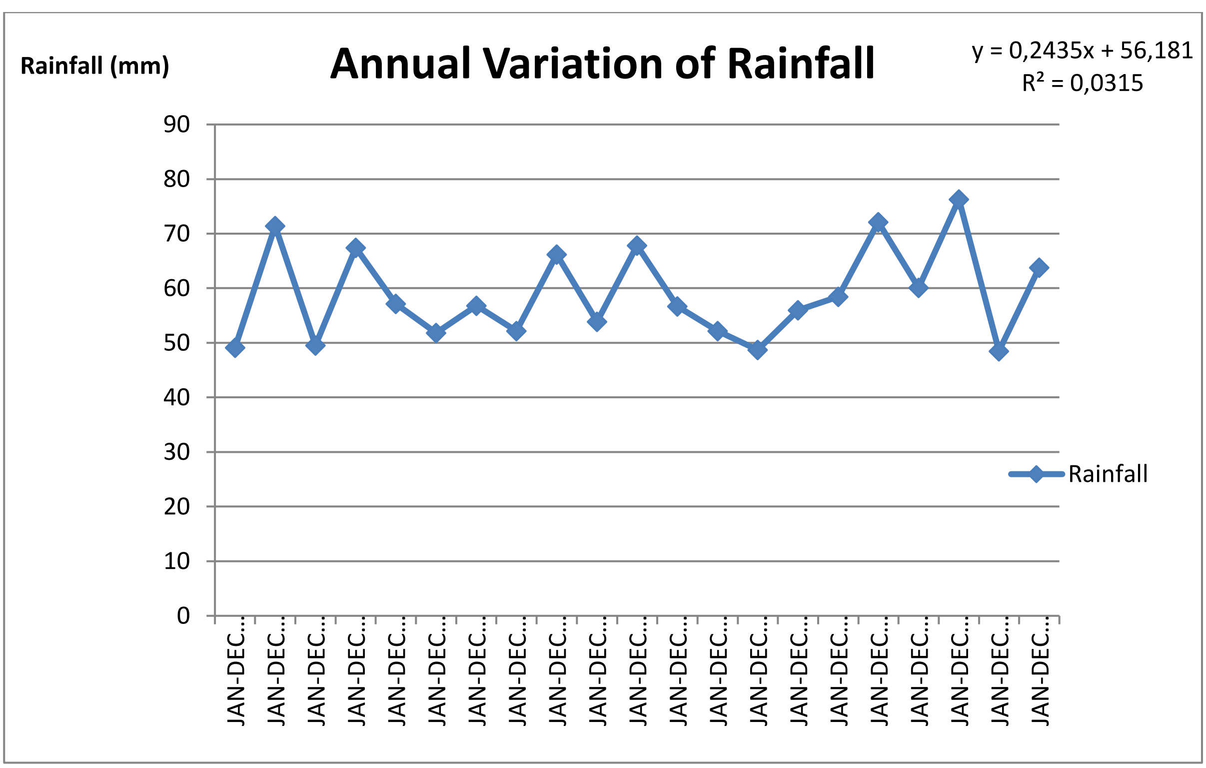

Figure 7. Inter-Annual Distribution of Rainfall Pattern (2002-2022).

3. 3. Analysis of Temperature

Temperature variability in Nigeria has been characterized by significant upward trends across various eco-climatic zones, with implications for agriculture and environmental sustainability[17, 18]. Studies indicate an average increase in surface air temperatures of approximately 0.036 °C per year, leading to projections of a 4.3 °C rise by the year 2100[19].

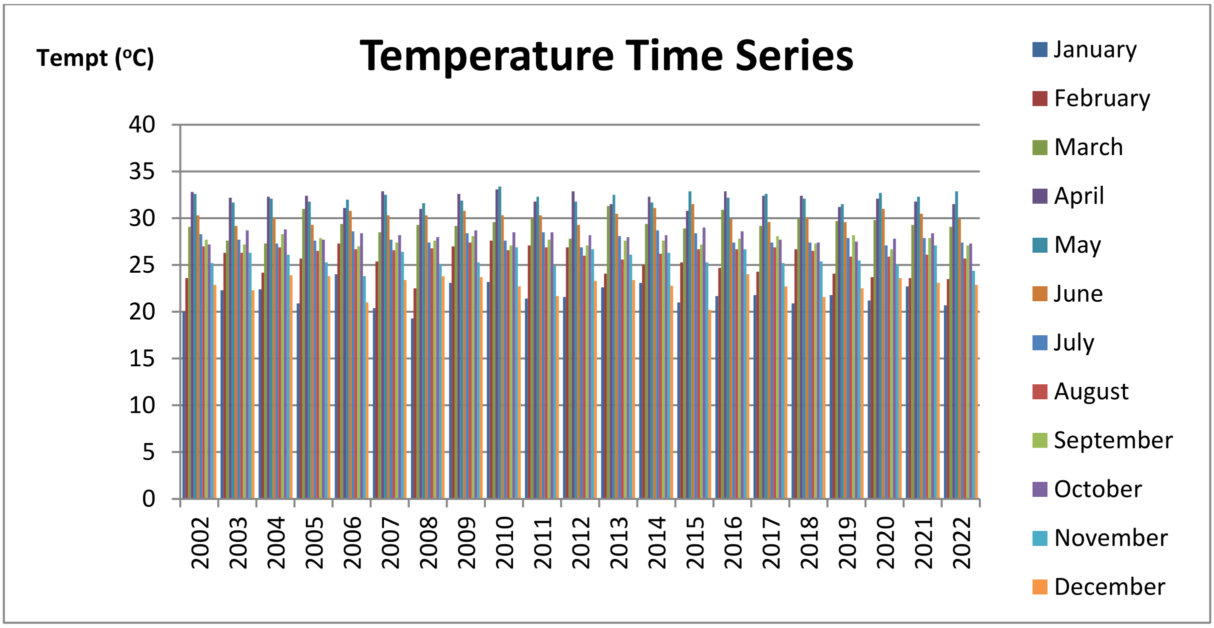

Figure 8. Time Series of Temperature (2002-2022).

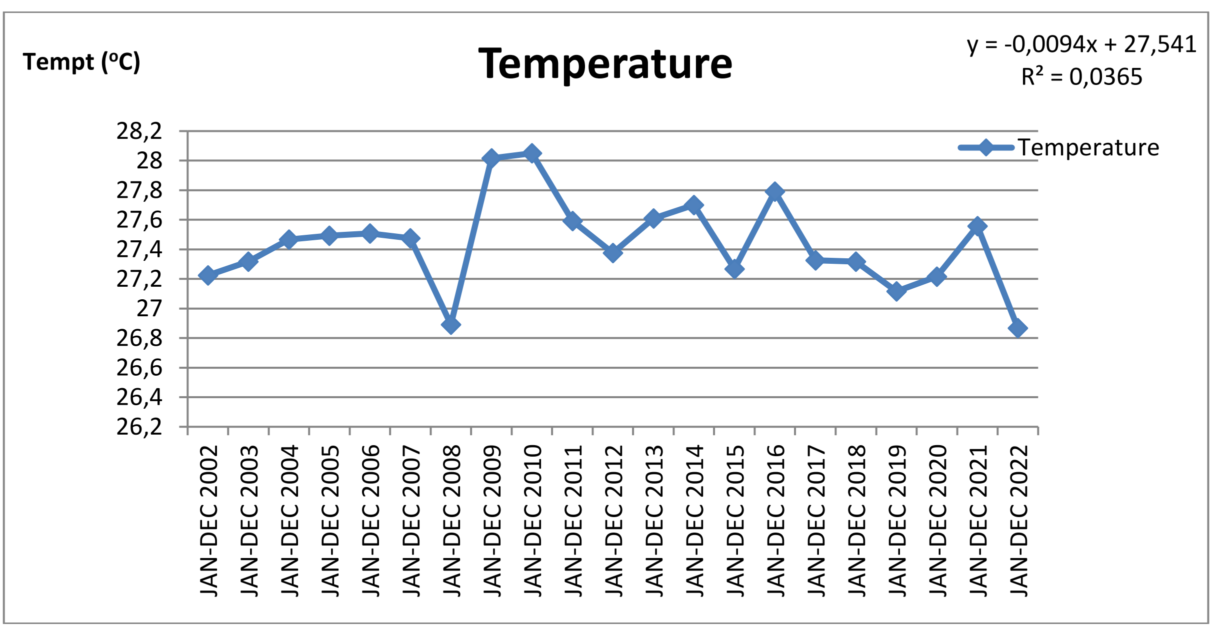

Figure 9. Inter-Annual Variation for Temperature (2002-2022).

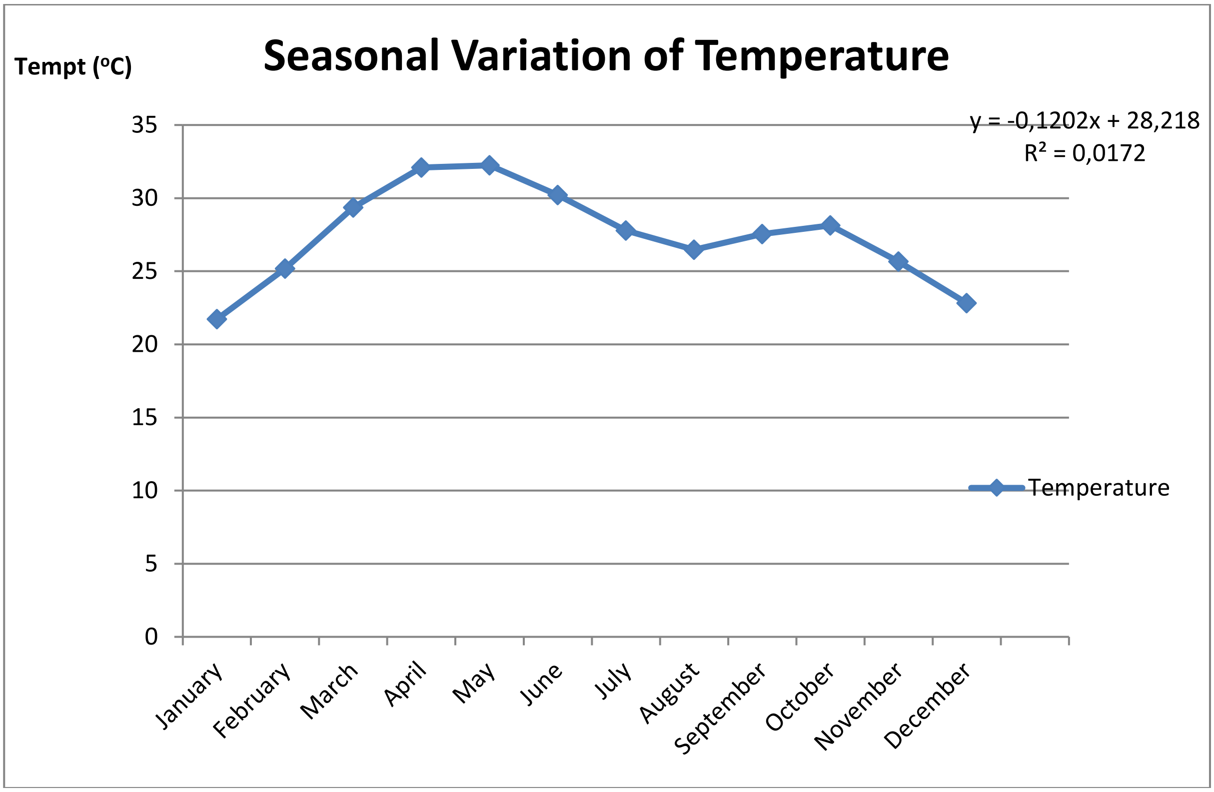

Figure 10. Mean Monthly Variation of Temperature (2002-2022).

In Figure 8 above, it can be observed that between December –January can be considered to have experienced a cooler temperature while months like March-June and some part of July have been generally hot. The months of July-September had a varying temperature between hot and cool, we also observe from Figure 5 above that these months are at the peak of rainfall.

In Figure 9, we can observe a consistent upward trend in the annual temperature pattern of above 300 °C. We can also observe that the annual temperature was hotter in 2016. We can also observe the mean monthly variation of temperature during the study period in Figure 10 where the average temperature per month is above 20 °C during the study period over the location.

3. 4. Correlation between Aerosol Optical Depth and Climatic Parameters

The evaluation of correlation between AOD and climatic parameters (rainfall and precipitation) for Katsina City, Nigeria, for a period of 10 year (2013-2022), was carried out to unravel the effects of aerosol on the meteorological variables or the other way round.

Figure 11 shows the relationship between aerosol and rainfall. The study evaluated a correlation coefficient of -0.8097 between aerosol optical depth and rainfall. The value indicates a strong negative correlation, which means that as the concentration of aerosols in the atmosphere increases, the amount of rainfall tends to decrease. A possible reason for the negative correlation could be that aerosols can act as cloud condensation nuclei, which can affect cloud formation and precipitation. It can be implied from this study that aerosol can lead to more numerous but smaller cloud droplets, which can reduce rainfall efficiency.

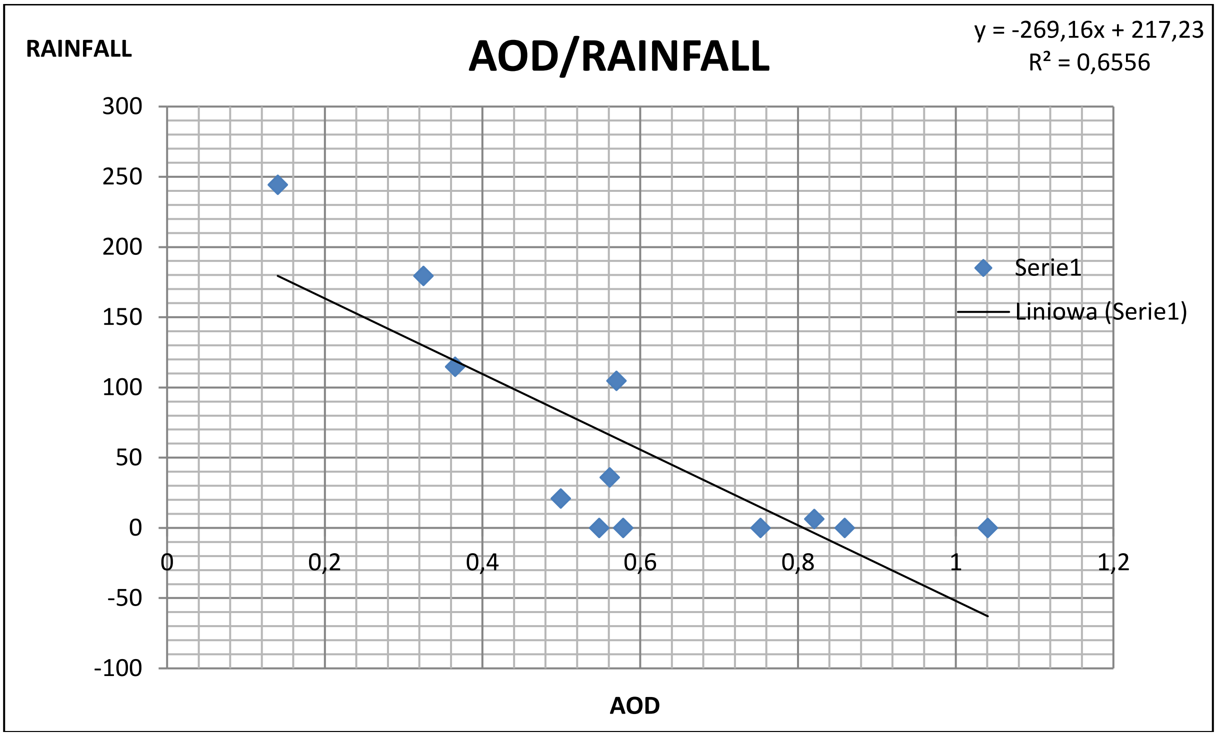

Figure 11. Relationship between rainfall and AOD.

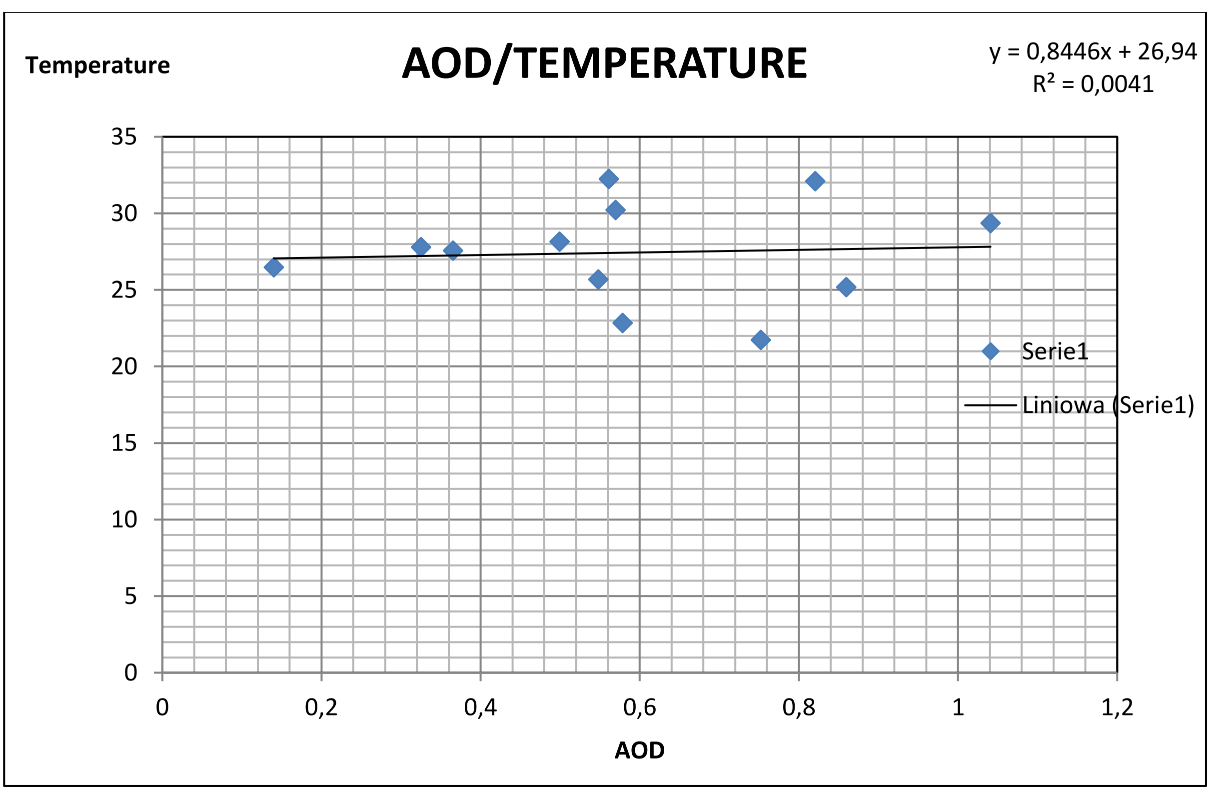

Figure 12. Relationship between Temperature and AOD.

The scattering and absorption of sunlight property of aerosol can affect the earth's energy balance. This can lead to changes in atmospheric circulation patterns and might influence rainfall patterns. The relationship between AOD and temperature was observed (Figure 12) and correlation coefficient of 0.064023 was evaluated. The value shows a weak positive correlation. This can be implied that there's a slight tendency for temperature to increases as AOD increases, but the relationship is not strong. This weak relationship, points to the fact that the relationship between AOD and temperature is complex and influenced by various factors, such as aerosol type, altitude, and local meteorological conditions.

4. CONCLUSIONS

This study analyzed the temporal variability of Aerosol Optical Depth (AOD), rainfall, and temperature in Katsina City, Nigeria, from 2002 to 2022. AOD exhibited pronounced seasonal variations, with higher values observed during the dry season, likely attributed to the influence of Saharan dust and local anthropogenic emissions. Rainfall patterns displayed distinct seasonal trends, concentrated between April and October. Correlation analysis revealed a significant negative relationship between AOD and rainfall, suggesting that increased aerosol loading may inhibit precipitation. This finding aligns with the understanding that aerosols can modify cloud microphysics, potentially leading to less efficient rain formation. However, the relationship between AOD and temperature was found to be weak, indicating that other factors likely exert a stronger influence on temperature variations in the study area. These findings highlight the importance of considering aerosol-cloud interactions and other atmospheric processes when studying climate variability and predicting future weather patterns. Further research is needed to fully understand the complex mechanisms driving these relationships and to improve our ability to model and predict the impacts of aerosols on climate and to assess the potential impacts of these findings on regional climate and air quality management.

References

[1] Li, J., Carlson, B.E., Yung, Y.L. *et al.* Scattering and absorbing aerosols in the climate system. *Nat Rev Earth Environ* 3, 363-379 (2022). https://doi.org/10.1038/s43017-022-00296-7

[2] Charlson, R. J. et al. Climate forcing by anthropogenic aerosols. *Science* 255, 423-430 (1992).

[3] Carter, S., & Chang, Y. (2023). Anthropogenic Contributions to Aerosol Radiative Effects. *Journal of Applied Meteorology,* 18(7), 672-689

[4] Dangayach, R., Pandey, A.K. (2024). Unraveling the Complex Relationships Between Aerosol Optical Depth and Temperature: A Review. In: Gautam, S., Kumar, R.P., Samuel, C. (eds) Aerosol Optical Depth and Precipitation. Springer, Cham. https://doi.org/10.1007/978-3-031-55836-8_1

[5] Zielinski, Tymon; Willems, Amandine; Lartigaud, Mathilde. (2024). Impact of biomass burning, wildfires, and wind events on aerosol optical depth: implications for climate change. *Applied Sciences* 14(13): 5633

[6] Brown, P. et al. (2020). Anthropogenic Particles and Cloud Dynamics. *Atmospheric Chemistry and Physics*, 23(9), 3421-3437

[7] Bell, S. (2020). Mitigation Strategies for Aerosol-Induced Climate Change. *Journal of Climate Solutions*, 19(6), 874-889

[8] Aturamu, O. A., Thompson, O. A., & Akintuyi, B. O. (2021). Forecasting the effect of climate variability on yam yield in rainforest and Guinea Savannah agro-ecological zone of Nigeria. *Journal of Global Agriculture and Ecology*, 11(4), 1-12

[9] Alexander, Chinago, Budnukaeku., Ojule, Soldier, Emmanuel. (2024). Historical Analysis of Climate Variability and Agricultural Production in Nigeria (1931-2020). *Journal of World Economy*, 3(3), 1-14. doi: 10.56397/jwe.2024.09.01

[10] Kalpana P, Prathibha S, Gopinathan P, Subramani T, Roy PD, Gautam S, Brema J (2020). Spatio-temporal estimation of rainfall patterns in north and northwestern states of India between 1901 and 2015: change point detections and trend assessments. *Arab J Geosci* 13: 1116

[11] Olawale, Emmanuel, Olayide., Tunrayo, Alabi., John, A., Oyedepo., R.U., Okechukwu. (2024). Assessing rainfall and extreme weather variability for climate resilient agricultural production systems in Nigeria. *Research Square* 1-31. DOI: https://doi.org/10.21203/rs.3.rs-3808332/v1

[12] Ibe, O.C., Nwofor, O.K. & Okoro, U.K. Aerosol loading in the guinea coast climate region of Nigeria: comparison of MODIS and AERONET data sources. *Discov Atmos* 2, 14 (2024). https://doi.org/10.1007/s44292-024-00018-2

[13] Ochei, M., Oluleye, A., Wolke, R. *et al.* Aerosols' variability and their relationship with climatic parameters over West Africa. *Environ Monit Assess* 195, 672 (2023). https://doi.org/10.1007/s10661-023-11204-x

[14] Offor, I. F., Adie, G. U., & Ana, G. R. (2016). Review of particulate matter and elemental composition of aerosols at selected locations in Nigeria from 1985-2015. *Journal of Health and Pollution*, 6(10), 1-18

[15] Ibebuchi, C.C., Abu, IO. Rainfall variability patterns in Nigeria during the rainy season. *Sci Rep* 13, 7888 (2023). https://doi.org/10.1038/s41598-023-34970-7

[16] Offor, I. F., Adie, G. U., & Ana, G. R. (2016). Review of particulate matter and elemental composition of aerosols at selected locations in Nigeria from 1985-2015. *Journal of Health and Pollution*, 6(10), 1-18

[17] Agbonaye, A. I., & Okonofua, E. S. (2024). Trends and spatial variability of climate change in Nigeria's coastal region. *Malaysian Journal of Civil Engineering*, 36(2), 19-32

[18] Olufemi, O. S., Joshua, M. I., & Salamatu, E. A. (2020). Assessment of temperature variability effect on rice production in Nasarawa State, Nigeria. *Int. J. Environ. Clim. Change*, 10, 91-100

[19] Franzke, C. L., Barbosa, S., Blender, R., Fredriksen, H. B., Laepple, T., Lambert, F., ... & Yuan, N. (2020). The structure of climate variability across scales. *Reviews of Geophysics*, 58(2), e2019RG000657