NATIONAL BOARD FOR TECHNICAL EDUCATION
NIGERIAN JOURNAL OF TECHNICAL EDUCATION
Volume 22 Nos. 1 2024
ISSN No. 2992-3522

DEVELOPING A TRIGONOMETRIC MODEL TO ESTIMATE AEROSOL OPTICAL DEPTH IN ILORIN, NIGERIA UTILIZING AERONET DATA

BY

[1]IBRAHIM, B.B. AND [2]ZUBAIR, R.O.

[1]Department of Science Laboratory Technology, Institute of Applied Sciences, Physics/ Electronics unit
[2]Department of Mathematics, Institute of General Studies
Kwara State Polytechnic, Ilorin.
Corresponding author: bb_fulani@yahoo.com,
Phone: +234 7063401453
ORCID NUMBER: 0000-0003-3679-6111

ABSTRACT

In the course of this research, we acquired Aerosol Optical Depth (AOD) data from the archive of AERosol Robotic NETwork (AeroNet) for Ilorin, Nigeria (latitude 8.32°N, longitude 4.34°E) spanning a period of 13 years from 2002 to 2014. We examined three distinct trigonometric models, namely Sine, Cosine, and Sine Cosine, using the R software package for analysis. To evaluate the performance of these models, we employed statistical error metrics, including the root mean square error (RMSE), mean bias error (MBE) and mean percentage error (MPE). Additionally, we calculated the correlation coefficient (R) and coefficient of determination (R^2) for each model. After thorough evaluation, it was observed that the Sine Cosine model outperformed the other models, exhibiting the highest values for both R and R^2, as well as the lowest RMSE. Therefore, we recommend the utilization of the Sine Cosine model for researchers engaged in air quality assessment and atmospheric studies.

Key Words: Aerosol, Aerosol Optical Depth, AERONET, Condensation Nuclei, Ilorin

INTRODUCTION

Aerosols encompass combination of solid and liquid particles, including elements like mist, dust, fog, industrial emissions, Man-made (anthropogenic) pollutants, and biological particles. These particles have a substantial impact on the balance of energy within the Earth's atmosphere (Glantz et al., 2019). The scientific community places significant importance on understanding the climatic and ecological effects of atmospheric aerosols, as they have wide-ranging consequences for air quality, human health, climate change, and the Earth's radiation budget (Tan et al, 2016). On a global scale, aerosols are estimated to induce a cooling effect on the Earth's system (Pataud & Acqua, 2014; Sharafa et al, 2020; Tian & Sun, 2016). Recent research has indicated that implementing aggressive air pollution reduction measures could lead to an accelerated global warming of approximately +1.0°C by 2030, in addition to +1.2°C attributed to rise in long-lived greenhouse gas abundances (Chen et al, 2014; Nwofor et al, 2007; Ruiz-Arias et al, 2014).To comprehend the immediate radiative influence of atmospheric aerosols, it is crucial to consider both their optical properties and non-aerosol characteristics, such as surface albedo and solar declination angle. These elements have a central role in shaping the Earth's radiation equilibrium. Because of the diverse sources and relatively short life spans of aerosols, their properties can vary signifi cantly both in terms of time and location. Moreover, aerosol optical properties exhibit variability on longer time scales, especially in regions closer to the equator (Lihavainen et al, 2017; More et al, 2013; Mu, 2014).

Emissions from burning agricultural biomass have become a noteworthy origin of different atmospheric contaminants, exerting adverse effects on quality of air at community, regional, and worldwide scales (Menut et al., 2016; Sharma et al., 2017; Zhu et al, 2017). These emissions occur over relatively short periods, spanning weeks to months, posing substantial challenges to quality of air and posing severe health risks to humans (Ibi et al., 2016; Shah et al, 2019; Sun et al, 2019).To evaluate the influence of human-made aerosols, including those arising from emissions resulting from the burning of agricultural biomass, on climate change and the radiation budget, researchers employ radiative forcing in coupled aerosol-chemistry-climate models (Butt et al., 2017; Tan et al., 2016; Zeb et al, 2019). These models aim to provide a more accurate representation of the physical, chemical, and optical properties of aerosols, which can differ over both space and period. However, due to significant uncertainties surrounding factors such as emission levels, dispersion, optical characteristics, and blending conditions of these aerosols, achieving precise estimations of their direct radiative impacts on a regional to worldwide scale remains highly uncertain. Additionally, it's important to mention that aerosols from biomass burning can effectively act as cloud condensation nuclei. This can impact the creation and life span of clouds, thus influencing the radiation balance in the troposphere.

Instrument failures are a common occurrence when dealing with AERONET data, and this frequently results in significant gaps in the series of Aerosol Optical Depth (AOD) data in Sub-Saharan West Africa, specifically at the Ilorin station. These gaps, sometimes spanning many days or even months, occur due to the need for equipment maintenance or servicing, which makes continuous data unattainable for meteorological and atmospheric studies (Nwofor and Chineke, 2007). To address the issues of instrument failures and data gap, we develop a model using available data from the AERONET archive to estimate AOD for the region to solve the persistent problems of the data series. The approach involved utilizing a Trigonometric Model for predicting AOD over the study area, allowing for a more comprehensive evaluating aerosol optical properties remains possible even when dealing with occasional data interruptions.

MATERIALS AND METHODS

Overview of the research location

The study site is located at the University of Ilorin in Nigeria, with specific coordinates of 8.50 degrees north latitude and 4.50 degrees east longitude, at an elevation of approximately 375 meters above sea level. Ilorin is situated in the Guinea Savannah area of West Africa, serving as a shift arealocated amidst the Guinea coast and the Sahel region of West Africa. Ilorin is positioned in the intermediary zone between the Sahara Desert and the savanna region of northern Nigeria, which leads to the presence of the dry and dusty Harmattan winds influencing the area. (Ginoux et al., 2010). To be more specific, Ilorin is located at the northern boundary of the Guinea savanna region, where the typical monthly temperature averages around 30.2degrees Celsius, and the annual rainfall averages approximately 873 millimeters(Falaiye et al., 2013).

Figure 1 shows (a) the map of Nigeria, (b) map of Ilorin and (c) map of the site respectively.

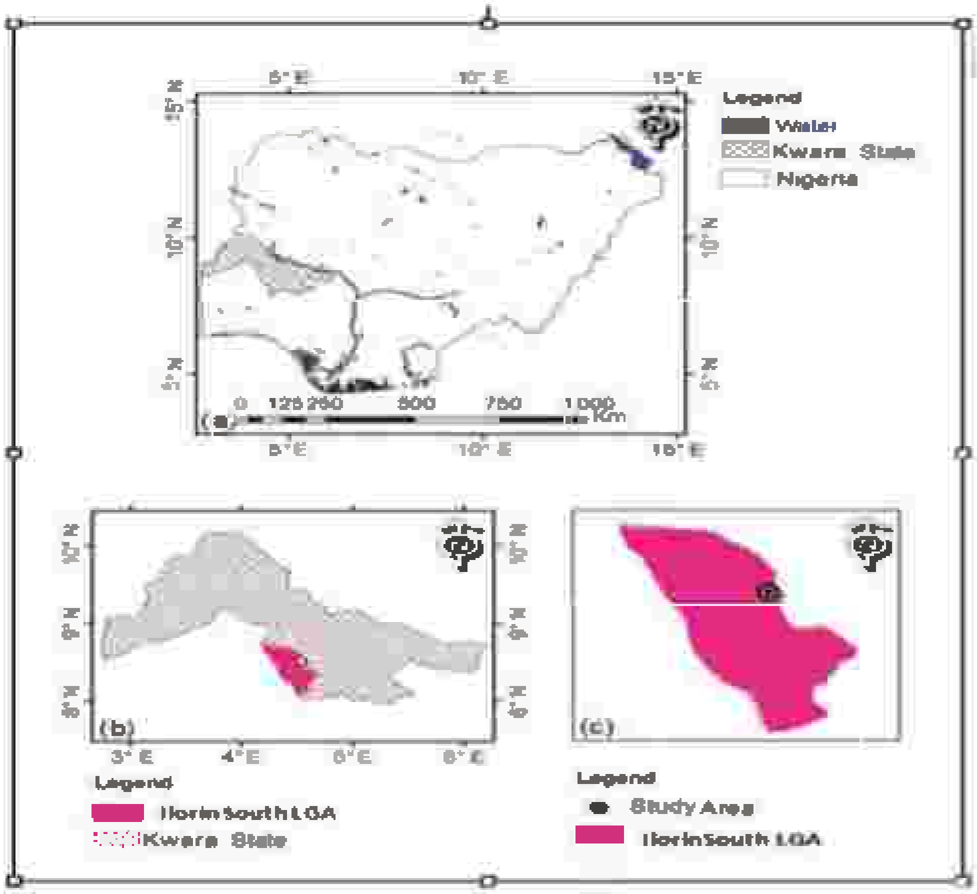

Figure 1Digitized maps: (a) Nigeria with Kwara State, (b) Kwara State with Ilorin SouthLGA, and (c)Ilorin SouthLGA with the study area.

AERONET is short for the AERosol Robotic NETwork, which consists of a network of CIMEL Sun Photometers. Since 1995, about twenty (20) stations have been set up in West Africa as part of the PHOTONS segment of the AERONET network. Each of these stations has been conducting observations for different periods and durations (Dubovik et al., 2010).A CIMEL Sun photometer is an automated radiometer designed for sun-sky scanning with filter capabilities. It allows for the measurement of direct solar irradiance at precise wavelengths: 340, 380, 440, 500,675, 870, 940, and 1020 nm. These photometers are solar-powered, sturdy, and capable of robotic pointing. The data gathered is sent to the NASA Goddard Space Flight Center using a satellite data telemetry antenna.

NASA performs initial processing of the real-time data, including the daily Aerosol Optical Depth (AOD) patterns at all operational wavelengths. The Aerosol Optical Depth (AOD) data is obtained using the ASTPwin software, developed by Cimel Ltd.Co. and is presented at various levels: Level 1.0 AOD (raw data without cloud screening), Level 1.5 AOD (AOD after cloud screening, following the method outlined by Smirnov et al., 2002), and Level 2 AOD (a quality-assured dataset)). Additionally, the Angstrom Exponent is computed between 440 and 870 nm.The information stored in the photometer's control box microprocessor is subsequently transmitted using a conical-shaped antenna to one of three geosynchronous satellites: GOES, METEOSTAT, or GMS. Afterward, this data is relayed to the relevant ground station for processing and is subsequently made available to the public on the internet at http://aeronetgsfcnasagov/. figure 2 offers a visual depiction of a standard AERONET CIMEL Sun-Photometer setup on a rooftop.

Figure 2: AERONET CIMEL Sun-photometer at block 9 of the faculty of physical science, University of Ilorin, Nigeria.

Model Development

We developed a straightforward mathematical model to estimate the monthly Aerosol Optical Depth (AOD) for Ilorin. This model is based on a trigonometric function and was designed to replicate the measured data over a 13-year span from 2002 to 2014. The function involves just one independent parameter, which is the month of the year. You can estimate the monthly AOD using the equation provided below:

$$Y = \bar{Y} + A\sin\left(\frac{2\pi t}{12}\right) + K \qquad (1)$$

$$Y = \bar{Y} + A\cos\left(\frac{2\pi t}{12}\right) + K \qquad (2)$$

$$Y = \bar{Y} + A\left[\left(\sin\frac{2\pi t}{12}\right) + \left(\cos\frac{2\pi t}{12}\right)\right] + K \qquad (3)$$

where t is the number of month starting from $t = 1$ for January 2002 and $t = 168$ for December 2014. $\bar{Y}$ Represents the monthly mean AOD for the whole period of years studied.

$$A = \frac{Y_{max} - Y_{min}}{2} \qquad (4)$$

$$K = \frac{Y_{max} + Y_{min}}{2} \qquad (5)$$

12 in the equations 1 to3 represents the total number of months in a year.

To fit the trigonometric functions and optimize their performance, we employed a computer software package called R. This involved making adjustments by subtracting a specific value from K and multiplying A by another value until we achieved the best possible fitness, as outlined in a custom-written R program (Husamettin, 2007). Subsequently, we utilized this model to make predictions for the data in the year 2015.

RESULTS and DISCUSSIONS

The model comprising the three trigonometric functions is expressed in the following equations.

$$Y = \bar{Y} + 075A\sin\left(\frac{2\pi t}{12}\right) + (K - 0.78) \qquad (6)$$

$$Y = \bar{Y} + 0.75A\cos\left(\frac{2\pi t}{12}\right) + (K - 0.78) \qquad (7)$$

$$Y = \bar{Y} + 0.6A\left[\left(\sin\frac{2\pi t}{12}\right) + \left(\cos\frac{2\pi t}{12}\right)\right] + (K - 0.78) \quad (8)$$

where $\bar{Y} = 0.7744$, $A = 0.6905$, $K = 0.9841$.

The plots of the measured and predicted data for the three trigonometric functions is presented in Figure 3 to 5 for sine, cosine and sine + cosine model respectively. Table 1 presents the observed and forecasted data for the three trigonometric models in 2015.

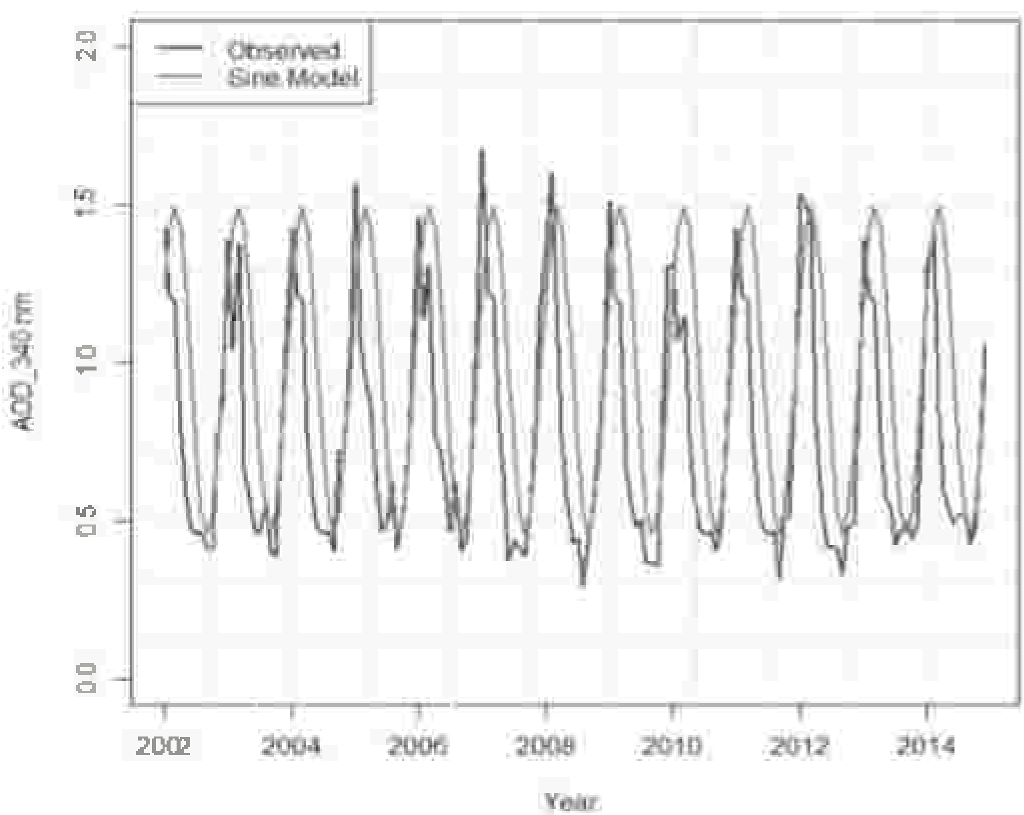

Figure 3: Time series chart illustrating the measured and forecasted AOD at 340 nm for the sine model.

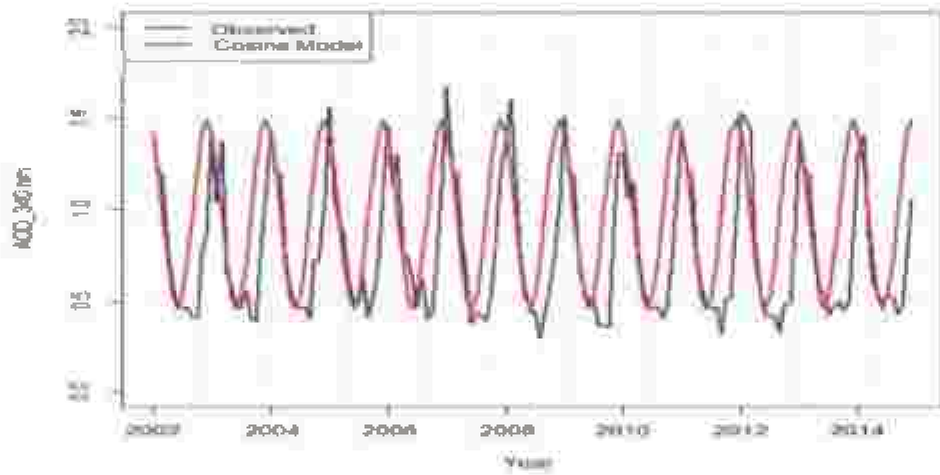

Figure 4: Time series chart illustrating the measured and forecasted AOD at 340 nm for the Cosine model.

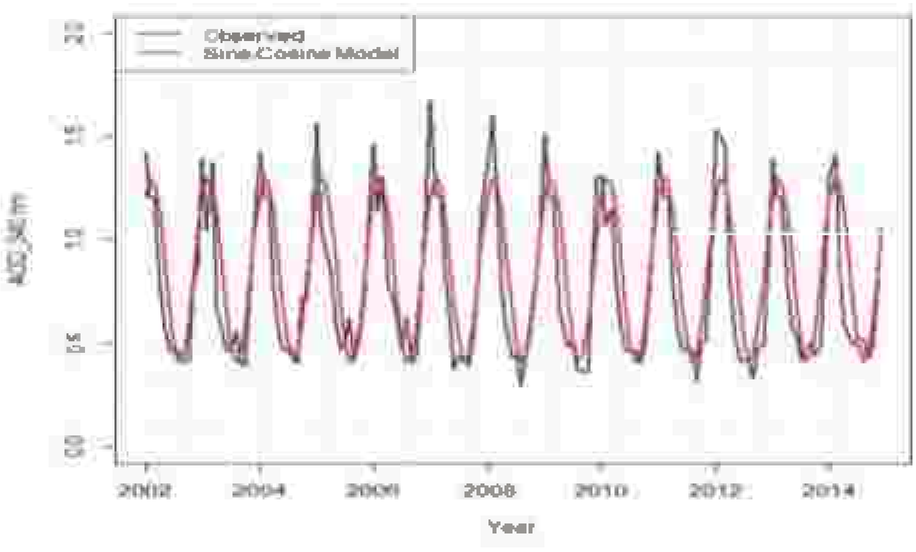

Figure5: Time series chart illustrating the measured and forecasted AOD at 340 nm for the sinecosine model.

Table 1: Measured and Predicted AOD at 340 nm for 2015 for Ilorin

2015 Forecast	Sine Model	Cosine Model	SineCosine Model	Measured 2015
Jan	1.2347256	1.5737983	1.2786702	1.119353
Feb	1424292	1.3210431	1.3393314	1053027
Mar	1.4936781	09757731	12705431	1.120758
Apr	1424292	0.6305031	1090737	1.122485
May	12347256	0.377748	0848092	0.639123
Jun	0.9757731	0.2852331	06076247	0.547588
Jul	07168206	0.377748	0433768	0474944
Aug	05272543	0.6305031	03731068	0487607
Sep	0.4578681	09757731	04418951	0.364249
Oct	05272543	1.3210431	0.6217012	0432197
Nov	07168206	1.5737983	08643462	0.581512
Dec	0.9757731	1.6663131	1.1048135	1.164366

Table 2: Regression Equation and Statistical Metrics

Equations	R	R^2	MBE	MPE	RMSE
$Y = \bar{Y} + 0.75A\sin\left(\frac{2\pi t}{12}\right) + (K - 0.78)$	0835	0.914	0.019	-272	0296
$Y = \bar{Y} + 0.75A\cos\left(\frac{2\pi t}{12}\right) + (K - 0.78))$	0404	0636	0.217	43.05	0.259
$Y = \bar{Y} + 0.6A\left[\left(\sin\frac{2\pi t}{12}\right)\left(\cos\frac{2\pi t}{12}\right)\right] + (K - 0.78)$	0924	0962	0.097	-14.35	0.163

The results, as shown in Table 2, reveal important statistical indicators for our models. For the sine model, we observed a correlation coefficient of 0.835 between AOD and the months of the year, with a coefficient of determination (R^2) of 0.914. This signifies that 91.4% of the AOD can be explained by considering the months of the year. On the other hand, the cosine model demonstrated a lower correlation coefficient of 0.404 between AOD and the months of the year, with an R^2 value of 0.636. This suggests that 63.6% of the AOD variation can be attributed to the months of the year when using the cosine model. However, the sine cosine model exhibited the most promising results, with a high coefficient of determination (R^2) of 0.962. This implies that a substantial 96.2% of the AOD can be accounted for by considering the months of the year within this model. These findings indicate that the sine and sine cosine models are the most suitable for describing the data. Furthermore, it's important to note that the sine cosine model outperforms the sine model, as the R^2 value for the former is greater, and the root mean square error (RMSE) is lower. Nevertheless, it's worth mentioning that the mean bias error (MBE) and mean percentage error (MPE) for the sine model are closer to zero compared to the sine cosine model. Visualizing the results in Figure 6 to 8, it becomes evident that the sine cosine model provides the best fit for the AOD data for Ilorin in 2015.

CONCLUSION

We collected monthly Aerosol Optical Depth (AOD) data spanning a period of thirteen years, from 2002 to 2014, from the AERONET archive for Ilorin. Subsequently, we employed the R software package to fit various trigonometric functions to this dataset. Through our analysis, we developed three simple trigonometric models, all of which demonstrated excellent predictive capabilities when compared to the actual measured data. After a thorough assessment using statistical indicators, it became evident that the Sine Cosine Model provided the most accurate description of the correlation between AODand the months of the year

Acknowledgement

I extend my gratitude to the Principal Investigators of the Ilorin AERONET station and their committed personnel for their dedication in creating and sustaining this station.

REREFRENCES

Butt, M. J., Assiri, M. E., & Ali, M. A. (2017). Assessment of AOD variability over Saudi Arabia using MODIS Deep Blue products. *Environmental Pollution*, *231*,143–153. https://doi.org/ 10.1016/j.envpol .2017.07. 104

Chemistry, A., Atmospheric, P., & Techniques, M. (2013). *Effective aerosol optical depth from pyranometer measurements of surface solar radiation (global radiation) at Thessaloniki, Greece*. 3733–3741. https://doi.org/10.5194acp-13-3733-2013

Chen, J., Xiao, B., Chen, C., Wen, Z., & Jiang, Y. (2014). Journal of Atmospheric and Solar-Terrestrial Physics Estimation of monthly-mean global solar radiation using MODIS atmospheric product over China. *Journal of Atmospheric and Solar-Terrestrial Physics*,*110–111*, 63–80. https://doi.org/10.1016/ j.jastp.2014.01.017

Dubovik, O., Smirnov, A., Holben, B. N., King, M. D., Kaufman, Y. J and Slutsker, I. (2000). Accuracy assessments of aerosol optical properties retrieved from AERONET sun and sky radiance measurements, *Journal of Geophysical Research*, **105**: 9791 –9806.

Falaiye, O., Yakubu, A., Aweda, F., & Abimbola, O. (2013). Mineralogical characteristics of harmattan dust in ilorin, sub-sahara africa.*Ife Journal of Science*, *15*(1), 175–181.

Fawole, O.G., Cai, X., Levine, J.G., Pinker, R. T., & MacKenzie, A. R. (2016). Detection of agas flaring signature in the AERONET optical properties of aerosols at a tropical station in West Africa. *Journal of Geophysical Research*, *121*(24), 14513–14524. https://doi.org/10.1002/2016JD025584

Ginoux, P., Garbuzov, D., & Hsu, N. , (2010). Identification of anthropogenic and natural dust sources using Moderate resolution Imaging Spectrometer (MODIS) deep blue level2 data. D 5204. *Journal of Geophysical Research*, *115*(*D01*)(5204), 1–10. https://doi.org/10.1029/2009JD012398

Glantz, P., Freud, E., Johansson, C., Noone, K.J., & Tesche, M. (2019). Trends in

MODIS and AERONET derived aerosol optical thickness over Northern Europe. *Tellus, Series B: Chemical and Physical Meteorology, 71*(1), 1–21. https://doi.org/10.1080/16000889.2018.1554414

Ibi., H.U.B., Lam, K. H. A.N. A., Laschke, T. H.B., & Ibi., S.A.B. (2016). *Long-term (2007 – 2013) analysis of aerosol optical properties over four locations in the Indo-Gangetic plains. 55*(23).

Lihavainen, H., Alghamdi, M. A., Hyvärinen, A., Hussein, T., Neitola, K., Khoder, M., ... Almehmadi, F. M. (2017). Aerosol optical properties at rural background area in Western Saudi Arabia. *Atmospheric Research, 197*(November 2016), 370-378. https://doi.org/10.1016/j.atmosres.2017.07.019

Menut, L., Siour, G., Mailler, S., Couvidat, F., Bessagnet, B., Dynamique, D.M., ... Atata, P. F. (2016). *Observations and regional modeling of aerosol optical properties, speciation and size distribution over Northern Africa and western Europe. 5*, 12961–12982. https://doi.org/10.5194/acp-16-12961-2016

More, S., Kumar, P. P., Gupta, P., Devara, P. C. S., & Aher, G. R. (2013). *Comparison of Aerosol Products Retrieved from AERONET, MICROTOPS and MODIS over a Tropical Urban City, Pune, India.* 107–121. https://doi.org/10.4209/aaqr.2012.04.0102

Mu, T. (2014). *Influence of water uptake on the aerosol particle light scattering coefficients of the Central European aerosol. 1*, 1–14.

Nwofor, O.K., Chineke, T. C., & Pinker, R. T. (2007). Seasonal characteristics of spectral aerosol optical properties at a sub-Saharan site. *Atmospheric Research, 85*, 38–51. https://doi.org/10.1016/j.atmosres.2006.11.002

Nwofor, OK. and Chineke, OK. (2007). **Mathematical** representation of seasonal cycles of aerosol optical depths at Ilorin Nigeria using AERONET data. *Global Journal of Pure and Applied Sciences* 3 (1):285-293.

Putaud, J.P., Cavalli, F., Santos, S. M., & Acqua, A. D. (2014). Long-term trends in aerosol optical characteristics in the

Po Valley, Italy. *Atmospheric Chemistry and Physics Chem. Phy*,9129–9136. https://doi.org/10.5194/acp-14-9129-2014

Ruiz-Arias,J. A., Dudhia, J., & Gueymard,C. A. (2014). A simple parameterization of the short-wave aerosol optical properties for surface direct and diffuse irradiances assessment in a numerical weather model. *Geoscientific Model Development*, *7*(3), 1159–1174. https://doi.org/10.5194/gmd-7-1159-2014

Sayer, A. M., Smirnov, A., Hsu, N.C., Munchak, L. A., & Holben, B. N. (2012). Estimating marine aerosol particle volume and number from Maritime Aerosol Network data. *Atmospheric Chemistry and Physics*, *12*(18), 8889–8909. https://doi.org/10.5194/acp-12-8889-2012

Shah, Z., Suo, H., Liu, M., Ma, L., Alam,K., Gul,A., ... Bahadar, S. (2019). Aerosol clustering in an urban environment of Beijing during (2005 – 2017). *Atmospheric Environment*, *213*(May), 534–547. https://doi.org/101016/j.atmosenv.2019.06027

Sharafa, S. B., Aliyu, R., Ibrahim, B. B., Tijjani, B.I., Darma,T. H, Gana, U. M., ... Tete,K. A.N., OS(-2020). MODEL PREDICTION AND CLIMATOLOGY OF AEROSOL OPTICAL DEPTH(τ 550) AND ANGS TROM EXPONEN T(α 470-660)OVER THREE AEROSOL ROBOTIC NETWORK STATIONS IN SUB-SAHARAN AFRICA USING MODERATE RESOLUTION IMAGING SPECTRORADIOMETER DATA. *Nigeria Journal of Technology*, 39(1),255–268.

Sharma,D.,Srivastava, A.K., Ram, K., Singh, A., & Singh, D.(2017). Temporal variability in aerosol characteristics and its radiative properties over Patiala , northwestern part of India : Impact of agricultural biomass burning emissions *. *Environmental Pollution*, *231*, 1030–1041. https://doi.org/101016/j.envpol2017.08.052

Smirnov, A., Holben, B. N., Dubovik, O., O'Neill,N.T.,Eck, T. F.,Westphal, D. L., ... Slutsker, I. (2002). Atmospheric Aerosol Optical Properties in the Persian Gulf. *Journal of Atmospheric Science*, *59*,620–634.

Sun,T., Che, H., Qi, B., Wan g, Y., Dong, Y., Xia,X., ..., Zhang,X. (2019). Science of the Total Environment Characterization of vertical distribution and radiative forcing of ambient aerosol over the Yangtze River Delta during 2013 – 2015. *Science of the Total Environment, 650*, 1846–1857. https://doi.org/10.1016/j.scitotenv.2018.09.262

Tan, F., Lim, H. S., Abdullah, K., & Holben, B. (2016). Estimation of aerosol optical depth at different wavelengths by multiple regression method. *Environmental Science and Pollution Research, 23*(3), 2735–2748. https://doi.org/10.1007/s11356-015-5506-3

Tian,X., peng, & Sun, L. (2016). Retrieval of aerosol optical depth over arid areas from MODIS data. *Atmosphere, 7*(10), 1–16. https://doi.org/10.3390/atmos7100134

Tirelli, C., Manzo, C., Curci, G., & Bassani, C. (2015). Evaluation of the aerosol type effect on the surface reflectance retrieval using CHRIS/PROBA images over land. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives, 40*(7W3), 1311–1316. https://doi.org/10.5194/isprsarchives-XL-7-W3-1311-2015

Zeb, B., Alam, K., Sorooshian, A., Chishtie, F., Ahmad, I., & Bibi, H. (2019). Temporal characteristics of aerosol optical properties over the glacier region of northern Pakistan. *Journal of Atmospheric and Solar-Terrestrial Physics, 186*, 35-46. https://doi.org/10.1016/j.jastp.2019.02.004

Zhu, J., Xia, X., Wang, J., Che, H., Chen, H., Zhang, J., ..., Ayoub, M. (2017). Evaluation of Aerosol Optical Depth and Aerosol Models from VIIRS Retrieval Algorithms over North China Plain. *Remote Sensing, 9*(432), 2–18. https://doi.org/10.3390/rs9050432