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Research Article

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Seasonality of Atmospheric Aerosols and Prediction Using Classical Decomposition Modeling

Abidina Bello[1]*, Musa H. Mahmud[2a], Muhammad Z. Ahmad[2b], Salisu Mohammed[2c]

[1*,2a,2b]Department of Scientific and Industrial Research, National Research Institute for Chemical Technology (NARICT), Zaria, PMB 1052, Kaduna State, Nigeria
[2c]Department of Pilot Plant and Fabrication Technology, National Research Institute for Chemical Technology (NARICT), Zaria, PMB 1052, Kaduna State, Nigeria.
*(Email: abideenbello45@yahoo.com)

Abstract AERONET is one of the global sources of data that provides useful information on aerosol climatology. In this work, level 2.0 of the Aerosol Optical Depth (AOD) data at 440nm and Angstrom_440nm-870nm (α) were retrieved from Ilorin AERONET data base between 1998 and 2008. Both the AOD and the Angstrom were analyzed based on their overall magnitude of occurrence. Furthermore, the seasonality of each of the AOD and α was also analyzed according to Harmattan and summer seasons. Finally, classical decomposition technique was employed to predict the occurrence of the AOD in 2009. The results show that there exists a varying magnitude of aerosol loading within the range of $0.5 < \text{AOD} \leq 1.5$ with higher loading during harmattan. It also shows the existence of different aerosol particle sizes within the range of $0.3 \leq \alpha \leq 1.3$ with lower particle size during summer. The decomposition model used to predict the loading in 2009 was found to have given a decent prediction.

Keywords Aerosols, AOD, Angstrom, particle size

Introduction

Aerosols emission is one of the major sources of global environmental challenges, responsible for acute and chronic human ailments and climate change [1]. It comprises of different substances, including dust from the Sahara; smoke from biomass, fossil fuel and vehicular emission; organic matter; gas pollutants and airborne particles [2]. Aerosols are commonly defined as tiny particles (solid, liquid) suspended in air [3].

Some typical ways through which aerosols can cause weather and climate changes are through radiative forcing, cloud modification and visibility impairment [3]. This is in addition to the many health effects, particularly in the role they play in causing respiratory and cardiovascular diseases [4, 5]. Recent studies have identified aerosol droplets as the major carriers of SARS-CoV-2, which had been declared as a global pandemic [6].

In order to monitor and keep track the global record of aerosol emission, many organizations have developed strategies of monitoring and documenting data of different aerosol parameters. For instance, National Aeronautics and Space Administration (NASA) had come up with Aerosol Robotic Network (AERONET), with over 400 ground based sun-photometer observatory stations for accurate retrieval of aerosol optical depth (AOD), angstrom exponent (α), single scattering albedo (SSA) and aerosol particle size distribution (PSD), by taking into account direct solar measurement and scattering measurement [7, 8].

Aerosols vary greatly based on, not only geographic locations, but also human activities that lead to aerosols generation [9]. For instance, [9] have found some discrepancies between the AOD data retrieved from Beijing and that from Xianghe AeroNet sites, even though the two locations belong to the same region. This prompted the need to have regional and even local aerosol observatories.

Despite all the effort being made to monitor the global aerosol emission, Nigeria suffers greatly from the shortage of aerosol monitoring facilities, which resulted in very limited amount of information available regarding aerosols. This makes it difficult for policy makers in the country to formulate effective and workable mitigation and management strategies for dealing with the unwanted effects of aerosols. In the light of this, any effort to boost a proper understanding of aerosol trend pattern, variability and types can be a highly regarded.

Ilorin is located in Kwara State in the north central part of Nigeria. It is located on latitude 8.48° N, longitude 4.67° E and elevation of 400 m above sea level. It is the only location with AERONET data station in the country [10].

AOD is the extinction or attenuation of solar radiation in a given column of air, reaching the ground from top of the atmosphere, at any point of time, at a specific wavelength of irradiance, due to aerosol loading [11]. The magnitude of AOD signifies the prevalence of aerosol in a given area. The AOD for each band is calculated under direct sun radiance at cloud-free conditions by eliminating gaseous absorption, and molecular scattering as, thus [9]:

$$\tau_{aerosol}\,(\lambda) = \tau_{total}\,(\lambda) - \tau_{gas}\,(\lambda) - \tau_{molecular}\,(\lambda) \qquad (1)$$

Angstrom exponent (α) is regarded as a measure to determine aerosol size; it has been used to discriminate various aerosol types and it is estimated by using two wavelengths, 870 nm and 440 [9, 12 & 13]

$$\frac{\tau_{870}}{\tau_{440}} = \left(\frac{870}{440}\right)^{-\alpha} \qquad (2)$$

In this paper, we analyzed the ten years worth of AOD and α data in the study area. The analyses were done based on two seasons, namely; rainy (April-October) season and harmattan season (November-March). We also employed classical decomposition technique to fragment the AOD data into its seasonal and trend components. At the end of the paper, we made a one year prediction of the AOD data via the classical multiplicative decomposition technique.

Data and Methods

Ten years worth of level 2.0 of AOD_440 and Angstrom_440-870 data were retrieved from AERONET site using the Standard Algorithm for retrieving aerosol climatology. The data were checked and prepared for use. The overall and seasonal relative frequency of the AOD_440 data as well as that of the Angstrom_440-870 was computed and plotted. This procedure is adopted from [2]. The time-series data was plotted and decomposed into seasonal and trend component using classical multiplicative decomposition. The real time-series data were used to model new data points of the AOD from 1998 to 2008. These modeled data were then used to predict the AOD in 2009. The method was found to be a valuable tool for the prediction

Results & Discussion

Total and Seasonal AOD (τ)

Fig. 1a presents the relative frequency distribution of the AOD at 400µm spectral band. The Figure presents a mixture of high and low aerosol loading. This variation is attributable to a number of factors, including mateorological, seasonal and human activities. For instance, Figs. 1a and 1b discriminates the aerosol loading based on winter and harmattan seasons. This reveals the existing contrast of the loading magnitude in the two seasons. The harmattan season presented in Fig. 1b is characterized with dryness, desert dust migration and at some points bush burning, and it lasts for almost five months (November through March)[14-16]. Around December through January, thermal energy demand increases to keep the temperature warm. People tend to burn more biomass and fossil fuel products to keep their homes warm. Besides, around March through April, farmers engage in bush burning activities in preparation of the rainy season. Furthermore, dry air transports desert dust from the Sahara, emanating from neighboring countries like the Niger Republic. This may explain why over 60% of the AOD values was higher than 0.5, which signifies high aerosol loading in most of the days.

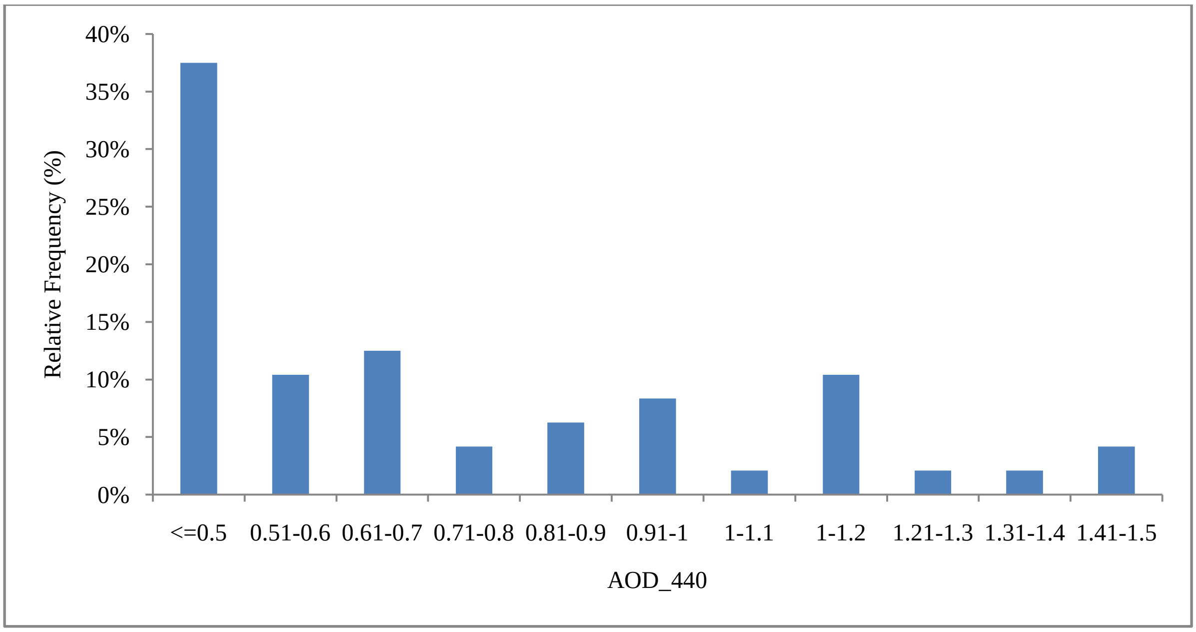

Figure 1a: Relative frequency distribution of the overall AOD_440 (1998-2008)

Wet season is typically associated with low aerosol loading. This is due to frequent removal of the aerosol from the atmosphere by the rain. In most of the days, the atmosphere is full of water vapor which the water soluble aerosols can absorb and sediment. Fig. 1c presents lower aerosol loading found in the summer (April-October). The summer is characterized with a heavy rainfall which may be the reason for the low AOD.

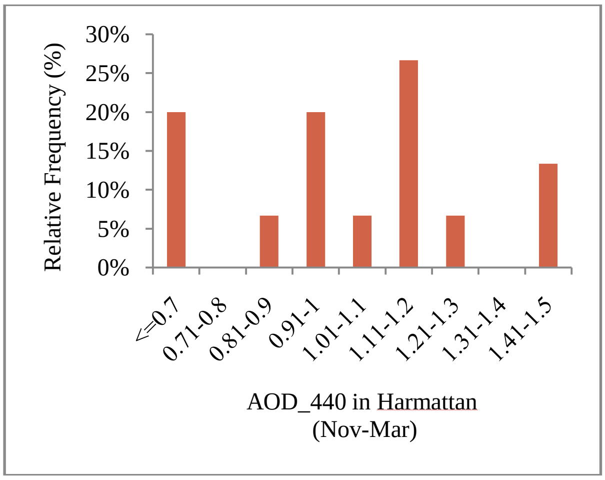

Figure 1b: Relative frequency Distribution of AOD_440 during harmattan season (Nov.-Mar.)

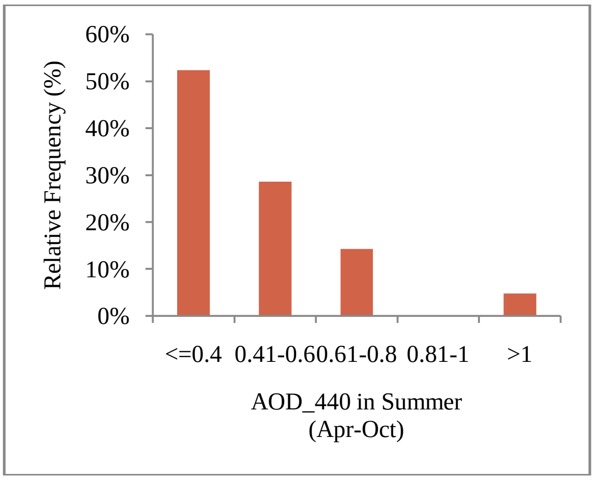

Figure 1c: Relative frequency distribution of AOD_440 during summer season (Apr.-Oct.)

Overall and Seasonal Angstrom Exponent (α)

This subsection deals with the analysis of (α). Values of α in order of~ 0 signify prevalence of coarse-mode aerosols, mostly from dust and maritime aerosols, whereas α-values between 1and 2 is attributed to fine-mode aerosol produced from anthropogenic emission [17-20]. The bimodal nature of atmospheric aerosols might be the reason why we have both lower and higher α-values as depicted in Fig. 2a. [9] reported that α-value <0.6 indicates dominance of coarse mode particles with low concentration of fine particles, whereas α-value >0.6 but <1 may indicate coarse-mode from other sources such as maritime aerosols [2]. The relative frequency distribution presented in Fig. 2a indicates about 89% of α-values less than 1 which reveals how prevalent the coarse-mode species are. The remaining 11% account for the fine-mode species.

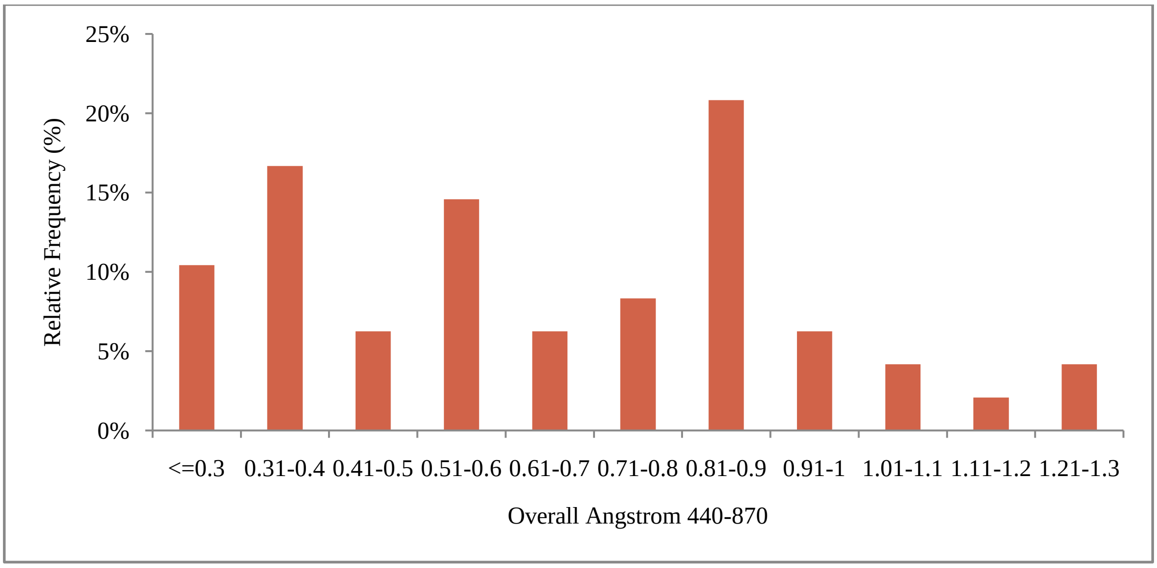

Figure 2a: Relative frequency distribution of overall $\alpha_{(440-870)}$ *(1998-2008)*

Fig. 2b and Fig. 2c discriminate the α-values into harmattan and summer seasons. During harmattan season (November-March), coarse-mode is the dominant aerosol specie and this may be attributed to dry nature of the air which favors dust and marine aerosol transportation. During that season, about 60% of the aerosols are in coarse-mode range and the remaining 40% are in fine-mode range. During summer (April-October), on the other hand, only about 80% belongs to coarse-mode category. The remaining 20% belongs to the fine-mode class.

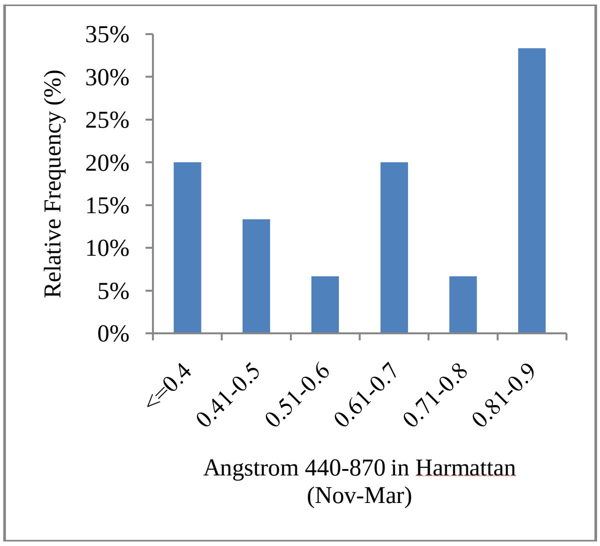

Figure 2b: Relative frequency distribution of $\alpha_{(440-870)}$ *during harmattan season (Nov.-Mar.)*

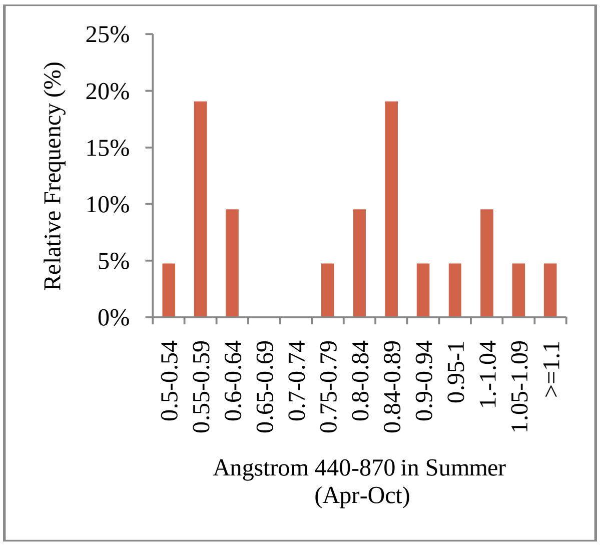

Figure 2c: Relative frequency distribution of $\alpha_{(440-870)}$ *during summer season (Apr.-Oct.)*

Prediction of one year AOD data Prediction

This sub-section presents time-series data of the AOD; the time-series data were also decomposed into seasonal and trend components. Fig. 3a presents the 10 years time series data (1998-2008); it also presents the trend of the data. Employing the classical multiplicative technique, the data points were successfully modeled from which we made a decent prediction of the AOD in 2009. In Fig. 3c the outliers were smoothed and the prediction was limited to only 1-year for accuracy.

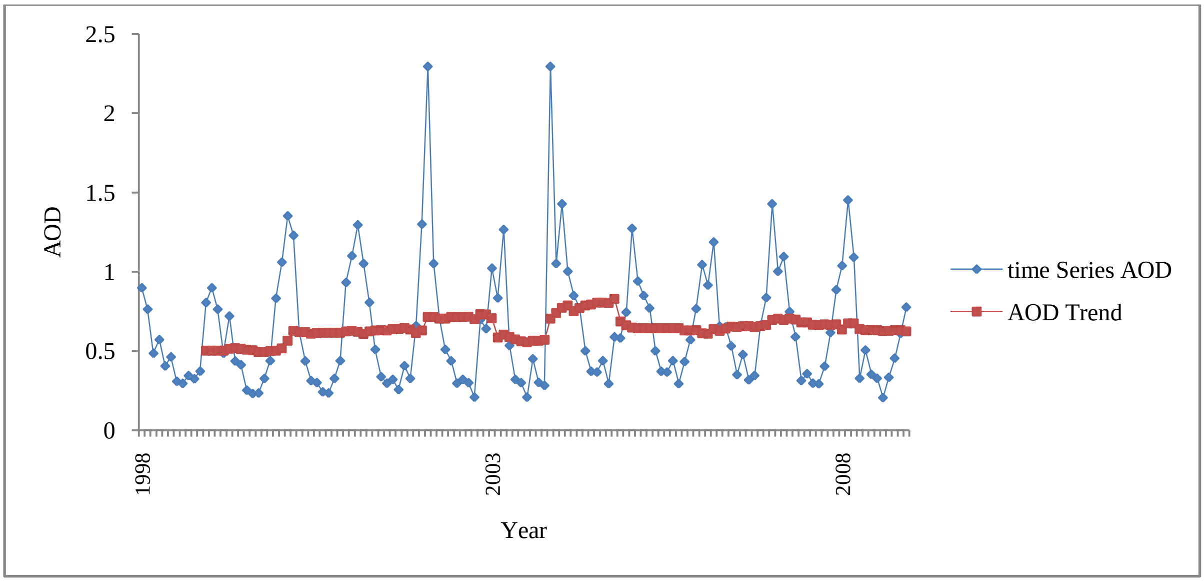

Figure 3a: Ten years time-series data for the AOD

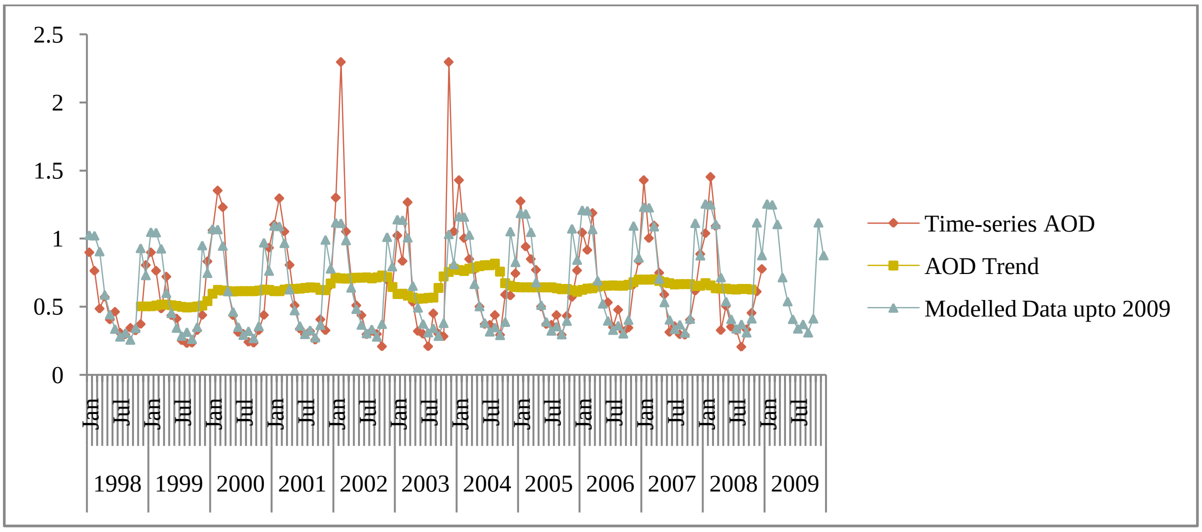

Figure 3b: Time-series data and the one-year predicted data

Conclusion

Ten years worth of AOD and Angstrom data were analyzed based on harmattan and summer season. The analyses revealed that there exists a mixture of different aerosol from different source, with harmattan season having the higher aerosol loading. It also shows that coarse-mode aerosols were the dominant aerosol, mainly from dust and maritime source. During summer, more than 80% of the aerosols were found to be in coarse-mode. Moreover, the multiplicative decomposition model used to predict one-year aerosol loading was found to be a useful an accurate technique for AOD prediction.

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