GRAPHICAL ANALYSIS OF AEROSOL OPTICAL DEPTH AT THE SAVANNAH BELT OF NIGERIA

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Abstract: Aeronet Aerosol Optical Depth (AOD) data of Ilorin in the Savannah belt of Nigeria (8^0, 32ʹN: 4^0, 34ʹE) for a five year period (2005-2009) were graphically analyzed with a view to deduce the trend and level of aerosols load in the region. Shaping and scaling constants were determined to classify the prevalent aerosols in the region and determine the concentration of aerosol load in the region respectively. The annual variation of the shaping constant showed prevalence of coarse mode aerosols (soil particles) indicating activeness of desertification in the region. Maximum and minimum average aerosol sizes were recorded in the month of March and August, respectively showing the impact of dry season dust and wet season precipitation on aerosol load in the atmosphere. Annual average scaling constant showed a moderate aerosol concentration in the atmosphere of the region. An analysis of the inter-annual variation of the scaling constant showed a 6.8% increase in aerosol concentration between 2005 and 2007 and a 10.6% decrease between 2007 and 2009 indicating that the activeness of desertification in the region can be contracted by controlled anthropogenic activities since aerosols concentration in the region did not increase continuously over the five year period under investigation.

Keywords: Aerosol, aeronet, desertification, shaping constant, scaling constant, precipitation

Introduction

Aerosol information at global and local level is a very useful tool in monitoring the Radiation Budget of a planet. Aerosols come from natural sources such as condensation, freezing of water vapour, volcanoes, dust storms, forest and grassland fires, vegetation and sea spray (IPCC, 2001). Aerosols are also formed from human activities such as burning fossil fuels and biomass, ploughing or digging up soil. These particles affect the composition of the natural atmosphere (Andreae, 1996; Oyem & Igbafe, 2010). Aerosols have the potential to significantly influence our entire planet through their role in heterogeneous chemistry in the troposphere and stratosphere (Finlayson-Pitts & Pitts, 2000), as well as their effect on the Earth's climate as they scatter solar radiation and serve as condensation nuclei for cloud droplet formation (Penner *et al*., 2001).

Atmospheric aerosols consist of a mixture of different substances such as organic matter and sea salt. Organic matter constitutes an important fraction of aerosol mass, both in remote and urban locations; the presence of organic compounds in aerosols is due to primary emission and secondary organic formation. These aerosols exert a strong influence on solar radiation, cloud formation, meteorological variables and chemistry of the marine atmosphere. A measure of the extent to which aerosols affect the transmission of sun light is known as aerosol optical depth (Oyem & Igbafe, 2010). The intensities of aerosols within an area are indication of the level of loading across that region. Atmospheric aerosol loading is known to be precursor of desertification and is associated with alterations in seasonal weather pattern. This was based on observations during the evaluation of the global climate balance (WMO, 1991; James, 1995; Oyem & Igbafe, 2010).

In recent years, global warming has made large areas of the earth to become dry on the surface. This increased surface dryness has resulted in reduction in land cover in parts of the world especially in the savannah region of Nigeria. Human activities, especially farming, bush burning, road and building constructions and animal grazing have been on the increase due to increase in human population. As at 2005, Nigeria has the highest rate of deforestation in the world according to the Food and Agriculture Organization of the United Nations (FAO, 2005). Between 2000 and 2005, the country lost 55.7% of its primary forest and the rate of forest change increased by 31.2% to 3.12% per annum (Wikipedia, 2014). The reduction in land cover leads to an upsurge in wind-assisted erosion of the topsoil which increases atmospheric dust load (Marticorena and Cairo, 2006). In the sub-Sahel region of West Africa, the Sahara encroached into previously forested areas in what seems to be the world's most accelerated desertification process and this has been accompanied by exceptional rise in aerosols loading with severe consequence for the weather and climate system (Anuforom *et al.*, 2007; Nwofor 2010).

The consequences of high aerosols loading on an environment are severe on human beings and climate. In the atmosphere, aerosols are regarded as pollutants because they impair visibility by reflecting, scattering and absorbing solar radiation and indirectly affect cloud and precipitation formation. In human beings, they cause a number of diseases including respiratory failures and black lung (Pope *et al.,* 2002). The potential impacts of aerosols loading scenario in parts of the Sahel and sub-Sahel belt of West Africa and the associated threat of desert encroachment have necessitated continuous monitoring of aerosols optical depth and particulate properties by the National Aeronautics and Space Administration (NASA), Aerosol Robotic Network (AERONET) of ground-based sun photometers. The Ilorin AERONET site located in the savannah region of Nigeria has been providing data since 1998 on aerosols concentration as well as optical and size distribution characteristics which are invaluable for the validation of the Earth Observation System (EOS) datasets with respect to aerosols climatology and desert encroachment (Holben *et al.,* 1998).

In Nigeria, the savannah belt is a region of grassland with scattered trees and annual rainfall ranging between 1100 and 2000 mm. The vegetation of the region is constantly threatened by persistent felling of trees for fuel wood, bush burning and over grazing by animals. These anthropogenic activities reduce land cover which subsequently leads to an upsurge in wind-assisted erosion of the topsoil with an increase in atmospheric aerosols load (Oyem & Igbafe, 2010; Adimula *et al*., 2010).

Currently, the northern region of Nigeria is under the threat of desertification, which is often caused by aerosols loading. Therefore, measurement of aerosols loading of the atmosphere at the savannah region of Nigeria will provide information on the expansion and contraction rates of desertification over the period under review and further enhance the knowledge on the impact of climate change and human activities in the region. The study of aerosols loading in this sub Saharan region in Nigeria will contributes to the current global monitoring of aerosols.

Materials and Methods

Materials

The optical depth data of Ilorin located at lat. 8^0 32' N and long. 4^0 34' E, in the savannah region of Nigeria for five years (2005 – 2009) were used in this study. The Aerosols Optical Depth (AOD) data were accessed from National Aeronautical and Space Administration (NASA) and Aerosol Robotic Network (AERONET) website, (http://aeronet.gsfc.nasa.gov/). The access to these data was granted by Professor R. T. Pinker, the principal investigator of the site on request through this link (pinker@atmos.umd.edu). The AERONET data are on aerosol optical depth at wavelengths 500 and 675 nm. The AERONET is a federation of ground based remote sensing aerosol network established by NASA which is presented in Plate 1, and is greatly expanded by collaborators from National Agencies, Institutes, Universities, Individual Scientists and Partners. The programme provides a long term, continuous and readily accessible public domain database of aerosol optical, micro physical and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases. The network imposes standardization of instruments, calibration, processing and distribution.

Plate 1: Aeronet sun photometer system (NASA, 2000)

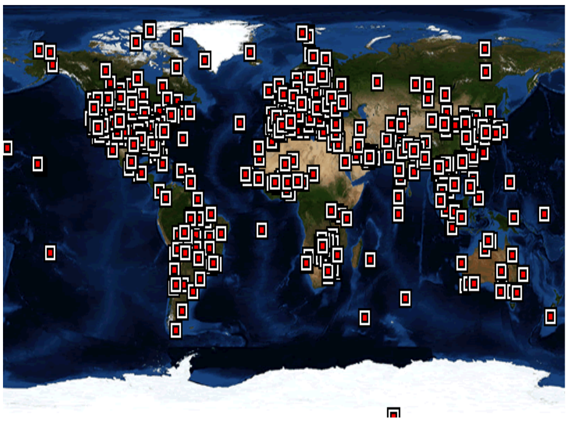

Plate 2: Aeronet aerosol measurement locations in the world (NASA, 2000)

AERONET collaboration provides globally distributed observations of spectral Aerosols Optical Depth (AOD), inversion products, and precipitable water in diverse aerosol regimes presented in Plate 2. Aerosol optical depth data are computed for three data quality levels: Level 1.0 (uncensored), Level 1.5 (cloud screened), and Level 2.0 (cloud screened and quality assured). Inversions, precipitable water, and other AOD dependent products are derived from these levels and may implement additional quality checks (NASA, 2000).

A computer software was developed to handle the computation of shaping constant (v) and scaling constant (k) using the equation 1. According to Kuo-Nan (1980), aerosol optical depth (τ_λ), is expressed as:

$$\tau_\lambda = k\lambda^{-v+2} \qquad (1)$$

Where τ_λ = aerosol optical depth at the wavelength λ

λ = wavelength of the measured solar radiation

v = the shaping constant

k = the scaling constant

Shaping and scaling constants are calculated from equation (1) when aerosol optical depth is measured at two wavelengths. The shaping constant (v) normally lies within the range $2 \le v < 4$ for particles sizes ranging from 0.01µm to about 10µm (ref. required). Values of $v \ge 3$ denotes fine particles of small size, e.g. biomass burning while $v < 3$ denotes coarse particles of large size, e.g. soil dust. The scaling constant (k) of the aerosols load is directly proportional to aerosol number concentration in the atmosphere (ref. required). Generally, an increase in k- value suggests increase in the concentration of aerosols present in the atmosphere. Aerosols are classified in term of their concentrations as low, moderate, or high. In Sub-Sahel Africa, aerosols load are classified as low: ($0.1 \le k \le 0.8$), moderate: ($0.5 \le k \le 1.5$) and high: ($1.0 \le k \le 4.0$), Adimula *et al.* (2011).

Methods

AERONET (AErosol RObotic NETwork) is a network of ground-based sun photometers which measure atmospheric aerosol properties. The measurement system is a solar-powered CIMEL Electronique 318A spectral radiometer that measures sun and sky radiances at a number of fixed wavelengths within the visible and near-infrared spectrum (Plate 1). The radiometer makes two basic measurements, either direct sun or sky, both within several programmed sequences. The direct sun measurements are made in eight spectral bands requiring approximately 10 seconds. Eight interference filters at wavelength of 340, 380, 440, 500, 675, 870, 940 and 1020 nm are located in a filter wheel which is rotated by a direct drive stepping motor. The 940 nm channel is used for column water abundance determination. A preprogrammed sequence of measurements is taken by these instruments starting at an air mass of 7 in the morning and ending at an air mass of 7 in the evening.

Optical depth is calculated from spectral extinction of direct beam radiation at each wavelength based on the Beer - Bonguer Law. Attenuation due to Rayleigh scattering, absorption by ozone and gaseous pollutants is estimated and removed to isolate the aerosol optical depth. A sequence of three such measurements is taken 30 seconds apart creating a triplet observation per wavelength. During the large air mass period, direct sun measurement are made at 0.25 air mass interval while at smaller air mass, the interval between measurements is typically 15 min. The time variation of clouds is usually greater than that of aerosols causing an observable variation in the triplets that can be used to screen clouds in many cases. Additionally the 15 – min interval allows a longer temporal frequency check for cloud contamination (NASA, 2000).

In this study, Aerosols Optical Depth (AOD) data at wavelengths, 500 and 675 nm Level 2.0 (cloud screened and quality assured) are used. The daily average values of aerosol optical depth in the five year period (2005 – 2009) are calculated. The shaping constant (v) which relates to the aerosol size distribution and the scaling constant (k) which gives an indication of the aerosol loading concentration are calculated from the daily average readings of the Aerosol Optical Depth data. Due to gaps in the daily data, monthly and annual averages of the constants, (v and k) are calculated and are graphically analyzed to determine the active source(s) of the aerosols regime and the trend of aerosols loading in the atmosphere of the savannah belt of Nigeria within the years under study.

Results and Discussion

Monthly averages of shaping constant and scaling constant for the five year period under review are shown in Table 1. The graphical illustrations of the yearly variation of these constants are shown in Figs. 1 – 5. Annual averages of shaping constant and scaling constant for 2005 to 2009 are shown in Table 2. Graphical illustration of the variation of these constants is shown in Fig. 6.

Table 1: Monthly averages of shaping constant and scaling constant in 2005 - 2009

Month	2005		2006		2007		2008		2009	
	V	K	V	K	V	K	V	K	V	K
Jan.	2.61	0.89	3.08	0.50	2.50	1.04	2.84	0.60	2.90	0.62
Feb.	2.30	0.78	2.58	0.60	2.58	0.71	2.35	1.18	2.51	0.78
March	2.20	0.75	2.36	1.01	2.32	0.91	2.26	0.91	2.30	0.88
April	2.27	0.66	2.42	0.51	2.38	0.61	0.00	0.00	2.62	0.40
May	2.42	0.40	2.39	0.55	2.34	0.49	2.30	0.43	2.32	0.40
June	2.64	0.26	2.55	0.40	2.64	0.21	2.55	0.25	2.51	0.30
July	2.81	0.20	3.02	0.18	2.75	0.24	3.05	0.17	2.87	0.20
Aug.	3.30	0.18	3.15	0.25	3.24	0.13	3.28	0.09	3.22	0.10
Sep.	2.97	0.15	2.91	0.20	2.98	0.17	2.88	0.20	2.96	0.15
Oct.	2.67	0.29	2.96	0.21	2.94	0.18	2.56	0.32	3.27	0.10
Nov.	2.75	0.37	2.57	0.51	2.87	0.36	2.73	0.38	2.32	0.67
Dec.	3.20	0.36	2.84	0.48	2.88	0.60	2.92	0.44	3.28	0.39

Month without readings due to instrument failure are indicated with 0.00 on the Table

Table 2: Annual average of shaping constant and annual scaling constant for 2005 - 2009

Year	V	K
2005	2.68	0.44
2006	2.74	0.45
2007	2.70	0.47
2008	2.70	0.41
2009	2.76	0.40

Ilorin (8^0 26' N, 4^0 29', 344.5) falls in the climate region of the savannah belt of Nigeria. The climate is a transition between the equatorial rain forest in the south and the Sahel in the north. The savannah climate exhibits a well marked wet season and a dry season. The hot dry season begins about the middle of October to about late March, when the North Easterly (NE) winds from the Sahel dominates the climate pattern. Between April and mid October, the climate is dominated by the rain bearing South Westerly (SW) winds from the Atlantic. Consequently, the meteorological conditions of the atmosphere vary between these seasons, hence revealing the local contrast in these conditions of the atmosphere from one year to another.

In this work, an aerosols loading of the savannah region of Nigeria was studied by graphically analyzing a five year (2005 – 2009) Aeronet Aerosols Optical Depth (AOD) data of Ilorin. The Shaping constant of the AOD data was determined to classify the prevalent aerosol in the region and hence determine their sources. The level of aerosol concentration in the region was also determined by the scaling constant of the AOD data to infer the level of air quality of the region and the threat of desert encroachment in the region.

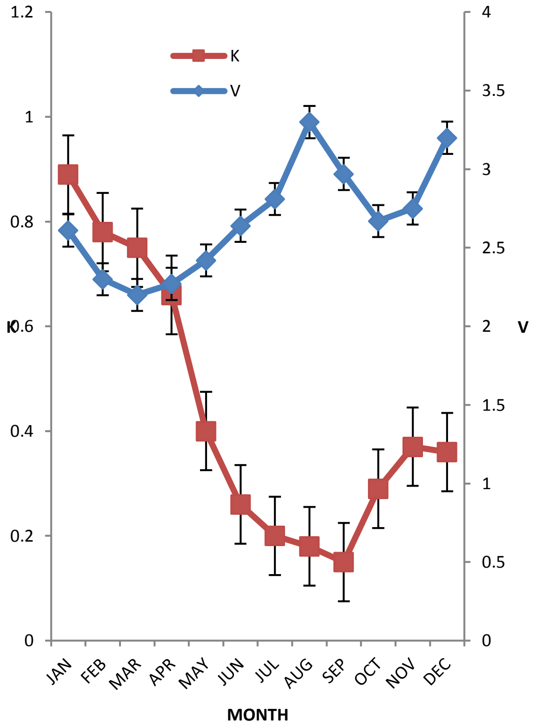

Fig 1: Variation of monthly averages of shaping constant (V) and Scaling constant in 2005

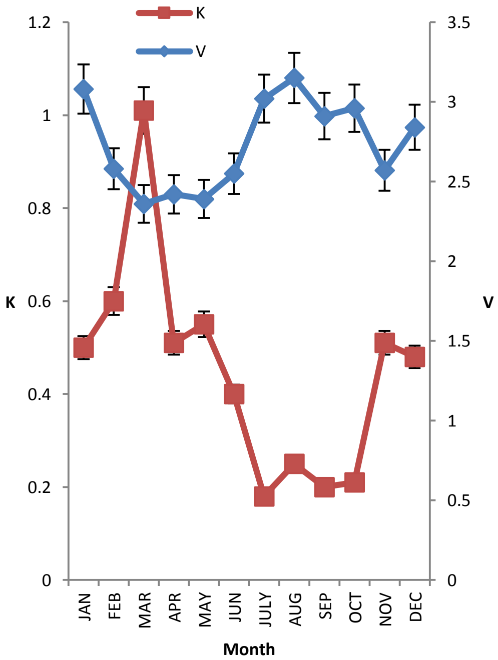

Fig 2: Variation of monthly averages of shaping constant (V) and scaling constant (K) in 2006

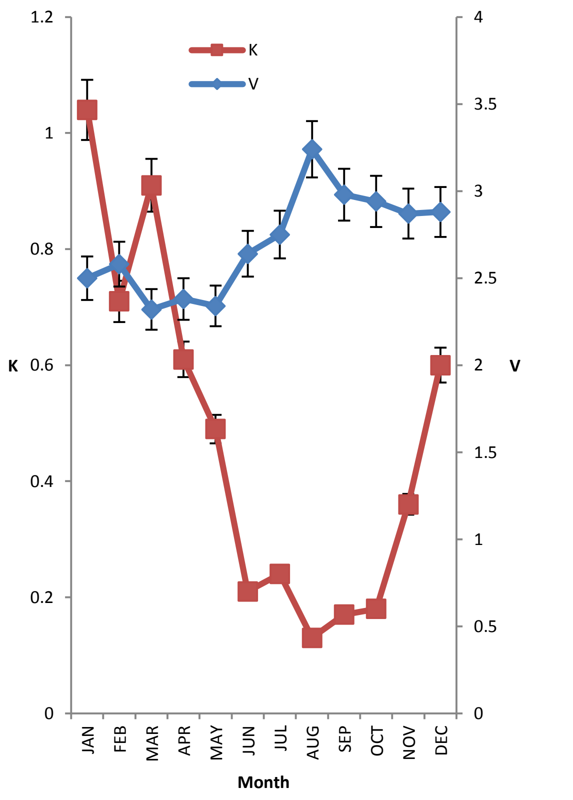

Fig 3: Variation of monthly averages of shaping constant (V) and scaling constant (K) in 2007

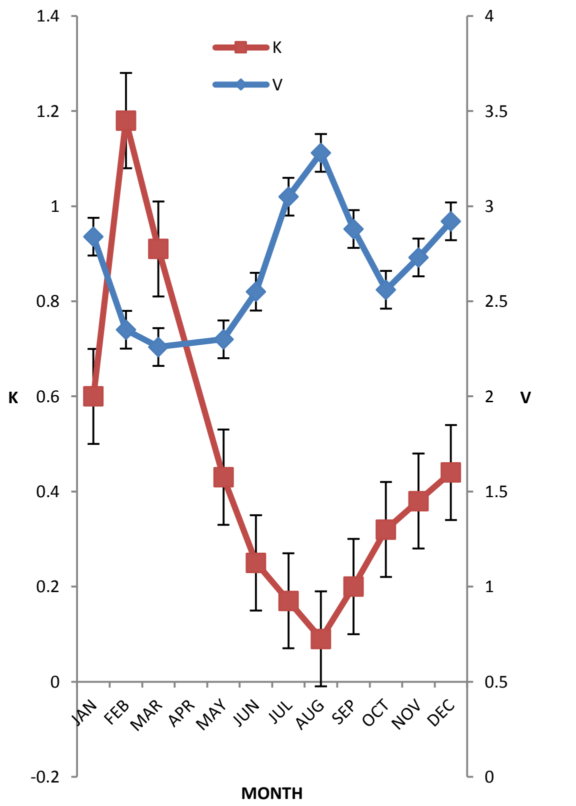

Fig 4: Variation of monthly averages of shaping constant (V) and scaling constant (K) in 2008

Note: Graph lines are extrapolated across month without readings

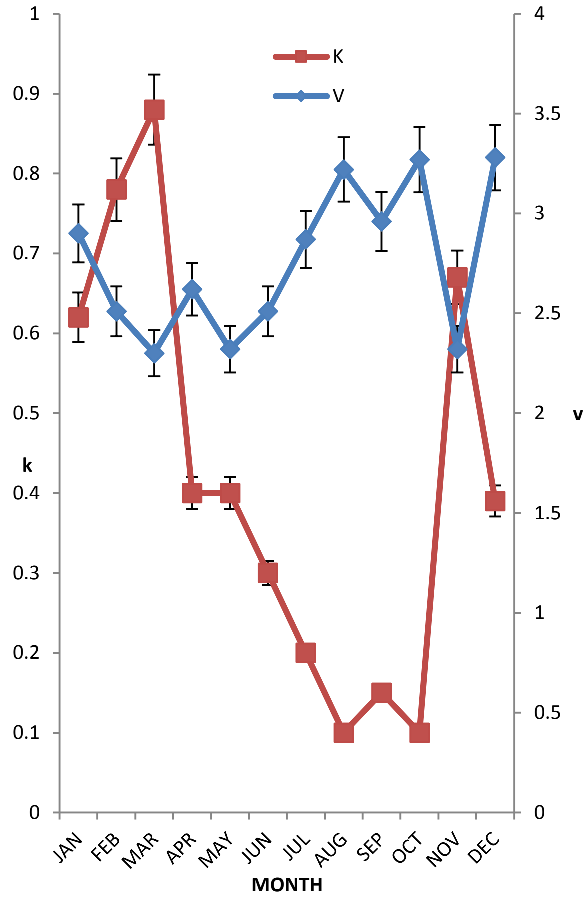

Fig 5: Variation of monthly averages of shaping constant (V) and scaling constant (K) in 2009

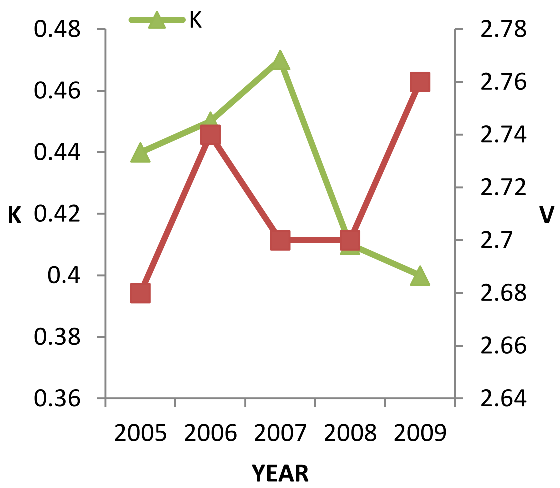

Fig. 6: Variation of annual average shaping constant and annual scaling constant for 2005 - 2009

Shaping constant (V) of AOD

The values of the shaping constant (v) recorded over the five year period are predominantly below the threshold value, v = 3 in both dry and wet seasons. These values indicate dominance of coarse particles in the atmosphere over the region. The minimum monthly average shaping constant values which indicates maximum average aerosol sizes were recorded in the dry season in the month of March. The similarity of these values validates the homogeneity of the aerosols in the region. The coarse particles that prevails in the dry season could be associated with the advected soil dusts deposited by the North Easterly winds that blows across the Sahara desert towards the Savannah and rainforest regions of the country in addition to soil erosion and the mechanically generated aerosols from anthropogenic activities such as construction works, quarrying, ploughing of farm lands and vehicular emissions.

The maximum monthly average shaping constant values, which indicate the minimum average aerosol size were recorded in the month of August each year. The similarity of the values revalidates the homogeneity of the aerosols in the region over the five year period. These fine mode aerosol that are recorded in the peak of the wet season are attributable to the removal of coarse particles from the atmosphere by the process of wet deposition and injection of fine particles into the atmosphere through biomass fuel consumption in the region.

Scaling constant (K) of AOD

The Scaling Constant is a parameter that gives a measure of aerosol concentration of the atmosphere. It is directly proportional to aerosol concentration (Kuo-Nan, 1980). Generally, an increase in the value of the constant indicates increase in aerosol concentration of the atmosphere. The maximum monthly average scaling constant values which give the maximum aerosol concentration of the period were recorded in the dry season between the months of January and March. The values indicate moderate to high aerosol load in the atmosphere within the dry season. The minimum monthly average scaling constant values which give the minimum monthly average aerosol concentration of the period were recorded in the wet season between the months of July and September. However the annual average values of the scaling constant values indicate low annual aerosol concentration in the region within the period under review though there was an increase in aerosol concentration in the region between 2005 and 2007 and a decrease between 2007 and 2009.

Conclusion

The findings of this study show that:

- ✓ Aerosol concentration at the savannah region of Nigeria varies from year to year with no definite trend but remains moderate.
- ✓ Aerosol load at the savannah regions of Nigeria is dominated by coarse particles from natural and anthropogenic sources.
- ✓ Maximum aerosol sizes are found in the atmosphere of the region during the dry season between the months of January and March while the minimum aerosol sizes are found in the region during the wet season in the month of August
- ✓ Aerosol concentration varies from low in the wet season to moderate and high in the dry season within the region.

Acknowledgment

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