CHARACTERISTIC AEROSOL LOADING OF THE SAVANNAH BELT OF NIGERIA USING A TEN YEAR AERONET DATA

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Abstract: The climate of the savannah belt of Nigeria is a transition between the equatorial rain forest in the south and the Sahel in the north. It 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 dominate 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 aerosol loading of the atmosphere vary between these seasons, hence revealing the local contributors to the aerosol load of the atmosphere from one year to another. In this work, aerosols load of the savannah region of Nigeria was studied by graphically analyzing a ten year (2005 – 2014) AERONET Aerosol Optical Depth (AOD) data of Ilorin. The Shaping Constant of the AOD was determined to classify the prevalent aerosol in the region and hence determine the contributors to the aerosol load while the level of aerosol concentration in the region was also determined by the Scaling Constant of the AOD to infer the level of aerosol load in the region. The study revealed that aerosol loading of the atmosphere in the savannah region of Nigeria is characterized by maximum load towards the end of the dry harmattan season especially in the month of March with very large (coarse) particles and minimum aerosol load during the peak of raining season in the month of August with very small (fine) particle size. It was therefore, recommended that Human activities that expose the top soil to wind erosion such as bush burning, open grazing and felling of trees for fuel wood should be controlled through legislation and social work such as tree planting

Keywords: Aerosol, aerosol optical depth, shaping constant, scaling constant

Introduction

Information on aerosol at any level is a very useful tool in monitoring the Radiation Budget of the earth. Air quality parameters generally include; ground level ozone, aerosol load, carbon monoxide, sulfur dioxide and nitrogen dioxide. Aerosol pollution is usually the main factor used in assessment of air quality of a location (Pope *et al*., 2002).

Aerosols come from natural sources such as condensation, freezing of water vapour, volcanoes, dust storms, forest and grassland fires, vegetation and sea spray. These particles affect the composition of the natural atmosphere (IPCC, 2001). Aerosols are also formed from human activities such as burning fossil fuels and biomass, ploughing or digging up soil. This anthropogenic contribution to the atmospheric aerosol loading is not well established neither is the level of the total aerosol loading currently well defined (Weingartner *et al*., 2003; Oyem & Igbafe, 2010). 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 atmosphere. In the atmosphere, aerosols influence the Earth's climate system; both solar and terrestrial radiation budget impair visibility by scattering and absorption and indirectly by providing the condensation nuclei for cloud droplet. Upon deposition, aerosols can harm humans, sensitive aquatic as well as terrestrial ecosystem (IPCC, 2007).

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 associated with alterations in seasonal weather pattern. This was based on observations during the evaluation of the global climate balance (IPCC, 2007; Oyem & Igbafe, 2010; Adimula *et al*., 2010). 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 (Adimula *et al*., 2010; Oyem & Igbafe 2010). This study therefore investigates the variation in aerosol loading of the atmosphere during the dry and wet seasons to ascertain the characteristics of the aerosol load of the savannah belt of Nigeria using a ten year AERONET Aerosol Optical Depth data of Ilorin, Nigeria.

Theoretical Framework

The expression used to determine Aerosol Optical Depth (AOD) is the Lambert – Beer – Bougher Law, expressed as;

$$I(\lambda) = I_0(\lambda)\left(\frac{r_m}{r}\right)^2 exp(-m\tau) \quad 1$$

$$m\tau = m_m\tau_m + m_r\tau_r + m_o\tau_o$$

Where $I(\lambda)$ is the observed direct solar flux density at wavelength(λ), $I_o(\lambda)$ is the solar flux density at the top of the atmosphere, r_m is the mean sun-Earth distance, r is the distance at the time of measurement; m_m, m_r, and m_o are the Aerosol, Rayleigh and Ozone air masses respectively at the time of measurement and τ_m, τ_r, and τ_o are the Aerosol, Rayleigh and Ozone Optical Depths, respectively.

Thus, by subtracting the Rayleigh and Ozone Optical Depths (which can be theoretically computed) from the total Optical Depth, the Aerosol Optical Depth can be inferred.

It was reported by Kuo-Nan, (1980) that the aerosol optical depth (τ_λ), is expressed using the Junge size distribution as;

$$\tau_\lambda = k\lambda^{-v+2} \quad 2$$

Where τ_λ is aerosol optical depth at the wavelength λ; λ is wavelength of the measured solar radiation in nanometer; v is the shaping constant; and k is the scaling constant.

The shaping constant (v) of the aerosols load relates to aerosols size distribution. It normally lies within the range $2 \leq v < 4$ for particles sizes ranging from 0.01μm to about 10μm. Values of $v \geq 3$ denotes fine particles of small size (e.g., biomass burning) while $v < 3$ denotes coarse particles of large size (e.g., soil dust). It shall be used to characterize the prevailing aerosols source(s) in the area. The scaling constant

(K) of the aerosols load is directly proportional to aerosol number concentration in the atmosphere. Generally, an increase in K- value suggests increase in the concentration of aerosols present in the atmosphere. Aerosols are classified in terms 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).

When measurements are taken at two Wavelengths λ_1 and λ_2 (e.g., 500 and 675 nm), the shaping constant (V) and Scaling constant (K) are obtained as:

$$v = \left(\frac{2\, ln\left(\frac{\lambda_1}{\lambda_2}\right) - \ln\left(\frac{\tau_{\lambda_1}}{\tau_{\lambda_2}}\right)}{\ln\left(\frac{\lambda_1}{\lambda_2}\right)} \right) \quad 3$$

and

$$k = \frac{\tau_{\lambda_1}}{\lambda_1^{-v+2}} \quad 4$$

Materials and Methods

Materials

The Aerosol 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 a ten year period (2005 – 2014) were used in this study. The Aerosols Optical Depth (AOD) data were accessed from National Aeronautical and Space Administration (NASA, 2011) Aerosol Robotic Network (AERONET) website, (http://aeronet.gsfc.nasa.gov/) on request and access granted by the principal investigator of Ilorin site, Professor R. T. Pinker (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 and is greatly expanded by collaborators from national agencies, institutes, universities, individual scientists and partners. The measuring system certified by NASA consists of sun photometer mounted on robot base which systematically points the sensor head at the sun, satellite transmitter, antenna, solar panel and data logger. 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 (NASA, 2011).

A computer software was developed to handle the computation of Shaping Constant (V) and Scaling Constant (K) for a 10 year period under investigation. The software was developed at the ICT center of University of Jos, Nigeria

Methods

In this study, Aerosols Optical Depth (AOD) data at wavelengths, 500 and 675 nm Level 2.0 (cloud screened and quality assured) were used. The daily average values of aerosol optical depth in the ten year period (2005 – 2014) were calculated. The Shaping Constant (V) which relates to the aerosol size distribution and the Scaling Constant (K) which give an indication of the aerosol loading concentration (Kuo-Nan, 1980) were calculated from the daily average values of the Aerosol Optical Depth.

A C++ computer program was used to handle the computation of the Shaping Constant (V) and Scaling Constant (K) for the 10 year period under investigation. The monthly average values of the Shaping Constant and Scaling Constant were graphically analyzed to determine the active source(s) of the aerosols regime and hence determine the contributors to the aerosol load of the atmosphere during different seasons.

Results and Discussion

Table 1 shows the monthly average values of Shaping and Scaling Constants for the years 2005 to 2009 with graphical illustration of the variation shown in Fig. 1. Table 2 shows the monthly average values of the Shaping and Scaling Constants for the years 2010 to 2014 with graphical illustration of the variation shown in Fig. 2. Table 3 shows the decade average values of Shaping and Scaling Constants between 2005 and 2014 with graphical illustration of the variation shown in Fig. 3. Table 3 and Fig 3 which are summaries of the values in Tables 1 and 2 and Figs 1 and 2, respectively are used for the discussion.

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

Month	2005		2006		2007		2008		2009		AVE	
	V	K	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	2.79	0.73
Feb	2.30	0.78	2.58	0.60	2.58	0.71	2.35	1.18	2.51	0.78	2.46	0.81
Mar	2.20	0.75	2.36	1.01	2.32	0.91	2.26	0.91	2.30	0.88	2.29	0.89
Apr	2.27	0.66	2.42	0.51	2.38	0.61	0.00	0.00	2.62	0.40	2.42	0.55
May	2.42	0.40	2.39	0.55	2.34	0.49	2.30	0.43	2.32	0.40	2.35	0.45
Jun	2.64	0.26	2.55	0.40	2.64	0.21	2.55	0.25	2.51	0.30	2.58	0.28
Jul	2.81	0.20	3.02	0.18	2.75	0.24	3.05	0.17	2.87	0.20	2.90	0.20
Aug	3.30	0.18	3.15	0.25	3.24	0.13	3.28	0.09	3.22	0.10	3.24	0.15
Sep	2.97	0.15	2.91	0.20	2.98	0.17	2.88	0.20	2.96	0.15	2.94	0.17
Oct	2.67	0.29	2.96	0.21	2.94	0.18	2.56	0.32	3.27	0.10	2.88	0.22
Nov	2.75	0.37	2.57	0.51	2.87	0.36	2.73	0.38	2.32	0.67	2.65	0.46
Dec	3.20	0.36	2.84	0.48	2.88	0.60	2.92	0.44	3.28	0.39	3.02	0.45

Note: Month without readings are indicated with 0.00 on the Table

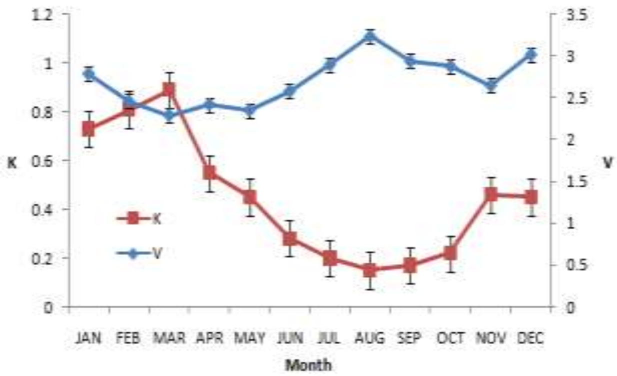

Fig. 1: Variation of shaping and scaling constants between 2005 and 2009

Table 2: Monthly averages of shaping constant and scaling constant between 2010 and 2014

Month	2010		2011		2012		2013		2014		AVE	
	V	K	V	K	V	K	V	K	V	K	V	K
Jan	3.22	0.38	0.00	0.00	2.72	0.78	2.92	0.56	3.02	0.48	2.97	0.55
Feb	2.89	0.41	0.00	0.00	2.45	1.05	0.00	0.00	2.64	0.73	2.66	0.73
Mar	2.44	0.78	0.00	0.00	2.37	1.08	0.00	0.00	2.55	0.40	2.79	0.75
Apr	0.00	0.00	0.00	0.00	2.36	0.60	0.00	0.00	2.44	0.36	2.40	0.48
May	0.00	0.00	0.00	0.00	2.51	0.32	0.00	0.00	2.39	0.37	2.45	0.35
Jun	0.00	0.00	0.00	0.00	2.68	0.24	2.74	0.29	2.49	0.30	2.64	0.28
Jul	0.00	0.00	0.00	0.00	3.00	0.16	2.97	0.18	3.06	0.19	3.01	0.18
Aug	0.00	0.00	0.00	0.00	3.29	0.12	0.00	0.00	3.20	0.16	3.25	0.14
Sep	0.00	0.00	3.36	0.09	3.50	0.09	2.90	0.20	3.06	0.15	3.21	0.13
Oct	0.00	0.00	2.68	0.30	2.95	0.21	2.85	0.20	0.00	0.00	2.83	0.24
Nov	0.00	0.00	3.07	0.18	3.04	0.18	2.87	0.21	0.00	0.00	2.99	0.19
Dec	0.00	0.00	2.83	0.47	2.90	0.40	2.87	0.35	0.00	0.00	2.87	0.41

Note: Month without readings are indicated with 0.00 on the Table

The variation of average values of the Scaling Constant between 2005 and 2014 as shown in Fig. 3 shows increasing phase of aerosols concentration and size between January and March during the dry harmattan season with another increasing phase occurring between October and December during the onset of another dry harmattan season but with a fluctuating aerosol size that might have arisen due to injection of fine particles from bush burning that occurs within the period. The increase in aerosols load of the atmosphere is associated with advected aerosols (dust particles) by North Easterly winds that blow across the region within these periods and the locally generated aerosols by wind erosion of the exposed top soil that results from increasing anthropogenic activities such as bush burning, felling of trees and construction works within the region. A declining phase of aerosols concentration occurs between March and May during the transitional period (from dry to raining season). This declining phase is characterized by prevalence of coarse particles. The decrease in concentration is attributable to change in the driving force on the contributors to the aerosols load, a change from dust laden North Easterly winds to rain bearing south westerly winds (Akoshile, 2016). A mean low aerosols load and size occurs between May and October during the raining season. The low aerosols load and size is attributable to the removal of coarse particles from the atmosphere by rain.

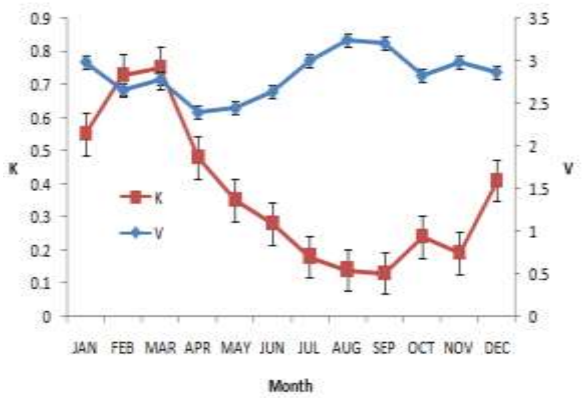

Fig. 2: Variation of average shaping and scaling constants between 2010 and 2014

Table 3: Decade average values of shaping and scaling constants between 2005 and 2014

Month	V	K
January	2.87	0.65
February	2.54	0.78
March	2.35	0.84
April	2.42	0.52
May	2.38	0.42
June	2.60	0.28
July	2.94	0.19
August	3.24	0.15
September	3.06	0.16
October	2.86	0.23
November	2.78	0.36
December	2.96	0.44

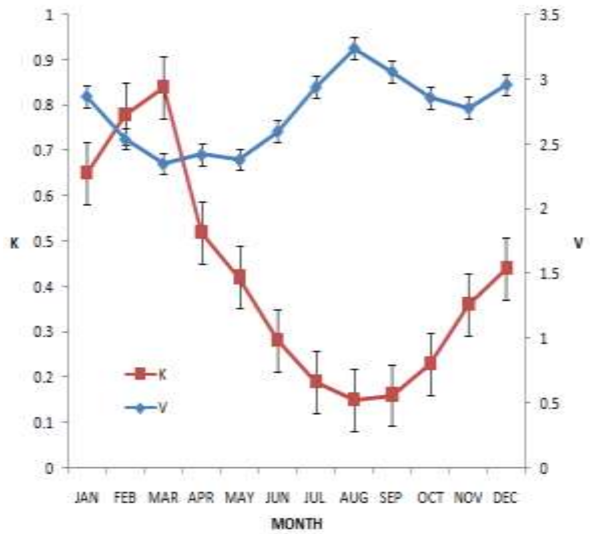

Fig. 3: Variation of decade average shaping and scaling constants between 2005 and 2014

An examination of the variation of the Scaling Constant and Shaping Constant show a maximum aerosol load occurring with a maximum aerosol size in March during the dry harmattan season and a minimum aerosol load with a minimum aerosol size in the month August during the raining season. It is therefore recommended that anthropogenic activities that expose the top soil to wind assisted erosion such as bush burning, open grazing and felling of trees for fuel wood should be controlled through legislation and social works.

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Conflict of Interest
Authors declare that there is no conflict of interest in this study.

References
Adimula IA, Falaiye OA & Adindu C 2010. Effects of Aerosols Loading in the Atmosphere on the visibility changes in Ilorin. Retrieved July 1, 2011, from http://www.unilorin.edu.ng, .

Akoshile CO, Ajibola TB, Falaiye OA & Pinker RT 2016. A BSRN Station in Developing Country: Need, Challenge, Effort and Progress. 14th BSRN Workshop, Canberra, Australia. April 26 – 29, 2016.

Andreae MO 1996. Raising dust in the greenhouse. *News and Views*, 297(5590): 2250-2253. from http://aeronet.gsfc nasa.gov/.

IPCC 2001. Climate Change: The scientific Basic. In: JT Houghton, Y Ding, DJ Griggs, M Nogher PJ, Vananddder Linden, Dai X, MacKell K & Johnson CA (Eds.), The Climate System: An Overview New York: Cambridge University Press, pp. 180-881.

IPCC 2007. Climate Change: The Physical Science Basis. New York: Cambridge University Press.

Kuo-Nan L 1980. An Introduction to Atmospheric Radiation. New York*:* Academic Press.

NASA 200. Spectral Aerosol Optical Measurement. National Aeronautical and Space Administration (NASA); Retrieved May 5, 2011.

Olivier J & Berdowski J 2001. Global Emissions Sources and Sinks: The Climate System. The Netherlands: Swets and Zeitlinger Publishers.

Oyem AA & Igbafe AI 2010. Analysis of the atmospheric aerosol loading over Nigeria. *Environmental Research Journal*, 4(1): 145-156.

Pope CA, Burnett RT, Thun MJ, Calle EE, Krewski D, Ito K & Thurston GD 2002. Cancer, cardiopulmonary mortality and long-term exposure to fine particulate air pollution. *J. Am. Med. Assoc.*, 287(9): 1132-1141.

Weingartner E, Saathoff H, Schnaiter M, Streit N, Bitnar B & Baltensperger U 2003. Absorption of light by soot particles: Determination of the absorption coefficient by means of aethalometers. *Journal of Aerosol Science*, 34: 1445–1463.