



Aerosols Loading Trends and its Environmental Threats Over Cotonou-Benin

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 14-02-2016
Accepted: 16-04-2016

Key Words:

Environmental security
Aerosols
Bamako, MISR
Cotonou-Benin

ABSTRACT

Environmental security is totally relegated in countries of West Africa. The monitoring of the aerosols loading over Cotonou was the aim of this study. The outcome of our finding has salient links to food security, aviation and communication industry, thermal comfort and climate system of Benin. Cotonou is located on longitude 2.43°E and latitude 6.37°N. Fifteen years data were obtained from the multi-angled spectro-reflectometry (MISR). The aerosol loading was monitored using analytical and statistical techniques. The aerosols retention over Cotonou was high in 2000 (69.91%), 2008 (72%) and 2013 (42.45%). This means that there is the possibility of higher rising sea levels and exposure to coastal erosion due to a twisted cloud formation.

INTRODUCTION

Aerosols in the atmosphere are colloid particles that are generated from natural and industrial sources with diameters in the range between 0.002 μm to 100 μm (Gradon et al. 2000). The sources of aerosol loading are smoke, dust and haze which may be anthropogenic or naturally induced. They have direct and indirect climate forcing effects. Direct radiative forcing is caused by scattering and absorbing solar radiation in the earth while indirect radiative forcing is caused by radiative properties of clouds through cloud condensation nuclei (CCN) (Kahn et al. 2009). It is also involved in cloud formation and precipitation processes by increase in particle number and mass concentrations which varies in the range of about 10^2 - 10^5 cm^{-3} and 1-100 $\mu\text{g m}^{-3}$ respectively. Therefore the size, chemical composition, concentration and distribution in space and time of atmospheric aerosol particles are highly variable (Poschl 2015).

To predict and estimate aerosol influences on our climate, models need to be developed to control future emission by reducing the uncertainties in atmospheric aerosols mass loading and aerosol optical depth (AOD) estimates. The mass or the amount of aerosols in the earth is determined by emission (physical and chemical formation), transport (source to other areas) and removal (wet deposition and dry deposition) which serve as a control to the aerosol lifetime (Remer et al. 2009). However, the aerosol parameters vary with time and space because of the variations of aerosol composition and relative humidity.

The influence of climate change on coastal cities like Cotonou most time results in rising sea levels and exposure

to coastal erosion (Dossou & Bernadette 2007). The relation between aerosols and climate change is primarily the cooling of the Earth as aerosols directly reflect sunlight back away from the Earth and interacts with the cloud. The aerosols interact with clouds in complex ways leading to changes in cloud reflectivity, cloud lifetime, cloud height and cloud precipitation. Hence, volume of aerosols retention is directly proportional to the aerosol-cloud interaction. Aerosol loading may be approximately proportional to the aerosol-cloud interaction due to the self-cleansing forces like 'rain wash' that reduce its lifetime in the atmosphere. Therefore, it is important to consider both the aerosols retention and loading over Cotonou to see the allowable limits to guide against environmental and food threat in the future.

Therefore, this paper tends to focus on estimation of thirteen years ground measurement of atmospheric aerosol distribution size to test the consistency of the data in northern part and their effect on the climate change in the geographical area. This will help us to formulate model based on significant weather pattern.

THEORIES: STATISTICAL DISTRIBUTION

The standard error (SE) of the mean was used (in this research) to estimate the population mean for each month of the year. SE technique used for this research captures the standard deviation of the monthly means of samples for over three decades. The standard error of the mean is expressed mathematically as seen in equation 1:

$$SE = \frac{\sigma}{\sqrt{n}} \quad \dots(1)$$

Here σ is the population standard deviation and n is the population size.

Standard error measures the degree of uncertainty in obtaining the true value of aerosol optical depth and the deviations of the monthly mean from the thirteen-year mean. Standard deviation (σ) measures the amount of visible dispersion from the monthly mean. Like the SE, a low magnitude standard deviation signifies that the monthly mean is closer to the thirteen-year mean which is also termed the expected value while, a high magnitude standard deviation reveals how far the monthly mean deviates from the thirteen-year mean. The equation for standard deviation is given in equation 2.

$$\sigma = \sqrt{\frac{1}{N} \sum_{j=1}^N (y_i - \bar{y})^2} \quad \dots(2)$$

Here, y , in the context of this research is the monthly-mean and \bar{y} is the mean value of the thirteen-year mean. The concept of variance is intrinsically connected to the effects of the difference between the monthly mean and the thirteen-year mean for the AOD performance in Bamako, Mali. The coefficient of variation is a measure of the normalized dispersion for a probability distribution i.e., the thirteen-year mean for each parameter used. In statistics, coefficient of variation is referred to as relative standard deviation and expressed in percentage. Coefficient of variation is not used to determine few meteorological parameters because of the inconsistency of its interval scale. For example, coefficient of variation is appropriate for the Kelvin scale but inappropriate for the Celsius scale because its data are characterized by such interval scale therefore, we adopted the coefficient of variation because the scale used has a characteristic interval scale and appropriate for comparison between data sets of widely different yearly or monthly means. Coefficient of variation can be represented mathematically as

$$CV = \frac{\sigma}{\mu} \quad \dots(3)$$

In equation 3, σ is the standard deviation and μ is the monthly mean. Skewness, also known as skew (X), is a measure of the asymmetry of the probability distribution of the monthly mean about its thirteen-year mean. For a normal distribution, the skewness is equivalent to zero. 'Skew' can be positive, negative, or undefined; when negative, it simply implies that the mass of the distribution is concentrated on the right side of the plotted graph i.e., left-skewed. When the skew is positive, the mass of the distribution is concentrated on the left side of the plotted graph i.e., it is right-skewed. Equation 4 gives the mathematical equation for estimating the skew of a distribution.

$$X = \frac{(\mu - \nu)}{E(|X - \nu|)} \quad \dots(4)$$

Here, ν is the median and E is the expectation error.

Kurtosis (β) is any measure of the flattening or "peakedness" of the probability distribution of the monthly mean for each month of the year. Like skewness, kurtosis is a descriptor which gives the description of the shape of a probability distribution where $\beta > 3$ (i.e., a region of high probability for extreme values, also known as the region of the Leptokurtic distribution). For $\beta < 3$ i.e., within the region of Platykurtic distribution, the probability for extreme values is less than that of a normal distribution while for $\beta = 3$, the region exhibits the Mesokurtic distribution which is equally known as a normal distribution. The Kurtosis can be estimated mathematically from equation 5.

$$\beta = \frac{\mu^4}{\sigma^4} \quad \dots(5)$$

All parameters retain their usual meanings. The simulation was carried out using Surfer analytical tool.

VALIDATION OF DATA SOURCE

Cotonou is the most populous city in Benin and it is located on longitude 2.43°E and latitude 6.37°N in the Sahelian geographic region south of the Sahara (Fig. 1), hence, we expect a high impact of the north east winds alongside Sahara dust. The coastal strip on which Cotonou is built is composed of alluvial sand with a maximum depth of four metres. It is also under the influence of the local steppe climate. Its metropolitan area is about 836 km². Cotonou has average temperature and precipitation of 26.8°C and 1244 mm respectively. The distance of Cotonou to the Sahara is about 3126 km. In the past, no aerosols ground observation was available; hence, the satellite observation was adopted. Fourteen years satellite observation was obtained from the Multi-angle Imaging SpectroRadiometer (MISR). The MISR operates at various directions i.e. nine different angles (70.5°, 60°, 45.6°, 26.1°, 0°, 26.1°, 45.6°, 60°, 20.5°) and gathers data in four different spectral bands (blue, green, red and near-infrared) of the solar spectrum. The blue band is at wavelength 443nm, the green band is at wavelength 555nm, the red band wavelength 670nm and the infrared band is at wavelength 865nm. MISR acquire images at two different levels of spatial resolution i.e. local and global mode. It gathers data at the local mode at 275 meter pixel size and 1.1km at the global mode. Typically, the blue band is to analyse coastal and aerosol studies. The green band is to analyse bathymetric mapping and estimating peak vegetation. The red band analysis the variable vegetation slopes and the infrared band analysis the biomass content and shorelines.

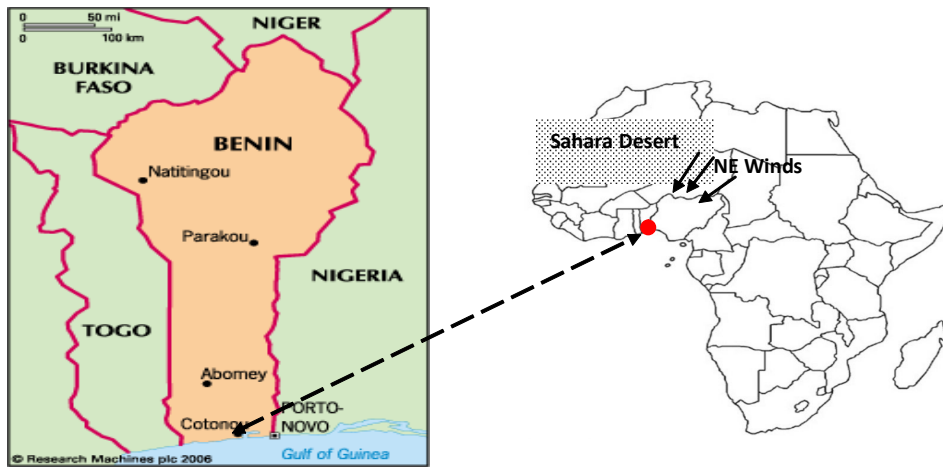


Fig. 1: Map of Cotonou and the Sahara influence.

METHODOLOGY

The raw MISR dataset was processed using the Excel package. The means for each month were calculated for each year. We tested the accuracy of the data by applying the aerosol dispersion model that was propounded by Emeter et al. (2015a). An extension of the dispersion model used is given as:

$$\psi(\lambda) = a_1^2 \cos\left(\frac{n_1 \pi \tau(\lambda)}{k_y} + \alpha\right) \cos\left(\frac{n_1 \pi \tau(\lambda)}{k_z} + \alpha\right) + a_2^2 \cos\left(\frac{n_2 \pi \tau(\lambda)}{k_y} + \beta\right) \cos\left(\frac{n_2 \pi \tau(\lambda)}{k_z} + \beta\right) \dots(7)$$

Here α and β are the phase differences, k is the diffusivity, τ is the AOD, ψ is the concentration of contaminant, λ is the wavelength, a and n are atmospheric and tuning constants respectively. This technique had been severally adopted for environmental modelling to determine coefficient or constants from a set of available data (Holzbecher 2012). The Matlab curve fitting tool resolves numerically the constants highlighted in Equation [6] and gives the statistical analysis of the MISR dataset.

The percentage of retention can be determined from the coefficient of variance for each year. This was done by considering the previous and current years which are denoted as G_p and G_r respectively. Hence we propound that the aerosols retention between two years as:

$$A = \left| \frac{G_p - G_r}{G_p} \right|^2 \times 100\% \dots(6)$$

The aerosols retention can be calculated from Tables 1-2 to obtain Tables 3-4. Any statistical tool could be used to obtain the atmospheric aerosols retention. In this paper, the

Table 1: Atmospheric constants over Cotonou.

Location	α_1	α_2	n_1	n_2	α	β
Cotonou	0.7602	0.81	0.185	0.1304	$\pm \frac{\pi}{2}$	$\pm \frac{\pi}{2}$

Matlab and the Excel package were used to obtain the results shown in the succeeding section.

RESULTS AND DISCUSSION

The scanty AOD data in July (Cotonou-Benin) may not be due to ‘rain washing’ as proposed (Fig. 2). UNEP (2015) clarified that there is a minor dry season from the middle of July to the middle of September. However, the minor rainy season from the middle of September to the middle of November cannot be substantiated in Figs. 3 and 4. The aerosols loading in Cotonou is non-uniform because of excessive emission of anthropogenic pollution from automobiles, household generators, local cooking stoves and bush burning. Like Ouagadougou, Cotonou has poor ventilation in the evening and every particulate released into the atmosphere is localized at a particular layer. The AOD retrieval in Cotonou is very unique because despite its proximity to Atlantic Ocean and Lake Nokove, the coastal features did not influence its AOD retrieval. Secondly, like Lagos, Cotonou is constantly influenced by oceanic trade winds, hence it can be inferred that its aerosol loadings are majorly stratospheric (Hasebe & Noguchi 2015). The proposed model agreed with the AOD trend in Cotonou.

From Figs. 2 to 4, the atmospheric constants, phase differences and tuning constants can be inferred from the Matlab curve fit tool and equation (6) as given in Table 1.

It is important to note that this paper has significant

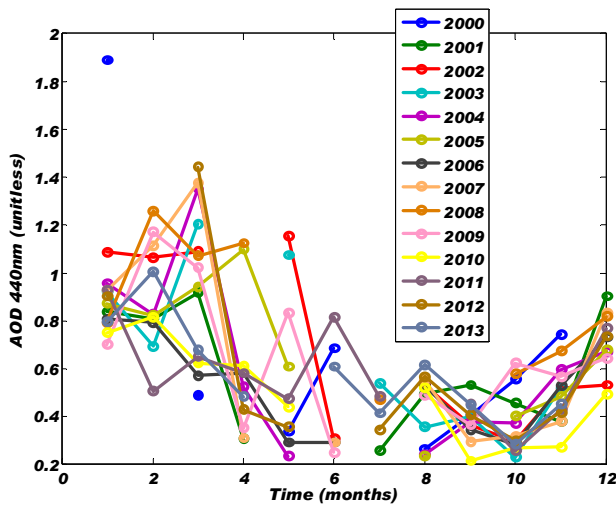


Fig. 2: AOD pattern for Cotonou 2000-2013.

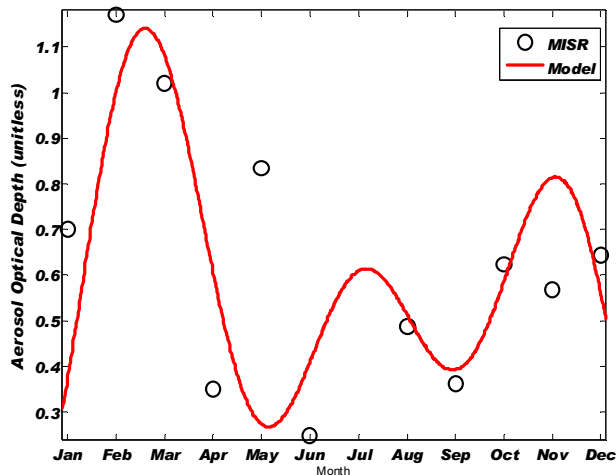


Fig. 3: AOD for new model and MISR for the year 2001.

interest to the ITU model because it suggests an alteration in its known model shown in equation (7)

$$N = \frac{77.6P}{T} + 3.73 de \times 10^5 \frac{e}{T^2} = N_{dry} + N_{wet} \quad (N - units) \quad \dots(7)$$

Where e is the water vapour pressure, P is the atmospheric pressure (hpa) and T is the absolute temperature (K). The mathematical relationship between relative humidity and water vapour pressure is expressed in the following equation:

$$e = \frac{RH}{100} a \exp \left[\frac{bT}{T+c} \right] \quad \dots(8)$$

Here T is the temperature in the above equation is given in °C and the coefficients a , b and c take the following

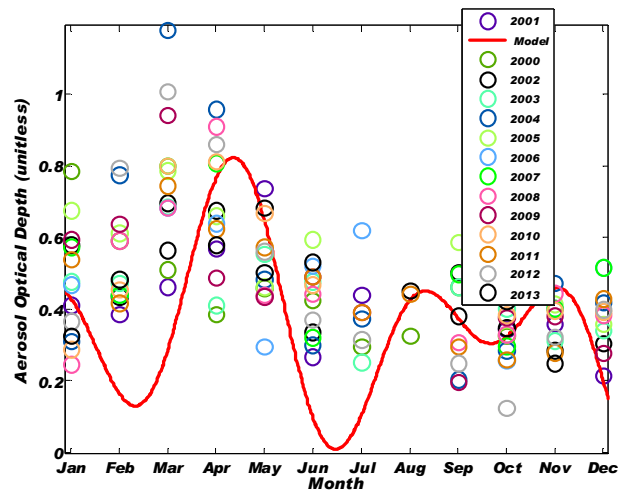


Fig. 4: AOD for new model and MISR for the year 2000-2013.

values: $a = 6.1121$, $b = 17.502$, and $c = 240.97$. The implication of this research upon the understanding of the results from Leck and Svensson (2015) is that the determination of coefficients a , b and c are influenced by the optical state over a geographical location. This study proposes an inclusion of the attenuation due to moving aerosols layer into the ITU model which is significant via the atmospheric constants over Cotonou. Upon this concept, we statistically examine the AOD distribution over Cotonou as provided in Tables 2 and 3.

The highest AOD mean, 95% confidence interval, 99% confidence interval, variance, standard deviation and coefficient of variation were in 2000. The highest skew and kurtosis can be found in 2010. The highest Kolmogorov-Smirnov stat can be found in 2000. This result shows that the lower atmosphere of Cotonou may not be dynamic as cities in the southern Benin (Emetere et al. 2015b). Hence, we examine the atmospheric aerosol retention given in Tables 4 and 5.

The undulating nature of all the statistical values is an evidence of the influence of climatic change on the yearly aerosols loading (Geerts 2015). However, the negative skew values as shown in 2005 are subject to investigation. Visser (1997) gave the significance of negative skew. It was explained that it reflects synergism of the events. The aerosols retention over Cotonou was high in 2000 (69.91%), 2008 (72%) and 2013 (42.45%). This means that there is the possibility of higher rising sea levels and exposure to coastal erosion due to a twisted cloud formation.

The increase in aerosol retention from 2010-till date shows a major fault in the self-cleansing process. This results is expected to lead to cloud reflectivity, cloud life-time, cloud height and cloud precipitation.

Table 2: Statistical AOD analysis 2000-2006.

Statistical Tool	2000	2001	2002	2003	2004	2005	2006
Mean	0.67	0.59	0.69	0.66	0.61	0.68	0.52
95% confidence interval	0.43	0.18	0.26	0.26	0.25	0.21	0.13
99% confidence interval	0.64	0.26	0.37	0.38	0.36	0.31	0.19
Variance	0.27	0.06	0.13	0.11	0.12	0.08	0.04
Standard deviation	0.52	0.25	0.36	0.34	0.35	0.28	0.2
Coefficient of variation	0.77	0.43	0.52	0.51	0.57	0.41	0.38
Skew	2.29	0.17	0.29	0.5	1	-0.16	0.12
Kurtosis	5.74	-1.79	-2.1	-1.11	0.75	-0.83	-1.4
Kolmogorov-Smirnov stat	0.32	0.21	0.27	0.19	0.15	0.14	0.18

Table 3: Statistical AOD analysis 2007-2013.

Statistical Tool	2007	2008	2009	2010	2011	2012	2013
Mean	0.64	0.85	0.64	0.5	0.58	0.59	0.58
95% confidence interval	0.28	0.23	0.19	0.15	0.13	0.25	0.15
99% confidence interval	0.41	0.35	0.27	0.21	0.19	0.37	0.22
Variance	0.16	0.08	0.08	0.04	0.04	0.13	0.04
Standard deviation	0.4	0.28	0.28	0.21	0.2	0.36	0.21
Coefficient of variation	0.62	0.33	0.45	0.41	0.34	0.6	0.36
Skew	0.82	0.19	0.58	0.02	0.39	1.81	0.81
Kurtosis	-0.7	-1.3	-0.3	-1.12	-0.33	3.25	0.62
Kolmogorov-Smirnov stat	0.24	0.17	0.14	0.17	0.19	0.28	0.17

Table 4: Atmospheric aerosols retention over Cotonou 2001-2006.

	2001	2002	2003	2004	2005	2006
Aerosol deposition	61.91	2.79	0.018	1.1	15.89	0.47

Table 5: Atmospheric aerosols retention over Cotonou 2001-2006.

	2007	2008	2009	2010	2011	2012	2013
Aerosol deposition	14.77	79.22	6.9	0.71	3.97	18.49	42.45

The year of highest atmospheric aerosols retention was found between 2007 and 2008. This shows that the skew and kurtosis are good indicators of atmospheric aerosols retention. The significance of the atmospheric aerosols retention in a geographical region has great influence on aviation schedules (Gettelman & Chen 2013), human health (Wyzga & Lawrence 1995), measuring instruments, energy budget and meteorology (Emetere & Akinyemi 2013).

CONCLUSION

The validation of the statistical aerosol optical depth (AOD) and atmospheric aerosols retention over Cotonou for 13 years has been established. The results show that the increase in aerosol retention from 2010-till date is a major fault in the self-cleansing process. This result is expected to

lead to cloud reflectivity, cloud lifetime, cloud height and cloud precipitation. The atmospheric aerosols retention is found to be relatively higher in Cotonou, dust particulates from the northeast wind may be found to be responsible. The results also indicate that northeastern region (Cotonou) may experience less AOD than cities in the southern Benin. The understanding of Aerosol Optical Depth (AOD) and Atmospheric aerosols retention will help aerosol-climate scientists to know the aerosol effects on climate, weather, and cloud.

ACKNOWLEDGEMENT

The authors gratefully acknowledge NASA for the data provided. The authors thank the host institution for partial sponsorship

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