Monitoring The Aerosols Loading Over Bamako: Likely Threats To Environmental And Food Security

Emetere M.E., Akinyemi M.L., Sanni S.E. and Akinwumi S.A.
Department of Physics
Covenant University,
Ota, Nigeria
moses.emetere@covenantuniversity.edu.ng

Abstract— **Environmental security is totally relegated in countries of West Africa. The monitoring of the aerosols loading over Bamako 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 Bamako and Mali. Bamako is located on longitude 12.65 °N and latitude 8 °W. Fifteen years data was obtained from the multi-angled spectro-reflectometry (MISR). The aerosol loading was monitored using analytical and statistical techniques. The outcome is expected to enrich policy making in the nation of Mali.**

Keywords— Environmental security, aerosols, Bamako, MISR

I. INTRODUCTION

Aerosols are mixtures of tiny particles and liquids which may be homogenous or heterogeneous by nature [1]. The homogenous nature of aerosols allows for its absorption into the clouds [2] to form the direct radiative effect (DRE) of aerosol above clouds. Aerosols concentration in the lower atmosphere has been on the steady increase owing to industrial activities and burning of biomass [3]. Recent research has shown that there is poor ventilation over West Africa [4]. It is theoretically expected that the self-cleansing mechanism over the atmosphere of Bamako may be over burdened. An over-burdened atmosphere may initiate other processes. The increase in the aforementioned parameter was due to aerosols dispersion rate. Also, an overburden atmosphere may lead to poor visibility and the regular initiation of radar distress signaling. This aspect is of great importance to the aviation industry. [5] revealed that Bamako is mostly cloudy with a visibility of 12 km. Another effect of a burdened atmosphere is the alteration of communication signals [1]. Hence, the continued environmental security of Bamako is of great importance. Also, the importance of aerosols on climate change in Bamako is very important because it could threaten the food security of the nation. Therefore in this paper, the aerosol loading was monitored using analytical and statistical techniques. The outcome is expected to enrich policy making in the nation of Mali.

II. VALIDATION OF DATA SOURCE

Bamako is the capital and largest city of Mali, with a population of 1.8 million (2009 census, provisional) and it is located on longitude 12.65 °N and latitude 8 °W in the Sahelian geographic region, south of the Sahara (see Figure 1), therefore, we expect a high impact of the north east winds alongside Sahara dust. Furthermore, it is also under the influence of local steppe climate. Its metropolitan area is about 499 km^2. Bamako has an average temperature and precipitation of 27.4 °C and 662 mm respectively. The distance of Bamako to the Sahara is about 742 km. In the past, no ground observation of aerosols was available; hence, the satellite observation was adopted. Satellite observation was obtained from the Multi-angle Imaging Spectro-Radiometer (MISR) for a period of fourteen years. The MISR operates at various directions i.e. at 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, green, red and infrared bands stretch through wavelengths of 443nm, 555nm, 670nm and 865nm respectively. MISR acquires images at two different levels of spatial resolution i.e. via local and global mode. It gathers data from the local mode at 275 meter pixel size and at 1.1Km from the global mode. Typically, the blue band is to analyze coastal and aerosol studies. The green band analyzes Bathymetric mapping and helps in the estimation peak vegetation. The red band analyses the variable vegetation slopes while the infrared band analyses the biomass content and shorelines.

Fig. 1. Map of Bamako and the Sahara influence.

III. METHODOLOGY

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 is characterized by interval scale i.e. the ability to possess positive and negative value. 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

$$CV=\sigma/\mu \qquad (1)$$

In equation 3, σ is the standard deviation and μ is the monthly mean.

The raw MISR dataset was processed using Spread Sheet Application (Excel). The monthly mean was calculated for each year. We tested the accuracy of the data by applying the aerosol dispersion model that was propounded by [6]. An extension of the dispersion model used is given as

$$\psi(\lambda) = a_1{}^2\cos\left(\frac{n_1\pi\tau(\lambda)}{2}x + \alpha\right)\cos\left(\frac{n_1\pi\tau(\lambda)}{2}y + \alpha\right) + a_2{}^2\cos\left(\frac{n_2\pi\tau(\lambda)}{2}x + \beta\right)\cos\left(\frac{n_2\pi\tau(\lambda)}{2}y + \beta\right) \qquad (2)$$

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 [7]. The Matlab curve fitting tool resolves numerically the constants highlighted in Equation (2) and gives the statistical analysis of the MISR dataset.

The percentage 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 propounded the aerosols retention between two years as:

$$A = \left|\frac{G_p - G_r}{G_p}\right|^2 \times 100\% \qquad (3)$$

The aerosols retention can be calculated using values in tables 1-2 to obtain the corresponding values in tables 3-4. Any apt statistical tool could be used to obtain the atmospheric aerosols retention. In this paper, Matlab and the Excel packages were used to obtain the results shown in the following section.

IV. RESULTS AND DISCUSSION

The AOD pattern of Bamako shows a gamma distribution with the maximum in April (Figure 2). The aerosol content in Bamako gradually reduced from April to December. Since, Bamako is located on the same tropical savanna climate, it is expected that the influence of north-east dust may be high. Out of fourteen years data, three years 2004, 2010 and 2012 had their maximum in March. The AOD pattern over Bamako agreed with the proposed model (Figures 3 and 4). Majority of the satellite observation in October and November did not correspond with the model. This may be as a result of excess influx of the north east dust into the environment. Hence, the aerosol retention which is expected to be high in March and April could rise above 30% as predicted by [8]. The inability of the self-cleansing mechanism over Bamako to reduce its aerosols retention and loading could lead to a maximum AOD in June as shown in Figure 2.

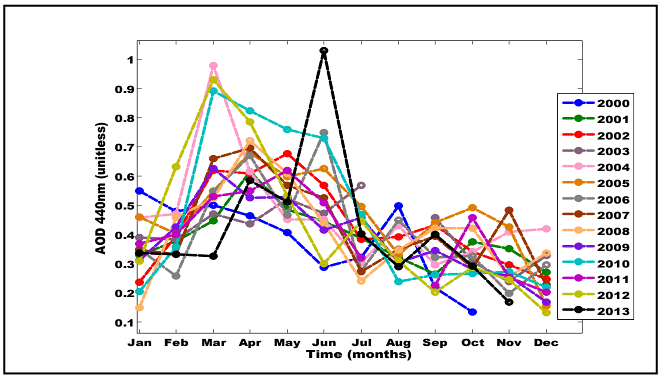


Fig. 2. AOD pattern for Bamako 2000 - 2013

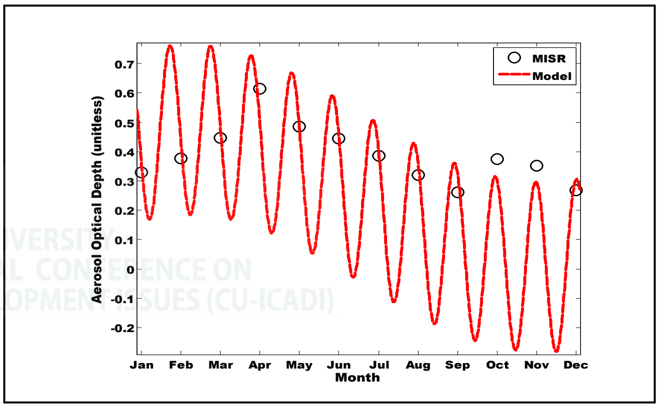


Fig. 3. AOD for new model and MISR for the year 2001.

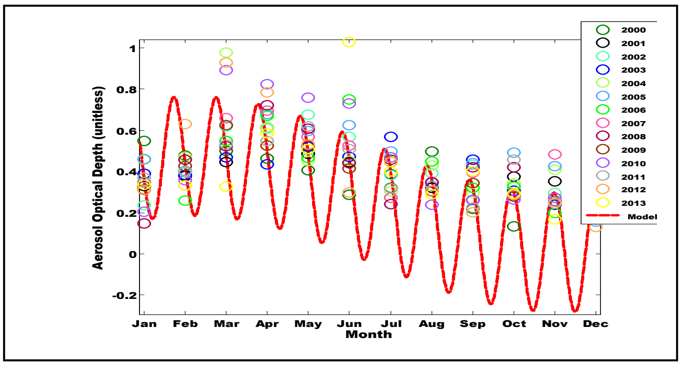


Fig. 4. AOD for new model and MISR for the year 2000-2013.

From figures 2 to 4, the atmospheric constants, phase differences and tuning constants were obtained using the Matlab curve fit tool and equation (2) and the values are as shown in Table 1 below:

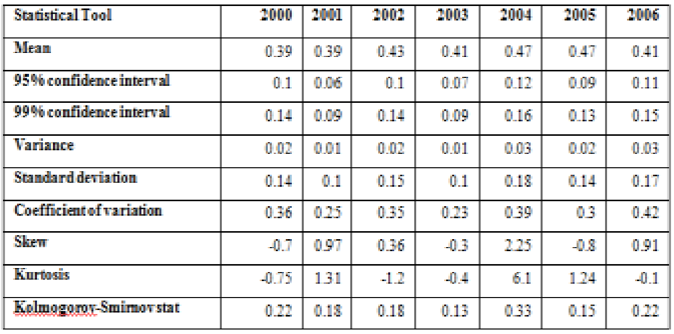
Table 1: Atmospheric constants over Bamako

Location	a_1	a_2	n_1	n_2	α	β
Bamako	0.7616	0.6676	-0.04547	0.8321	$\frac{\pi}{3}$	$\frac{\pi}{3}$

Based on variability in aerosols yearly dispersion, we statistically examined the AOD distribution over Bamako as shown in tables 2 & 3.

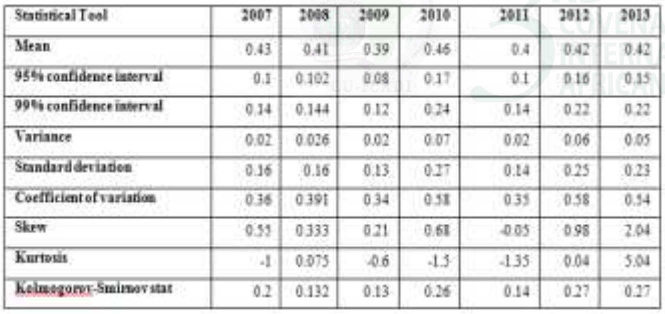
The highest AOD mean within the 95% confidence interval, 99% confidence interval, variance, standard deviation and coefficient of variation was obtained in 2010. The highest skew and kurtosis can be found in 2004. The highest Kolmogorov-Smirnov stat can be found in 2004. These results show that the lower atmosphere of Bamako may not be dynamic as cities in the northern Mali [8]. Hence we examined the atmospheric aerosol retention shown in Tables 4 & 5.

Table 2: Statistical AOD analysis 2000-2006



Statistical Tool	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**
Mean	0.39	0.39	0.43	0.41	0.47	0.47	0.41
95% confidence interval	0.1	0.06	0.1	0.07	0.12	0.09	0.11
99% confidence interval	0.14	0.09	0.14	0.09	0.16	0.13	0.15
Variance	0.02	0.01	0.02	0.01	0.03	0.02	0.03
Standard deviation	0.14	0.1	0.15	0.1	0.18	0.14	0.17
Coefficient of variation	0.36	0.25	0.35	0.23	0.39	0.3	0.42
Skew	-0.7	0.97	0.36	-0.3	2.25	-0.8	0.91
Kurtosis	-0.75	1.31	-1.2	-0.4	6.1	1.24	-0.1
Kolmogorov-Smirnov stat	0.22	0.18	0.18	0.13	0.33	0.15	0.22

Table 3: Statistical AOD analysis 2007-2013

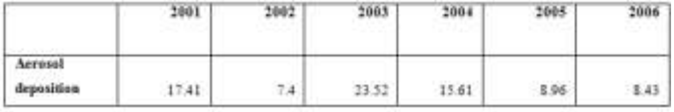


Statistical Tool	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Mean	0.43	0.41	0.39	0.46	0.4	0.42	0.42
95% confidence interval	0.1	0.102	0.08	0.17	0.1	0.16	0.15
99% confidence interval	0.14	0.144	0.12	0.24	0.14	0.22	0.22
Variance	0.02	0.026	0.02	0.07	0.02	0.06	0.05
Standard deviation	0.16	0.16	0.13	0.27	0.14	0.25	0.23
Coefficient of variation	0.36	0.391	0.34	0.58	0.35	0.58	0.54
Skew	0.55	0.333	0.21	0.68	-0.05	0.98	2.04
Kurtosis	-1	0.075	-0.6	-1.5	-1.35	0.04	5.04
Kolmogorov-Smirnov stat	0.2	0.132	0.13	0.26	0.14	0.27	0.27

The undulating nature of all the statistical values is an evidence of the influence of climatic change on the yearly aerosols loading [9]. However, the negative Skew values as shown in 2000, 2003, 2005 and 2011 are subject to investigation. [10] gave the significance of negative Skew. It was explained that it reflects synergism of the events. Therefore, there is a positive synergy in the AOD data set in 2000, 2003, 2005 and 2011. This means that the aerosol retention in other years were very conspicuous on an annual basis. Also, a negative kurtosis exists in 2000, 2002, 2003, 2006, 2007, 2009, 2010 and 2011. This means that the probability of the AOD data (in the aforementioned years) to conform to model is low. This assumption can be seen in the non-conformity of October and November readings of these years to the proposed dispersion model (Figure 2).

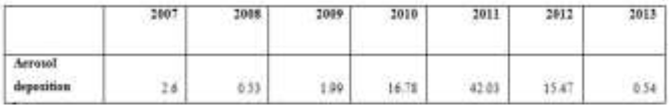
The statistical results shown above necessitate the use of equation (3) to examine the aerosols retention in the atmosphere of Bamako (Table 4 & 5). The aerosols retention can be used to monitor the performance of the atmospheric self-cleansing mechanism. The most significant highest values of aerosols retention can be found in descending order in 2011 (42.03%), 2003 (23.52%), 2001 (17.41%), 2010 (16.78%), 2004 (15.61%) and 2012 (15.47%). It can be shown the possibility of aerosols retention build-up for the space of 3 years, that is, 2001-2003.

Table 4: Atmospheric aerosols retention over Bamako 2001-2006



	2001	**2002**	**2003**	**2004**	**2005**	**2006**
Aerosol deposition	17.41	7.4	23.52	15.61	8.96	8.43

Table 5: Atmospheric aerosols retention over Bamako 2007-2013



	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Aerosol deposition	2.6	0.53	1.09	16.78	42.03	15.47	0.54

V. CONCLUSION

Aerosols have the capacity to influence climatic conditions as shown in the statistical analysis. In this paper, a good statistical analysis and prediction of annual aerosol retention in Bamako state has been presented as a necessary step towards knowing the aerosol concentration, deposition or degree of aerosols loading for 14 consecutive years. The optical state values over Bamako (Table 1) showed the reality of both environmental and food security in the nearest future if the excess aerosol loading is not checked or controlled. This is because the optical state over an area affects photosynthesis, agricultural production and the energy balance of the atmosphere. From the studies/statistical analyses, the skew and Kurtosis are reliable tools for predicting the aerosol loading and concentration in Bamako although, they do not reveal the actual loading potential (aerosol loading rate) of the aerosols in the area. The most significant highest values of aerosols retention can be found in descending order in 2011 (42.03%), 2003 (23.52%), 2001 (17.41%), 2010 (16.78%), 2004 (15.61%) and 2012 (15.47%).

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