Verification of Aerosols Loading Over Kano: A Theoretical Estimation via Mathematical Rudiments

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Verification of Aerosols Loading Over Kano: A Theoretical Estimation via Mathematical Rudiments

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Abstract—**The danger of aerosols loading is dangerous to human as well as the atmosphere. The estimation of the aerosol loading can be very difficult in any location in West Africa because of its proximity to the influence of the north-east winds from the Sahara desert. An established analytical and statistical approach was used to estimate the aerosol loading over Kano. The maximum aerosol retention over Kano is 31.28%. The atmospheric constant which also describes the aerosols loading over Kano was found to be 0.708 and 0.8984. This means that Kano may be facing high thermal discomfort as well as spread of disease if not checked.**

Index Terms—**aerosols loading, aerosols retention, atmospheric constant**

I. Introduction

Aerosols are mixtures of tiny particles and liquids which may sometimes appear as colloids. Their presence in the atmosphere affects the earth's climate and radiation reflection potential. Their high concentration poses risks to human health, vegetation, agriculture and human safety [1,2]. They also constitute and contribute pollutants to the atmosphere and the air we inhale. Aerosols concentration in the lower atmosphere has been on the steady increase owing to industrial activities and burning of biomass. Report has it that, aerosols distribution and concentration affect the earth's radiation at the surface and at the top of the atmosphere Wenying et al [7].

In recent years, the importance of aerosols on climate change has yielded concerted effort towards data acquisition of spatial dispersion and depth of aerosols. However, space and ground based remote sensing deployed in the past, were targeted at understanding aerosol effects on climate change. The ground-based measurement network tool (SKYNET) is the data generating instrument which has several monitoring stations equipped with a sky radiometer, a pyranometer and pyrgeometer at various locations of East Asia. Inversions of the measured radiations from the radiometer integrated in SKYNET finds importance in determining aerosol optical thickness, single scattering albedo, volume size distribution, and refractive index of aerosol particles [5].

One of the major challenges facing scientist (about the aerosol) is the inability to adequately estimate – aerosol distribution, aerosol-cloud interactions, physical and chemical properties [3]. The other effect of aerosols can be found in the initiation of varying degrees of thermal comfort. The estimation of aerosols loading in Kano and other parts of West Africa is a currently a major problem. The aerosol loading controls the cloud formation as well as the precipitation over any geographical location. In this study, established analytical model and the statistical model were used to estimate the aerosols loading over Kano.

II. Validation of Data source

Kano is the second most populous city in Nigeria and it is located on longitude 8.52^{o}E and latitude 12^{o}N in the Sahelian geographic region, south of the Sahara, 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. Kano has an average temperature and precipitation of 26.1 °C and 752 mm respectively. The distance of Kano to the Sahara is about 2826 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^{o}, 60^{o}, 45.6^{o}, 26.1^{o}, 0^{o}, 26.1^{o}, 45.6^{o}, 60^{o}, 20.5^{o}) 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.

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III. METHODOLOGY

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 Emetere et al. [1]. An extension of the dispersion model used is given as

$$\psi(\lambda) = a_1{}^2\cos\left(\frac{n_1\pi\tau(\lambda)}{k_y} + \alpha\right)\cos\left(\frac{n_1\pi\tau(\lambda)}{k_z} + \alpha\right) + a_2{}^2\cos\left(\frac{n_2\pi\tau(\lambda)}{k_y} + \beta\right)\cos\left(\frac{n_2\pi\tau(\lambda)}{k_z} + \beta\right) \quad (1)$$

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.

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:

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

The aerosols retention can be calculated to obtain the corresponding values in Tables 2-3. 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

Kano's monthly AOD trend agreed perfectly with the proposed model (see figure 1a to c). The AOD pattern over Kano is a gamma distribution with its average maximum in February, March and April for the years 2005, 2001 and 2003 respectively, while the month of April in the year 2010 shows the highest aerosol optical depth. Also, it could be seen that the patterns for nearly all the years show an initial rise in the aerosol depth within the first quarter and drops subsequently within the remaining months. From figure 1a-c, it can be trivially inferred that the type of aerosols in Kano are majorly dust particulates from the northeast wind. The AOD retrieval technique by MISR is perfect over Kano. A simple explanation is that Kano falls within the satellite orbit. Beyond this simple reason, Accuweather [8] showed that Kano has a more stable weather compared to other parts of northern Nigeria.

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

The highest AOD mean within the 95% confidence interval, 99% confidence interval, variance, standard deviation and coefficient of variation was obtained in 2005. The highest skew and kurtosis can be found in 2010. The highest Kolmogorov-Smirnov stat can be found in 2004. These results show that the lower atmosphere of Kano may not be dynamic as cities in the southern Nigeria [2]. Hence we examined the atmospheric aerosol retention shown in Tables 2 & 3.

From Table 2, it could be seen that, the mean for all the years between 2001 and 2006 is oscillatory with values rising and falling between 2000 and 2003. There was a rise in the mean as expected (0.52) in the year 2004 but the trend was different in 2005 where the mean is 0.63 and dropped in 2006. Within the 95% confidence interval, the confidence levels between 2000 and 2003 were 17%, 12%, 15% and 14% respectively until the year 2004 where, instead of decreasing in the year 2005, the confidence level increased by 5% and dropped in 2006 with about 7% when compared with the value for the previous year. Within the 99% confidence interval, the confidence levels showed the same trend for all six years i.e. 24%, 16%, 22%, 20%, 28% and 18% respectively; this then implies with higher confidence interval, there is a boost in the confidence level of the predicted aerosol depth. For the estimated variances, the pattern seemed unchanged as the variances for the six years (2000-2006) are 0.06, 0.03, 0.06, 0.05, 0.06 and 0.04 respectively, although the estimated variance for the predicted aerosol depth was the same for 2001, 2003 and 2005. The standard deviation for all the years dropped from 0.24 to 0.18 between 2000 and 2001. It rose to 0.24 in 2002 and dropped to 0.22 in 2003. In 2004, the value rose slightly by 1%. It increased by 6% (0.29) in 2005 and dropped by 7% the year after. The coefficient of variation dropped from 0.44 in 2000 to 0.37 in 2001. It rose by 6% in 2002 against the previous year and remained constant all through 2002 to 2003. The value dropped to 0.41 in 2004, rose to 0.46 in 2005 and dropped significantly by 13% in 2006 as compared with the value for the previous year. Considering the calculated skews for the six years, the highest skews were recorded for the years 2000 and 2006. It dropped from 1.3 in the year 2000 to 0.06 in 2001, it rose to 0.6 in 2002, it was 0.92 in 2003, 1.13 in 2004, 0.85 in 2005 and rose again to 1.3 in 2006. Based on the calculated Kurtosis (K-value), the highest value (2.46) was obtained in 2006 with that of the year 2000 being the second highest value with 0.75. In 2001, the K value dropped significantly from 0.75 (i.e. the value for year 2000) to -1.5, it rose to 0.18 in 2002, dropped to zero in 2003 with recorded decrease of 0.5 and 0.6 for the years 2004 and 2005 respectively.

Considering Table 3, it is clear that the highest estimates for all the parameters were recorded in the year 2010. Comparing all the means from 2007 down to 2013, it is evident that the highest mean (0.57) was recorded for the year 2010. Within the 95% confidence interval, the highest level of confidence (i.e. 0.19) was also recorded for the year 2010. The confidence level within the 99% confidence interval was 0.26 for the same year while it was 0.18 in 2000, 2009 and 2012 and lower for the remaining years. The year 2010 is also characterized by a variance of 0.08; it can also be seen that, the standard deviations for the years having same confidence levels within the confidence limits, are the same i.e. for the years 2007, 2009 and 2012, the values of the aforementioned parameters are the same, it is 0.23 for 2008, 0.2 for 2007 and 2009 and 0.17 for 2011 and 2013. The recorded standard deviations for the three years are also the same with the value for 2010 being the highest. The coefficient of variation is also highest for the year with a value of 0.49, while others are 0.36, 0.42, 0.38, 0.31, 0.34 and 0.33 for the years 2007, 2008, 2009, 2011, 2012 and

2013 respectively. From the calculated skews, the highest skew (1.93) was calculated for the year 2010; it was 1.02 in 2007 and dropped to 0.53 in 2008 with a very significant drop of 62% (i.e. -0.2). In 2011, it was 0.55. It rose to 0.67 in 2012 with a significant drop of about 87% in 2013. For the estimated Kurtosis, the highest K-value of 4.38 was obtained in 2010 while it dropped significantly between 2007 and 2008 from 0.37 to -0.9. It was even lower in 2009 (i.e. -1.6), it then rose to 4.38 in 2010 after which it continued to drop for the last three years. For the Kolmogorov, the highest value (0.2) was obtained in the year 2010 with the difference between the value in 2010 and other years ranging between 0.01-0.05.

Based on the calculated skews and Kurtosis, the years of highest atmospheric aerosols retention are 2010 and 2011 with estimated aerosol deposits of 4.52 and 31.28 respectively. 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 and Chen, 2013), human health (Wyzga and Lawrence, 1995), measuring instruments, energy budget and meteorology (Emetere and Akinyemi, 2013).

V. CONCLUSION

Aerosols have the capacity to influence climatic conditions via cloud formation thus dispersing light which in turn alters the earth’s reflectivity i.e. they affect the way the clouds absorb and reflect light. They form tiny seeds in the atmosphere called cloud condensation nuclei which influences cloud formation and precipitation pattern. In this paper, a good statistical analysis and prediction of annual aerosol distribution in Kano state has been presented as a necessary step towards knowing the aerosol concentration, deposition or degree of precipitation. This study has successfully made good predictions of the aerosol loading for a total of 14 consecutive years. One of the dangers of this finding is the possibility that the current state of aerosols loading over Kano may affect photosynthesis, agricultural production and the energy balance of the atmosphere. These effects would have been more significant in the years 2010 and 2011. From the studies/statistical analyses, the skew and Kurtosis are reliable tools for predicting the aerosol loading and concentration in Kano state although, they do not reveal the actual loading potential (aerosol loading rate) of the aerosols in the area. Among the health risks of aerosols include bronchial infections in areas of high aerosols loading and short/long term adverse reactions to such toxic pollutants or contaminants hence, it is therefore necessary to ascertain the aerosol concentration or loading of the place in order to determine and avoid potential hazards. Furthermore, the year with the highest aerosol deposition was 2011 and this may be due to the high rate of human activities, industry operations and other factors responsible for climate change in the area considered.

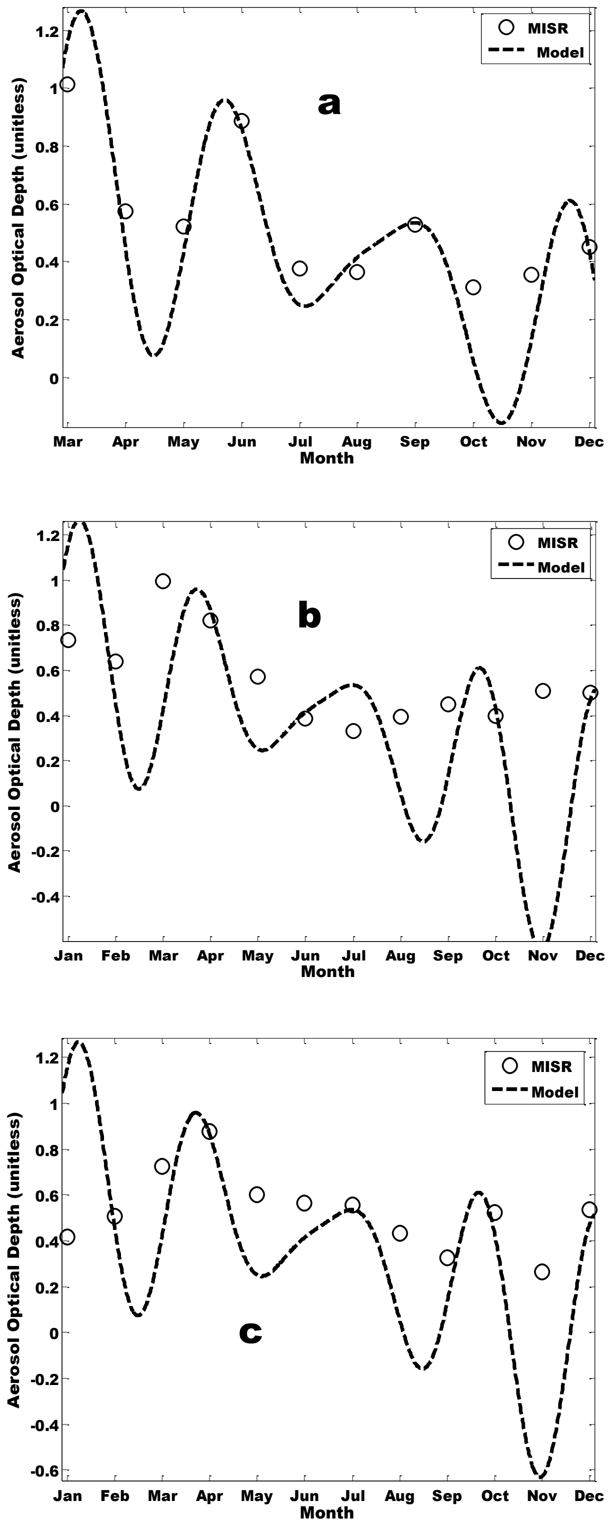

Fig. 1. Aerosols optical depth for fourteen years

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Table 1: Atmospheric constants over Kano

Location	a_1	a_2	n_1	n_2	α	β
Kano	0.708	0.8984	0.3173	0.3863	$\pm\frac{\pi}{2}$	$\pm\frac{\pi}{2}$

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Table 2: Statistical AOD analysis 2000-2006

Statistical Tool	2000	2001	2002	2003	2004	2005	2006
Mean	0.54	0.49	0.56	0.52	0.57	0.63	0.61
95% confidence interval	0.17	0.12	0.15	0.14	0.15	0.2	0.13
99% confidence interval	0.24	0.16	0.22	0.2	0.21	0.28	0.18
Variance	0.06	0.03	0.06	0.05	0.06	0.09	0.04
Standard deviation	0.24	0.18	0.24	0.22	0.23	0.29	0.2
Coefficient of variation	0.44	0.37	0.43	0.43	0.41	0.46	0.33
Skew	1.3	0.06	0.6	0.92	1.13	0.85	1.3
Kurtosis	0.75	-1.5	0.18	0	-0.5	-0.6	2.46
Kolmogorov-Smirnov stat	0.24	0.15	0.15	0.17	0.31	0.22	0.2

Table 3: Statistical AOD analysis 2007-2013

Statistical Tool	2007	2008	2009	2010	2011	2012	2013
Mean	0.56	0.54	0.51	0.57	0.53	0.58	0.51
95% confidence interval	0.13	0.14	0.13	0.19	0.11	0.13	0.11
99% confidence interval	0.18	0.2	0.18	0.26	0.15	0.18	0.16
Variance	0.04	0.05	0.04	0.08	0.03	0.04	0.03
Standard deviation	0.2	0.23	0.2	0.28	0.17	0.2	0.17
Coefficient of variation	0.36	0.42	0.38	0.49	0.31	0.34	0.33
Skew	1.02	0.53	-0.2	1.93	0.55	0.67	0.09
Kurtosis	0.37	-0.9	-1.6	4.38	0.88	0.71	-1.4
Kolmogorov-Smirnov stat	0.19	0.18	0.19	0.2	0.17	0.15	0.18

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