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Statistical examination of the aerosols loading over Kano – Nigeria: the Satellite observation analysis

Key words: aerosols retention, aerosols loading, statistical tool, analytical dispersion model

Introduction

Aerosols are systems of solid or liquid particles suspended in air or other gaseous environment. They vary in size and composition and can be naturally or manmade generated, thus there are a wide range of them, from flame synthesized nanoparticles and nanomaterials (Stahlmecke et al., 2009). The number of particles, mass distribution, dusty flows, the deposition rate and the mean size of the particles have been estimated in several countries, especially in Ghana (Sunnu et al., 2008) Mali (McTainsh et al., 1997), and Nigeria (Anuforom, 2007). Nigeria is one of the countries in west Africa most exposed to desert dust because of its proximity to the main emission source area and its location with regard to the dominant winds. Studies show that the dust quantity which varies from year to year is greater in the Northern parts of these countries and the dust particles become finer in size as they move further south (Rutherford et al., 1999; Anuforom, 2007; Uduma and Jimoh, 2013). Kano has about 9.4 million inhabitants and thus becomes one of the megacities in West Africa who confront severe challenges of air quality management. Along with rapid economic growth and vehicle increase, the features of air pollution in Kano are changing from typical firewood and/or fossil fuel combustion pollution to a complex pollution case (Zhang et al., 2004). The current climate change is affecting the environment in diverse ways. Among the atmospheric aerosols, mineral dust produced from windblown soils and deserts is one of the largest contributors to the global aerosol loading and has strong impacts on human health (Emetere et al., 2015a, b). Harmathan dust is considered to be among the most harmful of all air pollutants due to the toxic effect of the dust constituents. When aerosols absorb pollutants, it facilitates the deposition of

pollutants to the surface of the earth as well as to bodies of water (Kommalapati et al., 2009) which has the potential to cause damage to both the environment and human health. Aerosol particles with an effective diameter smaller than 10 μm can enter the bronchi, while the ones with an effective diameter smaller than 2.5 μm can enter as far as the gas exchange region in the lungs (Kommalapati et al., 2009), which can be hazardous to human health. Recent reasearches show that people experience nasal congestion, cough, muscular aches and pains, painful watery eyes (Apollo), and unusual high body temperature during the Harmattan periods in Northern Nigeria. Respiratory infections make up more than 20% of the causes of infant mortality and morbidity (Morris et al., 2003; Bryce et al., 2005). Therefore an in-depth study of the aerosols over Kano is paramount to protect life forms against natural disasters that accompany aerosols loading. In the present study, a stastistical examination of the aerosols loading over Kano – Nigeria was observed and an analytical dispersion model were adopted to monitor the aerosols loading, as well as the aerosols retention.

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. Standard error technique used for this research captures the standard deviation of the monthly means over three decades sample. The standard error of the mean is expressed mathematically as

$$SE = \frac{s}{\sqrt{n}} \tag{1}$$

where:
s – population standard deviation,
n – population size.

Standard error measures the uncertainty in aerosol optical depth parameter and the deviations of the monthly mean from the thirteen-years 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-years mean also called expected value. Also, a high magnitude standard deviation signifies how far monthly mean is from the thirteen-years mean. Standard deviation is given as

$$\sigma = \sqrt{\frac{1}{N}\sum_{j=1}^{N}(y_i - \overline{y})^2} \tag{2}$$

where:
y_i – context of our research is the monthly-mean,
$\overline{y}$ – mean value of the thirteen-year mean.

The concept of variance is intrinsically connected with the effects of the difference between the monthly mean and the thirteen-years mean on the AOD performance in Kano, Nigeria. The coefficient of variation is the measure of a normalized dispersion of probability distribution, i.e. the thirteen years 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 for few meteorological para-

meters because of the inconsistency of its interval scale. For example, coefficient of variation is appropriate for the Kelvin scale and inappropriate for the Celsius scale because its data has interval scale. Therefore, we adopted the coefficient of variation because the scale used has interval scale and appropriate for comparison between data sets of widely different yearly or monthly means. Coefficient of variation can be represented mathematically as

$$CV = \frac{\sigma}{\mu} \tag{3}$$

where:
σ – standard deviation,
μ – 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. The skewness value can be positive, negative, or undefined. When the skew is negative, it indicates that the mass of the distribution is concentrated on the right of the plotted graph, i.e. left--skewed. When the skew is positive, the mass of the distribution is concentrated on the left of the plotted graph, i.e. right--skewed. The skew of a distribution can be written mathematically as

$$X = \frac{(\mu - \upsilon)}{E(|X - \upsilon|)} \tag{4}$$

where:
υ – median,
E – 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 of the shape of a probability distribution which can be interpreted as $\beta > 3$ (Leptokurtic distribution – high probability for extreme values), $\beta < 3$ (Platykurtic distribution – probability for extreme values is less than for a normal distribution) and $\beta = 3$ (Mesokurtic distribution – normal distribution). Kurtosis mathematically written as

$$\beta = \frac{\mu^4}{\sigma^4} \tag{5}$$

All parameters retain its usual meaning. The simulation was carried out using Surfer analytical tool.

Validation of data source

Kano is the second populous city in Nigeria and it is located on longitude 8.52°E and latitude 12°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. Also, it is also under the influence of the local steppe climate. Its metropolitan area is about 499 km^2. Kano has average temperature and precipitation of 26.1°C and 752 mm respectively. The distance of Kano to the Sahara is about 2,826 km. In the past, no aerosols ground observation was available; hence, the satellite observation was adopted. Fourteen years satellite observation was obtained

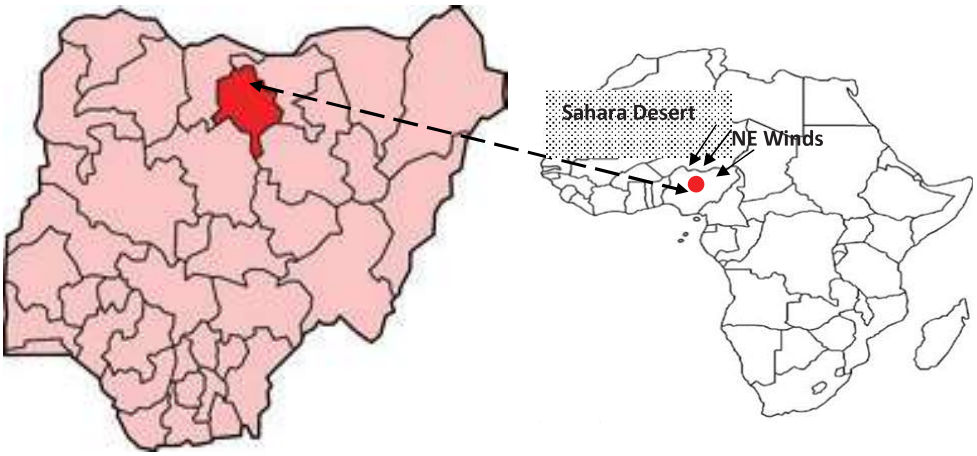

FIGURE 1. Map of Kano and the Sahara influence

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 wave-length 443 nm, the green band is at wave-length 555 nm, the red band wave-length 670 nm and the infrared band is at wave-length 865 nm. 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 m pixel size and 1.1 km at the global mode. Typically, the blue band is to analyze coastal and aerosol studies. The green band is to analyze Bathymetric mapping and estimating peak vegetation. The red band analysis the variable vegetation slopes and the infrared band analysis the biomass content and shorelines.

Methodology

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

$$\psi(\lambda) = a_1^2 \cos\left(\frac{n_1 \pi \tau(\lambda)}{k_y} + \alpha\right)\cos\left(\frac{n_1 \pi \tau(\lambda)}{k_z} + \alpha\right) + \\ + a_2^2 \cos\left(\frac{n_2 \pi \tau(\lambda)}{k_y} + \beta\right)\cos\left(\frac{n_2 \pi \tau(\lambda)}{k_z} + \beta\right) \tag{6}$$

where:
ψ – concentration of contaminant,
α, β – phase differences,
τ – the AOD,
λ – wave-length,
k – diffusivity,
a, n – atmospheric and tuning constants.

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:

$$A = \left| \frac{G_p - G_r}{G_p} \right|^2 \times 100\% \qquad (7)$$

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

Results and discussion

Kano monthly AOD trend agreed perfectly with the proposed model (Figs 2 to 5). The AOD pattern over Kano is a gamma distribution with the average maximum in March. From Figure 6, it can be inferred that the type of aerosols in Kano is majorly dust particulates from the northeast wind. The AOD retrieval technique by MISR is perfect over Kano. A trivial explanation is that Kano falls within the satellite orbit. Beyond the trivial reason, Accuweather (2015) showed that Kano has a more stable weather compared to other parts of the northern Nigeria.

From Figures 2 to 5, the atmospheric constants, phase differences and tuning constants can be inferred from the Matlab curve fit tool and equation (6) as shown in Table 1.

The statistical analysis of the proposed model in Kano was within 95% confidence bounds (Figs 3–5). The properties of the "goodness of fit" for all the curves in Figures 3–5 have sum of squares due to error (*SSE*) of 0.006216. *SSE* measures the total deviation of the response values from the fit to the response values. The R-square is given as 0.9468. *R*-square measures how successful curve fits in explaining the variation of AOD data. From the data, it is shown that the proposed model is able to explain 94.68% of the total variation in the MISR data. It is important to note

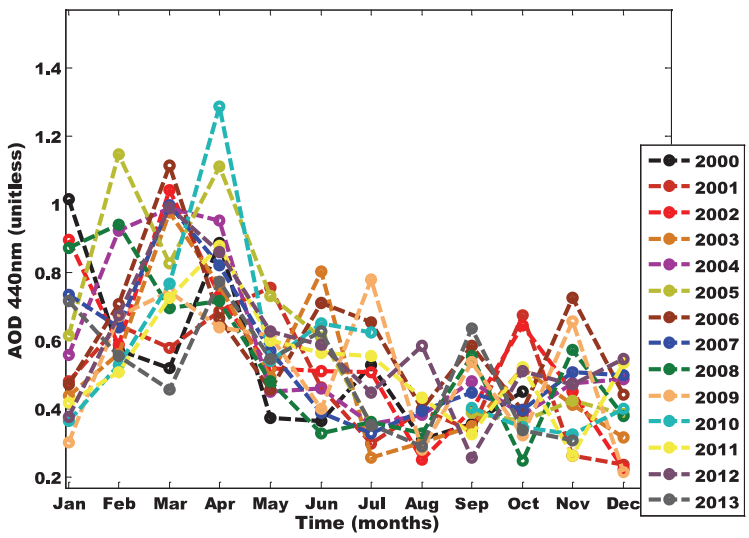

FIGURE 2. AOD pattern for Kano 2000–2013

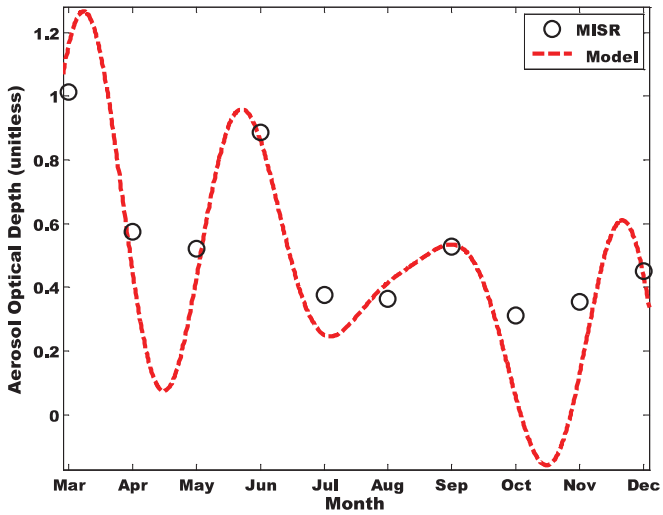

FIGURE 3. AOD pattern for Kano 2000

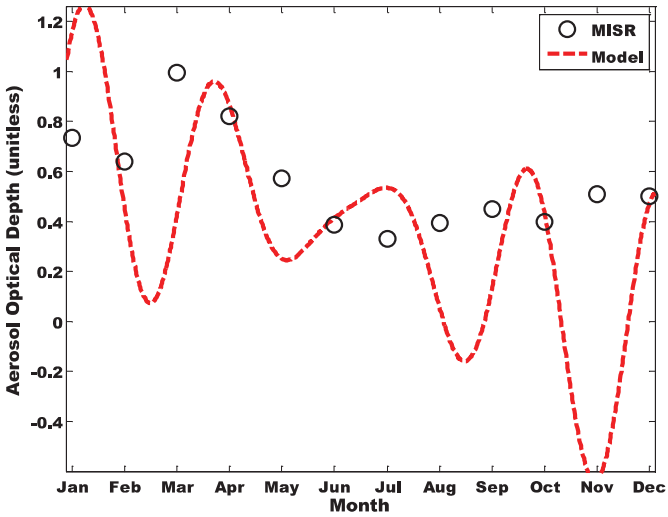

FIGURE 4. AOD pattern for Kano 2003

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	$\pm\frac{\pi}{2}$	$\pm\frac{\pi}{2}$

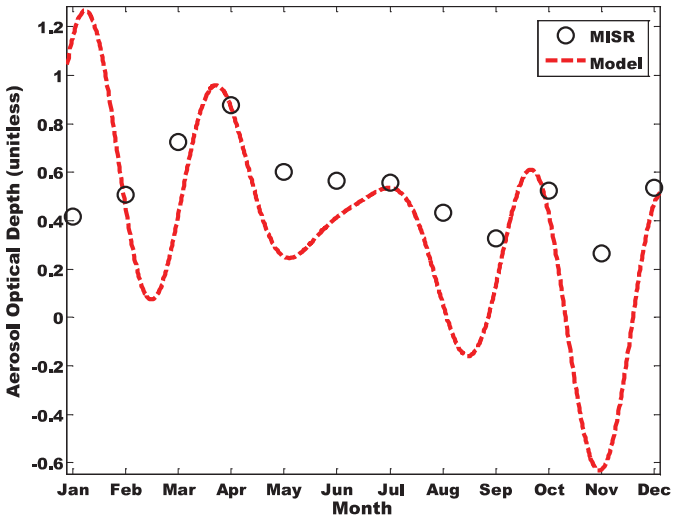

FIGURE 5. AOD for new model and MISR for the year 2007

that this paper has significant interest to the ITU model because it suggests an alteration in its known model shown in equation

$$N = \frac{77.6P}{T} + 3.73 \times 10^5 \frac{e}{T^2} = \\ = N_{dry} + N_{wet} (N - units) \tag{8}$$

where:
e – water vapour pressure [hPa],
P – atmospheric pressure [hPa],
T – absolute temperature [K].

The mathematical relationship between relative humidity and water vapour pressure is expressed in the following equation:

$$e = \frac{RH}{100} a \exp\left[\frac{bT}{T+c}\right] \tag{9}$$

where:
T – temperature [°C],
$a = 6.1121$,
$b = 17.502$,
$c = 240.97$.

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 Kano. Upon this concept, we statistically examine the AOD distribution over Kano as shown in Tables 2 and 3.

The highest AOD mean, 95% confidence interval, 99% confidence interval, variance, standard deviation and coefficient of variation was in 2005. The highest skew and kurtosis can be found in 2010. The highest Kolmogorov–Smirnov stat can be found in 2004. This results shows that the lower atmosphere of Kano may not be dynamic as cities in the southern Nigeria (Emetere et al., 2015b).

Hence we examine the atmospheric aerosol retention shown in Tables 4 and 5.

The year of the highest atmospheric aerosols retention was found between 2010 and 2011. 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

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

TABLE 4. Atmospheric aerosols retention over Kano 2001–2006

Item	2001	2002	2003	2004	2005	2006
Aerosol deposition	2.96	1.5	0.04	0.38	1.3	15.2

TABLE 5. Atmospheric aerosols retention over Kano 2001–2006

Item	2007	2008	2009	2010	2011	2012	2013
Aerosol deposition	0.63	1.87	0.73	4.52	31.28	0.82	0.094

(Gettelman and Chen, 2013), human health (Ronald and Lawrence, 1995), measuring instruments, energy budget and meteorology (Emetere and Akinyemi, 2013).

Conclusion

A stastistical examination of the aerosols loading over Kano – Nigeria was observed and analytical dispersion model was used to estimate the aerosols loading for each month of the year. The atmospheric constants show that the volume of pollution in Kano is enough to alter the ITU model. The average aerosols retention over Kano is 5%. This shows that the self-cleansing mechanism of the atmosphere is gradually becoming weak to purge itself. Kano monthly AOD trend agreed perfectly with the analytical dispersion model. The aerosols gamma distribution over Kano is maximum in March. Hence, the type of aerosols in Kano is majorly dust particulates emanating from the north-east wind. The year of highest atmospheric aerosols retention was found between 2010 and 2011. This skew and kurtosis are also good indicators of atmospheric aerosols retention. The significance of the atmospheric aerosols retention in a geographical region has great influence on aviation schedules, human health, measuring instruments, energy budget and meteorology.

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Summary

Statistical examination of the aerosols loading over Kano – Nigeria: the Satellite observation analysis. The problem of underestimating or overestimating the aerosols loading over Kano is readily becoming a global challenge. Recent health outcomes from an extensive effect of aerosols pollution has started manifesting in Kano. The aim of the research is to estimate the aerosols loading and retention over Kano. Thirteen years aerosol optical depth (AOD) data was obtained from the Multi-angle imaging spectroradiometer (MISR). Statistical tools, as well as analytically derived model for aerosols loading were used to obtain the aerosols retention and loading over the area. It was discovered that the average aerosols retention over Kano is 4.9%. The atmospheric constants over Kano were documented. Due to the volume of aerosols over Kano, it is necessary to change the ITU model which relates to signal budgeting.

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