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Mass Concentration Gradient Of Aerosol Across Selected States In Northwestern Nigeria

A. O. Essienimo, M. Momoh, D. O. Akpootu

M. Sc. Student, Department of Physics, Usmanu Danfodiyo University Sokoto, Nigeria
Department of Physics, Usmanu Danfodiyo University Sokoto, Nigeria
Email: essienic70@gmail.com

ABSTRACT: A study of the mass concentration of aerosol across four selected states in Northwestern Nigeria during 2014 harmattan season has been conducted. The region which is located within latitude 10° and 14°N and longitude 2° and 8°E has a wide spatial variation in the mass concentration of aerosol. The mass concentrations of aerosol were observed to decrease as their distance from the dust source increases. In addition, it was observed that the mass concentration gradient of aerosol tends to be higher in the East-west direction with 9.36 $\mathbf{mgm^{-3}}$ per degree than in the North- south direction with 8.88 $\mathbf{mgm^{-3}}$per degree. The intensity of solar radiation during the study period was also observed to be affected by the mass concentration of aerosol.

Keywords: Concentration gradient, Mass concentration, Solar radiation, Harmattan dust, visibility.

1 INTRODUCTION

The winter season in Northwestern Nigeria, which usually covers a period of about five months has for years been associated with the presence of large volumes of dust particle over the atmosphere. In West Africa, it dominates during the dry season from November to March conveying dust across West Africa to the Atlantic Ocean [1]. The wind system that is associated with the ejection and transportation of dust from the Sahara desert periodically to some areas in West Africa is known as the harmattan [2]. [3] observed that the dust that affects a greater part of West-Africa in winter south of latitude 15°N particularly the Nigerian zone comes mainly from North Eastern Sahara, usually along the alluvian plain of Bilma (18°N, 12°E) in the Southern Niger and Faya largeau (18°N,19°E) Chad of the Western slope of Tibesti Massive. The dust particles travel as far as Southern Africa [4]. The northern Chad basin in West Africa is fed with sediments by streams from wetter areas [5]. This is because the intense heating over the Sahara desert causes sand and dust particles to be uplifted into the atmosphere by convective forces to a great height estimated to reach 6.0 km above sea level [6]. [7] reported that at the leading edge of the storm, winds may attain velocity greater than 14 ms^{-1}. On average, it takes about 24 hours for the dust to reach the northern border of Nigeria with dust front of about 5 to 7 ms^{-1} [3]. The dust particles mainly settle under gravity aerodynamic forces. Thus, sedimentation of dust particle begins immediately after it has been transported with the largest particle dropping first and quickly [8] and thereafter, there is a systematic reduction in the dust concentration and particle sizes with distance from the source areas along the flow downstream. Particles that remain in suspension for a long time are expected to supply condensation nuclei for cloud formation and rain [8]. The general properties of harmattan season include low humidity and the degradation of visibility [9], depletion of solar radiation [10], pollution of ambient air [11] and high level of particulate matter [12]. [13] noted that, the huge amount of dust and sand particles raised and transported by the harmattan dust haze strongly reduces visibility and reflects the Sun ray over the affected area for a long number of days. This indicates that the intensity of solar radiation reaching the earth's surface of such affected region is dependent on the concentration of harmattan dust across the region. Recent study by the Nigerian meteorological agency [NIMET] also show that visibility reduced to 100-900 m in the north and 600-800 m in the south [14]. Moreover, the signal of climate change in Nigeria has become visible as observed in other parts of the world. These include the general increase in mean temperature, short rainfall duration, increasing storm frequency, shift in onset and duration of little dry season (August break) and most importantly increasing heat wave in the extreme north [15]. Therefore, there is the need for adequate understanding of the past, present and future harmattan dust concentration distribution as well as how it is being transported across Nigeria. This particular study aimed mainly at determining the mass concentration of the harmattan dust over the atmosphere of four (4) states selected randomly across North Western region of Nigeria (Fig.1) covering an area of about 126 727km^2. The four states include Sokoto, Katsina, Kebbi and Zamfara. The region lies between latitude 10° and 14°N and longitude 2° and 8°E.

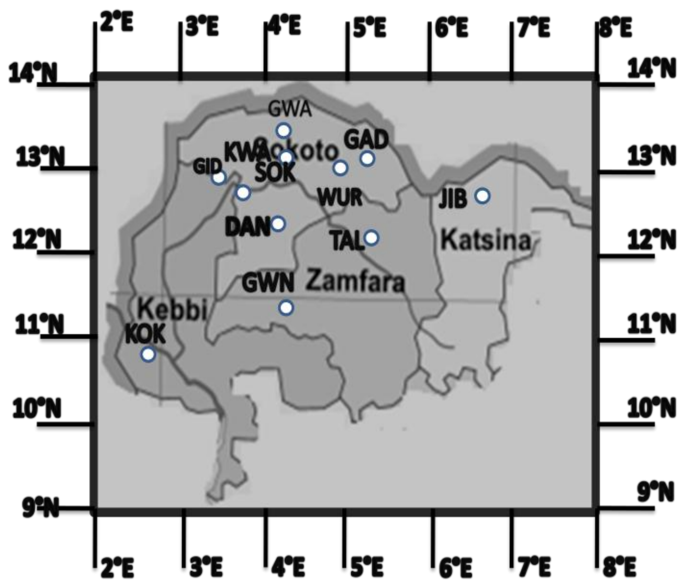

Fig. 1. *The location of regional and sub-regional sites of sampled data for this study.*

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2 METHODOLOGY

2.1 Apparatus

The apparatus used for this research were carefully selected in order to sample and evaluate the mass concentration of harmattan dust in the atmosphere of the study area and correlate its influence on global solar radiation during the season of winter in the North West of Nigeria. Therefore, the following apparatus were employed for this research work.

1. **The Series 296 Marple Cascade Impactor**. (Measures the concentration of the harmattan dust particle and its particle size distribution)
2. **The LI-200 Pyranometer**. (Measures The Global radiation)
3. **A LI-1400 Data Logger** (Displays the data sensed by the sensor)
4. **An Electronic Weighing Micro Beam Balance**. (Measures the mass of dust particle sampled).

2.2 Methods

The tests were carried out during the harmattan season months of January, February and March, 2014 in four states of Northwestern Nigeria. Eleven (11) test sites were mapped out for the measurement across the region of which seven (7) are in Sokoto; two (2) in Zamfara and one (1) each from Kebbi and Katsina as indicated in Fig. 1 and Table 1.

Table 1: *site location, and Distance from Aerosol source.*

State	Sub-regions	Code	Lat	Long	Dist(m)
Sokoto	**Gwadabawa**	**GWA**	**13.35**	**5.21**	**1578712**
Sokoto	**Kware**	**KWA**	**13.20**	**5.28**	**1577985**
Sokoto	**Sokoto**	**SOK**	**13.05**	**5.23**	**1589187**
Sokoto	**Dange Shuni**	**DAN**	**12.81**	**5.36**	**1585719**
Sokoto	**Gada**	**GAD**	**13.75**	**5.98**	**1485410**
Sokoto	**Wurno**	**WUR**	**13.28**	**5.41**	**1561152**
Sokoto	**Gida madi**	**GID**	**13.21**	**5.21**	**1584039**
Kebbi	**Koko**	**KOK**	**12.03**	**4.53**	**1703770**
Kastina	**Jibiya**	**JIB**	**13.08**	**7.21**	**1390007**
Zamfara	**Gwandi**	**GAN**	**12.03**	**4.75**	**1682342**
Zamfara	**Talata Mafara**	**TAL**	**12.53**	**6.11**	**1524077**

2.3 Determination of the mass concentration of harmattan dust.

In order to measure the mass concentration of the suspended dust particles over the study area, a 296-Marple Personal Cascade Impactor was used. Simultaneously, a solar power meter (LI-2003SA Pyranometer) measured the solar radiation intensity on a leveling Surface (LI-20003S mounting and leveling fixture) in the site during the test A total of about 25 sampling was carried out across the 11 test sites selected for this study in Table 1. The average sampling period was $1\frac{1}{4}$ hour and the dust sampled has an average flow rate of 2LPM. Meanwhile the following relations were used to calculate the mass concentration of the dust collected during each sampling period. The mass of dust on each substrate of the impactor is.

$$W_i = W_2 - W_1 \qquad (1)$$

The total mass of dust collected becomes:

$$W_{tot} = \sum_{i=1}^{n} W_i \qquad (2)$$

Where i = 1,2,3…..n

n = number of substrate on impactor

i = substrate number

Volume of the air sampled during the sampling period was calculated [16]

$$V = \frac{1}{16.7} Q(T_2 - T_1) \qquad (3)$$

Where:

V= the sampling volume (m^3)

Q= the sampling Flow (LPM)

T_2= the sampling end time (hours)

T_1=the sampling start time (hours)

And the total mass concentration, C_{tot} of the harmattan dust in mgm^{-3} collected in each sampling period was obtained by the following equation:

$$C_{tot} = \frac{W_{tot}}{V} \qquad (4)$$

The mass concentration of the various particle size range, ΔC_i, separated by the individual substrate is given as

$$\Delta C_i = \frac{W_i}{V} \qquad (5)$$

3 RESULTS AND DISCUSSION

3.1 Mass concentration levels across the study area

The seasonal averages of the total mass concentration from the various regions selected for the study is shown in Fig. 2 and 3. The result indicated that there is a wide spatial variability with the highest mass concentration recorded for the North East area of the studied region ranging between $30.67\, mgm^{-3}$ and $22.77\, mgm^{-3}$. The South West recorded the lowest ranging from $11.35\, mgm^{-3}$ to $8.02\, mgm^{-3}$. The North East and South West regions correspond to the farthest and nearest respectively away from the dust source region. For instance, Jibiya, in the North East area which is about $1390\, km$ away from the source region recorded the highest dust concentration while Koko, Kebbi in the south west of the studied region, about $1704\, km$ from the source recorded the least of about $8.02\, mgm^{-3}$. Thus, the farther the area from the source, the finer the particles dust. This is to be expected as indicated by [8] and [6].

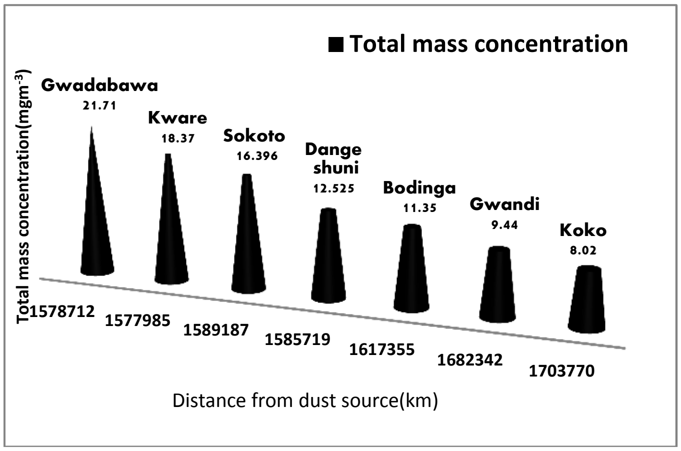

Fig. 2. *Variation of harmattan dust concentration form North to South of the studied location.*

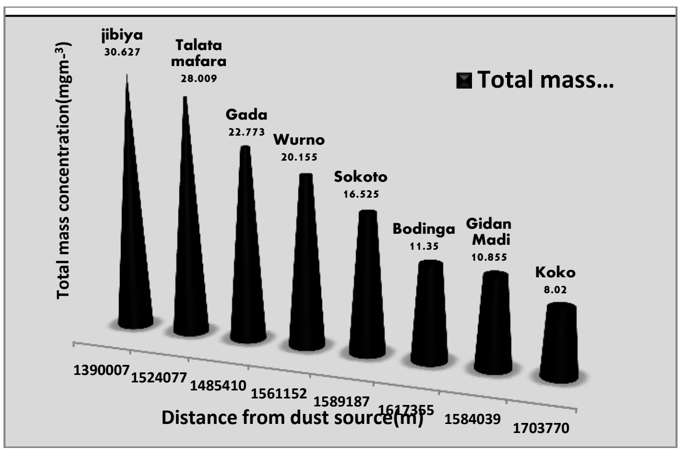

Fig. 3. *Variation of harmattan dust concentration form North East to South west of the studied location.*

Intermediate mass concentrations were recorded in the central part of the selected sub-regions. For instance, Gwadabawa recorded $21.71 mgm^{-3}$; kware recorded $18.37 mgm^{-3}$ and Sokoto recorded $16.53\ mgm^{-3}$. [6] in Nigeria measured mass concentration in Bauchi, Jos and Makurdi to be 1.70 mgm^{-3}, 1.60 mgm^{-3} and 1.40 mgm^{-3} respectively. These areas do not fall under the center line of the harmattan dust trajectory; they are quite far away from the dust source. Bauchi, Jos and Makurdi are about 1304 km, 1415 km and 1615 km respectively from the dust source furthermore, the region are standing on a very high altitude. Hence the reason for the low recorded mass concentration of harmattan dust in that area. In Kumasi, Ghana, [8] measured the average daily mass concentration of harmattan dust as 1130±994 µgm^{-3} . Kumasi is about 2563 km from the harmattan dust source.

3.2 Concentration gradient

Fig. 4 shows the total mass concentration of harmattan dust across the North-West of Nigeria in the North-south direction for 2014 harmattan season. The chart reveals that there is a decreasing gradient of harmattan dust concentration from the North to South of North Western Nigeria, that is, the mass concentration decreases with increasing distance away from the source. The linear equation indicates that the total mass concentration decreases by 0.00008 mgm^{-3} per 1m or by 0.08 mgm^{-3} $per\ 1km$ away at a distance of 142.8 m from the harmattan dust source in the North-South direction. The coefficient of determination R^2 for the model is 0.686 which indicates that the model explains roughly 68.6% of the total variation of the particle concentration

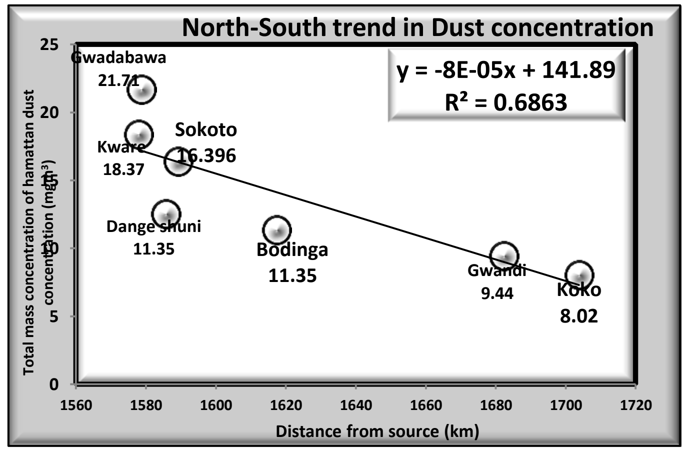

Fig. 4. *A plot total mass concentration (mgm^{-3}) against distance from the source.*

Fig. 5 shows the variation of total mass concentration of harmattan dust across the latitude over the North West of Nigeria during 2014 harmattan season.

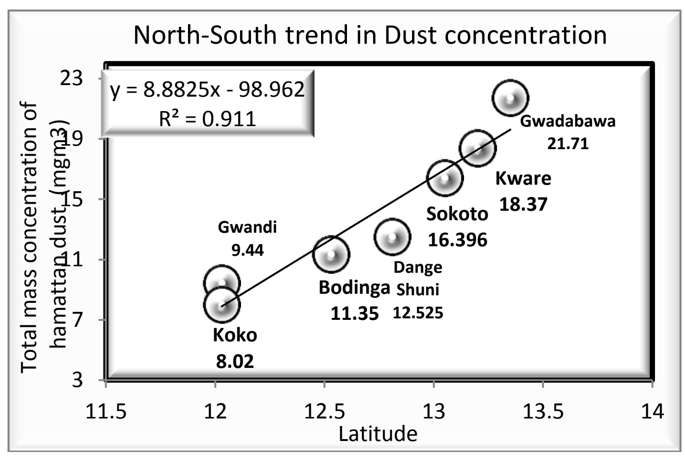

Fig. 5. *A plot total mass concentration (mgm^{-3}) against Latitude across the North West of Nigeria.*

The concentration gradient is 8.882 mgm^{-3} per unit latitude in degree. The coefficient of determination R^2 for the model is 0.911 which indicates that the model explains roughly 91.1% of the total variation of the particle concentration. In fig. 6, the concentration gradient is 9.368 mgm^{-3} per unit longitude in degree. The coefficient of determination R^2 for the model is 0.859 which indicates that the model explains roughly 85.9% of the total variation of the particle concentration. The decrease in dust concentration is more pronounced in the East-West direction than in the North-South direction.

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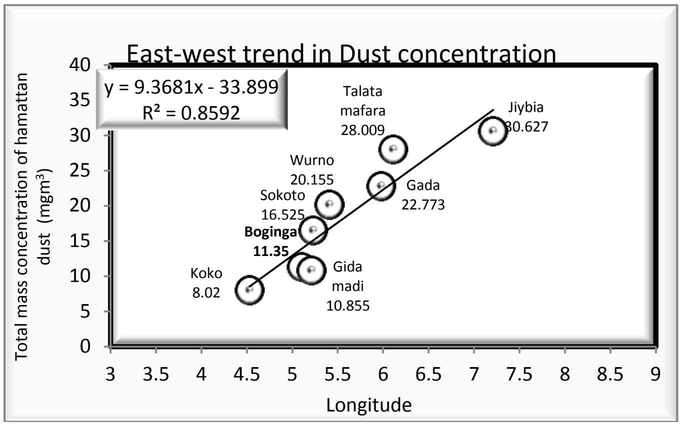

Fig. 6. *A plot total mass concentration (mgm^{-3}) against Longitude across the North West of Nigeria.*

On a general note, it was observed that in north western Nigeria, there was a gradual decrease in the mass concentration of harmattan dust from the North down South as well as from the East towards the West of the region. A similar trend was also noticed when tracking the mass concentration from the Northeast through the Central region to the Southwest. This confirmed that the dust source is located to the North East of the studied area. [3] observed that the dust that affects a greater part of West-Africa in winter south of latitude 15°N particularly the Nigerian zone comes mainly from North Eastern Sahara, usually along the alluvian plain of Bilma (18°N, 12°N) in the southern Niger and Faya largeau (18°N,19°N) in Chad of the Western slope of Tibesti Massive. Furthermore, our results also Strengthens the fact that the dust concentration decreases as it travels farther away from the source region. A similar observation was made by [8], [6] and [17]. The reason for the decrease in total mass concentration is that the dust particles mainly settle under gravity aerodynamic forces. Thus, sedimentation of dust particle begins immediately after it has been transported with the largest particle dropping first and quickly [8]. [18] in their study on the average frequency of African dust out break across the Mediterranean basin during the period of 2001-2010, observed a decreasing gradient of harmmatan dust particle from South to North of the Mediterranean basin. The Mediterranean basin is located to the North of the dust source region while our study site, North-western Nigeria is located to the south of the dust source. But it is important to note that the dust concentration decreases as the distance from the source increases. Furthermore, the small mass concentration recorded in Kumasi, Ghana as 576 μgm^{-3} or 0.567 mgm^{-3} by [8] when compared to that in North-West of Nigeria Confirms that there is steady reduction in harmmatan dust mass concentration with distance away from dust source.

2.2 Effects of harmattan dust concentration on the intensity of solar radiation

One of the most fascinating characteristics of the harmattan dust occurrence is observed in the intensity of incident solar radiation. It was observed that during the period, the intensity of solar radiation is generally low, especially in days when the harmattan dust concentration is high. Our inference here is that the presence of the dust particle in the atmosphere reflects and scatters a greater percentage of the incoming solar radiation thereby reducing its intensity on the regions affected by its presence. [19] in his work reported that the intensity of solar radiation reduces by about 15%. He added that this reduction could be more in winter than in summer due to the presence of suspended harmattan dust particles. Further studies by [20], supported the work of Landsberg, he reported that this observed reduction in the intensity of solar radiation is more during the months of January, February and early March. Furthermore, [21] reported that, the direct solar radiation with wave-length of about 0.5µm was reduced by 75% whereas in Abidjan, it was reduced by 40% during the harmattan period while [22] reported the solar radiation in northern Nigeria to reduce by 28%. The observed difference in percentage reduction in various regions mentioned could be attributed to the reduction in the harmattan dust concentration with distance from dust source. An hourly measurement of the intensity of solar radiation daily over the studied region points to the fact that the intensity of solar radiation peaks at about 1.00pm daily. It begins rises at about 7.00am in the morning and falls to zero at about 7pm in the evening, as depicted in fig. 7.

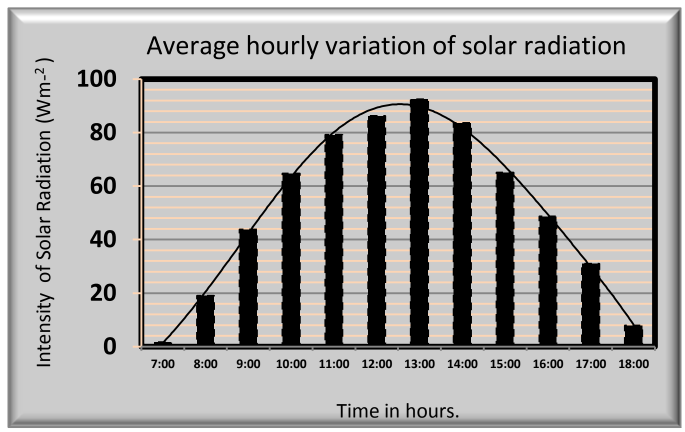

Fig. 7. *Average hourly variation of the intensity of incdent solar radiation in day time during the harmattan period.*

During the course of the study, measurements obtained in the field revealed that the peak value of intensity of solar radiation varies on a daily basis. The results obtained were compared with the daily average concentration of the harmattan dust.

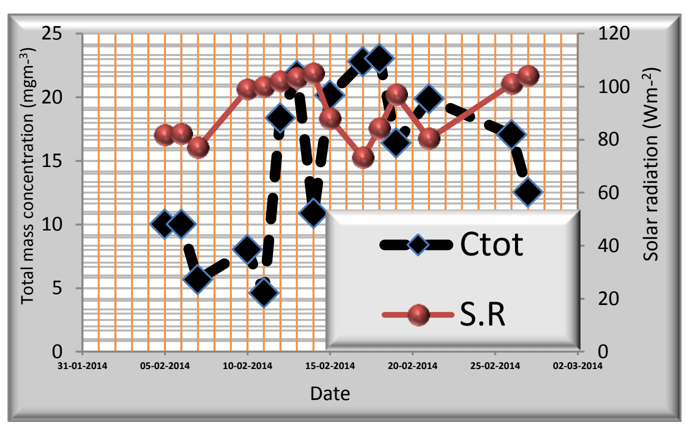

Fig. 8. *Harmattan dust mass concentration compared with the peak value of the intensity of incident solar radiation over the studied location for the month of February.*

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The chart above in fig. 8 shows that the occurrence of the harmattan dust concentration in the atmosphere is responsible for the daily variation on the intensity of solar radiation. The intensity of solar radiation increases when the amount of dust concentration present in the atmosphere per unit volume declines. On the 17th of February 2014, it was observed that when the total concentration of dust increased to about 22.77 mgm^{-3}, the maximum intensity of solar radiation reduced to 73.22 Wm^{-2}. During this period the highest daily intensity of solar radiation was recorded as 104 Wm^{-2} on the 27th of February 2014. The corresponding harmattan dust concentration was sampled as 12.52 mgm^{-3}. The occurrence of low visibility in the months of harmattan season (November to March) corresponds to the periods when the entire Sahel region is under the influence of dry dust-laden north easterly winds [23]; [9]. The visibility is low because, the concentration of the harmattan dust particles in the atmosphere absorbs and scatters the light rays coming from the sun [24]; [10]. Therefore, higher concentrations of harmattan dust lower the intensity of solar radiation which in turn lowers the visibility. Recent studies by the Nigerian meteorological agency [NIMET] in 2011 shows that visibility reduced to 100-900m in the north and 600-800m in the south [14]. During this period the north and central parts experienced visibility between 100-800m, Kano for instance recorded a visibility of zero meter on the 19th of February for almost 6hrs while the southern part reported visibility of between 200-900m [14].

4 CONCLUSION

Having carefully analysed the result of our measurements across the North-western segment of Nigeria, we have arrived at the following conclusions. The aerosol mass concentration of harmattan dust particle is not uniformly distributed across the study area; the mass concentration varies spatially as the distance or position of the aerosol mass concentration changes from the source. Sub-regions closer to the harmattan dust source tends to record very high mass concentration of aerosol than sub-regions farther away from the harmattan dust source. The aerosol mass concentration gradient of harmattan dust particle during winter period in North-western Nigeria is greater along the wind direction than across the wind direction. The aerosol mass concentration gradient is 8.88 mgm^{-3} in the North-south direction and 9.37 mgm^{-3} in the East-west direction. The mass concentration of aerosol in Jibiya, Katsina is higher than the mass concentration of aerosol in kware, Sokoto; Talata mafara, Zamfara and Koko, Kebbi. This is because it is closer to the dust source than any other sub-region. The mass concentration of aerosol during harmattan season is responsible for the low intensity of incidence global solar radiation over North-western Nigeria. Higher mass concentration of aerosol lowers the intensity of incidence solar radiation which in turn reduces its visibility.

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