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Differential Particle Size Distribution of Aerosol across North Western Region of Nigeria

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Abstract - ***This paper established the differential particle size distribution of aerosol during the 2014 winter season across North Western region of Nigeria. The study area is located between latitudes $10^{\circ} N$ and $14^{\circ} N$ and longitudes $2^{\circ}E$ and $8^{\circ}E$ and covers a land area of approximately $126,727 km^2$. It is made up of four states of Sokoto, Kebbi, Katsina and Zamfara. The dust particles according to their various size ranges were sampled using the Series 296 Marple Cascade Impactor. Our result indicated that Katsina which is nearest to the dust emission source,has particles with larger geometric mean diameter ranging between 4.58 μm and 12.12 μm tend to populating the atmosphere during the harmattan dust episode while dust particles with geometric mean diameter of 2.32 μm, 1.20 μm and 0.36 μm recorded lower mass concentration ΔD_i per particle size band. In the central part of the study area, i.e Sokoto and Zamfara, there was a sharp increase in the mass concentration ΔD_i per particle size band for particles with geometric mean diameter of 0.69 μm. The sharp increase in the mass concentration ΔD_i per particle size band for the smaller size particles was attributed to the attrition process of the larger dust as they collide and rub against each other as the particles are being transported away from the harmattan dust source. Kebbi, located in the extreme South Eastern part of the study location and having the longest distance away from the dust source presents a very distinct chart of the differential particle size distribution recorded a general decrease in the total mass concentration of the harmattan dust in the region. In addition, there was a further drop in the mass concentration ΔD_i per particle size band of harmattan dust particles having larger geometric mean diameter such as 7.67 μm, and 12.12 μm.***

Key Words: *Differential particle size distribution, Geometric mean diameter, Mass concentration, Harmattan dust particles.*

1. INTRODUCTION

The type of aerosol dust particles that is breathed into the human respiratory system and the areas where these particles are being deposited is greatly dependent on the dimension, form, concentration and some other physical properties making up the flowing size of the particles [1]. In differential particle size distribution, the mass concentration in each size range is listed in order of sizes. It is most suitable for use when a particular ideal mid-size range is being required [2].

The harmattan is a natural phenomenon which describe the very dust-laden atmosphere which rises in the Sahara desert and is carried south by wind from that area to the West-African region periodically [3]. In West Africa, it dominates during the dry season from November to March conveying dust across West Africa to the Atlantic Ocean [4]. The harmattan dust particles are also found in regions like America, Europe and near the Middle East [5].

At the leading edge of the storm, winds may attain velocity greater than 14 ms^{-1} [6] and dust particle of radius ranging between 0.1mm and 1mm are transported over a long distance of about 6000Km [7]. 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} [8]. The harmattan dust haze which affects the entire Northern Nigeria arrives there at equilibrium phase [8]. In West Africa and Nigeria in particular, this stage is usually marked by a gradual reduction in visibility from say 30km (under normal weather) to about 5km (in the dust haze), within say 6 hours. Thereafter, the visibility deteriorates rapidly becoming poorest when perhaps the core of the dusty plume comes over the station. One significant thing about the equilibrium phase is that it usually takes place some hundred of kilometer downwind.

The harmattan dust which blows across Nigeria each winter is refined from median grain size of 0.0743mm (74.3μm) at Maiduguri in the Northwest to 0.0089mm (8.9μm) at Sokoto in the Northeast [9]. [10] reported to have measured the harmattan haze particle sizes in three cities in northern Nigeria with average diameter of 7.5±0.6mm at Bauchi, 3.9±0.3mm at Jos and 2.8±0.5mm at

Makurdi. They observed that the particles were entrained southwards from the latitude of Bauchi to Makurdi. In the South West of Nigeria, [11] determined the mean diameter as 3.12±1.59 μm with mode of 2.5 μm for Ile-Ife. The result tends to agree with the work of [12] who measured the harmattan dust particle size range arriving West Africa to range from 1.3 μm to 2.0 μm in diameter.

The presence of the settling mineral aerosol in the West African environment creates an opalescent atmosphere, reduced visibility, soiling of materials in the environment, causes scattering of solar radiation and pollutes the ambient air, hence affecting the economy and quality of life [13]. Negative forcing such as scattering and reflection of solar radiation by aerosols and clouds tends to cool the earth's surface, while positive forcing such as the absorption of terrestrial radiation by greenhouse gases and clouds tends to warm it [14].

[15] reported that small fractions of aerosol measured as PM_{10} and $PM_{2.5}$ rather than larger particles are considered to be responsible for most of the health effects since such particles have a relatively long residence time in the atmosphere. Harmattan dust is considered to be one of the most harmful of all air pollutants due to the toxic effects of the dust constituent [16]. They also noted that respiratory infections make up more than 20% of the causes of infant mortality.

The concentration of aerosols in some parts of Nigeria has been measured and recorded [8]; [17]. There are still greater parts of Nigeria where the harmattan dust concentration in terms of various particle sizes are not known. Since Nigeria is one of the countries in West Africa most exposed to the harmattan dust due to its nearness to the dust emission source area, it is important that we adequately study and monitor the properties and effects of the harmattan dust on the environment.

The objective of this present paper is to give an insight into the distribution characteristics of the harmattan dust across the North West of the country. It would also enable us to understand the relationship that exists between the dust concentration and some meteorological parameters influencing the distribution and transportation pattern.

2. METHDOLOGY

2.1 Study area and prevailing Meteorological Conditions

The study area is North-Western Nigeria, comprising of the four states of Sokoto, Katsina, Kebbi and Zamfara as shown in Figure 1. The area is found between latitudes $10^{\circ}N$ and $14^{\circ}N$; and longitudes $2^{\circ}E$ and $8^{\circ}E$ and covers a land area of approximately $126{,}727 km$. It lies to the North West of Nigeria and shares its borders with Niger Republic to the North, Kano State to the East, Niger State to the South-east, Kwara State to the South and Benin Republic to the West. The Southern boundary is arbitrarily defined by the Sudan Savanna. The general relief of the area ranges between 300m and 600m above sea level. It is generally a plain land [18]

Figure 1: Showing the study sites in North Western regions of Nigeria

The climate of Nigeria, like the rest of West Africa, is controlled largely by the two dominant air masses affecting the sub-region [19]. These are the dry, dusty, tropical- continental (CT) air mass (which originates from the Sahara desert), and the warm, tropical-maritime (MT) air mass (which originates from the Atlantic Ocean) [20]. The influence of both air masses on the region is determined largely by the movement of the Inter-Tropical Convergence Zone (ITCZ), a zone representing the surface demarcation between the two air masses [18]. The interplay of these two air masses gives rise to two distinct seasons within the sub-region. The wet season (April to October) is associated with the tropical maritime air mass, while the dry season from November to March is a product of the tropical continental air mass. The influence and intensity of the wet season decreases from the West African coast northwards. The tropical continental air mass is dusty and creates a haze within the atmosphere of West Africa and Nigeria when it predominates. The haze is as a result of dust within the air mass limiting visibility and blocking much of the sun's rays from reaching the earth [21].

2.2 Apparatus

The apparatus used for this research were carefully selected in order to sample and evaluate the particle size distribution of harmattan dust in the atmosphere of the study area and correlate its influence on wind speed during the season of winter/harmattan in the North West of Nigeria. The following apparatus were employed for this research work.

The Series 296 Marple Cascade Impactor. (Measures the concentration of the harmattan dust particle and its particle size distribution)

AR-837 Smart Sensor. (For sensing temperature and relative humidity).

An Electronic Weighing Micro Beam Balance. (Measures the mass of dust particle sampled).

2.3 Methods

The measurements were taken during the months of January February and March of 2014 harmattan seasons in four (4) states of Sokoto, Kebbi, Katsina and Zamfara. Eleven (11) 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 Table 1.

Table-1: location, state, sub-region and source distance of site selected for this study

State	Sub-regions	Code	Lat.	Long.	Dist.(Km)
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

2.4 Determination of particle size

Since the fraction of inhaled dust particles retained in the respiratory system and site of deposition vary with size, it has become important to make use of a sampling device which can be used to substitute respiratory tract as collector of air born particles. In this regard, the series 296-marple cascade impactor would be most suitable.

Figure 2: Showing the individual collection substrate and back-up filter to be weighed.

The series 269-marple Cascade impactor is a multi-stage Cascade impactor used to measure the particle size distribution of particulate matter together with their respective mass concentrations. It is made up of six impaction collection stages numbered 3, 4, 5, 6, 7, and 8 with diameter of about 34mm and six radial slots Figure 2. Each impaction collection stage has a unique stage cut-point in microns. The stage cut-point reduces from one stage to the next. At the base of the impactor is a back up filter which collects very fine particles. As shown in Table 2 below.

Table-2 : Series 296-Impactor Cut-Point at 2LPM.

Impactor Stage Number	Cut-Point Dp(microns)
1	21.30
2	14.80
3	9.80
4	6.00
5 or 5A	3.50
6	1.55
7	0.93
8	0.52
Back-up Filter	0.00

When the contaminated air flows into the impactor, larger dust particles suspended in the air with diameter greater than the cut- point in the first stage (3) impact on the perforated collection substrate. Smaller particles with diameter less than the Cut-point of the first Stage (3) flows into the second stage (4). The procedure in the first stage (3) is repeated until the jets of air gets to the final stage (8). The remaining fine dust particles are then collected by a built-in 34 mm back-up filter.
After the sampling period, the dust sampler is carefully conveyed to the laboratory in an upright position for further analysis. In the laboratory, the impactor is carefully disassembled preferably in the absence of drought. Each stage is removed gently weighed and recorded according to the stage number.

2.5 Differential Particle Size Distribution

This approach provides a detailed picture of the particle size distribution. It could be viewed as a differential of the cumulative particle size distribution. It is usually presented on the log-log graph sheet where the amount in each size range is stated in order of magnitude. In this work, we shall display the particle size distribution using a plot of the particle mass concentration, ΔC_i in each particle size against the geometric mean diameter, GDM_i [1]. That is.

$$\frac{\Delta C_i}{\Delta_i log_{10} D_p} \ vs \ GDM_i$$

The particle mass concentration ΔC_i in each particle size range i, is determined by dividing the mass of the particle weighed, W_i in stage i be the volume of air sampled, V.

$$\Delta C_i = \frac{W_i}{V} \qquad (6)$$

The change in logarithm of the stage Cut-point D_p ($log_{10} D_p$) is obtained by taking the difference between the logarithm of the stage cut-point of the particles in stage (i), and the logarithm of the stage cut-point of the particles in previous stage ($i-1$) [1].

$$\Delta_i log_{10} D_p = log_{10} D_{p_i} - log_{10} D_{p_{i-1}} \qquad (7)$$

The Geometric Mean Diameter of the particles i, GMD_i is given as

$$GMD_i = \sqrt{D_{p_i} \ x \ D_{p_{i-1}}} \qquad (8)$$

D_{p_0} = Is the largest particle size sampled. In this work we used 50microns.

D_{p_i} = Stage Cut-point for stage i (microns)

$D_{p_{i-1}}$ = Stage Cut-point for the stage preceding i (microns)

3. RESULTS AND DISCUSSIONS

3.1. Differential particle size distribution across the area

The behavior of the various particle size bands across the study area can best be established pictorially by presenting graphically the differential particle size distribution across the study area using the log-log plot of the mass concentration ΔC_i per particle size band against the Geometric Mean Diameter (GMD). Figure 3 shows that particles with larger Geometric mean diameter ranging between 4.58 μm and 12.12 μm tend to populate the atmosphere in katsina during the harmattan dust episode. Furthermore, it is observed that smaller dust particles with geometric mean diameter of 0.69 μm have the least mass concentration ΔD_i per particle size band. Dust particles with geometric mean diameter of 2.32 μm, 1.20 μm and 0.36 μm also recorded lower mass concentration ΔD_i per particle size band.

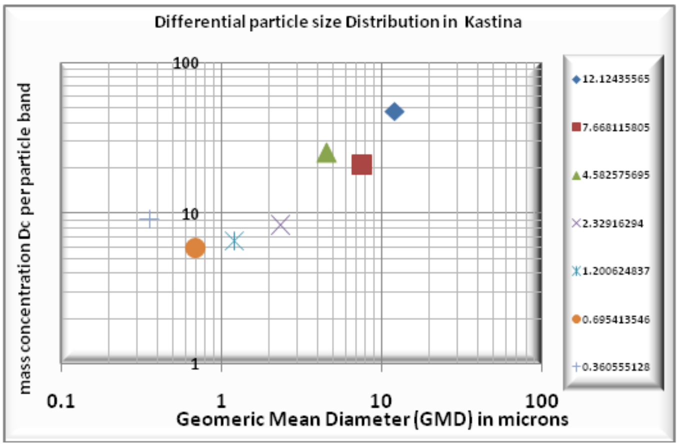

Figure 3: Differential size Particle Distribution in Katsina.

The differential particle size distribution in Figure 4 for Zamfara shows that dust particles with Geometric mean diameter ranging between 4.58 μm and 12.12 μm have a high mass concentration ΔD_i per particle size band. There was a sharp increase in the mass concentration ΔD_i per particle size band for particles with Geometric mean diameter of 0.69 μm. The sharp increase in the mass concentration ΔD_i per particle size band for the smaller size particles could be attributed to the fact that attrition process of the larger dust particles as it moves away from the harmattan dust source [22]. The increase in the mass concentration ΔD_i per particle size band for larger particle sizes could be as a result of it nearness to the dust source or due to the fact that some of the dust particles could have been lifted up from the surrounding area as the wind speed becomes intense [23].

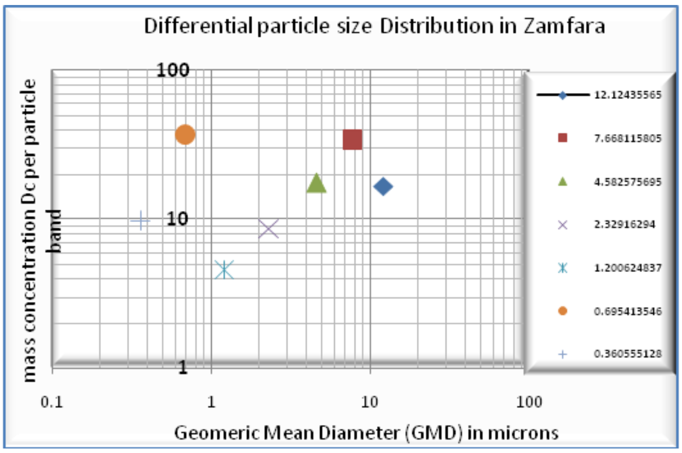

Figure 4: Differential size Particle Distribution in Zamfara

Figure 5 representing Sokoto area shows that there has been a sharp decrease in the general concentration of the harmattan dust particles. The mass concentration ΔD_i per particle size band for particles with geometric mean diameter of 7.66 μm and 12.12 μm dropped significantly while the mass concentration ΔD_i per particle size band for particles with geometric mean diameter of 1.20 μm is increasing. The increase in mass concentration ΔD_i per particle size band could be due to attrition of the lager harmattan dust particle sizes as it rub and collide against each other as it is being transported downwind [22]. Another 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 [24]. [25] also reported that a coarse dust particle settles back to the earth by gravity in places where wind speed declines, around topographic obstacles or where vegetation increases the surface roughness. Moderately fine dust is deposited on vegetated ground and, at the far end of the spectrum, particles smaller than 15 μm are deposited only if they are washed by rain, if they are aggregated by electrostatic charges or if they are brought down by adhering to coarse grains.

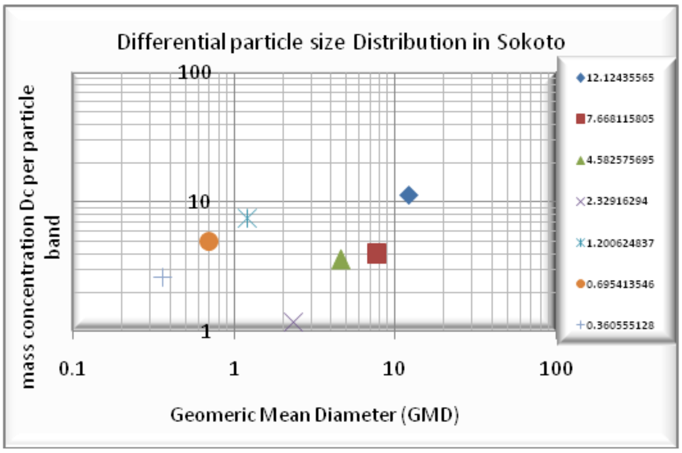

Figure- 5: Differential size Particle Distribution in Sokoto

Kebbi, located in the extreme South Eastern part of the study location and having the longest distance away from the dust source presents a very distinct chart of the differential particle size distribution in Figure 6 The chart reveals that there was a general decrease in the total mass concentration of the harmattan dust in the region. In addition there is a further drop in the mass concentration ΔD_i per particle size band of harmattan dust particles having larger geometric mean diameter such as 7.67 μm, and 12.12 μm. The emergence of larger particle with geometric mean diameter of 4.58 μm having a highest mass concentration ΔD_i per particle size band could be as result dust particles being lifted up from surrounding sandy soil within the background region since the wind speed across the region is observed to be generally high during the period [23].

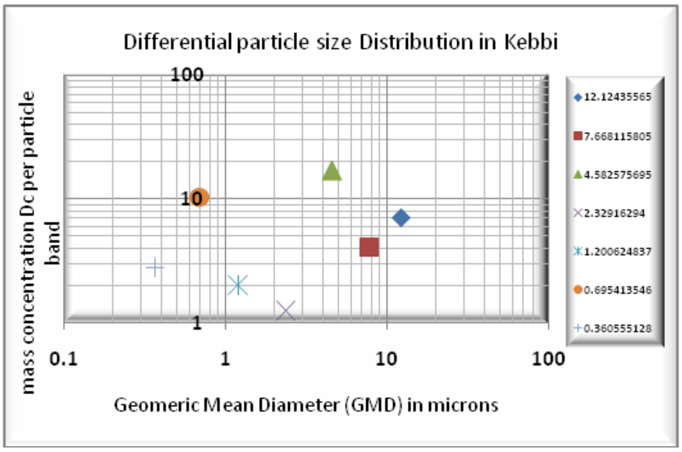

Figure 6: Differential size Particle Distribution in Kebbi

3.2 Effects of the Harmattan Dust Concentration on Relative Humidity.

The relative humidity could be used to describe and model the amount of harmattan dust concentration that is present in the atmosphere over a given time. The hourly measurement carried out revealed that the relative humidity follows a regular repeating trend daily.

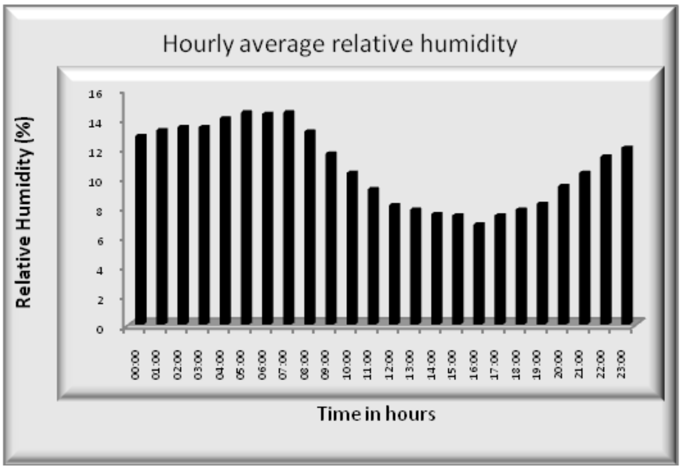

Figure 7: Average hourly relative humidity variation pattern during the harmattan season.

Fig. 7 shows that the daily relative humidity is maximum during the early morning hours of 7am and minimum during the day at 4pm. Relative humidity during the day is generally low when compared with the relative humidity at night during the harmttan season over the north west of Nigeria.

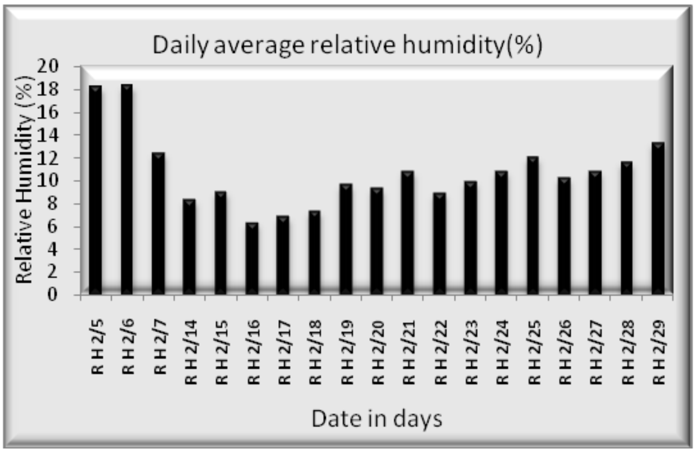

Figure 8: Average Daily relative humidity variation pattern during the harmattan season.

From Figure 8, it was observed that the highest relative humidity recorded during this season was on the 5th and 6th of February. This gradually reduces as the day progressed to a minimum value of 6.3% on the 16th of February. The daily average relative humidity during the harmattan season (November to March) for the North East of Nigeria, was observed to be generally low [17] and made similar observation. It was observed to vary from one day to the next.

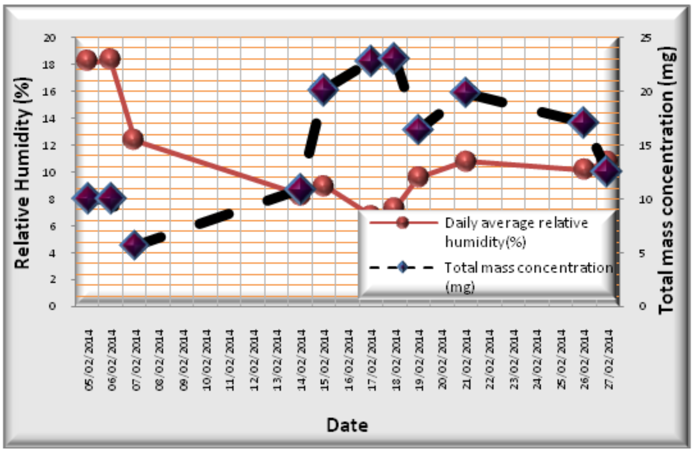

Figure 9: Chart showing the effects of the harmattan dust concentration and daily average relative humidity

An increase in the total mass concentration of harmattan dust particles will result in the decrease in the daily average relative humidity [26]. This is similar to the information deduced from Fig. 9 above. From the graph, one can conclude that lower relative humidity favours the transportation of the dust particles. The low relative humidity is as a result of the high wind speed which causes evaporation thereby reducing the presence of moisture both in the atmosphere and soil [27]. Sandy surface dry out very quickly so that a shower has little long term effect on the rate of movement but water if sufficient can have a much longer term effect on sand movement if it encourages the growth of vegetation [28]. [29], noted that the effects of atmospheric relative humidity are more demanding to measure than those of soil moisture and its effects even more uncertain.

4. CONCLUSIONS

This research was aimed at determining the differential particle size distribution of aerosol during winter period in north eastern Nigeria and relating the effects of total mass concentration on daily relative humidity. The following findings were made

Particles with larger Geometric mean diameter ranging between 4.58 μm and 12.12 μm tend to populate the atmosphere in katsina during the harmattan dust episode. Furthermore, it is observed that smaller dust particles with geometric mean diameter of 0.69 μm have the least mass concentration ΔD_i per particle size band. Dust particles with geometric mean diameter of 2.32 μm, 1.20 μm and 0.36 μm also recorded lower mass concentration ΔD_i per particle size band.

In Zamfara, There was a sharp increase in the mass concentration ΔD_i per particle size band for particles with Geometric mean diameter of 0.69 μm. The sharp increase in the mass concentration ΔD_i per particle size band for the smaller size particles could be attributed to attrition process of the larger dust as they collide and rub against each other as particles are being transported away from the harmattan dust source.

For Sokoto state, the mass concentration ΔD_i per particle size band for particles with geometric mean diameter of 7.66 μm and 12.12 μm dropped significantly with the mass concentration ΔD_i per particle size band for particles with geometric mean diameter of 1.20 μm increasing. The increase in mass concentration ΔD_i per particle size band could be due to attrition of the lager harmattan dust particle sizes as it rub and collide against each other as it is being transported downwind. Another 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.

The chart reveals that there was a general decrease in the total mass concentration of the harmattan dust in Kebbi which has the longest distance away from the harmattan dust source. In addition there is a further drop in the mass concentration ΔD_i per particle size band of harmattan dust particles having larger geometric mean diameter such as 7.67 μm, and 12.12 μm. The emergence of larger particle with geometric mean diameter of 4.58 μm having a highest mass concentration ΔD_i per particle size band

could be as a result dust particles being lifted up from surrounding sandy soil within the background region.
Lower relative humidity favours higher mass concentration of harmattan dust. Furthermore, relative humidity is higher during the day that at night. This explain the cooling in the early morning hours.

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