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Percentage Composition of Particle Size Distribution of Aerosol mass concentration during 2014 Winter Season for some Selected Regions in Northwestern Nigeria

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Abstract - ***This research is aimed at investigating the percentage composition of particle size distribution of aerosol mass concentration during 2014 winter season for some selected regions across northwestern Nigeria comprising of Sokoto, Katsina, Kebbi and Zamfara. The Northwestern region of Nigeria lies between latitudes*** $10^{\circ}N$ ***and*** $14^{\circ}N$ ***and longitudes*** $2^{\circ}E$ ***and.*** $8^{\circ}E$***. The general relief of the area ranges between 300m and 600m above sea level. It is generally a plain land. Our findings reveals that out of the total mass of 2.02*** mg ***of the dust sampled,*** $0.54mg$ ***of the dust are those with diameter less than*** $0.52\ \mu m$***;*** $0.29mg$ ***of the dust range between 0.53*** μm ***and 1.55*** μm ***;*** $0.30mg$ ***between 1.56*** μm ***and 3.55*** μm***;*** $0.36mg$ ***between*** $3.56\ \mu m$ ***and*** $9.70\ \mu m$***;*** $0.53\ mg$ ***are greater than*** $9.80\ \mu m$***. Comparing results from each of the regions making up the study area; it was observed that there is a gradual reduction in the total mass of harmattan dust sampled across the study area. The extreme North East, Jibiya in Katsina of the study area which is nearer to the dust particle source records 3.00 mg. kware in Sokoto 2.4 mg, Talata Mafara in Zamfara 1.9mg while Koko in Kebbi recorded 1.9 mg. In this study, it was also observed that the harmattan dust affecting the North western region of the study area arrives the area at Equilibrium stage of the dust transportation. The wind speed at this stage has little or no effect on the total mass concentration of the harmattan dust since the wind speed appears to be low and stable.***

Key Words: *Harmattan dust concentration, Mass concentration, north western Nigeria, percentage composition, particle size distribution.*

1. INTRODUCTION

The best way to perfectly define the attributes of tiny suspended particles within a given geographic location is to first of all have a sound knowledge of how the particle sizes are being distributed. It is the size distribution of a given suspended particle that determines the life-span of the particle in the atmosphere and how far it can travel. The North West of Nigeria, during winter periods of between late November and early march has been observed to be very dusty [1]. This is as a result of the ejection and transportation of dust from the Sahara desert periodically to some areas in West Africa [2]. The wind system that transport or disperse the harmattan dust particles from the dust source is known as the Trade wind [3]. The wind is highly size-selective, picking a few sizes of grains in preference to others, and picking them according to controls such as velocity and turbulence [4].

Generally, harmattan dust has a wider size range. It has moved further than it was before [5]. A distinction can be made between "proximal" coarser deposits, generally near source and "distal" finer deposits further down wind [6] coarser settles back to the earth by gravity in places where wind speed declines, as around topographic obstacles or where vegetation increase the surface roughness. Moderately fine dust is deposited on vegetated ground and, at the far end of the spectrum, particles smaller than 15μm 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 [7]. Coarse dust with the potential to travel short distance in suspension, has diameter range of 20-70μm. particles smaller than 20μm are defined as fine dust, with the potential to travel right around the globe [8].

Furthermore, a recent study of samples of dust-yielding surface soils found no naturally occurring grains smaller than 80μm and most populations to range between 100 and 300μm in size, suggesting strongly that finer mode in dust can only come from attrition [9]. Another study found that only 8 per cent of fine particles were lifted directly from the surface (rather than being created by attrition) [10].

The harmattan dust which blows across Nigeria each winter is refined from median grain size of 0.0743mm (74.3μm) at Maiduguri in the Northeast to 0.0089mm (8.9μm) at Sokoto in the Northwest [11]. [12] 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.

The direct effects of Sahara dust on climate consist of any direct interaction of the radiation with the Sahara dust through a range of possible influences and mechanisms. They may affect air temperature through the absorption and scattering of solar radiation [13]. Sahara dust modifies short wave solar radiation transmitted to the earth's surface and long wave infra-red radiation emitted to space. However, the balance between these two tendencies determines whether this creates cooling or warming and this in turn, depends in part upon such variables as size distribution of the dust particles and their chemical composition. [14] found that warming or cooling could take place in a Saharan dust event largely dependent upon the number/size distribution of the mineral particle population. Other important factors include cloud cover and the albedo of the underlying surface [15]. In the case of clouds, their altitude and optical depth are important determinants of the direct radiative impact of the dust [16].

The North West of Nigeria is closer to the dust source making it one of the region that is worst affected by the impact of the dust. For better control and management of the polluted environment during the winter season it has become important to have a quantitative insight into the particle size distribution over the area. The information derived from this study would enable environmental protection agency to better forecast the possible climate change harmattan aerosol may pose to the environment [17].

It is with this view that we opt to investigate and present the percentage composition of aerosol during the winter season for 2014 harmattan season for four selected states of Sokoto, katsina, Kebbi and Zamfara within the study location.

Furthermore, this study examines the general characteristics of the hourly and daily wind speed within the study area as well as investigates the characteristics of the average mass concentration of harmattan dust particles in relation to the daily average wind speed within the North West of Nigeria.

2. METHODOLOGY

2.1 Sampling Location 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 $8^{\circ}E$. The area so defined covers a land area of approximately $126{,}727km$. 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 [3].

Fig.- 1: Showing the study sites in North Western region 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 [18]. 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) [19]. 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 [3]. The interplay of these two air masses gives rise to two distinct seasons within the sub-region. The wet season is associated with the tropical maritime air mass, while the dry season 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 Maritime Air mass (CT) locally known as the harmattan, is a wind originating from North Africa which crosses the Sahara desert into West Africa to Nigeria. The Air mass dominates the Nigerians climate during the dry season from November to March. 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 [20].

2.2 Apparatus

The data used for this study were measured directly and simultaneously using the latest modern measuring devices. 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 in the North West of Nigeria. Therefore, the following apparatus were employed for this study.

1. **The Series 296 Marple Cascade Impactor**. (Measures the concentration of the harmattan dust particle and its particle size distribution)
2. **The AM-4202 Digital Anemometer** (Measures the wind speed and wind direction)
3. **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 in four (4) regions of Sokoto, Kebbi, Katsina and Zamfara. Eleven (11) sub-regional 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: 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
Katsina	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 Distribution

One of the purposes of this work was to study and understand the manner in which the harmattan dust particles are distributed across the atmosphere of the study area in terms of the various particle size ranges. We also saw the need to investigate how the particle size distribution is affected with respect to its distance from the harmattan dust source. Another important reason was to know the particle size range that is dominant in the study area. We also relate the particle size ranges to reported cases of respiratory tract infections within the study area. 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.

Fig-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 34 mm and six radial slots Fig. 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. See 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 34mm back-up filter [21].
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 Wind Speed Measurement.

The measurement of wind speed was performed using the Lutron AM- 4202 Digital Anemometer / Thermometer (fig. 3).

The Lutron AM- 4202 Digital Anemometer / Thermometer provides fast accurate readings with the convenience of a separate remote sensor. It is multifunctional that is it can measure wind speed in meter per second (m/s), kilometer per hour (Km/h), foot per minute (ft/min) and knots. Attached to the data logger is a low friction ball bearing designed to allow free vane movement providing accurate high and low velocities. The vane wheel rotates freely in response to air flow.

There is also an in-built temperature measurement thermocouple sensor designed for fast response to temperature changes within seconds. The temperature could be measured in degree centigrade (°C) or degree farnhit (°F)

Fig.-3: Lutron Am- 4202 Digital Anemometer / Thermometer

3. RESULTS AND DISCUSSIONS

3.1 Particle Size Distribution across the Study Area

The particle size distribution of harmattan dust across the North West of Nigeria was studied for various particle size ranges. Our findings indicated that an average of 2.02 mg of the dust particle was sampled from the atmosphere daily during the harmattan period. Further analysis indicated in Table -3 revealed that out of the total mass of 2.02 mg of the dust sampled, 0.54 mg of the dust are those with diameter less than 0.52 μm; 0.29 mg of the dust range between 0.56 μm and 1.55 μm ; 0.30 mg between 1.56 μm and 3.55 μm; 0.36 mg between 3.56 μm and 9.70 μm; 0.53 mg are greater than 9.80 μm.

Table- 3: Particle size distributions of harmattan dust mass concentration and Percentage composition across the studied location.

Particle size (μm)	Mass (mg)	Percentage(%)
greater than 9.80	0.53	26.50
3.56- 9.70	0.36	18.00
1.56 – 3.55	0.30	15.00
0.53 – 1.55	0.29	14.50
less than 0.52	0.54	27.00
Total mass	2.02	

This implies that out of an average total mass of 2.02mg of dust particles sampled from the atmosphere, 26.50% of the particle masses have diameter greater than 9.80μm .18.00% of the particle mass are particles with diameter ranging between 3.56 μm and 6.00 μm; 15.00% ranging between 1.56 μm and 3.56 μm another 14.50% ranging between 0.92 μm and 1.56 μm while the remaining 27.00% of the dust particle mass represent those with diameter less than 0.52 μm. Taking the median of the particle size distribution we can conclude that the average particle size range of harmattan dust in the study area lies between 1.56 μm and 3.56 μm in diameter for the study area of North West Nigeria across the four selected regions comprising of Sokoto, Kebbi, Katsina, and Zamfara. [22] reported that for Kumasi in Ghana the particle size fall between 0.1 μm and 2.0 μm in diameter. [23] measured the daily mean diameter of harmattan dust in Kano to be 8.9 μm. [12] recorded the average diameter in Jos, Makurdi and Bauchi of North Central Nigeria as 7.5±0.6mm with range of 2 to 40mm. In the south west of Nigeria, [24] 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 [25] who measured the harmattan dust particle size range arriving West Africa to range from 1.3 μm to 2.0 μm in diameter.

Table- 4: Particle size distributions of harmattan dust mass concentration and percentage composition across Jibiya, Katsina in the studied location

Particle size(μm)	Mass (mg)	Percentage (%)
greater than 9.80	0.95	31.67
3.56- 9.70	0.47	15.67
1.56 – 3.55	0.64	21.33
0.53 – 1.55	0.47	15.67
less than 0.52	0.47	15.67
Total mass	3.00	

In Table 4, The extreme north eastern region, Jibiya, Katsina of the studied area recorded that out of a total mass of 3.00mg sampled, 31.67% of the particle mass have diameter greater than 9.80 μm; 15.67% of the particle mass are particles with diameter ranging between 3.56 μm and 9.70 μm; 21.33% ranging between 1.56 μm and 3.55 μm; 15.67% ranging between 0.53 μm and 1.55 μm while the remaining 15.67% of the dust particle mass represent those with diameter less than 0.52 μm. The modal particle size in this region can therefore be said to be 9.80 μm. This result is understandable as the region is closest the dust source region than the rest of the selected areas. [11] in their study reported that, 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 West.

Table -5: Particle size distributions of harmattan dust as well and percentage composition across Kware, Sokoto in the studied location.

Particle size(µm)	Mass (mg)	Percentage (%)
greater than 9.80	0.63	26.25
3.56- 9.70	0.25	10.41
1.56 – 3.55	0.25	10.41
0.53 – 1.55	0.64	26.67
less than 0.52	0.63	26.25
Total mass	2.40	

In Table 5, The Northern region, Kware, Sokoto of the studied area recorded that out of a total mass of 2.40mg sampled, 26.25% of the particle mass have diameter greater than 9.80 μm; 10.41% of the particle mass are particles with diameter ranging between 3.56 μm and 9.70 μm 10.41% ranging between 1.56 μm and 3.55 μm; 26.67% ranging between 0.53 μm and 1.55 μm while the remaining 26.3% of the dust particle mass represent those with diameter less than 0.52 μm. It can be observed therefore, that larger grained particles tend to reduce in concentration as it travels away from the dust source while the concentration of smaller grained size particles tends to increase in concentration. This is because most of the fine dust is created by the attrition of coarse particles [5].

Table- 6: Particle size distributions of harmattan dust and percentage composition across Talata Matara,Zamfara in the studied location.

Particle size (µm)	Mass (mg)	Percentage (%)
greater than 9.80	0.25	13.16
3.56- 9.70	0.16	8.42
1.56 – 3.55	0.70	36.84
0.53 – 1.55	0.16	8.42
less than 0.52	0.63	33.13
Total mass	1.90	

In Table 6, The Southern region, Talata Mafara, Zamfara of the studied area recorded that out of a total mass of 1.90mg sampled, 13.16% of the particle mass have diameter greater than 9.80 μm; 8.42% of the particle mass are particles with diameter ranging between 3.56 μm and 9.70 μm; 38.84% ranging between 1.56 μm and 3.55 μm; 8.42% ranging between 0.53 μm and 1.55 μm while the remaining 33.13% of the dust particle mass represent those with diameter less than 0.52 μm. In this region, it is important to note that the modal particle size range has changed from particle sizes greater than 9.8 µm in Katsina to particle size ranges that fall between 1.56 μm and 3.56 μm. This further confirms the work of [5].

Table -7: Particle size distributions of harmattan dust mass concentration and percentage composition across Koko,Kebbi in the studied location.

Particle size (µm)	Mass (mg)	Percentage (%)
greater than 9.80	0.19	10.00
3.56- 9.70	0.44	23.16
1.56 – 3.55	0.25	13.16
0.53 – 1.55	0.26	13.68
less than 0.52	0.76	41.05
Total mass	1.90	

Table 7, shows that the south western region of the studied area, Koko, Kebbi recorded a total mass of 1.90mg, out of which 10.00% of the particle mass have diameter greater than 9.80 μm, 23.16% of the particle mass are particles with diameter ranging between 3.56 μm and 9.70 μm; 13.16% ranging between 1.56 μm and 3.55 μm; 13.68% ranging between 0.53 μm and 1.56 μm while the remaining 41.05% of the dust particle mass represent those with diameter less than 0.52 μm.

Comparing results from each of the region making up the study area, one would observe that there is gradual reduction in the total mass of harmattan dust sampled across the study area. The extreme North East, jibiya in katsina of the study area which is nearer to the dust particle source records 3.00mg. Kware in Sokoto 2.4mg, Talata Mafara in Zamfara 1.9 mg while Koko in Kebbi recorded 1.9mg. The observed reduction in total particle mass could be ascribed to locations distance from the source. This trend is also observed in some of the particle size ranges but not as pronounced in the case of the total mass of dust sampled for each of the sub-regions. It is in this view that the graphical differential particle size distribution was established in this study.

3.2 Effects of the Wind Speed on Harmattan Dust Concentration

Fig. 4 shows the average hourly variation pattern for the area during the harmattan season. The graph shows that the average wind speed is maximum at 10am and minimum at 7pm. The wind speed drops from a maximum value of 19.6 ms^{-1} at 10am to a minimum value of 11.5 ms^{-1} at 7pm. The average wind speed per day during the season is 14.8 ms^{-1}. [26] recorded that at the leading edge of the harmattan dust storm, the winds may attain velocity greater than 14 ms^{-1}. On the contrary, [27] reported that, the average wind speed to reach the Nigerian border from the harmattan dust source ranges between 5 ms^{-1} and 6 ms^{-1}. The location of measurement, topographical nature and surrounding settlements could affect the magnitude of the wind speed. The value obtained for this research was measured in an open area, free from trees, settlements and other obstacles of wind speed. Besides, the wind speed data for our study was taken on an hourly basis during the month of February. The month of February has been identified as one of the months of intense harmattan dust episode, that is, the harmattan dust concentration reaches its highest within this month. That of [27] which is lower than ours, represents a general average of the wind speed during the harmattan season.

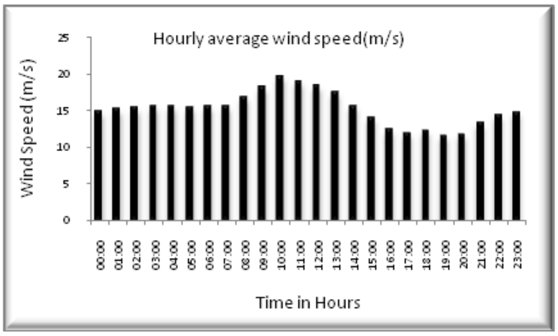

Figure 4: Average hourly wind speed variation pattern during the harmattan season.

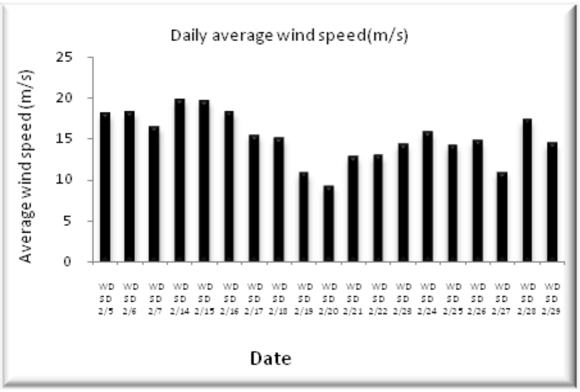

Fig.- 5: Average daily wind speed variation pattern during the harmattan season.

In fig. 5, the average wind speed per day was observed not to be uniform throughout the season. The highest average daily wind speed recorded was about 19.8 ms^{-1} on the 14th of February while the least recorded wind speed was 9.2 ms^{-1} on the 20th of February. A general overview of the intensity of the wind speed for the month of February during the harmattan season indicates a high wind speed with an average of about 14.8 ms^{-1}. This value is by far greater than 5.5 ms^{-1} which was observed by [28] as the minimum value that favours higher dust concentration. The high wind speed is due to the absence of vegetation in the area [29]. Another reason is that the air in the region is denser due to its lower temperature [30].

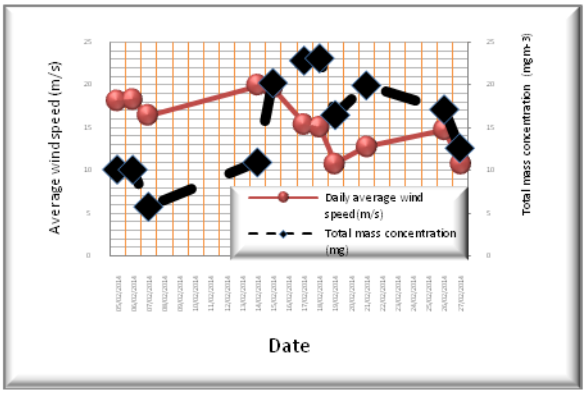

Figure 6: Chart showing the effects of the harmattan dust concentration and Average daily wind speed.

Figure 6 shows that there is a direct effect of harmattan dust concentration on the average daily wind speed. The harmattan dust concentration increases as the daily average wind speed. Therefore, the wind speed plays the central role in the transportation of harmattan dust particles. A thorough inspection of fig. 6 above, it could be deduced that higher wind speed favours the ejection, entrainment and transportation of the harmattan dust particles. Between the 15th and 18th of February, there appear to be a inverse relation between the daily average wind speed and total mass concentration but this is not the case. The increase in total mass concentration between the 15th and 18th of February is as a result of the fact that the harmattan dust concentration is at the equillbrum stage of its transportation process. 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. For example, the

harmattan dust haze which affects the entire Northern Nigeria arrives there at equilibrium phase [27]. The wind speed at this stage has little or no effect on the total mass concentration of the harmattan dust concentration since the wind speed appears low and stable.
The other reason could be deduced from the fact that the number of smaller particle size has increased due to the process of attrition of larger sized dust particle leading to a higer total mass concentration of the harmattan dust particles [5]. [31] Noted that the effects of local wind speed on harmattan dust concentration is positive. That is, the particle number is higher when the wind speed is higher, except for wind coming from North East, South and South West. Which are areas of high population and direction to the mountain. In a separate study by [28]after sorting data sets of wind speed with their respective dust concentration, observed that, wind speed greater than 5.5 ms^{-1}results in an increase in the overall dust concentration while wind speed less than 5.5 ms^{-1}results in lower dust concentration. He also noted that, the concentration of the suspended dust particle is greatly dependent on the direction of wind, confirming the works of [31]

4. CONCLUSION.

Having carefully observed our result, we can summarize our findings as follows:
Out of the total mass of harmattan dust affecting the North West of Nigeria, 26.50% of the particle masses have diameter greater than 9.80 μm , 18.0% of the particle mass are particles with diameter ranging between 3.55 μm and 9.70μm ; 15.0% ranging between 1.56 μm and 3.55 μm ; 14.50% ranging between 0.53 μm and 1.55 μm while the remaining 27.0% of the dust particle mass represent those with diameter less than 0.52μm.
The extreme north eastern region Jibiya, Katsina of the studied area recorded that, 31.67% of the particle mass have diameter greater than 9.80 μm; 15.67% of the particle mass are particles with diameter ranging between 3.56 μm and 9.70 μm; 21.33% ranging between 1.56 μm and 3.55 μm; 15.67% ranging between 0.53 μm and 1.55 μm while the remaining 15.67% of the dust particle mass represent those with diameter less than 0.52 μm. The modal particle sizes in this region are particle greater than 9.80 μm recording 31.59% of the particle mass.
Comparing results from each of the region making up the study area, one would observe that there is gradual reduction in the total mass of harmattan dust sampled across the study area. The extreme North East, Jibiya in katsina of the study area which is nearer to the dust particle source records 3.00mg. kware in Sokoto 2.4mg, Talata Mafara in Zamfara 1.9mg while Koko in Kebbi recorded 1.9mg. The observed reduction in total mass of harmattan dust is as a result of regions distance from the harmattan dust source.
The harmattan dust affecting the North Eastern region of Nigeria arrives at Equilibrium stage of dust transportation. The wind speed at this stage has little or no effect on the total mass concentration of the harmattan dust concentration since the wind speed appears low and stable.

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