Ochei et al., J Pollut 2018, 1:2

Journal of Pollution

Research Article Open Access

Variability of Harmattan Dust Haze Over Northern Nigeria

Michael Chukwuemeka Ochei* **and Emmanuel Adenola**

Federal University of Technology Akure, Akure, Ondo State, Nigeria

***Corresponding author:** Michael Chukwuemeka Ochei, Federal University of Technology Akure, Akure, Ondo State, Nigeria, Tel: +234-803-074-6145; E-mail: mcochei@futa.edu.ng

Received date: January 22, 2018; **Accepted date:** February 14, 2018; **Published date:** February 21, 2018

Abstract

The spatial and temporal variability, trend of visibility, frequency of occurrence (FOO) of 'thick dust haze' (TDH) and of 'light dust haze' (LDH) during the Harmattan season (November to February) were examined, using 27-year visibility data for 8 synoptic stations located in northern Nigeria. Visibility target used to differentiate TDH and LDH occurrence is that when visibility ≤ 1,000 m (Vx ≤ 1,000 m), which indicates Thick Dust Haze (TDH); while visibility range of >1,000 m and ≤ 5,000 m (1,000 m < Vx ≤ 5,000 m) indicates Light Dust haze (LDH). The visibility pattern showed a decreasing trend throughout the study period as lowest visibility was observed in the month of January. Highest FOO of TDH and LDH conditions were also observed in this month, identifying January as the month of poorest visibility conditions and high occurrence of dust haze. The average frequency of TDH days observed was about 2– 4 days and LDH days from 2 – 11 days. The FOO of LDH days increases southwards which could be attributed to the predominance of fine dust particles and lower wind speed towards the south. TDH days follows a decreasing trend all through the study period, while LDH follows an increasing trend. TDH and LDH occurrences showed an inverse in relationship with respect to latitude. Visibility deterioration during the harmattan period is largely caused by the prevalence of dust particles in the atmosphere.

Keywords: Visibility; Harmattan dust haze; Thick dust haze; Light dust haze; Frequency of occurrence

Introduction

Dust has become the most abundant aerosol type in the atmospheric column worldwide. It is the most significant source of atmospheric aerosol in the western Sahel (including Nigeria); this is due to the location of Nigeria in Sub-Saharan West Africa [1]. Aerosols are transported regularly from dust sources across Nigeria towards the Atlantic Ocean. The intensity of dust transport is a seasonal phenomenon due to the existence of the Inter-tropical Discontinuity (ITD) which is the driving mechanism for weather phenomenon and season in West Africa and Nigeria.

During the dry season, the entire country is usually dominated by the Northeasterly trade winds commonly referred to as Harmattan and experiences large quantities of dust and smoke from biomass burning that is transported by the prevailing north-east trade winds. This dust accompanied by harmattan is referred to as harmattan dust. During this period, dust emission, circulation and distribution in the atmosphere are significantly influenced by favorable weather conditions. This is in addition to anthropogenic activities that normally arise from high-energy demands and increase the pressure on land for agricultural purposes and infrastructure. Nigeria is described as one of the heavily aerosol-laden regions of West Africa, where aerosol studies are of great interest [1]. The period of dust transport (harmattan period) over Nigeria is characterized by lower than normal temperatures in the early morning and night time, and hotter temperature during the day time.

Dust entrained from sediments or soils can be transported by the wind for several thousands of kilometres. The Bodélé Depression in the Republic of Chad has been found to be the world's largest source of mineral dust [2]. Dust entrained in this basin is transported over great distances as far as the Caribbean Sea, the Amazon Basin, the United States and Europe [3]. The Bodélé low level jet (LLJ), which is the strongest in northern hemisphere winter according to Washington et al. [4], plays a major role in dust mobilization from this source region. In forecasting dust weather over this region, the initiation and occurrence of the Bodele LLJ could therefore signal the incidence of episodes of dust influx and hence visibility reduction in parts of the region. Aerosols are introduced or injected into the atmosphere from natural and anthropogenic sources such as soil dust, sea salt, volcanic dust, forest fires, photochemical activities, gas-to-particle conversions, etc. and are distributed in the atmosphere by turbulent movement of air masses; however, they are removed from the atmosphere by ice, rainfall, dew and other forms of precipitation as well as dry sedimentation.

Dust aerosol has become the most abundant aerosol type in the atmospheric column worldwide [5] and is the most significant source of atmospheric aerosol in the western Sahel (including Nigeria) [6]. The most observable dust aerosol effect across Nigeria is visibility reduction resulting from scattering and absorption of solar radiation by suspended particles in the atmosphere. During low-visibility events, many flight operations are suspended or delayed, which leads to a significant economic loss for the Aviation sector in Nigeria [7]. It has been recognized that dust affects not only the regional but also the global climate system [1], respiratory tracts, and cloud microphysical properties [5].

Dust aerosols also affect the cooling and heating rates at different lattitudes, regional air quality and human health [4], as a result of these numerous effects of dust aerosol, it has become an essential parameter in atmospheric aerosol studies that require constant monitoring and evaluation. Visibility is influenced by the presence of suspended particles in the atmosphere; these particles are emitted by both natural and anthropogenic sources such as dust storms, biomass burning, forest fire, fog, vegetation, etc. Studies have however shown that the major or principle pollutant in Nigeria is dust aerosol and the strength of dust transport towards the Atlantic Ocean increases annually worsening the visibility condition of Nigeria [8]. Therefore, there is considerable interest at the global, regional and local levels in climate variability and the distribution of aerosols, including dust [5,9].

In studying and understanding the dust phenomena, the use of visibility and wind data obtained from ground meteorological observations to track the trajectory of propagation of dust plumes and forecast the outbreak of dust weather have been employed. Harmattan dust haze has been investigated using visibility data [10,11].

Adebayo and Kalu [10,12] used visibility data to establish the trajectory of dust over West Africa citing the Harmattan dust haze in Kano. N'Tchayi et al. [6] used visibility data from 53 synoptic stations to investigate the diurnal and seasonal variability of dust over North Africa.

Mukthar et al. [8] stated that visibility is better during summer and worse during the harmattan period in which the corresponding AI was found to have increased during this period. The high concentration of the aerosol in the atmosphere is the major reason for visibility degradation in Harmattan. Other authors also used Aerosol Index data (AI) obtained from the Total Ozone Mapping Spectrometer (TOMS) and Ozone Monitoring Instrument (OMI) in investigating or analyzing the temporal and spatial variability of dust aerosol. Balarabe et al. [13] analyzed the temporal and spatial variability of the monthly mean aerosol index obtained from TOMS and OMI in comparison with the available ground observations in Nigeria and revealed a strong seasonal pattern of monthly distribution and variability of absorbing aerosols along a north – south gradient.

The monthly mean AI showed higher values during the dry months (harmattan) and lower values during the wet months (summer) in all zones. Anuforum et al. [1] established that a strong negative correlation (r= -0.91) exists between TOMS AI and visibility; hence, the key factor responsible for visibility reduction in the Sahel region of Nigeria is dust. Both the Harmattan season visibility and TOMS AI vary in response to the variability in atmospheric dust loading over the region. The authors showed that TOMS AI data adequately captures the seasonal and long-term variability of Harmattan dust loading of the atmosphere over the semi-arid Sahel region of Nigeria. AI could therefore complement horizontal visibility data in the monitoring of dust events in the region (although a possible limitation of this method is that the TOMS instrument is not very sensitive to dust loading in the lower troposphere i.e., less than 500 m above the ground, which was pointed out by Prospero et al. [14].

The aim of this study is to investigate the spatial and temporal variability of harmattan dust haze over northern Nigeria with reference to thick dust haze (TDH) and light dust haze (LDH) distribution. In achieving this, the visibility variation due to dust prevalence will be assessed, pattern of dust occurrence will be identified and thus determine temporal and spatial pattern of harmattan dust haze in the study area.

Data and Methodology

Sample collection

The data for this work consist of daily visibility and dust haze occurrence. The visibility and dust haze data were obtained from the archive of the Nigerian Meteorological Agency (NIMET), Oshodi, Lagos State, Nigeria. The data span from 1982 to 2008 (27 years) for the eight (8) stations which are located in the northern Nigeria (see fig. 1). The stations include; Abuja (Lat. 9.15°N, Long. 7.00°E), Bauchi (Lat. 10.17°N, Long. 9.49°E), Kaduna (Lat. 10.36°N, Long. 7.27°E), Maiduguri (Lat. 11.51°N, Long. 13.05°E), Minna (Lat. 9.37°N, Long. 6.32°E), Nguru (Lat. 13.01°N, Long. 10.47°E), Sokoto (Lat. 13.01°N, Long. 5.15°E) and Yola (Lat. 9.14°N, Long. 12.28°E).

The daily mean horizontal visibility value (Vx) and daily dust haze occurrence was calculated. Visibility classification or target for dust haze occurrence used are as follows; visibility $\leq$ 1,000m ($Vx \leq 1{,}000$ m) indicates Thick Dust Haze (TDH), visibility >1,000 m and visibility $\leq$ 5,000 m (1,000 m $< Vx \leq$ 5,000 m) indicates Light Dust haze (LDH), following that which was adopted by Anuforum AC [15], and are also similar to that used by Goudie et al. [16] and Engelstaedter et al. [17].

The data were graphically analyzed for the eight (8) stations to determine the dust trend, variation and the spatial and temporal distribution with respect to visibility for the months and years over the stations.

Some statistical analysis such as summation and averaging will be carried out on the data. The output will be subjected to graphical analysis in order to show the temporal and spatial variation of dust occurrence over the study area. Some statistical analysis such as summation and averaging will be carried out on the data. The output will be subjected to graphical analysis in order to show the temporal and spatial variation of dust occurrence over the study area.

Results and Discussion

Visibility variation

Figure 1 shows the mean annual variation and trend of visibility for all the stations, it could be observed that over all the stations there is a significant decreasing trend throughout the study period. It could be seen that from 1982-1990, the visibility seems not to vary widely as observed in the remaining years. The decreasing trend in visibility during the study period indicates that the region generally experienced increasing concentration of dust aerosols during the harmattan season.

In recent years the average visibility has reduced considerably when compared with those of the 1980s. The highest visibility was recorded in 1982 and the least was recorded in 2007. In the year 2003, there was a slight increase in the visibility but was immediately followed by a rapid decrease in the year 2004 and 2005.

Citation: Ochei MC, Adenola E (2018) Variability of Harmattan Dust Haze Over Northern Nigeria. J Pollut 1: 107.

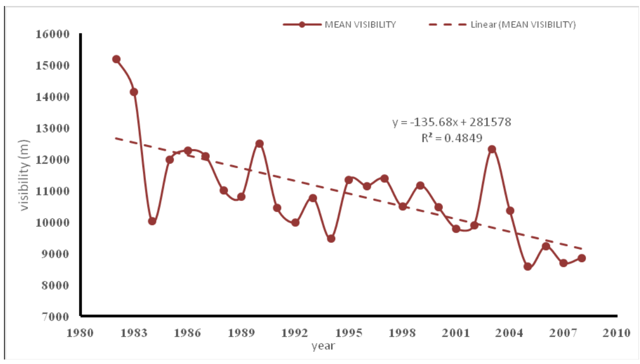

Figure 1: Mean annual visibility variation for all stations during the harmattan period.

Figure 2 shows the monthly mean variability and trend of visibility during the harmattan season over the study area. It was seen that in the month of November visibility was at its peak and thus begins to experience a downward trend through December and to January. This could be attributed to the fact that the ITD retreats further southward allowing for the predominance of the dust laden winds (Northeasterly trade wind) which transports dust from the source regions southwards into the country at this time of the year.

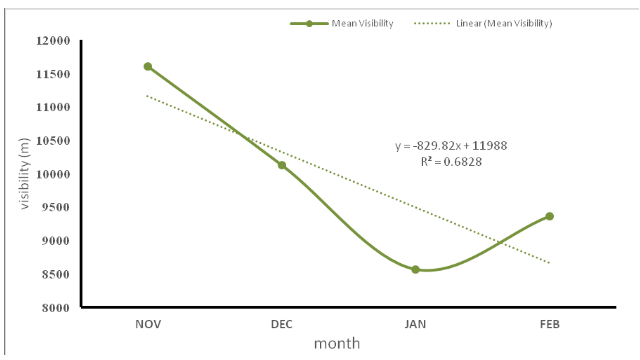

Figure 2: Mean monthly visibility variation for all stations during the harmattan period.

The least value of visibility was observed in the month of January which implies that the occurrence of dust storms would be the highest during this month throughout the study area. It can thus be deduced that since January recorded the least visibility, it can be concluded that the month has the highest number of dust haze occurrences (dust storms).

Visibility increases in the month of February and even throughout the remaining part of the year as the dust laden wind would begin to retreat at this time as a result of the northward advancement of the ITD, the moisture laden wind (southwesterly wind) moves with the advancement of the ITD bringing rainfall with it which serves as a sink for dust in the atmosphere and this is in support of Zender et al. [18] which reveals that the temporal variability of dust haze is determined by rate of injection and removal of dust particles from the atmosphere. Wet deposition or scavenging by moisture in the atmosphere is the predominant mechanism through which smaller dust particles (accumulation mode) are removed from the atmosphere. Also, Han et al. [19] noted that dry deposition is predominant in the vicinity of source regions, while the influence of wet deposition increases along the transport pathway of dust. The more humid conditions in southern Nigeria (especially at the beginning and end of the seasons) therefore favor fast removal, while the incoming northeast trade wind quickly re-supplies dust particles from the source region.

Spatial distribution of TDH (thick dust haze) occurrence

The TDH sets in from the extreme northern part of the region in the month of November (Figure 3a) with an average frequency of about 2 days (per month) and decreases southwards. Lowest frequency of an average of about 1 day in Abuja and Yola i.e., south of the study region; and this can be attributed to the fact that the month of November is the beginning of the winter season in which the ITD has moved considerably southwards and the prevailing wind over the northern region of Nigeria is the North Easterly trade winds which begin to transport dust particles from the dust source regions, as stated by Flamant C et al. [20], while Schwangwart and Schutt [21] showed that dust emission in the Bodélé. Depression is largely controlled by the variability of Sea Level Pressure (SLP) in the south central Mediterranean in which positive anomalies of SLP in this area relate to positive nomalies in daily dust concentrations in the Bodélé Depression.

In the month of December (Figure 3b), the trend follows the same pattern as that of the pattern of November, but with increased TDH frequency of about three (3) days in the north eastern part of Nigeria and decreases considerably towards the other stations southwards. Generally, in the northern region, the average occurrence of TDH days is about 2 days (per month), hence, the dust prevalence has increased as a result of the increasing prevalence of the harmattan winds. Also, generally throughout the study area, the frequency of occurrence of TDH days increased considerably.

In the month of January (Figure 3c), the highest frequency of TDH days are seen in all parts of the region and this peak values range from about 3 to 5 days. This month can be regarded as the month with the highest number of TDH days or dust occurrences which is in alignment with the earlier study of Anuforum AC [15] which showed that during the month of January, dust occurrences peak especially in the northern part of the country. The number of TDH days also decreased southwards in this month also.

Figure 3d showed that in the month of February, generally the number of TDH days has reduced compared to that of January, hence there is a considerable decrease in dust occurrence in the month of February after it must have peaked in January. The average number of days of TDH occurrence range from about 2 to 3 days (per month). This could be due to the fact that this period is the latter end of the harmattan season and the dust laden wind could either have weakened in its strength to raise and carry dust particles across the region or have started retreating northwards.

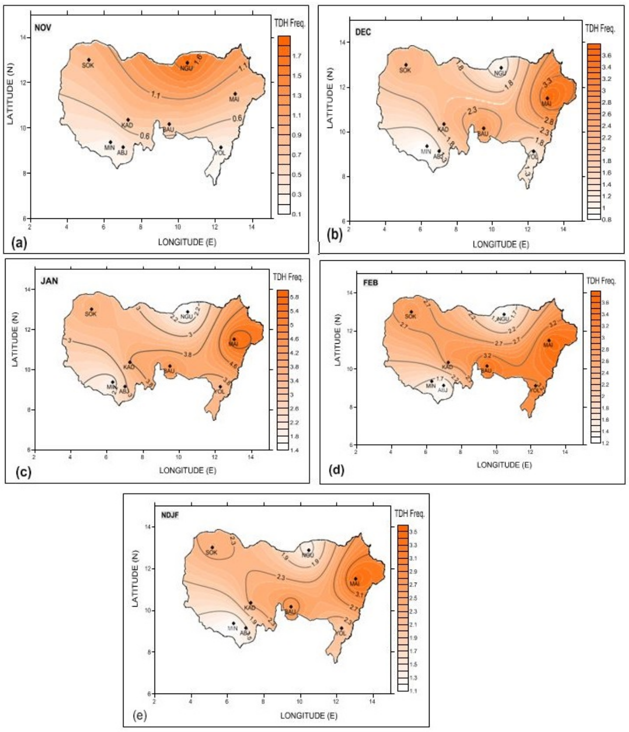

Figure 3: The mean monthly variations of TDH occurrence in the study area; (a) November, (b) December,(c) January, (d) February; and (e) NDJF (harmattan months).

Figure 3e shows the variation in the mean number of TDH occurrence days for the harmattan season which illustrates the pattern of dust occurrences across the stations. It can thus be seen that the average number of TDH days is about 2 to 4 days (per month). Generally, the frequency of dust occurrence days' decreases southwards in a south – west direction which can be due to the direction of the prevailing wind (North Easterlies). Hence, the higher frequency of occurrence of TDH in the northern parts of the study area can be attributed to the proximity of this area to the Saharan dust source region. The concentration of dust in the atmosphere decreases as the distance from the source region in the windward direction increases since the larger particles (coarse mode particles) are easily removed from the atmosphere such that they readily and easily settle down since they are heavy enough to be pulled down by the force of gravity as the speed of the wind would reduce as it moves further southward [15]. This was also explained by Goudie AS et al. [16], which stated that the particle size and rate of deposition of Saharan dust decrease (decreasing TDH) with increasing distance from the sources. Hence, the atmosphere is therefore richer in dust concentration in the north than in the south. In addition to proximity to the main dust sources in the Bodélé depression, the extreme northern fringe of Nigeria actually falls within the West African Sahel which has also been noted to be one of the sources of dust [6]. Also, additional local injection of dust particles as a result of anthropogenic activities such as agricultural activities will generally increase the dust load over the zone. Temporal variability of dust haze is determined by the rate of injection and removal of dust particles from the atmosphere.

Spatial distribution of LDH (light dust haze) occurrence

In the month of November (Figure 4a), the frequency of LDH days range from an average of about 5 to 16 days (per month) which decreases northward i.e., increases southwards. The lowest number of LDH days is observed in the northernmost part of the study region which has closer proximity to the dust source regions and as such dust concentration would be increased in these areas. Also, in the other months – December, January, February (Figures 4b-4d), the pattern of the LDH occurrence is the same as that of February as they follow the same trend. The LDH occurrences range from 2 to 6 days (per month) in December, 5 to 17 days (per month) in January and 4 to 13 days (per month) in February. Thus, similar to the pattern of the TDH occurrence, the FOO of LDH peaked in the month of January. Generally, Nguru has the lowest number of LDH days while Abuja records the highest number of LDH occurrences throughout the study period. The LDH days for Sokoto range from 5 to 13 days (per month) from November to February.

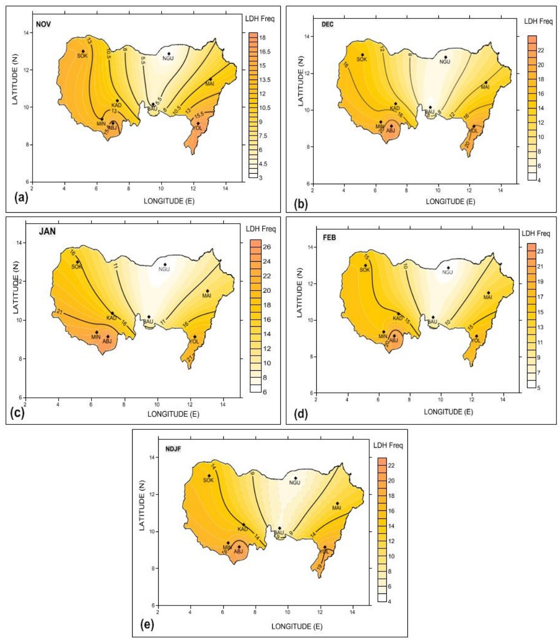

Figure 4: The mean monthly variations of LDH occurrence in the study area; (a) November, (b) December, (c) January, (d) February and (e) NDJF (harmattan months).

Figure 4e illustrates the variation in the mean number of the frequency of LDH occurrence days for the harmattan months (November, December, January and February). It was observed that during the harmattan period the frequency of occurrence of LDH days range from 2 to 11 days (per month) on the average over the study area; with its least number of LDH days observed in Nguru – 2 days, and the highest number of LDH days observed in Yola – 9 days (per month), and Abuja – 10 days (per month), in the south. Generally, it was also observed that the frequency of occurrence of LDH days increases southwards which could be attributed to the predominance of fine dust particles and lower wind speed towards the south. Mctanish GH [11] showed in a study that the mean size of harmattan dust particles is generally larger in the northernmost parts of Nigeria, which are closest to the dust source regions, and decreases southwards in the direction of the northeasterly wind from the source region. The MODIS satellite data also show that the mean harmattan period day time aerosol fine mode fraction increases southwards i.e., the aerosol coarse mode fractions increases northwards. Fine mode dust particles have low settling velocity and therefore longer residence time in the atmosphere. Thus they remain suspended in the atmosphere for a longer period of time than the coarse mode particles once they are airborne resulting in more number of days with LDH conditions. This was also further explained by Goudie AS et al. [16], which stated that the particle size and rate of deposition of Saharan dust decrease (increasing LDH) with increasing distance from the sources.

Mean annual variation of TDH (thick dust haze) and LDH (light dust haze) occurrence

The Figures 5 and 6 shows the mean annual variability and trend of the frequency of occurrence of TDH (Thick Dust Haze) for the individual stations throughout the study period. For Abuja, the trend shows that for the earlier years, the number of occurrence of TDH days is more than that recorded in recent years and as such it follows a decreasing trend indicating that in recent years the frequency of occurrence of TDH days per month has decreased.

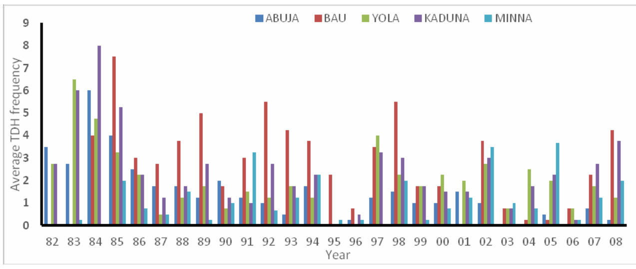

Figure 5: Mean annual variation of the frequency of occurrence of TDH days per month for Abuja, Bauchi, Yola, Kaduna and Minna.

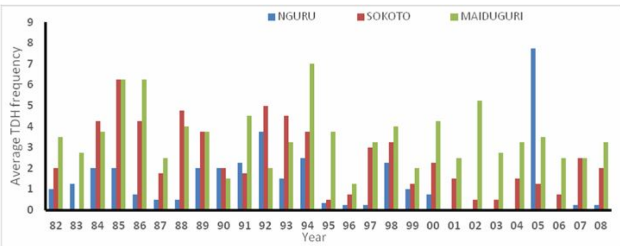

Figure 6: Mean annual variation of the frequency of occurrence of TDH days per month for Nguru, Sokoto and Maiduguri.

Bauchi, Yola, Kaduna, Nguru, Sokoto and Maiduguri follow the same trend as that of Abuja, as they all have decreasing trend over the years of the study period. Minna on the other hand, follows a somewhat different trend as it has a slightly increasing trend over the years of the study period. The average TDH frequency over the stations however ranges from about 1 to 8 days.

Figure 7 shows the mean annual variation and trend of the frequency of occurrence of TDH for all the stations. A decreasing trend was observed and therefore shows that over the study period, TDH occurrence has decreased in recent years. From 1982 – 1994, the frequency of occurrence of TDH conditions is relatively high and then from 1998 to 2006, a significant decrease was observed which shows the decreasing trend. In 1995 and 1996, a very low value in the occurrence of TDH was observed before recording a high value in 1997.

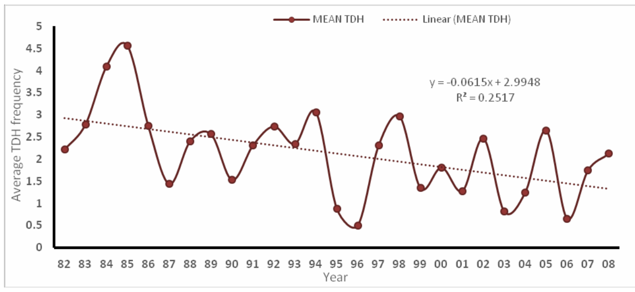

Figure 7: Mean annual variation of the frequency of occurrence of TDH days per month for all the stations.

Figures 8 and 9 shows the mean annual variability and trend of the frequency of occurrence of LDH (Thick Dust Haze) for the individual stations throughout the study period. The variation for all the stations except Nguru, show that for the earlier years, the number of occurrence of LDH days is less than that recorded in recent years and as such it follows an increasing trend indicating that in recent years the frequency of occurrence of LDH days per month has decreased throughout the study period.

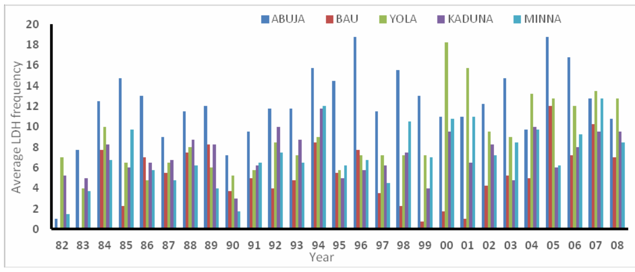

Figure 8: Mean annual variation of the frequency of occurrence of LDH days per month for Abuja, Bauchi, Yola, Kaduna and Minna.

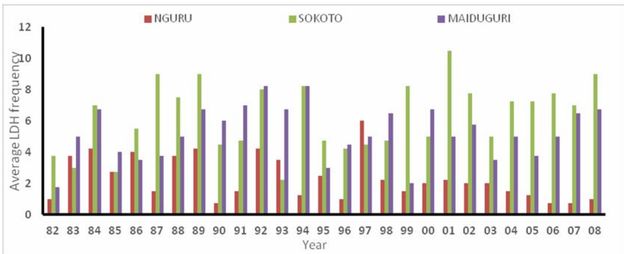

Figure 9: Mean annual variation of the frequency of occurrence of LDH days per month for Nguru, Sokoto and Maiduguri.

Citation: Ochei MC, Adenola E (2018) Variability of Harmattan Dust Haze Over Northern Nigeria. J Pollut 1: 107.

Figure 10 shows the mean annual variation and trend of the frequency of occurrence of LDH for all the stations. An increasing trend was observed and therefore shows that over the study period, LDH occurrence has increased in recent years. It was also observed that the increase in the frequency of LDH conditions increased significantly from the year 2000 to 2008 which is in contrast to that which was observed for the TDH conditions. Hence, it can be deduced that TDH and LDH occurrences are negatively correlated in that they have a negative relationship over the years and even differ spatially.

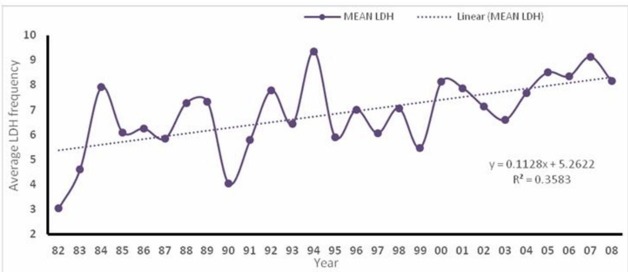

Figure 10: Mean annual variation of the frequency of occurrence of LDH days per month for all the stations.

Latitudinal relationship between TDH and LDH occurrence

Figure 11 showed that on the average, the frequency of TDH days increases with increasing latitude. This could be due to the closeness of the higher latitudes to the source regions of dust. Thus, the higher the latitude the higher the frequency of TDH occurrences during the harmattan season. Anuforum AC [15] also stated that a high correlation exists between the frequency of occurrence of TDH days and latitude, and that the latitude of a given location is a major factor that determines how often or severe visibility impairment due to dust influx occurs in that location.

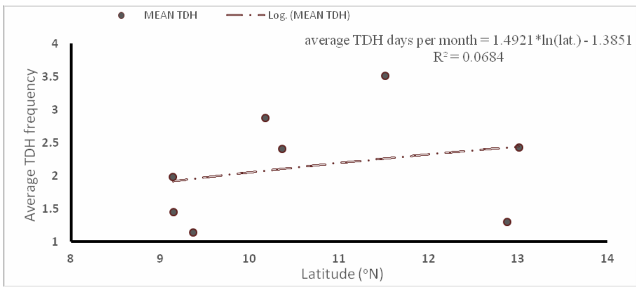

Figure 11: Variation of mean FOO of Thick Dust Haze (TDH) per month with latitude.

On the other hand, Figure 12 shows that the frequency of LDH days decreases with increasing latitude, thus, a negative relationship exists between LDH occurrences at a station and the latitude of that particular station. Hence, the higher the latitude, the lower the frequency of occurrence of LDH days. Therefore, TDH and LDH conditions or days at a location depend largely on the latitude of that location in relation to the source region. For Nigeria, the dust source region is located towards the north; hence, high latitudes are at close proximity to the source regions. It is therefore notable that the prevalence of dust concentration depends on the distance of a particular station from the source region. Also, anthropogenic activities, climatological processes and the vegetation or type of land cover could influence the dust concentration in a region, for example, the northern part of Nigeria is mostly arid lands and as such dust could be easily raised and transported during farming activities by prevailing winds.

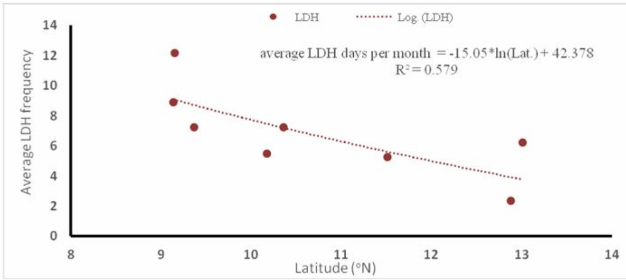

Figure 12: Variation of mean FOO of and Light Dust Haze (LDH) per month with latitude.

Decadal spatio-temporal variation of the FOO (frequency of occurrence) Of TDH and LDH days

For the first decade, the TDH occurrences range from 1 to 4 days. The highest occurrences for dust storms were seen majorly over Bauchi and Maiduguri, then Sokoto. The least number of TDH occurrences were observed over Minna. In the second decade, the average frequency of occurrence of TDH days reduced generally when compared with the first decade, and least number of TDH days were also recorded in Minna even throughout the study period. Maiduguri records the highest number of TDH conditions throughout this period (second decade). In the third decade, the average numbers of TDH days across the stations have relatively reduced when compared with the other decades apart from Maiduguri which still records the highest number of TDH days. Hence, the average number of occurrence of TDH days over the study period is seen to have reduced in recent years. Generally, it was also observed from Figure 13 that the average number of occurrence of TDH days decreases southwards in a westward direction which could be as a result of the northeasterly trade wind pattern and speed over the years [22].

Figure 13 shows the seasonal and temporal variation of the FOO of LDH days or conditions on a ten year mean basis by comparing each decade. It could be observed in the first decade the pattern of the LDH days distribution follows such that the highest number of LDH days were observed towards the southern zone of the study area as earlier discussed. Considering the three decades, there exist significant increases in the average LDH occurrences. The highest number on the average of LDH occurrences were about 10, 12 and 13 days for the first, second and third decade respectively. Comparing the third decade with the second, and the second with the third, it can be seen that the number of LDH days has increased over the years especially to the south which is of course the opposite to the pattern of TDH occurrences (which decreased in recent years). As discussed earlier, it could be seen that throughout the study period, the average number of LDH days increases southwards and is least in the north [15].

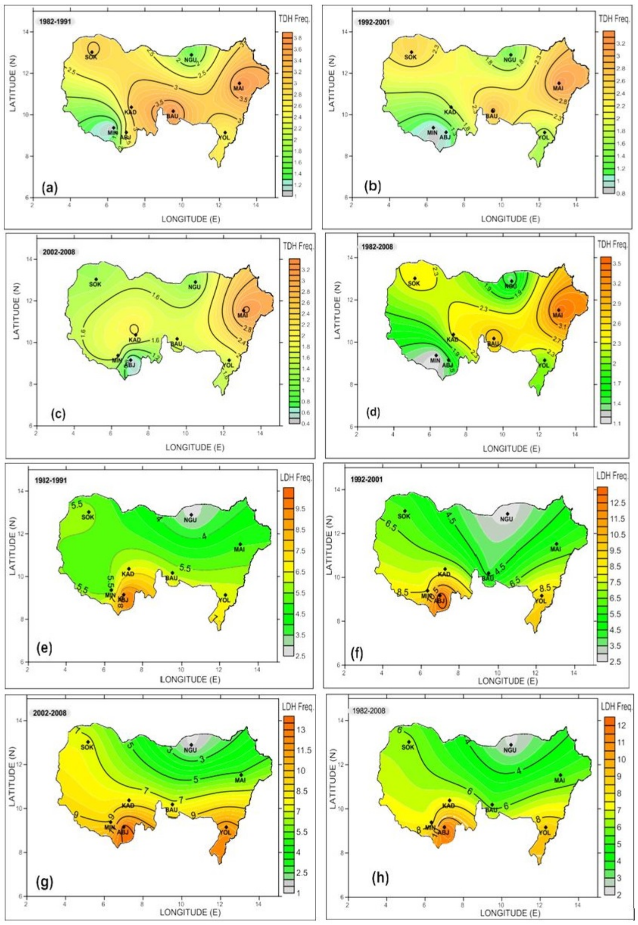

Figure 13: Decadal (ten year) mean variations of the frequency of occurrence of TDH days: (a) 1982-1991, (b) 1992-2001, (c) 2002-2008, (d) 1992-2008 (27 years); and LDH days: (e) 1982-1991, (f) 1992-2001, (g) 2002-2008, (h) 1982-2008 (27 years).

Conclusion

The pattern of visibility variation over the study area shows a somewhat decreasing trend indicating that visibility on a general scale has deteriorated over the years. At the beginning of the harmattan period, visibility starts to decline reaching its least values in January suggesting that the frequency of Occurrence of dust haze (light and thick) is highest in this month, and then starts to increase in the month of February and all through the rest of the year due to the commencement of the rainy season in which moisture serves as a sink for dust/aerosols in the atmosphere. The spatial and temporal variability of the FOO of TDH over the study area shows that during the harmattan season, the average number of TDH days is about 2 to 4 days (per month). The frequency of dust occurrence days' decreases southwards in a southwest direction which can be due to the direction of the prevailing wind (North Easterlies). The high frequency of occurrence of TDH in the northern parts of the study area can be attributed to the proximity of this area to the Saharan dust source region. The spatial and temporal variability of the FOO of LDH over the study area shows that during the harmattan season, the frequency of occurrence of LDH days range from 2 to 11 days (per month) on the average throughout the study area (northern Nigeria) with its least number of LDH days observed in Nguru. Also, the LDH follows a similar pattern to that of the TDH on a monthly basis, such that it has its highest values in the month of January. It was also observed that generally, the Frequency of Occurrence of LDH days increases southwards which could be attributed to the predominance of fine dust particles and lower wind speed towards the south. The yearly variation of TDH occurrences over all the stations show that the frequency of TDH days follows a decreasing trend all through the study period, while that of LDH follows an increasing trend all through the study period. The frequency of TDH days increases with increasing latitude and this could be due to the closeness of the higher latitudes to the source regions of dust. Thus, during the harmattan season, the higher the latitude, the higher the frequency of TDH occurrences; hence, the latitude of a given location is a major factor that determines how frequent or severe visibility impairment occurs in such location due to dust influx. But the reverse was the case in LDH such that the frequency of LDH days decreases with increasing latitude, thus, a negative relationship exists between LDH occurrences at a station and the latitude of that particular station. The prevalence of dust concentration therefore depends on the distance of a particular station from the source region. The pattern of TDH and LDH occurrence during the harmattan period is directly opposite to the pattern of visibility i.e., when visibility is least in the month of January, the frequency of TDH and LDH days peaks in this month. Hence, visibility deterioration or reduction during the harmattan period is largely affected by the prevalence of dust particles (coarse and fine) in the atmosphere, their life span in the atmosphere before settling or sunk.

References

1. Anuforom AC, Akeh LE, Okeke PN, Opara FE (2006) Inter-annual variability and long-term trend of UV-absorbing aerosols during harmattan season in sub-saharan west Africa. Atmos Environ 41: 1550-1559.
2. Herrmann L, Stahr K, Jahn R (1999) The importance of source region identification and their properties for soil-derived dust: the case of harmattan dust for eastern west Africa. Contrib Atmos Phys 72: 141–150.
3. Koren I, Kaufman YJ, Washington R, Todd MC, Rudich Y (2006) The bodélé depression: a single spot in the Sahara that provides most of the mineral dust to the Amazon forest. Environ Res Lett 1: 1–5.
4. Wei HJ, Tan HK, Weimin S, Guixiang S, Guohai C (2009) Visibility, air quality and daily mortality in Shanghai China. Sci Total Environ 407: 3295-3300.
5. Kaskaoutis DG, Kambezidis HD, Nastos PT, Kosmopoulos PG (2008) Study on an intense dust storm over Greece. Atmos Environ 42: 6884-6896.
6. N'Tchayi MG, Bertrand JJ, Nicholson SE (1997) The diurnal and seasonal cycles of desert dust over Africa north of the equator. J Appl Meteorol 36: 868-882.
7. Kehinde OO, Ayodeji O, Vincent OA (2012) A long-term record of aerosol index from toms observations and horizontal visibility in sub-saharan west Africa. Int J Remote Sens 33: 6076-6093.
8. Mukhtar B, Khiruddin A, Mohd N (2015) Long-term trend and seasonal variability of horizontal visibility in Nigerian troposphere. Atmosphere 6: 1462- 1468.
9. Habib G, Venkataraman C, Chiapello I, Ramachandran S, Boucher O (2006) Seasonal and inter-annual variability in absorbing aerosols over India derived from toms: relationship to regional meteorology and emissions. Atmos Environ 40: 1909-1921.
10. Adebayo SI (1989) Trajectories of advected Sahara dust in Nigeria. Atmos Environ 2: 1581-1589.

11. Mctanish GH (1980) Harmattan dust deposition in northern Nigeria. Nature 286: 587-588.
12. Kalu AE (1979) The African dust plume: its characteristics and propagation across west Africa in winter. in: morale c (ed.). Saharan dust mobilization, transport, deposition. Wiley, New York. pp: 95-118.
13. Balarabe M, Abdullah K, Nawawi M, Khalil AE (2016) Monthly temporal- spatial variability and estimation of absorbing aerosol index using ground-based meteorological data in Nigeria. Atmos Climate Scie 6: 425-444.
14. Prospero JM, Ginoux P, Torres O, Nicholson SE, Gill TE (2002) Environmental characterization of global sources of atmospheric soil dust identified with the nimbus-7 total ozone mapping spectrometer (toms) absorbing aerosol product. Rev Geophys 40: 2-1-2-31.
15. Anuforum AC (2007) Spatial distribution and temporal variability of harmattan dust haze in sub-sahel west Africa. Atmos Environ 41: 9079-9090.
16. Goudie AS, Middleton NJ (2001) Sahara dust storms: nature and consequences. Earth Sci Rev 56: 179-204.
17. Engelstaedter S, Tegen I, Washington R (2006) North African dust emissions and transport. Earth Sci Rev 79: 73-100.
18. Zender CS, Bian H, Newman D (2003) Mineral dust entrainment and deposition (dead) model: description and 1990s dust climatology. J Geophys Res 108: 4416.
19. Han L, Zhuang G, Sun Y, Wang Z (2005) Local and non-local sources of airborne particulate pollution at beijing. sc china ser b-chem 48: 253-264.
20. Flamant C, Lavaysse C, Todd MC, Chaboureau JP, Pelon J (2009) Multi-platform observations of a springtime case of bodélé and sudan dust emission, transport and scavenging over west Africa. Q J Royal Meteorol Soc 135: 413-430.
21. Schwanghart W, Schütt B (2007) Meteorological causes of harmattan dust in west Africa. Geomorphology 95: 412-428.
22. Adefolalu DO (1984) On bioclimatological aspects of harmattan dust haze in Nigeria. Arch Met Geoph Biocl Ser B 33: 387-404.