ISSN 2347-4289

Seasonal And Monthly Estimation Of Mean Residence Time Of The Harmattan Dust In Kano, Northern Nigeria Using Horizontal Visibility Data

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

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

ABSTRACT: Kano, (12.05° N, 8.56° E) located in the extreme North of Nigeria, with an altitude of 476 m above sea level (*asl.*) and station number 650460 (DNKN), is one of the regions that records the least horizontal visibility of near zero in northern Nigeria during winter season due to the presence of harmattan dust particles in the air. This paper therefore, investigates the Mean Residence Time (MRT) of aerosol dust during the harmattan (winter) season using horizontal visibility data of the area. The horizontal visibility data of Kano was obtained from historical meteorological database of Tutiempo Network, for 12 harmattan seasons (2003/2004-2014/2015) with each season covering a period of the five months of harmattan season from (November–March). The results obtained, indicates that there is a downward trend in mean seasonal horizontal visibility by 0.016km per harmattan season. The seasonal average is $6.8 \pm 1.5\ km$. The maximum and minimum seasonal average visibility are $8.9 \pm 1.1\ km$ (10-7.8 km) and $5.4\ \pm 2.8\ km$ (8.2-2.6 km) respectively. Similarly, the estimated result of Mean Residence Time of dust aerosol shows a seasonal average Mean Residence Time (MRT) of 6 ± 2.4 days, with maximum and minimum seasonal average of $8.4\ \pm 4.7$ days and $2.7\ \pm 1.8$ days respectively. The trend reveals that the seasonal Mean Residence Time (MRT) decreases by 0.165km per harmattan season.

Keywords: Horizontal Visibility, Harmattan season, Mean Residence Time, kano, Aerosol dust.

1 INTRODUCTION

Recent study revealed that there is a slight down drift in the value of seasonal Mean Residence Time (MRT) in northern Nigeria. [1] While comparing the trend in the seasonal Mean Residence Time (MRT), for twenty harmattan seasons in Sokoto, Nigeria, observed that the seasonal Mean Residence Time (MRT), decreases by 0.02 days seasonally. Mean Residence Time (MRT), therefore, can be defined as the average time a substance is likely to spend in a reservoir before being removed by some processes [14]. [9] opined that, the residence time of aerosol is influenced by some key removal processes, some of which include: Dry deposition and Wet deposition. Dry deposition refers to the removal mechanisms that do not involve precipitation [14]. It could be caused by Impaction, Brownian diffusion, turbulent transfer or gravitational sedimentation process [10]. The Mean Residence Time is variable and largely affected by climatic parameters such as wind speed and relative humidity [11]. The impact created by climate change in our world today calls for serious concern. It is a common knowledge today that the general characteristics of our world's climate is fast changing. This change is evident in the area of global warming [8]. Dust aerosol affects the earth's radiative budget in many ways and one of its most significant effects on the climate is actually in cooling [16]. The National Oceanic and Atmospheric Administration (NOAA) and National Aeronautic and Space Administration (NASA) declared 2014 as the warmest in its 134 years of keeping records [19]. NOAA further stated that December 2014 recorded a temperature of about 0.69° C above the 20th century average in the 1880-1940 records surpassing the previous records of 2005 and 2010 by 0.04° C. In another report published by Japan Meteorological Agency also confirmed 2014 as the warmest year in more than its 120 years of record keeping [12]. Recent report by World Meteorological Agency (WMO) has declared 2015 as the warmest year in record history. NASA report in January 2015 warned that 2015 temperature could exceed that of 2014. And if that holds, it should serve as a source of worry and concern. British meteorological office has already released a report that the year 2016 would likely be the warmest year on record [28]. In northern Nigeria, the two months identified as the warmest months in recent time falls within the five months of harmattan season. During the months of (November-March), the trade wind systems from the East and North east are prevalent in the country [17], extreme dryness and hazy conditions are the properties of these wind system. The visibility is usually so low that it renders near object obscured. The sun is thus concealed for a greater part of the day, and appears only for a few hours [7]. The presence of dust aerosol reduces the horizontal visibility in the area [1]. This is because the suspended dust particles affects the radiative transfer directly by scattering the incident solar radiation [7], and indirectly affects cloud droplet size distribution and concentration [9]. [18] Noted that, the Sahel region of northern Nigeria has experienced a dramatic increase in dustiness particularly since the 1980s, he added that this increase in the wind-borne dust reaches the Caribbean, from the Sahel region. For the residents of West Africa, it is a hazardous fact of life. The reduced visibility can cause problems for road and air traffic. Flights are commonly delayed, diverted or cancelled during severe harmattans dust episode and sometimes accidents occur [23]. The annual meningities epidemics in West Africa which affects up to 200,000 people are also closely related to the harmattan season in their timing [22]. There are various Models proposed by different authors for the evaluation of Mean Residence Time of dust aerosols, some of these models employed use of radioactive tracers which are classified into three categories according to their origin: (1) cosmogenic radionuclides (^{7}Be, ^{22}Na, ^{32}P, ^{33}P, ^{35}S etc.), which are formed in the upper layers of the atmosphere (Stratosphere and Troposphere) by spallation methods of light atomic nuclei (e.g. Nitrogen and Oxygen) when they absorb primary (mostly protons) and secondary (neutrons) cosmic radiation [15]; (2) artificial radionuclides (^{89}Sr, ^{90}Sr, etc.), generated by nuclear weapon tests, nuclear power plants, nuclear fuel reprocessing facilities etc. [21]; and (3) natural radionuclides (^{222}Rn, ^{210}Pb, ^{210}Bi, ^{210}Po, etc.), formed during element evolution in the earth [3]. [1] Used hori-

ISSN 2347-4289

zontal visibility data covering a period of 20 harmattan seasons to calculate the Mean Residence Time, for each of the seasons in Sokoto, Northwestern Nigeria. The natural radionuclides (^{222}Rn, ^{210}Pb, ^{210}Bi, ^{210}Po,) are more commonly used by most authors to study the transport process of atmospheric dust aerosols because of its prolonged residence in the atmosphere [11]. This paper would therefore present the seasonal mean residence time for 12 harmattan sesons in Kano, Northern Nigeria using visiblility data. The findings in this research would further strengthen the findings by [1]. Furthermore, more information on the effect of dust aerosol on climate change as it relates to Global warming would be provided.

2 MTHODOLOGY

2.1 Site Description

Kano (12.05° N, 8.56° E), a city located in the Northern region of Nigeria in West Africa, lies in the Sahel savanna vegetation zone [27]. It is situated on an altitude of about 476 m above sea level (*asl*.). It shares it boarder with four states Katsina and Jigawa to the Northwest and Northeast respectively, Kaduna and Bauchi to the southwest and Southeast respectively. It covers a land area of about 499 Km^2 with an estimated population of over 2,828, 861 from the 2006 Nigerian census. Kano is typically very hot throughout the year. The months of December January, February and March records the highest maximum temperature of between 30.6° C and 38° C. Though, night time temperatures is usually cooler during the months of December, January, and February ranging between 11° C and 14° C [24].

Figure 1: *Map of Kano and location in Nigeria*.

2.2 Theory and Methods

The term "visibility distance" is used to denote the maximum distance at which a small dust can be seen and recognized as dust [6]. The "Visual range" of a given object may be defined as the maximum distance at which an object can just be seen by an observer with normal vision. For complex objects (objects having two of more parts) the various parts of which are resolved (seen as separate), the visual range is the maximum distance at which the resolution is just possible. Therefore, it is arbitrarily assumed that visibility distance of dust column is 70% of visual range. The apparent contrast between distant object and its background υ may be defined by the equation

$$\upsilon = \pm \frac{H_0 - H}{H} \quad (1)$$

In which υ is always considered positive. H is the apparent brightness of a distant background, H_0 is the apparent brightness of a distant object. The retinal threshold contrast $\mathcal{U}_t$ is related to the object background contrast by the equation [4]; [5].

$$\mathcal{U}_t = \upsilon f(\propto), \quad (2)$$

Where $f(\propto)$ is some function of angular diameter of the object, and its form depends on the nature of the object. In general, $\mathcal{U}_t$ depends on the background brightness H, but the nature of this relation is such that for observation in daylight $\mathcal{U}_t$ is nearly independent of H. In radian measure the apparent angular diameter of the test object may be written to a close approximation as:

$$\propto = \frac{MD}{x} \quad (3)$$

If binocular or telescope is not used, the magnification M is set equal to unity. For an object in the form of long band thin band or rectangle, $f(\propto)$ may be written approximately [5] as:

$$f(\propto) = A \propto \quad (4)$$

$$f(\propto) = A\left(\frac{MD}{x}\right) \quad (5)$$

Where A is a constant, D is the linear diameter of object. Eliminating υ *and* $\propto$ between equation (2), (3) and (5), gives the visual range equation for an object in the form of a long rectangle x_l.

$$x_l = \left(\frac{\mathcal{U}_t}{A}\right)\left(\frac{x}{MD}\right) \quad (6)$$

For a dislike object, the function $f(\propto)$ is approximately [4]

$$f(\propto) = B \propto^2 \quad (7)$$

$$f(\propto) = B\left(\frac{MD}{x}\right)^2 \quad (8)$$

Where B is a constant, eliminating υ and $\propto$ between equation (2) and (8) gives the visual range equation for a dislike ject x_d.

$$x_d = \left(\frac{\mathcal{U}_t}{B}\right)\left(\frac{x}{MD}\right)^2 \quad (9)$$

Equation (6) and (9) can be used to estimate the visual range of an object if all of the other variables in the equation are known. They can also be used to estimate the effects of colour filters, polarizing filters, and magnification on visual range. The transmission properties of the filter determine the appropriate value of σ to use in equation (6) and (9), since σ is a function of wavelength λ.The relation between σ and wavelength λ was computed from the equation .

$$\sigma_\lambda = \sigma_{0.555}\left(\frac{\lambda}{0.555}\right)^{-r} \quad (10)$$

Where σ_λ is the attenuation coefficient for some wavelength λ and $\sigma_{0.555}$ the attenuation coefficient for a wavelength of

0.555μ. The exponent is not a constant but depends on σ. [20] presented data showing the relation between r and the mean value of σ for wavelengths of $0.459\mu\ 0.528\mu\ and\ 0.636\mu,$ respectivly. The three values of $\sigma_{0.555}$ used in computing $\frac{1}{\sigma_{0.555}}$ were 0.711, 0.192 and 0.455. The corresponding values of r from Middleton's data are 0.82, 1.26, and 2.09. The haze-meter reading d is related to σ by the equation

$$\sigma = -\frac{1}{d}\log 0.40 \quad (11)$$

The simplest of visual range equation is that of a large black object viewed against the horizon sky which is

$$\sigma x = -\log u_t \quad (12)$$

The threshold contrast u_t is usually assigned the value of 0.02 for high brightness levels [5].

2.3 The Degradation of Light Passing Through the Atmosphere: The Mean Free Photon Path

If a beam of light rays is passed through a scattering and absorbing medium, such as a hazy atmosphere, its intensity decreases with the distance traversed. The differential equation describing this change is [6].

$$dI = -\sigma I dx \quad (13)$$

When integrated, this equation gives the intensity I at a distance x as:

$$I = I_0 e^{-\sigma x} \quad (14)$$

Where I_0 is the initial intensity, and σ is the attenuation coefficient representing the total coefficient for both scattering and absorption processes. Therefore the expected mean free path $\bar{x}$ of a photon in the atmosphere is given as:

$$\bar{x} = \frac{1}{\sigma} \quad (15)$$

The average photon path is therefore equal to $\frac{1}{\sigma}$ and is the distance that will reduce the intensity of light beam to $\frac{1}{e}$ of its initial value. The distance $\bar{x}$ is nearly equal to haze-meter reading d, which is the distance that will reduce the intensity of light to 0.40 of its initial value. Therefore the dark ridge visual range is related to $\bar{x}$ by the equation

$$y = -\bar{x}\log_e(0.02) \quad (16)$$

$$y = 3.912\bar{x}$$

2.4 Mean Residence Time

The mean residence time of a particle is an important indicator of particles cycle in the atmosphere. Factors influencing residence time include the production rate, accumulation rate, removal and growth of aerosols [13]; [26]. The residence time of particles in each size bin is dynamically calculated using the formula:

$$\tau = \frac{\mathbb{V}}{\left[\frac{d\mathbb{V}}{dt}\right]} \quad (17)$$

Where $\mathbb{V}$ is the Visibility in meter and $\left[\frac{d\mathbb{V}}{dt}\right]$ the rate of change in visibility calculated at each time interval per day.

2.5. Data And Methods

To determine the mean residence time of harmattan dust particles in Kano (12.05° N, 8.53° E), a city located in the Northern region of Nigeria in West Africa, the visibility data for Kano were obtained from public Tutiempo Network, (http://en.tutiempo.net/m/climate/ws650460.htm) database for 12 harmattan seasons with each covering a period of the five harmattan months of (November-March). The station number is 650460(DNKN) and situated at an altitude of 476 m above sea level (asl.).

3 RESULTS AND DISCUSSIONS

3.1 Horizontal Visibility in Kano

A statistical description and Summary of the monthly visibility seasonal average for 12 harmattan seasons of 2003/2004-2014/2015, for the 5 months of (November-March), is presented in Table 1. The table reveals that 2005/2006 hamattan season recorded the highest mean visibility of about 8.9 $\pm$ 1.1 km, the least visibility of 5.4 $\pm$ 2.8 km was recorded for the 2003/2004 harmattan season. [2] also reported the 2005/2006 harmattan season as the month with the highest recorded visibility of 13.08 $\pm$ 4.14 km in Bauchi (10.17° N, 9.49° E). Generally it was observed that the month of November recorded the highest mean monthly visibility of about 7.4 $\pm$ 1.5 km indicating that the month of November recorded the least concentration of dust during the harmattan season. The month of November in Kano usually marks the beginning of harmattan season. Furthermore, it was observed that the months of December and March recorded the least Mean monthly visibility of abouth 6.5 $\pm$ 1.5 km. Suggesting that these are months with higher records of harmattan dust concentration during the season.

Table 1: *Mean monthly Horizontal visibility data in Kilometers (km) for Kano (2003/2004-2014/2015).*

Mths	Nov	Dec	Jan	Feb	Mar	Mean	Std. Dev	Var S^2
03/04	NA	3.5	6.9	8.6	2.6	5.4	2.8	7.9
04/05	9.1	8.0	9.6	6.1	9.5	8.5	1.6	2.7
05/06	NA	8.8	10.0	9.3	7.4	8.9	1.1	1.2
06/07	6.0	6.3	1.4	8.8	NA	5.6	3.8	14.2
07/08	NA	NA	4.2	5.0	6.9	5.4	1.4	1.9
08/09	6.3	6.5	7.7	6.7	5.9	6.6	0.7	0.6
09/10	5.5	7.9	6.7	8.0	4.7	6.6	1.5	2.4
10/11	8.6	7.3	10.0	6.0	7.3	7.8	1.7	2.8
11/12	8.6	6.3	6.7	5.8	5.8	6.6	0.4	0.2
12/13	7.7	5.7	7.3	6.6	7.7	7.0	0.9	0.8
13/14	8.1	5.0	7.2	5.1	7.1	6.5	1.2	1.5
14/15	6.7	5.8	7.3	6.8	6.7	6.7	0.6	0.4
mthly mean	7.4	6.5	7.1	6.9	6.5	6.8	1.5	3.0

Figure 2: is a graphical display of the mean monthly visibility pattern. During the winter season, November recorded the highest visibility while the months of December and March recorded the least visibility in Kano. The chart is a pointer to the fact that the first major dust spell of the harmattan season occurs in the month of December. The second major dust spells took place in the month of March, hence, the reason for lower visibility. [24] in their annual report noted that December

14th -19th recorded low visibility ranging between 0.8km and 1.5km in that region of the country. They also announced that thick dust haze was experience between 2nd and 8th of March adding that Kano had the poorest visibility of about 0.5km during this period [24].

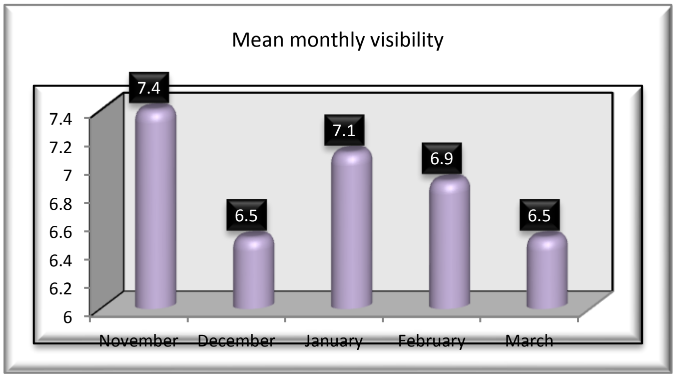

Figure 2: *Mean monthly Visibility pattern in Kano, Northern Nigeria.*

Figure 3. depicts the seasonal cycles of visiblilty form 2003/2004 hamattan season to 2014/2015 harmattan season for the dry season months of (November-March) in Kano, covering 12 harmattan seasons. The graph shows that there is a seasonal variation in the mean seasonal visibility during the period. In addition, it can be deduced that the 2004/2005 and 2005/2006 recorded the highest seasonal visibility distance of 8.5 $\pm$ 1.6 km and 8.9 $\pm$ 1.1 km respectively. [2] also reported 2005/2006 as the season with the highest recorded seasonal visibility for Bauchi with visibility of about 16 km. it is also important to note that NASA also declared the year 2005 as the warmest year since 1880 increasing by 0.04 ° C [25]. This could be an indicator that the presence of higher concentration harmattan dust during harmattan season contributes to the reduction in the annual mean temperature. The least visibility was observed during the 2003/2004 harmattan season with average visibility of about 5.4 $\pm$ 2.8km, making it the season with the highest recorded harmattan dust concentration. It was also observed from our analysis that the visibility trend during the study period revealed a downward trend with the following relation.

$$V(s_n) = -0.016s_n + 6.909 \qquad (19)$$

$V(s_n)$ is the mean seasonal visibility, s_n is the season number.

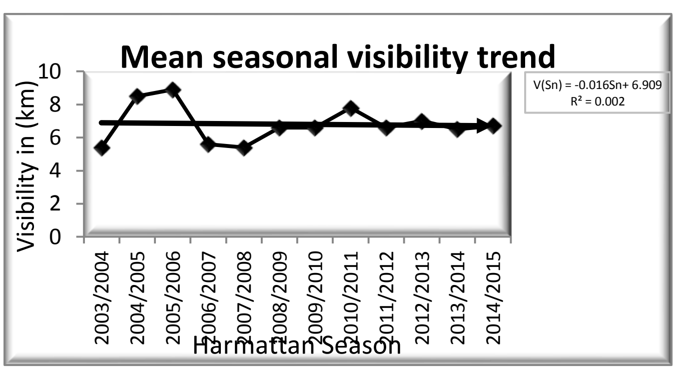

Figure 3: *Mean seasonal Visibility trend for Kano, Northern Nigeria.*

In figure 4, the seasonal visibility trends for each of the five months associated with the harmattam season are presented. The highest visibility in months of November, December, January, February and March where recorded in the 2004/2005, 2005/2006, 2005/2006 and 2010/2011, 2005/2006 and 2004/2005 harmattan seasons respectively as 9.1$\pm$ 1.6 km, 8.8 $\pm$ 1.1 km, 10 $\pm$ 1.1 km and 10 $\pm$ 1.7 km, 9.3 $\pm$ 1.1 km, and 9.5 $\pm$ 1.6 km. while the least visibility for the months of November, December, January, February and March were recorded during the 2009/2010, 2003/2004, 2006/2007, 2007/2008 and 2003/2004 harmattan seasons respectively as 5.5$\pm$ 1.5 km, 3.5$\pm$ 2.8 km, 1.4 $\pm$ 3.8 km, 5.0 $\pm$ 1.4 km, and 2.6 $\pm$ 2.8 km.

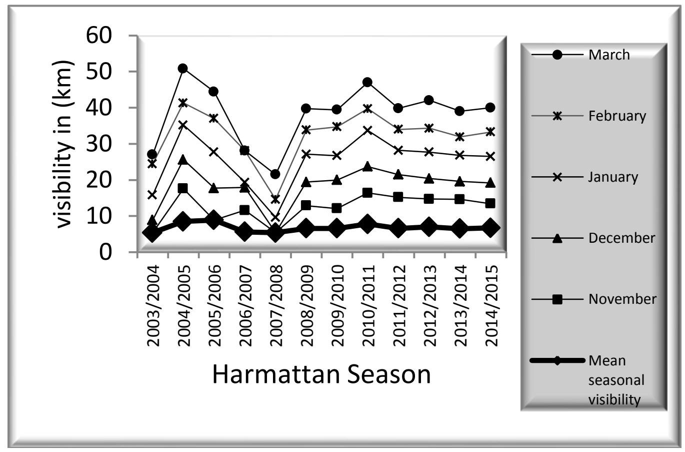

Figure 4: *seasonal mean and Monthly Visibility trend for Kano, Northern Nigeria.*

3.2 Estimated Mean Residence Time

Table 2. Presents a summary of Estimated mean residence time τ_{AV} for each of the months that makes up the harmattan season in Kano, Nigeria. The mean monthly residence time was estimated for 12 harmattan seasons using visibility data. In each of the seasons, the mean monthly residence time was estimated using the formula proposed by [9] The formular was used by [1]to estimate the mean residence time in Sokoto, North eastern Nigeria.

Table 2. *Mean monthly Estimated Residence time τ data in daysfor Kano for(2003/2004-2014/2015) Harmattan seasons.*

	Months							
Seasons	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Mean (τ_{AV})**	**Std dev**	**Var (S^2)**
03/04	NA	11.5	5.9	3.1	13	8.4	4.7	21.7
04/05	2.3	4.1	1.5	7.2	1.6	3.3	2.4	5.7
05/06	NA	2.8	0.8	2.0	5.1	2.7	1.8	3.3
06/07	7.4	6.9	14.9	2.8	NA	8.0	5.0	25.4
07/08	NA	NA	10.3	9.0	5.9	8.4	2.3	5.1
08/09	6.9	6.6	4.6	6.2	7.5	6.4	1.1	1.2
09/10	8.2	4.3	6.2	4.1	9.5	6.5	2.4	5.6
10/11	3.1	5.2	0.8	7.4	5.2	4.3	2.5	6.2
11/12	3.1	6.9	6.2	7.7	7.7	6.3	1.9	3.6
12/13	4.6	7.9	5.2	6.4	4.6	5.7	1.4	2.0
13/14	3.9	9.0	5.4	8.9	5.6	6.6	2.3	5.2
14/15	6.2	7.7	5.2	6.1	6.2	5.9	0.6	0.4
mthly mean	5.1	6.6	5.6	5.9	6.5	6.0	2.4	7.1

ISSN 2347-4289

The trend in mean residence time was highly uneven throughout the 12 harmattan seasons. But there appear to be strong decline in the seasonal mean resident time from 2003/2004 harmattan season down to the 2014/2015 harmattan season. The trend revealed that the seasonal residence time decrases by 0.165km per harmattan season and s_n is the season number. As shown in the relation

$$\tau = -0.165 s_n + 2.872 \qquad (20)$$

$R^2 = 0.353$ for the harmattan season. The maximum mean monthly residence time was calculated as 14.9 $\pm$ 5.0 days in January 2006/2007 harmattan season. while the least mean monthly residence time was computed as 0.8 $\pm$ 1.8 days during the 2005/2006 and 0.8 $\pm$ 2.5 days during the 2010/2011 harmattan season. The seasonal average residence time stands at 6 $\pm$ 2.4 days. Generally, it was observed that the month of November recorded the least seasonal monthly mean residence time of 5.1 ± 2.4 days while the month of December recorded the highest seasonal monthly mean residence time of 6.6 $\pm$ 2.4 days.

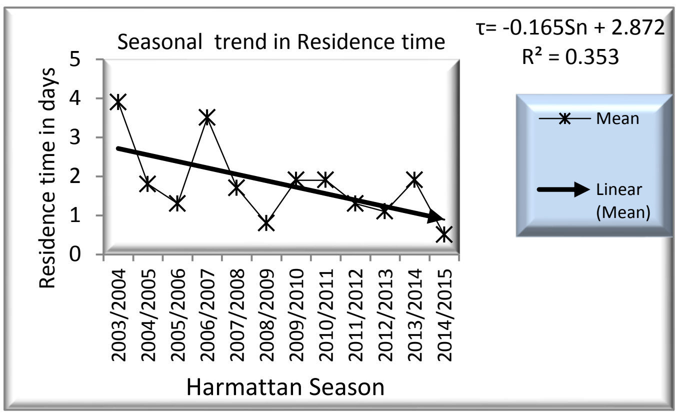

Figure 5: *seasonal mean Residence time trend for Kano, Northern Nigeria.*

A closer observation of the trend in the mean seasonal visibility and mean seasonal residence time reveals that there appears to be an inverse relation between the two parameters. Harmattan with low visibility recorded higher mean residence time while seasons with higher residence time recorded lower visibility as shown in figure 6.

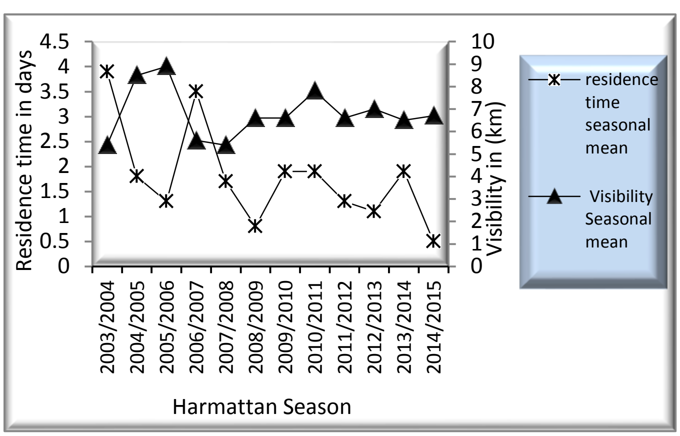

Figure 6: *Comparing Seasonal mean Visibility and Residence timefor Kano, Northern Nigeria.*

The mean monthly Residence time appears to show a direct relation with the mean monthly visibility throughout the harmattan season as presented in figure 7.

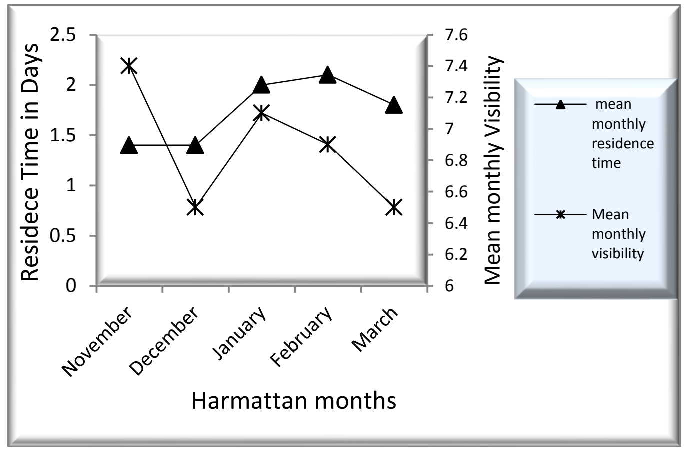

Figure 7: *Comparing Monthly Mean Visibility and Residence timefor Kano, Northern Nigeria.*

In Figure 8, the seasonal mean residence time trend for each of the five months associated with the harmattan season are presented. The highest residence time in November, December, January, February and March where recorded during the 2009/2010, 2003/2004, 2006/2007, 2007/2008 and 2003/2004 harmattan seasons respectively as 8.2$\pm$ 2.4 days, 11.5 $\pm$ 4.7 days, 14.9 $\pm$ 5.0 days, 9.0 $\pm$ 2.3 days, and 13.0 $\pm$ 4.7 days. while the least residence time for November, December, January, February and March were recorded during the 2004/2005, 2005/2006, 2010/2011, 2005/2006 and 2004/2005 harmattan seasons respectively as 2.3$\pm$ 2.4 days, 2.8$\pm$ 1.8 days, 0.8 $\pm$ 2.5 days, 2.0 $\pm$ 1.8 days, and 1.6 $\pm$ 2.4 days.

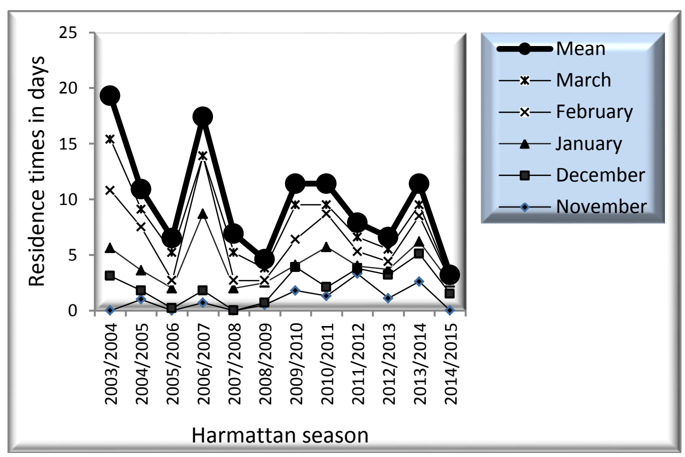

Fig. 8: *seasonal mean and Monthly Residence time trend for Kano, Northern Nigeria.*

4 CONCLUSION

A study of the mean visibility data in kano shows that for the 5 months of November, December, January, February and March, 2005/2006 hamattan season recorded the highest mean visibility of about 8.9 $\pm 1.1\ km$ (10-7.8km) and least visibility of 5.4 $\pm 2.8\ km$ (8.2-2.6km) was recorded for the 2003/2004 harmattan season. In addition, it was observed that the months of December and March recorded the least Mean monthly visibility of about 6.5 $\pm 1.5\ km$ ranging between (8 and

5km). The average seasonal visibility for the 12 harmattan season was 6.8 $\pm 1.5\ km$. The Estimated residence time for the harmattan dust in Kano indicates that the maximum mean monthly residence time was calculated as 14.9 $\pm$ 5.0 days during January 2006/2007 harmattan season while the least mean monthly residence time was computed as 0.8 $\pm$ 2.5 days during the 2010/2011 harmattan season. The seasonal average residence time stands at 6 $\pm$ 2.4 days. Generally, it was observed that the month of November recorded the least seasonal monthly residence time of 5.1 ± 2.4 days while the month of December recorded the highest seasonal monthly residence time of 6.6 ± 2.4 days. The average residence time for the entire 12 harmattan season is 6.0 ± 2.4 days that is, ranges between 3.6 and 8.4 days. Finally The trend reveals that the seasonal residence time decrases by 0.165km per harmattan season.

References

[1] J. O. Akande, M. Momoh, I. G. Saidu, M. I. Ilyasu, D. O. Akpootu, M. B. Abubakar, and M. B. Abdullahi, Evaluation of Residence time of Dust Aerosol during Harmattan Season in Sokoto Area of Northern Nigeria, using visibility Data, Journal of Environmental Science, Toxicology and Food Technology., **4**(4), 2013, 71-74.

[2] F. O. Anjorin, E. U. Utah, and D. Buba, An Investigation on Effects of Harmattan Dust (aerosol) on horizontal Visibility Deterioriation over Bauchi, North-eastern Nigeria. Iranica Journal of Energy and Environment., **6**(2), 2015, 92-97.

[3] W. M. Burton, and N. G. Stewart Use of long-lived natural Radio-activity as an atmospheric tracer. Nature., **186**: 1960, 584-589.

[4] G. M. Byram, The Physical and Photochemical Basis of Visual Resolving Power. Part I. The Distribution of illumination in Retina Images. Jour. Optic. Soc. Amer., **34**: 1944a, 718-738, illus.

[5] G. M. Byram, The Physical and Photochemical Basis of Visual Resolving Power. Part II. Visual Acuity and the Photochemistry of Retina. Jour. Optic. Soc. Amer**., 34**: 1944b, 718-738, illus.

[6] G. M. Byram, and G. M. Jemison, Some Principles of Visibility and Their Application to Forest Fire Detection. United States department of Agriculture, Washington, D. C. 954, 1948, 5-55.

[7] O. A. Essienimo, M. Momoh, and D. O. Akpootu, Mass Concentration Gradient of Aerosol Across Selected States in Northern Nigeria, International Journal of Technology Enhancement and Emerging Engineering Research., **4**(1), 2016, 17-21

[8] W. Gisela, Dust and its impact on Earth's climate system. Earths Institute, Columbia University. 2010

[9] S. L. Gong, L. A. Barrie, and J. P. Blanchet, Modelling Sea-salt Aerosol in the atmosphere 1, Model Development. Journals of Geophysics Research. **102**(3), 1997, 3805-3818.

[10] S. L. Gong, L. A. Barrie, J. M. Prospero, D. L. Savoie, G. P. Ayers, J. P. Blanchet, and L. speck, Modelling Sea-salt Aerosol in the atmosphere: 2. Atmospheric concentration and Fluxes, Journals of Geophysics Research. **102**(3), 1997, 3819-3830.

[11] A. Jia, and J. Jia, Atmospheric Resident time of Fine-aerosol in the region of south Italy estimated from the activity Concentration Ratio of $210_{Po}/210_{Pb}$ in Air particulate, J. Anal. Bioanal. Tech. 5, 216. Dio: 10.472/2155-9872-1000216. 2014.

[12] J. Romm, 2014 was the hottest year on record globally by far. Thinkprogress. Org. accessed on 22/1/16,http://thinkprogress.org/climate/2015/01/15/3067735/2014-hottest-year-by-far, 2015.

[13] C. E. Junge, Residence time and Variability of tropospheric trace gases, Tellus, **26**, 1974, 477-488.

[14] L. Kristian, Direct Radiative Effect of sea-salt on Regional scale. Scientific Publishing, 2012, 11-16

[15] P. K. Kuroda, Use of radioactive isotops as atmospheric tracer in application of Nuclear and rediachemistry., Lambrecht, R. M. and Morcos, N. (Eds.). New York, Pergamon press, 1982, 457-481.

[16] C. Lauren, Dust in the Wind, Engeenering Magazine, Cornell University. 2016

[17] R.H. Laurie, Memoir, Descriptive and Explanation: To accompany the new Chart of the Atlantic Ocean and Comprising Instructions, General and Particular, for the Navigation of that Sea. Fifth edition, John Purdy (Ed.) london, University of Wisconsin library. 1825,

[18] C. Marshall, Arebian Penisula: world and its people. New York, Marshall Cavendish (**1**), 2006,1309

[19] D. Matt, Global Temperature Percentile for 2014. www.earthsky.org accessed on 23/1/2016, http://earthsky.org/2014-warmest-year-on-record, 2015.

[20] W. E. K. Middleton, Visibility in meteorology. Illus,Toronto, University Toronto press, 1941,165.

[21] H. E. Moore, S. E. Poel, E. A. Martel, 222_{Rn}, $210_{Pb}, 210_{Bi},\ and\ 210_{Po}$ profile and aerosol residence time versus altitude. J. Geophys. Res., **78**, 1973, 7065-7075.

[22] M. Nick, Deserts: A Very Short Introduction. New York, Oxford University press inc. 2009, 12.

[23] NIMET, Nigerian Climate Bulletin 2011. **7**. 2011, 27-29.

[24] NIMET, Nigerian climate bulletin 2012. **8**. 2012, 20-30

ISSN 2347-4289

[25] B. Shaoni, 2005 was the warmest year on record: Daily news, 2006.

[26] W. G. N. Slinn, Precipitation Scavenging, in Atmospheric Science and Power production, D. Randerson (Ed.)., Tech. Inf. Cent. Off. Sci. and techn. Inf., Dep. Of Energy Washington D. C., 1984.

[27] R. K. Udo, *Geographical regions of Nigeria*. University of califonia press. Los Angeles., **1**, 1970, 1-12.

[28] WMO, (2015). 2015 likely to be the warmest on record, 2011-2015 warmest five year periods. Media center. Accessed on 23/1/16, http://www.wmo.int/media/content/wmo-2015-likely-be-warmest-recorded-2011-2015-warmest-five-year-period.