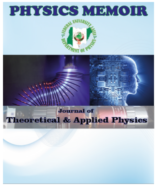

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Original Research

The Thirty Years Trend Analysis of Harmattan Season Visibility and Temperature in Sahel Zone of Nigeria

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Abstract

Climate anomalies have created short-duration climatic oscillations as against the normal cycle and this has posed and is still posing a threat to life and properties in Nigeria. A special climate change unit was created by Nigerian government in 2006 to address this problem. In this study, the meteorological data were obtained from National Oceanic Atmospheric Agency-National Climate Data Centre (NOAA-NCDC) for Sahel zone of Nigeria to analyse the long-term (1988-2017) trend and variability of visibility and temperature. The result reveals that visibility exhibited a decreasing trend while temperature shows an increasing trend over 30-years period. The 30-years seasonal mean visibility is 9.2 ± 2.39, km while the corresponding temperature is $25.12 \pm 3.87^{o}C$ respectively. Decade analysis revealed that the most obvious changes happen during the third decade. Standardize anomaly chart of visibility and temperature also reveal that changes in visibility and temperature are consistent over the study period. A simple regression analysis at$p < 0.05$ significant level were conducted with visibility as dependent and temperature as independent variables. The results show that the magnitude and nature of the relationship between temperature and visibility depend upon time. However, the trend line is consistently exponential. By dividing the data into ten years interval a much stronger and more significant relationship were obtained.

Keywords: Harmattan season; Sahel zone; Visibility; Temperature; Trend

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1. Introduction

Carbon dioxide has been neglected as the primary causes of climate change owing to the intensive aerosol emission (dust inclusive) [1-3]. This implies that mineral dust aerosol is a crucial factor in the earth climate system and will continue to influence the future climate [4].

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West Africa, (including Nigeria) is closer to the world biggest natural reservoir (Sahara and Sahel) for dust particles that give rise to the possibilities for dust been transported across the country. The transport of dust particles from Sahara across Nigeria is associated with the movement of the Inter-Tropical Convergence Zone (ITCZ) to and from the equator. The transport of the dust southward (towards Atlantic Ocean) occurs during the month of November of a year to March of the following year also known as Harmattan season year [5]. In addition to the dust transport from sahara and Sahel, the Harmattan season dry weather are also essential for dust aerosol production, distribution, and transport at local level [2]. This is in addition to soil excavation for Agricultural and irrigation purposes. Therefore, it is believed that during Harmattan season, dust transported from Sahara and anthropogenic dust aerosol is the principal pollutant in Nigeria.

The dust pollutant during Harmattan are said to be responsible for low visibility [3, 6, 7] in Nigeria affecting seriously the health, the economy and climate of Nigerians in a number of ways [8, 9]. The statistically significant relationship between visibility and dust concentration has been esterblished by Anuforom et al. [10]. The authors used Aerosol index (AI) from the Total Ozone Mapping Spectrometer (TOMS) to complement visibility at the ground level. Despite that the authors highlighted some of limitations of the two (visibility and AI) to complement each other, a significant correlation ($R = 0.92$) between TOMS AI and visibility as well as TOMS AI and rainfall ($R = 0.72$) were obtained in Sahel zone of Nigeria. Similarly, [8, 11] obtained a significant statistical correlation between TOMS AI and visibility on one hand and Ozone Monitoring Instrument (OMI AI) and visibility on the other hand. The authors revealed that, these significant relationship between visibility and dust aerosol concentration during Harmattan suggest that poor visibility during the period is an integral of high dust concentration as such used in this analysis to characterize dust trend and variability in Sahel zone of Nigeria.

A number of studies at different regional and temporal scales [12-16] also revealed a significant decreasing trend in visibility and fluctions in climatic parameters. one of these authors described temperature as the most important parameter in earth climate [15]. The studies by [12, 15] have argued on global temperature increase in the past and future projection. Studies at different regional level across Nigeria also revealed a significant positive trend in temperature [13, 14, 17]. Despite the fact that, constant monitoring and evaluations of visibility and temperature at different regions and time are necessary, long-term studies on these parameters and their relationship were ignored in Nigeria. Therefore, in this work, we focused on the recent thirty years trend and variability of Harmattan season visibility and temperature in Sahel zone of Nigeria. This is due to favorable weather condition for dust emission, large transport of dust and high anthropogenic activities during Harmattan. The goal was to explore whether any significant regional climatic change has occurred during low visibility (high dust aerosol) season from 1988 to 2017 period. The result can serve as a base for future studies on the radiative aspect of dust aerosol in the Sahel zone of Nigeria. It is expected to provide a new perspective/theoretical basis for assessing regional climate variability.

2. Data and Methodology

The visibility and temperature data used were obtained from NOAA-NCDC data base. In this study, visibility data is used as an important factor for indicating the activities of dust particles in Sahel zone of Nigeria as in line with [8, 10, 11]. These parameters in addition to 21 other meteorological observations were downloaded from htt://gis.ncdc.noaa.gov. The files were in ASCII format accompanied by specification code, data quality control flag, flags for the occurrence of fog, rain, snow or ice pellets, hail, thunder, and tornado of clouds. For this study, the hourly data were downloaded from 8 meteorological stations across the Sahel zone of Nigeria based on 75% data availability, closeness of stations to each other, and availability of years of overlapping data for all the parameters. The stations were grouped into Sahel climatic zones following the method of Anuforom [5].

The hourly meteorological data files from NOAA-NCDC were imported into Excel spreadsheet for ease of analysis. In accordance with NOAA-NCDC convention of documenting meteorological observation, visibility data were documented in miles and temperature in degree Fahrenheit. For the purpose of calculations they were converted into kilometer, and degree Celsius respectively. For each station and each year of the study period, the hourly data were arranged in to monthly (January-December) and the series of daily averages were calculated. Monthly averages for each year within the period are calculated from the daily data. The data was filtered and spurious values were removed. The monthly averages from each station were grouped into zone, and the monthly zonal mean was determined. For this analysis, we focused on Harmattan season means as well as simple statistical regression analysis for simplicity of presentation. Therefore, the Harmattan season‘s month were separated and the monthly averages were obtained for each year in the zone. This has been plotted as time series graphs to depict the pattern of Harmattan season variability of visibility and temperature in the study zone.

The Harmattan season's cumulative mean during ten year's interval (i.e., 1988-1997, 1998-2007, 2008-2017) were also calculated to enable relationship analysis for the whole Harmattan period and after each ten years as a means of exploring the hiding information from voluminous record of visibility and temperature. Both the trend and correlation analysis were determine at 95% confidence level. Visibility and temperature standardize anomaly has been calculated, and the charts were plotted for comparison.

3. Result and discussion

3.1. Harmattan season trend and variability of visibility and temperature

Figure 1 shows the temporal trends of visibility and temperature during the 30 years (1988-2017) Harmattan season for the study zone. The 30-years seasonal mean visibility is 9.25 ± 2.39, km while the corresponding temperature is $25.12 \pm 3.87^{o}C$ respectively.

It is observed from Figure 1 that, there are significant decreasing trend in Harmattan season visibility with corresponding increasing trend in temperature. The decreasing trend in visibility suggests that during the 30 years Harmattan seasons under study, there had been an increase in the concentration of dust particles that affect visibility. This is because the low visibility at the surface has been related to high concentration of the dust aerosol in the Sahel zone of Nigeria [10]. Inline with this, the increased trend of aerosol index (qualitative indicator of dust concentration) for Nigeria during the period of 1984-2013 has also been revealed in the previous work of Balarabe et al. [3]. However, the increasing trend in temperature in the zone suggest that the increased dust concentration influences green house blanket which has result in increasing heat trapped in the earth and eventually rises temperature [11]. This is because Quijano etal [18] has demonstrated that the absorption of radiation which give rise to temperature increase is predominant in the interaction of Saharan dust with solar radiation. The observed upward and downward trends of visibility and temperature are inline with many other global trends documented in various literature [13, 15, 16, 19, 20, 21]. Using students t-test, it is found that the trends are statistically significant as such require future attention.

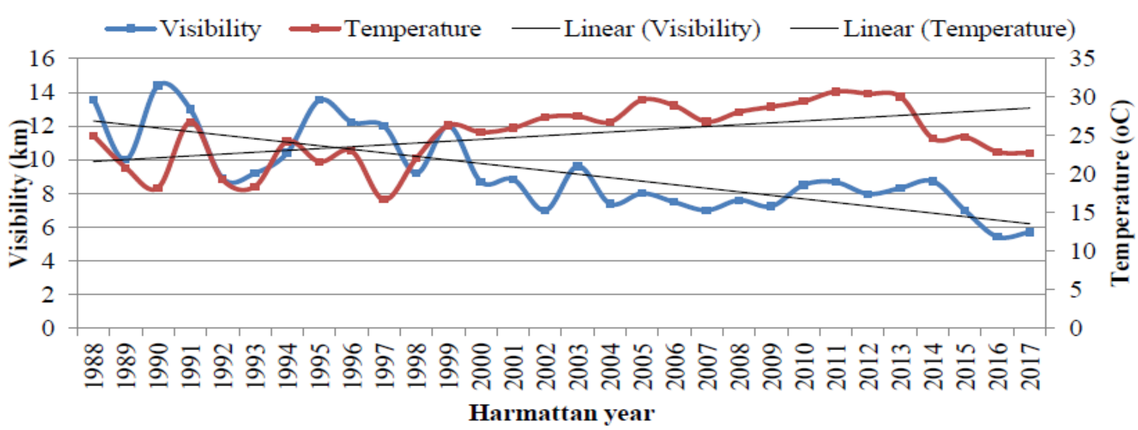

Figure 1. The 30- years Harmattan season mean visibility and temperature trend in Sahel zone.

Other noticeable features from Figure. 1 can be seen that Harmattan season visibility and temperature showed similar fluctuation until 1998/1999 season. However, after this period Harmattan season visibility sharply decreases while temperature increases continuously until 2012/2013 season maintaining close relation in their pattern of fluctuations. From 2013, both visibility and temperature fall below the average values until the end of the decade.

Also from Figure 1, decade analysis has shown that, in the first ten years (1988-1997), visibility changes are found closely related to temperature changes, and the growing rate seems uniform. This implies that a warmer season has correspondence with high visibility values, and low-temperature season showed low visibility values. Such similarities in the trend pattern suggest that in the first decade, the high visibility and temperature correspond to a period when majority of the dust aerosol confined to a high altitude as such may not influence visibility at the ground level but however increased aerosol absorption which in turn increases temperature. The low visibility and temperature correspond to the period during Harmattan when majority of the dust aerosol are confine to a lower altitude near the ground surface as such influence aerosol scattering and reduce the visibility at the ground level. Table 1 showed mean average of visibility and temperature as well as their decreasing rate over the ten years period of study. The Table revealed that the first decade is characterized by the lowest temperature values followed by the second decade and finally last decade. These imply that the first decade corresponds the coldest decade and the last correspond to the hottest decade. It is also observed that during the decade, visibility is generally highest, followed by second and finally last decade. This is very consistent, the lower the visibility (higher aerosol concentration) the higher the temperature in the Sahel zone of Nigeria.

Table 1. Ten years interval average visibility and temperature as well as their decreasing rate for Sahel zone of Nigeria

Period	Average visibility (km)	Decreasing rate per decade	Average Temperature	Decreasing rate per decade
1988-1997	11.72	-0.18	21.41	-0.36
1998-2007	8.52	-0.07	26.69	0.46
2008-2017	7.52	-0.01	27.26	-0.08

In the second decade, the pattern of fluctuations varies compared to the first decade (Figure 1). This can be related to changing pattern of the rate at which dust aerosol are emitted as a result of increased anthropogenic activities and transport of dust. During this decade, visibility decreases while temperature increases. The third decade is characterized by irregular and short fluctuations in the seasonal trend pattern (Figure 1) except in the last three years (2015-2017) where they exhibit similar fluctuations. Table 1 show that this decade experiences the lowest visibility values with corresponding highest temperature values. The lowest visibility can be associated with increased dust concentration due to increased emission strength from the dust source regions [22] and regional anthropogenic emission [10]. In this decade, both visibility and temperature rises except in the last three years where both decreased.

Figure 2 revealed the Harmattan season's visibility and temperature anomaly. It is evident from the figure that in the first decade, positive visibility corresponds to negative temperature anomaly while in the second and third decades negative visibility corresponds to positive temperature anomaly except in the last four years where temperature anomaly showed positive anomaly. These suggest that Harmattan season of the recent decades are dustier than the previous ones and that, Harmattan season of the recent decades become hotter than the previous decade. This could be due to the fact that the absorption ability of the dust aerosol in this region has increased over time. This is similar to the findings of Anuforom et al. [10] and Ogunjobi et al. [11] who found an increased trend in Absorbing Aerosol Index in Nigeria.

In order to investigate the relationship between visibility and temperature in the Sahel zone of Nigeria. Their correlation coefficients from 1988-2017 and simple linear relationship are summarized in Table 2 and Table 3. The fact that this data set has a much longer history of thirty years and variation in existing trend, the generalization or rather taking 30 years seasonal mean may exclude much meteorological information. As such this study period is divided into 3 decades, and the visibility values for each ten years period were correlated with the corresponding temperature as shown in Table 2. By dividing the 10, years interval, we obtain much stronger and more significant relationship. This is because the variation of temperature due to low visibility caused by dust aerosol depends on the aerosol concentration, nature, meteorological condition and the size of aerosol in a particular region and time. The amount of data set could also give a considerable variation in the correlations between temperature and visibility.

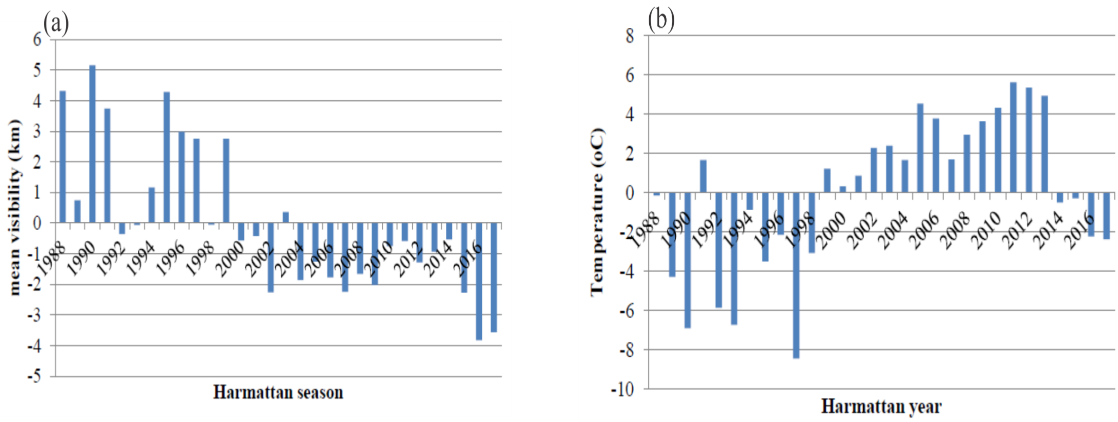

Figure 2. Comparism between Harmattan season mean visibility and temperature anomaly of Sahel zone of Nigeria from 1988-2017.((a) Visibility; (b) Temperature)

Table 2. Correlation coefficients between visibility and temperature for Sahel zone of Nigeria during Harmattan season of 1988-2017

Period	r
1988-2017	-0.41
1988-1997	0.52
1998-2007	-0.57
2008-2017	0.74

Note: r, correlation coefficient

The relatively large differences in the average temperature and visibilities from one decade to another during the Harmattan season (Table 1) suggest that these variations in the relationships are associated with a positive impact of transported dust. From Table 2, the obtained results showed that the relationship between temperature and visibility is a temporal phenomenon with respect to magnitude and effects. Therefore, the magnitude and signs of the correlation coefficients between visibility and temperature indicate that dust appears to have a considerable effect in the Sahel zone of Nigeria.

The comparison of the signs and magnitudes of the correlation coefficients (Table 2) reveal that, the responses are strong and positive in the first and the last decade while strong and negative in the second decade. The magnitude of correlations are higher in the third decade and lowest in the first decade. The negative correlation suggests that temperature decreases with decreasing visibility and vice versa. However, the positive correlation indicates that dust concentration results in increasing temperature in the zone. This is similar to the observation by Junjun et al. [23] who found a positive relationship between visibility and temperature in Taiwan Strait. The differences in the nature and degree of relationships in different decades signify the contribution of some other factors such as aerosol size distribution, mineralogy composition of the dust particles, and meteorological factors. This is in addition to presences of cloud, altitude and height of the dust layer and surface albedo of underlying surface. For instance, in line with theoretical evidence that, in Sahel, the mean diameter of dust particles decreases as the distance from the sources increases. This implies that, dust aerosol in Sahel is richer in coarse mode particles. These sizes mode respond differently to solar and infra-red radiation. It is therefore possible that the aerosol size of dust particles in Sahel zone changes overtime. The low correlation in the first 10 years can be understood due to fact that aerosol causes low visibility mostly through scattering [24]. However, biomass and charcoal burning aerosol, industrial and combustion from vehicle and industries causes low visibilities through absorption. So dust and other aerosol interaction may weakened the relationship as there could be no large amount of smoke to produce equal amount of absorption to scattering the cause by dust particles. It is therefore concluded that the relationship between visibility and temperature in all the three decades are strong and significant at ($p < 0.05$). However, in the overall data, visibility is poorly correlated with temperature.

Table 3 shows the simple regression equation between visibility and temperature at $p < 0.05$ during Harmattan period of 1988-2017 in the Sahel zone of Nigeria. From the scatter plot (not shown here), different line of fit were tested, and it was found that the trend of visibility and temperature is consistently exponential. These equations are compared well with the linear equations found between visibility and temperature by Usman et al. [25] and To et al. [26] at Sokoto Nigeria and Hong Kong China.

Table 3. Correlation coefficients between visibility and temperature for Sahel zone of Nigeria during Harmattan season of 1988-2017

Period	Relationship between vis
1988-2017	$V_s = 16.41e^{-0.02}$T
1988-1997	$V_s = 8.392e^{0.015}$T
1998-2007	$V_s = 17.70e^{-0.02}$T
2008-2017	$V_s = 2.458e^{0.040}$T

Note: V_s, Visibility; T, Temperature

4. Conclusions

The temporal trend and variability of visibility and temperature data as well as the relationships between them during Harmattan period of 1988-2017 in the Sahel zone of Nigeria has been discussed in this paper. The correlation analysis between visibility and temperature was done using 30 years (1988-2017) data and ten years interval data obtained from NOAA-NCDC. The result reveals that visibility exhibited a decreasing trend while temperature showed an increasing trend over 30-years period. It is found generally that visibility and temperature changes are closely related. The 30-years seasonal mean visibility is 9.252.39, km while the corresponding temperature is 25.123.87 C respectively. It was also found that, Harmattan season visibility and temperature showed similar fluctuation until 1998/1999 season. However, after this period Harmattan season visibility sharply decreases while temperature increases continuously until 2012/2013 season maintaining close relation in their pattern of fluctuations. From 2013, both visibility and temperature fall below the average values until the end of the decade last decade.

Decade analysis was carried out and it is obvious that changes are observed in each decade. However, the most obvious changes happen during the third decade. This decade experiences the worse visibility with highest corresponding temperature. Standardize anomaly chart of visibility and temperature also reveal that changes in visibility and temperature for the study periods are consistent.

The regression analysis results showed that the relationship between temperature and visibility is a temporal phenomenon but the trend between visibility and temperature is consistently exponential. By dividing the ten years interval we obtain much stronger and more significant relationship whose sign and magnitude also varies from one decade to another compared the overall data. This implies that the impact of dust on temperature in the Sahel zone of Nigeria during Harmattan period of the period is not uniform. Interestingly a consistent (strong and positive) relationship between temperature and visibility at $p < 0.05$ significant level in the first and last decade was obtained. Another interesting feature of this relationship is that third decade indicated the strongest correlation in Sahel at $p < 0.05$ significant level.

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