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RESEARCH ARTICLE

Temporal and spatial variations of ground surface visibility during Harmattan season in North-Eastern Nigeria

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Abstract: Ground surface visibility during Harmattan season over the years has impeded road and air transportations, causing numerous infectious diseases in West African sub region. Surface degraded visibility is one of the prominent climatic parameters that define Harmattan season in the region. The presence of dust in the atmosphere brought by the North east trade winds during the Harmattan season plays a vital role in absorbing and scattering solar radiation. The degraded visibility has various effects on low temperature and relative humidity experienced during the season. The study assessed the temporal and spatial variations of surface visibility in Northeastern Nigeria during the Harmattan season with the aim of ascertaining its variability, patterns and trends in the last three decades. Descriptive statistics of mean, standard deviation, coefficient of variation, and time series analysis with ArcGIS10.3 was used in assessing the temporal and spatial variations of surface visibility from 1984–2014 in six synoptic stations of Northeastern Nigeria. The findings show that surface visibility varied both temporally and spatially over the years. The pattern of visibility in the last three decades has shown rising trends with above mean variations dominating the entire distributions in all the six synoptic stations of the study area.

Keyword: Harmattan season, visibility, trade wind, inter tropical discontinuity.

INTRODUCTION

Visibility, a climatic parameter, is the ability to clearly discern an object against the bright atmosphere from reasonably a far distance. In Meteorology, visibility is defined as maximum distance at which a dark object can be clearly discerned against a light sky or the transparency of the air (Huizheng *et al.,* 2005; Adimula *et al.,* 2008). In aviation industry, it is defined as the greatest horizontal distance at which a large object can be seen and recognized against a bright sky (Usman *et al.,* 2013). Though the term visibility is variously defined, it generally indicates the distance to which human visual perception is limited by atmospheric conditions (Anjorin *et al.,* 2015). The reduced visibility experienced in the study area during the Harmattan season is due to the dust plume blown by the north-east trade winds from the Sahara desert specifically from the Bodele depression. The movements of the Inter-Tropical Discontinuity (ITD), which is the boundary between the two air masses (Tropical continental and Tropical maritime), plays a significant role in determining the Harmattan season in the region.

The retreat of the ITD southwards, which marks the end of the wet season in Northeastern Nigeria in the months of October and November, paves the way for the northeast trade winds to advance into the study area which marks the beginning of the Harmattan season, engulfing the region with atmospheric dust. The relatively low wind speed experienced during the Harmattan season is responsible for poor visibility (Kehinde *et al.,* 2012) as the weak wind speed may cause aerosol particles to be trapped in the atmosphere causing poor visibility. Degraded visibility is the main climatic parameter that makes Harmattan season conspicuous in the region and it normally reduces visibility to below 1,000 m. This position was corroborated by climate review bulletin (NIMET, 2014) that the visibility recorded as low as 800 m in the first and second weeks of January. During Harmattan season, visibility in the Sahel may deteriorate to as low as 200 –500 m (Balarabe *et al.,* 2015). They further noted that about 30% of Nigeria's total land area lies within the Sahel belt of West Africa, thus a reasonable part of the study area to the north too falls within the Sahel belt.

Theoretical background

The two distinct seasons (wet and dry) in the study area is controlled by the movements of the ITD, a zone where a cool, dry and dust-laden air from the Sahara desert, locally known as Harmattan, converges with the warm and moist air from the Atlantic Ocean. The southward movement of the ITD between October and November paves the way for the arrival of the cool, dry and dust plume weather event to the Savannah belts of Northeastern Nigeria, confirming the Harmattan season. During the Harmattan season, cool, dry and dust-laden winds driven by the Northeast trade winds engulf the whole of West Africa from November to March (Danlami, 2017). During this season, the ITD is normally found in the southern part of the country around Latitude

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8 ^{0}N (Ayoade, 2004). During this season, dust plumes transported by the Harmattan wind cover West African countries along the Gulf of Guinea (Afeti and Resch, 2000; Washington *et al.,* 2005, Sunnu *et al.,* 2013). The ITD is an offshoot of the general circulation of the atmosphere, which facilitates the redistribution of energy from the tropical area to balance out the area of deficiency in the temperate and the Polar Regions. In the months of December, January and February, the Azores high pressure system is normally strong and therefore, it intensifies the raising of the dust over the Bodele depression in Chad Republic for southward movement across West Africa sub region. The rising of the dust, as a result of the intensification of the Azores high pressure system, uses the Northeast trade wind as a vehicle to navigate across the study area, thus degrading the visibility experienced during the Harmattan Season.

The visibility in northeastern Nigeria during the Harmattan seasons is usually poor due to the presence of dust trapped in the atmosphere locking out the incoming solar radiation (Anjorin *et al.,* 2015). They also opined that dust aerosols transported from Sahara is the predominant cause of the low visibility in the Sahel region of Nigeria, during the Harmattan months. It is important to note that visibility in the Savannah belts of Nigeria deteriorates to as low as to between 200 -500 m particularly in the Sahel Savannah during the Harmattan season (Balarabe *et al.,* 2015). The pattern of visibility deterioration during the Harmattan season in the study area shows that it deteriorates with the increasing latitude.

Study area

The study area is approximately located between latitudes $9^{0}30^{1}$N and $14^{0}.00^{1}$N and longitudes $9^{0}14^{1}$E and $15^{0}.00^{1}$N (Danlami *et al.,* 2017). The study area in the Northeastern part of Nigeria comprises of Adamawa, Bauchi, Borno, Gombe and Yobe states. It shares border with Niger Republic to the North, Lake Chad to the North-east, Cameroon Republic to the East, Plateau and Taraba states to the South and Jigawa state to the West. The locations and elevations of the six synoptic stations are given in table 1.

Northeastern Nigeria similar to any other parts of Northern Nigeria is characterized by two major seasons, rainy and dry seasons (Oguntoyinbo *et al.,* 1978). The visibility variation during the Harmattan season, which is the focus of this study, is experienced, during the dry season. The dry season starts from early November to late May and the hottest months are March, April and May with temperatures ranged between 39˚C and 42˚C (Naibi *et al.,* 2014). The tropical continental air mass from the Sahara desert is responsible for the dry season because of its coolness and dryness. During this season the ITD is normally found in the southern part of the country around Latitude $8^{0}.00^{1}$N (Ayoade, 2004).

The Northeastern Nigeria cut across the Northern Guinea, the Sudan and the Sahel savannah in the extreme Northern parts of the study area. The substantial part of Adamawa state with the capital in Yola falls within the Northern Guinea Savannah, the whole of Bauchi and Gombe states and reasonable parts of Yobe and Borno states fall within the Sudan Savannah. The Sahel Savannah is found in the extreme Northern parts of Borno and Yobe states. These six synoptic stations are the functional meteorological stations in Northeastern Nigeria. The locations of these stations run by the Nigerian Meteorological Agency (NIMET) are guided by their latitudinal points to adequately cover the entire region. Kriging and Inverse Distance Weighting (IDW) methods of interpolation were used in the spatial analysis of visibility variations. Kriging and IDW methods have been often used to interpolate temperature and precipitation data (Su-na *et al.,* 2010).

MATERIALS AND METHODS

The Meteorological data (1984 – 2014) used in this study was obtained from the Nigerian Meteorological Agency (NIMET). In the analysis, the temporal and spatial variations, patterns and trends of visibility in the six synoptic stations were determined. Monthly and seasonal means were plotted for each station to depict the variations and trends in the last three decades. It is important to note that visibility is measured in meters with an instrument, called transmission meter.). From the six synoptic stations of the study area, visibility records are taken from January to December during the Harmattan season. The records from May to September which correspond with the wet season show near zero values which implies almost clear atmosphere during the season. The raw data was analyzed using Statistical Package of Social Sciences (SPSS) and ArcGIS 10.3 for temporal and spatial analysis respectively.

Table 1: Locations of the Six Synoptic Stations in the study area.

S/No	Synoptic Stations	Latitude (^{0}N)	Longitude (^{0}E)	Elevation (m)
1	Bauchi	10^{0} 28'	09^{0} 50'	616 m
2	Gombe	10^{0} 27'	11^{0} 10'	449 m
3	Maiduguri	11^{0} 27'	13^{0} 09'	300 m
4	Nguru	12^{0} 88'	10^{0} 29'	321 m
5	Potiskum	11^{0} 70'	11^{0} 04'	475 m
6	Yola	09^{0} 23'	12^{0} 27'	163 m

Source: Danlami (2017).

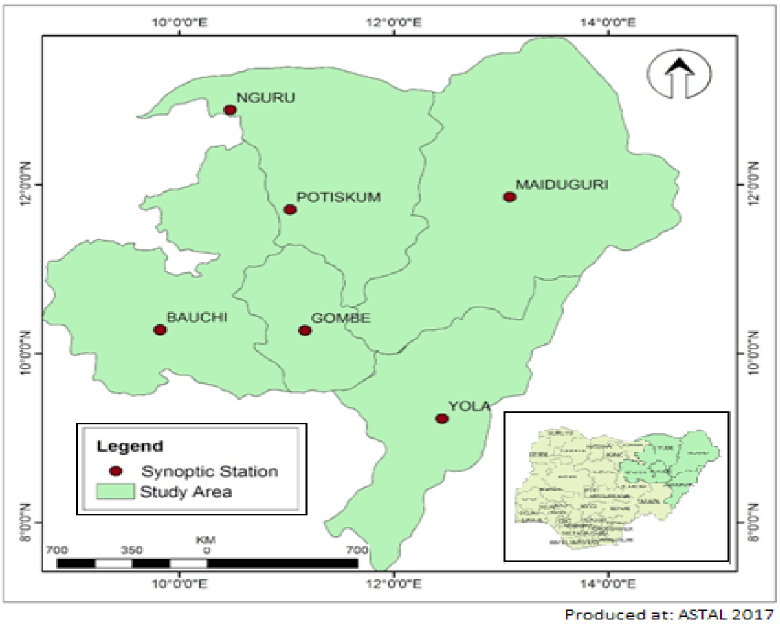

Figure 1: A map showing the study area including the six synoptic stations (Source: Danlami *et al*., 2017).

RESULTS AND DISCUSSION

The variations and trends of visibility for the six synoptic stations in Northeastern Nigeria were determined by their monthly and seasonal means. The Figures show clearly the variations in visibility due the presence of dust in the atmosphere that causes poor visibility. Air visibility is reduced by scattering of sunlight by these fine particles or dust in the atmosphere. The Biu plateau is the most important geomorphologic formation in the study area. The Plateau is a structural and topographical divide between the Upper Benue Basin to the south and the Chad Basin to the north. The strategic location of the Biu plateau on the path of the Harmattan wind is responsible for the reduction in the speed of the wind thus reducing the amount of dust reaching the extreme south of the study area resulting moderate visibility in areas around Yola station.

The visibility appears to be on the rise in all the synoptic stations. These rising trends of visibility indicate improved visibility and this may not be unconnected with the environmental education and awareness among countries within the Sahara desert and its fringes, coupled with the international collaborations to fight against desert encroachment through tree planting campaigns in the last few decades, which is in congruent with (Balarabe *et al*., 2015); where they reported that visibility became stable in the in the region in the last ten years owing to government controlled strategy to minimize the dust outbreak.

Monthly distribution of visibility

The Harmattan season in West Africa is due to the presence of dust which is the major cause of visibility degradation. Visibility is reduced by scattering of solar energy by these fine particles of dust thrown into the atmosphere by the North east trade wind in the study area. It is measured during the Harmattan season or dry season, when the atmosphere is filled with dust or crustal materials in the study area. The long-term mean monthly visibility was low in all the synoptic stations, which vary between 1,500m to 3,000m. However, in some stations daily records are given in the range of 5,000m to 10,000m especially in the months of October and April, which can be regarded as moderate and good visibility. These months represent the beginning and the end of the Harmattan season, respectively. It is important to note that from May to September (wet season) the monthly distribution of visibility in (Figure 2) show near zero values and that is why the months show near zero values which represent clear atmosphere and good visibility during the season; the good visibility experienced during the wet season is due to the influence of moisture-laden south-westerly wind that blows from Atlantic Ocean (Balarabe *et al*., 2015). These moisture-laden air masses are responsible for rainfall across West Africa, thus removing the dust from the atmosphere improving the visibility.

Seasonal distribution of visibility

The movement of the ITD Southwards, which marks the cessation of the wet season between October and November, paves the way for the Northeast trade winds to advance into the Savannah belts of Northeastern Nigeria, marking the beginning of the Harmattan season. The relatively low wind speed experienced during the Harmattan season is responsible for poor visibility (Kehinde *et al.,* 2012).

The severity of the Harmattan season is determined by the high amount of dust in the air, the low relative humidity and the low temperature of the air. The slower the wind moves the more dust are trapped in the atmosphere. The more dust in the atmosphere, the more solar radiations are blocked and the moreit lowers the temperatureand invariably the lower the relative humidity.It is imperative to note that vertical movement of air current reduces the speed of the wind and therefore, more dust are trapped, hence the poor visibility experienced in the study area. The Harmattan season can be regarded as aproduct of chain reactions, i.e. one action leading to another. The Northeast trade wind that drives the season normally sets the ball rolling by blowing the dust from the Sahara desert, specifically from the Bodele depression in Chad Republic into the savannah belts of Nigeria. The arrival of the dust in the study area creates a degraded visibility. The blocking and scattering of the solar radiation by the dust helps in lowering the temperature and relative humidity during the Harmattan season. The coefficient of variations decreases as the Harmattan wind moves southwards. In other words, the degraded visibility increases with increase in latitude and by implication, the Harmattan season could be more severe in the North than in the south of the study area because of the influence of latitude

The coefficient of variation in (Table 2) above reveals that Potiskum has the highest visibility variation with 29.7 % and Gombe station with the lowest (6.36 %) due to the effect of continentality.

Looking at the seasonal means distribution of visibility in all the synoptic stations (Figures 3 to 8), the seasonal means oscillate around the linear means, thereby classifying them above and below the means. The distributions of visibility in the study area shows that Bauchi recorded its lowest visibility in 1998/1999 and the highest in 2002/2003, Gombe recorded its lowest visibility in 2002/2003 and the highest in 2000/2001, Maiduguri recorded its lowest visibility in 1994/1995 and the highest in 1989/1990, Nguru recorded its lowest visibility in 1998/1999 and the highest in 2004/2005, Potiskum recorded its lowest visibility in 1997/1998 and the highest in 2003/2004 and Yola recorded its lowest visibility in 1993/1994 and the highest in 2005/2006 (Danlami, 2017) the patterns of visibility distributions in all the synoptic stations show significant variations, which conforms (Balarabe *et al*., 2015) they reported that visibility in Nigeria are not uniform, its variation depends strongly and significantly on latitude and season both temporally and spatially. The pattern of visibility during the Harmattan season in the study area are cyclical in nature; the above mean distributions correspond with the below mean distributions.

The trends of visibility appear to be on the rise in all the synoptic stations of the study area. The rising trends of visibility indicate improved degraded visibility and this may not be unconnected with the environmental awareness, among countries within and at the fringes of the Sahara desert coupled with the international collaborations to fight desert encroachment through tree planting campaign in the last few decades (Balarabe *et al.,* 2015) reported that the visibility becomes stable in the last 10 years owing to government control strategy to minimize the dust outbreak.

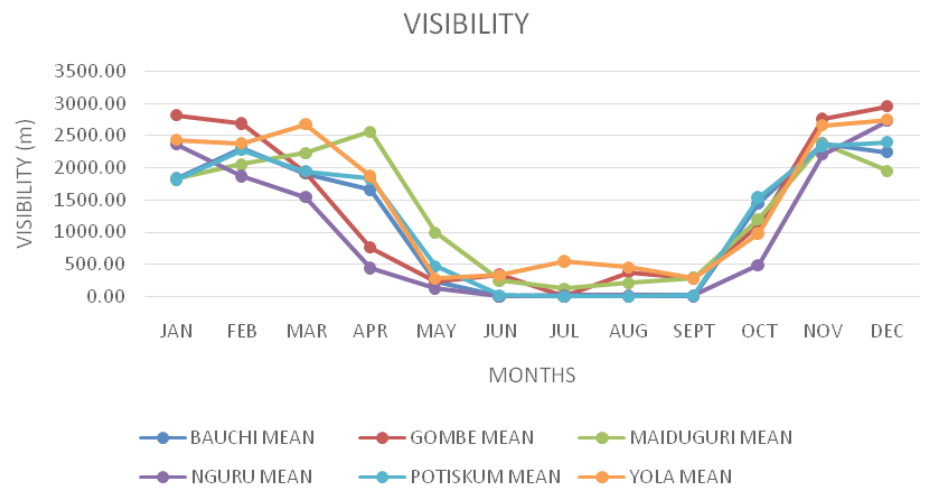

Figure 2: Long-term means monthly distribution of visibility (1984-2014).

Table 2: Descriptive Statistics of Seasonal Air Visibility and Coefficient of Variation.

S/NO	Station	Latitude (Y) (^{0}N)	Mean Seasonal Visibility (m)	Standard Deviation	CV (%)
1	Bauchi	10.28	2125.27	339.42	15.97
2	Maiduguri	11.85	2070.51	215.23	10.39
3	Gombe	10.27	2602.99	165.56	6.36
4	Nguru	12.88	2150.20	329.38	15.32
5	Potiskum	11.70	2125.58	630.76	29.67
6	Yola	9.23	2581.56	391.87	15.18

Source: Danlami, 2017.

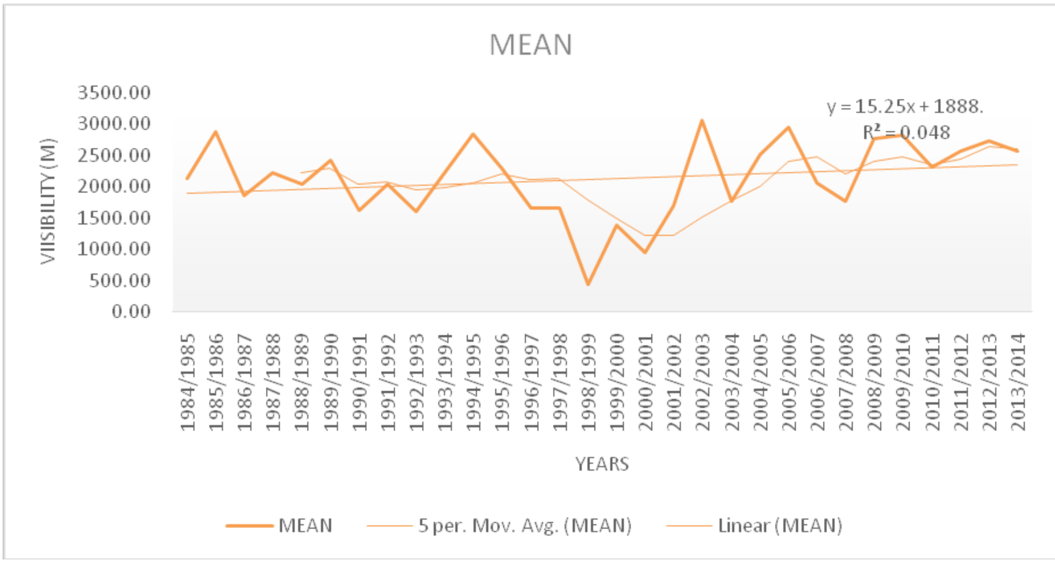

Figure 3: Seasonal mean distribution and trend of visibility for Bauchi station (1984-2014).

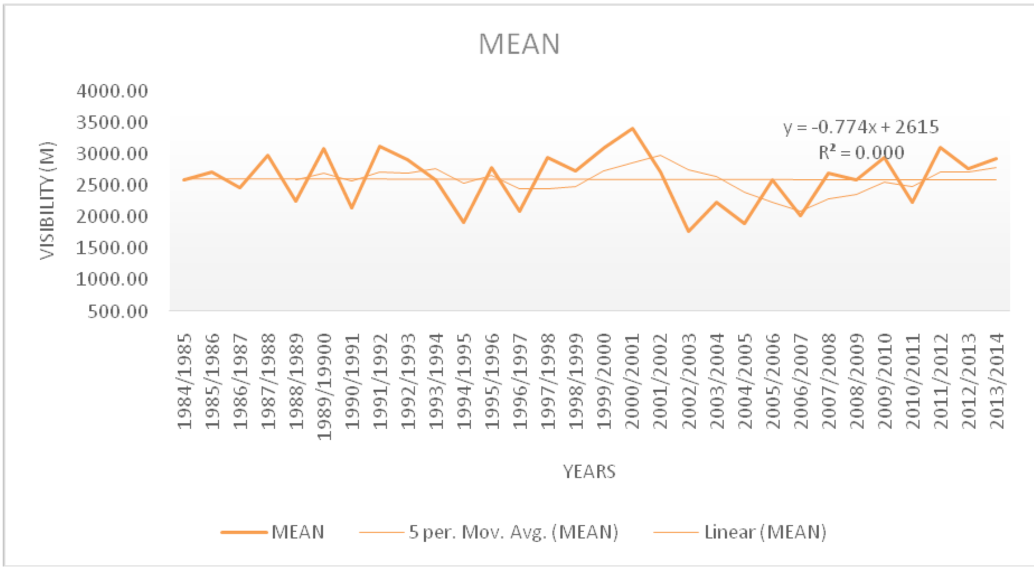

Figure 4: Seasonal mean distribution and trend of air visibility for Gombe station (1984-2014).

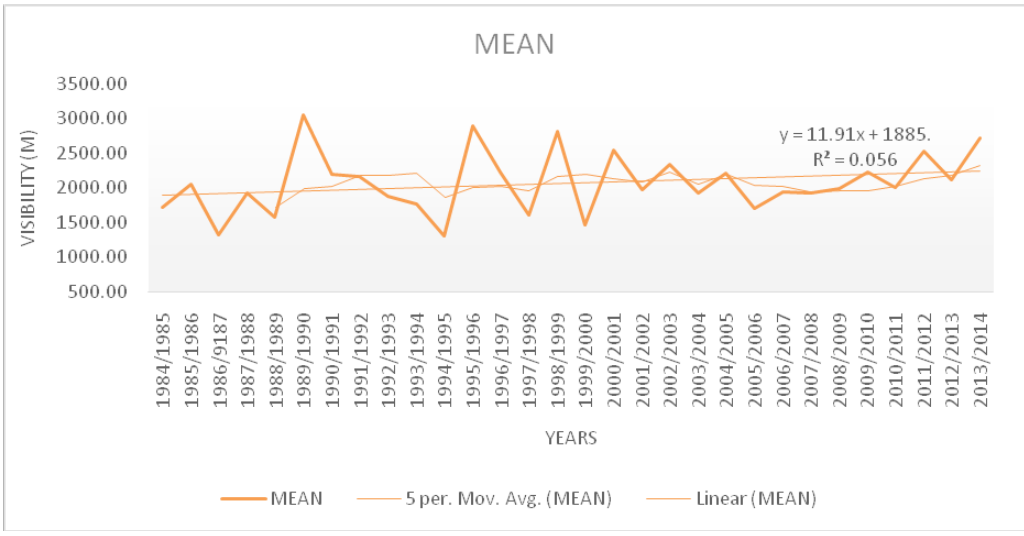

Figure 5: Seasonal mean distributions and trend of visibility for Maiduguri station (1984-2014).

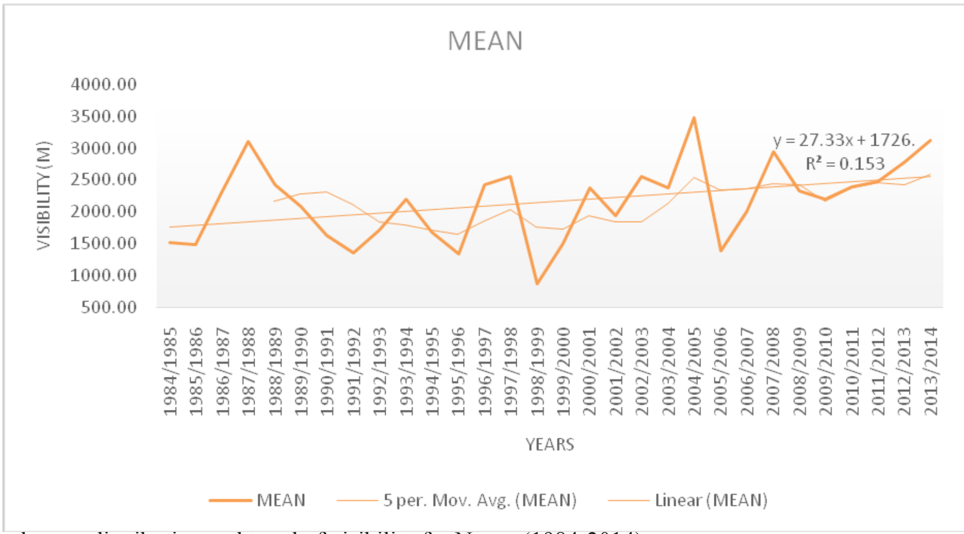

Figure 6: Seasonal mean distribution and trend of visibility for Nguru (1984-2014).

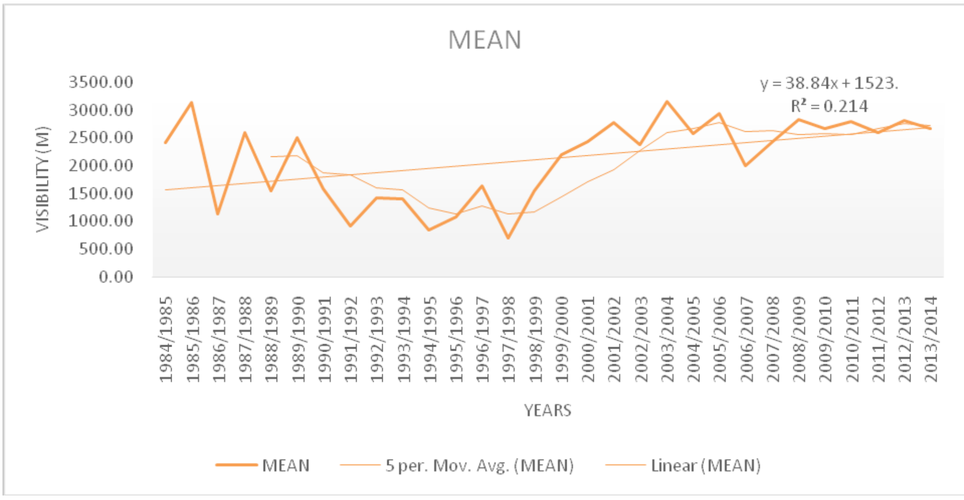

Figure 7: Seasonal mean distribution and trend of air visibility for Potiskum station (1984-2014).

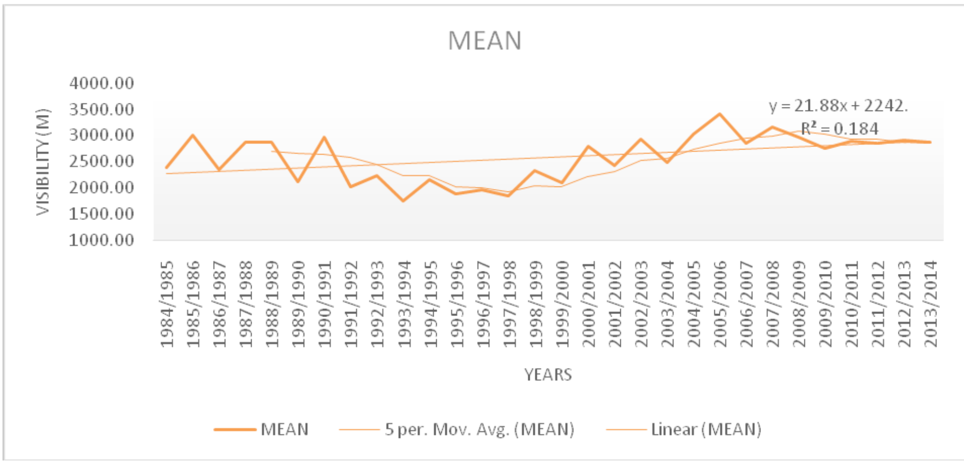

Figure 8: Seasonal mean distributions and trend of air visibility for Yola station (1984-2014).

Spatial interpolation of sub periods mean of visibility

The surface visibility degradation experienced in the study area is caused by the arrival of the dust brought by the north east trade wind from the Bodele depression at the heart of the Sahara desert. The arrival of this dust that usually engulfs the region is the most conspicuous sign of Harmattan season and therefore, responsible for the degraded visibility. Harmattan season low visibility is mainly due to transported dust from the Sahara (Balarabe *et al*., 2015). An attempt was made to look at the spatial interpolation of sub period means of surface visibility distribution in the study area with the sole aim of assessing the patterns of the distribution. Kriging method of spatial interpolation was employed in this analysis so as to determine the spatial variations of visibility in the study area. Kriging is a geostatistical technique similar to IDW in that it uses a linear combination of weights at known points is used to estimate values at other unknown points (Willmott *et al*., 1985; Shuman, 2007). Kriging and IDW methods have been often used to interpolate temperature and precipitation (Su-na *et al*., 2010). IDW measures values closest to the prediction location which will have the greatest influence on the predicted values than those farther away (Johnston *et al*., 2001).Thespatial distribution of surface visibility in the study area shows a progressive reduction of visibility from the lower latitudes to the higher latitudes in the region (Figures 9 – 14) poor visibility is experienced in areas that recorded low values whilemoderate andgood visibilityare experienced in areas that recorded high values. The southern parts of the study area show good visibility with relatively high values and the northern parts show degraded visibility with low values.

The spatial sub period means of visibility for 1984/1985 – 1988/1989 and 1989/1990 – 1993/1994 show slight variations. The sub period for 1984/1985 – 1988/1989 in (Figure 9) shows variations between 1716.87m and 2705.24m, and the period for 1989/1990 - 1993/1994 in (Figure 10) shows variations between 1566.8 m and 2768.6 m. From the two periods, more degraded visibility was witnessed in Maiduguri, Nguru and Potiskum stations in the northern parts. While improved visibility were witnessed in Bauchi, Gombe and Yola areas in the southern parts of the study area. Air visibility in the two sub periods decrease with increase in latitudes, during the Harmattan seasons in the study area.

The spatial distribution of air visibility for 1994/1995 – 1998/1999 in (Figure 11) shows variations between 1161.2 m and 2484.8 m, a more degraded visibility compared to the two previous periods. Nguru station, western parts of Potiskum and Bauchi show more degraded visibility and relatively improved degraded visibility witnessed in Maiduguri, Gombe and Yola stations in the south. The sub period for 1999/2000 – 2003/2004 in (Figure 12) shows improvement over the previous period with variations between 1770.99m and 2639.95m across the study area. The pattern of distribution is the same with the previous (Figure 12).

The spatial distribution of air visibility for 2004/2005 – 2008/2009 in (Figure 13) shows more remarkably improved degraded air visibility, than all the other periods in Northeastern Nigeria. It varies between 1956.7 m and 3088.4 m across the study area. The extreme north and areas around Nguru and Maiduguri stations witnessed improved degraded visibility this time around and more improved degraded visibility witnessed towards the southern parts of the study area.

The sub period means distribution of air visibility for 2009/2010 – 2013/2014 in (Figure 14) shows another improved degraded visibility in the study area with variations between 2322.19m and 2864.79m. The extreme north and some parts of Maiduguri and Nguru witnessed another improved degraded visibility. Areas around Potiskum, Bauchi, Gombe and Yola in the south witnessed more improved visibility.The visibility in the study area decreases as one move from the south to the north. Kriging and IDW interpolate visibility of unknown cell with the measured data. Spatial patterns by Kriging and IDW showed the Well-known spatial phenomenon of temperature in which the temperature gradually decreases from south to north and from west to east. This can be attributed to the fact that the Kriging and IDW interpolate the temperature of unknown cell with only the measured data (Su-na *et al*., 2010).

From the foregoing the spatial distribution of air visibility has shown that the sub periods 2004/2005 – 2008/2009 in (Figure 13) and 2009/2010 – 2013/2014 in (Figure 14) have recorded remarkably improved visibility especially 2004/2005 – 2008/2009 in (Figure 13). The pattern of the spatial distribution of air visibility in Northeastern Nigeria remains the same in the last three decades with latitude as the major determining factor. The southern parts of the study area always showing improved visibility over the northern parts which conforms with the position of spatial variability of air visibility in Nigeria (Balarabe *et al*., 2015).

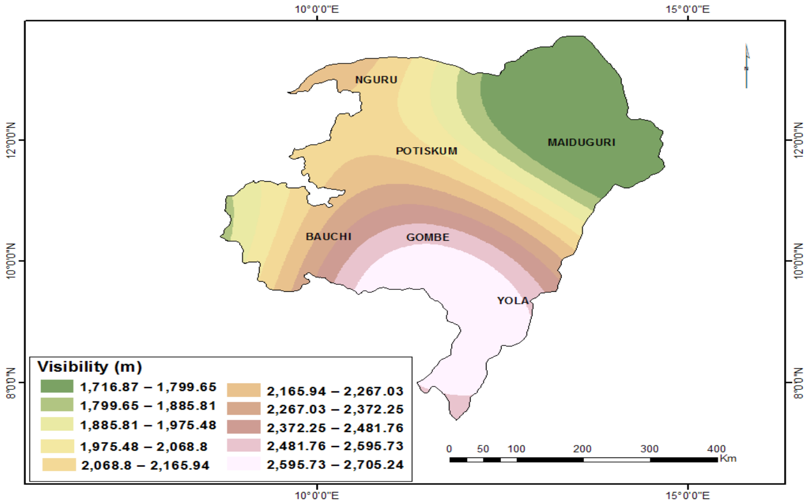

Figure 9: Spatial visibility distribution in Northeastern Nigeria (1984/1985 – 1988/1989).

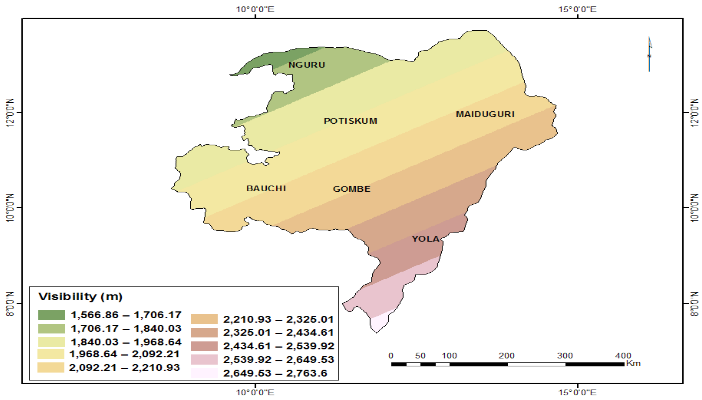

Figure 10: Spatial Air Visibility Distribution in Northeastern Nigeria (1989/1990 – 1993/1994).

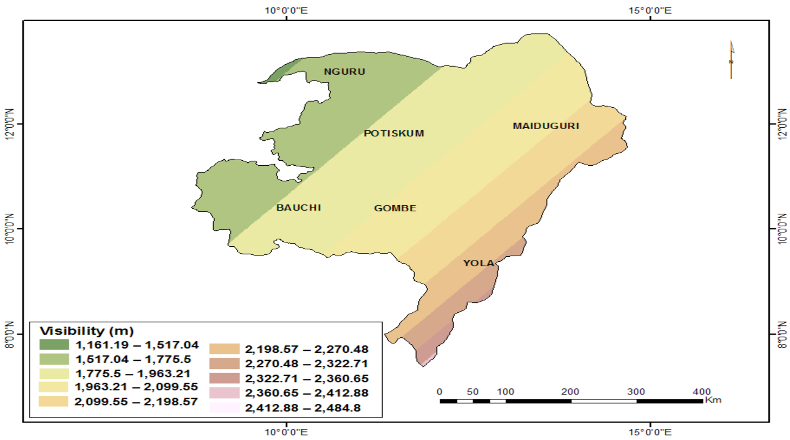

Figure 11: Spatial Air Visibility Distribution in Northeastern Nigeria (1994/1995 – 1998/1999).

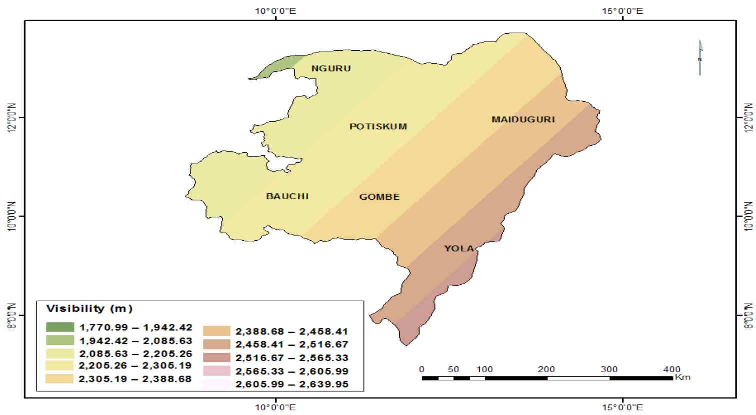

Figure 12: Spatial Air Visibility Distribution in Northeastern Nigeria (1999/2000 – 2003/2004).

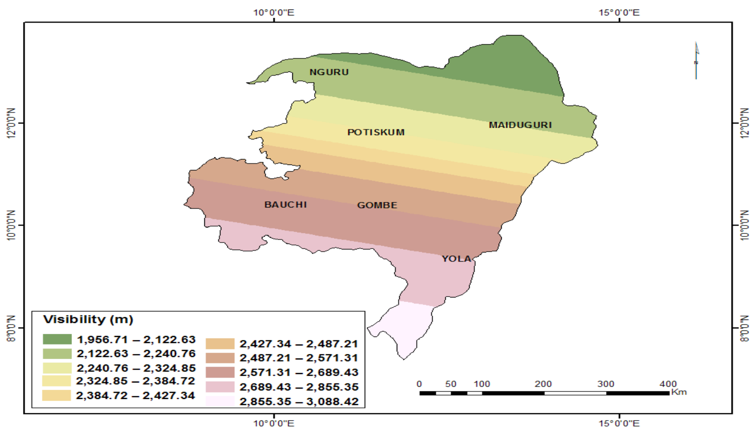

Figure 13: Spatial Air Visibility Distribution in Northeastern Nigeria (2004/2005 – 2008/2009).

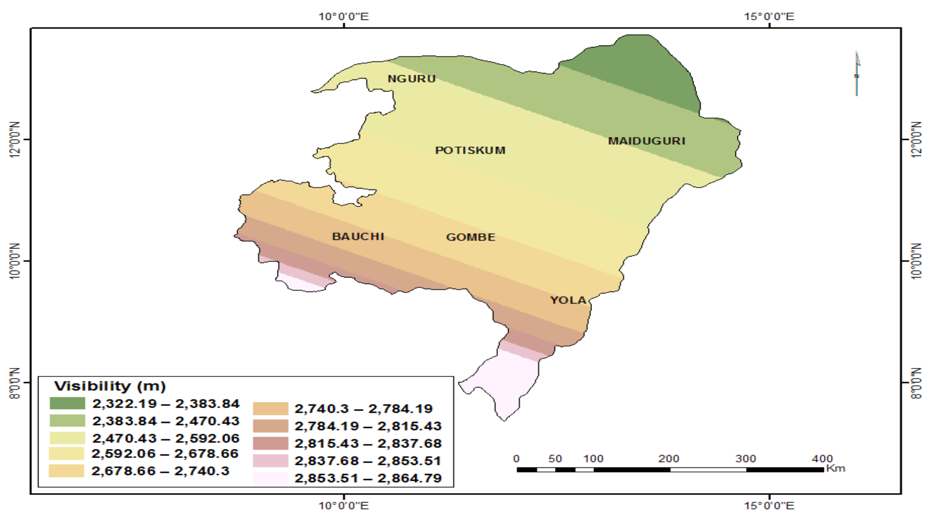

Figure 14: Spatial Air Visibility Distribution in Northeastern Nigeria (2009/2010 – 2013/2014).

CONCLUSIONS

The northeast trade winds drive the Harmattan season in West Africa. It brings huge amount of dust from the Bodele depression and the Sahara desert across the study area. The arrival of dusts normally brings about the poor visibility in the study area. The mean monthly and seasonal means of visibility have shown variations in the last three decades. Visibility has shown a rising trend in all six synoptic stations of the study area over the past three decades. The spatial distributions of visibility in the study area suggested that the visibility decreased with increase in latitude. The spatial analysis also revealed an improved visibility in the Yola station located in the south of the study area while an increasing visibility in the north, specifically the extreme Northern parts of Maiduguri and Nguru stations of the study area.

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