The Influence of Meteorological Parameters on Atmospheric Visibility over Ikeja, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. The data for the work was sourced and analyzed by author DOA. Author DOA also design the study, draft and edited the manuscript. Authors MII, WM, SA and SOY assisted in literature searches. All the authors read and approved the final manuscript.

Original Research Article

ABSTRACT

This present study investigates the variation of atmospheric visibility with meteorological parameters of measured monthly average daily visibility, mean temperature, relative humidity, atmospheric pressure, rainfall and wind speed for a period of 12-years over Ikeja, Lagos State, South Western, Nigeria (Latitude $6.58°N$, Longitude $3.33°E$ and altitude 40 m above sea level). The results indicated that the seasonal variation of atmospheric visibility is greater during the rainy season than in the dry season. The best visibility was observed during the rainy season with an average value of $9.73\ km$ in the month of April while the worst visibility was during the dry season with an average value of $5.88\ km$ in the month of January. The results from regular observation of atmospheric visibility for the study area during the period under investigation indicated that the observed visibility ranged between $5.88 \pm 1.03\ km$ and $9.73 \pm 1.03\ km$ with annual mean of

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$8.68 \pm 1.03\ km$ which implies that the atmosphere is mostly clear. The average atmospheric extinction coefficient computed for the study area is approximately $0.4628\ km^{-1}(4.628 \times 10^{-4}\ m^{-1})$. Simple linear regression equation relating the atmospheric visibility and the meteorological parameters were developed from which the regression equation relating atmospheric visibility with relative humidity was recommended based on the coefficient of correlation (R), coefficient of determination (R^2), standard error of estimates (SEE) and p-value. The skewness and kurtosis for the atmospheric visibility are negatively skewed with value -1.514 and positive kurtosis (leptokurtic distribution) with value 1.244.

1. INTRODUCTION

Visibility impairment has become a major public concern in most metropolises in Nigeria [1]. Ikeja the capital of Lagos State in South-western Nigeria was selected for this present study owning to its rapid population growth and increasing industrialization over the past decades. Visibility in meteorology is defined as the maximum distance at which a dark object can be discerned against a light sky [2–3]. On the other hand, it is defined in aviation as the greatest horizontal distance at which a large object can be seen and recognized against a bright sky [4].

Despite the relatively conducive weather of Nigeria compared to other countries (such as Mauritania, Somalia, Japan etc.), there has been a marked increase in the cases of recorded flight delay, diversion and cancellation, which in most cases, are attributed to poor weather conditions [5]. Aircraft accident has not been an exception, but its occurrence, though resulting to very devastating losses, has been on a low rate compared to other defects, with its highest occurrence between 2003 and 2006 [6]. Most of the air crashes, delays and cancellations were caused by poor weather conditions such as thunderstorm occurrence, poor visibility (associated with fog, dust haze etc) wind shear and squall [7–8].

The term weather describes the state of the atmosphere in terms of air pressure, temperature, humidity, clouds, wind, and precipitation [9]. Meteorological phenomena such as relative humidity and temperature are known to be natural causes of changes in aerosol extinction coefficient and decrease in atmospheric visibility. These meteorological parameters influence visibility through dispersion of aerosols, or by changing their properties or formation and removal rate. Visibility reducing weather phenomena caused by aerosols include precipitation, fog, mist, haze and dust storm. Precipitation is defined as any or all of the forms of water particles, whether liquid or solid, that falls from the atmosphere and reach the ground [10], so that it can be easily identified by the observer. Fog is defined as a hydrometeor suspended in the atmosphere near the earth's surface [10]. Fog reduces visibility below one kilometer. However, the criterion of the relative humidity for fog is not well defined [11]. Mist is defined as a hydrometeor consisting of an aggregate of microscopic and more-or-less hygroscopic water droplets suspended in the atmosphere. Mist produces a thin, greyish vein over the landscape and reduces visibility to a lesser extent than fog. The relative humidity with mist is often less than 95%. Mist is intermediate in all respects between haze and fog [10]. On the other hand, haze is defined as fine dust or salt particles dispersed through a portion of the atmosphere; a type of lithometeor. The particles are so small that they cannot be felt or individually seen with the naked eye, but they diminish horizontal visibility and give the atmosphere a characteristic opalescent appearance that subdues all colors. Haze formations are caused by the presence of an abundance of condensation nuclei which may grow in size to become mist, fog or cloud [10].

It is well known that the atmospheric visibility varies significantly with regions and season. This study aimed to find out the important roles played by the meteorological parameters of mean temperature, relative humidity, atmospheric pressure, rainfall and wind speed on the variation and evaluation of atmospheric visibility in Ikeja, Nigeria over the period under investigation. The atmospheric extinction coefficient was also evaluated based on the atmospheric visibility.

2. STUDY AREA

The study region is Ikeja (Fig. 1), a coastal area, the capital of Lagos State, Nigeria. The state is located in the south-western part of Nigeria. The state has common boundary with Ogun State, Republic of Benin and terminates in Atlantic Ocean in the south; making it a coastal city where several long and attractive sandy beaches (like Bar Beach) are located [12]. The state has twenty local government areas in which sixteen are within the metropolitan Lagos while the land coverage is about 3,475 km^2. However, this size is reduced by Lagoons, rivers, creeks and swamps. The Lagos city is the commercial centre of Nigeria where several businesses are found. For example, the busy Murtala International Airport in Ikeja and head offices of many airlines are within and around the airport while the city and the state also accommodates headquarters of many companies. As a coastal city, rising temperature and increase in sea level could lead to disappearance of the beaches under erosion and flooding while the area might also be damaged by storm [12]. The state is essentially a Yoruba-speaking environment. The seasons in the area is broadly divided into dry and wet under the influence of Intertropical Convergence Zone, ITCZ (where easterly trade winds originating from northern and southern hemispheres converge) that migrates along with the position of strongest rainfall [13]. Nigeria being a tropical region has two seasons – the wet and the dry. The wet season is characterized with heavy rainfall. It falls between the months of April and October. The dry season, on the other hand, is characterized with scanty or no rainfall and dry dust laden atmosphere. The season lies between the month of November and March [14]. It must be noted that some areas in Lagos State, which is very close to the Atlantic Ocean experience rainfall in all the months of the year [15].
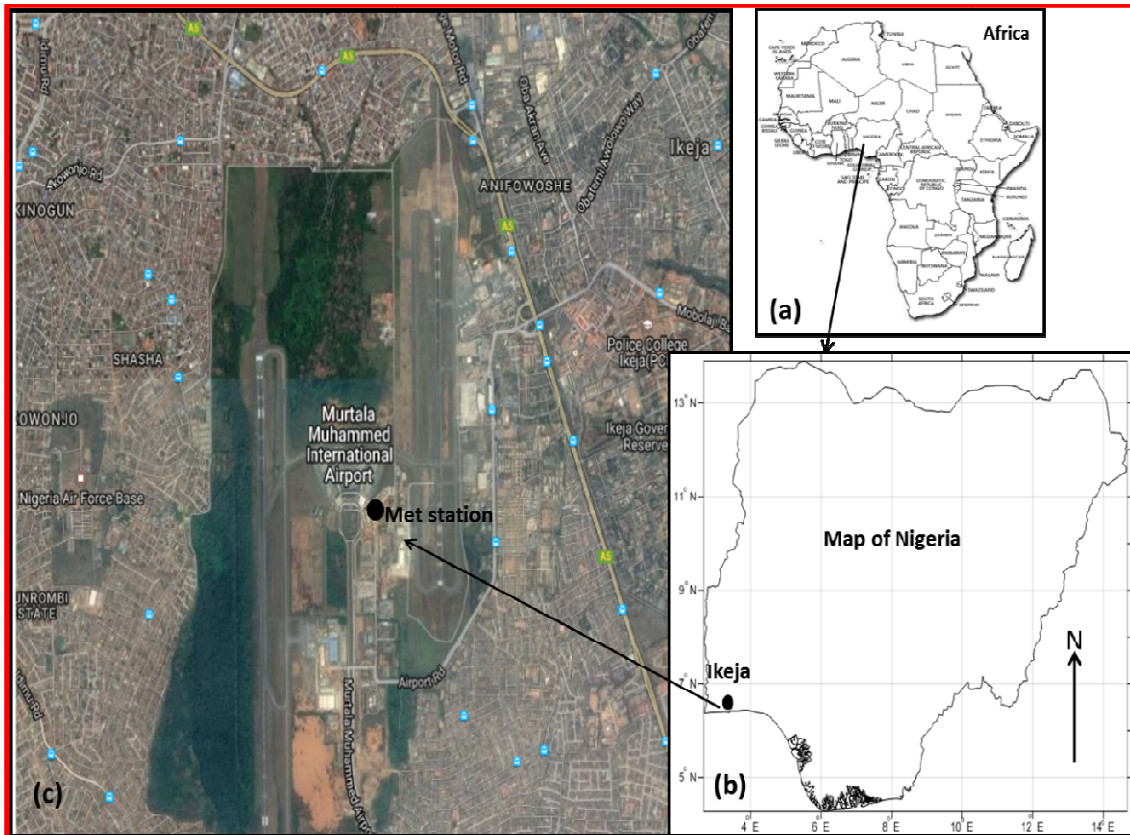
Fig. 1. Map of (a) Africa showing the location of Nigeria (b) Nigeria showing the location of Ikeja in Southwest Nigeria and (c) Ikeja showing the location of the meteorological station in Muritala Muhammed International Airport

3. METHODOLOGY

The measured daily climatic data of atmospheric visibility, mean temperature, relative humidity, atmospheric pressure, rainfall and wind speed utilized in this present work were obtained online from Tutiempo Network (en.tutiempo.net/climate/ws-652010.html). The daily data were averaged into monthly data. The study area under investigation is Ikeja (Latitude 6.58^0N, Longitude 3.33^0E and altitude 40 m above sea level) with weather station number 652010 (DNMM). To avoid possible misleading indications related to year to year variation in weather condition, the period under focus is twelve years (2001, 2005 – 2007, 2009 – 2016) in order to obtain a good climatological average. The quality assurance of the meteorological measurements was determined by checking the overall consistency of the monthly average of the climatic parameters used in the study area.

The atmospheric visibility models proposed in this study are

$$Vis = a + b\,T \tag{1}$$

$$Vis = a + b\,RH \tag{2}$$

$$Vis = a + b\,AtmP \tag{3}$$

$$Vis = a + b\,RF \tag{4}$$

$$Vis = a + b\,WS \tag{5}$$

where Vis is the atmospheric visibility (km), T is the mean temperature (^{0}C), RH is the relative humidity (%), AtmP is the atmospheric pressure (hPa), RF is the rainfall (mm), WS is the wind speed (ms^{-1}) and a, b, c, d, e and f are the empirical constants/coefficients.

In this study the coefficient of correlation (R), coefficient of determination (R^2), standard error of estimates (SEE) and p-value are examined. High values of R and R^2 is ranked the best while low values of standard error of estimates (SEE) and p-value is ranked the best. The R and R^2 give the best fitting between the measured and predicted models. The SEE signifies the error associated with the estimated/predicted models and the p-value signifies the most contributing model to the visibility estimation.

In this study, the skewness and kurtosis tests were also carried out. The skewness test (σ_k) measures the asymmetry of the five independent meteorological parameters data around their mean value; it is a measure of symmetry, or more precisely, the lack of symmetry. It tells us about the direction of variation of the dataset. If $\sigma_k = 0$, the data have a Gaussian distribution (normal distribution), while $\sigma_k < 0$ indicates that the data are spread out more to the left of the mean value than to its right (negatively skewed), when $\sigma_k > 0$ indicates that data are spread out more to the right than to its left (positively skewed) [16].

The Kurtosis test (k_u) describes the shape of a random variable's probability distribution, that is it characterizes the relative peakedness or flatness of a distribution compared to the normal distribution. It measures the degree of normality of each of the meteorological parameters under investigation [16]. For $k_u = 0$ the data have normal distribution, for $k_u > 0$ the data have positive kurtosis which implies peaked distribution, that is, leptokurtic distribution (that is, too tall), when $k_u < 0$ the data have negative kurtosis which implies flat distribution, that is, platykurtic distribution (that is, too flat, or even concave if the value is large enough).

The visual contrast $C_v(x)$ obeys the Beer-Lambert law

$$\frac{dC_v(x)}{dx} = -b_{ext}C_v(x) \tag{6}$$

This means that the contrast decreases exponentially with the distance from the object.

$$C_v(x) = exp(-b_{ext}x) \tag{7}$$

where x is the path length and b_{ext} is the total extinction (scattering + absorption). Lab experiments have determined that contrast ratios between 0.018 and 0.03 are perceptible under typical daylight viewing conditions. Usually, a contrast ratio of $2\%(C_v = 0.02)$ is used to calculate visual range. A simplified relationship developed by Koschmeider which relates the visual range and extinction coefficient is given by [17]. This is obtained by plugging this value into equation (7) and solving for x produces the following visual range equation as

$$x_v = \frac{3.912}{b_{ext}} \tag{8}$$

where x_v is the distance at which the object is just barely visible in units of length. At sea level, the Rayleigh atmosphere has an extinction coefficient of approximately 13.2×10^{-6} m^{-1} at a

wavelength of 520 nm. This means that in the cleanest possible atmosphere, visibility is limited to about 296 km.

4. RESULTS AND DISCUSSION

The developed models obtained from this study using equations 1 – 5 are

$$Vis = 14.8 - 0.226\,T \qquad (9)$$

$$Vis = -6.26 + 0.182\,RH \qquad (10)$$

$$Vis = -300 + 0.305\,AtmP \qquad (11)$$

$$Vis = 7.64 + 0.000809\,RF \qquad (12)$$

$$Vis = 4.55 + 1.44\,WS \qquad (13)$$

Table 1. Validation of the models under different statistical test

Models	R	R^2	SSE	P-value
Temp	21.7	4.7	1.32785	0.40914
RH	66.5	44.2	1.01615	0.00015
AtmPre	33.2	11.0	1.28364	0.02796
RF	53.5	28.6	1.14988	0.04889
WS	60.7	36.8	1.08177	0.00024

Based on R, R^2, SEE and p-value shown in Table 1. The visibility model relating the relative humidity is ranked the best performing model and the visibility model relating the temperature is ranked the least. Therefore the regression equation model given in equation (10) is most suitable for predicting atmospheric visibility for the study area under investigation based on R, R^2, SEE and p-value.

In Fig. 2. The atmospheric visibility increases from January and attained its maximum value in April and decreases from April to June. The visibility then increases from June and attained another peak value in August and drop subsequently from August to December. The highest values of visibilities were observed during the rainy season with an average value $9.42 \pm 1.03\,km$ and the lowest value was observed during the dry season with an average value $7.62 \pm 1.03\,km$. The maximum visibility was observed during the rainy season with an average value of $9.73\,km$ in the month of April while the minimum visibility was during the dry season with an average value of $5.88\,km$ in the month of January. The average annual atmospheric visibility for the study area under investigation is $8.68 \pm 1.03\,km$. The atmospheric visibility for the study area is low compared to

that of Port Harcourt, Rivers State, Nigeria, and a coastal zone as well where the average value during the rainy and dry seasons are $12.3\,km$ and $11.3\,km$ as reported by [18]. This may be attributed to more industries, deposition of atmospheric air pollution caused by the "Danfo drivers", sea salt, numerous secondary aerosols precursors and rapid population growth encountered in the study area. The international definition of fog is a visibility of less than 1 km; mist is a visibility of between 1 km and 2 km and haze from 2 km to 5 km. fog and mist are generally assumed to be composed principally of water droplets, haze and smoke can be of smaller particle size. The results revealed that the atmosphere in the study area is relatively clear.

In Fig. 3. The atmospheric visibility and mean temperature increases from January to March. The mean temperature decreases from March and attained its minimum value in August and subsequently increases to December while the visibility increases and attained its maximum value in April and decreases to June. The visibility further increases from June to August and decreases subsequently from August to December. The maximum values of temperature were observed during the dry season while the visibility was during the rainy season and the minimum values of temperature were observed during the rainy season while the visibility was during the dry season. The highest value of temperature was observed during the dry season in the month of March with an average value of $29.13°C$ and the minimum value during the rainy season in the month of August with an average value of $25.38°C$. The highest value of atmospheric visibility was observed during the rainy season in the month of April with an average value of $9.73\,km$ and the minimum value during the dry season in the month of January with an average value of $5.88\,km$. The average annual atmospheric visibility value observed is $8.68 \pm 1.03\,km$ while that for the mean temperature is $27.27 \pm 1.09°C$. A dip was observed for the visibility and temperature in the months of June and August respectively.

In Fig. 4. The atmospheric visibility and relative humidity increases from January to April while the relative humidity increases continuously and attained its maximum value in July, however, there was almost a constant value between the month of June and July. The relative humidity decreases slightly from July to August and increases gradually to September. The visibility

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and relative humidity drop from September to December. The maximum values of visibility and relative humidity was observed during the rainy season and minimum values during the dry season. The highest values of visibility and relative humidity were observed during the rainy season in the months of April and July with average values of $9.73\ km$ and 87.23% respectively. The lowest values of visibility and relative humidity were observed during the dry season in the month of January with average values of $5.88\ km$ and 73.15% respectively. The average annual atmospheric visibility value observed is $8.68 \pm 1.03\ km$ while that for the relative humidity is $82.26 \pm 4.30\%$. A dip was observed for the visibility and relative humidity in the months of June and August respectively.
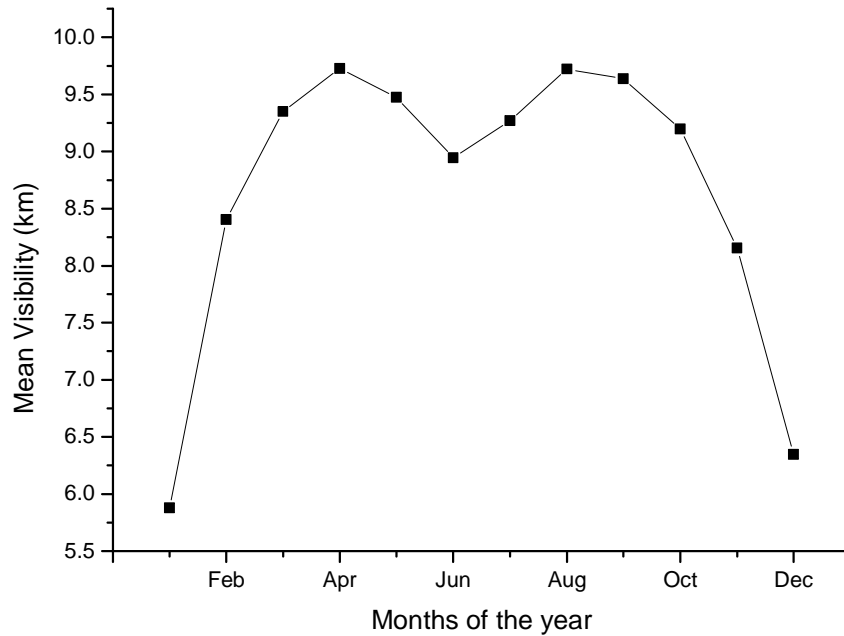

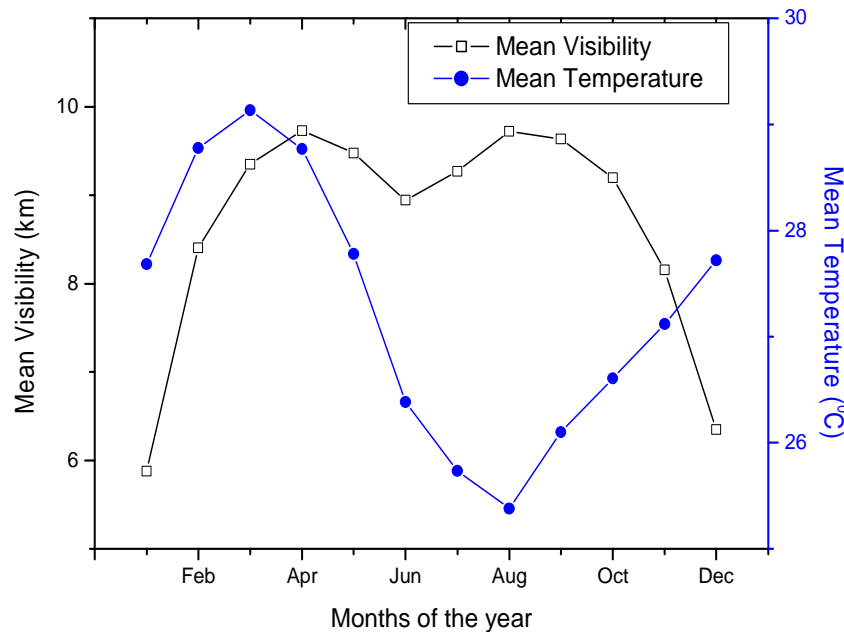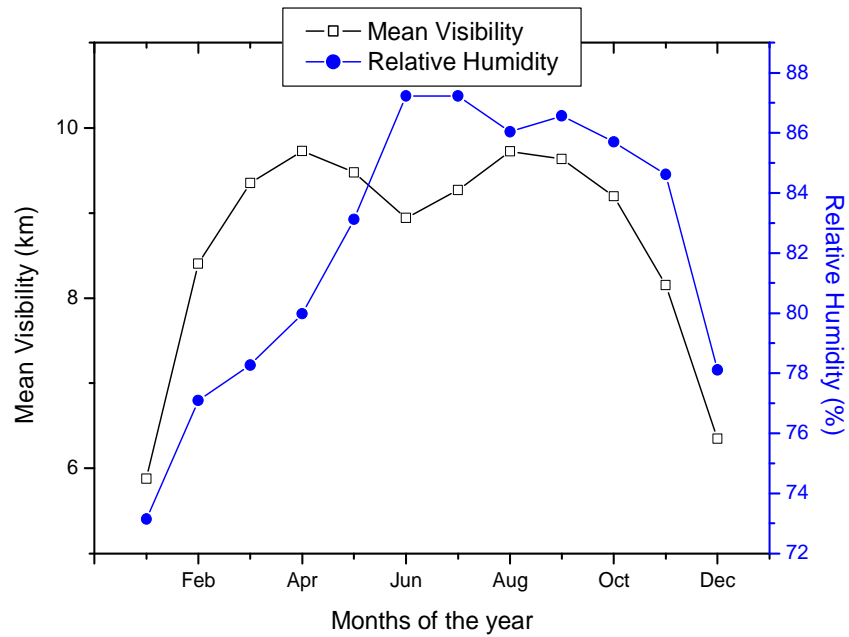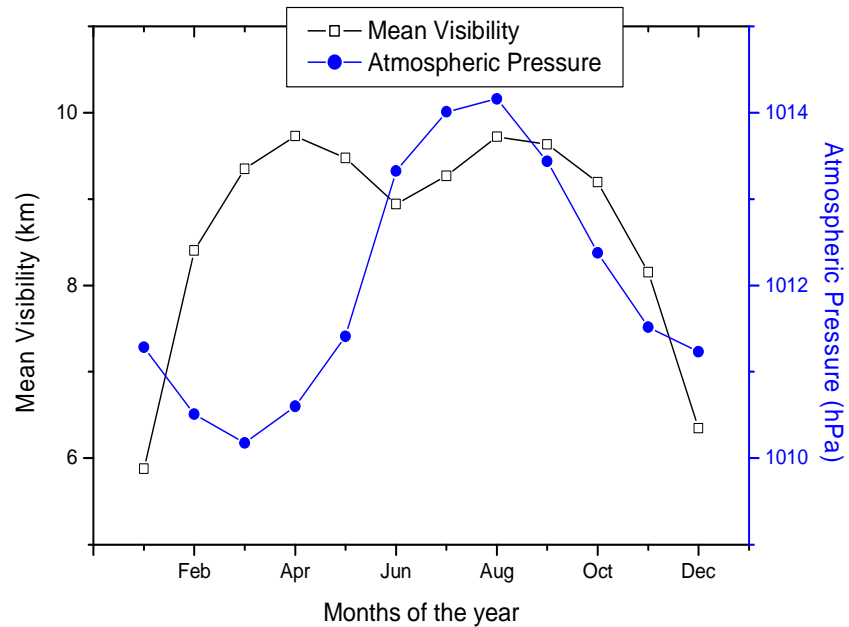**Fig. 2. Variation of mean visibility for Ikeja, Nigeria**

Fig. 3. Variation of mean visibility with mean temperature for Ikeja, Nigeria

Fig. 4. Variation of mean visibility with relative humidity for Ikeja, Nigeria

Fig. 5. Variation of mean visibility with atmospheric pressure for Ikeja, Nigeria

In Fig. 5. The atmospheric pressure decreases from January to March and increases from March and attained its maximum value in August while visibility increases from January and attained its maximum value in April and decreases from April to June and subsequently increases from June to August. The atmospheric pressure and visibility decreases from August to December. The maximum values of visibility and atmospheric pressure was observed during the rainy season and minimum values during the dry season. The highest values of visibility and atmospheric pressure were observed during the rainy season in the months of April and August with average

values of $9.73\ km$ and $1014.16\ hPa$ respectively. The lowest values of visibility and atmospheric pressure were observed during the dry season in the month of January and March with average values of $5.88\ km$ and $1010.18\ hPa$ respectively. The average annual atmospheric visibility value observed is $8.68 \pm 1.03\ km$ while that for the atmospheric pressure is $1012.004 \pm 1.269\ hPa$. A dip was observed for the atmospheric visibility and pressure in the months of June and March respectively.
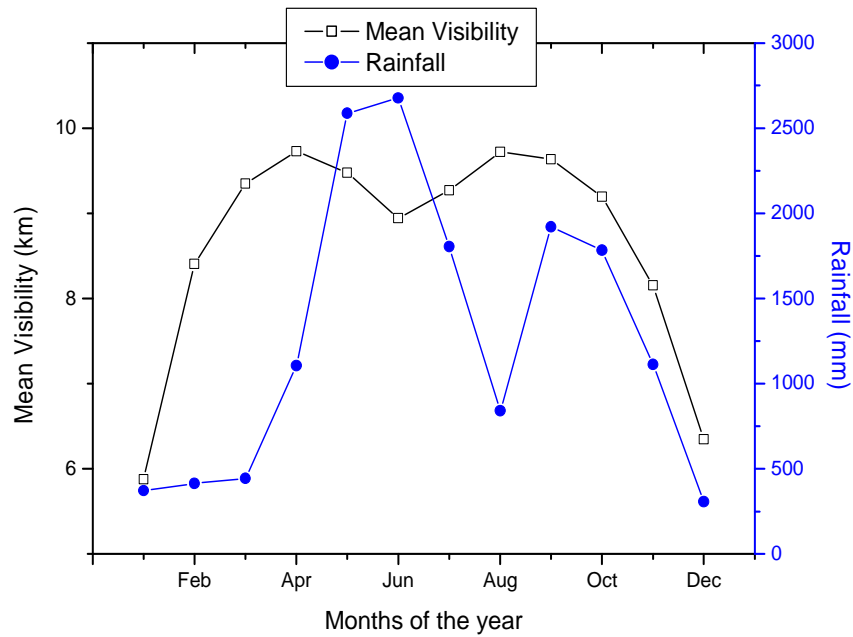

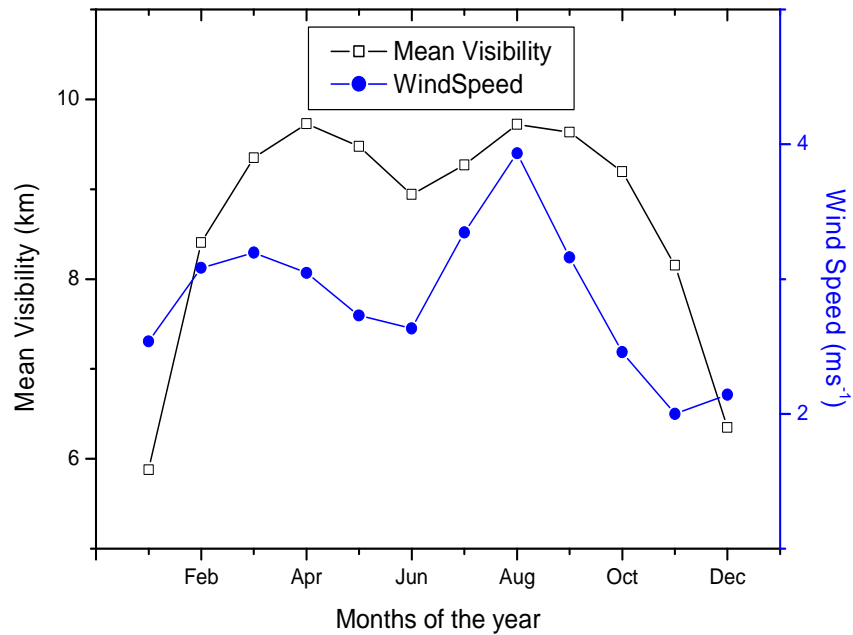**Fig. 6. Variation of mean visibility with rainfall for Ikeja, Nigeria**

Fig. 7. Variation of mean visibility with wind speed for Ikeja, Nigeria

In Fig. 6. The rainfall increases slightly with almost constant value from January to March and increases from March and attained its maximum value in June and decreases subsequently from June to August and increases to September. The atmospheric visibility and rainfall drop from September to December. It was observed that the highest values of rainfall was recorded in the months from April to October and the lowest values from November to March, this is expected as this is the period of rainy and dry seasons in the study area and Nigeria. It was observed that the study area has double peaks of rainfall in the months of June and September during the rainy season. The highest values of visibility and rainfall were observed during the rainy season in the months of April and June with average values of $9.73\ km$ and $2677.83\ mm$ respectively. The lowest values of visibility and rainfall were observed during the dry season in the month of January and December with average values of $5.88\ km$ and $307.32\ mm$ respectively. The average annual atmospheric visibility value observed is $8.68 \pm 1.03\ km$ while that for the rainfall is $1280.86 \pm 760.7\ mm$. A dip was observed for the atmospheric visibility and pressure in the months of June and August respectively.

In Fig. 7. The atmospheric visibility and wind speed increases from January to March while the visibility increases to its maximum value in April

and decreases from April to June. The wind speed decreases from March to June. The wind speed increases from June and attained its maximum value in August. The visibility decreases from August from December while the wind speed decreases from August and attained its maximum value in November and slightly increases from November to December. The highest values of visibility and wind speed were observed during the rainy season in the months of April and August with average values of $9.73\ km$ and $3.93\ ms^{-1}$ respectively. The lowest values of visibility and wind speed were observed during the dry season in the month of January and November with average values of $5.88\ km$ and $2.00\ ms^{-1}$ respectively. The average annual atmospheric visibility value observed is $8.68 \pm 1.03\ km$ while that for the wind speed is $2.86 \pm 0.46\ ms^{-1}$. A dip was observed for the atmospheric visibility in the month of June and wind speed in the months of June and November respectively.

The atmospheric visibility and extinction coefficient shown in Fig. 8 shows an inverse relationship. The least atmospheric visibility and maximum extinction coefficients are observed in January while the best atmospheric visibility and least extinction coefficients are in April. The figure shows that as the atmospheric extinction coefficient increases the aerosol particle size in
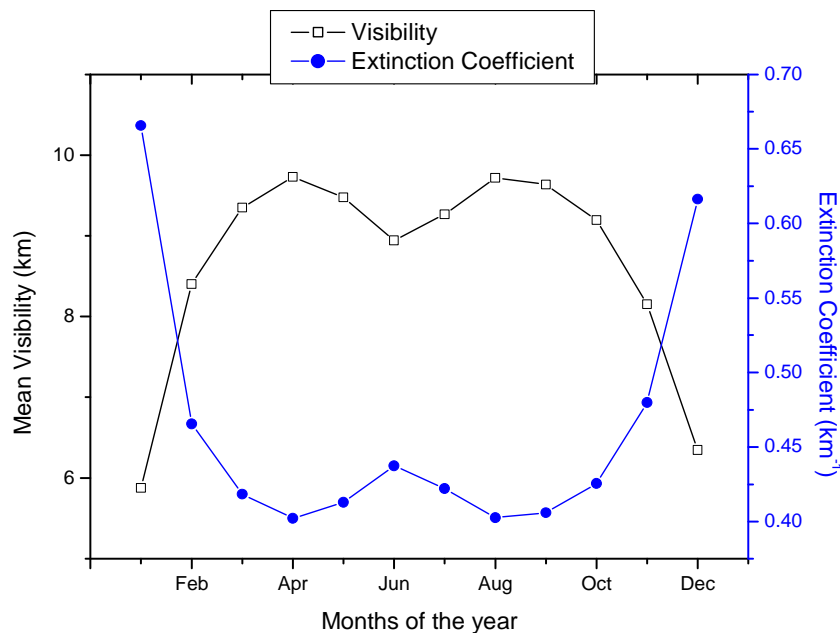

Fig. 8. Variation of visibility with extinction coefficient for Ikeja, Nigeria

the atmosphere will become larger, thereby decreases the atmospheric visibility. The atmospheric extinction coefficient ranged between 0.4011 in April and 0.6656 km^{-1} in January. The average extinction coefficient is $0.4628\ km^{-1}\ (4.628 \times 10^{-4}\ m^{-1})$. Our results is in agreement with that of [19] carried out for West Africa, where they reported that during the dry/harmattan season the extinction coefficient is $> 0.4 - 0.6\ km^{-1}$ while our result is within the range $0.4184 - 0.6656\ km^{-1}$ with the lowest in March and the highest in January, though, our result is in contrast with their result during the wet season as extinction coefficient is $< 0.2\ km^{-1}$ while our result is within the range $0.4021 - 0.4374\ km^{-1}$ with the lowest in April and the highest in June.

The results shown in Table 2 revealed that the atmospheric visibility and relative humidity data spread out more to the left of their mean value (negatively skewed), while the temperature, atmospheric pressure, rainfall and wind speed data spread out more to the right of their mean value (positively skewed). The temperature, atmospheric pressure, rainfall and wind speed data seem to have a quassi-Gaussian distribution with the temperature data been symmetric as a skewness of exactly zero is quite unlikely for real world data. The atmospheric visibility and relative humidity data are more divergent away from the normal distribution. Standard error of the skewness of 0.637 was obtained for all the meteorological variables.

It is obvious from Table 2 that the atmospheric visibility data have positive kurtosis which indicates a relatively peaked distribution and possibility of a leptokurtic distribution. The temperature, relative humidity, atmospheric pressure and rainfall data have negative kurtosis which indicates a relatively flat distribution and possibility of platykurtic distribution. The wind speed indicates kurtosis of normal distribution and considered as mesokurtic. Standard error of the kurtosis of 1.232 was obtained for all the meteorological variables.

Table 2. Descriptive data statistics for measured weather parameters for Ikeja, Nigeria

Variable	Visibility	Temp	RH	AtmPres	RF	WS
Mean	8.675	27.2651	82.2557	1012.00	1280.86	2.8551
SE mean	0.37444	0.36067	1.37149	0.40691	247.313	0.15719
Std Dev	1.29709	1.24941	4.75099	1.40958	856.717	0.54451
Variance	1.682	1.561	22.572	1.987	733965	0.296
Range	3.85	3.75	14.08	3.99	2370.51	1.93
Minimum	5.88	25.38	73.15	1010.18	307.32	2.00
Maximum	9.73	29.13	87.23	1014.16	2677.83	3.93
Skewness	-1.514	0.047	-0.617	0.392	0.431	0.238
SESkewness	0.637	0.637	0.637	0.637	0.637	0.637
Kurtosis	1.244	-1.224	-0.906	-1.401	-1.194	0.020
SEKurtosis	1.232	1.232	1.232	1.232	1.232	1.232

Table 3. Difference between values for the predicted models and the measured visibility

Month	V-Temp	V-RH	V-AtmP	V-RF	V-WS
Jan	2.6665	1.1754	2.5647	2.0637	2.3262
Feb	-0.108	-0.6336	-0.1991	-0.4297	0.5849
Mar	-1.1337	-1.3654	-1.2454	-1.3496	-0.1985
Apr	-1.4302	-1.4322	-1.4947	-1.1942	-0.7922
May	-0.9538	-0.607	-0.9946	0.258	-0.9939
Jun	-0.1073	0.6706	0.1197	0.862	-0.601
Jul	-0.2835	0.3471	0.0048	-0.1685	0.098
Aug	-0.6565	-0.3227	-0.4011	-1.4004	0.491
Sep	-0.7347	-0.142	-0.537	-0.4425	-0.534
Oct	-0.4082	0.1414	-0.4198	-0.1118	-1.1053
Nov	0.5183	0.9865	0.3598	0.3864	-0.7248
Dec	2.1882	1.6082	2.0781	1.5409	1.2855
Sum	-0.4431	0.4262	-0.1649	0.0143	-0.1641

It is clear from Table 3 that the temperature decreases the atmospheric visibility estimation by 0.4431 (44.31%) annually at temperature between 25.38 and 29.13 ^{0}C. The relative humidity increases the atmospheric visibility estimation by 0.4262 (42.62%) annually at relative humidity between 73.15 and 87.23%. However, it has been reported that high relative humidity can cause increase in aerosol hygroscopic growth to enhance its scattering ability [20] and hence affect visibility. In one of such observation [21] found a nonlinear increase in scattering across section of an ammonium sulfate particle by a factor of five or more relative to that of dry particles when relative humidity is 90%. The atmospheric pressure decreases the atmospheric visibility estimation by 0.1649 (16.49%) annually at atmospheric pressure between 1010.18 and 1014.16 hPa. The rainfall increases the atmospheric visibility estimation by 0.0143 (1.43%) annually at rainfall between 307.32 and 2677.83 mm. The wind speed decreases the atmospheric visibility estimation by 0.1641 (16.41%) annually at wind speed between 2 and 3.93 ms^{-1}.

5. CONCLUSION

The changes of atmospheric visibility under changing meteorological parameters condition have been addressed. The results obtained from simple regression equation and variation of visibility with meteorological parameters indicates that the atmospheric visibility was highly influenced by meteorological parameters, especially the relative humidity. It was observed that the visual range during the rainy season is greater than in the dry season. The best atmospheric visibility occurred during the rainy season with an average value of $9.42 \pm 1.03 \, km$ and the worst atmospheric visibility occurred during the dry season with an average value of $7.63 \pm 1.03 \, km$. The good visibility during the rainy season is due to the washing out of aerosol particles in the atmosphere by rainfall. The observed atmospheric visibility ranged from $5.88 \pm 1.03 \, km$ and $9.73 \pm 1.03 \, km$ indicating that the atmosphere in the region is mostly clear as fog, mist and haze which can reduce visibility to near zero making driving extremely dangerous rarely occur in the study area under investigation. The average atmospheric visibility extinction coefficient obtained for the study area is approximately $4.628 \times 10^{-4} \, m^{-1}$ as the atmospheric extinction coefficient increases the aerosol particle size in the atmosphere will become larger, thereby decreases the

atmospheric visibility. The maximum values of temperature and atmospheric visibility were observed during the dry season and rainy season respectively while the minimum values of temperature and atmospheric visibility were observed during the rainy season and dry season respectively. The maximum and minimum values of relative humidity and atmospheric visibility were observed during the rainy and dry seasons respectively. The maximum and minimum values of atmospheric pressure and atmospheric visibility were observed during the rainy and dry seasons respectively. The maximum and minimum values of rainfall and atmospheric visibility were observed during the rainy and dry seasons respectively. The maximum and minimum values of wind speed and atmospheric visibility were observed during the rainy and dry seasons respectively.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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