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Spatio-Temporal Characteristics of Visibility Levels Over The Eastern Humid Area of Nigeria and The Roles of Aerosols and Climate

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Abstract

This study examines a 20-year (188-2008) monthly mean visibility data of four locations in the humid region of eastern Nigeria (Enugu, Owerri, Port-Harcourt and Calabar). The data shows some useful spatio-temporal characteristics: In all the 4 locations, annual lows (< 8km) are encountered at the onset of the harmattarn season (i.e. December) and during the periods of heaviest rains (July for Enugu, Owerri and Port-Harcourt and September for Calabar). Slightly lower visibility levels occur at the coastal locations (Port-Harcourt and Calabar) during the rainy season compared to the more inland sites (Enugu and Owerri) with differences of ~ one order of magnitude. At the onset of the *harmattarn* period, visibilities are however higher at the coastal locations than at the in-land sites. From the 20-year data examined there are no significant long-term variations in the visibility levels at all the sites. This suggests that anthropogenic visibility-reducing emissions are still not significant at the locations studied. The observed spatio-temporal trends are explained on the basis of aerosol loading mechanisms and associated climatic parameters. The eastern humid region of Nigeria pose immense ecological challenges to the Governments of Nigeria, owing to land degradation from oil exploration and erosion, hence this study is useful in planning satellite remote sensing operations for rapid mapping of various surface problems.

Keywords: : Visibility, Aerosols, Climate, Spatio-Temporal, Eastern Humid Area, Nigeria

1.0 Introduction

Visibility in the day time is defined as the greatest distance at which a black object of suitable dimensions situated near the ground can be seen and recognized by the unaided eye when observed against a background fog or sky or, in the case of night observations, could be seen and recognized if the general illumination were raised to daylight level (WMO, 1971). Visibility range (VR) is equivalent to the reciprocal of the atmospheric light extinction parameter [redacted]. The later is computed by considering a flux (Φ) of parallel monochromatic beam of light passing through an elemental layer (dh) of the atmosphere. The amount of attenuated energy of the beam is; - $\sigma_e \Phi dh$, hence an atmosphere of large light extinction records a low visibility and vice-versa. The light extinction [redacted] has two components; one associated with absorption [redacted] and other associated with scattering (σ_b).

Visibility is important in air, road and marine transport as reduced visibilities often lead to delays or cancellations of vital missions at huge economic costs (see Andre, 1995). In Nigeria, the increased frequency of fatal air mishaps especially between 2004 and 2005 raised serious awareness of the importance of meteorological facilities for visibility measurements among others at the airports and the need to step up fundamental research on environmental situations that affect air safety (also see Aderinto and Dahunsi: un-serialized monograph).

Visibility is a critical factor in satellite remote sensing operations of the earth's surface since it may affect scene brightness considerably. This potential problem is of immense significance in Nigeria's eastern humid area because of various problems of environmental degradation occasioned by oil exploration activities and other ecological disasters such as surface and gully erosions. Satellite information is necessary for rapid monitoring of these phenomena as well as pipeline vandalizing which is common. Nigeria's first

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Satellite (NIGERIA-SAT1) is essentially a geographical information satellite designed to monitor such problems. (www.nasrda.gov.ng/aboutnasrda.php. Furthermore, the Niger Delta area which is located in the eastern humid axis of Nigeria is home to Nigeria's oil industry and with a rather complex terrain. There has been growing incidences of militancy in recent years owing to what many people generally perceive as lack of government presence. Sky and space remote sensing are considered very useful not only for monitoring ecological degradation of the area but also for planning civil construction aimed at ameliorating the suffering in the region.

Although aerosols principally affect visibility when water vapor condenses on the particles under "clean" background atmosphere (Trijonis, 1982), the degree of aerosol pollution and the interaction with climatic factors such as wind and rainfall are also very essential to their visibility impacts. When cloud, mist, and rain droplets are present in the atmosphere, complicated light attenuation conditions impair vision through multiple scattering and absorption (See Alfano, 1994; Bergin, 2000). The intake of water by aerosols is determined by aerosol type and particulate characteristics, namely the aerosol size and shape with the aerosol light extinction usually growing exponentially with humidity especially for hygroscopic particles (Tang *et al.*, 1981; Shehelkanov *et al.*, 1999; also see CARB, 2002). There are however no well known parametric relations with other meteorological parameters.

In this study the monthly mean levels of visibility for the following locations; Enugu, Owerri, Port-Harcourt and Calabar are examined. These sites are chosen from the area referred to in this paper as "eastern humid" which includes six of the Niger Delta states (Rivers, Bayelsa, Akwa Ibom, Cross River, Imo and Abia) and the three more inland states (Anambra, Enugu and Ebonyi). The objective is to identify any similarities or discrepancies in the temporal and spatial levels of visibility and use such to deduce the possible roles of atmospheric aerosol loading and some meteorological parameters in the observed visibility trends at the sites. The results will in addition to the objectives earlier discussed be useful in predicting the consequence of future changes in atmospheric aerosol loading and climate on visibility changes in the area.

2.0 Data and Sites

The data used in this study are monthly average values of meteorological visibility (at 9a.m) for 20 years (1988-2008) and associated data on relative humidity (%), rainfall(mm) and wind direction for the four sites: Enugu (long;7°27'31"E; latt;6° 27'3"N), Owerri (long; 7°1'33"E; latt; 5°29'34"N), Port-Harcourt (long; 7°0'17"E; latt; 4°47'5"N), and Calabar (long; 8°18'50"E; 4°57'25"N). The data were obtained from the Federal Ministry of Aviation Oshodi Lagos and the Nigerian Meteorological Agency (NIMET). The four sites chosen experience the usual seasonal climates moderated by the West African monsoon. The wet season usually begins from April and ends in September while the dry season begins in October and ends in March of the following year. There are minor yearly fluctuations in the inception and duration of these seasons for the different sites. For the purpose of this work, we retain the classical separation of the seasons into the definite months described above.

Being on the equatorial humid area, rainfall at all the sites are amongst the highest in the country (1500-4000mm per-Annum). Relative humidity is also considerably large in both the wet and dry seasons compared to the moist and dry sub-humid areas of the northern region of Nigeria. Low humidity (< 60%) is usually experienced only during the harmattarn period, when Sahara dust is transported southwards towards the sea. The sites are therefore under the influence of harmattarn dust aerosols in the dry season and other multiple anthropogenic aerosol sources during both seasons. The later aerosol types are brought about by bush and refuse burning and activities of various industries such as oil companies, petrochemicals plants, Liquefied Petroleum Gas (LNG) plants, and industries for fertilizer, pesticides, asbestos, wood processing etc. Sea salts and numerous secondary aerosol precursors may also be encountered especially for the coastal locations.

3.0 Data Analysis and Results

3.1 Temporal Variations

In Figure 1, the mean annual visibility variations for all the sites are presented. These are computed from the averages of the monthly means from January

1988 to December 2008. The curves show a seasonal pattern with two annual visibility range (VR) lows. The first troughs of VR levels occur at the peak of rainfall for each site. This occurs by July at Enugu, Owerri, and Port-Harcourt but extends to August and September as well for Calabar. Figure 2 shows the inverse correlation between VR and rainfall for Calabar. The other sites also show similar inverse relations. The second trough in the annual variation occurs is at the onset of the *harmattarn* period which is usually by December in this region. Between these two lows are considerably high (> 8km) visibility levels.

The wet season as well as the *harmattarn* on-set visibility lows can be adequately explained in terms of the rainfall and wind direction averages of the various locations. We show in Table 1 that the highest Relative humidity (RH %) and Rainfall (mm) values occur during the wet season months (July, August, September) and both RH and rainfall have the tendency to reduce visibility: Under high relative humidity aerosol particles in the atmosphere absorb water to enhance their refractive index (since they become more spherical) and therefore scatter solar radiation more efficiently thereby reducing the visibility of the atmosphere. Rain water contains three optically active components; pure water, dissolved substances (organic and inorganic) and aerosols (mineral and organic), hence the optical properties of a precipitating atmosphere are much more complicated than for non-precipitating one and obviously leading to reduced visibility. The degrading effect of rainfall on atmospheric visibility can be appreciated by comparing light extinction characteristics of a body of water such as the ocean (under average conditions) with that for the cloudless atmosphere as shown in Table 2 (adapted from Shifrin, 1983). The table shows that the light extinction is by far more for the water body than for the "free" atmosphere. The lowest range of visibility disparities for the sites are observed in January / February when minimum relative disparities in rainfall occur for all the sites (~ 1 to 2 orders of magnitude) and highest range by August when the largest rainfall disparities occur (~2 to 3 orders of magnitude).

3.2 Spatial Variations

Figure 1 also shows that visibilities are lower in the coastal locations (Port-Harcourt and Calabar) during the wet season compared to the more inland sites (Enugu and Owerri). During the *harmattarn* period (December-February) however he visibility is lower for the more inland locations than for the coastal sites. This spatial trend can be explained on the basis of varying *harmattarn* dust aerosol loading at the sites using data on wind direction.

Table 2: Comparison of extinction properties of the ocean and atmosphere (After Shifrin, 1983).

Medium	σ_a	σ_b	σ_e
Ocean	0.07	0.16	0.23
Cloudless Atmosphere	0	0.00021	0.00021

Table 1: Average Relative Humidity (%) and Rainfall (mm) at Stations: Enugu (ENU), Owerri (OWE), Port-Harcourt (PH) and Calabar (CAL) from 1988-2008.

						RH (%)						
STN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ENU	55	59	68	75	80	82	84	84	84	81	73	61
OWE	64	69	77	78	79	84	87	87	85	82	76	71
PH	76	76	81	82	83	85	89	88	87	85	82	78
CAL	79	79	82	84	84	87	90	91	89	87	86	82
						Rainfall (mm)						
STN	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ENU	7.8	12.2	52.4	169.6	242.5	271.2	278.7	243.8	274.0	213.3	23.4	3.0
OWE	30.6	35.7	114.4	196.1	275.2	371.6	382.6	356.3	386.3	231.4	63.2	15.9
PH	30.7	58.1	113.9	135.0	294.7	279.8	379.4	292.0	365.2	258.3	94.5	32.2
CAL	32.4	37.1	185.6	249.4	279.8	391.7	467.4	408.9	397.3	299.5	154.6	33.3

Figure 1: Mean annual variations of visibility of the two decades (1988-2008) and for the four sites.

Figure 2: Correlation between Visibility and Rainfall for Calabar. Other sites have similar visibility/rainfall correlations.

Figures 3 (a-d) show the frequency of occurrence of wind of different directions during the core *harmattarn* months (December, January, February) for the four sites. These frequencies were evaluated by using the averages of the dominant wind directions for each *harmattarn* month as the wind direction for that month and thereafter computing the wind direction averages for all the *harmattarn* months for the 20-year period. The letters N, E, S, W, NE, NW, and SW, stand for the usual wind directions; North, East, South, West, North-East, North-West and South-West respectively. The figures show that whereas the *harmattarn* wind which has a northern origin (from the Sahara) as represented by the NE and NW winds are dominant at the inland sites (Enugu and Owerri) it is only mild at the coastal locations (Port-Harcourt and Calabar). The mild coastal *harmattarn* translates to low Sahara dust aerosol volume concentration at the coastal sites during this period and this explains the higher visibility values at these sites during this period compared to the more in-land locations.

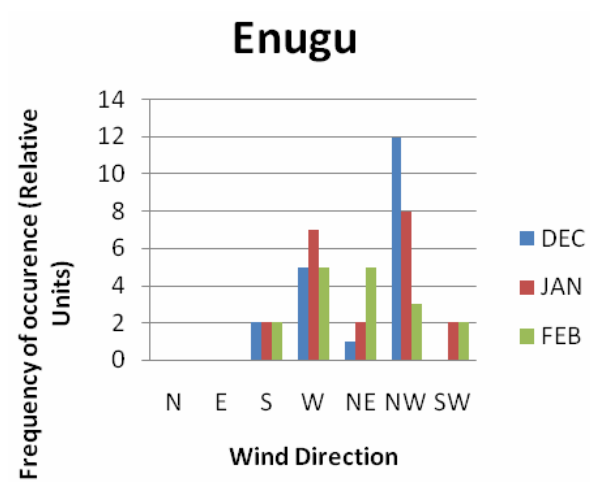

Figure 3a

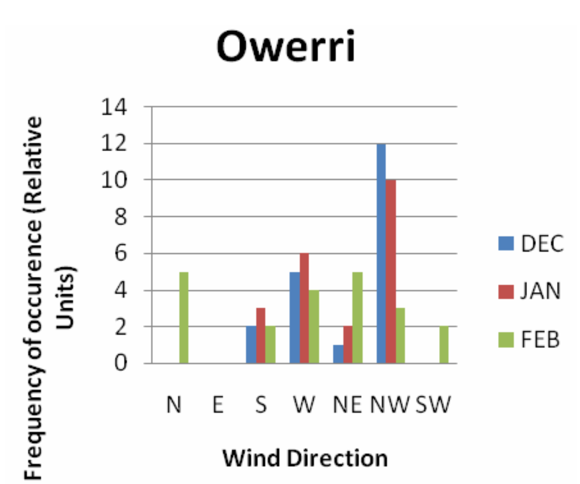

Figure 3b

3.3 Influence of Hygroscopic Aerosols

Although humidity contributes to light attenuation efficiency of the free hygroscopic (water -absorbing) aerosol, it is not easy to model the relationships using composite visibility data. The analytical relations between humidity and visibility can only be roughly estimated using light extinction parameters and such variation can be used to infer the influence of hygroscopic aerosols. Since dust is only weakly

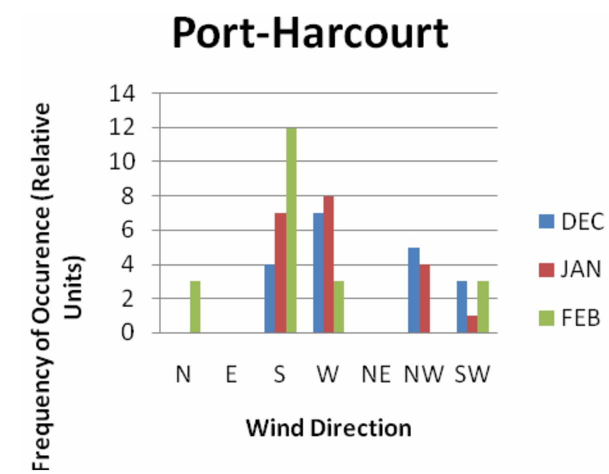

Figure 3c

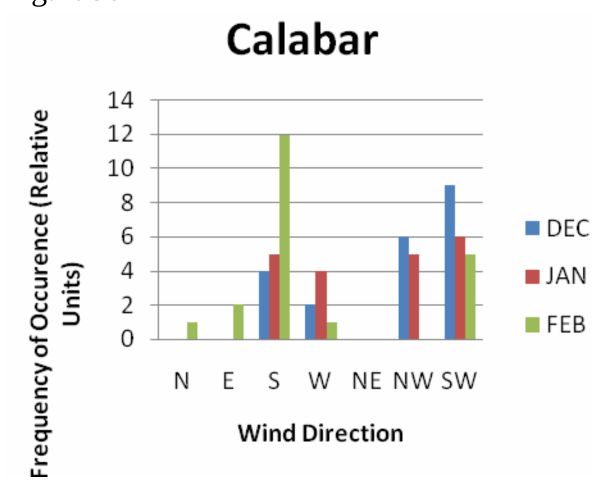

Figure 3d

Figures 3(a-d): Frequency of occurrence of wind from different directions during the core harmattarn months (December, January and February) for the four sites.

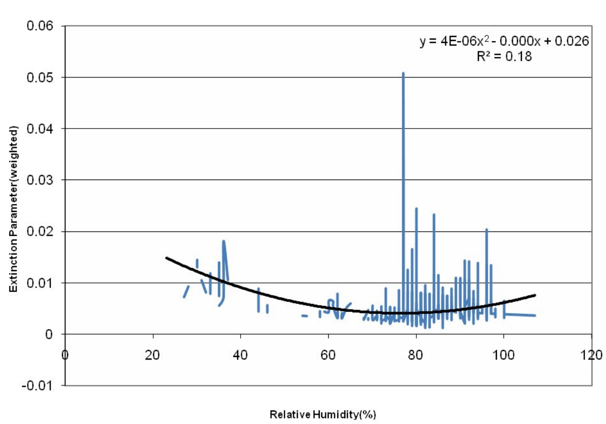

Figure 4: Graph of the atmospheric extinction parameter (weighted with RH values) versus the Relative-Humidity (%) for Port-Harcourt using daily data between 2003 and 2005. (Adapted from Nwofor, 2010b).

hygroscopic, the only reasonable humidity-dependence of scattering (visibility) would be in the coastal areas where hygroscopic sea salt particles could be advected from the sea are readily deposited during the wet season. We show the humidity dependence of visibility for the coastal site of Port-Harcourt in Figure 4 using three year daily visibility data between 2003 and 2005 (see Nwofor, 2010b). In order to improve the correlation, the visibility data was first converted to atmospheric extinction values using the equation $R_v = 3.912/\sigma_e$ (Middleton, 1952). These extinction values were then correlated with relative humidity (RH) data for the same period. The sensitivity of the plot was enhanced by weighting the extinction values with the *RH* according to the expression: $\bar{\sigma}_a = \sigma/RH$ after which ($\bar{\sigma}_a$) and *RH* were then plotted. The relation between the two parameters is then fitted by the polynomial equation; $\bar{\sigma}_a = 3\times10^{-6}RH^2 - 0.0005RH + 0.0241$. From the graph, at *RH*<60% the extinction tends to drop with *RH* while at *RH*>80% the extinction tends to rise moderately with *RH*. Considering the fact that *RH* < 60% occur mainly in the first part of the dry season (*harmattarn* months) whereas *RH* > 80% occur in the wet and the later part of the dry season, it is inferred that the *RH* < 60% part of the correlation is attributable to the influence of mineral dust aerosols advected from the Sahara during the dry *harmattarn* period and these particles essentially shows non-hygroscopic character (Baltensperger *et al.*, 2000;

Figure 5: Long-Term Trends in Visibility at the sites.

Feingold and Morley, 2003). Overall, only a marginal growth in extinction with *RH* is observed. This, together with the fact that no discernible long-term trends (Figure 5) in visibilities are observed for all the sites suggest that the influence of anthropogenic aerosols on visibility levels could still be minimal at these localities.

4.0 Conclusions and Recommendations

This study has shown that a wide range of visibility levels scenarios are observed at locations in the eastern humid area of Nigeria. Factors which determine aerosol uplift, dispersal, and refractive properties such as rainfall, humidity and wind direction are found to play major roles in the observed visibility levels. The influence of latitude was evident with the coastal sites showing slightly different visibility patterns compared to the more inland locations.

It is concluded that although the total atmospheric extinction is a summation of the aerosol extinction and the extinction due to scattering and absorption by gases and droplets (Bergin, 2000); atmospheric aerosols likely produce the most serious near-ground optical effects such as visibility degradation. In fact in West Africa, where pronounced light attenuation by aerosols occurs, some studies have linked surface visibility directly to the degree of aerosol loading (Husar *et al.*, 2000; N'tchayi Mbourou *et al.* (1997). Aerosols particles in most parts of southern Nigeria shows strong seasonality and consist mainly of fine dust and sea salt in the wet season and coarse dust and biomass burning aerosols in the dry season. (Nwofor, 2006; Nwofor *et al.*, 2007; Okeke & Okoro (2006). Several scattering scenarios potentially occur. At ambient conditions aerosols of different properties i.e. chemical composition, shapes and size are found and these are capable of producing complicated visibility-humidity growths. It is noteworthy that data on some aerosol properties have been acquired for some sites in Nigeria but only for very short periods covering mostly the *harmattan* season. For instance Utah and Ngadda (1994) acquired aerosol size and mass concentration information which produced good correlations with *harmattan* season visibility data at the Jos Plateau in the middle belt areaof Nigeria; Okeke and Okoro (2006), studied aerosol size and mass concentration during the *harmattarn* season at Nsukka a tropical humid-Sahel savanna transition site; while Chiemeka *et al.*, (2007) measured aerosol chemical composition during the *harmattarn* season at Uturu in the tropical humid area of Nigeria. More data need to be acquired in a systematic manner (to cover more locations in Nigeria and for an extensive period to cover all the seasons (in addition to the *harmattar*n period).

Although many airports in Nigeria are now equipped with visibility monitoring instruments, there is the immense need to improve our capacity in the area of visibility forecasting and scenario construction. The importance of well spread continuous monitoring of aerosol properties and functional meteorological stations to provide baseline data for visibility forecasting cannot be overstated. It is only when particulate data on aerosols are obtained for a site that the different extinction behavior corresponding to different aerosol species can be derived and composite visibility scenario derived which can be useful for forecasting.

Given the significant climate changes in West Africa resulting in prolonged drought, aerosol loading is expected to intensify and increasing industrial activity will as well lead to upsurge in hygroscopic particles with serious consequences for visibility variations (see Nwofor, 2010a).

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