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Atmospheric Stability Pattern over Port Harcourt, Nigeria

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Abstract This study examined the atmospheric stability pattern over Port Harcourt in Nigeria from 2011-2015. Six hourly synoptic data retrieved from ECWMF Re-analysis Interim data set (Era-Interim) platform was used in the analysis. The Era-Interim platform provides a viable standard most especially for the exploration of temperature and wind speed data which are critical indicators of stability conditions. The widely and acceptably used Pasquill-Gifford stability technique was employed in assessing the stability variations. Results showed that very stable (class F) and neutral (class D) conditions occur during the early hours of dawn. While class D prevails from June to September, class F dominates from October to May. During the afternoon, slightly unstable condition (class C) exists and prevails from February to November. Stability class B was more dominant at sunset throughout the year while very unstable condition (class A) only prevails from December to January during noon time. The pattern of atmospheric stability conditions in the study area suggests that emissions will be restricted at ground level receptors during the early hours of dawn if emission sources are below inversion level. However, if the emission sources are above inversion level, dispersion will take place aloft. Emission dispersion during the day for elevated sources will not adversely affect close downwind receptors for most of the months due to the moderately unstable categories B-C dominant in the area as well as low wind speed. However, in December and January, vigorous mixing brings emissions to ground level at receptors close to emission sources due to the prevalent very unstable condition (class A) at moderate wind speed. The reverse will be the case for low level emission sources. Policy makers must ensure that pollution from industries within the study area are mitigated as well as keep potential emitters from being sited close to city areas.

Keywords: *atmospheric stability, Port Harcourt, emission, Era-Interim, receptors*

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1. Introduction

The propensity of the lower troposphere to repel or boost vertical motion is referred to as the stability state of the atmosphere. It is intensely associated with the variation of temperature and altitude, termed the lapse rate [1]. Stability is associated with both wind stratification and temperature change with altitude [2], however, it is the latter that is utilised as a pointer of the situation. The circulation of temperature within the planetary boundary layer contained within the lower troposphere has substantial bearing on atmospheric stability [3]. Various studies have shown the pattern and degree of stability classification across geographical locations [4,5,6,7]. The extent and degree of atmospheric stability is assessed by the modification between the shortwave radiation striking the earth surface and the terrestrial radiation released from the surface. This modification brings to bear the exchange of the sensible and latent heat fluxes with the earth surface. The continual exchange of masses between the earth surface and the lower troposphere portrays the lower atmosphere as an open system [8]. Regarding grouping, there are three basic schemes of stability conditions. This includes the unstable, stable and neutral conditions. It has been noted that atmospheric stability regulates the degree of turbulence within the lower troposphere that directly impacts on emission dispersion [9]. Emission dispersions in the atmosphere are controlled by the vertical transfer of air mass [10] conditioned by the pattern of stability conditions. Therefore, a proper understanding of the stability conditions of any local environment is important to accessing the periods of high and low ground level emission concentrations across sensitive receptors. If the local atmosphere is neutral, emission dispersion will continue unmixed as the atmosphere does not repel or boost spreading. The local atmosphere will tend to limit and enhance upward motions during stable and unstable conditions respectively. At coastal environments like Port Harcourt, unstable atmospheric conditions are normally responsible for cloudy conditions associated with low pressure systems while stable and neutral conditions breeds' high pressure systems [9]. The aim of this work is to assess the stability conditions of the lower atmosphere across the various months in the coastal area of Port Harcourt using the Pasquill-Gifford stability classification.

2. Materials and Method

2.1. Description of Study Location

Port Harcourt is positioned in Nigeria's Niger Delta area within Latitudes 4°45' – 4°60' N and Longitudes 6°55' – 7°56' E (Figure 1). The area is located around the coastal zone subjugated by low setting coastal plains of sedimentary formations [14]. Port Harcourt has a humid equatorial monsoon climate influenced by its closeness to the Ocean. This influence from large water bodies exposes the area to continental effects [9]. Two air masses control rainfall: moist northward moving maritime air coming from the Atlantic Ocean and the dry continental air coming from the African Landmass. The Inter-Tropical Convergence Zone (ITCZ) plays a controlling factor. The movement of the ITCZ is associated with the warm humid maritime Tropical air mass with its south-western winds and the hot and dry continental air mass with its dry north-easterly winds. Due to the stronger presence of the moist south-west wind, the area receives abundant rainfall amount of annual mean above 2300mm [15]. The annual distribution begins with the early rains in March, which ceases in November. The bi-modal rainfall regime observed in the areas peaks in July and September [16]. Average peak and lowest temperature trend of 32°C and 26°C are observed in January and July respectively [17]. The average relative humidity for the area varies from 66%-96% throughout the year [18] with high and low peaks during the wet and dry seasons respectively. Cloud cover pattern in the area is constantly being enhanced with monthly average of over 6 oktas. This is due to the massive water vapour that ascends the atmosphere as a result of adjacent water bodies. However, cloud cover is highest and lowest during the wet and dry months respectively. This reflects on the average daily sunshine hours where less than 3 hours is observed in July and about 4-5 hours observed in January and December. Average monthly wind speed pattern range from 0-3m/s with period of lower and higher trend observed during the night and evening periods respectively. Figures 2-5 show the average wind direction pattern for the area from December-February (DJF) and July-August (JJA) during 0000H and 1200H.

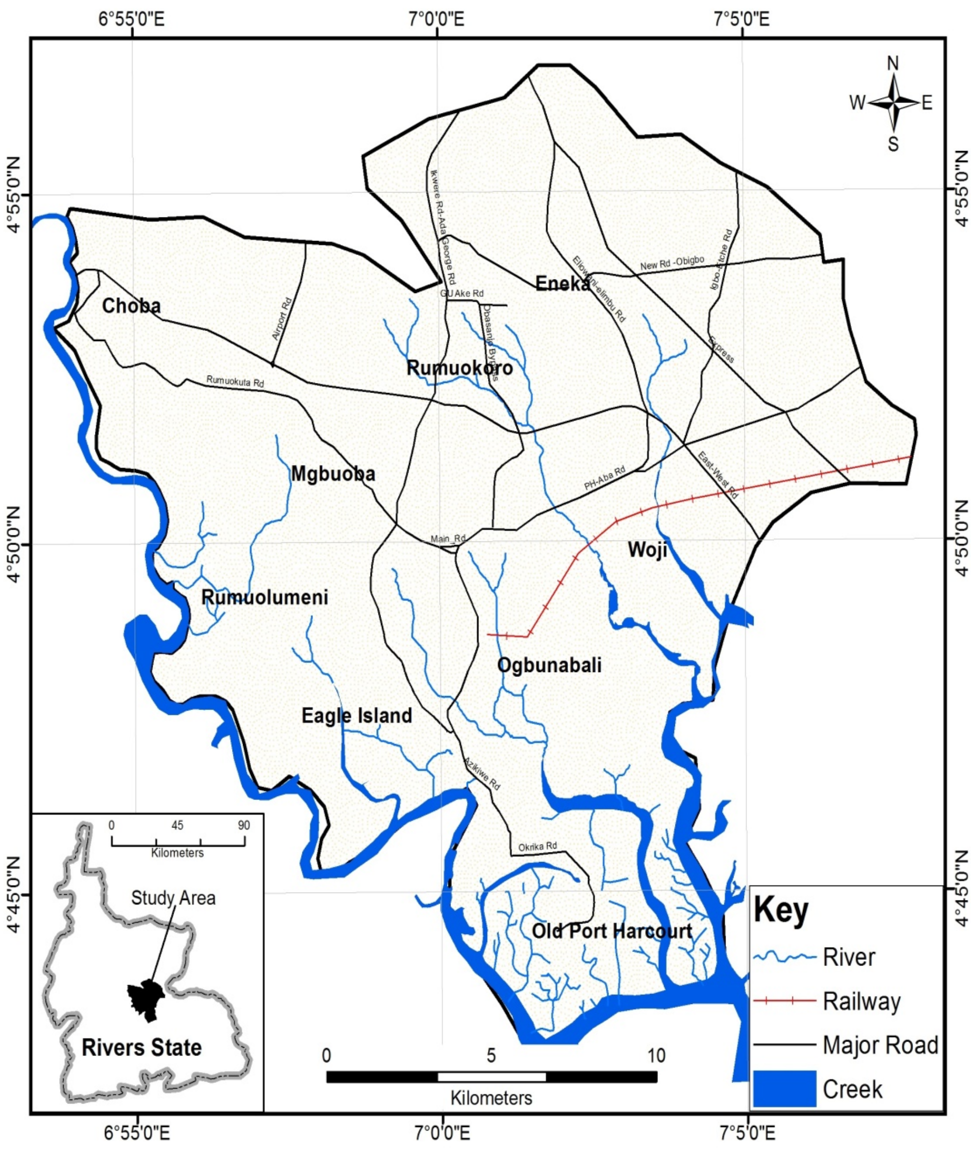

Figure 1. Map of Study Area.

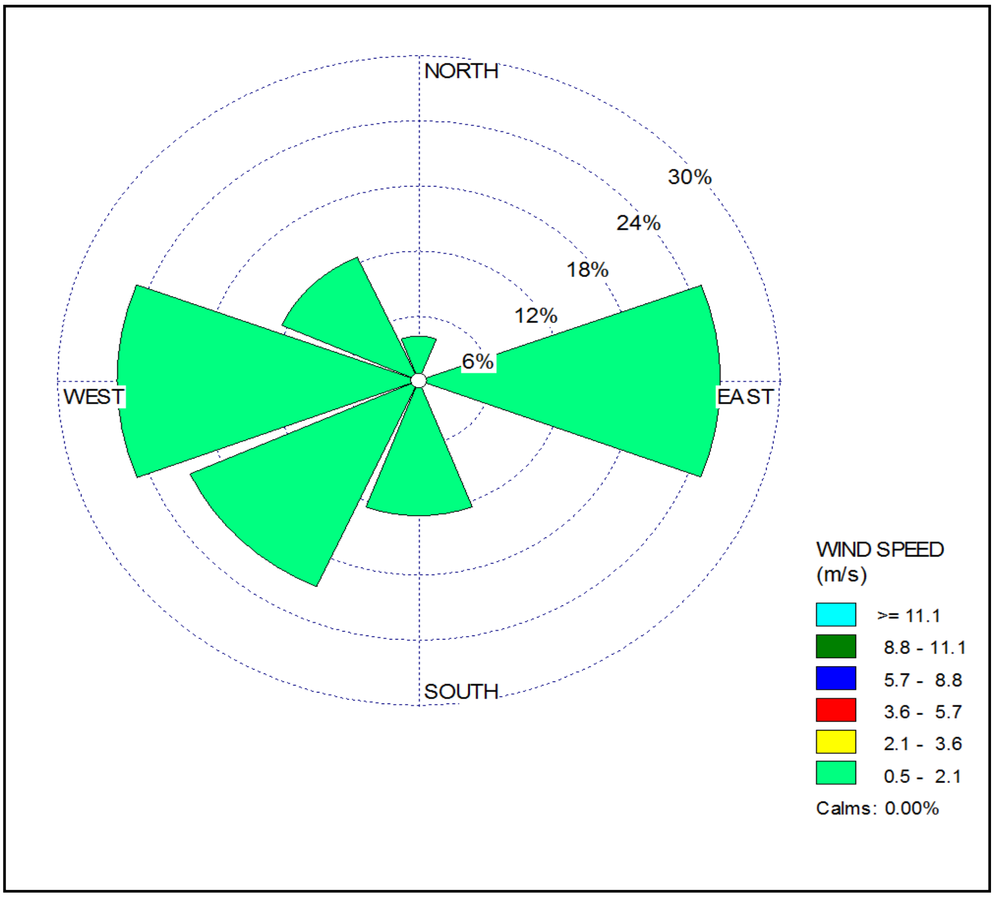

Figure 2. Wind Direction Pattern for Port Harcourt at 0000H (DJF)

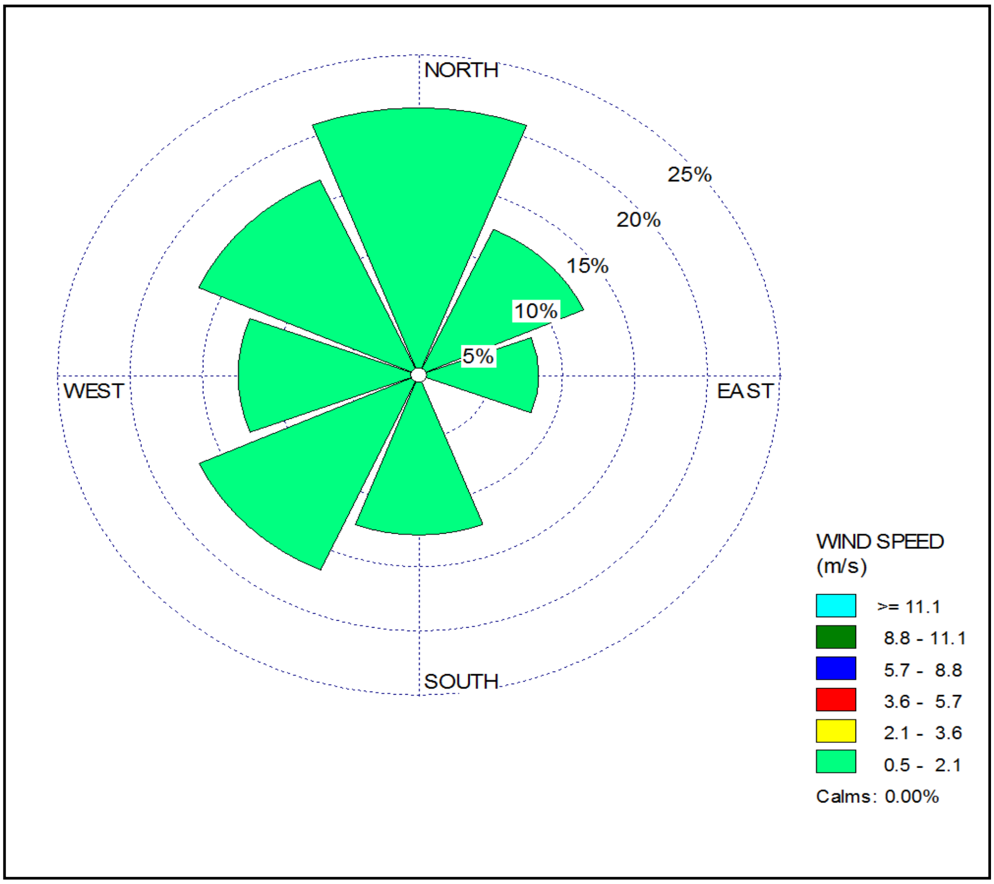

Figure 3. Wind Direction Pattern for Port Harcourt at 0600H (DJF)

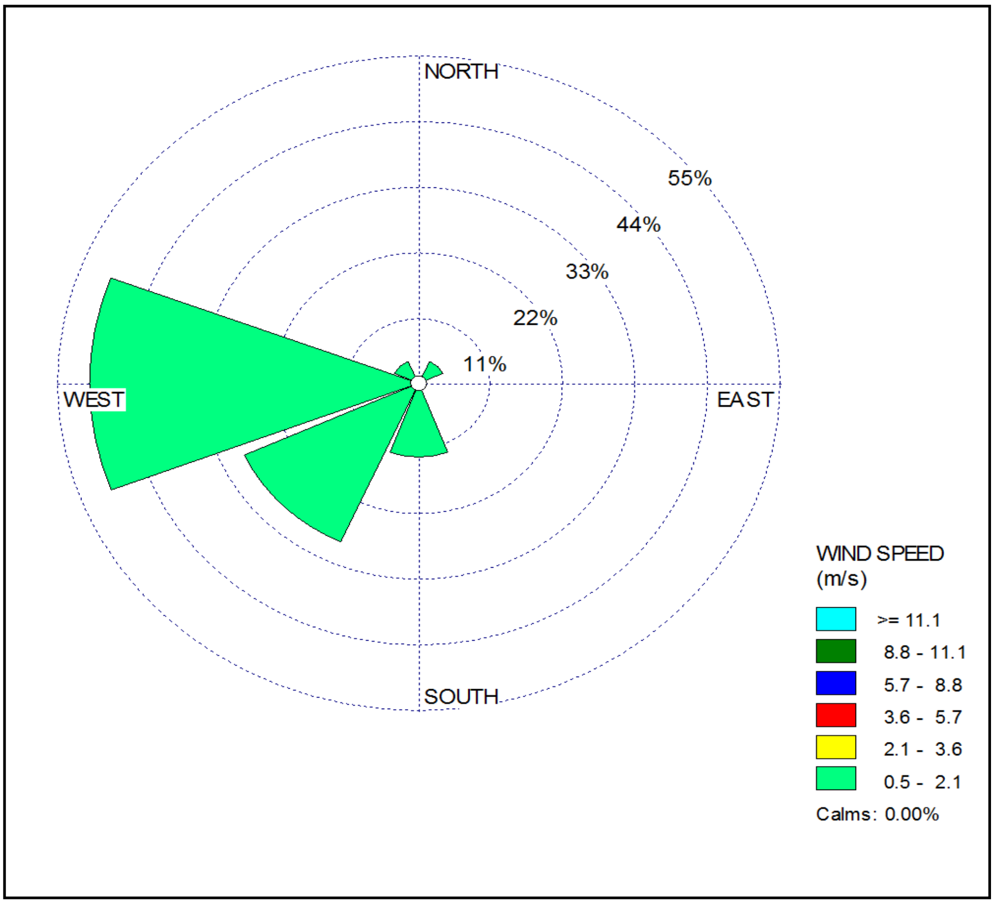

Figure 4. Wind Direction Pattern for Port Harcourt at 0000H (JJA)

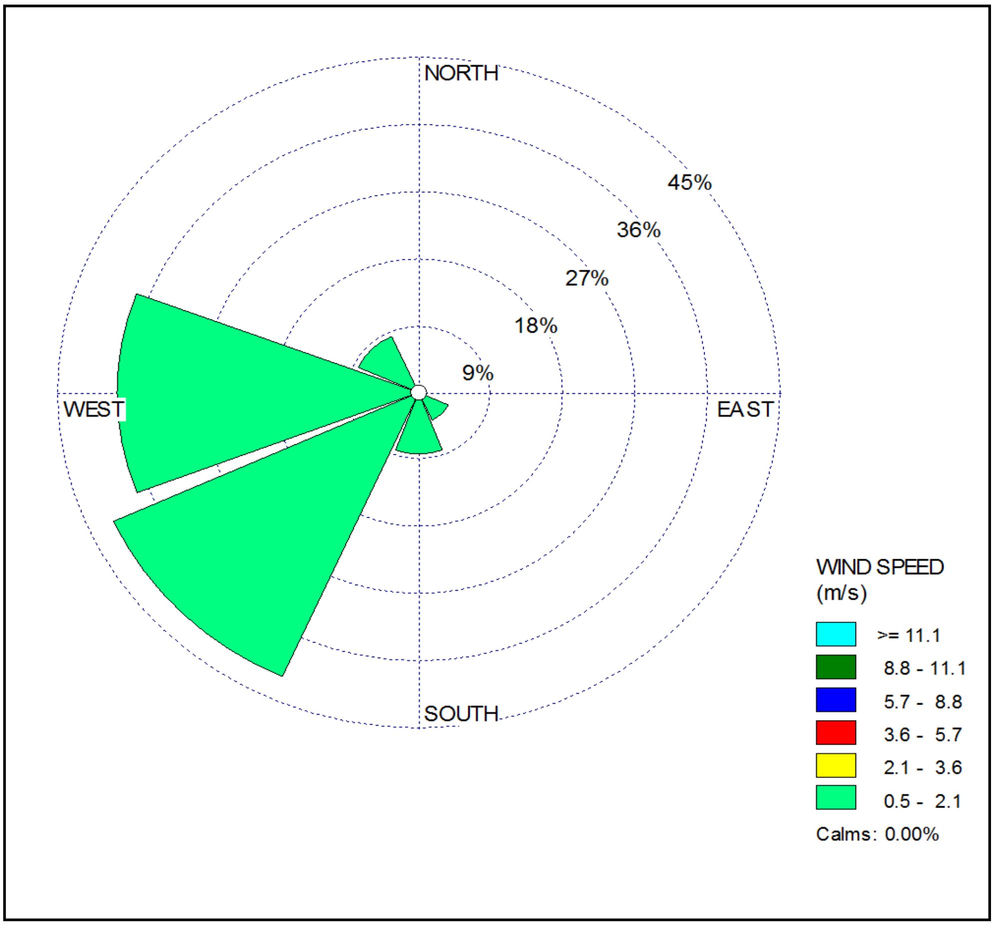

Figure 5. Wind Direction Pattern for Port Harcourt at 1200H (JJA)

2.2. Data

The data used for this study was retrieved from the ECMWF Re-analysis Interim data set (Era-Interim) platform. Temperature, wind speed and cloud cover at surface level were obtained from 2011-2015 at the following synoptic hours: 0000H, 0600H, 1200H and 1800H. The data was acquired at 0.125° latitude by 0.125° longitude grid resolution. The Era-Interim data is the newest global reanalysis data which covers periods from 1979 and continues to this moment [19]. It is highly proficient and competently represents the climate variability of the atmosphere over West Africa. The data set are reliable at any given time as well as at spatial level [20]. Average solar insolation for the area for 22 years was gotten from the NASA atmospheric science data centre.

2.3. Method of Data Collection

The Pasquill-Gifford (PG) scheme branded stability index into six categories i.e., very unstable (A) to very stable (F). The category 'G' which denotes extremely stable conditions was later introduced and mostly occurs at about 1.4% of the time [21]. Daytime stability categories were assessed by relating wind speed at 10m altitude and solar radiation while Night-time stability categories were assessed by relating wind speed and cloud cover. Daytime solar Insolation was defined as strong, medium and slight when greater than 600W/m^2, 300-600W/m^2 and less than 300W/m^2 respectively [13]. The procedure in Table 1 and Table 2 describes a method of ascertaining the stability classification in the absence of comprehensive meteorological data. The assessment of atmospheric stability conditions were carried out using a computer excel program.

3. Results and Discussion

Average monthly distribution as shown on Table 3 reveals that stability class A (very unstable condition) maintained a uniform percentage of 15% in December and January. The frequency diminished between May and October; the period of rainfall and massive cloud cover in the study area. Stability classes B and C (moderately and slightly unstable conditions) show a slight constant trend throughout the year. The high frequency occurrence of stability classes B and C was 26.6% and 20.4% in November and September respectively. The low frequency occurrence was 15.1% and 7.1% in February and December respectively. This dominant unstable stability classes (B-C) indicates the low patronage of solar insolation received at the study area almost throughout the year when compared to the central and northern axis of Nigeria. On the neutral-stable stability classification, classes D and F showed vigorous pattern while stability classes E and G were meagre intruders. Stability class D was highest in September with 41.7% occurrence and lowest in December with 13.2% occurrence. Stability class F was higher in January and lower in September i.e. 41.4% and 19.6% respectively (Table 3).

Table 1. Pasquill-Gifford (PG) Day Time Classification Scheme

Wind Speed (at 10m) (m/s)	Day Time Solar Insolation (W/m^2)			Radiation Overcast
	Strong >600	Moderate 300-600	Slight < 300	
<2	A	A-B	B	C
2-3	A-B	B	C	C
3-5	B	B-C	C	C
5-6	C	C-D	D	D
>6	C	D	D	D

Table 2. Pasquill-Gifford (PG) Night Time Classification Scheme

1Hr Before Sunset or After Sunrise	Cloud Cover (Oktas) Night-time		
	0 -3	4 – 7	8
D	F or G	F	D
D	F	E	D
D	E	D	D
D	D	D	D
D	D	D	D

Source: Muir, 2004.

Table 3. Average Monthly Distribution of Stability Classes from 2011-2015

MONTH	Frequency of Stability Class Occurrence (%)						
	A	B	C	D	E	F	G
JAN	15.1	21.5	7.8	13.7	0.0	41.4	0.5
FEB	9.6	15.1	13.9	26.8	0.1	34.1	0.3
MAR	8.2	19.5	12.0	23.0	0.0	37.4	0.0
APR	0.8	26.0	13.5	25.8	0.0	33.9	0.0
MAY	0.0	23.3	17.8	27.1	0.1	31.6	0.1
JUN	0.0	19.9	19.3	36.0	0.3	24.2	0.4
JUL	0.0	19.8	18.3	40.2	0.4	21.4	0.0
AUG	0.0	17.7	21.5	40.2	0.0	20.6	0.0
SEP	0.0	17.4	20.4	41.7	1.0	19.6	0.0
OCT	0.0	21.6	19.0	30.4	0.1	28.6	0.3
NOV	1.0	26.6	12.9	24.1	0.0	34.8	0.6
DEC	15.4	21.7	7.1	13.2	0.1	40.9	1.5

The stability pattern for the area at 0000H and 0600H as shown in Figure 6 and Figure 7 indicates that stability classes D and F (neutral and very stable conditions) are dominant during the periods. Stability class F prevails from November to May while stability class D dominates from June to September. This reveals that stability class D is deeply associated with the bi-modal periods of peak rainfall at the study area. The opposite trends observed during the specified hours between stability classes D and F compared to the study result of Mazoe in Northern Zimbabwe [1].

Atmospheric stability pattern for the area at 1200H (Figure 8) shows that stability class C dominates from February to November. Stability class B assumes a moderate trend with low peaks in January and December than class A (Figure 8). Stability class A was more prevalent in January and December than classes B and C.

This is due to the increased solar insolation observed during the months under low cloud cover. The position of the ITCZ over the Ocean during December and January coincides with the position of the sun over the coast of southern Nigeria ready to move the ITCZ towards the northern region.

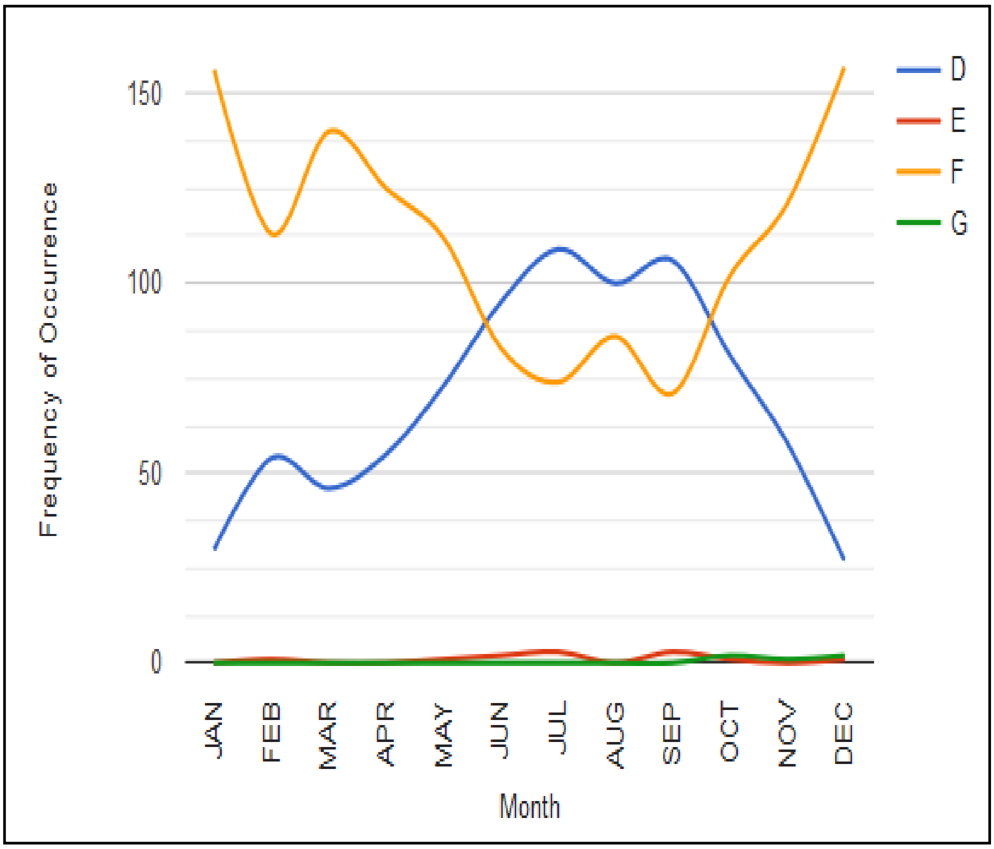

Figure 6. Atmospheric Stability Pattern in Port Harcourt at 0000H

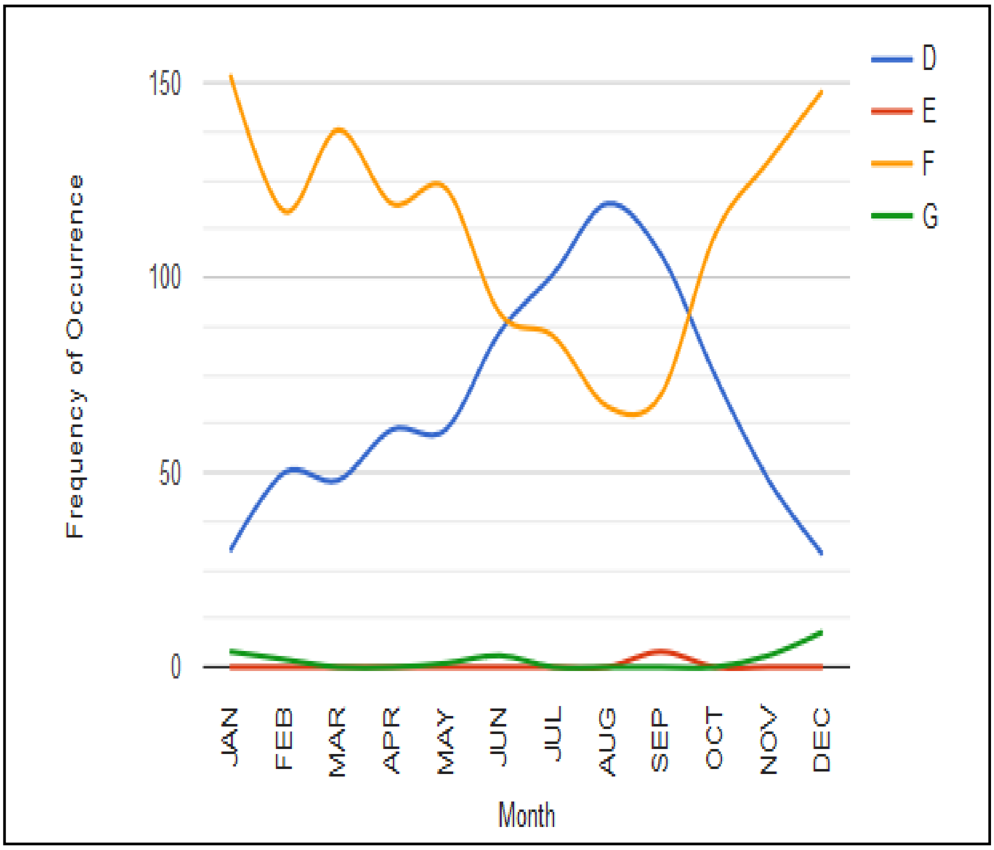

Figure 7. Atmospheric Stability Pattern in Port Harcourt at 0600H

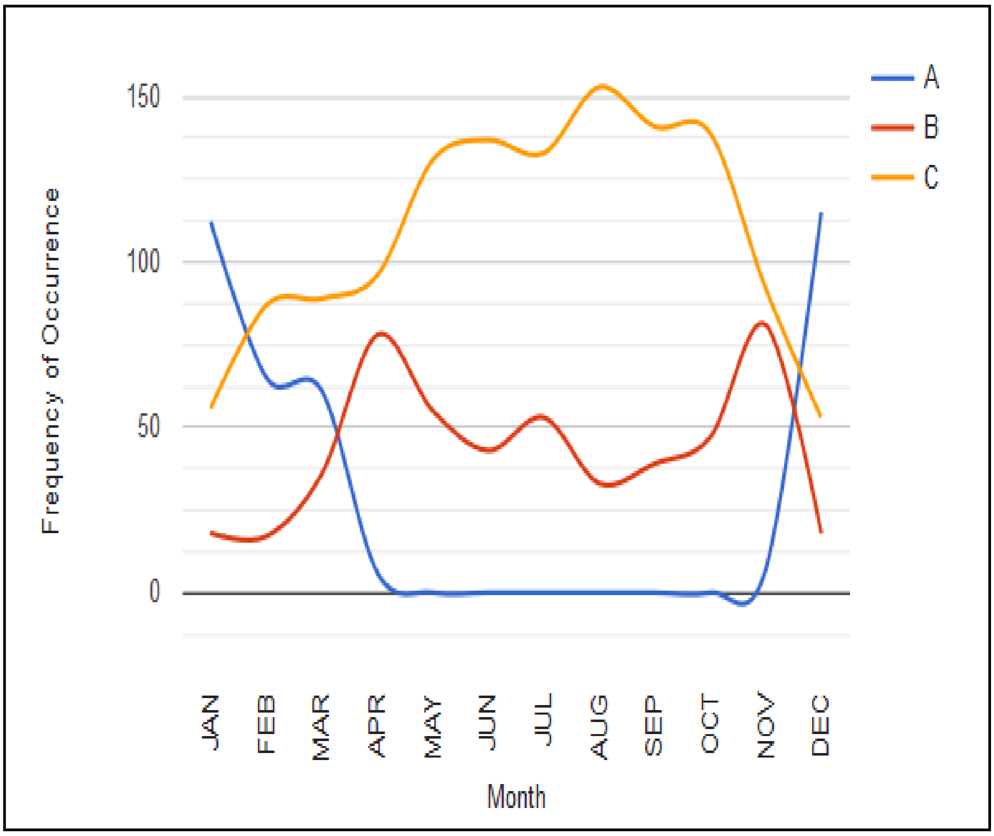

Figure 8. Atmospheric Stability Pattern in Port Harcourt at 1200H

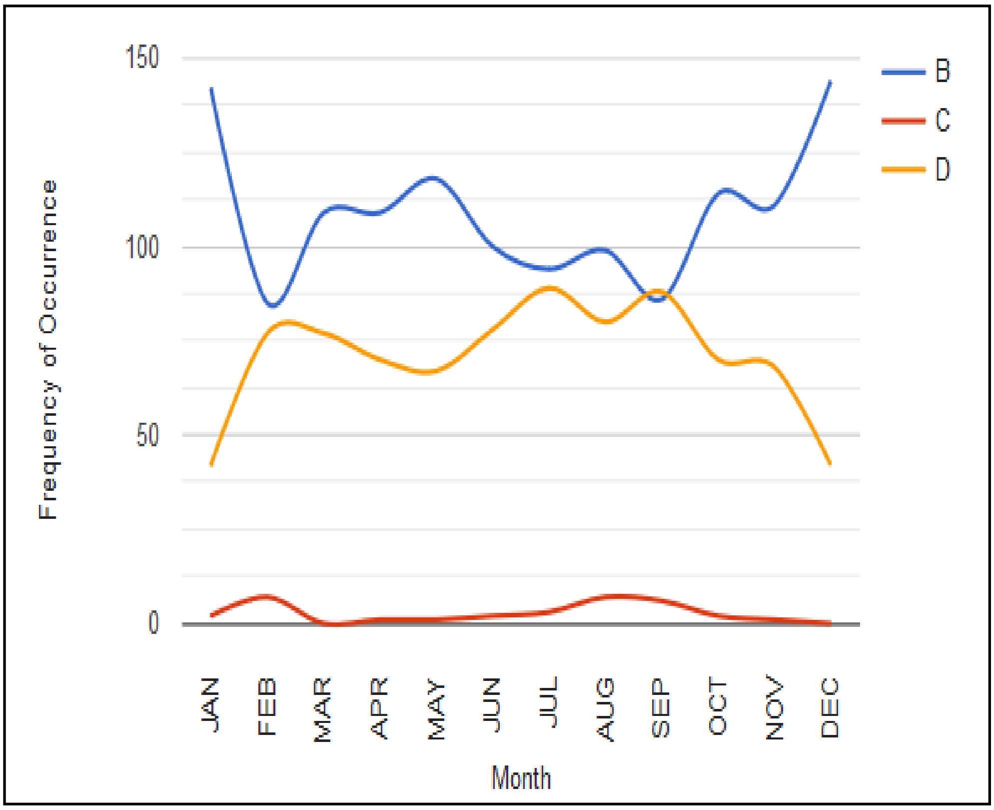

Figure 9. Atmospheric Stability Pattern in Port Harcourt at 1800H

At 1800H, around sunset in the study area, stability class B dominates over the entire months with high peaks in January and December and low peaks in February and September. Stability class D assumes a moderate trend with low peaks in January and December (Figure 9). The occurrence of stability class D indicates the beginning of transition periods where increased wind speeds moderates the effects of heat fluxes from the earth surface. During this hour, terrestrial radiation from the earth surface exceeds shortwave radiation.

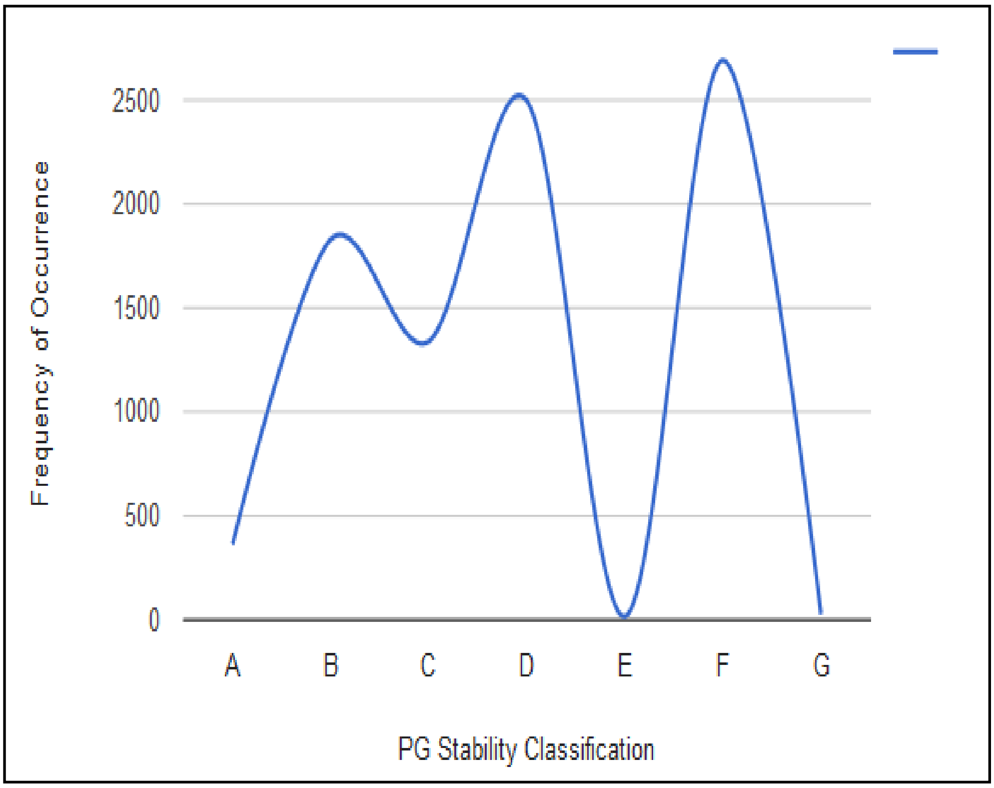

Figure 10. Cumulative Stability Pattern in Port Harcourt

With respect to emission dispersion, periods of very stable atmospheric conditions where strong inversion layer exist will keep pollutants concentrations perpetually at ground level. This is achievable when emission sources are below inversion layers. Stable atmospheric conditions entail significantly less atmospheric mixing, hence heavy accumulation of ground level pollutants concentrations. Under this condition, adverse effects of ground level pollutants concentrations at sensitive receptors will be determined by the magnitude of emitted pollutants. As a result of radiative cooling of the earth surface at nights and early morning hours, the boundary layer height (ABL) during stable conditions could range between 20-500m [3] and this depends on the degree of stable atmospheric situations i.e. classes E, F or G. During the afternoon periods, the height of boundary layer could attain several kilometres and this depends on the magnitude of solar radiation. Therefore, the ABL height increases and reduces in reaction to diurnal heating and cooling phases.

Port Harcourt metropolis is close to oil and gas processing industries such as the Eleme Petrochemical Company known as Indorama and Port Harcourt Refinery Company. This industries releases gas flares which impacts on close distant receptors due to associated pollutants emissions such as carbon monoxide, particulate matter, nitrogen oxide etc. A survey was conducted [22] on emission propagation from gas flaring in Nigeria with source height of 30m. Study revealed that under unstable conditions at wind speeds range 1-3m/s, ground level emission concentrations will impact receptors distance 0-8km. The lower the wind speed, the farther the ground level concentrations on receptors downwind of source. The rougher the unstable condition, the closer the impact distance on downwind receptors. It was also noted that during stable periods at the same wind speeds range, ground level emission concentrations at receptors downwind of source will be farther than 8km and beyond [22]. United States EPA categorizes lower emission sources from 0 to 10m and higher emission sources from 10 to above 100m.

The annual cumulative pattern as shown on Figure 10 reveals that the average stability pattern for the study area are ranked in the following order: F>D>B>C>A>G>E.

4. Conclusion

Atmospheric stability situations at any local environment play a key role in what is being transferred in the atmosphere from one point to another. From the assessed stability conditions of the study area, it can be observed that unstable and stable conditions are distributed during the day and night times respectively. The influence of heat fluxes resulting from solar insolation and terrestrial radiations impacted on the stability pattern of the study area. Findings noted that at late night and early morning period very stable (class F) and neutral (class D) conditions occurs. While class D peak of rainy season, class F dominates during the periods of peak dry season as well as early rainy season. During the afternoon period, the study area is slightly stable (class C) and dominants from February to November. Stability class B is more prevalent at sunset throughout the months while stability class A only prevails at noon time from December to January. The implication of this atmospheric stability pattern in the study area with respect to emission dispersion indicates that dispersion will be moderate during the day and severe at night. The severity of the night time dispersion will depend on the height of inversion level in relation to emission source height as well as the magnitude of emission released from sources.

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