*Journal of Geography, Environment and Earth Science International*

*15(2): 1-10, 2018; Article no.JGEESI.41167*
*ISSN: 2454-7352*

# Atmospheric Stability across the Lower Troposphere in Enugu City, Nigeria

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***Authors' contributions***

*This work was carried out in collaboration between both authors. Author DOE designed the study and performed the numerical analysis. Author MON wrote the protocol, wrote the first draft of the manuscript and reviewed the analyses of the study. Both authors read and approved the final manuscript.*

***Article Information***

DOI: 10.9734/JGEESI/2018/41167
Editor(s):
(1) Anthony R. Lupo, Professor, Department of Soil, Environmental, and Atmospheric Science, University of Missouri, Columbia, USA.
Reviewers:
(1) Chin-Hsiang Luo, Hungkuang University, Taiwan.
(2) Eric S. Hall, USA.
Complete Peer review History: http://www.sciencedomain.org/review-history/24572

***Original Research Article***

***Received 10th February 2018***
***Accepted 18th April 2018***
***Published 10th May 2018***

## ABSTRACT

This study surveyed the atmospheric stability pattern in the lower troposphere over Enugu from 2010-2015. The widely and acceptably used Pasquill-Gifford stability scheme was utilized in evaluating the stability categories. Six-hourly synoptic data parameters for temperature, wind speed and cloud cover acquired from the Era-Interim platform at 1000 mbar pressure level were used in the analysis. The data were obtained at 0.125 degree resolution. Results showed that very stable stability classes D (neutral), E (stable), and F (very stable) conditions occurred during the night and early hours of dawn. Also, while class D dominated during the wet season, classes E and F portrayed a reverse trend during the dry season. During the Day, stability classes A (very unstable), B (moderately unstable) and C (slightly unstable) prevailed, however, (class C) prevailed throughout the year. While stability class A was dominant from December to January, with its least influence during the peak of the wet season at noontime, stability classes B and C prevailed during the wet

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season and was lowest at the peak of the dry season. The occurrence of stability class D at 6:00 pm local time indicates the beginning of transition periods, where increased wind speeds moderates the effects of heat fluxes from the earth's surface. The surveyed atmospheric stability conditions in Enugu city indicates that emissions will be constrained at ground level during the night, where anthropogenic sources of emissions remain beneath the inversion layer. Nevertheless, where the sources are beyond the inversion layer, dispersion will take place upward away from ground level. Therefore, it is compelling that governments, agencies, and industries control emissions from industries within the city especially at night time to avoid ground level pollutant concentrations that will affect boundary layer dwellers. Also, potential emitters should be restrained from being sited at locations where pollutants could be concentrated with sensitive receptors.

*Keywords: Atmospheric stability; lower troposphere; Enugu, emission; era-interim; receptors.*

## 1. INTRODUCTION

The tendency of the lower atmosphere to prevent or enhance altitudinal motion is known as its stable condition. It is closely linked to how temperature changes vertically in part of the troposphere contained in the planetary boundary layer. Different studies have revealed the level and degree of stability conditions across geographical regions [1-5]. Atmospheric stability has an important effect on the boundary layer by enhancing local air mass circulation between the surface and the lower troposphere. The level and magnitude of stability conditions are by radiation heating of the ground surface, and the longwave radiation is emanating from the surface. This modifies the surface and sensible heat fluxes on the earth. The recurrent interaction of air masses within the boundary layer highlights the atmosphere as a dynamic system. Three significant stability categories conditions exist; these are unstable, neutral and stable conditions. The prevalence of either condition depends on the energy state of the surface-atmosphere interface at any point in time. The stability of the atmosphere is a direct measure of its dispersive ability. Atmospheric stability plays a vital part in the turbulence existing in the troposphere and consequently affects atmospheric diffusion processes [6]. Atmospheric stability controls the amount of turbulence within the boundary layer, which influences the manner air pollutants dispersed within the lower troposphere [7]. Emission dispersions in the troposphere are manipulated by altitudinal forcing created by the existence of stability conditions. Thus, an assessment of atmospheric stability for any location is paramount for estimating the times of high and low ground level emission concentrations across ground level receptors. When the lower atmosphere is unstable, emission dispersion is enhanced and does not severely impact ground level receptors. When neutral conditions exist, emissions will continue unmixed as the atmosphere does not prevent or improve diffusion. The atmosphere will be likely to limit emissions mixing during stable conditions by holding emissions at the ground level due to temperature inversion. An undulating landscape like Enugu city, where varied microclimatic conditions will be prevalent across the spatial expanse due to pressure differences, will make the alterations of stability conditions more frequent diurnally, and increase uneven spatial precipitation. The undulating terrain over a large area can significantly impact the weather and climate pattern of the local environment. This type of landscape can considerably create temperature gradients, thereby enhancing the local atmospheric circulation direction near earth's surface, thus affecting the urban wind environment [8]. This forms the local terrain wind that could aid mechanical turbulence at the earth's surface.

The purpose of this study is to evaluate the stability conditions of the lower troposphere in Enugu city using the Pasquill-Gifford stability technique.

## 2. MATERIALS AND METHODS

### 2.1 Description of Study Location

Enugu city is situated within latitudes 6º24ʹ– 6º30'N, and longitudes 7º27ʹ – 7º32ʹE (Fig. 1) on an approximate altitude range of 150-250m above sea level [9,10]. The area is located within the humid tropical rainforest zone and has two distinct seasons: wet period (April-October) that is accompanied by moist warm air from the Ocean, and; dry period (November-March), associated with Harmattan north-easterly trade wind [11]. The month of March is the transition period to the wet season. The Inter-Tropical Convergence Zone (ITCZ) influences the distinct seasons by its south-north oscillation with the overhead sun. The oscillation of the ITCZ is accompanied by opposing bands of warm, humid air masses and the hot and dry continental air masses. With the area's location being close to the dominant of south-west moist air, the area receives ample average annual precipitation amounts above 2000 mm [10], with double maximal rainfall peaks in July and September. The average precipitation days ranged from 1 in January to 14, 16, 15 and 18 from June to September respectively [12]. Average daily temperature is about 26ºC from July to September and 29ºC from February to March. The average monthly hours of available sunshine is above 200 in November and December, and below 200 from January to October. The average relative humidity for the area varies from 47% - 89% throughout the year, with high and low peaks during the wet and dry seasons respectively. Average monthly cloud cover in the area ranged between 4-7 oktas, with higher and lower values during wet and dry season respectively. Average daily wind speed ranges from 0-5m/s, with periods of lower and higher trends observed during the night and transition periods respectively. Figs 2-5 show the average wind direction for the study area from December-February (DJF) and July-August (JJA) from midnight to noon local time. The Enugu city, which lies on the south-eastern foot of Udi hills, is flanked by hills and valleys in an undulating manner [13]. This difference in altitude within the city creates a variation of atmospheric elements [14].

### 2.2 Data

The data utilized for this study were acquired from the universally acceptable reanalysis Interim data set (Era-Interim) platform. Temperature, wind speed and cloud cover at 1000 mbar pressure level were retrieved from 2011-2015 at synoptic hours: midnight local time, 6:00am local time, noon local time and 6:00pm local time at 0.125º grid resolution. The Era-Interim data are the modern reanalysis data accessible from 1979 [15]. They are extremely viable in characterizing the atmospheric dynamics over West Africa. The data set is dependable at any point in time, and also at any spatial level [16]. Mean short wave radiation for 22 years was acquired for the study area from NASA's atmospheric science data centre.

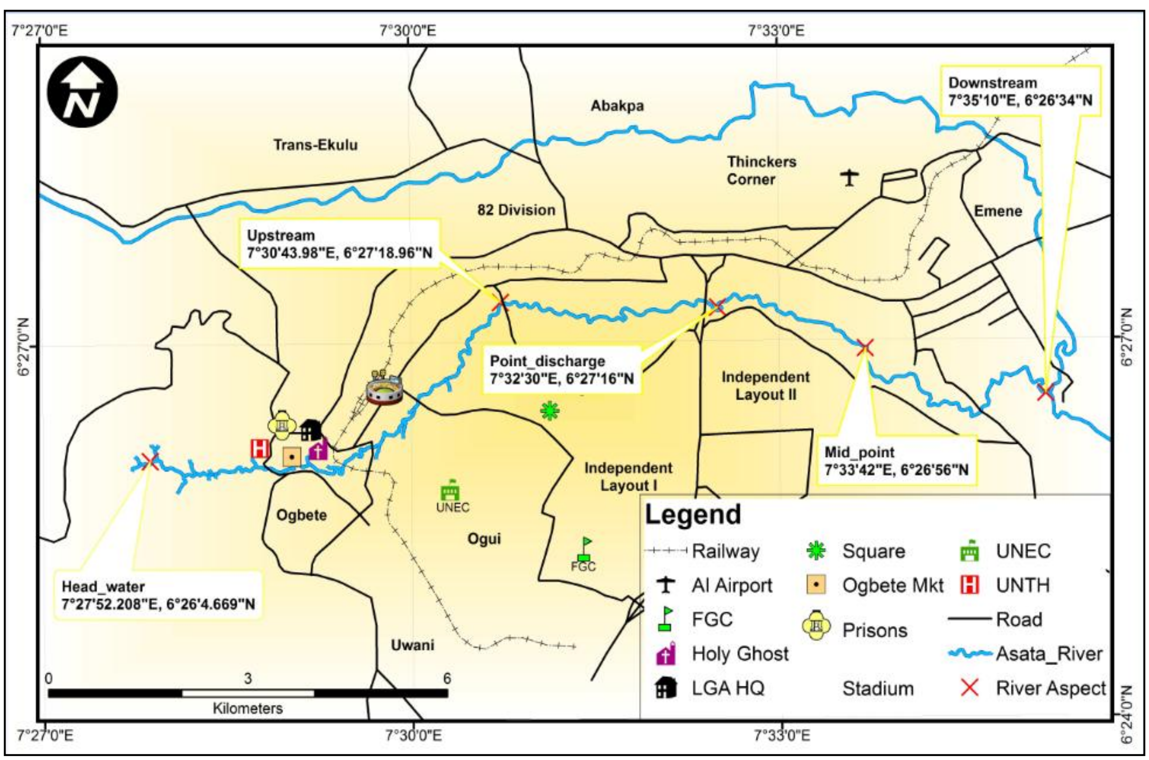


**Fig. 1. Map of study area**

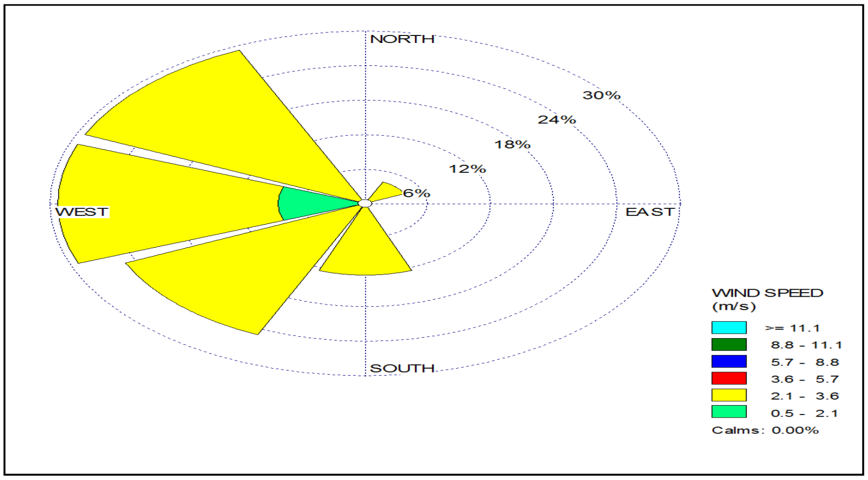


**Fig. 2. Wind direction pattern for Enugu city at midnight (local time), DJF**

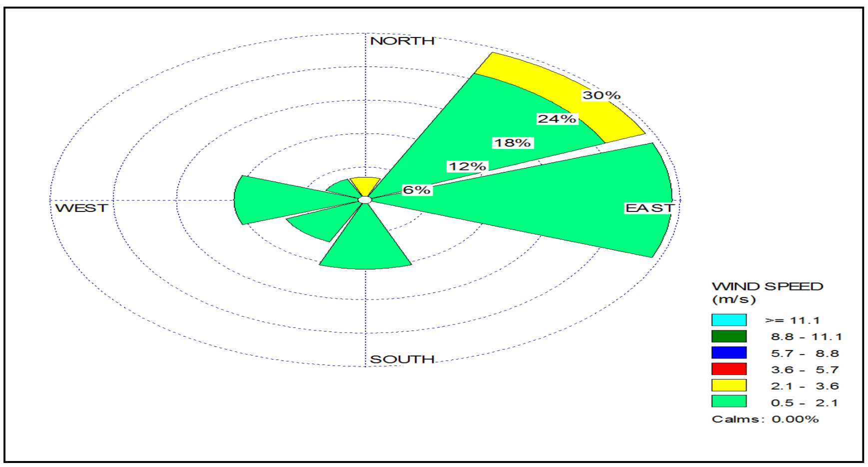


**Fig. 3. Wind direction pattern for Enugu city at noon (local time), DJF**

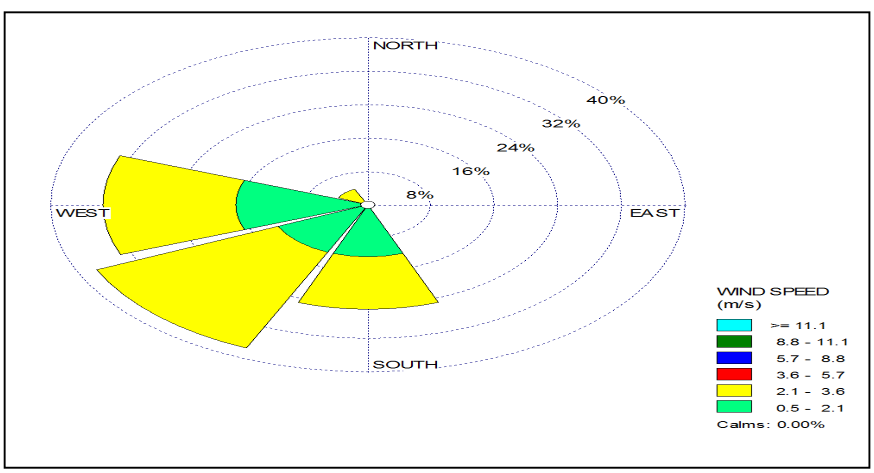


**Fig. 4. Wind direction pattern for Enugu city at midnight (local time), JJA**

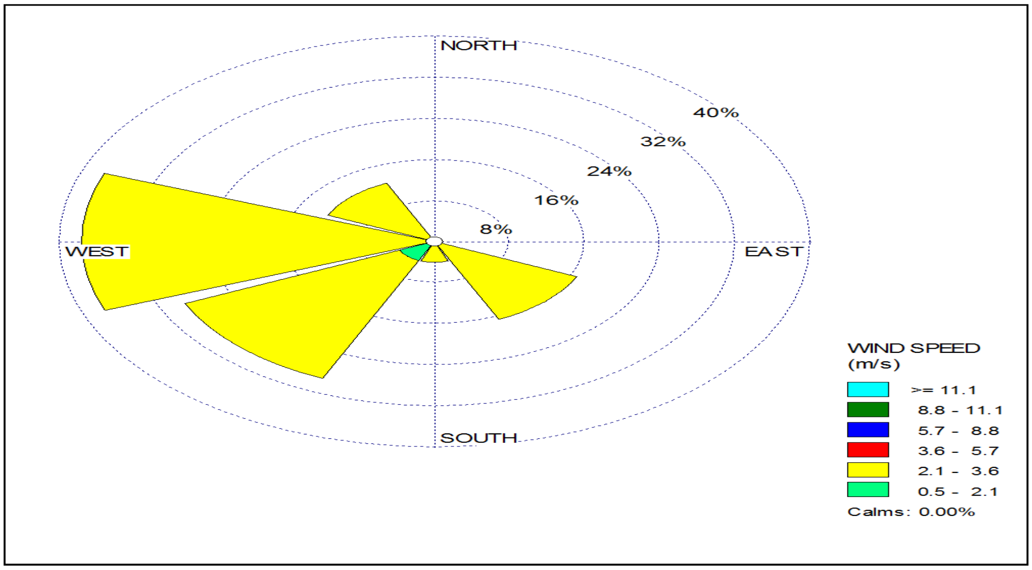


**Fig. 5. Wind direction pattern for Enugu city at noon (local time), JJA**

## 2.3 Method of Data Collection

Pasquill-Gifford (PG) [17] categorized the atmospheric stability scheme into six classes, i.e., very unstable (A) to very stable (F). The category G which indicates extremely stable conditions was later introduced, and typically occurs at about 1.4% of the time [18]. Daytime stability classes were evaluated by relating surface wind speed at 10 m altitude to solar radiation, while night-time stability classes were evaluated by relating surface wind speed to cloud cover. Daytime solar insolation was defined as strong, medium, and slight, when greater than 600 W/m$^2$, 300-600W/m$^2$, and less than 300 W/m$^2$ respectively [19]. The technique in Tables 1 and 2 designates a method of determining the stability classes in the absence of radiosonde data. The evaluation of atmospheric stability situations was achieved with the aid of an excel spreadsheet.

**Table 1. Pasquill-Gifford (PG) Day time classification (Classes)**

| Wind speed (at 10 m) (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 (Classes)**

| 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: [1].*

## 3. RESULTS AND DISCUSSION

Average monthly distribution displayed in Table 3 shows that stability class A (very unstable condition) was noticeable between November and February, with the highest rate in November, i.e., 20.8%. The frequency diminished between March and October, the period of the wet season, and increased cloud cover in the study location. Stability classes B and C (moderately and slightly unstable conditions) were somewhat uniformly distributed throughout the year. The high frequency occurrence of stability classes B and C was 26.7% and 23.4% in September and August respectively. The lowest rate for both occurred in November, i.e., 14.7% and 9.2% for classes B and C respectively. However, the dominance of class A in November occurred during the dry season, when more solar insolation reaches the surface, with less cloud cover. For the neutral and stable stability categories (D, E, and F), class D displayed a stronger pattern from February to November, while stability classes E and F followed suit during the same period. Stability class D was lowest in December, with 9.7% occurrence, and highest in August, with 36.3% occurrence. Stability class E was higher in March and lower in September, i.e., 20.2% and 9.7% respectively, while that of class F was highest and lowest in December and March, i.e., 29.7% and 5.1% respectively (Table 3).

**Table 3. Average monthly distribution of stability classes from 2010-2015**

| Month | Frequency of stability class occurrence (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | A | B | C | D | E | F | G |
| JAN | 12.9 | 21.1 | 13.4 | 12.4 | 17.1 | 23.0 | 0.1 |
| FEB | 10.8 | 15.5 | 16.0 | 34.2 | 14.5 | 9.0 | 0.0 |
| MAR | 9.3 | 17.9 | 16.9 | 30.6 | 20.2 | 5.1 | 0.0 |
| APR | 5.0 | 23.2 | 15.3 | 31.7 | 17.2 | 7.6 | 0.0 |
| MAY | 5.2 | 23.1 | 15.5 | 28.0 | 17.3 | 10.9 | 0.0 |
| JUN | 1.4 | 22.8 | 22.2 | 26.9 | 16.4 | 10.3 | 0.0 |
| JUL | 0.9 | 23.0 | 21.1 | 33.5 | 13.3 | 8.2 | 0.0 |
| AUG | 0.4 | 18.8 | 23.4 | 36.3 | 13.6 | 7.5 | 0.0 |
| SEP | 1.1 | 26.7 | 17.1 | 34.0 | 9.7 | 11.4 | 0.0 |
| OCT | 8.2 | 26.2 | 10.8 | 21.5 | 14.8 | 18.5 | 0.0 |
| NOV | 20.8 | 14.7 | 9.2 | 21.4 | 16.8 | 17.1 | 0.0 |
| DEC | 11.4 | 23.0 | 12.4 | 9.7 | 13.6 | 29.7 | 0.3 |

*Source: Authors' Fieldwork, 2016*

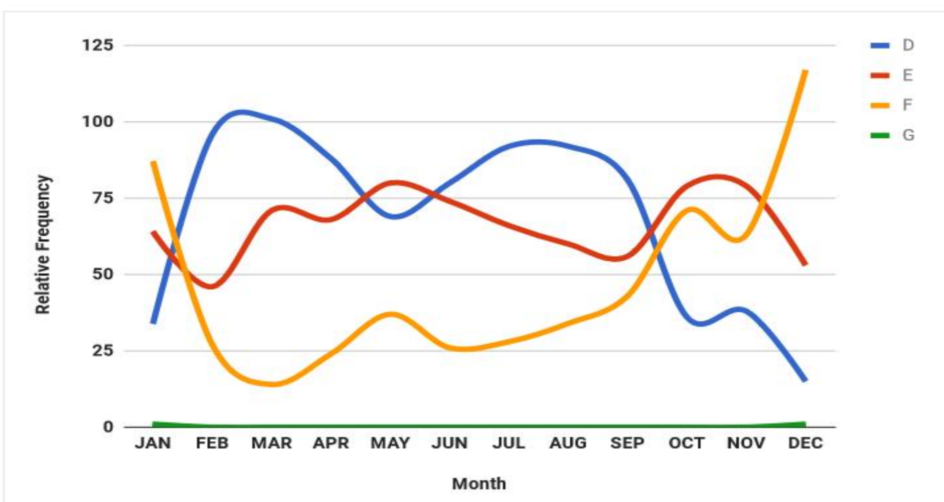


**Fig. 6. Atmospheric stability pattern in Enugu city at midnight (local time)**

The Figs 6-9 shows the average stability trend for the study location at the specified synoptic hours. For the midnight local time and 6:00 am local time, Stability class F was dominant from December to January, and lowest in March and during the wet season (Fig. 6). Stability class D dominates all through the wet season, and was lowest during the peak dry season, i.e., December and January. This shows that stability class D is closely associated with the period of rainfall at the study area. The reverse trends observed during the peak rainy period between stability classes D and F, compared to the study result in Port Harcourt [20]. The stability class E shows a fluctuating pattern between classes D and F, indicating a switch from neutral to stable atmospheric conditions.

Atmospheric stability pattern for the area at noon local time (Fig. 8) shows that stability class C dominates from February to November. Stability class B assumes a moderate trend, with lower peaks in January and December than class A (Fig. 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 those 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, preparing to move the ITCZ towards the northern region.

At 6:00pm local time, around sunset in the study area, while stability class B peaks in the month of October and is lowest in February, class C peaks in March and is lowest between October – November. Stability class D portrayed a moderate drift, with low peaks in January and December (Fig. 9). This trend for class D is similar to the condition in Port Harcourt [20]. The occurrence of stability class D indicates the beginning of transition periods, where increased wind speeds moderate the effects of the heat fluxes from the earth's surface [20].

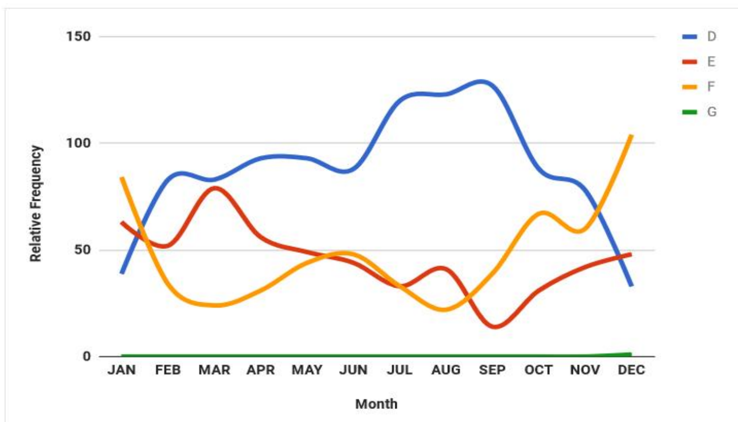


**Fig. 7. Atmospheric stability pattern in Enugu city at 6:00pm (local time)**

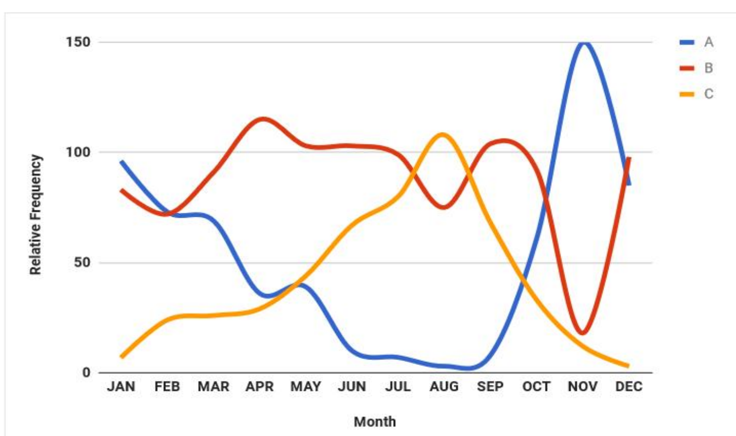


**Fig. 8. Atmospheric stability pattern in Enugu city at noon (local time)**

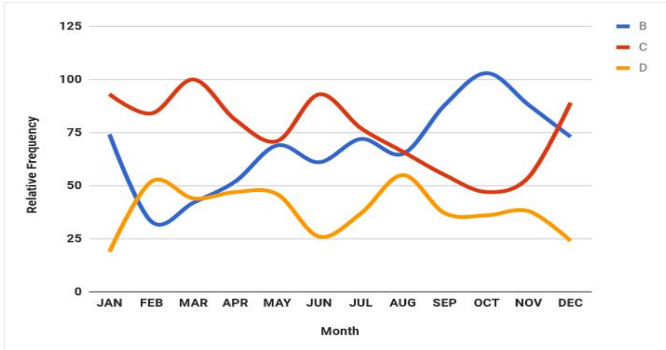


**Fig. 9. Atmospheric stability pattern in Enugu city at 6:00pm (local time)**

Associating atmospheric stability with pollutant dispersion, times of stable and very stable atmospheric conditions (classes E & F), where an inversion layer exists, will keep impurities and their associated concentrations continually at ground level. This occurs when both anthropogenic and natural sources are located beneath the inversion layers. Stable atmospheric conditions mean less atmospheric mixing, and this leads to the build-up of ground-level emission concentrations at sensitive receptors. The higher the emissions rate from the source, the more impactful the effect is on sensitive ground level receptors. However, the vertical mixing height of emission concentration levels on the surface depends on the height of the boundary layer at any point in time. Boundary layer heights are lower at night (below 500 m) and higher during the day (above 500 m – 2 km), depending on intensity of the surface and sensible heat fluxes [21].

Pollutant emissions in Enugu city are from the combustion of petroleum products and to an insignificant extent, solid waste disposal by open burning. As the population increases with the quest for jobs, ground level pollutant concentrations will continue to increase. The degree of air pollution depends on the interaction between the emitting source, atmospheric transport, and dispersion, as well as the sensitive receptor [22]. Atmospheric stability influences the atmospheric transport component of this interaction. Due to the high wind speeds in Enugu between December to March [22], emission concentrations are rapidly transported to receptors. With the dominance of stability class F both at night and the early hours of the day, ground level emissions will be high at night. With the dominance of unstable classes A, B and C during the day, and transition periods under moderate wind speed, this will ensure the vigorous mixing of ground level pollutant concentrations. The slower the wind speed, the more the emission concentrations will impact ground level receptors downwind of a source. The more unstable the atmospheric conditions at higher wind speeds, the more dispersed the air pollutants will be on downwind receptors. United States EPA categorizes lower emission sources from 0 to10 m and higher emission sources from 10 to above 100 m.

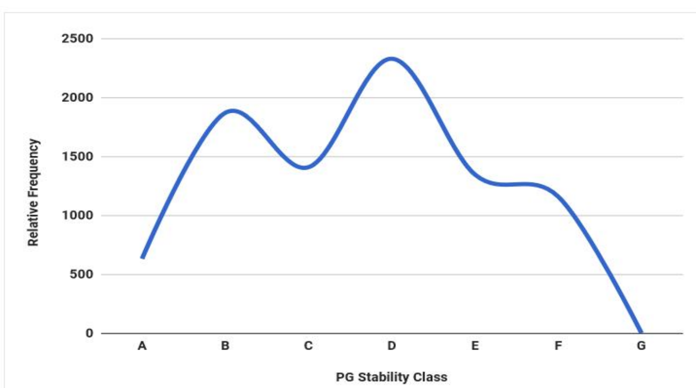


**Fig.10. Cumulative stability pattern in Enugu city**

The annual cumulative pattern as shown in Fig. 10 shows that the average stability shape for the study location is placed in the following order: D>B>C>E>F>A>G.

## 4. CONCLUSION

Atmospheric stability conditions at any locality influence what is being transported in the atmosphere from one point to another. From the evaluated stability categories of the study area, based on specified periods, unstable atmospheric conditions are distributed during the day, while neutral conditions exist during the night time and early hours of the day. The effect of surface and sensible heat fluxes, as well as the undulating environment, influences the stability pattern of the study location. Findings noted that at late night and early morning periods, very stable (class F) conditions dominate between December and January. While class D dominates during the rainy season, class F remains low. Stability classes B and C dominate during the day in the wet season, while class A remains low. However, during the dry period, class A is dominant from December to February. Results suggest that atmospheric stability patterns in the area, concerning emission dispersion, indicates that pollutants will be dispersed moderately during the day, but will be stagnated at night. The impact of the night time dispersion depends on the inversion height, as well as the height of the emission sources.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES


1. Muir DM. Air pollution control technology. Department of Chemical and Process Engineering, University of Strathclyde Publications, United Kingdom; 2004.
2. Essa K, Mubarak S, Elsaid F. Effects of plume rise and wind speed on extreme values of air pollutants concentration. Meteorology and Atmospheric Physics. 2006;93(3):247-253.
3. Alharbi ND. Mathematical modelling of atmospheric dispersion of radioactive cloud passing over Jedday. JKAU: Sci., 2011;23(1):23-37.
4. Das S. Modeling atmospheric dispersion of pollutants; 2013. Available:http://www.eoearth.org/view/article s/154653 (Retrieved on June 12, 2017)
5. Magidi S. Determining the atmospheric stability classes for Mazoe in Northern Zimbabwe. International Journal of Engineering Research and Applications. 2013;3(2):178-181.
6. Ayoade JO. Introduction to Building and Urban Climatology. Ibadan: Agbo Areo Publishers; 2012.
7. Ayoade JO. Introduction to Climatology for the Tropics (2nd Edition). Ibadan: Spectrum Books; 2004.
8. Chen XPS. An analysis of climate impact on landscape design. Atmospheric and Climate Sciences. 2016;6:475-481.
9. Chinago AB. Length of rainfall season and its implication over Enugu, South-East Nigeria. Global Journal of Human-Social Science. 2015;15(4):46-55.
10. Okpani PE, Nnabuchi MN. Developing a model for predicting the global solar for enugu using maximum temperature data. Nigerian Journal of Physics. 2008;20(1): 112-117.
11. Enete IC, Okwu VU. Mapping Enugu city's urban heat island. International Journal of Environmental Protection and Policy. 2013; 1(4):50-58.
12. Ogbuna CF. Analysis of housing demand in Enugu metropolis, Enugu state, Nigeria. A Published Master's Dissertation in Urban and Regional Planning, University of Nigeria; 2015.
13. Emenike AI, Iloeje AF. Enugu shopping mall (Shoprite), the new urban design initiative in Enugu metropolis. IJSAR Journal of Physical and Environmental Sciences. 2014;1(2):10-15.
14. UK Essays. Analysis of rainfall pattern in Enugu state, Nigeria. Venture House, Cross Street, Arnold, Nottingham, Nottinghamshire, NG5 7PJ; 2016.
15. ECMWF (European Centre for Medium-Range Weather Forecast). European Centre for Medium-Range Weather Forecast Re-Analysis Interim (ERA-Interim) model data; 2009. Available:http://catalogue.ceda.ac.uk/uuid/00f58d1d7b6c8f38993e77c79e72da92 (Retrieved on May 7, 2016)
16. Bett PE, Thornton HE. The climate logical relationships between wind and solar energy supply in Britain. Renewable Energy. 2016;87:96-110.
17. Pasquill F. The estimation of the dispersion of windborne material. Meteorological Management. 1961;90(1):33-49.

18. Barratt R. Atmospheric Dispersion modelling. New York: Earth Scan Publications. 2011;70.
ISBN 1-85383-642-7
19. Essa KSM, Embaby M, Mubarak F, Kamel I. Estimation of seasonal atmospheric and mixing height by using different schemes. International Journal of Advanced Research. 2013;1(9):429-438.
20. Edokpa OD, Nwagbara MO. Atmospheric stability pattern over Port Harcourt, Nigeria. Journal of Atmospheric Pollution. 2017;5(1):9-17.
21. Arya P. Introduction to micrometeorology. 2nd Edition. San Diego: Academic Press; 1998.
22. Ezeh E, Okeke O, Nwosu D, Umeh J. Analysis, evaluation and stochastic modelling of emission levels of three greenhouse gases ($co_2$, $h_2o$ and $so_2$) through vehicular activities within Enugu Metropolis. World Environment. 2016;6(3): 79-83.



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