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The Dispersive Potential ofthe Lower Troposphere over Climate Zones in Nigeria

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Abstract

This study examined the dispersive potential pattern in the lower atmosphere across five areas in major climate belts of Nigeria; namely, Port Harcourt, Enugu, Jos, Kano and Maiduguri using the Gaussian Plume modelling technique. Prevailing atmospheric stability conditions in these areas were used to augment the model run. Hypothetical emissions for suspended particulate matter (SPM) released across these areas from three simple cycle power generating gas turbines (General Electric Frame 9) each of rating between 120-150MW was utilised. Results show that the maximum ground level concentrations for SPM range from 0.01-0.69µg/m^3, 0.01-1.29µg/m^3, 0.01-1.39µg/m^3, 0.01-1.39µg/m^3 and 0.01-1.78µg/m^{3}for Port Harcourt, Enugu, Jos, Kano and Maiduguri respectively. Findings show that very stable condition (Pasquill-Gifford stability class F) that exists in Port Harcourt and Jos during the night restricts ground level SPM concentrations than the neutral (class D) and stable (class E) stability conditions for Enugu, Kano & Maiduguri respectively for most of the seasons. The magnitude of emission concentrations impact for the prevailing stability conditions during night periods range from stability classes E>D>F. Results also revealed that during unstable conditions (Pasquill-Gifford stability classes A, B and C) at noon and transition periods, ground level concentrations is less in Port Harcourt than the rest areas. While pollutant concentrations increased beyond 100km under dominant stability class C in Port Harcourt, it was restricted to lessthan 50km under dominant stability classes A and B in Enugu, Jos, Kano and Maiduguri at noon time.During transition periods, distance of maximum impacts was restricted to 50km under stability class B in Port Harcourt but varied between 60-100km under stability classes B and C for the rest stations. This shows that increased surface mechanical turbulence during transitions periods in Enugu, Jos, Kano and Maiduguri will aid further transportation of ground level emissions. All ground level SPM concentrations were below acceptable limit, however, high emission sources must be discouraged across study areas especially during night time as prevailing stability conditions will ensure that emitted pollutants are trapped within the atmospheric boundary layer thereby impacting on the health of boundary layer dwellers.

Keywords: Atmospheric stability, Emission dispersion, Lower troposphere, Gaussian model

1.0Introduction

The lower troposphere is absolutely the most important component of the climate system since it is the processes and activities taking place there determines weather and climate (Ayoade, 2003). This zone which stretches between 0 to 4000 m (Delon *et al.* 2000) has an important role for the whole atmosphere-Earth system because it acts as an interface where the coupling between the atmosphere and the Earth's surface occurs. Knowledge of the lower troposphere layer is an important meteorological factor, due to its role in the dispersion of air. It is an important structure for the sustenanceof life and aid inthe regulation of climate forces includingthe distribution of momentum and heat fluxes around the entire atmosphere (Ao *et al.* 2012). The lower troposphere is a distinct zone, both chemically and dynamically due to its position from the very active processes near the earth surface and its proximity to the upper troposphere. It is the boundary zone between the surface layer and the upper atmosphere. Understanding the physical basis of the zone and its role in air dispersion is central to accurate evaluation of the dispersive and dynamic process of the zone. Due to consistent imbalance of vertical temperature gradient, stability of the zone changes with respect to the variability of meteorological variables thereby enhancing its dispersive potential (Nemuc *et al.* 2009, Edokpa, 2018).

Vertical motion of air in the lower troposphere regulates several atmospheric developments such as the dispersion of emissions introduced in the boundary layer (Edokpa and Ede, 2013; Weli and Kobah, 2014). The locally modified microclimates due to population expansion and other anthropogenic activities which increase air pollution are the most crucial issues about the boundary layer. The lower troposphere is now severely disadvantaged as increased emission releases from the various sources find its way there (Ukemenam, 2014). A vital parameter apart from wind speed and direction that enhances the dispersion of the released emissions is the atmospheric stability conditions of the local environment. One of the fundamental contributions of stability conditions is its influence on the diffusion of emissions. Air pollutants emissions and dispersions in the boundary layer are composite functions of dynamics which predominantly include atmospheric stability conditions which either boost or lessen the process of pollutants lateral or vertical spreading (Ayoade, 2012). The stability state of the lower atmosphere is the process in which air pollutants are moved away from sources and, for any given source strength, its actions govern the length of time, frequency and the concentrations to which any receptor is exposed (Edokpa, 2018). The currentdrift of industrialization and urban expansion in Nigeria has anenormouseffect on the environment as air pollution sources intensifies with the increase in population and cause contamination of air (Efe, 2008). Since atmospheric stability conditions enhance the local circulation of pollutants, knowing about the variation of the different stability conditions in Nigeria is essential.

With the growing increase of anthropogenic emissions in Nigeria, it is very likely that air pollutants will be felt by other areas since the advection and transport of air is unobstructed across terrestrialborders (Sonibare and Ede, 2009; Ede, Edokpa and Ayodeji, 2011). The recent black soot menace experienced within and outside the city of Port Harcourt which has left inhabitants agitating for survival is a genuine effect of the relationship between emissions introduced into the atmosphere and the critical atmospheric influence on its transport and diffusion (Ede and Edokpa, 2017). While dispersions of the black soot are critical mostly at night, during the period of day emission concentration is lesser and this depends on the atmospheric stability prevalent during the period (Edokpa and Nwagbara, 2017).

Diverse environmentscould have dissimilar or similar sources of emissions and atmospheric conditions such that the quality of air is dependent on the local atmospheric condition. Investigating what atmospheric stability conditions do to the emitted pollutants at various periods is vital to mitigating emission releases as well as the location of industries. Since, air quality in both urban and rural centres are affected by the stability of the atmosphere, an evaluation of the dispersive potential of the lower troposphere across selected locations in Nigeria using is necessary. Thisascertains the most predominant stability category in the Nigeria environment that could either enhance or suppress local air quality.

The Study Area

Nigeria which is situated approximately between Latitude 4^oN to 14^oN and Longitudes 3^oE to 15^oE is primarily within the low-lying moist tropics north of the equator and branded by a high-temperature system. About 1.4% (13,000km^2) of the land is covered by water while the remaining of the land cover ranges from thick mangrove forest and dense rain forest in the south to a near-desert formation in the north-eastern vicinity of the country. Nigeria has a land area of about 923,768km^2; with a north to the south span of around 1,450km and a west to the east extent of around 800km. Its total land boundary is 4,047km while the coastline is 853km (Adeyinka *et al.* 2005).Circulation in Nigeria is very varied, being more complex at the surface and in the lower layers, and progressively simpler at increasing latitude. It complexity in the lower layers is associated with the extra tropical origin of the fluxes which penetrates the tropical zone, and with the effects of relief.

The climate of Nigeria is influenced by two major air fronts, namely; the southern moist maritime air front (mT) from the northern Atlantic Ocean and the tropical continental air front (cT) from the Sahara desert. The mT and cT referred to as ‘trade winds’ is impacted by the seasonal shift of the inter-tropical discontinuity (ITD) and the inter-tropical convergence zone (ITCZ)creating a sledge of moisture discontinuity over the ocean and land.These seasonal shifts of moisture discontinuity between the southern and the northern fronts create two major seasons in Nigeria i.e. wet and dry seasons. When the zone of moisture discontinuity is entirely over the country between July-September at the northern end, wet season prevail over Nigeria while the reverse of the line of discontinuity at the southern end enhances the dry season. The duration of the varied seasons is being enhanced by the proximity of locations to the Ocean and the Sahara desert. While the southern areas experience wet season between March-September, the northern areas experience it between June-September. Across Nigeria, the dry season is predominantly between November-February. Ulor (2012) stated that Nigeria’s latitudinal position within the tropics and the largely low relief enhances the high-temperature all the year round.

The distinct climate sections between the southern and northern axis are: the damp equatorial climate in the south, the warm and dry tropical continental climate up north, the wet and hot tropical continental climate in the middle belt, and the mild sub-temperate climate around the highlands.Notably, however, the duration of the distinct seasons in Nigeria depends on the proximity of the locations to the ocean. Particularly, therefore, there is a higher period of precipitation in the locations near the ocean and the intensity of rainfall exceeds that in the parts further from the ocean. A representative example would be the location of Port Harcourt in the Southern end of Nigeria compared to locations far north such as Kano and Maiduguri. There are four major climatic zones in Nigeria based on the Köppen system of classification. These are the hot semi-arid climate (or Köppen's *BSh* climatic classification), the montane climate (recognized by another climatologist, Geiger), the tropical continental climate (or Köppen's *Aw* climatic classification), and the tropical wet climate (or Köppen's *Am* climatic classification). The major climatic belts in Nigeria are shown in Figure 1 with the study locations.

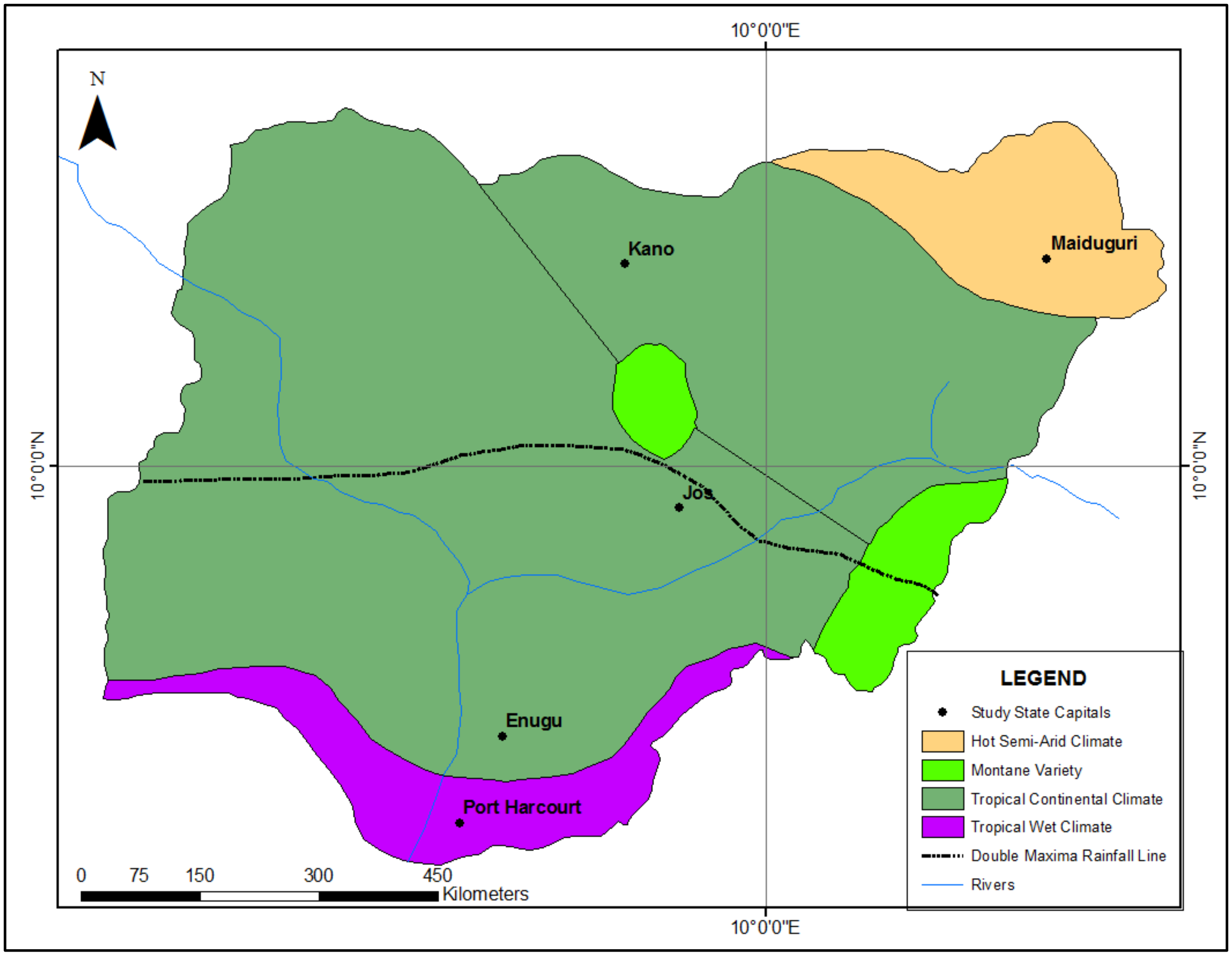


Figure 1: Climatic Belts in Nigeria Showing Study Areas.
After Ilioje(2007).

3.0 Materials and Methods

The most commonly used model for regulatory purposes is Gaussian steady-state model. It provides a steady state solution to the transport and diffusion equation (transport plus diffusion = dispersion). The simple Gaussian dispersion model is being used as a basis for the estimation of pollutant concentrations.

3.1The Model Equations

Once the plume has reached its effective stack height, dispersion of the plume sets in. Dispersion in the downwind direction is a function of the mean wind speed blowing across the plume. Dispersion in the crosswind direction and in the vertical direction will be governed by the Gaussian plume equations of lateral dispersion. Lateral dispersion depends on a value known as the atmospheric condition, which is a measure of the relatively stability of the surrounding air.

The Gaussian-plume model formula provides a better representation of reality if conditions do not change rapidly within the hour being modelled. Below is the Gaussian model for ground level receptors (Ede, 2007).

$$C = \left[\frac{Q}{\delta_y \delta_z u \pi} \right] \left[\exp\left[-\frac{1}{2}\left(\frac{\mathrm{y}}{\delta \mathrm{y}} \right)^2 \right] \right] \left[\exp\left[-\frac{1}{2}\left(\frac{H}{\delta_z} \right)^2 \right] \right] \quad \textit{(Eqn1)}$$

Where:

C = concentration of the emission, g/m^3 at any receptor location
Q = source pollutant emission rate, g/sec
U = horizontal wind speed along plume centre line, m/sec
H = the effective height of the emission above the ground in meters (m)
σ_y = horizontal standard deviation of the emission distribution, (m)
σ_z = vertical standard deviation of the emission distribution, (m)
π = is a constant given as 3.142

3.2 Plume Rise/Effective Stack Height

To determine the Gaussian point source plume rise, from Holland's formula, is given by:

$$\Delta H = \frac{\mathrm{V_s}}{\mathrm{u}} \left[1.5 + \left(2.68x10^{-2} (P) \left(\frac{T_s - T_a}{T_a} \right) d \right) \right] \quad \textit{(Eqn2)}$$

Where,

V_s = Stack gas exit velocity (m/s)
U = Wind speed (m/s)
P = Pressure (kPa)
T_s = Stack gas temperature (^oK)
T_a = Air temperature (^oK)
d = Stack diameter (m)

The effective stack height (physical stack height plus plume rise) is given by:

$$H = hs + \Delta H \qquad \textit{(Eqn 3)}$$

Where

H = Effective stack height (m)
h_s = Height of physical stack (m)
ΔH = Plume rise (m)

3.3Wind Speed Profile

The wind power law is used to adjust the observed wind speed, U_{ref}, from a reference measurement height, Z_{ref}, to the stack release height, h_s. The stack height wind speed, U_s, is used in the Gaussian plume equation.

The power law equation is of the form;

$$U_s = U_{ref} \left(\frac{h_s}{Z_{ref}}\right)^p \qquad \textit{(equation 3.7)}$$

Where P is the wind profile exponent. This P values can be estimated from the stability class categories for the Urban or Rural regimes as shown by Table 3. The urban regime was used in conjunction with that of the dispersion coefficients.

Table 3: Wind profile (P) Exponential values

Stability Class	Rural	Urban
A	0.07	0.15
B	0.07	0.15
C	0.10	0.20
D	0.15	0.25
E	0.35	0.30
F	0.55	0.30

Source: Turner(1994)

3.4 Determination of Dispersion Parameters

Dispersion parameters or coefficients are the horizontal, (δy) and vertical (δz) components used to define the rate of dispersion of contaminants in the plume in the horizontal and vertical directions (i.e. plume width and height). These coefficients are a function of atmospheric stability and distance from the source. The dispersion parameters values are fundamental to all Gaussian based air dispersion models. They can be accurately determined using the Pasquill – Gifford parameters for either the Urban or Rural Values. Tables 4 and 5 provide the equations that are used to determine the values.

Table 4: Dispersion Coefficients for the Urban Case

Stability	δ_y (meters)	δ_z (meters)
A	$0.32x(1.0 + 0.0004x)^{-0.5}$	$0.24x(1.0 + 0.001x)^{0.5}$
B	$0.32x(1.0 + 0.0004x)^{-0.5}$	$0.24x(1.0 + 0.001x)^{0.5}$
C	$0.22x(1.0 + 0.0004x)-^{0.5}$	$0.20x$

D	$0.16x(1.0 + 0.0004x)^{-0.5}$	$0.14x(1.0+ 0.003x)-^{0.5}$
E	$0.11x(1.0 + 0.0004x)-^{0.5}$	$0.08x(1.0+0.0015x)-^{0.5}$
F	$0.11x(1.0 + 0.0004x)-^{0.5}$	$0.08x(1.0+0.0015x)-^{0.5}$

Source:Turner(1994)

Table 5: Dispersion Coefficients for the Rural Case

Stability (Pasquill Type)	**δ_y (meters)**	**δ_z (meters)**
A	$0.22X(1+0.0001x)^{-0.5}$	$0.20x$
B	$0.16x(1+0.0001x)^{-0.5}$	$0.12x$
C	$0.11x(1+0.0001x)^{-0.5}$	$0.08x(1+0.0002x)^{-0.5}$
D	$0.08x(1+0.0001x)^{-0.5}$	$0.06x(1+0.00015x)^{-0.5}$
E	$0.06x(1+0.0001x)^{-0.5}$	$0.03x(1+0.0003x)^{-1}$
F	$0.04x(1+0.0001x)^{-0.5}$	$0.016x(1+0.0003x)^{-1}$

Source:Turner(1994)

The selection of either rural or urban dispersion coefficients in a specific application should follow a land use classification procedure. If the land use types including industrial, commercial and residential uses account for 50% or more of an area within 3km radius from the source, the site is classified as urban, otherwise, it is rural (EPA, 1995).

3.5 The Modelling Parameters

The modelling scenario adopted for the sampled areas was the utilisation of three simple cycle power generating gas turbines (General Electric Frame 9) each of rating between 120-150MW. The reason for adopting this scenario is the quest of both the State and Federal Government of Nigeria in boosting power supply from gas turbines across the country. A vital advantage of this mode of power supply is the low emission output most especially from GE Frame 9 turbines which is fitted with emission reduction measures (Peng *et al.* 2002). Gas turbines for electricity generation are already being utilised even in large industries across Nigeria.The Table 6 shows the modelling parameters. The Tables 7 and 8 show the wind speed and atmospheric stability categories prevalent across the study areas.

Table 6: Emission Modelling Parameters

Model Reference	**Stack Height (m)**	**Exit Temperature (^{O}C)**	**Exit Velocity (m/s)**	**Stack Diameter (m)**	**Emission Source Strength (g/s)**
					SPM
Pwr GT 1	45	200	49.75	3.34	1.6
Pwr GT 2	45	200	49.75	3.34	1.6
Pwr GT 3	45	200	49.75	3.34	1.6

Source: Edokpa (2018).

Table 7: Average Boundary Layer Wind Speed Profile(m/s) across Study Areas

Season	**Port Harcourt**	**Enugu**	**Jos**	**Kano**	**Maiduguri**
0000HR					
DJF	1.9	4.1	4.2	4.9	5.8
MAM	1.9	4.1	3.8	5.0	5.8
JJA	2.0	3.3	3.6	4.9	5.2
SON	1.7	3.3	2.8	3.9	4.1
Mean	1.9	3.7	3.6	4.7	5.2
0600HR					
DJF	1.6	3.6	3.8	4.2	5.0
MAM	1.6	3.6	3.8	4.8	5.7
JJA	1.3	3.1	3.6	5.0	6.0
SON	1.3	2.6	2.8	3.8	4.4
Mean	1.5	3.2	3.5	4.4	5.3
1200HR					
DJF	1.3	2.5	3.9	4.6	5.6
MAM	1.8	3.0	2.8	3.5	4.4
JJA	2.2	3.4	2.6	2.9	3.8
SON	1.6	2.1	3.3	3.3	3.9
Mean	1.8	2.8	3.2	3.6	4.4
1800HR					
DJF	1.4	2.7	3.8	4.2	5.1
MAM	1.3	2.8	2.8	3.4	4.2
JJA	1.5	2.5	2.5	2.4	3.1
SON	1.4	2.3	2.4	3.0	3.4
Mean	1.4	2.6	2.9	3.3	4.0

Source: Edokpa (2018)

Table 8: Prevailing Pasquill-Gifford Stability Categories at Study Areas

Time/Season	**Sampled Areas**				
	Port Harcourt	Enugu	Jos	Kano	Maiduguri
0000HR					
DJF	F	F	F	E	E
MAM	F	D	F	E	E
JJA	D	D	F	E	D
SON	F	E	F	F	E
0600HR					
DJF	F	F	F	F	E
MAM	F	D	F	E	E
JJA	D	D	D	E	D
SON	F	D	F	F	F
1200HR					
DJF	A	A	B	B	B
MAM	C	B	A	B	B
JJA	C	B	B	B	B
SON	C	A	B	B	B
1800HR					
DJF	B	C	C	C	C
MAM	B	C	C	C	C
JJA	B	B	B	B	C
SON	B	B	C	C	C

Source: Edokpa (2018)

4.5 Results and Discussion

Both momentum and buoyancy influence the plume rise from any stack. Nevertheless, most significantly, the atmospheric stability situationsboosted through mechanical or thermalgradientcontrol the extent of turbulent mixing of the plume, the effective height, and consequently the pattern of the pollutants in the atmosphere.

This study examines the pattern of air pollutants dispersion at specific receptors in the lower troposphere across the study areas. The specific pollutant considered was suspended particulate matter (SPM) which range from 0.01-0.69µg/m^3, 0.01-1.29µg/m^3, 0.01-1.39µg/m^3, 0.01-1.39µg/m^3 and 0.01-1.78µg/m^3 for Port Harcourt, Enugu, Jos, Kano and Maiduguri respectively. The SPM concentration result was used as an example in the analysis of pollutant dispersion patternin the lower troposphere under the various dominant stability conditions across the seasons in Nigeria. The choice of the receptors (0 – 100km) for the modelling application was applied to define the extent of pollutant dispersion from source under various atmospheric stability situations. Since atmospheric stability condition occurs diurnally, a 1-hour prediction of specified air pollution was modelled. It should be noted that the modelling results for the air emission scenario considered was below air quality standards (Table 9).

Table 9: Emissions Tolerance Limits and Standards for Ambient Air Quality

	Nigeria (FMEV)			
Pollutants	**Long-term Tolerance Limits 24-hours (mg/m^3)**	**Short-term Tolerance Limits 30 min (mg/m^3)**	**National Air Quality Standard for Nigeria**	**WHO Guidelines and World Bank Standards**
Suspended particulate matter	0.015	0.5	250 μg/m^3 (24-h) 600 μg/m^3 (1-h) (0.6mg/m^3)	60-90μg/m^3 (annual mean) 150-230μg/m^3 i.e. 0.15-0.23mg/m^3 (24h)

Sources: FMEV (1991); World Bank (1995); WHO (2006)

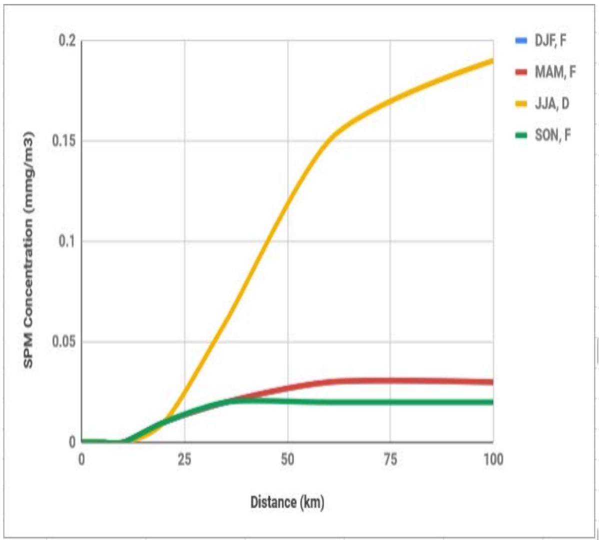
4.1 Emission Dispersion Pattern

The Figures 2-21 show ground level (GL) emission dispersion pattern in the lower troposphere across the sampled areas. In relating the rates of dispersion with respect to the stability categories, outcomes visibly show the pattern of plume behaviour in the various stability conditions. Throughout the seasons (DJF MAM, JJA and SON) at 0000H and 0600H, GL emission concentrations were minimal in Port Harcourt and Jos when compared to Jos, Kano and Maiduguri (Figures 2-6). The range of GL emission dispersion in the study areas either at increasing or decreasing distance within or outside locations of maximum impacts is essentiallyascribed to the variant PG stability Classes across the study areas and seasons. Both stability classes E and F areas had GL emission concentrations prompted at downwind distances within 3-10km while locations of maximum receptors impacts ranged from 10km to beyond 100km (Figures 2-11). However, while PG stability class E areas exhibit large expanse of pollutant concentrations, classesD and F is limited. This is due to the more lateral and vertical dispersion entrainment accommodated during class E situations. The magnitude of pollutant ambient concentrations under the stability conditions dominant for the study areas range in this order: E>D>F.With respect to GL SPM emission concentrations values, areas and seasons with PG class F had concentrations generally below 0.2µg/m3 with Port Harcourt being the least in most cases. Areas of PG class E dominance had concentrations levels above 0.75µg/m3 with Maiduguri and Kano topping the chart. The downwind distance across receptors of peak emission concentrations for classes E and F was within 5km and 50km respectively (Figures 2-11). It was noted that PG class D periods had GL emission concentrations and triggering distance in-between the extreme of PG class E and low side of PG class F, but more closer to the class F trend (Figures 2-11).

The PG stability classes E and F which are more prevalent both at 0000H and 0600H could be related to the periods of temperature inversion at the surface layer where stability conditions changes amid the height of emission source stacks. Emission stacks that are higher than inversion levels, near the ground surface, the air is either in a stable (class E or F) or neutral form. This condition on the surface impedes dispersion, except during stability classes D and E condition when mechanical turbulence enhances emission dispersion. At the layer above the inversion level, unstable condition persists and will allow turbulent mixing of the emitted pollutant with the air at the layer. During the period, the ground surface beneath the stack emission source will receive very insignificant pollutants as the emitted pollutants will be dispersed aloft. As stability of the lower atmosphere of boundary layer changes with time, receptors downwind of the emission source will be impacted. Specifically, as emissions begin above the earth surface, it takes a while for it to reach the surface due to twisting and dispersion. It was observed that emission concentrations were higher during periods of PG class E than classes F and D at the sample areas. In the first instance, this could be attributed to the type and height of inversion at the various sample areas. This is because the various areas have different climatic or physical characteristics such as variant wind speed pattern that could influence inversion forms. Since PG class F is very stable than E, inversion is therefore stronger under class F than E. Therefore, due to turbulent mixing at stack height above inversion level in areas of low inversion level, pollutants would be lower in concentration due to better dispersal rate aloft before it gets to ground level at farther distance. Stable condition entails very minimal atmospheric mixing and hence poor dispersal rate for surface level emission sources but improved dispersal rate for elevated emission sources. According to US EPA (1995), surface level emission sources are those that range from 0-10m while higher level sources are those that are above 10m. The height level for the emission source used in this study is at 45m. Emission dispersion under PG stability class D was moderate and within extremes of classes E and F. Under this atmospheric condition, the atmosphere does not hinder nor boost turbulence, until a stronger mechanism like high wind speed is able to distort it and impact GL receptors. Also, with stronger wind speeds in areas like Kano, Maiduguri, Jos and Enugu which range from 1-7m/ at emission source height, vigorous mixing of the released air pollutant could forcefully break weak inversion layer created under PG stability class E (McQuaid, 1989). Hence GL downwind receptors not too far from emission sources could be impacted with high emission concentrations before it reduces with increasing distance. From the stack height of 45m, the wind speed range in Port Harcourt is less than 3m/s.

During 1200H and 1800H periods, all the sample areas witnessed unstable atmospheric conditions but with various degrees with respect to the periods and seasons (Figures 12-21). Unlike stable atmospheric situations, unstable periods are times of turbulent atmospheric activities that could either be generated by mechanical, thermal or the mixture of both (Heinemann, 2011). Result indicates that maximum GL emission concentrations occurred at receptors distances closer to emission source than in stable and neutral atmospheric stability periods. Under the unstable categories (at noon), GL concentrations were triggered within range 0.5-10km for Enugu, Jos, Kano and Maiduguri, and, 0.5-25km for Port Harcourt(Figures 12-21). It was also noted that GL emission concentrations were higher in the northern and central sampled stations than in Port Harcourt under the order of PG stability class A, B and C (Figures

12-21). Also, under unstable conditions, ground level concentrations are closer to emission sources with magnitude distance impact ranging from C>B>A. Atmospheric stability periods are precarious times in the determination of the degree of turbulence that affects emission concentrations. The level of turbulence in the atmosphere can either intensify or reduce emission concentrations at specific downwind receptors. Under unstable atmospheric conditions, emissions from surface level sources are quickly dispersed thereby reducing GL concentrations. Emissions from elevated sources are brought to the surface and this generates higher surface level concentrations. The degree of wind speed is a contributory factor that affects the ground level concentrations either closer or farther from the source under unstable atmospheric conditions. Wind speed analysis at 45m emission source height shows that the wind speed increases from the coastal south towards the far northern axis (Table 7).



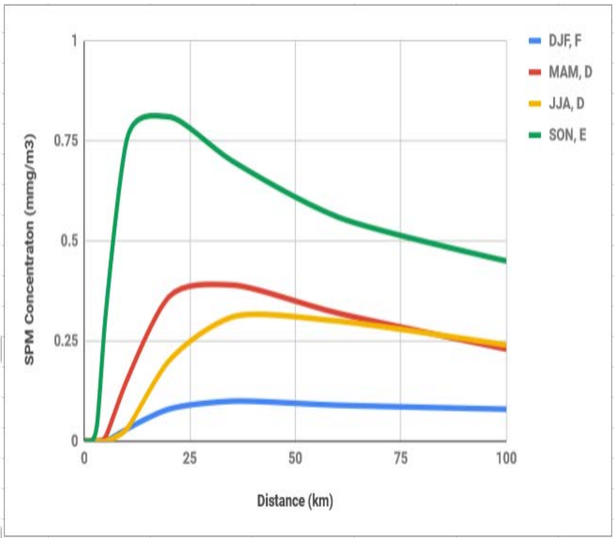
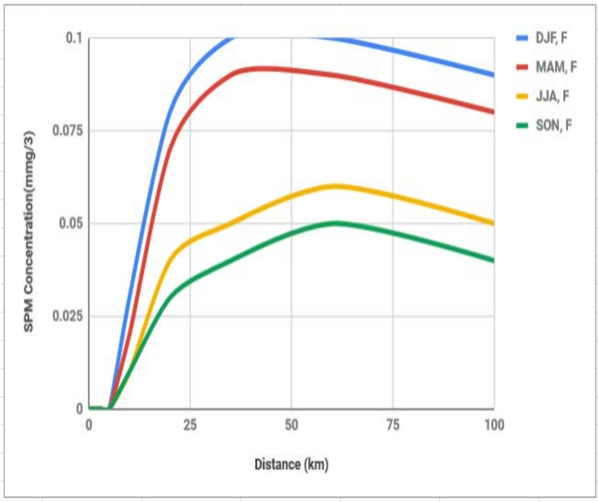


Figure 2: Dispersion Pattern for TWC at 0000Hr (PH) Figure 3: Dispersion Pattern for TCC (DMR) at 0000Hr (ENU)



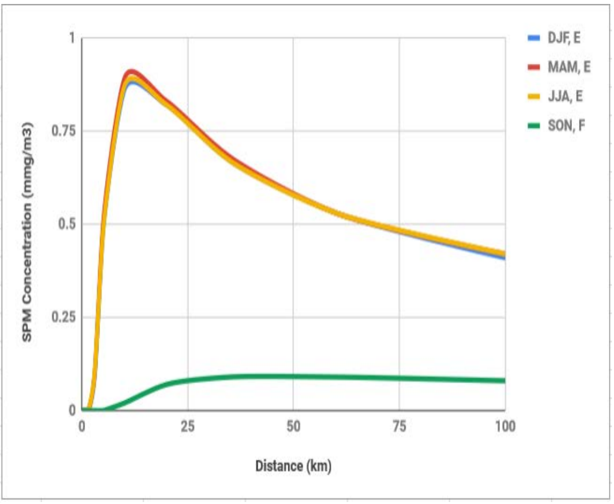


Figure 4: Dispersion Pattern for MC at 0000Hr (JOS) Figure 5: Dispersion Pattern for TCC (SMR) at 0000Hr (KN)

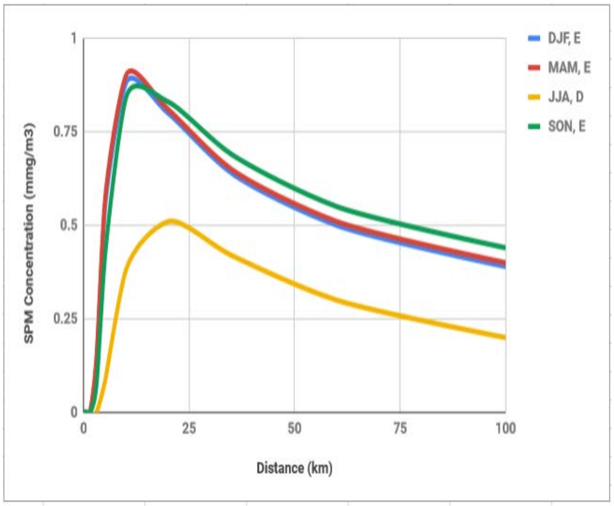


Figure 6: Dispersion Pattern for HS_AC at 0000Hr (MAID)

Key

TWC	Tropical Wet Climate
TCC (DMR)	Tropical Continental Climate (Double Maxima Rainfall Zone)
MC	Montane Climate
TCC (SMR)	Tropical Continental Climate (Single Maxima Rainfall Zone)
HS_AC	Hot Semi-Arid Climate
PH	Port Harcourt
ENU	Enugu
JOS	Jos
KN	Kano
MAID	Maiduguri

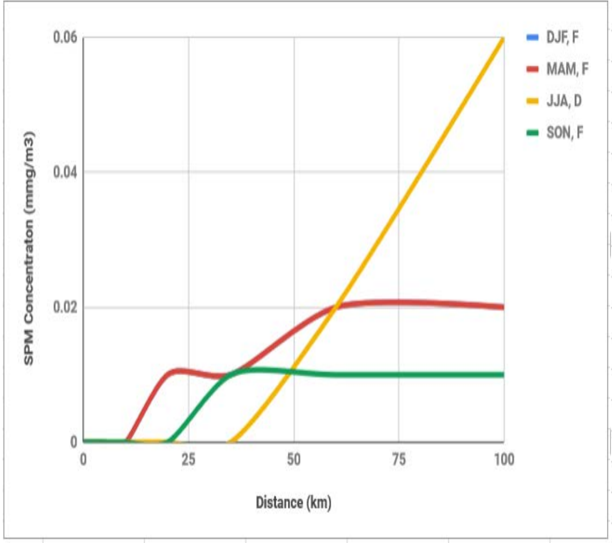


Figure 7: Dispersion Pattern for TWC at 0600Hr (PH)

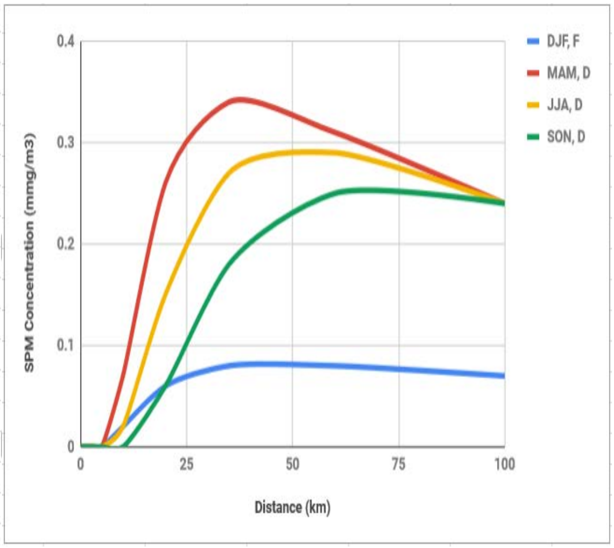


Figure 8: Dispersion Pattern for TCC (DMR) at 0600Hr (ENU)

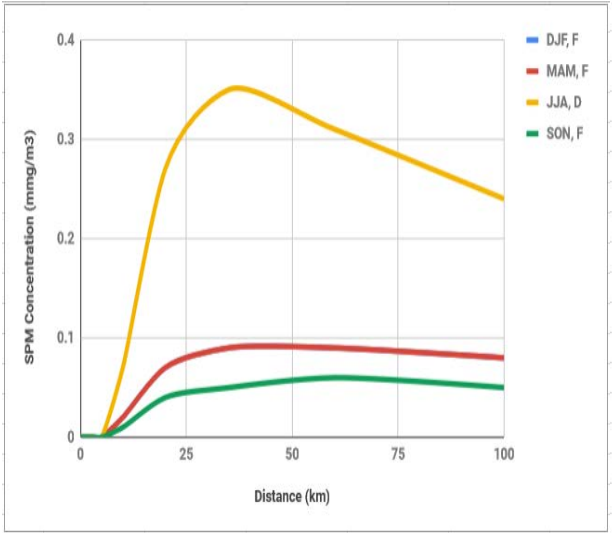


Figure 9: Dispersion Pattern for MC at 0600Hr (JOS)

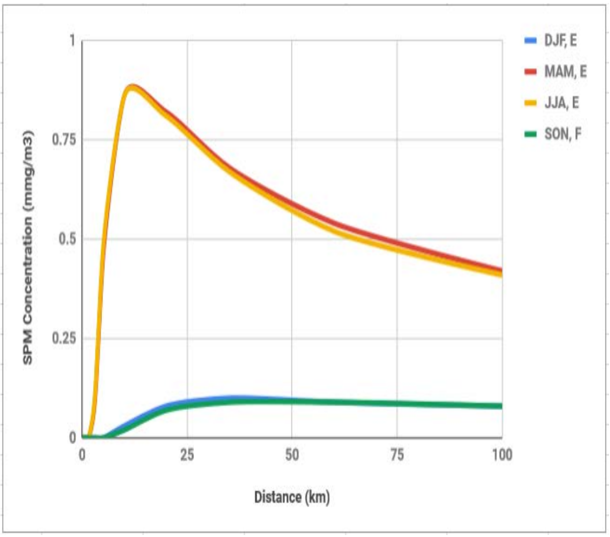


Figure 10: Dispersion Pattern for TCC (SMR) at 0600Hr (KN)

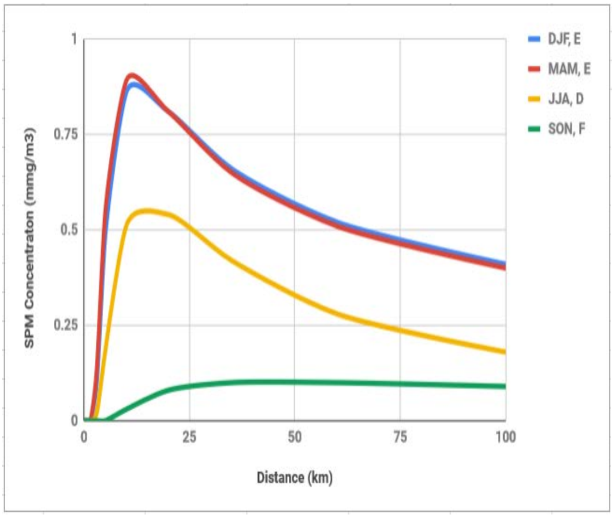


Figure 11: Dispersion Pattern for HS_AC at 0600Hr. (MAID)

Key

TWC	Tropical Wet Climate
TCC (DMR)	Tropical Continental Climate (Double Maxima Rainfall Zone)
MC	Montane Climate
TCC (SMR)	Tropical Continental Climate (Single Maxima Rainfall Zone)
HS_AC	Hot Semi-Arid Climate
PH	Port Harcourt
ENU	Enugu
JOS	Jos
KN	Kano
MAID	Maiduguri

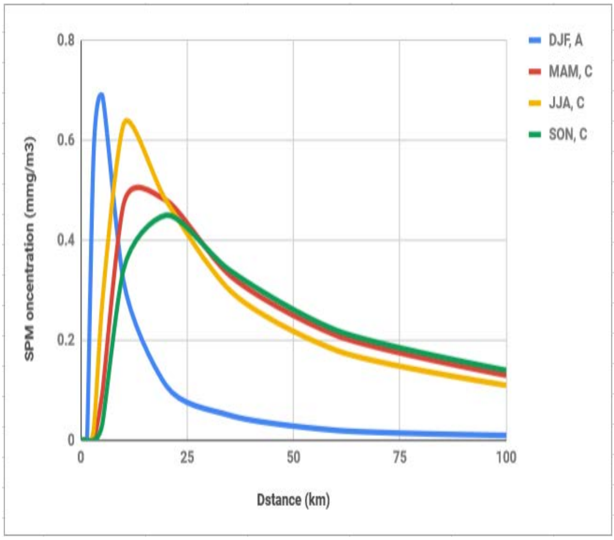


Figure 12: Dispersion Pattern for TWC at 1200Hr (PH)

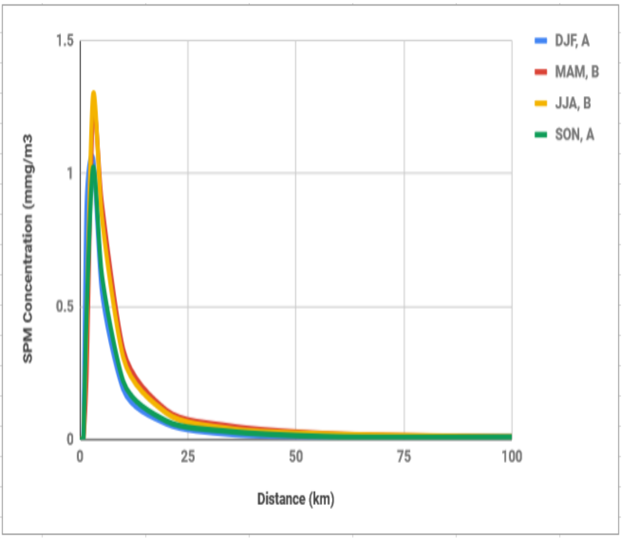


Figure 13: Dispersion Pattern for TCC (DMR) at 1200Hr (ENU)

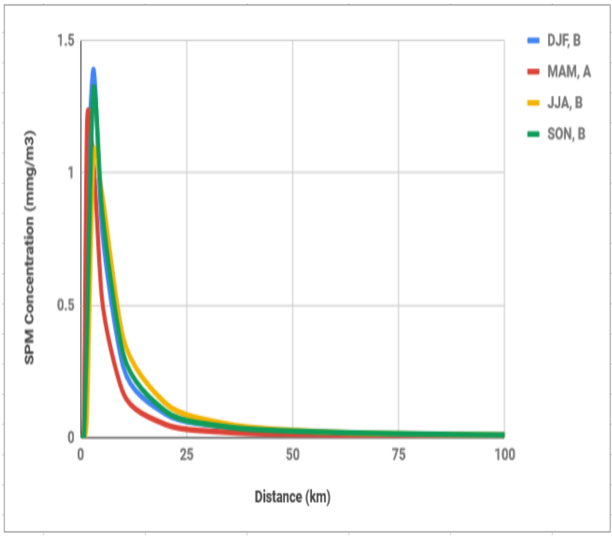


Figure 14: Dispersion Pattern for MC at 1200Hr (JOS)

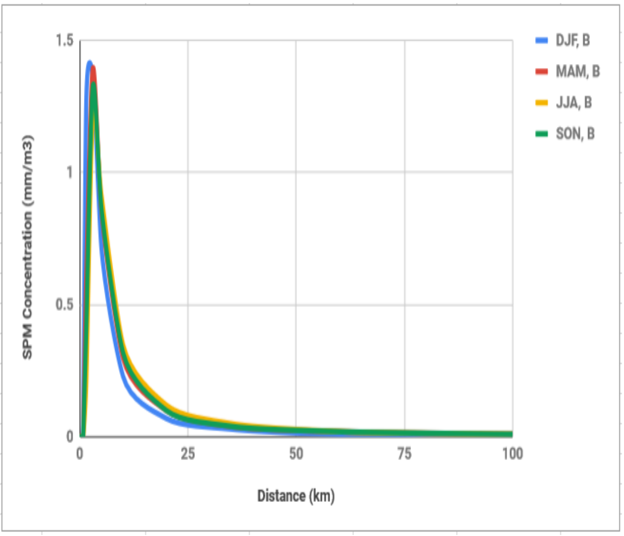


Figure 15: Dispersion Pattern for TCC (SMR) at 1200Hr (KN)

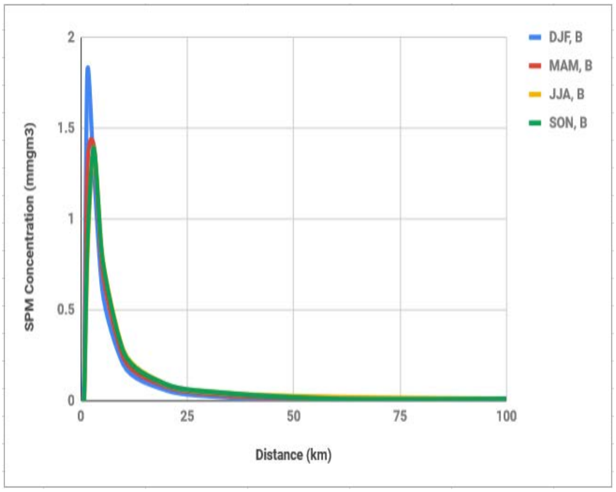


Figure 16: Dispersion Pattern for HS$_A$C at 1200Hr

Key

TWC	Tropical Wet Climate
TCC (DMR)	Tropical Continental Climate (Double Maxima Rainfall Zone)
MC	Montane Climate
TCC (SMR)	Tropical Continental Climate (Single Maxima Rainfall Zone)
HS$_A$C	Hot Semi-Arid Climate
PH	Port Harcourt
ENU	Enugu
JOS	Jos
KN	Kano
MAID	Maiduguri

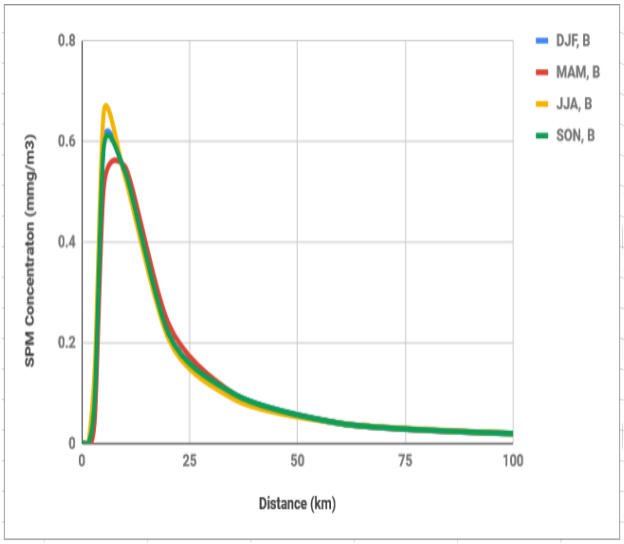


Figure 17: Dispersion Pattern for Port TWC at 1800Hr (PH)

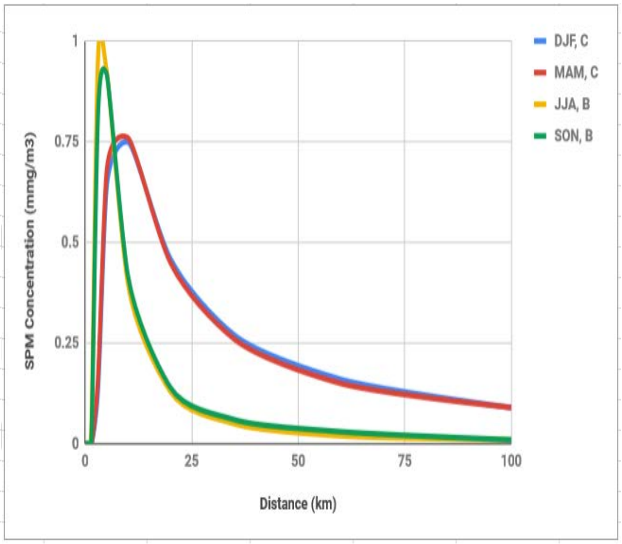


Figure 18: Dispersion Pattern for TCC (DMR) at 1800Hr (ENU)

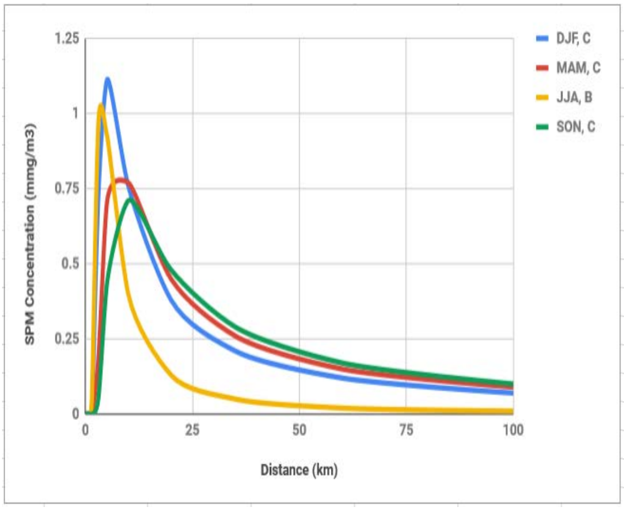


Figure 19: Dispersion Pattern for MC at 1800Hr (JOS)

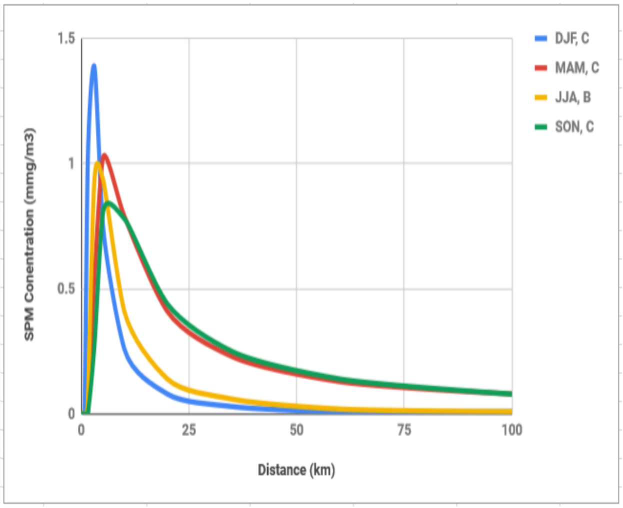
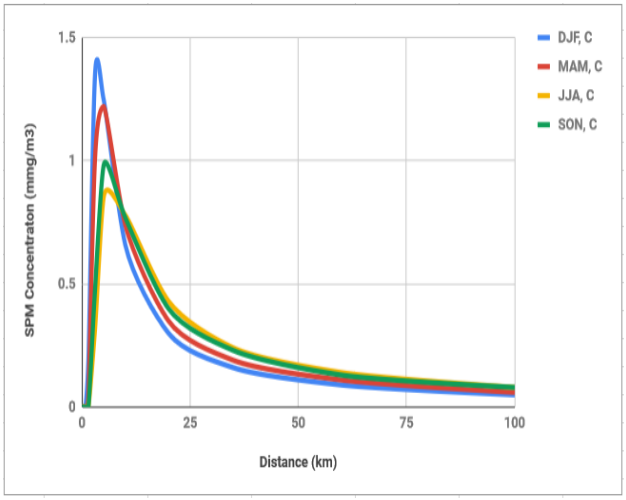


Figure 20: Dispersion Pattern for TCC (SMR) at 1800Hr (KN)



Key

TWC	Tropical Wet Climate
TCC (DMR)	Tropical Continental Climate (Double Maxima Rainfall Zone)
MC	Montane Climate
TCC (SMR)	Tropical Continental Climate (Single Maxima Rainfall Zone)
HS_AC	Hot Semi-Arid Climate
PH	Port Harcourt
ENU	Enugu
JOS	Jos
KN	Kano
MAID	Maiduguri

Figure 21: Dispersion Pattern for HS_AC at 1800Hr (MAID)

4.2 Study Implication for Emission Dispersion

With the recent black soot emissions within and outside the city of Port Harcourt causing serious discomfortand health concerns, the challenge of air quality has become paramount in the metropolis over the past two years. While it has been largely attributed that over 80% of the black soot emissions emanates from activities of illegal crude refineries being perpetrated at close proximity outside the boundaries of the Port Harcourt, the effects of the dispersion and depositionon sensitive receptors is being enhanced by atmospheric variables such as stability conditions. Various categories of lower tropospheric stability pattern as revealed from this study determine the extent of air pollutants dispersion. The concentration of the suspended particulate matters (PM_{10} and $PM_{2.5}$) in the range of between 0.1-600ug/m3 at strategic receptors which is severe mostly during night-time is known to have exceeded acceptable limits in Port Harcourt (Weli, 2014). Due to the very stable pattern of the lower atmosphere in Port Harcourt (PG class F) for most of the seasons as shown in this study, surface radiation inversion is mostly prominent. This inversion level which reduces the boundary layer height for Port Harcourt within the range 10-182m (Edokpa, 2018) ensures that the emitted soot is transported via advection at lower wind speed range within the boundary layer across sensitive receptors. During very stable conditions horizontal movement of emissions is enhanced by wind speed downwind while the vertical movement of emissions is hindered by the restricted nature of stable atmosphere due to inversion. The emissions of this black soot under the prevailing stable lower atmospheric stability conditions ensures that the Port Harcourt boundary layer is choked at night which could result in severe health implications for dwellers. However, during the periods of the day when boundary layer height extends to over 1km (Edokpa, 2018) at sunrise in Port Harcourt, vertical movement of air ensures that emissions are transported vertically thereby avoiding pollutants concentrations at close receptors from emission source. The implication for this black soot emission scenario for Enugu, Kano and Maiduguri is that concentrations will be high at close and distant receptors at night due to the prevalent stability classes D and E which allows for more spread of air pollutants that more the restricted stability class F dominant in Port Harcourt and Jos.

Conclusion

Air pollution from either natural or anthropogenic sources is being enhanced by notable atmospheric dynamic forces such as stability conditions. This study evaluates the potential of the lower troposphere within specific climate zones in Nigeria to disperse emissions introduced into it. It has been shown that air pollutants responds to a large extent the stability situation dominant within any locality due to the local micro-climatic conditions. Emission scenarios adopted for Port Harcourt, Enugu, Jos, Kano and Maiduguri have shown that pollutants concentration will be less severe in Port Harcourt and Jos (with dominant stability class F) during the night when compared to Enugu (class D), Kano and Maiduguri (class E). During very stable conditions (class F), emission spread is constrained while there are more allowable limits during neutral (class D) and stable (class E) atmospheric situations. Locations of maximum ground level concentrations range from less than 5km-100km. The magnitude of ground level pollutant concentrations during the periods of dawn for the prevalent stability classes across the study areas is in this order: E>D>F. Under unstable conditions, ground level concentrations are closer to emission sources with magnitude distance impact ranging from C>B>A. The more unstable the lower atmospheric stability situation thecloser the maximum pollutant ground level concentrations to emission sources.

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