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Satellite Determination of Particulate Load over Port Harcourt during Black Soot Incidents

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Abstract Port Harcourt is a coastal city in Nigeria that has been experiencing large deposits of soot whose origin is not well known since the last quarter of 2016. Laboratory analysis however showed the soot to be a by-product of petroleum combustion. The HYSPLIT model developed by NOAA and Australia's Bureau of Meteorology was used to compute airborne particulate load, trajectory and dispersion over the city. Model outputs of ground level concentrations of particulates from area sources across receptors over the city for the hours of 0100, 0300 and 0700 when the soot incidence was most prevalent is here presented. Minimum and maximum emission concentrations dispersion across Port Harcourt ranged from 0.000035 mg/m^3 to 0.18mg/m^3 (0.035-180 µg/m^3), respectively, for the hours considered. The maximum value obtained from these modelling results exceed the national annual average limits of 40-60 µg/m^3 by 77-85% for suspended particulate matter and black smoke. Particulates emissions as observed from the HYSPLIT model platform indicates that emission sources south of Port Harcourt contribute vastly to the particulate load across the lower atmosphere of Port Harcourt and environs especially during the night time and early hours of dawn. It is thus crucial that active measures and workable solutions be evolved to safeguard the air quality of the city.

Keywords: *black soot, HYSPLIT model, particulates*

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1. Introduction

Port Harcourt, a coastal city in Nigeria has been experiencing large deposits of soot, clearly visible since the last quarter of 2016; the prevalence of which depends on atmospheric condition. Laboratory analysis of the soot indicates that it is of petroleum combustion origin [1,2]. These conclusions are not surprising because the city is located within the oil-rich Niger delta and as a result emissions from petrochemical plants, petroleum refineries, natural gas liquefaction, flow stations and gas plants are routine. In addition to these, Port Harcourt with a population of over two million like the rest of Nigeria rely heavily on individually owned power generating sets to supply electricity to both businesses and households. These generators, especially the ubiquitous 2-stroke engine types are known to be heavy polluters [3]. Public mass transit is lacking in the city so urban commuting depend essentially on personal cars, mini buses and taxis, mostly old, poorly maintained and sometimes smoky. Port Harcourt is a city with poor air quality indices only made worse by the occurrence of the black soot, hence the panic. In the reports by the Rivers State Government [1] and [2], and expert opinion in the media, three recent activities were blamed for the black soot:

a) burning of used automobile tyres at various locations within the city ostensibly to extract and recycle copper wire, and in abattoir operations;
b) clandestine adaptation of a rogue distillation method for stolen crude oil into diesel using very basic technology borrowed from traditional distillation of a popular local gin called '*ögogoro*'; and,
c) open air burning of seized vessels and their contents of crude oil from thieves and refined products from illegal refineries.

The advent of black soot over the city of Port Harcourt caused the government to declare an environmental emergency in Rivers State and as a consequence, security forces, civil organizations and communities were mobilized and the public sensitized to arrest the situation, yet the problem persisted. This paper investigates the black soot phenomenon as experienced in Port Harcourt metropolis from a perspective different from the two other studies cited. Whereas the previous studies captured the soot and analysed its composition as to find a clue, this study investigates the origin, spread and spatial concentrations of the soot over the city.

2 Materials and Method

The Hybrid Single Particle Lagrangian Integrated Trajectory Model (HYSPLIT) developed by the United States National Oceanic and Atmospheric Administration (NOAA) and Australia's Bureau of Meteorology was used to compute airborne particulate load, path and dispersion. An important use of HYSPLIT model is to establish if maximum or minimum levels of particulates dispersion at any location are caused by transport of air contaminants from locations other than the one investigated. When HYSPLIT's modelling trajectories is combined with satellite images (from NASA's MODIS satellites) as was the case in this study, it can provide better understanding on how air pollutants levels are caused by local air pollution sources downwind across sensitive receptors.

HYSPLIT model is executed on a registered NOAA-server mode (HYSPLIT-WEB) from NOAA website, allowing registered experts to choose gridded historical or recent forecast data sets, in order to configure model runs, and retrieve model results with a web browser. Another advantage of this modelling platform is the ability to recall previous events in other to re-examine what happened. Depending also on the choices of the modeller, visual display of ground level concentrations overlaying spatial dimensions are achievable with the model. The phenomenon of black soot over Port Harcourt was most evident in the peak of the last dry season (December 2016-February 2017). In the first week of February there was so much flurry of it that it made national media headlines and was a major subject of conversation everywhere. On the basis of this, the authors chose February 1-8, 2017 as modelling period for this study, in the hours of 0100, 0300 and 0700. These hours are crucial because it was the period of eyewitness report of maximum soot deposition. Many residents of the city reported that as they woke early in the morning, deposits of black soot covered their floors, cars parked in the open and other surfaces.

A dry run of the model was executed at several locations within and outside of Port Harcourt's metropolis as a preliminary exercise to evaluate what scenario best fit the reported experience of the period. This approach provided insight to detailed atmospheric dispersion conditions and a clue to possible locations and trajectory of airborne materials encountered at ground level over the city. The results of these initial run of the model showed a trajectory originating southwest of the city, and a ground level concentration consistent with witnessed accounts and results of other studies of the Port Harcourt black soot earlier reported in this paper. The area south and southwest of Port Harcourt has scattered settlements separated by vast mangrove swamps. The authors realise that the black soot generating activity is not likely situated within an inhabited settlement; the name of the nearest settlements to the model coordinates was nevertheless applied to describe the potential sources. Average range of diurnal wind speed and air temperature for the area is between 0.5-6m/s and 23-31°C respectively.

3. Results and Discussion

Model outputs of ground level concentrations of particulates from area sources across receptors over the city of Port Harcourt for the hours of 0100, 0300 and 0700 are presented in Figure 1 – Figure 9. Figure 1 - Figure 3 shows particulate concentrations at 0100 hrs for locations southwest of Port Harcourt, but near the settlements tagged in the caption; Figure 4 – Figure 6 are for 0300 hrs; while Figure 7 - Figure 9 are for 0700 hrs.

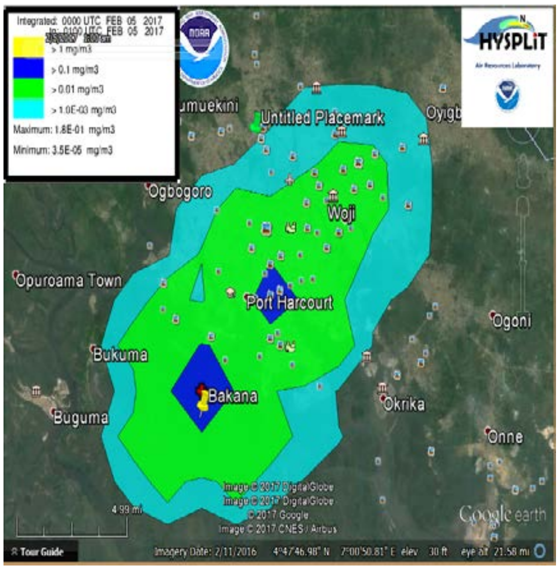

Figure 1. Emission source south of Bakana

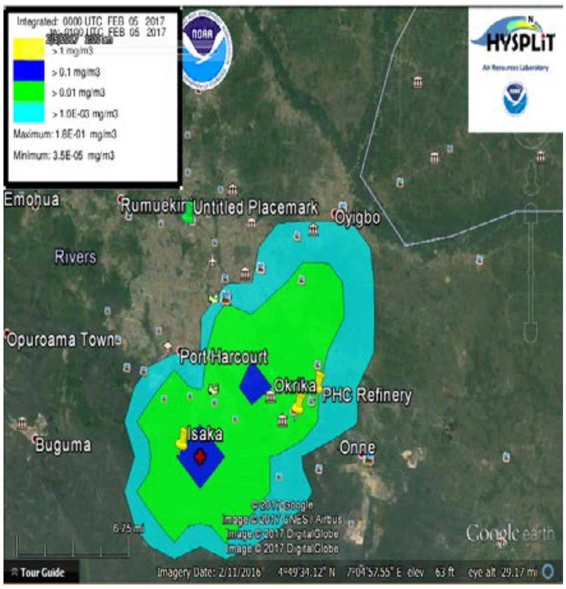

Figure 2. Emission source south of Isaka

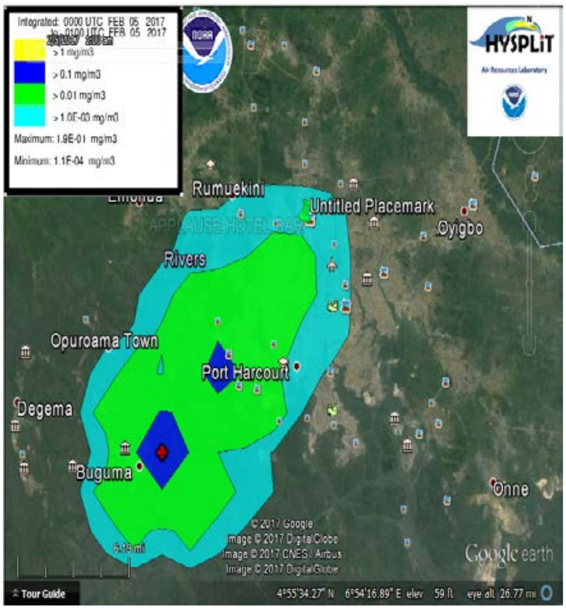

Figure 3. Emission source south of Buguma

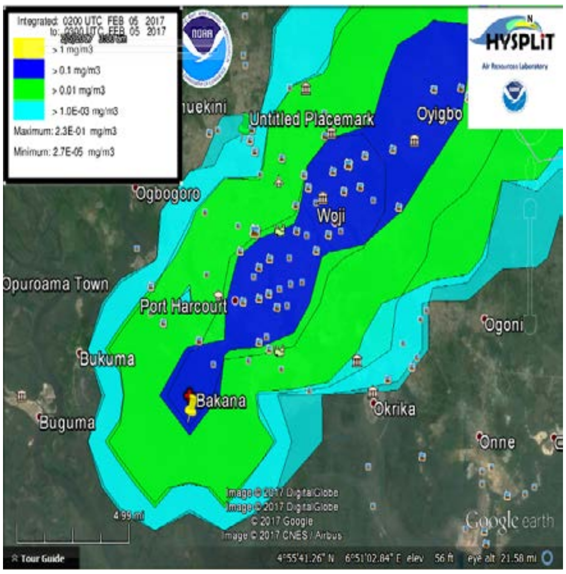

Figure 4. Emission source south of Bakana

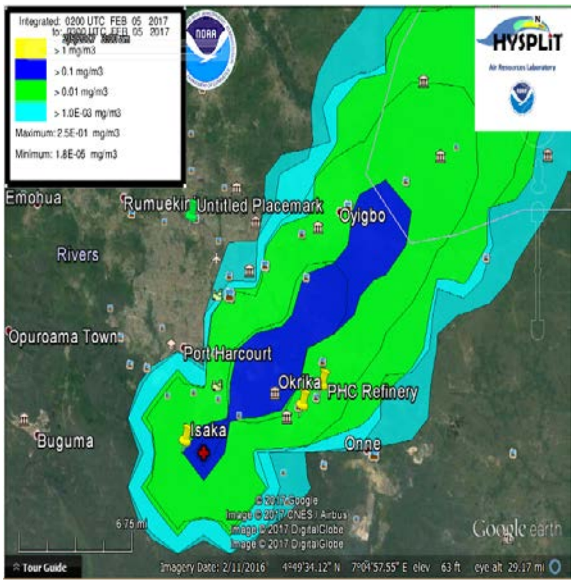

Figure 5. Emission source south of Isaka

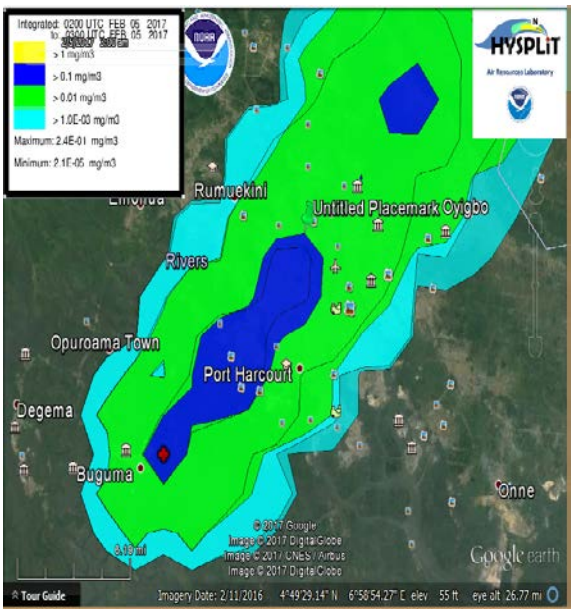

Figure 6. Emission source south of Buguma

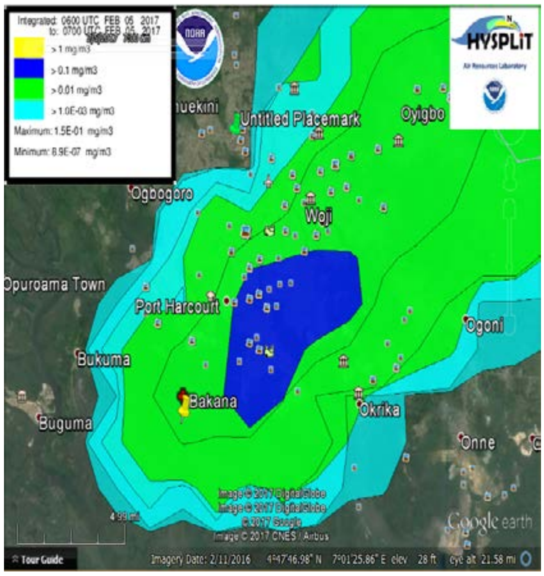

Figure 7. Emission source south of Bakana

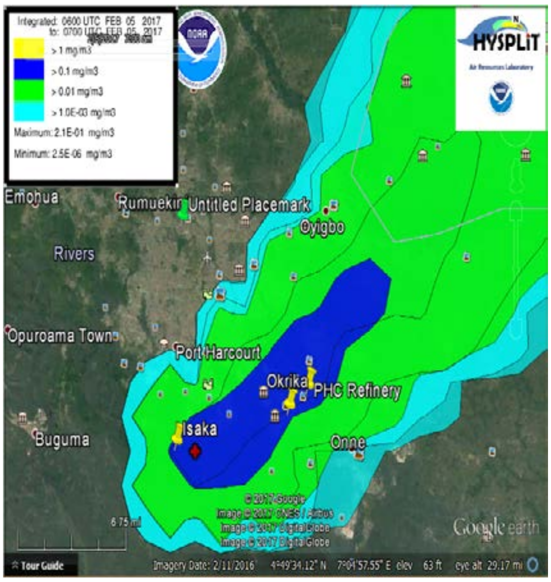

Figure 8. Emission source south of Isaka

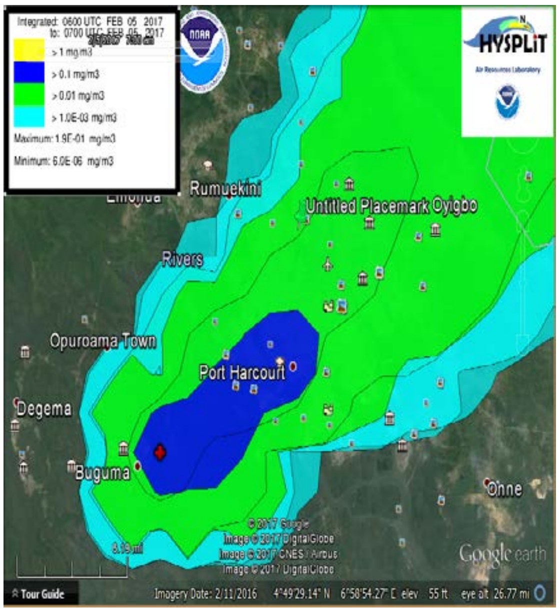

Figure 9. Emission source south of Buguma

From the plume diagrams, it is shown that emission sources close to south of Bakana and environs will have fitting spread over Port Harcourt city for the specific dispersion coordinates and prevailing atmospheric condition. Likewise, emissions sources from areas south of Isaka and Buguma will also impact on Port Harcourt and environs. Minimum and maximum emission concentrations dispersion across Port Harcourt ranged from 0.000035 mg/m^3 to 0.18mg/m^3 (0.035-180 µg/m^3), respectively, for the hours considered (i.e. 0100, 0300 and 0700). The maximum value obtained from these modelling results exceeds the national annual average limits of 40-60 µg/m^3 by 77-85% for suspended particulate matter and black smoke. The air quality monitoring study conducted by SPDC in Port Harcourt (i.e. Shell I.A, R.A and Kidney Island), late 2016 and early 2017 showed that average particulates concentrations ranged from 16.4-360 µg/m^3. In the SPDC [2] study it was PM_7, PM_{10} and TSP that had the highest concentrations in the ranges of 72.1-103.3 µg/m^3; 91.2-209.6 µg/m^3 and 120.6-360 µg/m^3. Similarly, the Rivers State Ministry of Environment Study [1] found TSP range of 62-270 µg/m^3. The modeling results compared well and within the air quality monitoring study sampled at some locations within Port Harcourt by SPDC and Rivers State Ministry of Environment. The percentage relation between the modeling result and baseline data for most of the areas range from 50-86%"

While ground level particulate concentrations downwind of sources in this study were minimal across Port Harcourt at 0100hr, it was higher for the hours of 0300 and 0700 (Figure 1 - Figure 9). The source areas with the greatest impact on Port Harcourt were south of Bakana and Isaka (Figure 4-Figure 9). The reason for low emission concentrations at 0100hr was indicative that the atmosphere over Port Harcourt has forced inversion aloft and so emissions could still be deposited within the vicinity of the source; but as this is lifted from about 0300am, emissions are transported above inversion layer laterally. One of the mysteries relating to the Port Harcourt black soot phenomenon which this study has tackled is the source. Figure 1 – Figure 9 unmistakeably align a trajectory of southwest-northeast direction over Port Harcourt; that is, the origin of the soot was a few kilometres south of the city. Daily concentrations over the city were not uniform, varying according to changes in atmospheric stability and transport, microclimatic conditions and urban surface configurations. The spatial extent of impact (of between 200-230 km^2) and locations of maximum ground level concentrations (in deep blue) is also determined by the same forces, as a consequence every receptor within the metropolis of Port Harcourt was of high risk.

Prior to the black soot crisis an analysis of particulate matter concentration trends in Port Harcourt have shown that acceptable limits have been exceeded across the metropolis [4]. Comparing Port Harcourt metropolis and its rural surrounding, it was found that (TSP) attains values up to 600 µg/ m^3 as against <300µg/m^3 at nearby rural areas. They strongly recommended the need for regular monitoring of atmospheric pollutants around Port Harcourt region to forestall the potential health and atmospheric related impacts of such air toxics. Recently (June, 2017), a neighbourhood in Port Harcourt suffered from fire outbreak due to illegal refining of oil and property worth millions of naira were destroyed. This act no doubt would have propelled black soot into the lower atmosphere. The World Health Organisation [5] air quality model of 2016 stated that about 92% of the world's population live in places where ambient air quality levels exceeds WHO limits. The interactive map for $PM_{2.5}$ as shown on Figure 10 reveals an ambient level for Port Harcourt (i.e. 36-69µg/m^3) above both national and international standards.

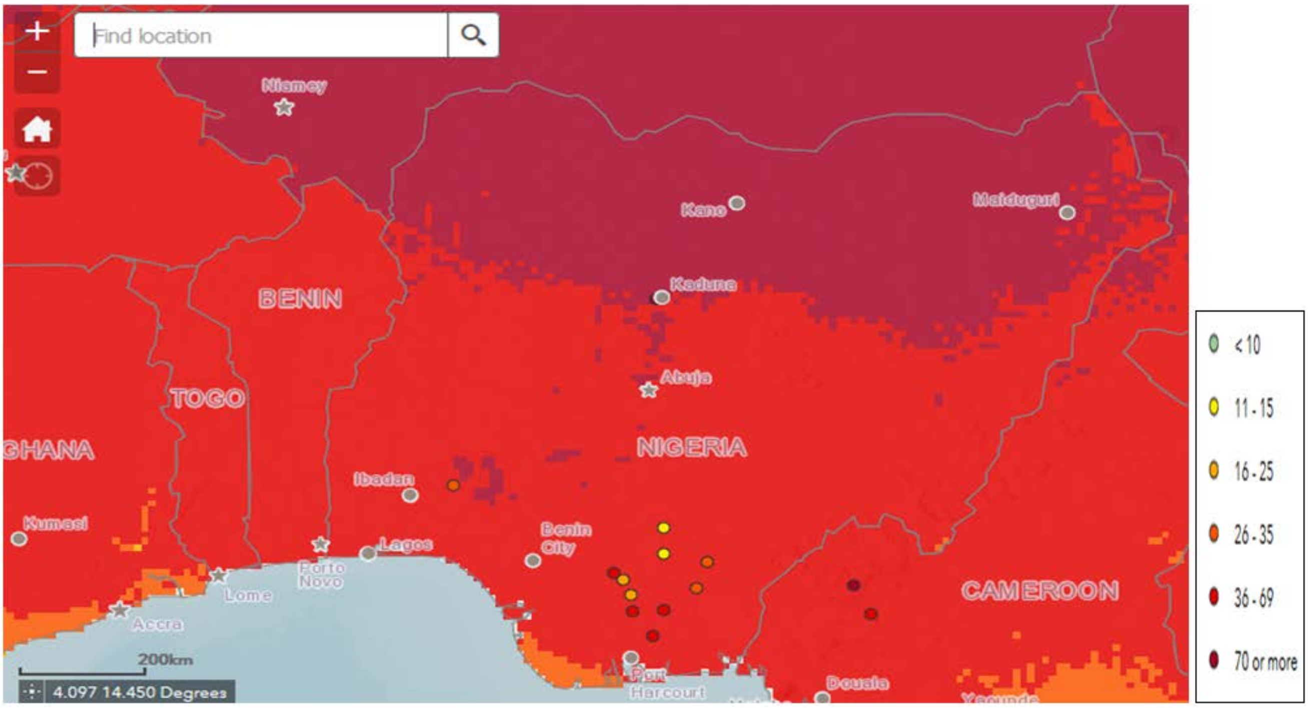

Figure 10. Particulates Concentration across Some West African Countries from WHO Database (Source: [5])

With respect to the recent urban air quality database, 98% of cities in low and middle income countries with population above 100,000 do not meet WHO air quality standards. As municipal air quality degenerates, the threat of stroke, heart disease, lung cancer as well as chronic and acute respiratory diseases, including asthma, increases for the people who live in them [5]. Air pollution can occur anywhere, but what distinguish the level of severity across areas or localities is the measures taken by the stakeholders to manage and curtail the situation even in its worst state. WHO [6] emphasised the urgency to decrease soot, ozone, methane as well as carbon dioxide emissions which all contribute to climate change. The report says emissions not only produce a strong global warming effect but also contribute to the over 7 million premature fatalities annually connected to air pollution. Although there is dearth of data on air pollution related morbidity in Nigeria, places such as the Niger delta groan under severe emissions impact. A global platform on Air Quality and Health created in 2014 by WHO in order to bring together national and international organisations to improve research and policy on outdoor and household pollution [7]. Stakeholders in Nigeria, most especially, the Niger delta area should key into such initiatives to promote improved air quality in the region.

3.1. The Role of Climate on the Air Quality of Port Harcourt

Average wind speed for the study area ranges from 1-6 m/s and 0.5-2.m/s during the day and night, respectively, and can be higher during occasional periods of storms and squalls. Figure 11 and Figure 12 show the dominant wind directions in Port Harcourt for most part of the year as well as wind speed ranges for the area acquired from the Nigeria Meteorological Agency, for Port Harcourt airport station. The wind pattern shows that during the day, emission concentrations will be high near the source and low at farther distances. At dawn when soot deposits were very noticeable in Port Harcourt, particulates concentrations will be confined near the source area due to temperature inversion and move downwind of source below inversion layer due to lateral displacement of air. Lateral displacement of air is always prominent during stable atmospheric conditions.

It has been determined that the atmospheric boundary layer stability conditions in Port Harcourt is very stable at night and unstable during the day [8]. The implication of these emissions concentrations around Port Harcourt is that ground level concentrations will be low for sensitive receptors under unstable atmospheric conditions during the day and severe for sensitive receptors under stable conditions at night [8,9]. The atmosphere plays a significant role in the problem of dispersion process of air pollutants. By association of being where Nigeria's petroleum is found, the atmosphere of the Niger delta is the primary sink to which the emissions are deposited [10]. Regarding local transport emission characteristics, the role of large-scale (synoptic) and local meteorological conditions (including low wind speed), as well as low value of the mixing-layer height are assumed to be key factors that influence high near-surface concentration levels within any locality [11,12,13]. Other studies have also shown that a significant amount of airborne water causes an increase in soot particulates concentration [14]; and a maritime airmass as prevalent in Port Harcourt can induce this. Moreover, the occurrence of temperature inversion may cause an additional accumulation of the pollutant near the ground surface of the boundary layer [15,16]. Another factor that influences changes in particulates concentration is influx of other airmasses pulled by the changing atmospheric circulation [13,17,18]. Simultaneously, a change in circulation pattern impacts not only meteorological conditions but also the transport of pollutants [19,20]. Trans-boundary airborne intrusions caused by the atmospheric circulation are unavoidable issue for many areas dealing with the problem of air pollution [21,22].

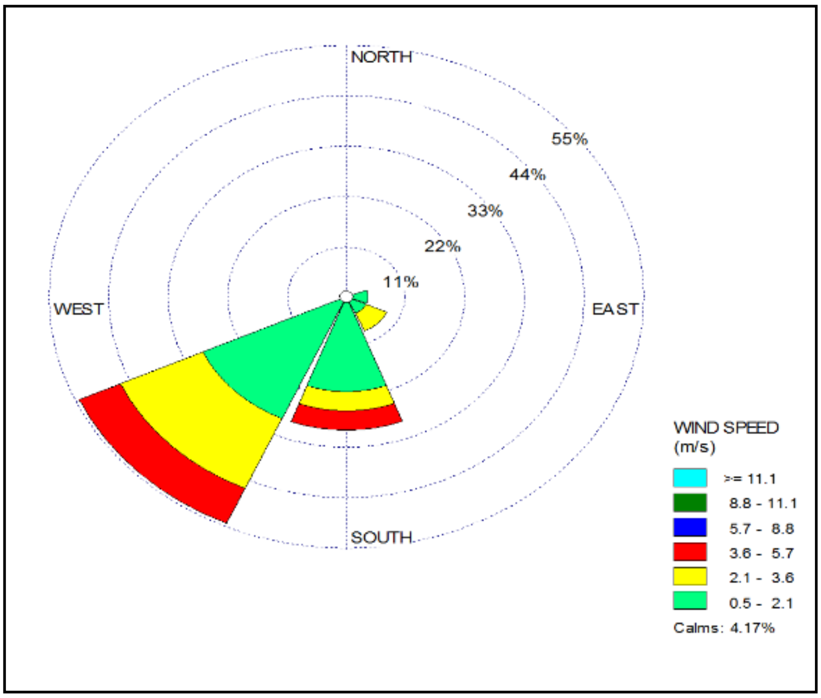

Figure 11. Diurnal wind rose pattern in Port Harcourt (Source: Data Sourced from Nigerian Meteorological Agency, Port Harcourt International Airport)

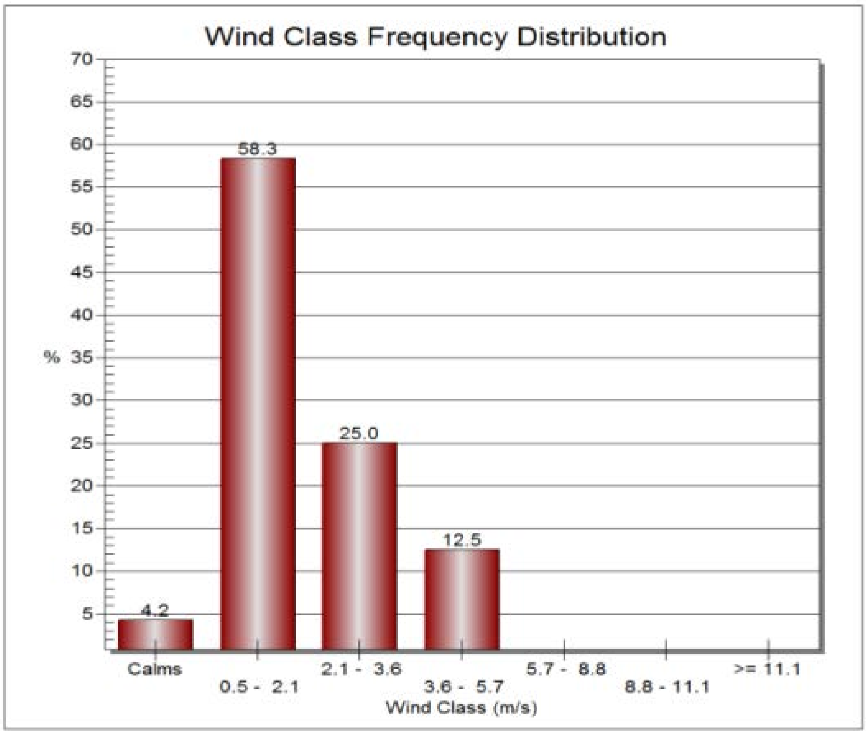

Figure 12. Diurnal Wind Speed Pattern in Port Harcourt (Source: Data Sourced from Nigerian Meteorological Agency, Port Harcourt International Airport)

4 Conclusions

This study has highlighted the average concentrations of particulates emissions associated with soot from sources south of Port Harcourt and the trajectory of dispersion downwind. Particulates emissions as observed from the HYSPLIT model platform indicates that emission sources south and southwest of Port Harcourt contributes vastly to the particulate load across the lower atmosphere of the city and its environs especially during night-time and early hours of dawn. The lower atmosphere is a dynamic energetic system that supports the sustenance of life; however, inhabitants of Port Harcourt are part of the millions of people predominantly in developing countries that live with detrimental air due to particulates emissions from vehicles, industries, illegal refineries and carefree burning of hazardous substances. The local and national governments' main objective is to provide the essential necessities for the people such as food, shelter and other basics; nevertheless, air pollution mitigation has not been given a deserved priority by all tiers of governments in the country. It is based on this context that concerned stakeholders expect that mitigating air pollution in the Niger delta of Nigeria will become more challenging in the nearest future if the present approach remains. It is thus crucial that active measures and workable solutions be evolved to safeguard environmental health in the region.

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