Scientific Research Publishing

International Journal of Geosciences, 2023, 14, 531-546
https://www.scirp.org/journal/ijg
ISSN Online: 2156-8367
ISSN Print: 2156-8359

# Air Pollution Prediction in Warri and Its Environs Using Quality Parameters

**Akinyemi Olufemi Ogunkeyede*, Chinonso Oliver Mbaoma, Aluya Duncan Iyogbon, Adedoyin Ayorinde Adebayo, Efe Jeffery Isukuru**

Department of Environmental Management and Toxicology, College of Science, Federal University of Petroleum Resources, Effurun, Nigeria

Email: *ogunkeyede.akinyemi@fupre.edu.ng

**How to cite this paper:** Ogunkeyede, A.O., Mbaoma, C.O., Iyogbon, A.D., Adebayo, A.A. and Isukuru, E.J. (2023) Air Pollution Prediction in Warri and Its Environs Using Quality Parameters. *International Journal of Geosciences*, **14**, 531-546.
https://doi.org/10.4236/ijg.2023.146029

**Received:** May 10, 2023
**Accepted:** June 26, 2023
**Published:** June 29, 2023



## Abstract

Air pollution is a major environmental problem in the Niger Delta Area (NDA) of Nigeria primarily due to oil and gas-related operational activities. Identifiable sources of air pollution in the NDA include gas flaring, vehicle emissions from internal combustion engines, crude oil pollution, etc. The aim of this research is to evaluate the concentration of air pollutants from crude oil-related activities using air quality parameters in Warri during seasons peculiar to the area of study. The Warri metropolis, one of Nigeria's largest oil cities, was the sampling region under research in this study. An Aeroqual handheld mobile multi-gas monitor fitted with different sensors of (Carbon Monoxide (CO), air quality multi-meter for Particulate Matter ($PM_{2.5}$ and $PM_{10}$), Volatile Organic (VOC), Sulphur dioxide ($SO_2$), Ammonia ($NH_3$), Methane ($CH_4$), and air quality index (AQI), was used for the collection of air quality parameter. Linear regression was used to create the model, which was then used to predict the extent of pollution in the locations of study. The average mean concentrations of air pollutants such as CO, $NO_2$, $CH_4$, VOC, $NH_4$, and $SO_2$ were measured at all sampling sites during wet and dry seasons. The results showed that the levels of these pollutants were above the WHO permissible limits for the majority of the air quality parameters studied in all sixteen locations. The concentration levels of most of the pollutants were higher in the dry season than in the rainy season. The study also found that the pollutants were mainly from fossil fuel combustion and road traffic emissions. Overall, the research provided monitoring data for all air quality pollutants under investigation in the study area and demonstrated that these concentrations exceed regulatory guidelines.

## Keywords

Geostatistics, Air Pollution, Fossil Fuel Combustion, Environmental Monitoring

## 1. Introduction

Air pollution refers to the existence of detrimental elements in the air that can result in adverse effects or discomfort for people, animals, plants, or the environment, whether natural or man-made [1]. Pollutants come in various forms such as solid particles, liquid droplets, or gases, and can be naturally occurring or human-made [2]. Air pollution is a major environmental problem in the Niger Delta Area (NDA) of Nigeria, a region rich in oil reserves and home to a variety of industries, including the upstream and downstream petroleum sectors [3]. These industries and other human activities, such as biomass combustion, refuse burning [4], and traffic emissions [5], release a range of substances including volatile organics, oxides of carbon, nitrogen, sulphur, particulate matter, heavy metals, and other toxins that often exceed national and international guidelines [6]. Despite the many benefits of the petroleum industry, it also has significant negative impacts on health and the environment. Air pollution caused by the oil and gas-related activities can pose harm to human health, agriculture, wildlife, and the economy and social fabric of communities. The impact of air pollution in the NDA is multifaceted, with local and regional effects such as acid rain, water pollution, soil pollution, impacts on plants and wildlife, effects on materials and artifacts, and contributions to global warming [7] [8] [9].

The exploration, production, refining, and transportation of crude oil generate hazardous and toxic air pollutants such as volatile organic compounds (VOCs), and criteria air pollutants including particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), organic carbon (OC), and sulfur dioxide ($SO_2$) [10] [11] [12]. Refineries also release lighter hydrocarbons such as natural gas (methane) and other volatile fuels and oils. Some of these chemicals are known or suspected to cause cancer and developmental and reproductive problems, and they may worsen respiratory conditions like childhood asthma [13]. In addition to the potential health impacts of exposure to these chemicals, the presence of these emissions can cause fear and concern among nearby communities. Air discharges originating from a petroleum refinery can stem from different origins such as the heating of process fluids and steam, equipment leaks, product transfer, and high-temperature combustion procedures. Typically, these contaminants are emitted into the environment on a yearly basis through regular discharges, accidental discharges, plant upsets, or fugitive releases, occurring in significant amounts [14] [15]. In Nigeria, the creation of ozone poses a major issue as it is produced by a mixture of volatile hydrocarbons and nitrogen oxides, both of which are present in the atmosphere. Quantifying the environmental pollutants associated with crude oil production activities in the study area can help inform the public and government agencies about the health risks associated with these emissions.

Many oil-producing countries face significant challenges regarding the health of their population due to environmental factors that fail to meet contemporary standards. Unfortunately, the implementation of safeguards such as scrubbers and atmospheric pollutant containment systems is often incomplete, and regulatory agencies may be inactive or susceptible to bribery, resulting in inadequate enforcement of regulations. In the Niger Delta region, where oil exploration and production activities are prominent, flaring of associated gas into the surrounding environment is a common occurrence. For instance, [16] conducted a comprehensive study on the quantity of air pollutants that have been flared in the Niger Delta region over the past half-century. Their research revealed that out of a total gas production of $1.78 \times 10^{12}$ $m^3$, $822.02 \times 10^9$ $m^3$ were utilized while $917.17 \times 10^9$ $m^3$ were flared. This flaring resulted in estimated emissions of $1.13 \times 10^6$ tons of NOx, $5.10 \times 10^6$ tons of CO, $1.46 \times 10^6$ tons of Non-Methane Volatile Organic Compounds (NMVOC), $1.05 \times 10^4$ tons of SOx, $6.56 \times 10^5$ tons of $PM_{2.5}$, and $8.90 \times 10^4$ tons of OC. In the specific area of study, [17] conducted research to determine the concentrations of air pollutants. Their findings highlighted the presence of VOC, $NO_2$, $PM_{2.5}$, and $PM_{10}$. However, their study focused on a limited coverage area, including residential areas, bus stations, roadsides, and business districts. To address this research gap comprehensively, the current study encompasses a wider coverage area that includes these aforementioned areas while also considering air dispersion and the spread of air pollutants resulting from oil and gas activities in the region.

It is essential that scientists continue to study air quality, understand the consequences, determine the extent of the damage, educate the public, and recommend solutions. The purpose of this research is to look into the concentration of volatile organic pollutants from crude oil activities in Effurun, a district in Nigeria's Niger Delta. The study is to assess the extent of air pollution produced by these substances using air quality measures. The issue is relevant because air pollution is a major environmental issue in the Niger Delta Basin, with negative consequences for health, agriculture, wildlife, and the economy and social fabric of communities. Furthermore, the measures intended to limit these effects are frequently not properly implemented, and the agencies in charge of ensuring compliance may be inactive or accept bribes rather than enforcing legislation. As a result, the findings of this study can inform the public and government organizations about the health hazards linked with crude oil emissions and contribute to the development of effective solutions to mitigate the problem.

## 2. Materials and Methods

### 2.1. Study Area

The Warri metropolis, one of Nigeria's largest oil cities and situated in Delta state in the Niger Delta, is the sampling region under research in this study. Warri houses the Warri Refinery and Petrochemical Company (WRPC), Nigerian Gas Company (NGC), other indigenous and international oil companies, and oil servicing companies [17]. Warri metropolis is the most populous metropolis in Delta, with a population of about 8000,000 (NBS, 2009). Warri metropolis lies between latitude 5˚33'44.52"N and longitude 5˚46'48.09"E. It has a temperature range of 23˚C - 37˚C and a humid (Relative Humidity, 50% - 70%) equatorial climate with a dry season that extends from about November to February, and a wet season that begins in March, and peaks in July and October.

### 2.2. Sample Collection

Spatial positioning of the different study locations was done using a handheld Global Positioning System (GPS) with sample locations and coordinates represented in Table 1 below. A map of the areas of study is presented in Figure 1 below. Sample collections were focused on air quality in the study area. Air quality samples were collected at different locations and coded as seen in Table 1 below. Sampling was carried out between October to early November 2021 for the wet season and late December through January 2022 for the dry season. An Aeroqual handheld mobile multi-gas monitor fitted with different sensors of (Carbon Monoxide (CO), air quality multi-meter for Particulate Matter ($PM_{2.5}$ and $PM_{10}$), Volatile Organic (VOC), Temperature and Relative Humidity was used for the collection of air quality parameters. Data was collected in triplicates and the mean concentration recorded. The Air Quality Index (AQI), as defined by [18], is a quantitative measure that determines daily air quality and assesses its cleanliness or contamination. It focuses on the health implications individuals may face after breathing polluted air for short periods, providing insights into potential risks associated with air pollution exposure.

**Table 1.** Sample locations and coordinates.

| CODE | LOCATION |
|---|---|
| S1 | Round-About Effurun/Sapele Park |
| S2 | Effurun Spare Parts Market |
| S3 | Hausa Market (Tomatoes) Adjacent Mercy-City |
| S4 | Hausa Market (Fowl Market) |
| S5 | Effurun Round-About Along |
| S6 | NPA Express-Way Opp Navy Hospital |
| S7 | NPA Express-Way Army-day School Gate |
| S8 | NPA Express-Way NIGERCAT Junction |
| S9 | Nigercat Tanker Park |
| S10 | Charlisco Residence NNPC Pipeline Right of Way |
| S11 | Shaguolor Refinery Round-about |
| S12 | Jeddo/Ubeji Junction |
| S13 | Tank Farm Depot Ifie |
| S14 | Ifie Residential Area |
| S15 | NPA Expressway Berger Junction |
| S16 | NIGERCAT Residential Area |

### 2.3. Geospatial Analysis

By fusing various maps and remote sensing data, GIS technology is quickly evolving into a vital tool for developing various models that are used in a real-time environment [19]. Using a small sample size of data points, the geostatistical technique of interpolation predicts the values of raster cells. Inverse distance weight (IDW) is a type of interpolation used in geostatistics to produce continuous raster surfaces with predetermined values and forecast values for unknown locations [20]. This method has been applied to anticipate uncertain numerical values for geographical point data, encompassing factors such as elevation, precipitation, noise levels, and chemical concentrations [21]. The interpolation method used by the IDW, which was chosen for this project, estimates cell values by averaging the values of sample data points about each processing cell. It has been used in several instances to interpolate the air pollutant concentrations because the closer a point is to the center of the cell being estimated, the more influence or weight it has in the averaging process.

## 3. Result and Discussion

### 3.1. Air Quality around Monitoring Stations

The average mean concentrations of air pollutants such as carbon monoxide (CO), Nitrogen dioxide ($NO_2$), volatile organic compounds (VOCs), ammonia ($NH_3$), Methane gas ($CH_4$), particulate matter 2.5 ($PM_{2.5}$), particulate matter ($PM_{10}$), and air quality index (AQI)) were measured at all sampling sites (S1 to S16) during wet and dry seasons. The results, shown in **Figures 1-8**, indicate that the concentration of pollutants was higher at all sampling sites during the wet season compared to the dry season. This suggests that the presence of moisture in the air may contribute to the formation and concentration of these pollutants. It is important to continue monitoring the levels of these pollutants

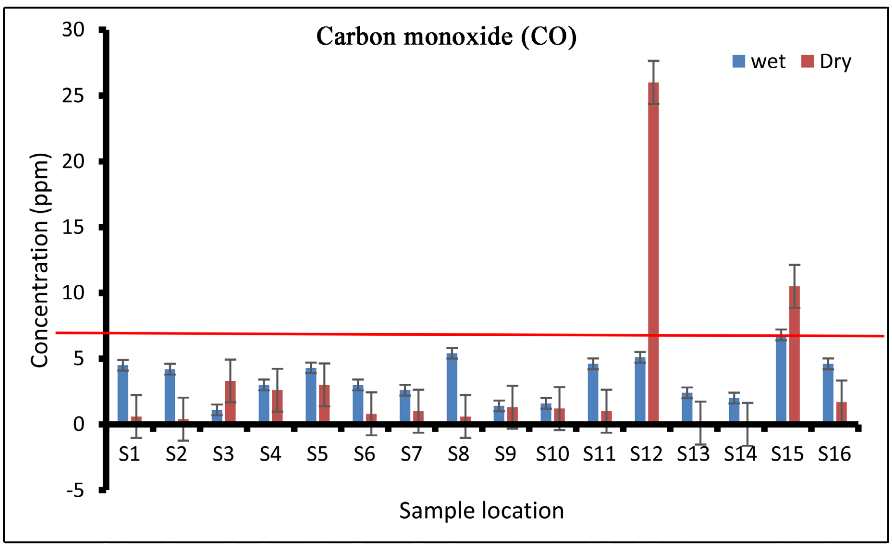


**Figure 1.** Concentrations of CO in study locations sampled during the wet and dry seasons.

in order to understand their sources and the potential impacts on human health and the environment.

The concentration of Carbon monoxide (CO) (**Figure 1**) was generally higher during the wet season when compared to the dry season with the exception of S12 and S15, which were higher in the dry season than in the wet season. This high concentration may be due to the fact that location S12 and S15 is a traffic junction with a high level of vehicular traffic, especially with the passage of heavy-duty trucks loading and transporting petroleum products to and from the area, which can contribute to the formation of CO. While all the 16 locations had concentrations below the World Health Organization (WHO) threshold limit of 9 ppm in the wet season, location S12 and S15 recorded concentrations above the permissible levels in the dry season. The levels of CO recorded in this study were higher than those observed at gas flaring stations in Rivers and Bayelsa states in the Niger Delta region during the wet and dry seasons, with an average concentration of 0.094 and 0.291 $mg/m^3$, respectively [12]. The levels of CO recorded in this study were also higher than those observed in selected communities in Okrika, Rivers State, Nigeria, where a mean concentration of 12.7 ppm was recorded during the dry season [22]. Long-term exposure to environments with high levels of CO can be lethal, as it reduces the capacity of the blood to carry oxygen by binding to haemoglobin. This impairs the flow of oxygen to the body's organs, causing symptoms such as fatigue, headaches, disorientation, and dizziness due to insufficient oxygen transport to the brain [23]. It is important to continue monitoring the levels of CO and implementing measures to reduce emissions in order to protect public health and the environment.

The measurements of nitrogen dioxide ($NO_2$) in the various sample locations show that fifteen out of sixteen locations (S1 and S3 to S16) were above the European Union permissible limit of $3.36 \times 10^{-6}$ ppm as shown in **Figure 2**. Location S15 had the highest concentration of $0.12 \pm 0.11$ ppm during the wet season. A concentration of $0.09 \pm 0.09$ was recorded in all locations during the dry season. This was the highest detectable limit of the equipment used for the monitoring exercise. Five locations (S2 - S6) were below the threshold limit. The higher values at certain locations may be due to fuel combustions and vehicular congestion in those areas. Nitrogen dioxide is emitted from internal combustion engines and fossil fuel combustion, as well as from artisanal refining and associated gas burning from oil and gas operations [24]. The concentrations observed in this study were lower than those recorded in a research project conducted near a refinery, which found values of up to 0.450 ppm [25].

The highest concentration of Methane ($CH_4$) was observed at locations S1 and S2, which had a value of $572 \pm 533$, and $986 \pm 900$ ppm during the wet season and $804 \pm 749$, and $179 \pm 114$ during the dry season respectively (**Figure 3**). This high concentration may be due to the congestion of vehicular traffic at this location. The concentrations of $CH_4$ recorded in this study were below the WHO threshold limit of 1000 ppm [26]. The concentration of $CH_4$ in the area is likely influenced by the activities taking place in the area. The concentrations of $CH_4$

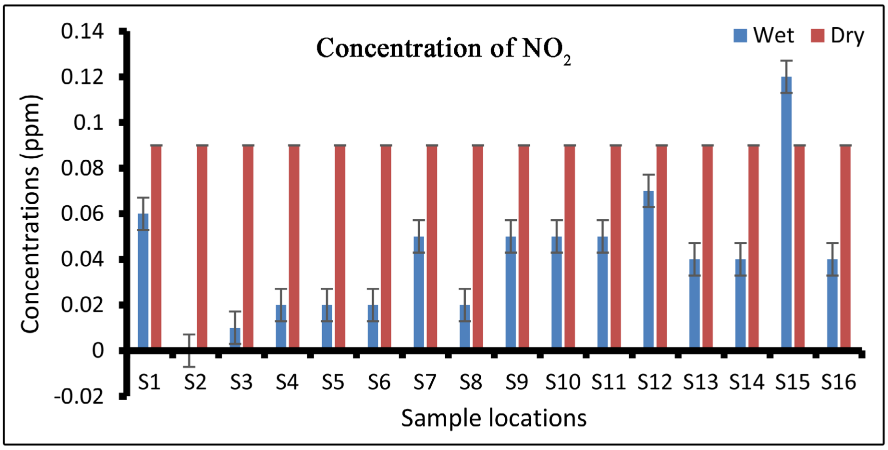


**Figure 2.** Concentrations of $NO_2$ in study locations sampled during the wet and dry seasons.

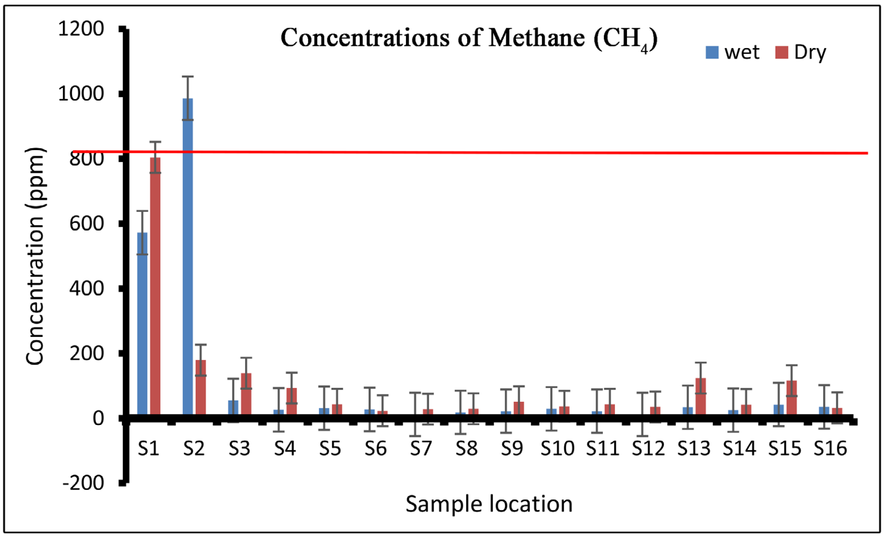


**Figure 3.** Concentrations of $CH_4$ in study locations sampled during the wet and dry seasons.

measured during the dry season were lower than those observed during the wet season. Temperature is one of the factors that can affect methane emissions, and it is possible that the higher temperatures during the dry season led to a decrease in $CH_4$ concentrations.

The measurements for volatile organic compounds (VOCs) in the wet season (**Figure 4**) were alarmingly high, with concentrations exceeding the threshold limit of 50 ppm set by the WHO in all sixteen locations. The concentrations measured ranged from 1014 ± 986 to 4407 ± 4200 ppm during the wet season and 890 ± 885 to 5828 ± 5824 ppm during the dry season. These high values may be caused by indiscriminate dumpsites, mechanic workshops, and congestion of vehicular movement along the road. VOC emissions, particularly from crude oil operations, are all activities peculiar to the majority of the study area [14] [27] [28]. They can also be released into the environment from internal combustion engines such as generators and vehicles [29]. In areas with accelerated industrialization, newly polluted areas are becoming increasingly significant. These compounds can persist in the atmosphere for a few minutes to several months, allowing them to travel long distances from the emission source [30]. This can be true for the study area considering the operation of the Warri Refinery and Petrochemicals Limited (WRPC), Chevron, Shell Development Commission (Ogunu) industrial activities, Nigerian Ports Authority, Loading Port at Ifie community coupled with the movement of a heavy-duty truck. Exposure to VOCs can have short and long-term adverse health effects, including eye and urinary respiratory tract irritation, liver and embryo/foetal damage, central nervous system impairment, kidney damage, testicular damage, and female reproductive issues such as pregnancy loss [31] [32] [33].

The concentration of Ammonium ($NH_4$) (**Figure 5**) during the wet season ranged from 234 ± 232 to 2558 ± 2558 and 630 ± 615 to 5438 ± 5309 during the dry season respectively. This concentration is at a high level above the permissible level of 50 ppm according to WHO [34]. The formation of ammonium-containing aerosols through the reaction of ammonium ($NH_4$) with acidic species can contribute to the formation of secondary particulate matter, which is a major component

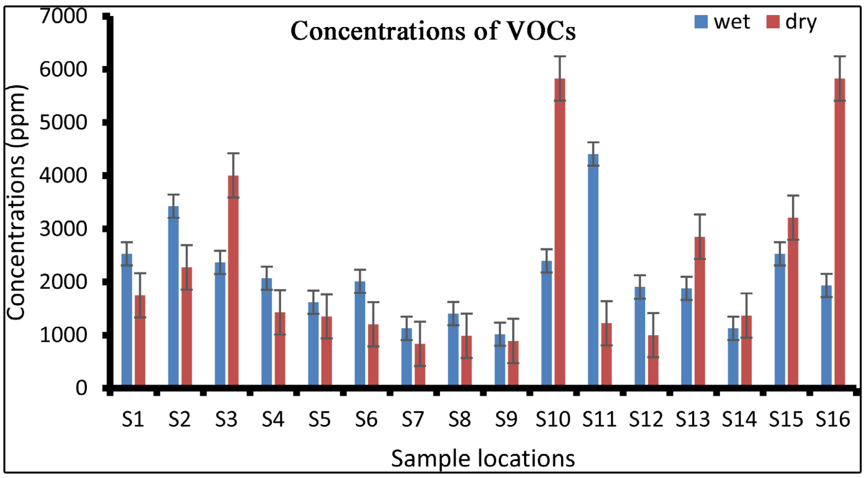


**Figure 4.** Concentrations of VOCs in study locations sampled during the wet and dry seasons.

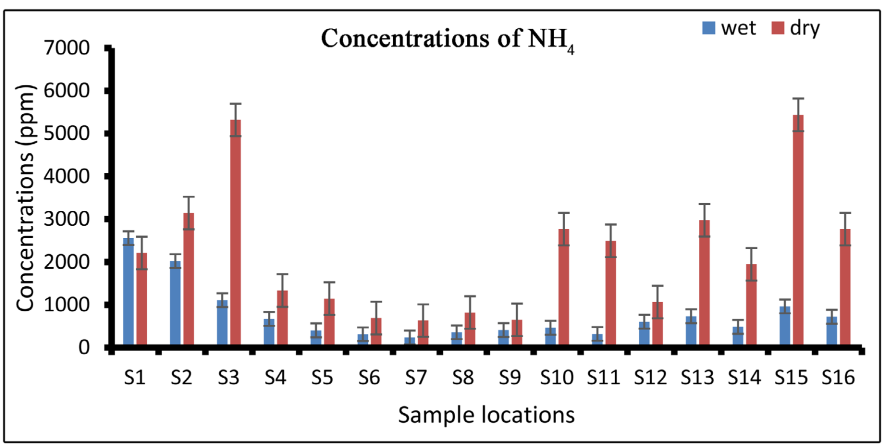


**Figure 5.** Concentrations of $NH_4$ in study locations sampled during the wet and dry seasons.

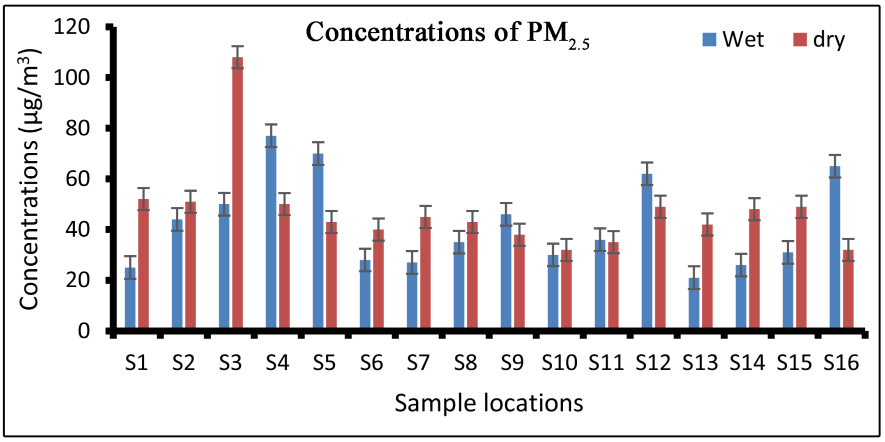


**Figure 6.** Concentrations of $PM_{2.5}$ in study locations sampled during the wet and dry seasons.

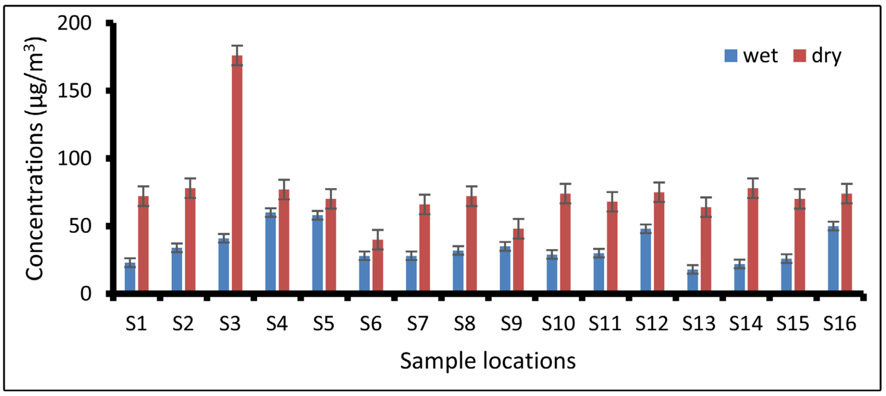


**Figure 7.** Concentrations of $PM_{10}$ in study locations sampled during the wet and dry seasons.

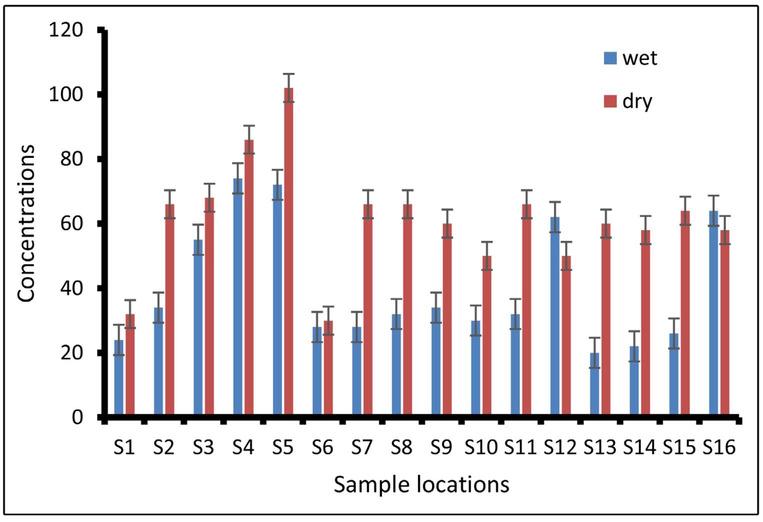


**Figure 8.** Concentrations of Air Quality Index (AQI) in study locations sampled during the wet and dry seasons.

of $PM_{2.5}$ in the atmosphere [35] [36].

The concentration of particulate matter 2.5 ($PM_{2.5}$) in this study ranged from

21 ± 17 - 77 ± 75 μg/m$^3$ during the wet season with points S13 and S4 recording the points with the lowest and highest concentrations respectively during the wet season. During the dry season the concentration ranged from 32 ± 20 to 108 ± 104 μg/m$^3$ with S10 and S3 recording the lowest and highest points respectively. Overall, it appears that $PM_{2.5}$ concentrations in urban areas can vary significantly depending on the location and season. The concentration of $PM_{10}$ recorded in all sixteen locations was higher in the dry season than in the rainy season. Results ranged from 18 ± 14 to 60 ± 55 with location S13 and S4 recording the lowest and highest values during the wet season and in the dry season, the concentrations ranged from 48 ± 44 to 176 ± 170 with S9 and S3 recording the lowest and highest values respectively. Results from this study were higher than those recorded in Eagle Island in Port Harcourt, Rivers State Nigeria, an area characterized by artisanal refining of crude oil where the highest value recorded was 34 μg/m$^3$ for $PM_{10}$ and 26 μg/m$^3$ for $PM_{2.5}$ [37].

It is important for authorities to monitor and regulate $PM_{2.5}$ concentrations in order to protect public health. $PM_{2.5}$ is more likely to travel into and deposit on the surface of the deeper regions of the lung, whereas $PM_{10}$ is more likely to deposit on the surfaces of the upper lung's bigger airways. Particles accumulated on the lung surface have the potential to cause tissue injury, chronic bronchitis, cardiovascular diseases, and asthma attack [38].

In this study, AQI ranged from 20 ± 18 to 74 ± 72 during the wet season with point S13 and S4 registering the lowest and highest values r respectively. During the dry season, the values were 30 ± 28 to 102 ± 100 with points S6 and S5 registering the highest and lowest points respectively.

In comparison to other cities in the Niger Delta where there is crude oil pollution, the results of air pollutants concentration according to the current study in Warri metropolis is higher than air pollutants results analyzed by [39] who sampled air pollutants in Port Harcourt city using a WolfSense Multiple Gas Analyzer. Results from this study were also higher than air pollutants in Uyo city in Akwa Ibom state as measured by [40], indicating the high pollution state of the area.

### 3.2. Geostatistical Modelling of Air Quality Analysis

According to a study by [41], the IDW-Geostatistical method is a reliable approach for integrating various maps and spreadsheet data on air pollution concentrations. The method can generate continuous surfaces of influence around sampled areas, including junctions and residential areas along the areas of study. These surfaces provide valuable insights into the spatial distribution of air pollution and can help researchers and policymakers mitigate the impacts of air pollution on public health and the environment.

The concentrations of CO, $NH_3$, $NO_2$, $CH_4$, and VOCs were used to generate GIS maps indicating areas of high concentration of air pollutants from lower ones. In this study an aggregate of results from the wet and dry seasons was used to produce GIS maps to show points of higher values and the corresponding influence of air pollutants around those areas. From the concentration map showing areas of influence for CO in Figure 9, locations S1, S5, S8, S11, S12, and S16, where S16 had the highest values with corresponding influence around the area, while locations S2, S3, S9, and S10 had the lowest values with corresponding low influence around it.

The high concentrations of CO at locations S8, S11, S12, and S16 were connected to the measurement of the pollutant during rush hour traffic. As shown in Figure 9 below, locations S8 and S15 had the highest values for concentration of $NO_2$; all other locations had corresponding low values and levels of influence on the areas of study. The value of the $NO_2$ was highest at S15 because it is a by-product of the combustion of fossil fuels that are being released of vehicles idling, accelerating, and deceleration. In addition, the contribution from the industrial activities near the road junctions added to the concentration of the $NO_2$.

All other locations had relatively low values of influence during the wet and dry seasons. The concentrations of methane observed resulted from the activities taking place at the Effurun roundabout and Spare parts market. The locations have mechanic villages and vehicles parked in high volumes. The organic materials (gasoline, diesel, lubricants, and spent engine oils) used release light hydrocarbons, part of which is methane observed in this study.

Locations, S1, S2, S3, and S5 had higher values of $NH_3$ concentrations with

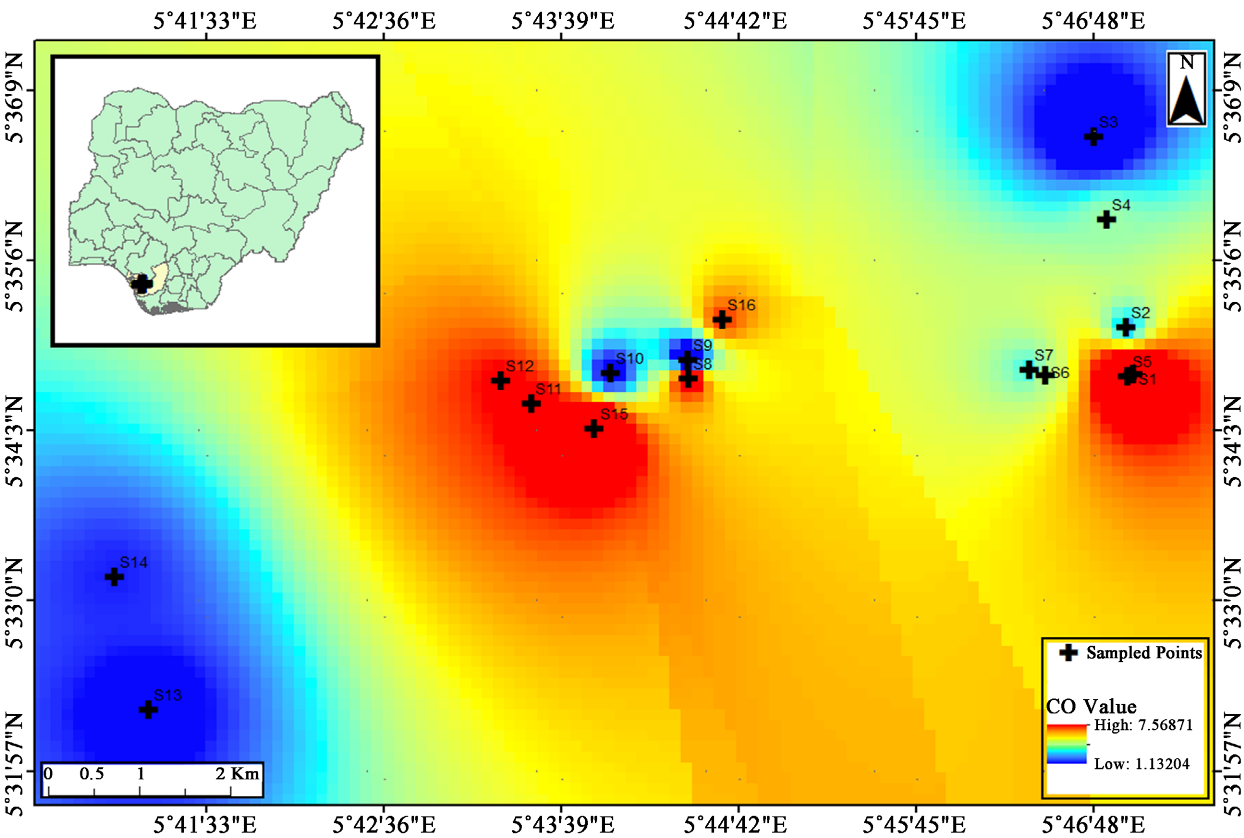


Figure 9. Map of CO concentrations at sampling locations.

corresponding high influence around it. All other locations had low values and correspondingly low levels of influence. The possible sources of $NH_3$ pollutants in the location could be from dumpsites and dirty environments because the measurements took place when the weather is warm and humid, which supports their releases from decomposing organic matter, such as food waste or animal waste.

S2, S3, S10, and S11 showed the greatest concentrations of VOCs across all sample locations, indicating significant dispersion and influence in the surrounding areas. Locations S4, S12, and S15 had medium concentrations and corresponding considerate levels of influence. All other points had low values and low levels of influence around them.

## 4. Conclusions

In conclusion, the study conducted in the Warri metropolis found that residents and visitors passing through the 16 major locations assessed are at risk of health issues due to air pollutants such as CO, $NO_2$, $CH_4$, VOC, $NH_4$, and $SO_2$. The concentrations of these pollutants were the highest in locations S1, S2, S8, S9, S12, S13, S14, and S16, and were primarily attributed to fossil fuel combustion and road traffic emissions. The concentrations of these pollutants exceeded the ambient air quality guidelines set by the WHO, with levels higher in the dry season than in the wet season. The monitoring data for CO, $NO_2$, $CH_4$, $NH_4$, and VOCs in the study area provided by this research demonstrates that the concentrations of these pollutants exceed regulatory guidelines, highlighting the urgent need for effective air quality management strategies in the Warri metropolis to protect public health.

Some limitations of research in this study include:

1) Sample size: The study collected air quality samples from a limited number of locations in the Warri metropolis.

2) Limited temporal scope: The research collected data during specific periods, focusing on the wet and dry seasons of a single year as peculiar weather conditions to the study area. Air pollution levels may vary throughout the year, and long-term trends or seasonal variations might not be fully captured by the limited sampling timeframe.

3) Absence of source identification: Due to funding restraints, the research did not employ specific methods to identify and attribute the sources of pollutants in the study area.

## Acknowledgements

The authors would like to thank the technologists at the Department of Environmental Management and Toxicology, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria, for providing the air quality kits that were used for conducting this research.

## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

## References

[1] Alabi, S.S. (2012) Concentrations of Green-House Gases (GHGs) around Tank Farms and Petroleum Tankers Depots, Lagos, Nigeria. *Journal of Geography and Regional Planning*, **5**, 108-114. https://doi.org/10.5897/JGRP11.053

[2] Anderson, I. (2005) Niger River Basin: A Vision for Sustainable Development. The World Bank, Washington DC, 131.

[3] Ite, A.E. and Ibok, U.J. (2013) Gas Flaring and Venting Associated with Petroleum Exploration and Production in the Nigeria's Niger Delta. *American Journal of Environmental Protection*, **1**, 70-77. https://doi.org/10.12691/env-1-4-1

[4] Opara, C.C., Nwadike, M.C., Evbuomwan, B.O. and Eniafe, B.O. (2015) Evaluation of Effluent Gases from a Waste Incineration Plant: Case Study of a Medical Facility in Abia State, Nigeria. *International Journal of Scientific & Engineering Research*, **6**, 1-11.

[5] Mbaoma, O.C., Ogunkeyede, A.O., Adebayo, A.A., Otolo, S.E. and Ikpinima, M. (2022) Geostatistical Analysis for Monitoring and Modelling Atmospheric Pollutants. *Journal of Geography, Environment and Earth Science International*, **26**, 65-76. https://doi.org/10.9734/jgeesi/2022/v26i6631

[6] Ana, G.R. (2011) Air Pollution in the Niger Delta Area: Scope, Challenges and Remedies. In: Khallaf, M.K., Ed., *The Impact of Air Pollution on Health, Economy, Environment and Agricultural Sources*, InTech, Rijeka, 181-198.

[7] Emoyan, O.O. (2008) The Oil and Gas Industry and the Niger Delta: Implications for the Environment. *Journal of Applied Sciences and Environmental Management*, **12**, 29-37. https://doi.org/10.4314/jasem.v12i3.55488

[8] Nnaemeka, A.N. (2020) Environmental Pollution and Associated Health Hazards to Host Communities (Case Study: Niger Delta Region of Nigeria). *Central Asian Journal of Environmental Science and Technology Innovation*, **1**, 30-42.

[9] Nwaogu, L.A. and Onyeze, G.O.C. (2020) Environmental Impact of Gas Flaring on Ebocha-Egbema, Niger-Delta, Nigeria. *International Journal of Energy and Environmental Research*, **8**, 1-11.

[10] Baltrėnas, P., Baltrėnaitė, E., Serevičienė, V. and Pereira, P. (2011) Atmospheric BTEX Concentrations in the Vicinity of the Crude Oil Refinery of the Baltic Region. *Environmental Monitoring and Assessment*, **182**, 115-127. https://doi.org/10.1007/s10661-010-1862-0

[11] Nwaichi, E.O. and Uzazobona, M.A. (2011) Estimation of the $CO_2$ Level Due to Gas Flaring in the Niger Delta. *Research Journal of Environmental Sciences*, **5**, 565-572. https://doi.org/10.3923/rjes.2011.565.572

[12] Nwosisi, M.C., Oguntoke, O., Taiwo, A.M., Agbozu, I.E. and Noragbon, E.J. (2021) Spatial Patterns of Gas Flaring Stations and the Risk to the Respiratory and Dermal Health of Residents of the Niger Delta, Nigeria. *Scientific African*, **12**, e00762. https://doi.org/10.1016/j.sciaf.2021.e00762

[13] Manisalidis, I., Stavropoulou, E., Stavropoulos, A. and Bezirtzoglou, E. (2020) Environmental and Health Impacts of Air Pollution: A Review. *Frontiers in Public Health*, **8**, Article No. 14. https://doi.org/10.3389/fpubh.2020.00014

[14] Koss, A., Yuan, B., Warneke, C., Gilman, J.B., Lerner, B.M., Veres, P.R., Peischl, J., Eilerman, S., Wild, R., Brown, S.S., Thompson, C.R., Ryerson, T., Hanisco, T., Wolfe, G.M., Clair, J.M.St., Thayer, M., Keutsch, F.N., Murphy, S. and de Gouw, J. (2017) Observations of VOC Emissions and Photochemical Products over US Oil- and Gas-Producing Regions Using High-Resolution $H_3O$+CIMS (PTR-ToF-MS).

*Atmospheric Measurement Techniques*, **10**, 2941-2968. https://doi.org/10.5194/amt-10-2941-2017

[15] Oghenejoboh, K.M., Babatunde, A.A. and Nwaukwa, C.T. (2007) Effects of Air Pollution Arising from Associated Gas Flaring on the Economic Life of the People of Oil Producing Communities in Nigeria. *Control Pollution*, **23**, 1-9.

[16] Giwa, S.O., Nwaokocha, C.N., Kuye, S.I. and Adama, K.O. (2019) Gas Flaring Attendant Impacts of Criteria and Particulate Pollutants: A Case of Niger Delta Region of Nigeria. *Journal of King Saud University—Engineering Sciences*, **31**, 209-217. https://doi.org/10.1016/j.jksues.2017.04.003

[17] Balogun, V.S. and Odjugo, P.A.O. (2022) Spatial Analyses of Air Pollutants Concentration around the Warri Refining and Petrochemical Company (WRPC), Delta State, Nigeria. *Ghana Journal of Geography*, **14**, 22-43. https://doi.org/10.4314/gjg.v14i2.3

[18] Atubi, A.O. (2015) Transport and the Environment: Towards Reducing Road Traffic Emissions in Nigeria. *AFRREV STECH: An International Journal of Science and Technology*, **4**, 58-78. https://doi.org/10.4314/stech.v4i1.6

[19] Van Westen, C.J. (2013) Remote Sensing and GIS for Natural Hazards Assessment and Disaster Risk Management. *Treatise on Geomorphology*, **3**, 259-298. https://doi.org/10.1016/B978-0-12-374739-6.00051-8

[20] Belief, E. (2018) GIS Based Spatial Modelling to Mapping and Estimation Relative Risk of Different Diseases Using Inverse Distance Weighting (IDW) Interpolation Algorithm and Evidential Belief Function (EBF) (Case Study: Minor Part of Kirkuk City, Iraq). *International Journal of Engineering & Technology*, **7**, 185-191. https://doi.org/10.14419/ijet.v7i4.37.24098

[21] Samanta, S., Pal, D.K., Lohar, D. and Pal, B. (2012) Interpolation of Climate Variables and Temperature Modeling. *Theoretical and Applied Climatology*, **107**, 35-45. https://doi.org/10.1007/s00704-011-0455-3

[22] Gobo, A.E., Ideriah, T.J.K., Francis, T.E. and Stanley, H.O. (2012) Assessment of Air Quality and Noise around Okrika Communities, Rivers State, Nigeria. *Journal of Applied Sciences and Environmental Management*, **16**, 75-83.

[23] Scovronick, N., Budolfson, M., Dennig, F., Errickson, F., Fleurbaey, M., Peng, W. and Wagner, F. (2019) The Impact of Human Health Co-Benefits on Evaluations of Global Climate Policy. *Nature Communications*, **10**, Article No. 2095. https://doi.org/10.1038/s41467-019-09499-x

[24] Tian, H., Yang, J., Xu, R., Lu, C., Canadell, J.G., Davidson, E.A. and Zhang, B. (2019) Global Soil Nitrous Oxide Emissions since the Preindustrial Era Estimated by an Ensemble of Terrestrial Biosphere Models: Magnitude, Attribution, and Uncertainty. *Global Change Biology*, **25**, 640-659. https://doi.org/10.1111/gcb.14514

[25] Barik, D., Murugan, S., Sivaram, N.M., Baburaj, E. and Sundaram, P.S. (2017) Experimental Investigation on the Behavior of a Direct Injection Diesel Engine Fueled with Karanja Methyl Ester-Biogas Dual Fuel at Different Injection Timings. *Energy*, **118**, 127-138. https://doi.org/10.1016/j.energy.2016.12.025

[26] Prasad, S., Zhao, L. and Gomes, J. (2011) Methane and Natural Gas Exposure Limits. *Epidemiology*, **22**, S251. https://doi.org/10.1097/01.ede.0000392463.93990.1e

[27] Aklilu, Y.-a., Cho, S., Zhang, Q. and Taylor, E. (2018) Source Apportionment of Volatile Organic Compounds Measured near a Cold Heavy Oil Production Area. *Atmospheric Research*, **206**, 75-86. https://doi.org/10.1016/j.atmosres.2018.02.007

[28] Zheng, H., Kong, S., Xing, X., Mao, Y., Hu, T., Ding, Y. and Qi, S. (2018) Monitor-

ing of Volatile Organic Compounds (VOCs) from an Oil and Gas Station in Northwest China for 1 Year. *Atmospheric Chemistry and Physics*, **18**, 4567-4595. https://doi.org/10.5194/acp-18-4567-2018

[29] Karbasian, H.R., Kim, D.Y. and Yoon, S.Y. (2017) A New Method for Reducing VOCs Formation during Crude Oil Loading Process. *Journal of Mechanical Science and Technology*, **31**, 1701-1710. https://doi.org/10.1007/s12206-017-0318-7

[30] Montero-Montoya, R., López-Vargas, R. and Arellano-Aguilar, O. (2018) Volatile Organic Compounds in Air: Sources, Distribution, Exposure and Associated Illnesses in Children. *Annals of Global Health*, **84**, 225-238. https://doi.org/10.29024/aogh.910

[31] Afshar-Mohajer, N., Fox, M.A. and Koehler, K. (2019) The Human Health Risk Estimation of Inhaled Oil Spill Emissions with and without Adding Dispersant. *Science of the Total Environment*, **654**, 924-932. https://doi.org/10.1016/j.scitotenv.2018.11.110

[32] Brand, A., McLean, K.E., Henderson, S.B., Fournier, M., Liu, L. and Kosatsky, T. (2016) Respiratory Hospital Admissions in Young Children Living near Metal Smelters, Pulp Mills and Oil Refineries in Two Canadian Provinces. *Environment International*, **94**, 24-32. https://doi.org/10.1016/j.envint.2016.05.002

[33] D'Andrea, M.A. and Reddy, G.K. (2014) Health Risks Associated with Crude Oil Spill Exposure. *The American Journal of Medicine*, **127**, 886.e9-886.e13. https://doi.org/10.1016/j.amjmed.2014.04.035

[34] National Research Council (NRC) (US) Committee on Acute Exposure Guideline Levels (2008) Acute Exposure Guideline Levels for Selected Airborne Chemicals: Volume 6. National Academies Press (US), Washington DC, 2. https://www.ncbi.nlm.nih.gov/books/NBK207883/

[35] Behera, S.N. and Sharma, M. (2010) Investigating the Potential Role of Ammonia in Ion Chemistry of Fine Particulate Matter Formation for an Urban Environment. *Science of the Total Environment*, **408**, 3569-3575. https://doi.org/10.1016/j.scitotenv.2010.04.017

[36] Updyke, K.M., Nguyen, T.B. and Nizkorodov, S.A. (2012) Formation of Brown Carbon via Reactions of Ammonia with Secondary Organic Aerosols from Biogenic and Anthropogenic Precursors. *Atmospheric Environment*, **63**, 22-31. https://doi.org/10.1016/j.atmosenv.2012.09.012

[37] Michael, A.O. and Joepen, E.P. (2021) Modeling of Pollutants from Artisanal Refining of Crude Oil in Port Harcourt: A Case Study of Eagle Island. *World Journal of Advanced Engineering Technology and Sciences*, **2**, 34-44. https://doi.org/10.30574/wjaets.2021.2.1.0013

[38] Kim, K.-H., Kabir, E. and Kabir, S. (2015) A Review on the Human Health Impact of Airborne Particulate Matter. *Environment International*, **74**, 136-143. https://doi.org/10.1016/j.envint.2014.10.005

[39] Augustine, C. (2012) Impact of Air Pollution on the Environment in Port Harcourt, Nigeria. *Journal of Environmental Science and Water Resources*, **1**, 46-51. http://www.wudpeckerresearchjournals.org/JESWR

[40] Ebong, G.A. and Mkpenie, V.N. (2016) Air Quality Monitoring in Uyo Metropolis, Akwa Ibom State, Niger Delta Region of Nigeria. *International Journal of Scientific Research in Environmental Sciences*, **4**, 55-62. http://www.ijsrpub.com/ijsres https://doi.org/10.12983/ijsres-2016-p0055-0062

[41] Zhang, Y., Xu, X., Liu, J., Wang, H., Zou, W., Zhang, L. and Pan, X. (2017) Spatial and Temporal Variation Characteristics of Air Pollutants in China during 2014-2016. *Atmospheric Environment*, **161**, 235-246. https://doi.org/10.1016/j.atmosenv.2017.05.008