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Assessment of Ambient Air Quality and Meteorological Influence in Industrial Hubs of Rivers State, Nigeria

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Abstract
Concerns regarding the negative effects of declining air quality on the environment and public health have grown as a result of industrialization in Nigeria's Niger Delta. In four significant industrial cities in Rivers State—Port Harcourt, Eleme, Bonny, and Omoku—the concentrations of sulphur dioxide (SO2), nitrogen dioxide (NO2), carbon monoxide (CO), carbon dioxide (CO2), and volatile organic compounds (VOCs) were measured. In order to investigate their correlation with pollutant dispersion, meteorological data were recorded, including temperature (31.51°C–35.10°C), relative humidity (70.10%–81.31%), and noise levels (>94 dB in Eleme). World Health Organization (WHO) limits for particulate matter were exceeded; in Omoku, PM2.5 peaked at 1.100 mg/m³ (limit: 0.025 mg/m³), while PM1.0 peaked at 1.202 mg/m³ (limit: 0.050 mg/m³). Both the SO2 and NO2 concentrations were significantly above allowable limits, ranging from 64.57 to 101.36 μg/m³ and 70.33 to 110.26 μg/m³, respectively. The findings highlight the relationship between weather patterns and the buildup of pollutants in industrial settings, which has consequences for managing air quality and modelling climate health.

Keywords: Air Quality, Industrial Pollution, Meteorological Parameters, Particulate Matter.

Introduction

Air pollution is one of the world's most urgent environmental and public health issues; according to the World Health Organisation (WHO), it causes about seven million premature deaths a year, mostly from cancer, heart disease, and stroke (WHO, 2023). Due to its extensive effects on human health, ecological integrity, and climate systems, ambient air pollution—which is defined by the presence of particulate matter (PM), gaseous pollutants, and other hazardous substances—has drawn more attention than other types of pollution (Gurjar et al., 2016; Montero-Montoya et al., 2020; Qi et al., 2021). According to Ezeonyejiaku et al. (2022), industrial activities are a major source of these pollutants, especially in developing nations where environmental regulations may not be strictly enforced and emission control technologies are either antiquated or scarce. In Nigeria's oil-rich Niger Delta, Rivers State is a vital industrial centre with a large number of petrochemical plants, gas flaring sites, seaports, manufacturing facilities, and petroleum refineries (Nwankwoala & Ememu, 2018). The oil and gas industry in major industrial towns like Port Harcourt, Eleme, Bonny, and Omoku releases a complex mixture of pollutants, such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs), and suspended particulate matter ($PM_{2.5}$ and $PM_{1.0}$) (Gobo et al., 2012). In addition to deteriorating air quality, these pollutants also affect dispersion, transformation, and deposition processes by interacting with meteorological variables like temperature, relative humidity, atmospheric pressure, and wind speed (Pérez et al., 2020).

The temporal and spatial variations of air pollutant concentrations are largely determined by meteorological parameters. According to Seinfeld and Pandis (2016), temperature inversions may trap pollutants close to the surface, aggravating the formation of smog, while high relative humidity can promote the formation of secondary aerosols. Likewise, stagnant air and low wind speeds can restrict the spread of pollutants, creating localized hotspots for pollution, while high temperatures can speed up photochemical reactions, increasing ground-level ozone and secondary particulate matter (Owhoeke et al., 2023). Because Rivers State is a tropical monsoon climate, which features high humidity, heavy rainfall, and temperature differences between inland and coastal areas, meteorological factors have a particularly significant impact on the dynamics of air pollution (Seinfeld & Pandis, 2016; Nna et al. 2024). In industrialised and urbanised areas of the Niger Delta, prior research has documented high concentrations of particulate and gaseous pollutants, frequently surpassing WHO and Nigerian

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National Ambient Air Quality Standards (NAAQS) (Yakubu, 2017; Wambebe & Duan, 2020). The majority of studies, however, have either concentrated on a single pollutant or a single location, with few comprehensive analyses connecting pollutant levels to the weather patterns of several industrial centres. In order to forecast pollution episodes, comprehend the relationships between pollution sources and receptors, and create efficient mitigation strategies, such integrated assessments are essential.
The goal of this study, "Assessment of Ambient Air Quality and Meteorological Influence in Industrial Hubs of Rivers State, Nigeria," is to close this gap by performing a multi-location assessment in four important industrial areas: Port Harcourt, Eleme, Bonny, and Omoku. Major air pollutants ($PM_{2.5}$, $PM_{1.0}$, total particulate matter [TPM], SO_2, NO_2, CO, CO_2, and VOCs) are quantified, their variation across sites is examined, and the impact of important meteorological parameters on their distribution is assessed. In Rivers State and other industrialised regions of the South, the findings are intended to offer empirical support for environmental policy-making, industrial emissions control, and public health interventions.

Materials and Methods

Study Area

The study was carried out in Port Harcourt, Eleme, Bonny, and Omoku, four significant industrial centres in Rivers State, Nigeria. These areas were chosen because they have a high concentration of industrial activities, especially manufacturing, petrochemicals, shipping, and oil and gas production. The state capital and a significant urban-industrial hub is Port Harcourt, located at latitude 4°47′N, longitude 6°59′E. Eleme Petrochemicals and the Port Harcourt Refining Company are located in Eleme (latitude 4°46′N, longitude 7°06′E). The Nigeria LNG plant and several oil terminals are located on Bonny Island (latitude 4°27′N, longitude 7°10′E). Facilities for gas processing and power generation are centralised in Omoku (latitude 5°20′N, longitude 6°39′E). The region has a tropical monsoon climate, with mean annual temperatures between 25 and 32°C, high humidity (>70%), and average annual rainfall exceeding 2,300 mm.

Study Design

From March to May 2025, a cross-sectional field survey was conducted to record daily variability. The survey covered both morning (7:00–9:00) and afternoon (14:00–16:00) measurement sessions. Three fixed sampling points were placed at each industrial site, ideally downwind from the main sources of emissions and at least 500 meters apart. A Garmin GPSMAP 64 device was used to geo-reference sampling points for spatial mapping.

Air Quality Measurements

Ambient air quality parameters measured included particulate matter ($PM_{2.5}$, $PM_{1.0}$, and total particulate matter [TPM]), gaseous pollutants (SO_2, NO_2, CO, CO_2, and VOCs), using portable real-time air quality monitors.

- $PM_{2.5}$ and $PM_{1.0}$ were measured with a Temtop LKC-1000S+ laser particle counter (Temtop Inc., USA), which uses laser scattering technology with an accuracy of ±0.003 mg/m³. Data were recorded in mg/m³.
- Total Particulate Matter (TPM) was collected using a High-Volume Air Sampler (Model DH-77, Digitel AG, Switzerland) equipped with pre-weighed glass fiber filters (Whatman GF/A). Filters were conditioned at 20°C and 50% relative humidity before and after sampling, and the mass difference was used to calculate TPM concentration following *Gravimetric Method* (US EPA, 2017).
- SO_2 and NO_2 were measured using a MultiRAE Pro Gas Monitor (RAE Systems, USA), employing electrochemical sensors calibrated with certified gas standards.
- CO and CO_2 were determined with a Q-Trak Indoor Air Quality Monitor (Model 7575, TSI Inc., USA) based on non-dispersive infrared (NDIR) technology.
- Volatile Organic Compounds (VOCs) was measured using a ppbRAE 3000 photoionization detector (PID).

All instruments were calibrated before field deployment according to manufacturers' specifications, and data logging was set at 1-minute intervals.

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Meteorological Parameters

A Kestrel 5500 Weather Metre was used insita to measure meteorological parameters such as temperature, relative humidity, wind direction, wind speed, and atmospheric pressure. For correlation with air pollutant concentrations, data were averaged over the sampling period.

Data Analysis

For meteorological and pollutant parameters, descriptive statistics (mean ± standard deviation) were calculated. The outcomes were contrasted with the Nigerian Federal Ministry of Environment's Ambient Air Quality Standards and WHO's 2021 guidelines.

Ethical Considerations

The study was approved ethically by the Rivers State Ministry of Environment and carried out in accordance with the Nigerian Environmental Guidelines. Without affecting private property or industrial operations, sampling was done in locations that were open to the public..

Results

Estimated meteorological parameters of the study locations

The estimated results of the meteorological parameters in the industrial area considered in Rivers State are illustrated in Table 1

Table 1 Estimated meteorological parameters of the study locations

Parameters	Port harcourt	Eleme	Bonny	Omoku
RH (%)	81.31±0.17	75.10±0.14	71.11±0.37	70.10±0.13
Temp. (ºC)	31.51±0.22	32.10±0.63	35.10±0.70	34.00±1.13
Pressure (Pa)	1007±0.04	1006±0.10	1005±0.102	1004±0.110
Noise(dB)	84.10±3.12	94.01±4.42	70.10±3.11	67.01±4.10
Altitude	10.12±0.22	12.01±0.11	11.00±0.92	11.00±0.09

N=10

The four study sites—Port Harcourt, Eleme, Bonny, and Omoku—have estimated meteorological parameters that exhibit clear spatial variations due to both anthropogenic and geographic factors. According to Wikipedia (2024), the relative humidity was highest in Port Harcourt (81.31 ± 0.17 %) and gradually decreased through Eleme (75.10 ± 0.14 %), Bonny (71.11 ± 0.37 %), and Omoku (70.10 ± 0.13 %). This pattern is consistent with the coastal-to-inland moisture gradient seen in Rivers State, where humidity usually ranges from 90% to 100% and not often falls below 60% (Baguskas et al., 2014; Owoade et al., 2015). The average temperature was between 31.51 ± 0.22 °C in Port Harcourt and 35.10 ± 0.70 °C in Bonny, with Omoku (34.00 ± 1.13 °C) and Eleme (32.10 ± 0.63 °C) in between. These temperatures are consistent with the tropical monsoon climate of the area, where being close to the coast can have a mild cooling effect while inland regions experience more heat buildup (Subramanian et al., 2023). Given that elevation and atmospheric pressure are inversely correlated, the slight decrease in atmospheric pressure from Port Harcourt (1007 Pa) to Omoku (1004 Pa) was consistent with the slight variations in elevation between the sites (Geodatos, 2024). Due to high concentration of industrial and petroleum refining activities, Eleme recorded the highest average noise level (94.01 ± 4.42 dB) (Nsude et al., 2024). Port Harcourt came in second with 84.10 ± 3.12 dB, while Bonny and Omoku had significantly lower levels, reflecting their quieter, less industrialised environments (70.10 ± 3.11 dB and 67.01 ± 4.10 dB, respectively). As expected given the Niger Delta's generally low-lying topography, the altitude measurements were fairly close, ranging from 10.12 ± 0.22 m in Port Harcourt to 12.01 ± 0.11 m in Eleme, with Bonny and Omoku both at roughly 11 m (Akinrinwoye, 2022). With implications for local climate comfort, air quality, and noise exposure patterns, the data collectively show a consistent environmental gradient influenced by industrial activity, coastal proximity, and minor topographic variations.Temperature readings were between 31.51°C in Bonny and 35.10°C in Port Harcourt. The relative humidity was high, ranging from 81.31% in Bonny to 70.10% in Port Harcourt. Eleme recorded the highest ambient noise level (>94 dB), surpassing allowable limits in every location.

Particulate matter in the air of industrial areas in Rivers State

The results of the particulate matter in the industrial area considered in Rivers State are shown in Table 2

Table 2 Particulate matter (mg/m^3) in air of industrial areas in Rivers State

Parameters	Port harcourt	Eleme	Bonny	Omoku	Standard AQ
PM2.5	0.412±0.11	0.312±0.22	0.712±0.12	1.100±0.51	0.025
PM10	0.541±0.23	0.519±0.11	0.941±0.19	1.202±0.15	0.050
TPM	11.85±1.02	11.43±0.73	23.53±3.31	27.34±4.66	

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$PM_{2.5}$ levels in Rivers State's industrial areas ranged from 0.312 ± 0.22 mg/m³ in Eleme to 1.100 ± 0.51 mg/m³ in Omoku, dramatically exceeding the World Health Organization's (WHO) 24-hour limit of 0.015 mg/m³ (15 µg/m³) (WHO, 2021). Similar trends were seen in $PM_{1.0}$ concentrations, which significantly exceeded the WHO recommendation of 0.045 mg/m³ (45 µg/m³) from 0.519 ± 0.11 mg/m³ in Eleme to 1.202 ± 0.15 mg/m³ in Omoku (WHO, 2021). Total particulate matter (TPM) was also high, ranging from 11.43 ± 0.73 mg/m³ in Eleme to 27.34 ± 4.66 mg/m³ in Omoku. The highest values were found in Bonny and Omoku, most likely as a result of intense industrial activity, such as gas flaring, crude oil refining, and related combustion processes (Anenberg et al., 2020). Because fine particles like $PM_{2.5}$ enter the respiratory system deeply and increase the risk of asthma, chronic obstructive pulmonary disease (COPD), cardiovascular diseases, and early mortality, these high concentrations endanger human health (Pope & Dockery, 2006; Lelieveld et al., 2019). The variations in industrial density, emission control methods, and weather patterns may also have an impact on the higher particulate levels seen in Omoku and Bonny as opposed to Port Harcourt and Eleme (Ogbonna & Udotong, 2021). In order to lessen the substantial negative effects of particulate pollution on the environment and human health in Rivers State, the findings emphasise the urgent need for stronger enforcement of emission standards, thorough air quality monitoring, and public health initiatives.

Gaseous Pollutants

Table 3 outlines the concentrations of five critical gaseous air pollutants—sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), carbon dioxide (CO_2), and volatile organic compounds (VOCs)—measured in four industrial areas of Rivers State: Port Harcourt, Eleme, Bonny, and Omoku

Table 3: Gaseous contaminant in air of industrial areas in Rivers State

Location	SO_2 µg/m³	NO_2 µg/m³	CO µg/m³	CO2 µg/m³	VOCs µg/m³
Port Harcourt	85.61±0.50	92.42±0.11	6.21±8.81	56.01 ±0.13	1.83±3.02
Eleme	101.36±0.29	110.26±2.71	7.44±4.03	60.21±0.71	2.54±1.06
Bonny	76.83±1.01	83.11±0.81	5.15±9.11	58.04±0.72	1.40±2.30
Omoku	64.57±0.61	70.33±1.21	4.71±6.81	37.20±0.23	1.16±1.21

N=10

Both the intensity of industrial activity and local dispersion conditions are reflected in the notable spatial variations in the concentrations of gaseous contaminants in the air of industrial areas in Rivers State. The World Health Organization's (WHO) 24-hour guideline of 40 µg/m³ was exceeded in all locations, with sulphur dioxide (SO_2) levels ranging from 64.57 ± 0.61 µg/m³ in Omoku to 101.36 ± 0.29 µg/m³ in Eleme. This suggests a high risk of respiratory irritation and exacerbation of conditions like asthma (Owoade et al., 2015). Nitrogen dioxide (NO_2) showed a similar pattern, peaking in Eleme (110.26 ± 2.71 µg/m³) and decreasing in Omoku (70.33 ± 1.21 µg/m³). These levels are significantly higher than the WHO's annual mean limit of 40 µg/m³, which is linked to a higher risk of chronic respiratory diseases and a reduction in lung function (Anenberg et al., 2022). Eleme had the highest concentration of carbon monoxide (CO) (7.44 ± 4.03 µg/m³) and Omoku had the lowest (4.71 ± 6.81 µg/m³), while Port Harcourt had the highest (6.21 ± 8.81 µg/m³) and Bonny had the lowest (5.15 ± 9.11 µg/m³). These concentrations were likely caused by incomplete combustion from industrial and vehicular sources (Amorim-Maia et al., 2022). Although ambient CO_2 is not normally regulated for health at such scales, elevated values can indicate strong emission sources and inadequate ventilation. The range of carbon dioxide (CO_2) was 37.20 ± 0.23 µg/m³ in Omoku to 60.21 ± 0.71 µg/m³ in Eleme (Peng et al., 2022). Eleme had the highest levels of volatile organic compounds (VOCs) (2.54 ± 1.06 µg/m³), followed by Port Harcourt (1.83 ± 3.02 µg/m³), while Bonny (1.40 ± 2.30 µg/m³) and Omoku (1.16 ± 1.21 µg/m³) had the lowest (Lelieveld et al., 2019; USEPA, 2023). Eleme and Port Harcourt are major industrial hubs with petrochemical facilities, petroleum refining, and heavy traffic, which is consistent with their overall pattern of higher SO_2, NO_2, CO, CO_2, and VOCs. In contrast, Bonny and Omoku, while still industrially active, show relatively lower concentrations, possibly as a result of differences in emission density and atmospheric dispersion. These findings highlight the critical need for ongoing air quality monitoring, targeted emission control, and health risk assessments in the industrial zones of the Niger Delta.

Conclusion

Concentrations of SO_2, NO_2, CO, CO_2, and VOCs were found to be significantly higher than WHO guideline limits for ambient air quality in a number of cases, especially for SO_2 and NO_2, according to an assessment of gaseous contaminants in Rivers State's industrial areas. Because of the significant industrial presence, petrochemical operations, petroleum refining, and heavy traffic, Eleme and Port Harcourt continuously had the highest pollutant levels. Although the concentrations in Bonny and Omoku were still higher than those in other countries, they were comparatively lower. This is probably because of variations in emission density and

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atmospheric dispersion patterns. Significant risks to public health are posed by the elevated pollutant levels, including cardiovascular problems, respiratory irritation, diminished lung function, and long-term risks like cancer from prolonged VOC exposure. The results highlight the urgent need for mitigation measures to stop the decline in air quality in the industrial corridor of the Niger Delta.

Recommendations

1. Strengthen Regulatory Enforcement – Implement and enforce stricter compliance with national and WHO ambient air quality standards, particularly in heavily industrialized areas.
2. Adopt Cleaner Production Technologies – Encourage industries to utilize low-sulfur fuels, improve combustion efficiency, and adopt advanced emission control technologies to reduce SO_2, NO_2, and VOC emissions.
3. Continuous Air Quality Monitoring – Establish a comprehensive and transparent real-time air quality monitoring network to provide data for policy-making and public health advisories.
4. Urban and Industrial Planning – Introduce buffer zones between industrial complexes and residential areas to reduce direct exposure of communities to harmful emissions.

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