Global Journal of Earth and Environmental Science
Volume 9(2), pages 55-68, August 2024
Article Number: 358BF6FA2
ISSN: 2636-6002
https://doi.org/10.31248/GJEES2024.152
https://integrityresjournals.org/journal/GJEES
Full Length Research

Assessment of emission levels at the Port Harcourt International Airport and its environs, Omagwa, River State, Nigeria

Rosemary N. Aroh[1], Aroloye O. Numbere[2]*, Udi O. Emoyoma[3] and Kenneth Aroh[4]

[1]Institute of Natural Resources and Environmental Studies, University of Port Harcourt, P. M. B. 5323, Choba, Nigeria.
[2]Department of Animal and Environmental Biology, University of Port Harcourt, P. M. B. 5323, Choba, Nigeria.
[3]African Centre of Excellence for Public Health and Toxicological Research (ACE-PUTOR), University of Port Harcourt, P. M. B. 5323, Choba, Nigeria.
[4]National Oil Spill Detection and Response Agency (NOSDRA) Reference Laboratory, Port Harcourt, Rivers State, Nigeria.

*Corresponding author: Email: aroloyen@yahoo.com

Received 2nd May 2024; Accepted 5th August 2024

ABSTRACT: The increase in migration worldwide has necessitated frequent air travel, which has put more pressure on the host communities of major airports. Many researchers have studied the environmental effects of aircraft. This study thus postulates that gaseous emissions from aircraft will negatively impact the atmosphere around the airport and neighbouring communities. To determine the concentration of atmospheric pollutants, total volatile organic compounds (TVOC), and particulate matters (PM_1, $PM_{1.5}$ and PM_{10}), air samples were collected using handheld Aeroqual monitors at nine different locations in and out of the airport and in dry and wet seasons to measure nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), particulate matter PM_{10}, $PM_{2.5}$, Hydrogen sulphide (H_2S), Methane (CH_4), Ammonia (NH_3), Ozone (O_3), Carbon IV oxide (CO_2). The result obtained gave a mean value of the noxious gases as SO_2 (0.00±0.00 - 0.04±0.03 ppm), NO_2 (0.00±0.00 - 4.60±2.82 ppm), CO (0.00±0.00 - 1.48±1.48 ppm), H_2S (0.00±0.00 - 2.40±0.82 ppm), NH_3 (0.00±0.00 - 0.28±0.17 ppm), CO_2 (0.04±0.01 - 0.18±0.08 ppm) and O_3 (0.02±0.01 - 0.15±0.04). Nitrogen dioxide (NO_2) in the cargo area (4.60±2.82 ppm) had the highest concentration followed by H_2S in cargo (2.40±0.82 ppm) and CO in apron and Ipo 3 (1.48±1.48 ppm). There was a higher concentration of SO_2 inside, while a higher concentration of NO_2, CO, H_2S, CO_2, and O_3 outside the airport. There was a higher concentration of all pollutants during the dry season except O_3, which was higher during the wet season. A One-way Analysis of variance (ANOVA) showed that there was a significant difference ($p<0.05$) in the concentration of TVOC across the stations, between indoor and outdoor environments, and in wet and dry seasons. The total mean volatile organic compound concentration is highest in the host community. Similarly, PM_1 was highest in Car Park 2, while $PM_{2.5}$ and PM_{10} had the highest concentration in the host communities. The result obtained implies that atmospheric pollutants may negatively affect members of the host communities and commuters near the airport. Thus, the atmosphere around the airport should be monitored daily to forestall increases beyond the acceptable limit. Similarly, vehicles that do not pass emission tests should be prevented from entering the vicinity of the airport.

Keywords: Airport, climate, emissions, particulate matter, pollutants.

INTRODUCTION

Air pollution is well-known to be very noxious to humans and the ecosystem since it is toxic. Its impacts are seen on humans, plants, and animals and can potentially harm the environment, which is a key factor for humans' existence (Chukwu Okeah *et al*., 2021).

Ambient air pollution is a global health challenge, with an

estimated 3.1 million deaths yearly (Lelieveld *et al*., 2015; Newby *et al*., 2015). Exposure to ambient contamination is the major health risk in the environment and grades ninth among modifiable infection risk factors (Newby *et al*., 2015). Most of the mortalities attributable to air pollution exposures are a result of acute ischemic cardiovascular eventualities. In addition to excess mortality, air contamination is connected to notable reductions in healthy life existence and productivity (Graff Zivin *et al*., 2023).

Air pollution comprises many gases and particulate constituents, harming the cardiovascular and respiratory systems. Its makeup differs significantly, subject to the source, emission rate, and sunlight and wind conditions (Kapoor *et al.,* 2024). Components of air pollutants include nitrogen dioxide (NO_2), nitric oxide (NO), sulphur dioxide (SO_2), Ozone (O3), and carbon monoxide (CO) (Hamanaka and Mutiu, 2018).

Aviation is a major source of social and economic benefits that also contribute to local air quality and affect people's health and quality of life around the airport vicinity (Zaporozhets and Synylo, 2019). An increase in demand for air transport also leads to an increase in aviation emissions. Air pollution in urban areas in both developing and developed countries adversely affects human health, urban ecosystems, building materials, and visibility (Cichowicz and Bochenek, 2024; Feng *et al*. 2024). The five most common air pollutants, are sulphur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NOx) (i.e., nitric oxide (NO) and nitrogen dioxide (NO_2)), Ozone (O_3) and particulate matter with an aerodynamic diameter of 10 um or less (PM_{10}) were investigated. The outlined pollutants acting individually or in combination can cause health challenges. For example, SO_2 is a respiratory irritant and can cause constriction of the airways of the lungs, particularly in people with asthma and chronic lung disease. NO_2 acts as an irritant, causing inflammation of the airways and increasing susceptibility to respiratory infections. Fine particulate matter can penetrate the airways, carrying surface-absorbed harmful compounds into the lungs, increasing the risk of health effects, including cancer. Ozone is an oxidising agent that acts as an irritant, causing respiratory tract inflammation and irritating the eyes, nose, and throat, causing coughing and discomfort while breathing (Satpathy *et al.* 2024).

Although several physical activities (volcanoes and fires) may release different environmental pollutants, anthropogenic activities cause environmental air pollution. Hazardous chemicals can escape into the environment by accident. However, several air pollutants are released from industrial facilities and other activities and may adversely affect human health and the environment (Omolaoye *et al*., 2024, Wei *et al*., 2024). An air pollutant is any substance in the air that may harm humans, animals, vegetation, or material (Saxena *et al*., 2019).

Air pollutant concentrations are not only influenced by the sources of emission but also by meteorological variables (Pearce *et al*., 2011; Habeebullah, 2013). Meteorological variables play an essential role in the dispersion, transport, photochemical reactions, and secondary pollutants formation, including ozone, NO_2, and particulate (e.g., sulphate and nitrate ions); however, despite the presence of a vast body of literature, many aspects of the association between air pollutants and meteorology are still not apparent (Pearce *et al*., 2011) due to the interaction between various meteorological variables, for example, the dependency of boundary layer height on surface temperature, the link between surface temperature and radiation, or the association between relative humidity and temperature, which makes separating the effects of individual parameters a highly complex task. Meteorological variables can affect the concentrations of air pollutants directly (e.g., photochemical ozone formation or dispersing locally emitted pollutants) or indirectly by affecting other meteorological parameters affecting other pollutants (Yan *et al*., 2024).

Increasing greenhouse gas (GHG) concentration, especially CO_2, is fundamental to climate change. Also, the aviation industry plays a vital role in the upsurge in the concentration of greenhouse gases. Statistics have shown that the emissions from the aviation sector contribute about 3.5% of total GHG emissions (Sreenath *et al*., 2022). Increased rates of adverse health outcomes ranging from hypertension, cardiovascular disorders, birth outcomes, respiratory diseases, and learning deficits in children have been observed near airports (Hudda *et al*., 2020).

The percentage of emissions by the aviation sector increases two-fold because of the combustion activities of aircraft, which emit greenhouse gases. Due to combustion activities, aircraft emit greenhouse gases (Tsukanov and Yepifanov, 2024). Continuous accumulation of emitted carbons from local and international flights over a long period contributes mainly to global warming and ozone depletion, resulting in severe environmental impacts on plants, animals, and humans at large (Murgan and Mustapha, 2017). Aircraft exhausts are only one of several emission sources at an airport (ICAO, 2013). Although exhaust plumes from aircraft engines were conventionally considered to account for most of the emissions, other sources are present within modern airports and contribute to air pollution at the local scale. Among these, tyre, brake, asphalt wear, and the re-suspension of particles due to the turbulence created by the aircraft movements can account for significant fractions of total particulate matter mass (Masiol and Harrison, 2014).

Globally, there is a continuous increase in the demand for air transport and intensification of growing cities near the airport vicinity, which also leads to an increase in the release of NO_2, CO_2, CO, and many others to the atmosphere and lithosphere (Boniface *et al*., 2021; Sinha, 2024). When hydrocarbon fuels, such as coal and natural gas, are utilized, their carbon constituent is transformed

into carbon dioxide and other forms of carbon. This emission adds to greenhouse gases and damages the environment and human health (Zaporozhets and Synylo, 2019). Aviation affects the environment by emitting pollutants from aircraft and supporting airport infrastructure, impacting human health, well-being, and climate (Rötger *et al*., 2023).

Also, an upsurge in the emission of toxic air pollutants may be a prevailing influence on the meteorological conditions of the airport. Most studies on air quality in Nigeria and Niger Delta, in particular, focused on pollutants emanating from the oil industry (Faronbi *et al*., 2024; Udoetok *et al*., 2009). More information on the non-oil sectors, such as aviation, waste dumpsites, food processing outfits, abattoirs, and the correlation with climatic and meteorological indicators is needed. In Port Harcourt International Airport, much attention has been given to assessing the noise level and microclimatic conditions, but limited studies on the emission of toxic air pollutants and their impact on the immediate environment and the neighbouring communities. It is therefore important for this study to be carried out to assess if the concentration levels of these toxic air pollutants are within WHO (2006) permissible limits.

This research aims to assess the emission of gases and noise pollution level of Port Harcourt International Airport and its environs in Rivers State. The objectives of the study are to:

1. Evaluate the micro-climatic parameters (relative humidity, wind speed, and air temperature) of the Port Harcourt International Airport and environs.
2. Determine the correlation between micro-climatic parameters and the air quality parameters of Port Harcourt International Airport.
3. Determine the seasonal variation of air quality parameters in Port Harcourt International Airport and its environs.
4. Correlate between indoor and outdoor air quality of the Port Harcourt International Airport.

MATERIALS AND METHODS

Study area

The study area is the Port Harcourt International Airport (Figure 1), located in Omagwa, a suburb of Port Harcourt, the capital city of Rivers State in Nigeria. Port Harcourt Airport (PHA) hosts both domestic and international flights. The airport has a single asphalt-surfaced runway length of 9,846 ft (3,001 m) and a width of 197 ft (60 m). The landing and take-off distances of the runway are 9,846 ft (3,001 m) and 10,246 ft (3,123 m), respectively. It is the third busiest airport in Nigeria in terms of passenger traffic. The airport recorded domestic and international passenger traffic of 862,550 and 83,810, respectively; only Abuja and Lagos recorded higher passenger traffic.

The geographical coordinates of Port Harcourt are 4.777 degrees latitude, 7.013 degrees longitude, and 52 ft elevation. Mean maximum monthly temperatures range from 28 to 33°C, while the mean minimum monthly temperatures are in the range of 17 to 24°C. The mean monthly temperature is in the range of 25 to 28°C. The mean annual temperature for the State is 26°C. The hottest months are February to May. Rain occurs, on average, every month of the year but with varying duration. The State is characterized by high rainfall, which decreases from south to north. Total annual rainfall decreases from about 4,700 mm on the coast to about 1,700 mm in the extreme north of the State.

Sample and sampling techniques

Monthly and seasonal sampling was carried out for eight months at nine (9) different locations within the Port Harcourt International Airport and nearby residences. The sampling was done in the mornings and evenings when most flights depart and arrive at the international airport**.** Coordinates for the various sampling locations were obtained using a Geographic Positioning System (GPS) – Garmin GPS map 76CSX (Table 1).

Method of data collection

The study's data were derived from primary and secondary sources. Secondary data were obtained from literature relating to the current study. These include related research reports in the field of study from journals, textbooks, and magazines. The primary data were obtained via field measurement of carbon emissions and prevailing micro-climatic parameters at different points within Port Harcourt International Airport and host communities.

Air quality

Sampling and measurements of the chemical constituents of atmospheric pollutants were measured *in situ* with handheld air quality monitors as follows: Ambient air quality measurements were carried out on site using the Aeroqual gas monitor series 500 and Met One Instrument Aerosol Mass Monitor, which had up-to-date calibration. The Aeroqual handheld monitors are specifically designed to give accurate ambient gas measurement, with a dedicated sensor per parameter. The parameters measured include nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), particulate matter PM_{10}, $PM_{2.5}$, Hydrogen sulphide (H_2S), Methane (CH_4), Ammonia

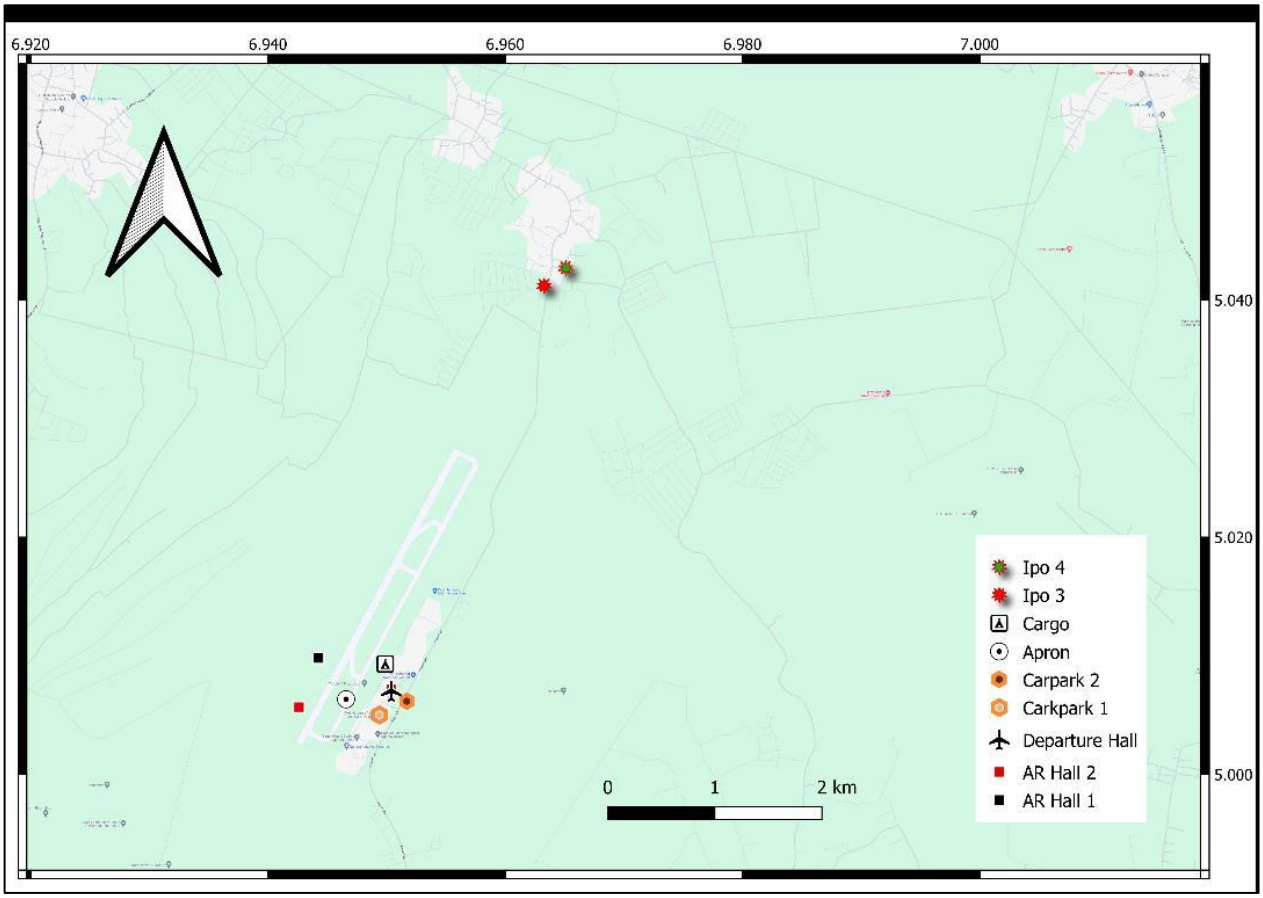

Figure 1. Map of study.areea showing the locations around the Port Harcourt, International Airport. Omagwa, Rivers State, Nigeria.

Table 1. Sampling point and coordinates.

Station	Name	Coordinate
1	AR Hall1	6.949617E, 5.006796N
2	AR Hall 2	6.949608E, 5.006888N
3	Departure Hall	6.950265E, 5.007697N
4	Car Park 1	6.950257E; 5.006556N
5	Car Park 2	6.950257E; 5.006556N
6	Apron	6.948950E, 5.006923N
7	Cargo	6.951959E; 5.008350N
8	Ipo 3	6.963888E; 5.043635N
9	Ipo 4	6.964213E; 5.045074N

(NH_3), Ozone (O_3), Carbon IV oxide (CO_2), and total volatile organic compounds (TVOCs). Met One Instrument Aerosol Mass Monitor was used for measuring the $PM_{2.5}$ and PM_{10}. The concentrations of particulate matter ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}) and gaseous pollutants (NO_2, SO_2, H_2S, CO, CO_2, O_3, NH_3, and TVOCs) were determined by interchangeably inserting sensor heads on the base monitor and allowing the required warming time before actual measurement.

Nitrogen Dioxide (NO_2)

An Aeroqual 500 Multi-Gas Analyzer, with up-to-date

calibration, was used to detect NO_2. Its detection range is between 0 and 20 ppm, with a resolution of 0.01 ppm. The alarm set point (low/high) was set at 2 and 10 ppm, respectively. Measurements were carried out by holding the sensor to a height of about 1.5 meters in the direction of the prevailing wind, and readings were recorded at stability.

Sulphur Dioxide (SO_2)

An Aeroqual 500 Multi-Gas Analyzer, with up-to-date calibration, was used to detect SO_2. It has a detection range between 0-20 ppm and a resolution of 0.01 ppm. The alarm set points (low/high) will be set at 2 and 10 ppm, respectively. Measurements were taken by holding the sensor to a height of about 1.5 meters in the direction of the prevailing wind, and readings were recorded at stability.

Atmospheric pollutants (i.e., Carbon Monoxide (CO), carbon dioxide (CO_2), ozone (O_3), hydrogen sulphide (H_2S) and ammonia (NH_3)

An Aeroqual 500 Multi-Gas Analyzer, with up-to-date calibration, was used to detect CO, CO_2 and O_3. The equipment detects CO via an electrochemical sensor that generates a signal linearly proportional to the gas concentration. The detection range is 0-500 ppm, and the detection limit is 1 ppm. Measurements were taken by holding the sensor to a height of about 1.5 meters in the direction of the prevailing wind, and readings were recorded at stability.

Suspended Particulate Matter (SPM) PM_{10}, $PM_{2.5}$ and TVOC

The measurement of Suspended Particulate Matter (SPM) was done using a Met One Instrument, Inc. aerosol Mass Monitor. The Ambient particulate Monitor with recorder collects and records "real-time" information on airborne particulate concentration and provides continuous particle monitoring. Measurements were taken by holding the equipment to a height of about 1.5 meters in the direction of the prevailing wind, and readings were recorded at stability.

Micro climatic parameters

Wind speed (m/s)

A Digital Sky master mini Weather Station AZ 8910 was used to measure the wind speed in meters per second (m/s). This portable equipment measures the wind speed once switched on and held in position.

Air temperature (°C)

The air temperature in degrees Celsius (°C) was measured with a Sky master mini Weather Station AZ 8910. The meter was carefully exposed to the air for a few minutes in the respective sampling positions. The temperatures were then read off and recorded.

Relative humidity (%)

A logger (Testo 450) was used to determine the relative humidity. The logger is equipped with an atmospheric pressure probe (Barometer) and a relative humidity probe (Hygrometer). The logger measures and gives the value in percentage (%).

All these methods are in line with the recommendations of the Federal Ministry of Environment.

Statistical analysis

All data from this study are presented as means, standard deviations, and standard error of the mean. Quantitative techniques in data presentation and analysis were employed in the study. SPSS version 22 was used for the statistical analysis. A one-way ANOVA was used to determine the significant difference in gaseous emissions. Microsoft EXCEL was used to illustrate graphs for the air quality parameters. Statistical significance of the values was considered at $p<0.05$ (Logan, 2010).

RESULTS

Concentration levels of emissions pollutants

In all, nine stations were identified and geo-referenced (Table 1). The results of the noxious gases across the study area are presented in Table 2 and Figures 2 to 5.

NO_2

The mean concentration of Nitrogen IV Oxide across the various stations ranged between 0.00±0.00 to 4.60 ± 2.82 ppm µg/m^3 with the lowest concentration observed at Arrival Hall 1, Car Parks 1 and 2. In contrast, the highest concentration (4.60±2.82) was observed in the cargo section. The ANOVA result showed a significant difference across the various stations ($p<0.05$).

Table 2. Mean concentration of noxious gases at different locations around the Port Harcourt International Airport, Rivers State, Nigeria (± SE).

Locations	Gases(ppm)						
	SO_2	NO_2	CO	H_2S	NH_3	CO_2	O_3
Apron	0.00±0.00	0.09±0.02	1.48±1.48	0.08±0.003	0.28±0.17	0.18±0.08	*0.08±0.03
Arrival H1	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.04±0.02	0.02±0.01
Arrival H2	0.00±0.00	0.004±0.002	0.00±0.00	0.00±0.00	0.00±0.00	0.04±0.01	0.1±0.04
Cargo	0.04±0.03	4.60±2.82	0.00±0.00	2.40±0.82	0.00±0.00	0.04±0.01	0.09±0.05
Car Park 1	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.00±0.00	0.16±0.03	0.23±0.06
Car Park 2	0.00±0.00	0.00±0.00	0.00±0.00	0.01±0.002	0.00±0.00	0.10±0.04	0.15±0.04
Departure	0.00±0.00	0.008±0.01	0.00±0.00	0.13±0.05	0.00±0.00	0.06±0.02	0.02±0.004
Ipo 3	0.00±0.00	0.05±0.03	1.26±1.26	0.004±0.004	0.00±0.00	0.07±0.02	0.07±0.06
Ipo 4	0.00±0.00	0.05±0.03	1.48±1.48	0.01±0.01	0.12±0.07	0.08±0.03	0.05±0.04
WHO Limit	0.02	0.20	>10.00		0.60		0.075

*higher than the WHO (20038) standard at the Port Harcourt International Airport.

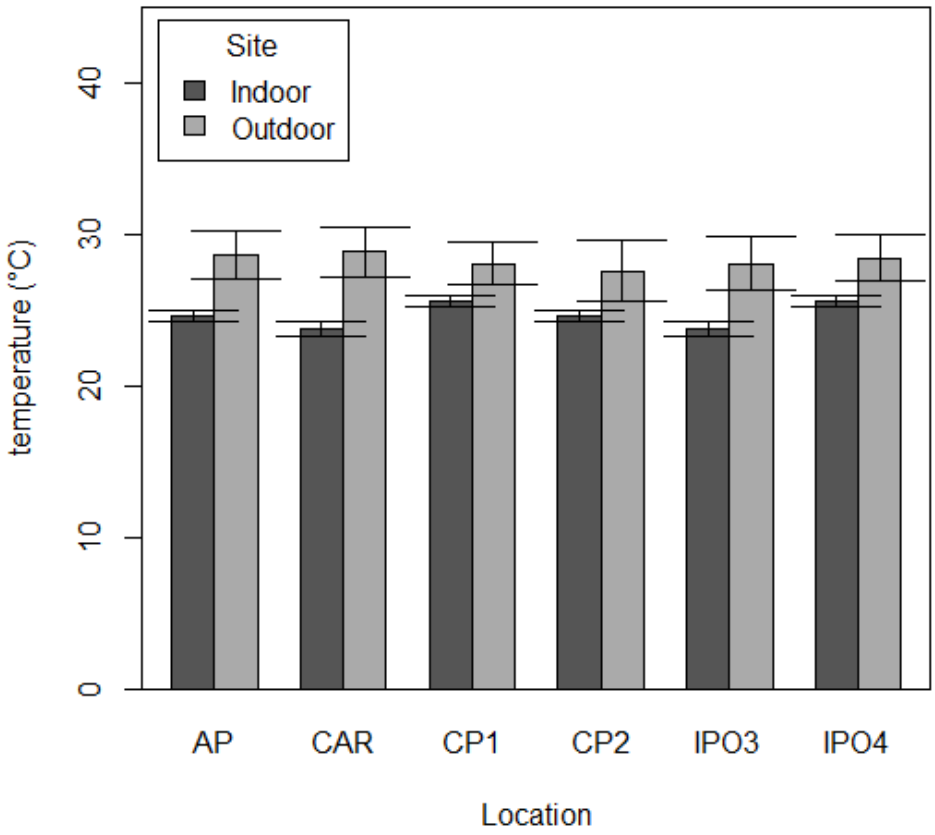

Figure 2. Indoor and Outdoor Temperature concentrations. Where AP = apron, CAR = cargo area, CP1 = car park 1, CP2 = car park 2, IPO 3 = ipo3 = host community to the airport, and IPO4 = host community to the airport.

SO_2

The mean concentration of SO_2 was 0.00 ppm across all stations except the cargo area (0.04±0.03 ppm). A One-way Analysis of variance (ANOVA) showed that there was no significant difference in the concentration of SO_2 across the various stations ($p>0.05$). SO_2 concentration was higher in the indoor area than in the outdoor (Table 3).

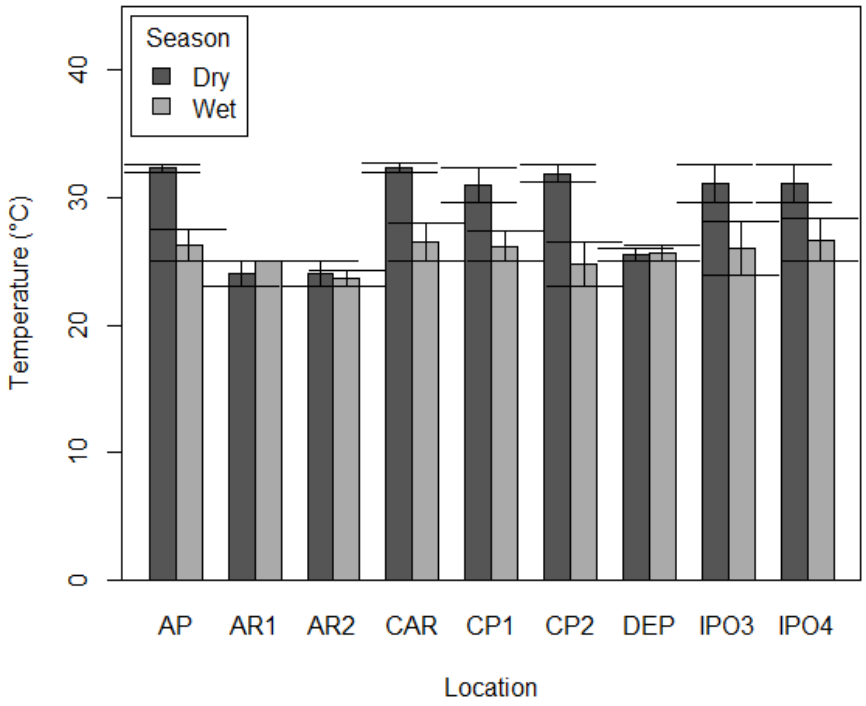

Figure 3. Seasonal concentration of Temperature in the study area. Where AP=apron, AR 1=arrival 1, AR 2= arrival 2, CAR= cargo area, CP1= car park 1, CP2= car park 2, DEP= departure, IPO 3= ipo3= host community to the airport, IPO4= host community to the airport.

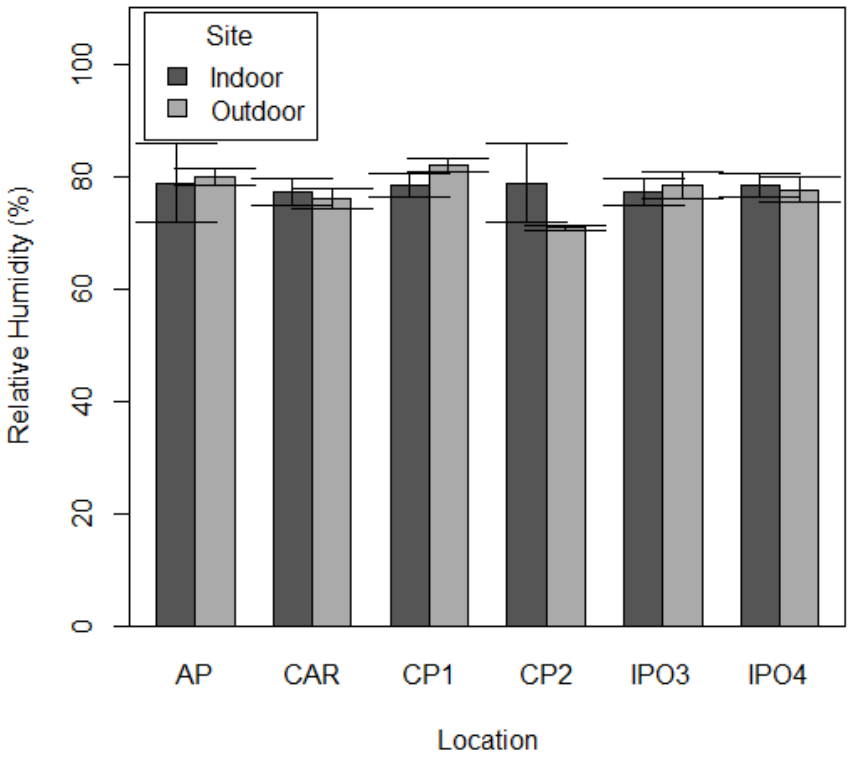

Figure 4. Indoor and outdoor Relative Humidity (%) across the study area.

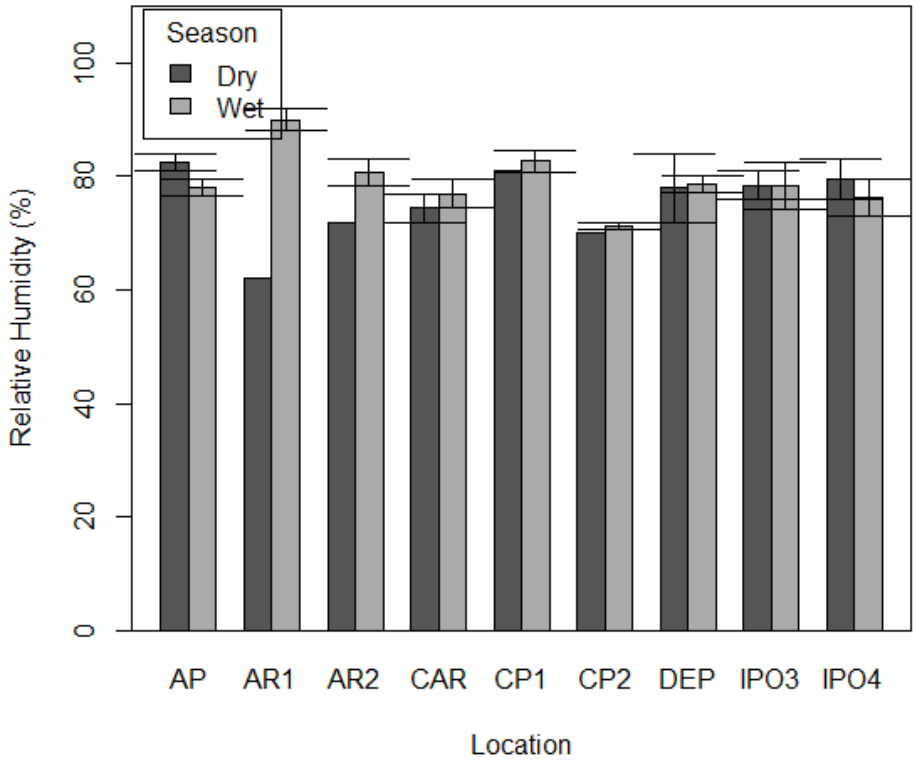

Figure 5. Seasonal variation of Relative Humidity (%) across the study area. Where AP=apron, AR 1=arrival 1, AR 2=arriving 2, CAR=cargo area, CP1=car park 1, CP2=car park 2, DEP=departure, IPO 3=ipo3=host community to airport, IPO4=host community to airport.

CO

The concentration of carbon monoxide ranged between 0.00±0.00 to 1.48±1.48 ppm. All the indoor areas recorded a concentration of 0.00 ppm, indicating that the outdoor area had the highest concentration of CO. In terms of seasons, the dry season recorded the highest carbon monoxide 1.17±0.64 ppm while the wet season recorded 0.00 ppm.

NH_3

The mean concentration of Ammonia in the study area ranged between 0.00 and 0.28±0.17 ppm. Ammonia was absent in all the indoor areas of the airport and only recorded in the Apron and Ipo 4 which are in the outdoor areas. Seasonal variation in the concentration of Ammonia (NH_3) showed that NH_3 was not present in the wet season but recorded in the dry season (0.11±0.06 ppm).

CO_2

The mean concentration of Carbon IV Oxide in the study area ranged between 0.04±0.01 and 0.18±0.08 ppm. The highest mean concentration was observed at the Apron, while the lowest concentration was recorded at the Arrival Halls. Seasonal variation in the concentration of CO_2 showed that Carbon IV Oxide was present in both seasons, with a higher concentration in the dry season (0.10±0.03 ppm). Also, the outdoor area of the airport recorded a higher concentration than the indoor area (Table 3).

H_2S

The mean concentration of Hydrogen sulphide in the study area ranged between 0.00±0.00 and 2.40±0.82 ppm. The highest mean concentration was observed in the Cargo area, while the lowest concentration was recorded in the Arrival Halls. Seasonal variation in the concentration of H_2S showed that the concentration of Hydrogen sulphide was higher in the dry season (0.70±0.67 ppm). Also, the outdoor area of the airport recorded a higher concentration than the indoor area (Table 3). Comparatively, the hydrogen sulphide concentration across the study area was below the WHO permissible limit of 10 ppm.

Table 3. Mean concentration of noxious gases inside and outside the Port Harcourt International Airport, Rivers State, Nigeria.

Area	Gases(ppm)						
	SO_2	NO_2	CO	H_2S	NH_3	CO_2	O_3
Inside	4.47±4.47	0.004±0.002	0.00±0.00	0.04±0.02	0.00±0.00	0.05±0.01	0.05±0.02
Outside	0.006±0.01	0.80±0.53	0.70±0.40	0.41±0.40	0.07±0.03	0.11±0.02	0.11±0.02

Table 4. Mean concentration of noxious gases between seasons at the Port Harcourt International Airport, Rivers State, Nigeria.

Area	Gases(µg/m³)							*p-value
	SO	NO_2	CO	H_2S	NH_3	CO_2	O_3	
Dry	3.73±3.72	1.32±0.87	1.17±0.64	0.70±0.67	0.11±0.06	0.10±0.03	0.05±0.02	< 0.05
Wet	0.00±0.00	0.01±0.01	0.00±0.00	0.01±0.01	0.00±0.00	0.08±0.01	0.12±0.02	

*Significant.

O_3

The mean concentration of Ozone (O_3) in the study area ranged between 0.02±0.01 to 0.23±0.06ppm. The highest mean concentration was observed at the Car Park 1 area, while the lowest was recorded at the Arrival Halls. Seasonal variation in the concentration of ozone showed that the concentration was higher in the wet season (0.12±0.02 ppm) than in the dry season (0.05±0.02 ppm). This is in contrast with higher concentrations observed during the dry season by Okon et al. (2024). Also, the outdoor area of the airport recorded a higher concentration than the indoor area (Table 3). Comparatively, the concentration of Ozone was higher than the WHO permissible limit of 0.075ppm at the Apron, Arrival Hall, and Car parks.

ANOVA results

The ANOVA result for the noxious gases reveals no significant difference in noxious gas concentration inside and outside the airport ($F_{1, 313}$ = 0.52, P=0.47, Table 3). However, the concentration of all the gases was higher outside the airport, apart from SO_2, which was higher inside the airport (Table 3). Sulphur oxide has the highest concentration of toxic gases. The ANOVA result reveals a significant difference in noxious gas concentration between seasons ($F_{1, 313}$ = 4.76, P=0.03, Table 4). This means that seasons influence the concentration of noxious gases in the atmosphere. Sulphur dioxide has the highest concentration in the dry season (3.73±3.72 ppm), while O_3 has the highest concentration in the wet season (0.12±0.02 µg/m³). Overall, SO_2 has the highest concentration of noxious gas, followed by NO_2 and CO.

The result reveals that NO_2 has the highest concentration, followed by CO and H_2S, whereas SO_2 has little or no concentration. The concentration of NO_2 in the Cargo area and O_3 in Arrival 2 and Car Park 2 were above the WHO limit. There was no significant difference in the concentration of pollutants between indoor and outdoor areas (p>0.05), while in contrast, there was a significant difference between seasons (p< 0.05).

Interaction effect

The one-way ANOVA result showed a significant difference in the concentration of noxious gas between seasons. Similarly, the interaction effect shows a significant difference when all factors are considered (Table 5).

Total volatile organic compounds and particulate matters

The mean concentration of Total Volatile Organic Compounds (TVOC) in the study area ranged between 0.00±0.00 and 588.83±588.54 µg/m³. The highest concentration was recorded at Ipo 3 and 4 (residence) and Apron (airport zone), while the lowest was recorded in all the indoor facilities. A One-way Analysis of variance (ANOVA) showed a significant difference in the concentration of TVOC across the stations, indoors and outdoors, and across seasons.

Particulate Matter (PM_1) was present across the various locations, with mean concentrations ranging between 4.84±0.59 to 27.32±8.52 µg/m³. The lowest concentration was recorded at Arrival Hall 2, while the highest concentration was recorded at the car park. $PM_{2.5}$ had a mean concentration ranging between 6.60±1.03 - 24.24±12.70 µg/m³, with the highest mean concentration observed at Ipo 3 and the least at the Arrival Halls 2. The mean concentration of PM_{10} across the locations ranged

Table 5. Interaction effect of noxious gases.

SOV	DF	SS	MS	F	p-value
Gases	6	69.6	11.59	0.916	0.485
Location	8	115.6	14.46	1.142	0.337
Season	1	74.7	74.73	5.905	0.016*
Gases × location	48	820.8	17.10	1.351	0.0812
Gases × season	6	114.2	19.04	1.504	0.179
Location × season	8	177.9	22.24	1.757	0.0879
Gases × location × season	48	1227.4	25.57	2.020	0.0005***
Residuals	189	2392.1	12.66		

Table 6. Total mean volatile organic compounds and particulate matter in the study location (±SE).

Locations	Gases (µg/m^3)				p-value
	TVOC	PM_1	$PM_{2.5}$	PM_{10}	
Apron	5.91±5.77*	26.62±10.73	6.59±4.89	16.51±10.62	
Arrival 1	0.00±0.00	11.22±3.89	8.90±1.55	8.00±3.52	
Arrival 2	0.00±0.00	4.84±0.59	6.60±1.03	8.36±2.49	
Cargo	0.06±0.06	10.44±3.54	23.00±13.62	16.00±3.38	
Car Park 1	0.00±0.00	18.62±6.40	11.80±1.99	5.80±0.20	> 0.05.
Car Park 2	0.00±0.00	27.32±8.52	13.60±2.71	8.60±0.40	
Departure	0.00±0.00	15.44±6.05	7.80±1.72	11.28±2.56	
Ipo 3	588.83±588.54*	21.84±8.46	24.24±12.70	42.27±24.03	
Ipo 4	40.43±40.14*	18.12±6.68	17.53±8.71	31.09±16.72	

Table 7. Seasonal concentration of TVOC and particulate matters.

Season	Gases (µg/m^3)				p-value
	TVOC	PM_1	$PM_{2.5}$	PM_{10}	
Dry	176.39±163.12	0.05	11.16±4.20	5.98±1.71	0.05
Wet	0.04±0.02	15.00±2.93	14.79±2.83	23.40±5.61	

Table 8. Site effect of total organic compounds and particulate matters.

Area	Gases (µg/m^3)				p-value
	TVOC	PM_1	$PM_{2.5}$	PM_{10}	
Indoor	0.00±0.00	10.50±2.44	7.77±0.82	9.21±1.60	0.05
Outdoor	105.87±98.06	20.49±3.06	6.12±3.44	20.04±5.31	

between 5.80±0.20 µg/m^3 in Car Park 1 to 42.27±24.03 µg/m^3 at Ipo 3, as presented in Table 6.

Across the sites, TVOCS and $PM_{1.0}$ had the highest concentration during the dry season, while $PM_{2.5}$ and PM_{10} had the highest concentration during the wet season (Table 7). The outdoor area has the highest concentration of particulate matter and TVOC (Table 8). Also, TVOC has the highest overall concentration.

Microclimatic parameters

Temperature (°C)

The mean results of temperature in this study ranged between 23.08±1.03°C in the Arrival Hall 2 to 28.88 ± 3.33°C in the Apron. Indoor areas have lower temperatures than outdoors. Similarly, the mean emperature

twas higher in the dry and wet seasons except for the controlled indoor areas, as presented in Figures 2 and 3.

Relative humidity (%)

The average relative humidity in the study area ranged from 70.8 ± 1.0% to 82.0 ± 2.25%. Across the seasons, the mean relative humidity was higher in the wet season than in the dry season; however, the results were similar in the indoor and outdoor areas, as presented in Figures 4 and 5.

DISCUSSION

The concentration of Sulphur (IV) Oxide in terms of locations across the study area was all within the WHO (2006) permissible limit except for the Arrival Hall 1 and the Cargo area. However, there were variations in the concentration of SO_2 between indoors (4.47±4.47 ppm) and outdoors (0.006±0.01 ppm) indicating a higher concentration in the indoors than outdoors. Higher concentrations of SO_2 in the indoor environment are due to space confinement which results in the slow distribution of indoor pollutants. In the same vein pollutants from vehicular activities flow indoors and stay longer compared to the outdoor pollutants that are dispersed by wind. Similarly, SO_2 concentrations were higher in the dry season (3.73±3.72 ppm) than in the wet season (0.00±0.00 ppm). Higher SO_2 in the dry season is caused by increased burning activities during the dry season such as bush burning and home fires due to the dry condition of the weather caused by the harmattan season. Adaku and Charles (2015), who reported a similar seasonal trend, ascribed it to the effect of rain diluting the atmosphere. The higher concentration of SO_2 in the dry season obtained from this study can be attributed to emissions from Aircraft and vehicle with less dilutions of the atmosphere from rain. The SO_2 concentration of the indoor area in this study is however higher than the WHO (2006) permissible limit (0.02 ppm), indicative of possible health challenges as a result of SO_2 inhalation. The sulphuric emissions are associated with fuel consumption and the sulphur content, which show a discrepancy by geographical location and changes with time (Hileman *et al*., 2010).

The mean range of NO_2 concentration (0.00 to 4.60±2.82 ppm) in the indoor airport is within the WHO permissible limit for NO_2 (0.2 ppm). However, the concentration of NO_2 in the outdoor areas (Cargo, Apron, Ipo 3, and Ipo 4) of the Port Harcourt International Airport was higher than the WHO permissible limit of 0.2 ppm. There was a higher concentration of NO_2 in the outdoor area than indoors because many cars waited outside the airport to carry travellers to their homes. Similarly, the concentration of NO_2 was higher in the dry season than in the wet season because of increased burning activities and metal-laden dust from the harmattan breeze. Furthermore, the higher concentration in the Cargo area can result from various substances such as chemicals that arrived at the cargo. Unal *et al*. (2005) ascribed NOx to contribute about 0.19% of airport pollution. A short-term exposure to NO_2 by asthmatic patients can lead to death (Dominski *et al.,* 2021).

Carbon monoxide results from the incomplete combustion of carbon fuel which is usually from vehicular exhaust and industrial processes. Carbon monoxide, when attached to haemoglobin, decreases the oxygen level in the body. Medium exposure of CO to people can spur cardiac disorders such as the brain and heart (Yousuf *et al*., 2013). Carbon monoxide also plays a part in the production of ground-level Ozone. The mean range of CO concentration across the various stations and seasons of 0.00 to 1.48±1.48ppm was higher than the WHO permissible value of 9-10.00µg/m^3. Asuoha and Osu (2015) reported a higher range in Akwa Ibom, Nigeria. The results of CO obtained in this study are similar to the 0.00ppm in Isaac Boro Park as reported by Augustine (2013) but lower than the results reported by Augustine (2013) in Harbour Road, Diobu, Airforce, and Link Road all in Port Harcourt Rivers State. The concentration of carbon monoxide outdoors in the airport results from emissions and vehicular activities around the airport.

Hydrogen sulphide concentration ranged between 0.00 - 2.40 ppm and is higher than the WHO permissible limit of 0.05 ppm. This, however, is similar to the results obtained by Weli and Adekunle (2014) at the Rumuolumeni in Port Harcourt but higher than the 0.15 - 0.40 ppm reported by Asuoha and Osu (2015) in Akwa Ibom. The high concentration of hydrogen sulphide in the Cargo area calls for major concern as H_2S can result in disorders such as irritation of the eyes, neurological, cardiac, cancer-causing, asthma, and respirational health effects. Other effects include coughs, breathing challenges, headaches, unconsciousness, nausea, and possibly death.

The mean CO_2 concentration across the study areas (0.04±0.01 - 0.18±0.08 ppm) was higher in the Apron and Car park areas, which could be a result of the emission from the exhaust of vehicles at the car park and emissions from the aeroplanes flying in and out of the airport. Generally, the CO_2 concentrations were higher in the outdoor area than indoors. These results are, however, within the WHO permissible limit indicative of a low spread of CO_2.

Ammonia (NH_3) concentration in the study area, which ranged between 0.00 - 0.28±0.17 ppm indicated that the primary source of ammonia across the study area is from aircraft exhaust as all locations recorded 0.00 ppm except the Apron and Ipo, where there is the presence of aircraft engines being active on land and air. These concentrations are fair and are below the WHO permissible limit (i.e., 0.6 mg/kg). The results obtained in this study are lower than 0.01 - 2.7 ppm reported by Gobo *et al.* (2012) in the

Okrika axis of Rivers State but in contrast with 0.00 ppm reported by Weli and Adekunle (2014) in the indoor areas of Rumuolumeni in Port Harcourt. The concentration of Ozone (O_3) across the various sites where higher than the WHO permissible limit (0.075 ppm) except for the Ipo 3, Ipo 4, Departure and the Arrival Hall 1. These results are similar to the 0.00 to 0.04 ppm reported by Augustine (2012) across various sections of Port Harcourt.

The concentration of $PM_{1.0}$ was slightly above the WHO limit (Table 6). These results are higher than the values reported by Gobo *et al*. (2012) at Okirika. Similarly, the concentration of $PM_{2.5}$ is within the WHO limit of 25 μgm^{-3}. These results are similar to the result of Gobo *et al*. (2012) at Okirika but lower than the range reported by Kumar and Dash (2018) in India.

The concentration of PM_{10} is below the WHO limit as compared to previous studies that were above the WHO limit (Yousuf *et al*., 2013). Akinfolarin *et al*. (2017) also reported a higher concentration of $PM_{2.5}$ and PM_{10} in the wet season and dry in Port Harcourt. It is also observed that the concentration of TVOC and PM_{10} was higher at the airport's host community (i.e., Ipo 3 and Ipo 4). The lower concentration of TVOC and Particulate matter in Arrival Hall 2 may be a result of fewer activities taking place there. This area of the airport is rarely used except when there is a high volume of passenger arrivals. Previous research has revealed that over 50% of fine particles ($PM_{1.0}$ and $PM_{2.5}$) are produced from vehicles. Furthermore, higher particulate matter concentrations of less than 2.5 µm are mainly from anthropogenic and urban activities and discharges from heavy-duty vehicles (D'Angiola *et al*., 2010).

Respiratory discomfort is caused by particulate matter, which is higher in the residential area. A similar observation was made by Riley *et al*. (2021), who revealed that ultra-fine particles come from aircraft engines and these fine particles are associated with lung inflammation among asthmatic patients. Additionally, He *et al*. (2018) reported that the composition of particles, size dispersal and the amount of internalized particles results in the promotion of mercurial organic compounds in the lung. An assessment of the global health impact of aircraft emissions by Yim *et al*. (2015) indicates that $PM_{2.5}$ concentration increases the rate of premature death annually.

Findings from this study revealed that noxious gases and suspended particles showed seasonal fluctuations due to the dry and wet seasons experienced in the region. Heavy rainfalls cleanse the atmosphere of anthropogenically emitted pollutants (Gobo *et al*., 2012). However, the concentration of the pollutants is not only affected by seasons but also by microclimatic conditions such as temperature, wind speed, and relative humidity.

Conclusion

The results of this study revealed a higher concentration of particulate matter and noxious gases in the outdoor part of the airport than in the indoor part, except for SO_2, which was higher in the indoor area. Generally, the wet season showed better air quality than the dry season concerning the pollutants except for O_3, which exhibited higher concentration in the wet season. The high concentration of TVOCs, Particulate matter ($PM_{1.0}$, $PM_{2.5}$ and PM_{10}), and the presence of NO_2, CO, NH_3, CO_2, and O_3 could result in respiratory defects.

Recommendations

Based on the results obtained from this study, the following are therefore recommended:

1. People with respiratory diseases, such as asthma, may be infected with continuous exposure to noxious gases and particulate matter at emerging industrial sites.
2. There should be regular air quality monitoring, especially in the residential area.
3. Enlightenment campaigns should be carried out at least yearly on the potential outcomes of consistent exposure to emissions in and around the airport.
4. The airport authority and the government should provide amenities to the local residents to cushion the impact of the exposure.
5. Further medical research should be carried out to assess other intricate medical concerns of the locals exposed to these aviation emissions.

CONFLICT OF INTEREST

The authors declare the they have no conflict of interest.

ACKNOWLEDGEMENT

We wish to thank our undergraduate and graduate students in Dr. Njumbere's lab for their assistance in sample collection.

REFERENCES

Adaku, A. N., & Charles, O. I. (2015). Seasonal variation of meterological factors on air parameters and the impact of gas flaring on air quality of some cities in Niger Delta. African *Journal of Environmental Science and Technology*, *9*(3), 218-227.

Akinfolarin, O. M., Boisa, N., & Obunwo, C. C. (2017). Assessment of particulate matter-based air quality index in Port Harcourt, Nigeria. *Journal of Environmental Analytical Chemistry*, *4*(4), 1-4.

Asuoha, A. N., & Osu, C. I. (2015). Seasonal variation of meteorological factors on air parameters and the impact of gas flaring on air quality of some cities in Niger Delta. *African Journal of Environmental Science and Technology*, *9*(3), 218-227.

Augustine, C. (2012). Impact of air pollution on the environment in Port Harcourt, Nigeria. *Journal of Environmental Science and Water Resources*, *1*(3), 46-51.

Boniface, K., Gioia, C. Pozzoli, L., Diehl, T., Dobricic, S., Fortuny Guasch, J., Greidanus, H., Kliment, T., Kucera, J., Janssens-Maenhout, G., Soille, P., Strobl, P., & Wilson, J. (2021). Europe's Earth Observation, Satellite Navigation, and Satellite Communications Missions and Services for the benefit of the Arctic - Inventory of current and future capabilities, their synergies and their societal benefits, EUR 30629 EN, Publications Office of the European Union, Luxembourg.

Cichowicz, R., & Bochenek, A. D. (2024). Assessing the effects of urban heat islands and air pollution on human quality of life. *Anthropocene*, 100433.

Chukwu Okeah, G. O., Ihekwoaba, R., & Umediegwu, P. (2021). Environmental and health risk implications of air quality in the vicinity of the Port Harcourt Airport road dumpsite. *Global Journal of Earth and Environmental Science*, *6*(1), 1-13.

D'Angiola, A., Dawidowski, L. E., Gómez, D. R., & Osses, M. (2010). On-road traffic emissions in a megacity. *Atmospheric Environment*, *44*(4), 483-493.

Dominski, F. H., Branco, J. H. L., Buonanno, G., Stabile, L., da Silva, M. G., & Andrade, A. (2021). Effects of air pollution on health: A mapping review of systematic reviews and meta-analyses. *Environmental Research*, *201*, 111487.

Faronbi, J., Doris, F., Clompus, S., & Hesslegrave, J. (2024). Global health pillar. In *Nursing Practice and Education* (pp. 99-118). Routledge.

Feng, T., Sun, Y., Shi, Y., Ma, J., Feng, C., & Chen, Z. (2024). Air pollution control policies and impacts: A review. *Renewable and Sustainable Energy Reviews*, *191*, 114071.

Gobo, A. E., Ideriah, T. J. K., Francis, T. E., & Stanley, H. O. (2012). Assessment of air quality and noise around Okrika communities, Rivers State, Nigeria. *Journal of Applied Sciences and Environmental Management*, *16*(1), 75-83.

Gobo, A. E., Richard, G., & Ubong, I. U. (2009). Health impact of gas flares on Igwuruta/Umuechem communities in Rivers State. *Journal of Applied Sciences and Environmental Management*, *13*(3), 27-33.

Graff Zivin, J., Neidell, M., Sanders, N. J., & Singer, G. (2023). When externalities collide: Influenza and pollution. *American Economic Journal: Applied Economics*, *15*(2), 320-351.

Habeebullah, T. M. (2013). An investigation of the effects of meteorology on air pollution in Makkah. *Assiut University Bulletin for Environmental Researches*, *4*(16), 63-85.

Hamanaka, R. B., & Mutlu, G. M. (2018). Particulate matter air pollution: effects on the cardiovascular system. *Frontiers in Endocrinology, 9*, 680.

He, R. W., Shirmohammadi, F., Gerlofs-Nijland, M. E., Sioutas, C., & Cassee, F. R. (2018). Pro-inflammatory responses to PM0. 25 from airport and urban traffic emissions. *Science of the Total Environment*, *640*, 997-1003.

Hileman, J. I., Stratton, R. W., & Donohoo, P. E. (2010). Energy content and alternative jet fuel viability. *Journal of Propulsion and Power*, *26*(6), 1184-1196.

Hudda, N., Durant, L. W., Fruin, S. A., & Durant, J. L. (2020). Impacts of aviation emissions on near-airport residential air quality. *Environmental Science & Technology*, *54*(14), 8580-8588.

ICAO (2013). Annual Report of the Council 2012 International Civil Aviation Organization. Retrieved from www.icao.int/ publications/pages/publication.aspx?docnum=10001.

Kapoor, N. R., Kumar, A., Kumar, A., Arora, H. C., & Kumar, A. (2024). A review of economic burden and negative health impacts due to air pollution. *Diseases and Health Consequences of Air Pollution*, 257-273.

Kumar, S. D., & Dash, A. (2018). Seasonal variation of air quality index and assessment. *Journal of Environmental Science and Management*, *4*(4), 483-492.

Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D., & Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature*, *525*(7569), 367-371.

Logan, M. (2010). Bio-statistical design and analysis using R: A practical guide. Hoboken, NJ: Wiley-Blackwell.

Masiol, M., & Harrison, R. M. (2014). Aircraft engine exhaust emissions and other airport-related contributions to ambient air pollution: A review. *Atmospheric Environment*, *95*, 409-455.

Murgan, M. G., & Mustapha, M. (2017). Towards regulation of aviation emission in Nigeria: A study of the environmental impact of aviation emission and the control laws. *Novena University Law Journal*, *2*(1), 170-188.

Newby, D. E., Mannucci, P. M., Tell, G. S., Baccarelli, A. A., Brook, R. D., Donaldson, K., Forastiere, F., Franchini, M., Franco, O.H., Graham, I., & Storey, R. F. (2015). Expert position paper on air pollution and cardiovascular disease. *European Heart Journal*, *36*(2), 83-93.

Omolaoye, T. S., Skosana, B. T., Ferguson, L. M., Ramsunder, Y., Ayad, B. M., & Du Plessis, S. S. (2024). Implications of Exposure to Air Pollution on Male Reproduction: The Role of Oxidative Stress. *Antioxidants*, *13*(1), 64.

Pearce, J. L., Beringer, J., Nicholls, N., Hyndman, R. J., & Tapper, N. J. (2011). Quantifying the influence of local meteorology on air quality using generalized additive models. *Atmospheric Environment*, 45(2011) 1328-1336.

Rötger, T., Eyers, C., & Fusaro, R. (2023). A Review of the Current Regulatory Framework for Supersonic Civil Aircraft: Noise and Emissions Regulations. *Aerospace*, *11*(1), 19.

Saxena, P., Sonwani, S., Saxena, P., & Sonwani, S. (2019). Primary criteria air pollutants: environmental health effects. *Criteria air pollutants and their impact on environmental health*, Pp. 49-82.

Sinha, B. R. K. (2024). Introduction: A Broad Perspective on the Concepts of Urban Dynamics, Environment, and Health. In *Urban Dynamics, Environment and Health: An International Perspective* (pp. 3-79). Singapore: Springer Nature Singapore.

Sreenath, S., Sudhakar, K., & Yusop, A. F. (2022). Carbon mitigation potential of the airport-based solar PV plants in the Indian context. *International Journal of Ambient Energy*, *43*(1), 1311-1319.

Tsukanov, R., & Yepifanov, S. (2024). Analysis of environmentally friendly commercial aviation development ways. *Aerospace Technic and Technology*, *1*(193), 4-21.

Udoetok, I. A., Akpanudo, N. W., Uwanta, E. J., & Ukpong, E. J. (2009). Associated petroleum hydrocarbons and heavy metals of an oil spilled site in the Niger Delta Nigeria. *Global Journal of Pure and Applied Sciences, 17*(3), 261-265.

Unal, A., Hu, Y., Chang, M. E., Odman, M. T., & Russell, A. G. (2005): Airport related emissions and impacts on air quality: Application to the Atlanta International Airport. *Atmospheric Environment* 39, 5787-5798.

Wei, X., Jiang, Y., & Gan, T. (2024). Air pollution and entrepreneurship: Evidence from China. *Applied Economics*, 56(24), 2860-2874.

Weli, V. E., & Adekunle, O. (2014). Spatial analysis of atmospheric pollutants from Rumuolemeni Landfill, Port Harcourt using GIS. *Journal of Environment and Earth Science*, *4*(14), 1-8.

WHO (2006). *Air quality guidelines. Global update 2005.* Particulate matter, ozone, nitrogen dioxide, and sulphur dioxide. Geneva, Switzerland: World Health Organization.

WHO (2008). World Health Organisation, Health risks of Ozone from long-range transboundary air pollution. A report prepared by WHO Regional Office for Europe, 2008. Retrieved from http://www.euro.who.int/Document/E91843.pdf.

Yan, Y., Ren, P., & Meng, Q. (2024). Quantitative evaluation of the synergistic effects of multiple meteorological parameters on air pollutants based on generalized additive models. *Urban Climate*, *55*, 101965.

Yim, S. H., Lee, G. L., Lee, I. H., Allroggen, F., Ashok, A., Caiazzo, F., Eastham, S. D., Malina, R., & Barrett, S. R. (2015). Global, regional and local health impacts of civil aviation emissions. *Environmental Research Letters*, *10*(3), 034001.

Yousuf, O., Mohanty, B. D., Martin, S. S., Joshi, P. H., Blaha, M. J., Nasir, K., Blumenthal, R. S., & Budoff, M. J. (2013). High-sensitivity C-reactive protein and cardiovascular disease: a resolute belief or an elusive link? *Journal of the American College of Cardiology*, *62*(5), 397-408.

Zaporozhets, O., & Synylo, K. (2019). Modelling of air pollution at airports. In *Environmental Impact of Aviation and Sustainable Solutions*. IntechOpen.