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A Comparative Analysis of Air Quality and Respiratory Health in Under-Five Children from Crude Oil-Impacted Communities

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Abstract: Crude oil spills create environmental hazards, leading to air pollution and respiratory health risks in under-five children due to their developing organs. This study compares ambient air quality (AAQ) and respiratory health (RH) of under-five children in crude oil-impacted and less-impacted communities. The study involved 450 under-five children (mean age: 3 years) from three Niger Delta communities: Bodo, K-Dere, and Beeri. AAQ was measured using sensors, and RH was assessed through interviewer-administered questionnaires between July and October 2022. Mean concentrations of pollutants, including PM2.5, PM10, TVOCs, and HCHO, were consistently higher in Bodo and K-Dere (oil-impacted communities) compared to Beeri (less-impacted community), with levels frequently exceeding both WHO and national standards. These concentrations were highest near spill sites and during evening periods, highlighting localized and temporal factors influencing air pollution. Respiratory symptoms such as cough, difficulty breathing, and persistent nasal congestion were significantly more prevalent among children in oil-impacted communities. Logistic regression analysis indicated a higher likelihood of respiratory issues in these communities, with odds ratios ranging from 2.53 to 14.18 for various symptoms.Elevated air pollution from crude oil spills correlates with a higher prevalence of respiratory conditions in children from impacted communities, underscoring the need for public health interventions in these areas.

Keywords: Ambient air quality; crude oil; under-five; children; respiratory health

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1. Introduction

Crude oil is a complex compound that is a blend of relatively volatile liquid hydrocarbons, primarily consisting of hydrogen and carbon, with traces of nitrogen, sulfur, and oxygen [1]. Crude oil is found in large reservoirs either beneath the ground or the ocean floors. The extraction of crude oil from these reservoirs through the drilling processes and its transportation through pipelines sometimes result in spillages with disastrous impact on the ecosystem. Crude oil spills can also be a result of sabotage of pipelines for political statement or economic gain [2,3].

According to the National Oil Spill Detection and Response Agency (NOSDRA), the Niger Delta experienced approximately 9,300 spills between 2006 and 2015 [4,5]. It is estimated that over 550 million gallons of crude oil was released into the environment from 1958 to 2010, amounting to an average of about 11 million gallons of crude spilled yearly (approximately 42 million liters) [6]. One consequence of the spillage is environmental degradation, particularly affecting the local mangrove forest and animal biodiversity. For example, it was estimated that environmental degradation resulting from oil spills led to the disappearance of over 50,000 acres of local mangrove forest and loss of animal biodiversity [6].

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Ambient air quality (AAQ) can be influenced by the concentrations of air pollutants in the environment. Since crude oil is a highly volatile compound, toxic chemicals such as volatile organic compounds (VOCs) and aerosolized particulate matter (PM) are released into the environment during its degradation, for instance, through evaporation and aerosolization [7,8], thereby disrupting AAQ [8,9]. An updated World Health Organization (WHO) AAQ guideline recommends a yearly average $PM_{2.5}$ concentration of not more than 5 µg/m^3, and a 24-hour average exposure of not more than 15 µg/m^3 for between 3 to 4 days per year. Other pollutants such as PM_{10}, NO_2, etc., with their annual concentration limits of 15 µg/m^3 and 10 µg/m^3 were also specified (WHO, 2022). In the year 2019, an overwhelming majority, 99% of the global population, resided in areas that failed to meet the AAQ standards set by the WHO (WHO, 2022). The Nigerian air quality guideline also recommends a yearly average $PM_{2.5}$ concentration of not more than 20 µg/m^3, and a 24-hour average exposure of not more than 40 µg/m^3 (ISIAQ STC34, 2020; National environmental regulations, 2021).

Roughly 300 million children inhabit regions where the levels of ambient air pollution (AAP) exceed international limits by at least of six times [10]. Additionally, 2 billion children live in areas where the concentration of ultra-fine particulate matter surpasses the annual recommended limit of 10 µg/m^3 set by the WHO [10].

Crude oil spill-related air pollutants have been found to have deleterious effects on air quality and public health [11]. In 2019, AAP was estimated to have caused approximately 4 million premature deaths worldwide [12]. Worldwide, AAQ has been severely impacted, leading to an increasing disease burden, particularly evident in middle and low-income countries compared to developed countries (WHO, 2022). About 90% of these premature deaths occurred in developing countries [12]. These air pollutants often exceed WHO air quality guidelines in many regions worldwide [13]. In the Niger Delta region of Nigeria, air quality has deteriorated due to various factors, with crude oil activities playing a significant role [14]. Air pollution poses a significant environmental risk to health. Pollutants from oil spills, when inhaled, can deposit in the respiratory tract, leading to inflammation depending on the particle dose and composition. This inflammation can increase airway responsiveness to irritants, leading to bronchoconstriction [15]. Furthermore, pollutants in the respiratory tract can generate reactive oxygen species and reduce antioxidant level, leading to oxidative stress and organ damage, resulting in various morbidities [16]. Pollutants released from spilled crude oils increase the risk of hospitalization for cardiovascular and respiratory diseases such as pneumonia, bronchitis, cough, rhinorrhoea, chronic obstructive pulmonary disease (COPD), asthma, and lung cancer [7,17]. In addition, pollutants from oil spills in general are known to cause a range of health issues including cardiovascular, and respiratory diseases and also increased hospitalization risks due to these diseases [7].

The proportion of respiratory symptoms associated with crude oil spills has been found to be greater in the exposed group compared to the non-exposed group. For example, according to a follow-up research on the prestige oil disaster and its respiratory health (RH) effects, those who were exposed were more likely to experience lower respiratory tract symptoms such as wheezing, difficulty in breathing, coughing, and producing phlegm (RR 1.4, 95% CI 1.0-2.0). In comparison to those who were symptom-free, there was an increase in the risk of developing chronic respiratory symptoms (e.g., wheeze, shortness of breath, cough, and phlegm) with increasing exposure levels: RR: 1.7 (95% CI 0.9-3.1) and 3.3 (95% CI 1.8-6.0) for those who were moderately or severely exposed, respectively [18].

According to research in the Niger Delta area of Nigeria by Ordinioha and Sawyerr, the oil spillage that occurred in Etiama Nembe in Bayelsa State, Nigeria, resulted in the release of 2,500 barrels of crude oil (about 400,000 litres) into the farms, forests, and waterbodies, contaminating about 20 hectares of land [19]. Due to its high volatility, spilled crude oil forms strong pungent fumes and mist, which, when inhaled, result in respiratory health consequences among the residents that were exposed [20].

By decreasing the level of air pollution, countries can lessen the burden of disease from stroke, cardiovascular diseases, lung cancers, and both acute and chronic respiratory diseases, including asthma (WHO, 2022). Despite government protocols on oil spill response and efforts by

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organizations like the WHO and United Nations Children's Fund (UNICEF) to prevent, manage, and control AAP and its impact on respiratory health, particularly among children under-five, crude oil spills and their pollutants remain a major public health concern. There is lack of data in Nigeria, especially in the Niger Delta area, comparing air quality and respiratory health outcomes in oil-polluted and less-oil-polluted communities. There is an increasing need for more studies to bridge this literature gap, raise awareness about the effects of crude oil spills on inhaled air quality and their resulting impact on the RH of children under-five years, and develop effective control measures. Hence, the significance of this study.

2. Materials and Methods

2.1. Study Area

The study was conducted in three communities in Ogoniland, namely Bodo, and Kegbara Dere (K-Dere) which are considered oil-impacted communities in Gokana Local Government Area (LGA), as well as Beeri, a less oil-impacted community in Khana LGA, Rivers State, Nigeria. Ogoniland is part of the Niger Delta, located within the southern region of Nigeria. The Niger Delta is fan-shaped, covering approximately 70,000 km^2 of land mass, and serves as the drainage basin for the Niger and Benue rivers into the Atlantic Ocean [6,21]. It is generally believed that all communities in the Niger Delta area of Nigeria are affected by crude oil spills, but to varying degrees [22]. According to information obtained from the inhabitants of these communities, there are no oil pipeline in Beeri and no direct oil spills, although spilled oil from other communities may affect it, hence its classification as less impacted.

2.2. Study Design and Sample Size Estimation

A comparative cross-sectional study design was employed, with data collected using a pre-tested, semi-structured interviewer-administered questionnaire. The questionnaires were administered to eligible parents or guardians of under-five children. Qualitative information from the questionnaire was analysed and published elsewhere [8]. The concentrations of air pollutants were measured with various equipment. Formaldehyde (HCHO), total volatile organic compounds (TVOCs), $PM_{2.5}$ and PM_{10} were measured using a portable, easy-to-use multiple air quality monitor (LHW-100).

The LHW-100 air quality monitor employs electrochemical sensors for detecting HCHO, with a detection range of 0–5 mg/m^3 and an accuracy of ±0.03 mg/m^3, enabling precise monitoring. To measure TVOCs, the monitor uses a metal oxide semiconductor (MOS) sensor, capable of detecting a wide variety of volatile pollutants, including benzene, toluene, and xylene, with a detection range of 0–10 mg/m^3 and an accuracy of ±10% of the measured value. This makes it suitable for assessing VOC concentrations in diverse settings. Both PM2.5 and PM10 concentrations were measured using an optical laser scattering sensor, which provides high sensitivity to particles as small as 0.3 microns. The detection range for PM2.5 and PM10 was 0–500 µg/m^3, with an accuracy of ±10–15%, accounting for environmental factors such as humidity and airflow.

Hydrogen sulfide (H_2S) and carbon monoxide (CO) were measured with a Bosean BH-4S portable multiple gas detector for combustible gasses, with an accuracy of ≦±5% full scale (F.S) and a response time of ≦30 seconds. Wind speed was measured using the Hyelec Ms6252a anemometer, Chuiouy brand, with an accuracy of ±(2.0% reading+50). All sensors were new and factory calibrated before use.

A total of 450 participants were recruited for the study, with 150 participants per community, in accordance with the sample size calculation described by Whitley and Ball [23].

2.3. Data Analysis

The collected data were coded, cleaned and analyzed with the Statistical Package for Social Sciences (SPSS 25.0, IBM, Armonk, New York, United States of America). Kolmogorov-Smirnov test was used to test for normality, which showed a significant deviation from the normal distribution. Descriptive statistics was presented in the form of frequencies, percentages, mean, median and standard deviation. They are presented in tables and charts. Chi-square test and bivariate logistic regression with Odds Ratio (OR) were used for hypothesis testing, assess the pattern of respiratory infections between communities, and significance was detected when $p \leq 0.05$ with 95% confidence interval. Analysis of variance (ANOVA) was used in the analysis of the air quality and meteorology data. A Tukey's post hoc test for multiple comparisons was also used to assess significant differences between mean concentrations of air pollutants. The mean concentrations of the air quality parameters were compared with both WHO and Nigeria acceptable limits.

2.4. Ethical Approval

The protocol for this study was approved by the Ethical Review Board of the University of Port Harcourt, Port Harcourt, Rivers State, Nigeria, with permission number UPH/CEREMAD/REC/MM79/031, and was conducted in accordance with the principles outlined in the Declaration of Helsinki. The decision was made on August 24, 2021. Participation in the study was voluntary and research subjects were referred to anonymously throughout the study. Written consent was obtained from all the participants before data collection, and they were informed of their right to withdraw from the study at any time. The safety of all participants was ensured.

3. Results

3.1. Socio-Demographic Characteristics

The descriptive statistics of the under-five children sampled in Bodo, K-Dere, and Beeri in this study are presented in table 1. The majority (90%) of the children were from 2 and 4 years old. The percentage of males in each community was as follows: 53% in Bodo, 58% in K-Dere, and 61% in Beeri.

Table 1. Socio-demographic characteristics of the participants (under-five children) in Bodo, K-Dere and Beeri .

Variables	Bodo n=150		K-Dere N=150		Beeri N=150	
	N	%	N	%	N	%
Children						
Age						
1	15	10.00	17	11.33	14	9.33
2	24	16.00	43	28.67	25	16.67
3	58	38.67	40	26.67	45	30.00
4	53	35.33	50	33.33	66	44.00
Median (IQR)	3 (2-4)		3 (2.5-4)		3 (2-4)	

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Gender						
Male	80	53.33	87	58.00	91	60.67
Female	70	46.67	63	42.00	59	39.33
Number of Siblings						
None	4	2.67	25	16.67	3	2.00
1-3	98	65.33	99	66.00	118	78.67
≥4	48	32.00	26	17.33	29	19.33
Median (IQR)	2 (2.5-3)		2 (1.5-3.5)		3 (2-4)	
Birth Position						
First	23	15.33	40	26.67	44	29.33
Second	34	22.67	42	28.00	53	35.33
Third	43	28.67	41	27.33	26	17.33
Fourth	25	16.67	13	8.67	16	10.67
Fifth	17	11.33	10	6.67	6	4.00
Sixth	5	3.33	2	1.33	5	3.33
Seventh	2	1.33	2	1.33	0	0.0
Eight	1	0.67	1	0.67	0	0.0
Number of years resident in your community						
1	15	10.00	16	10.67	14	9.33
2	30	20.00	52	34.67	25	16.67

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3	58	38.67	40	26.67	44	29.33
4	47	31.33	42	28.00	67	44.67
Median (IQR)	3 (2-4)		3 (2.5-4)		3 (2-4)	

In Bodo, approximately 70% of the respondents have resided in the community for 3 years and above, about 54% have resided in K-Dere for the same duration, and roughly 74% have resided in Beeri for 3 years and above. Table 2 presents descriptive statistics of the sampled parents/guardians of the under-five in Bodo, K-Dere, and Beeri.

Table 2. Socio-demographic characteristics of the Respondents (parent/guardian) in Bodo, K-Dere, and Beeri.

Variables	Bodo n=150		K-Dere n=150		Beeri n=150	
	N	%	N	%	N	%
Parent/Guardian						
Father's educational level						
None	6	4.00	5	3.33	0	0.0
Primary	31	20.67	24	16.00	5	3.33
Secondary	45	30.00	55	36.67	80	53.33
Tertiary	28	18.67	50	33.33	38	25.33
Post-Graduate	40	26.67	16	10.67	27	18.00
Mother's educational level						
None	8	5.33	10	6.67	0	0.0
Primary	32	21.33	45	30.00	11	7.33

Secondary	50	33.33	40	26.67	97	64.67
Tertiary	33	22.00	42	28.00	12	8.00
Post-Graduate	27	18.00	13	8.67	30	20.00
Father's occupation						
Professional	38	25.33	12	8.00	11	7.33
Civil servant	30	20.00	38	25.33	54	36.00
Fishing/Farming	59	39.33	32	21.33	31	20.67
Artisans	23	15.33	68	45.33	54	36.00
Mother's occupation						
Professional	21	14.00	13	8.67	6	4.00
Civil servant	47	31.33	24	16.00	32	21.33
Fishing/Farming	64	42.67	53	35.33	49	32.67
Artisans	18	12.00	59	39.33	63	42.00

Only a small proportion in Bodo, K-Dere and Beeri respectively (Father/Mother: 4%/5%, 3%/7%, 0/0) of all the sampled parents/guardian sampled had no formal education, while the majority (19%/22%, 33%/28%, 25%/8%) had completed Nigeria's compulsory basic education (tertiary education). The majority of the sampled parents/guardians were employed in blue-collar occupations for example parents/guardians who were civil servants were (father/mother: 20%/31%, 25%/16%, 36%/21%).

Table 3 compares the mean AAQ parameters measured at 0m, 50m, and 100m from the pollution site in Bodo with those in Beeri. Similarly, Table 4 compares the mean AAQ parameters measured in K-Dere with those in Beeri The mean concentration of measured pollutants were higher in the oil-impacted communities (Bodo and K-Dere) compared to the less-oil impacted community (Beeri). These concentrations were highest in the evenings and at the spill sites, and sometimes exceeded the WHO guidelines and also the national limits especially for $PM_{2.5}$. Additionally, concentrations decreased with increasing distance away from the spill site at most sampling points.

Table 3. Mean concentrations and standard deviations of crude oil spill-related air pollutants and meteorological data of Bodo and Beeri.

T-D	Temperature (°C)	Rel. Humidity	Noise (dB)	Wind Speed (m/s)	SO_2 (µg/m³)	NO_2 (µg/m³)	CO (µg/m³)	H_2S (µg/m³)	$PM_{2.5}$ (µg/m³)	PM_{10} (µg/m³)	TVOC (µg/m³)	HCHO (µg/m³)
M_0m	29.50 ± 1.02	85.56 ± 3.11	68.07 ± 10.85	25.76 ± 3.67	.00 ± 00	.47 ± .49	2.74 ± 1.43	.00 ± 00	21.26 ± 6.24	38.86 ± 8.37	.76 ± 1.07	.010 ± .01
A_0m	30.32 ± 1.10	84.07 ± 3.11	70.48 ± 10.85	25.82 ± 3.67	.00 ± 00	.55 ± .53	2.43 ± 1.58	.00 ± 00	19.76 ± 6.18	39.50 ± 8.40	.76 ± 1.07	.011 ± .01
E_0m	29.97 ± 1.24	85.16 ± 3.11	66.98 ± 10.85	25.73 ± 3.67	.00 ± 00	.69 ± .49	3.09 ± 1.27	.00 ± 00	27.26 ± 6.18	43.64 ± 8.54	.76 ± 1.07	.012 ± .01
M_50m	30.79 ± 1.06	84.86 ± 3.26	66.60 ± 7.27	26.05 ± 3.05	.00 ± 00	.29 ± .37	1.94 ± 1.09	.00 ± 00	15.79 ± 5.09	29.98 ± 4.60	.05 ± .06	.011 ± .01
A_50m	30.61 ± .98	84.41 ± 3.26	69.01 ± 7.27	26.11 ± 3.05	.00 ± 00	.39 ± .39	2.14 ± 1.38	.00 ± 00	15.86 ± 5.16	31.12 ± 4.53	.05 ± .06	.011 ± .00
E_50m	30.56 ± 1.13	84.66 ± 3.23	65.82 ± 7.30	25.98 ± 3.08	.00 ± 00	.49 ± .38	1.95 ± .97	.00 ± 00	17.71 ± 4.97	32.78 ± 4.64	.05 ± .06	.011 ± .00

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M_100m	30.57 ± 1.12	89.41 ± 1.93	73.55 ±4.85	25.25 ± 3.12	.00 ± 00	.03 ± .13	.49 ± .76	.00 ± 00	11.49 ± 3.03	12.72 ± 5.79	.34 ± .49	.007 ± .00
A_100m	30.48 ± .82	89.37 ± 1.95	74.85 ± 4.90	25.25 ± 3.14	.00 ± 00	.01 ± .01	.29 ± .42	.00 ± 00	11.26 ± 2.33	13.12 ± 4.82	.35 ± .50	.007 ± .00
E_100m	30.16 ± 1.11	89.39 ± 1.95	72.55 ± 4.90	25.16 ± 3.14	.00 ± 00	.00 ± .01	.23 ± .35	.00 ± 00	12.05 ± 2.20	15.83 ± 5.37	.35 ± .50	.007 ± .00
Beeri - Control	30.48 ± .55	82.00 ± 1.33	74.81 ± 4.95	18.90 ± 1.13	0.00 ± 00	0.00 ± 00	0.00 ± 00	0.00 ± 00	6.47± 4.64	11.95 ± 5.49	0.00 ± .00	0.00 ± .00
Nat'l Limit					80	80	10	6969.3	20	60		24.56
WHO Limit			53		40	10	7	0.03	5	15	0-0.05	0.814

T-D = Time- Distance, T = Temperature, R = Relative humidity, M = Morning, A = Afternoon, E = Evening .

For example, in K-Dere, the mean concentrations of $PM_{2.5}$, PM_{10}, NO_2, CO, TVOC and HCHO were highest in the evening, with a mean value of 20.60 μg/m³, 43.31 μg/m³, 0.89 μg/m³, 3.50 μg/m³ respectively. The detectable levels of H_2S, TVOC and HCHO was negligible in K-Dere. Additionally, there was no detectable levels of SO_2 concentration in Bodo and K-Dere. TVOC exceeded the WHO acceptable limits in Bodo.

Table 4. Mean concentrations and standard deviations of air quality parameters for K-Dere and Beeri.

T-D	**Temperature (°C)**	**Rel. Humidity**	**Noise (dB)**	**Wind Speed (m/s)**	**SO_2 (μg/m³)**	**NO_2 (μg/m³)**	**CO (μg/m³)**	**H_2S (μg/m³)**	**$PM_{2.5}$ (μg/m³)**	**PM_{10} (μg/m³)**	**TVOC (μg/m³)**	**HCHO (μg/**

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												m^{3})
M_0m	31.50 ± 1.09	86.48 ± 3.90	55.59 ± 2.13	25.78 ± 2.04	.00 ± 00	.73 ± .54	3.19 ± 1.69	.001 ± .00	14.60 ± 4.52	38.52 ± 15.57	.02 ± .15	.004 ± .01
A_0m	32.32 ± 1.16	84.99 ± 3.90	58.00 ± 2.13	25.84 ± 2.04	.00 ± 00	.76 ± .60	2.88 ± 1.77	.001 ± .00	13.10 ± 4.44	39.17 ± 15.59	.02 ± .02	.005 ± .01
E_0m	32.04 ± 1.29	86.08 ± 3.90	54.50 ± 2.13	25.75 ± 2.04	.00 ± 00	.89 ± .65	3.50 ± 1.63	.001 ± .00	20.60 ± 4.44	43.31 ± 15.66	.02 ± .02	.006 ± .01
M_50m	30.98 ± .55	84.15 ± 3.15	50.90 ± 4.46	26.09 ± 2.75	.00 ± 00	.58 ± .44	2.15 ± .96	.001 ± .00	12.79 ± 6.86	26.64 ± 10.21	.01 ±.01	.004 ± .01
A_50m	31.24 ± .99	83.70 ± 3.15	53.31 ± 4.46	26.15 ± 2.75	.00 ± 00	.63 ± .52	2.27 ± 1.39	.001 ± .00	12.86 ± 6.91	27.79 ± 10.18	.01 ± .01	.004 ± .01
E_50m	30.93 ± 1.03	84.05 ± 3.15	50.26 ± 4.46	26.06 ± 2.75	.00 ± 00	.79 ± .58	2.26 ± .70	.001 ± .00	14.86 ± 6.80	29.43 ± 10.20	.01 ± .01	.004 ± .01
M_100m	30.74 ± .59	91.69 ± 3.71	49.50 ± 6.90	25.12 ± 2.91	.00 ± 00	.12 ± .15	1.16 ± .77	.001 ± .00	7.86 ± 4.27	18.26 ± 7.28	.00 ± .00	.003 ± .00
A_100m	31.13 ± .94	91.64 ± 3.71	50.75 ± 6.90	45.86 ± 31.64	.00 ± 00	.12 ± .15	.74 ± .65	.001 ± .00	7.93 ± 4.26	19.12 ± 7.18	.00 ± .00	.004 ± .00
E_100m	30.88 ± 1.16	91.66 ± 3.71	48.45 ± 6.90	25.09 ± 2.91	.00 ± 00	.11 ± .15	.61 ± .61	.001 ± .00	8.71 ± 4.19	21.83 ± 7.54	.00 ± .00	.004 ± .00
Beeri - Control	30.48 ± .55	82.00 ± 1.33	74.81± 4.95	18.90± 1.13	.00 ± 00	0.00 ± .00	0.00 ± .00	0.00 ± .00	6.47 ± 4.64	11.95 ± 5.49	0.00 ± .00	0.00 ± .00
Nat'l Limit					80	80	10	6969.3	20	60		24.56

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WHO Limit	53	40	10	7	0.03	5	15	0-0.05	0.814

T-D= Time-Distance, T=Temperature, R=Relative humidity, M = Morning, A = Afternoon, E = Evening.

Tables 5 and 6 show a one-way ANOVA that revealed the statistically significant difference in the air quality parameters, between at least two groups (F(between groups df, within groups df) = [F-value], p = [p-value]).

[$PM_{2.5}$ (F:57.529, df (between groups -18; Within groups - 863) = [F = 57.529], $p <0.001$]
[PM_{10} (F:79.919, df (between groups -18; Within groups - 863) = [F = 79.919], $p < 0.001$]
[TVOC (F: 17.693, df (between groups -18; Within groups - 863) = [F = 17.693], $p < 0.001$]

Table 5. Comparing mean concentration between Bodo and Beeri.

	Time_Distance	$PM_{2.5}$	p-value 95%CI	PM_{10}	p-value (95%CI)	TVOC	p-value (95%CI)
Beeri (less oil impacted area)	Bodo, Morning_0m	-14.796* (0.893)	.000 (-17.95 to -11.65)	-30.040* (1.628)	0.000 (-35.78 to -24.30)	-0.741* (0.097)	< 0.001 (-1.040 to -0.481)
	Bodo Afternoon_0m	-13.296* (0.893)	.001 (-16.45 to -10.15)	-30.683* (1.628)	0.001 (-36.43 to -24.94)	-0.742* (0.097)	0.001 (-1.042 to -0.482)
	Bodo, Evening_0m	-20.796* (0.893)	.001 (-23.95 to -17.65)	-34.826* (1.628)	0.001 (-40.57 to -29.08)	-0.743* (0.097)	0.001 (-1.042 to -0.483)
	Bodo, Morning_50m	-9.320* (0.893)	.001 (-12.47 to -6.17)	-21.159* (1.628)	0.001 (-26.90 to -15.42)	-0.033 (0.097)	1.000 (-0.332 to 0.227)
	Bodo, Afternoon_50m	-9.392* (0.893)	.001 (-12.54 to -6.24)	-22.302* (1.628)	0.001 (-28.05 to -16.56)	-0.033 (0.097)	1.000 (-0.333 to 0.227)
	Bodo, Evening_50m	-11.392* (0.893)	.001 (-14.54 to -8.24)	-23.945* (1.628)	0.001 (-29.69 to -18.20)	-0.034 (0.097)	1.000 (-0.333 to 0.226)

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	Bodo, Morning_100m	-4.725* (0.893)	.000 (-7.88 to -1.57)	-3.445	0.828 (-9.19 to 2.30)	-0.328 (0.097)	0.002 (-0.627 to -0.068)
	Bodo, Afternoon_100m	-4.796* (0.893)	.001 (-7.95 to -1.65)	-4.302	0.449 (-10.05 to 1.44)	-0.328 (0.097)	0.002 (-0.627 to -0.068)
	Bodo, Evening_100m	-5.582* (0.893)	.001 (-8.73 to -2.43)	-7.017* (1.628)	0.003 (-12.76 to -1.27)	-0.328 (0.097)	0.002 (-0.627 to -0.068)

*The mean difference is significant at $p < 0.05$.

Table 6. Comparison of Mean (standard error) concentrations of air quality parameters measured between K-Dere and Beeri and their p-values (95%CI).

	Time_Distance	PM 2.5	p-value (95%CI)	PM10	p-value (95%CI)	TVOC	p-value (95%CI)
Beeri (less-oil impacted area)	K-Dere, morning_0m	-8.130* (0.893)	.001 (-11.28 to -4.98)	-29.707* (1.628)	0.001 (-35.45 to -23.96)	-0.001 (0.097)	1.000 (-0.299 to 0.260)
	K-Dere afternoon_0m	-6.630* (0.893)	.001 (-9.78 to -3.48)	-30.350* (1.628)	0.001 (-36.09 to -24.61)	-0.001 (0.097)	1.000 (-0.300 to 0.259)
	K-Dere, Evening_0m	-14.30* (0.893)	.001 (-17.28 to -10.98)	-34.493* (1.628)	0.001 (-40.24 to -28.75)	0.008 (0.097)	1.000 (-0.300 to 0.259)
	K-Dere, morning_50m	-6.320* (0.893)	.001 (-9.47 to -3.17)	-17.826* (1.628)	0.001 (-23.57 to -12.08)	0.008 (0.097)	1.000 (-0.291 to 0.268)
	K-Dere, afternoon_50m	-6.392* (0.893)	.001 (-9.54 to -3.24)	-18.969* (1.628)	0.001 (-24.71 to -13.22)	0.007 (0.097)	1.000 (-0.291 to 0.268)

K-Dere, Evening_50m	-8.392* (0.893)	.001 (-11.54 to -5.24)	-20.612* (1.628)	0.001 (-26.36 to -14.87)	0.007 (0.097)	1.000 (-0.292 to 0.267)
K-Dere, Morning_100m	-1392 (0.893)	.989 (-4.54 to 1.76)	-9.445* (1.628)	0.001 (-15.19 to -3.70)	0.018 (0.097)	1.000 (-0.281 to 0.278)
K-Dere, Afternoon_100m	-1.463 (0.893)	.982 (-4.61 to 1.69)	-10.302* (1.628)	0.001 (-16.05 to -4.56)	0.019 (0.097)	1.000 (-0.281 to 0.279)
K-Dere, Evening_100m	-2.249 (0.893)	.545 (-5.40 to 0.90)	-13.017* (1.628)	0.001 (-18.76 to -7.27)	0.019 (0.097)	1.000 (-0.281 to 0.279)

The mean difference is significant at 0.05 level.

A Tukey's post hoc test for multiple comparisons revealed statistically significant differences in the mean values of AAP, including $PM_{2.5}$, PM_{10} and TVOC, measured in Beeri compared to Bodo, and between Beeri and K-Dere at various distances and times, as shown in the tables 5 and 6. Significant differences were also observed between morning, afternoon, and evening measurements, as well as at 0m, 50m, and 100m distances, with $PM_{2.5}$ significantly higher in Bodo compared to Beeri at these different times and distances ($p<0.05$). Similar findings were observed for PM_{10} ($p<0.05$), except for air quality readings at 100m in the morning and afternoon. TVOC showed statistically significant differences only at 0m, indicating that TVOC was significantly higher in Bodo than in Beeri at the spill site throughout different times ($p<0.05$). No statistically significant difference in TVOC was observed between K-Dere and Beeri.

Respiratory symptoms in Bodo, K-Dere and Beeri

Parents reported respiratory symptoms among the under-five children studied are shown in Figure 1.

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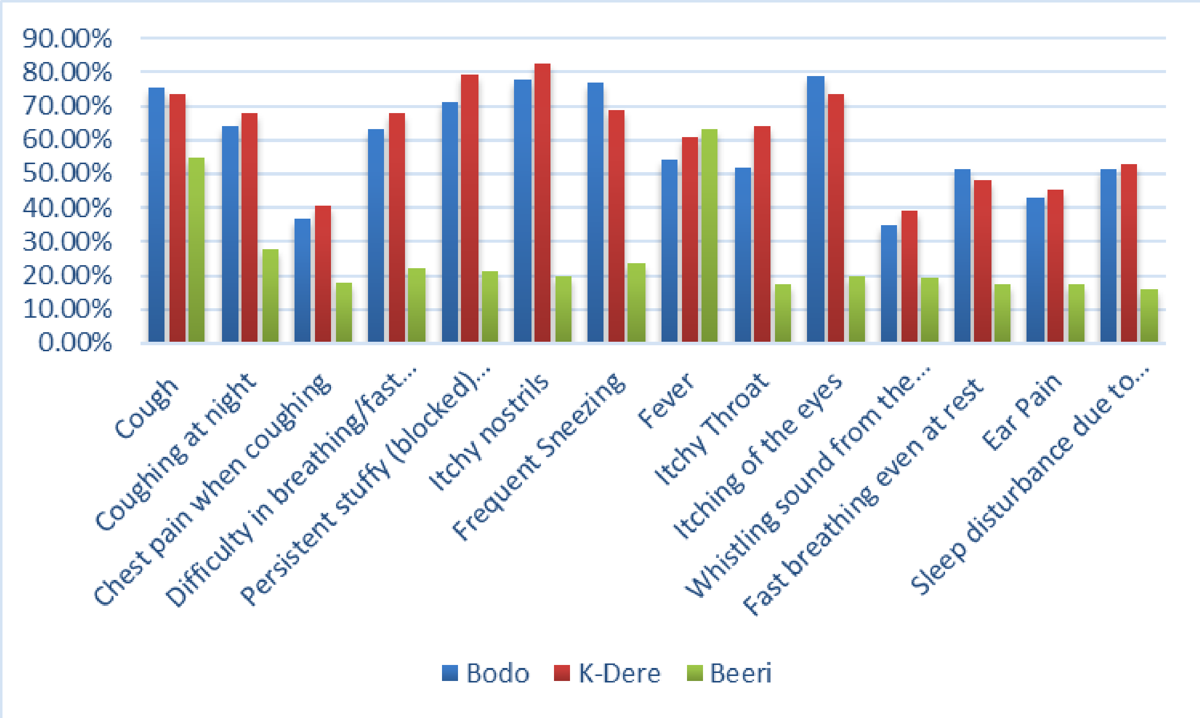

Figure 1. Respiratory symptoms in Bodo, K-Dere and Beeri.

Figure 1, indicates that Beeri had the lowest number of reported respiratory symptoms, except for fever, compared to Bodo and K-Dere. Cough at night, persistent stuffy nostrils, sleep disturbance due to troubled breathing, ear pain, itchy nostrils and fast breathing were found to be higher in K-Dere, while cough, frequent sneezing, fast breathing at rest, and itchy eyes were higher in Bodo.

The pattern of distribution of respiratory infections between Bodo and Beeri was assessed using Chi-square (χ) analysis and bivariate logistic regression with Odds Ratio (OR) and 95% confidence interval (CI), as shown in table 7.

Table 7. Comparison between Respiratory symptoms in Bodo and Beeri.

Variables	**Bodo n=150**		**Beeri n=150**		**χ2 (P-value)**	**Odds Ratio (OR) (95% CI)**	**p-value**
	N	**%**	**N**	**%**			
Cough							
Yes	113	75.33	82	54.67	14.08	2.53	**0.001***
No	37	24.67	68	45.33	**(0.001)***	(1.55-4.13)	
Coughing at night							
Yes	96	64.00	42	28.00	39.13	4.57	**0.001***
No	54	36.00	108	72.00	**(0.001)***	(2.81-7.44)	
Chest pain when coughing							
Yes	55	36.67	27	18.00	13.16	2.64	**0.002***
No	95	63.33	123	82.00	**(0.001)***	(1.55-4.49)	
Difficulty in breathing/fast breathing							
Yes	95	63.33	33	22.00	54.19	6.32	**0.001***

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No	55	36.67	117	78.00	**(0.001)***	(3.81-10.67)	
Persistent stuffy (blocked) nostrils							
Yes	107	71.33	32	21.33	79.65	9.18	**0.001***
No	43	28.67	118	78.67	**(0.001)***	(5.41-15.54)	
Itchy nostrils							
Yes	117	78.00	30	20.00	94.08	14.18	**0.001***
No	33	22.00	120	80.00	**(0.001)***	(8.13-24.73)	
Frequent Sneezing							
Yes	115	76.67	35	23.33	85.33	10.79	**0.001***
No	35	23.33	115	76.67	**(0.001)***	(6.32-18.44)	
Fever							
Yes	81	54.00	95	63.33	2.69	0.68	0.101
No	69	46.00	55	36.67	(0.101)	(0.43-1.08)	
Itchy Throat							
Yes	78	52.00	26	17.33	39.79	5.17	**0.001***
No	72	48.00	124	82.67	**(0.001)***	(3.04-8.78)	
Itching of the eyes							
Yes	118	78.67	30	20.00	103.27	14.75	**0.001***
No	32	21.33	120	80.00	**(0.001)***	(8.43-25.80)	
Whistling sound from the chest							
Yes	52	34.67	29	19.33	8.95	2.21	**0.001***
No	98	65.33	121	80.67	**(0.003)***	(1.31-3.75)	
Fast breathing even at rest							
Yes	77	51.33	26	17.33	38.46	5.03	**0.001***
No	73	48.67	124	82.67	**(0.001)***	(2.96-8.54)	
Ear Pain							
Yes	64	42.67	26	17.33	22.92	0.04	**0.001***
No	86	57.33	124	82.67	**(0.001)***	(0.02-0.067)	
Sleep disturbance due to troubled breathing							
Yes	77	51.33	24	16.00	41.93	5.54	**0.001***
No	73	48.67	126	84.00	**(0.001)***	(3.22-9.52)	

*Statistically significant ($p<0.05$); **$\chi 2$**=Chi-Square; γ=Fisher's Exact p.

Respondents residing in the oil-impacted community (Bodo) had a statistically significantly higher proportion (OR) for all respiratory symptoms except ear pain compared to those living in less-oil impacted community (Beeri). For example, cough (OR: 2.53, 95%CI: 1.55-4.13, p=0.001), cough at night (OR: 4.57, 95%CI: 2.81-7.44, p=0.001), chest pain when coughing (OR: 2.64, 95%CI: 1.55-4.49, p=0.001**),** and difficulty in breathing/fast breathing (OR: 6.32, 95%CI: 3.81-10.67, p=0.001) all had higher odds in Bodo. There was no statistically significant difference for fever between the two communities.

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Table 8. Comparison of Respiratory Symptoms between K-Dere and Beeri.

Variables	K-Dere n=150		Beeri n=150		χ2 (P-value)	Odds Ratio (OR) (95% CI)	p-value
	N	**%**	**N**	**%**			
Cough							
Yes	110	73.33	82	54.67	11.34	2.28	**0.001***
No	40	26.67	68	45.33	**(0.001)***	(1.40-3.70)	
Coughing at night							
Yes	102	68.00	42	28.00	48.07	5.54	**0.001***
No	48	32.00	108	72.00	**(0.001)***	(3.33-8.96)	
Chest pain when coughing							
Yes	61	40.67	27	18.00	18.58	3.12	**0.001***
No	89	59.33	123	82.00	**(0.001)***	(1.84-5.29)	
Difficulty in breathing/fast breathing							
Yes	102	68.00	33	22.00	64.12	7.53	**0.001***
No	48	32.00	117	78.00	**(0.001)***	(4.49-12.63)	
Persistent stuffy (blocked) nostrils							
Yes	119	79.33	32	21.33	100.92	14.16	**0.001***
No	31	20.67	118	78.67	**(0.001)***	(8.16-24.67)	
Itchy nostrils							
Yes	124	82.67	30	20.00	117.89	19.08	**0.001***
No	26	17.33	120	80.00	**(0.001)***	(10.66-34.14)	
Frequent Sneezing							
Yes	103	68.67	35	23.33	62.05	7.20	**0.001***
No	47	31.33	115	76.67	**(0.001)***	(4.32-12.02)	
Fever							
Yes	91	60.67	95	63.33	0.22	0.89	0.721
No	59	39.33	55	36.67	(0.634)	(0.56-1.42)	
Itchy Throat							
Yes	96	64.00	26	17.33	67.69	8.47	**0.001***
No	54	36.00	124	82.67	**(0.001)***	(4.98-14.53)	
Itching of the eyes							
Yes	110	73.33	30	20.00	85.71	11.0	**0.001***
No	40	26.67	120	80.00	**(0.001)***	(6.41-18.87)	
Whistling sound from the chest							
Yes	59	39.33	29	19.33	14.47	2.71	**0.001***
No	91	60.67	121	80.67	**(0.003)***	(1.60-4.55)	

Fast breathing even at rest							
Yes	72	48.00	26	17.33	32.06	4.40	**0.001***
No	78	52.00	124	82.67	**(0.001)***	(2.59-7.48)	
Ear Pain							
Yes	68	45.33	26	17.33	27.32	3.90	**0.001***
No	82	54.67	124	82.67	**(0.001)***	(2.33-6.71)	
Sleep disturbance due to troubled breathing							
Yes	79	52.67	24	16.00	44.72	5.84	**0.001***
No	71	47.33	126	84.00	**(0.001)***	(3.39-10.04)	

*Statistically significant ($p < 0.05$); **χ2**=Chi-Square; γ=Fisher's Exact p.

A statistically significantly higher proportion (OR) of all respiratory symptoms including ear pain was observed in the oil-impacted community of K-Dere, compared to observations from the less-oil impacted community of Beeri. There was no statistically significant difference in fever symptoms in K-Dere compared to Beeri.

4. Discussion

This study compared the air quality parameters in two oil-impacted communities with one less oil-impacted community in the Niger Delta region of Nigeria. Additionally, it compared the respiratory health symptoms of under-five children residing in these communities. Our results indicate that both Bodo and K-Dere exhibited higher mean concentrations of ambient air pollutants compared to Beeri.

According to Nriagu and colleagues, the entire Niger Delta region is affected by crude oil activities, directly or indirectly, due to continuous crude oil exploration, a major source of income for Nigeria [22]. Our measurements revealed that the mean concentrations of some of the pollutants exceeded WHO recommended levels, including $PM_{2.5}$, TVOC and PM_{10} (WHO, 2021). These mean concentrations specifically $PM_{2.5}$ also exceeded the National limits in the morning in Bodo community and in the evening in K-Dere community (ISIAQ STC34, 2020; National environmental regulations, 2021). Pollutants found in the air from oil spills may arise from various processes such as degradation, combustion, and mechanical disruption of spilled oil on water and land surfaces. The exceedance of WHO limits suggests that the degradation and combustion of spilled oil affected the AAQ of the oil-impacted communities. The mechanical disruption of the water surface and the breaking waves result in the eruption and ejection of spilt oil in the form of aerosolized PM containing these pollutants [24,25].

Our findings align with previous studies indicating that the combustion of oil releases pollutants like carbon black, CO_2, NO, heavy metals, and soot into the atmosphere [3,8,26]. Osaiyuwu & Ugbebor observed poor AAQ in oil-producing communities of the Niger Delta due to pollutants such as $PM_{2.5}$, CO, and nitrogen oxides (NOx) exceeding WHO recommendations [27].

The significantly higher levels of AAP measured in oil-polluted communities compared to less-oil polluted communities may also be influenced by meteorological factors. For instance, during the morning hours, low atmospheric temperature and stable atmospheric boundary layers, which represent the area of the atmosphere directly in contact with the Earth's surface, remain relatively stable. This stability leads to a lower height of the surface thermal inversion and reduced friction velocity. Consequently, the mixing and dilution of air pollutants released from various sources are inhibited [28]. This same phenomenon occurs again in the evenings as temperature decreases and the winds slow down, leading to a reduction in friction velocity and the height of the thermal inversion. Consequently, this results in an increase in the concentration of pollutants in the air. In contrast during the afternoon period, the height of the atmospheric boundary layer is high, providing a larger volume of air for the mixing and dilution of air pollutants. As a result, the concentration of air pollutants decreases [28,29]. In addition, the concentration of air pollutants is typically highest at spill sites due to the presence of surface thermal inversion. This phenomenon reduces the volume of air available for mixing and diluting local emissions from the spill sites, leading to increased pollutant concentrations. Temperature inversion, another meteorological phenomenon, further exacerbates this issue by trapping cool air and air pollutants close to the Earth's surface. This inhibits their upward movement due to the capping effect of warm air above, resulting in a decline in air quality in the region and contributing to associated respiratory and cardiovascular effects [29]. The mean concentrations of these pollutants were observed to be higher at the spill sites and gradually decreased with increasing distance from the spill site. This suggests that under-five children residing in close proximity to the spill sites may face greater exposure to pollutants, potentially increasing their susceptibility to respiratory diseases. Therefore, future studies should investigate this aspect to better understand the health risks associated with living near oil spills. In the study in Taean, Korea, under-five children residing close to the Hebei spirit oil spills were found to be exposed to higher concentrations of the measured toxicants [30]. This suggests that air pollutant concentrations were indeed higher around the oil spill sites. The respiratory symptoms assessed were cough, dry cough at night, chest pain while coughing, difficulty breathing/fast breathing, persistent stuffy (blocked) nostrils, itchy nostrils, frequent sneezing, fever, itchy throat, itchy eyes, whistling sound from the chest, fast breathing even at rest, ear pain, sleep disturbances due to troubled breathing. The majority of these symptoms exhibited significant differences when comparing participants' regions.

According to Jung and colleagues, children highly exposed to the Hebei Spirit oil spill exhibited higher respiratory symptoms compared to those less exposed [30]. Similarly, a study on the Prestige oil disaster found that individuals exposed to the spill experienced lower respiratory tract symptoms such as wheezing, dyspnoea, coughing, and sputum production (RR 1.4, 95% CI 1.0-2.0) [18].

Numerous studies have demonstrated the significant impact of inhaled air quality on human health, with particular emphasis on under-five children due to their unique vulnerabilities [31,32]. The findings of this study further corroborate this evidence, indicating that respiratory health in children is adversely affected in communities impacted by oil spills. Children's lungs and immune systems are still developing and they inhale more air per kilogram of body weight than adults, making them particularly susceptible to the harmful effects of air pollutants [33]. Yakubu highlighted the consequences associated with human exposure to particle pollution from crude oil exploration and exploitation processes in Nigeria. Petroleum industries, particularly in the Niger Delta, are identified as major sources of air pollution, contributing to a range of health challenges including difficulty in breathing, lung cancer, and asthma [34].

A high proportion of the study participants exhibited wheezing; a symptom associated with asthma. Michel and colleagues in their study stated that exposure to environmental pollutants in early childhood could lead to the symptoms of asthma in early childhood and later in life [35]. Furthermore, exposure to atmospheric VOCs can lead to the formation of ozone, which in turn can trigger acute and chronic IgE-mediated inflammation, including asthmatic crisis [36]. Additionally, oil-related irritants and toxicants have been implicated in damaging the bronchial epithelial structure, inducing oxidative stress, increasing cytokines and leukotrienes-mediated inflammation, promoting growth factor secretion, and enhancing bronchial hyper-responsiveness [33].

Children under the age of five living in oil-impacted communities in the Niger Delta can regularly be exposed to harmful toxicants through inhalation, ingestion, and contact, posing significant risks to their respiratory system and overall well-being. Addressing this environmental and health hazard requires a collaborative effort aimed at ensuring the safety of these children and the provision of clean air. Effective strategies to mitigate the adverse effects of exposure to toxicants in oil-impacted communities should include advocacy, raising awareness, education, and fostering

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community participation to preserve the environment and safeguard residents' health. Government intervention is crucial, necessitating the implementation and enforcement of regulatory laws regarding oil spills. Additionally, providing basic amenities, promoting personal hygiene practices, ensuring comprehensive immunization coverage to boost children's immunity, and facilitating prompt treatment of respiratory symptoms and diseases are essential measures to protect the well-being of community members.

While this study may be limited by the use of questionnaires alone to assess respiratory health outcomes of under five children, which could introduce recall bias, it is important to consider the context of limited healthcare infrastructure in the Niger Delta for gathering respiratory health data [37]. Furthermore, conducting invasive testing on children under five for scientific research raises serious ethical concerns due to their vulnerability. The study also possesses significant strengths. Notably, its comparative nature and the direct measurement of AAQ at various times of the day. By comparing the air quality and respiratory health of children under five exposed to air pollutants from oil spills with those less exposed in a community less impacted by oil, the study sheds light on the relationship between environmental factors and human health, particularly respiratory health in young children. This underscores the urgency to address this issue, especially in developing countries like Nigeria, heavily reliant on crude oil as a primary source of foreign earnings. We recommend future research to compare mean concentrations of air pollutants between oil-impacted communities and regions unaffected by oil spills. Furthermore, future studies should also consider gathering data on potential confounding variables and adjusting for them in their statistical analyses.

5. Conclusions

The air quality in the oil-impacted communities assessed was markedly poorer compared to less-impacted communities. Furthermore, the likelihood of under-five children experiencing respiratory symptoms was significantly higher in the oil-impacted communities investigated, compared to those less-impacted by oil pollution, across most of the respiratory symptoms assessed. As recommendations, we advocate for health education initiatives, timely oil spill clean-up efforts, improved regulatory control measures, and prompt treatment of respiratory diseases in these communities.

GLOSSARY

NOSDRA	National Oil Spill Detection and Response Agency
AAQ	Ambient air quality
VOC	Volatile organic compounds
PM	Particulate matter
WHO	World Health Organization
ISIAQ	International Society of Indoor Air Quality and Climate
AAP	Ambient air pollution
UNICEF	United Nations Children Fund
COPD	Chronic obstructive pulmonary disease
ANOVA	Analysis of Variance
TVOC	Total Volatile Organic Compound
CO	Carbon monoxide
NO	Nitrogen Oxide
NO_x	Nitrogen oxides
CO_2	Carbon iv oxide

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Institutional Review Board Statement: The protocol for this study was approved by the "Ethical Review Board of University of Port Harcourt, Port Harcourt, Rivers State, Nigeria, with permission number UPH/CEREMAD/REC/MM79/031" and carried out in conformity with the Declaration of Helsinki. The decision was made on August 24, 2021.

Informed Consent Statement: A written consent was obtained from the participants before data collection. Participants were told that they can leave the study at any time. The safety of all the participants was ensured.

Data Availability Statement: The data presented in this study are available in ACE-PUTOR and are available on request.

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