Evaluation of Air Pollution Exposure, Geographic Disparities, and Health Effects Stemming from the Port Harcourt Refinery in Eleme Local Government Area, Rivers State, Nigeria

[1]Osaro, H., [2]Alazigha, N. & [1]Dollah, O. C
[1]Institute of Geosciences and Environmental Management,
Rivers State University Nkpolu-Oroworukwo Port Harcourt,
Rivers State, Nigeria
[2]Department of Surgery, Faculty of Medical Sciences,
Rivers State University Nkpolu-Oroworukwo
Port Harcourt, Rivers State, Nigeria
Corresponding Email: osademe.dollah@ust.edu.ng / Helen.osaro@ust.edu.ng
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Abstract
This research evaluated the impact of pollution from the Port Harcourt Refinery on local residents, exploring the effects on public health, differences in air quality across locations, and community attitudes toward environmental hazards in Eleme Local Government Area, Rivers State, Nigeria. The investigation utilized a cross-sectional and quasi-experimental research approach. Air quality assessments for $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, O_3, VOCs, and CH_4 were performed at various distances (ranging from 0–100 m to over 400 m) from the refinery with the help of portable monitoring instruments, while structured surveys were completed by 398 participants chosen via systematic sampling. The data was evaluated through descriptive statistics and one-way ANOVA. The results indicated that the levels of particulate matter were alarmingly high, with $PM_{2.5}$ measured at 218.6 µg/m³ and PM_{10} at 342.8 µg/m³, both categorized as "very unhealthy" according to Air Quality Index standards. Additional pollutants like SO_2, NO_2, and CO also surpassed permissible thresholds, signaling a critical decline in air quality. Spatial analysis illustrated a pronounced distance-decay effect, revealing the highest concentrations of pollutants within the 0–100 m range, which decreased as distance increased beyond 400 m ($p < 0.001$). ANOVA findings demonstrated significant differences in the distribution of particulate matter among various distance categories. The health risk assessment highlighted increased risks for respiratory and cardiovascular illnesses, such as asthma, bronchitis, and ongoing respiratory discomfort in affected populations. Survey findings indicated a strong awareness of pollution among community members, with 85.4% of participants recognizing the refinery as a primary source of pollution and 53.8% experiencing respiratory issues. Nevertheless, proactive protective measures were limited, with 78.9% of respondents not wearing protective masks, despite their high inclination to do so. The study concludes that emissions from the refinery have a considerable impact on local air quality, exposure rates, and health consequences for the nearby population. It is recommended that stringent enforcement of emission regulations be implemented, regular air quality assessments be conducted, community health monitoring programs be established, and protective gear be provided to lessen exposure risks for residents in areas surrounding the refinery.

Keywords: *Evaluation, Air, Pollution, Exposure, Geographic, Disparities, Health & Effects*

Introduction

Air pollution is a major hazard to human health and a leading cause of illness and death worldwide**.** Human respiratory system is the organ directly affected by air pollution; the potential respiratory health effects of indoor and outdoor air pollution have been widely investigated but data on the localized exposure is still inadequate. The significance of air pollution as one of the contemporary issues and accelerating factors that propel climate change in both developed and developing countries cannot be overemphasized. The problem of air pollution has seemingly become intractable with the incessant failure of both global and local environmental policies purportedly emplaced to address its devastating trend, particularly in growing megacities of the world (Hashim et al., 2020). The devastating effects of the phenomenon are more pronounced in megacities of developing countries than in developed ones. Urban growth and industrialization have degraded the environment significantly. One of the numerous implications of industrial emission is air pollution and its associated public health impact Ogwu (2022). The case of Nigeria has revealed weak control of development which has led to the distortion of the master plan of urban paces. Location of refinery is sensitive to the distance from residencies. But the case of Alesa in Eleme poses grave concern due to the level of exposure and poor compliance to development code. The implication is that residents could be exposed to varying degree of health problems. When residents are exposed to $PM_{2.5}$ and PM_{10}, Nitogen dioxide (NO_2) Sulphur dioxide, methane carbon monoxide and Oxone (O_3), they also become susceptible to ailments such as respiratory and cardiovascular diseases. Ogwu (2020) posited that when exposure to air pollutants is prolonged, it would induce diseases such as reduced lung functioning, premature mortality and respiratory diseases. The low-income residents could be more vulnerable due to the lack of access to affordable health care services. Although global advocacy to improve air quality has been intensified, data on ambient air quality has remained largely inadequate. Exposure to air pollution is linked to mortality and shortening of life expectancy. In the short-term, exposure to air pollution (represented in the daily air pollution concentrations or air quality index values) can impact an individual's health. During certain high-pollution days, the effects can be more severe. However, the biggest impact comes from long-term exposure (weeks to months) to air pollutants, which increases a person's chances of dying from heart disease, chronic respiratory diseases, lung infections, lung cancer, diabetes, and other health problems. Not surprisingly, exposure to air pollution also reduces the number of years that a person is expected to live (Oguname, 2016) Among the air pollutants, fine particulate matter ($PM_{2.5}$) is the most consistent and robust predictor of mortality in studies of long-term exposure. Efforts made to reduce the impact of air pollution in developing countries are impeded by the over reliance on fossil fuel for transportation, production and revenue. The case of Nigeria has revealed high exposure to air pollution, but studies to provide the data on the level of exposure and associated public health impact is still inadequate. Literature also suggests that the residents in the communities lack the knowledge and understanding of the implication of their exposure to air pollution induced by industrial emission. The struggle for space for development and the informality of urban land delivery has been linked to contraction of the distance between the Port Harcourt refinery and residency. This is further exacerbated by the weak enforcement of development control to ensure public safety. Therefore, the lack of empirical investigation and integration of the perception of residents to examine the health implication of exposure to the Port-Harcourt refinery offers the rationale to conduct this study.

Methodology

This research implemented a combined methodological strategy that incorporated both quasi-experimental and cross-sectional designs to explore the environmental and public health aspects of air pollution linked to the Port Harcourt refinery within the Alesa community of Eleme Local Government Area in Rivers State. The quasi-experimental segment entailed collecting field-based environmental data to assess how ambient air quality varies at different distances from the refinery, while the cross-sectional segment involved distributing structured surveys to gather information on residents' exposure patterns, health issues, and perceptions regarding the effects of air pollution. The research drew from a variety of data sources, encompassing environmental, health, and perception-related datasets. Environmental data were gathered through direct measurements of air quality parameters in the field, which included particulate matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), volatile organic compounds (VOCs), and ozone (O_3). These measurements were conducted at carefully chosen sampling locations at differing distances from the refinery to identify spatial differences in pollutant concentration and to assess if the levels of pollutants diminish as the distance from the emission source increases. Data pertaining to health and exposure were collected using structured questionnaires distributed to residents in the research area. This dataset included details about the length of residence, time spent outdoors, occupational exposure, closeness to emission points, and the regularity of outdoor activities. Additionally, it captured self-reported health issues such as coughing, tightness in the chest, asthma, eye irritation, headaches, and breathing problems, which are typically linked to air pollution exposure. These factors were utilized to evaluate the extent of human exposure and the associated health hazards faced by residents nearby the refinery. Awareness and perception data were also gathered through the same questionnaire format. This section examined residents' understanding of air pollution, their perceived sources of emissions, their view on the seriousness of environmental damage, perceived health dangers, and their beliefs about the contribution of refinery operations to low air quality and negative health effects. This dataset offered valuable insights into the community's understanding of environmental risks and complemented the objective measurements of environmental parameters. Air quality monitoring was performed using standardized, portable devices, including the Aeroqual Series 500 gas monitoring meter for detecting gaseous pollutants, the MET One Aerocet 531 particle counter for measuring particulate matter, and the Weather Centre PCE 20N for recording meteorological data. The gas monitoring device measured levels of CO, SO_2, NO_2, O_3, and VOCs, while the concentrations of particulate matter were determined using laser-based detection methods. Meteorological factors such as temperature, humidity, wind speed, and wind direction were also monitored, since they affect pollutant dispersal and buildup. All equipment was calibrated before use according to manufacturers' specifications, and multiple measurements were recorded at various times throughout the day, including morning, afternoon, and evening, to capture changes in air quality conditions over time. Field procedures commenced with an exploratory assessment of the research area to pinpoint suitable sampling sites, analyze settlement distributions, and inspect environmental factors that might affect the spread of pollutants. Subsequently, monitoring devices were set up at specified locations and operated for predetermined periods to secure data collection consistency. Alongside quantitative measurements, qualitative insights were gathered via observations and interviews. The observational data concentrated on visible signs of environmental pollution, such as soot accumulation on rooftops, plant life, water storage containers, and community infrastructure. It also included other emissions sources like generator fumes, burning waste, and traffic from vehicles. Selected residents and stakeholders were interviewed to gain detailed insights into their perceptions of pollution sources, health repercussions, and potential mitigation approaches. Health data from Secondary sources were collected from Primary Health Care facilities catering to the Alesa community. These records were examined to extract summarized information about pollution-related illnesses, including asthma, bronchitis, pneumonia, respiratory illnesses, and eye irritation over a specified timeframe. A structured template was employed for data extraction, ensuring personal identifiers were not disclosed to maintain confidentiality. The study's population included individuals living in the Eleme Local Government Area, projected to increase from the 2006 census figure of 190,000 to around 270,000, applying an annual growth rate of 2.87 percent. The sample size for distributing questionnaires was calculated using the Taro Yamane formula, resulting in a total of 400 participants. A systematic sampling method was utilized to choose households from various spatial areas within the research locale, guaranteeing that communities situated near, within, and distant from the refinery's influence zone were adequately represented. The data gathering process involved direct measurements of the environment, administering structured questionnaires, recording observations, and reviewing records from health facilities. Questionnaires were given directly to individuals to cater to varying literacy levels among respondents, and answers were collected from diverse spatial regions to facilitate comparative assessments on exposure and perception patterns. A systematic approach was employed in household sampling, selecting every nth household along designated streets, and daily reviews of completed questionnaires were performed to ensure completeness and reduce instances of missing data. Data analysis was executed using a combination of descriptive and inferential statistical methods. Descriptive statistics, such as frequencies and percentages, were utilized to summarize the characteristics, exposure behaviors, and perception levels of respondents, with results displayed in tables and charts. Inferential statistical approaches included Analysis of Variance (ANOVA) to evaluate spatial differences in air quality at various distances from the refinery. Post-hoc analyses were conducted to determine specific group variances where significant differences were identified. Moreover, the Kruskal-Wallis test was employed to examine variations in perceived health impacts of air pollution among different study zones. The Air Quality Index calculations were also completed using established EPA-based formulas to categorize ambient air quality standards. The dependability and credibility of the research tool were guaranteed through various methods, including content validation, face validation, expert assessment, pilot testing, and evaluation of internal consistency. Content validation confirmed that the questions in the questionnaire aligned with the research aims and variables, while face validity verified that the language used was clear and suitable for respondents from various educational backgrounds. Validation by experts was performed by professionals in the fields of environmental science and public health to confirm the instrument's relevance and sufficiency. A preliminary study was executed in a comparable community that was not part of the sample to pinpoint any unclear aspects and enhance the tool. Reliability was measured using Cronbach's Alpha, with an acceptable level for the internal consistency of Likert-scale items being set at 0.70.

Results

1. To Investigates Exposure of residents to the pollution induced by the Port-Harcourt refinery

Table 4.1: Demographic characteristics of the respondents in the study area

Variables	Categories	Frequency	Percentage (%)
Sex	Male	237	59.5
	Female	161	40.5
	Total	**398**	**100**

Age (years)	Less than 20	22	5.5
	21–35	126	31.7
	36–50	148	37.2
	51–65	74	18.6
	66 and above	28	7
	Total	**398**	**100**
Occupation	Civil Servant	71	17.8
	Trading/Business	114	28.6
	Artisan	64	16.1
	Student	42	10.6
	Farming	76	19.1
	Others	31	7.8
	Total	**398**	**100**
Level of education	Primary School	38	9.5
	SSCE	103	25.9
	OND/Diploma	74	18.6
	HND	61	15.3
	B.Sc.	84	21.1
	Postgraduate degree	38	9.5
	Total	**398**	**100**
Years of residence	Less than 5 years	35	8.8
	6–10 years	61	15.3
	11–15 years	79	19.8
	16–20 years	87	21.9
	20 years and above	136	34.2
	Total	**398**	**100**

Table 1 presents the demographic characteristics of the 398 respondents who participated in the study. The results show that males constituted most respondents, accounting for 237 (59.5%), while females represented 161 (40.5%). This indicates a relatively higher participation of males in the survey, which may reflect their greater involvement in outdoor activities, occupational engagements, and environmental interactions within the refinery-hosting communities. The age distribution shows that most respondents were within the economically active age groups. Respondents aged 36–50 years constituted the largest proportion with 148 (37.2%), followed by those aged 21–35 years with 126 (31.7%). Respondents aged 51–65 years accounted for 74 (18.6%), while those aged 66 years and above represented 28 (7.0%). The youngest group, those below 20 years, had the least representation with 22 (5.5%). The dominance of middle-aged respondents suggests that the study captured individuals with considerable knowledge and experience of environmental conditions and changes within the study area. Regarding occupation, traders/business owners formed the largest occupational group with 114 (28.6%), followed by farmers with 76 (19.1%) and civil servants with 71 (17.8%). Artisans accounted for 64 (16.1%), students represented 42 (10.6%), while respondents engaged in other occupations constituted 31 (7.8%). The occupational distribution indicates that respondents were drawn from diverse economic activities, including groups that may experience different levels of exposure to refinery-related air pollution through residential, commercial, and outdoor activities. The educational characteristics reveal that respondents possessed varied levels of formal education. Those with SSCE constituted the highest proportion with 103 (25.9%), followed by respondents with B.Sc. degrees at 84 (21.1%) and OND/Diploma holders at 74 (18.6%). Respondents with HND represented 61 (15.3%), while those with Primary education and Postgraduate degrees accounted for 38 (9.5%) each. The educational profile suggests that a considerable proportion of respondents had sufficient educational background to understand issues relating to air pollution, environmental quality, and associated health implications. The years of residence indicate that many respondents had long-term experience within the study area. Respondents who had lived in the area for 20 years and above formed the largest group with 136 (34.2%), followed by those with 16–20 years of residence (87; 21.9%) and 11–15 years (79; 19.8%). Those who had stayed for 6–10 years accounted for 61 (15.3%), while respondents with less than 5 years of residence represented 35 (8.8%). The high proportion of long-term residents suggests that most participants had prolonged exposure to the refinery environment and were therefore better positioned to provide information on changes in air quality and perceived health effects. The demographic characteristics indicate that the study involved a diverse group of respondents, with a majority being male (59.5%), middle-aged (37.2% aged 36–50 years), economically active, and long-term residents (34.2% residing for 20 years and above). This demographic composition enhances the reliability of the responses regarding residents' awareness, perception, and experiences of refinery-related air pollution in the study area.

To determine Public health implication of exposure to the pollution induced by the Port Harcourt refinery

Table 2: Health risk assessment of air pollutants around the refinery environment in Eleme

Pollutant	Mean concentration	AQI value	AQI category	Health implication/risk assessment
$PM_{2.5}$ (µg/m³)	218.6±26.4	286	Very unhealthy	High risk of respiratory irritation, asthma aggravation, reduced lung function, cardiovascular stress, and increased vulnerability among children, elderly persons, and individuals with existing respiratory conditions.
PM_{10} (µg/m³)	342.8±38.7	268	Very unhealthy	Increased risk of respiratory tract irritation, coughing, bronchitis symptoms, and reduced pulmonary performance due to elevated inhalable particles.

SO_2 (µg/m³)	168.5±18.6	158	Unhealthy	Likely to trigger breathing difficulties, worsen asthma conditions, and cause irritation of the eyes, nose, and throat.
NO_2 (µg/m³)	142.7±15.4	151	Unhealthy	Associated with airway inflammation, increased respiratory infections, reduced lung function, and aggravation of asthma symptoms.
CO (ppm)	14.8±2.1	152	Unhealthy	Exposure may reduce oxygen transport capacity of blood, causing headaches, dizziness, fatigue, and increased cardiovascular stress.
O_3 (µg/m³)	126.3±12.8	112	Unhealthy for sensitive groups	May cause throat irritation, coughing, chest discomfort, and worsening of respiratory diseases.
VOCs (ppm)	3.84±0.62		Elevated exposure concern	Petroleum-related VOC exposure may contribute to headaches, irritation, nausea, and potential long-term toxic effects depending on composition and duration of exposure.
CH_4 (ppm)	9.6±1.7		Low direct AQI relevance	Mainly indicates petroleum hydrocarbon emissions and possible fugitive leakage from refinery operations.

Table 2 presents the health risk assessment of measured air pollutants around the refinery environment in Eleme based on their mean concentrations, Air Quality Index (AQI) values, and associated health implications. The results reveal that the air quality condition of the study area is generally unhealthy, with particulate matter and gaseous pollutants indicating varying degrees of potential risk to human health. The overall pollution profile suggests that residents and workers within the refinery environment are exposed to pollutant concentrations capable of producing adverse respiratory and cardiovascular effects. Among the assessed pollutants, $PM_{2.5}$ recorded the highest AQI value of 286, placing it within the “Very Unhealthy” category. The mean concentration of $PM_{2.5}$ was 218.6 ± 26.4 µg/m³, indicating a substantial presence of fine particulate matter in the atmosphere. This level of exposure presents a high risk of respiratory irritation, aggravation of asthma conditions, reduced lung function, and increased cardiovascular stress. The health implications are particularly concerning because $PM_{2.5}$ particles are small enough to penetrate deep into the lungs and potentially enter the bloodstream. Vulnerable groups such as children, elderly persons, and individuals with existing respiratory conditions may experience greater health impacts. Similarly, PM_{10} recorded an AQI value of 268, also classified as “Very Unhealthy”, with a mean concentration of 342.8 ± 38.7 µg/m³. The elevated PM_{10} level indicates significant exposure to inhalable particles generated from refinery operations, combustion activities, vehicular emissions, dust resuspension, and industrial material handling. Exposure to such concentrations may contribute to respiratory tract irritation, coughing, bronchitis symptoms, and reduced pulmonary performance. The dominance of particulate pollution highlights the importance of controlling both combustion and mechanical sources of particle emissions within the refinery environment. The gaseous pollutants also demonstrated considerable health concerns. Sulphur dioxide (SO_2) recorded an AQI value of 158, placing it in the “Unhealthy” category, with a mean concentration of 168.5 ± 18.6 µg/m³. The elevated SO_2 level indicates the influence of Sulphurcontaining fuel combustion and refinery processing activities. Continuous exposure may trigger breathing difficulties, worsen asthma symptoms, and cause irritation of the eyes, nose, and throat among exposed individuals. Nitrogen dioxide (NO_2) recorded an AQI value of 151, also categorized as "Unhealthy," with a mean concentration of 142.7 ± 15.4 µg/m³. The presence of elevated NO_2 suggests significant contributions from combustion processes associated with refinery operations, power generation, and vehicular activities. Exposure to NO_2 is associated with airway inflammation, increased respiratory infections, reduced lung function, and aggravation of asthma symptoms. The elevated NO_2 concentration also contributes to atmospheric reactions that promote the formation of secondary pollutants such as ozone and fine particulate matter. The health risk assessment further showed that carbon monoxide (CO) had an AQI value of 152, categorized as "Unhealthy," with a mean concentration of 14.8 ± 2.1 ppm. The observed concentration reflects the influence of incomplete combustion from refinery equipment, generators, and transportation activities. Prolonged exposure to elevated CO levels may reduce oxygen transport capacity in the blood, resulting in symptoms such as headaches, dizziness, fatigue, and increased cardiovascular stress, particularly among individuals with underlying health conditions. For ozone (O_3), the AQI value was 112, indicating that air quality was "Unhealthy for sensitive groups." The recorded mean concentration of 126.3 ± 12.8 µg/m³ suggests active photochemical reactions involving nitrogen oxides and volatile organic compounds released from refinery activities. Although ozone is not directly emitted from the refinery, its formation through atmospheric reactions may increase exposure risks. Sensitive individuals may experience throat irritation, coughing, chest discomfort, and worsening of respiratory diseases. The assessment of volatile organic compounds (VOCs) showed an elevated exposure concern, with a mean concentration of 3.84 ± 0.62 ppm. Although VOCs do not have a direct AQI classification in the assessment framework, their presence is environmentally significant because petroleum-related VOCs may originate from crude oil processing, storage facilities, and evaporative emissions. Depending on their composition and duration of exposure, VOCs may contribute to headaches, irritation, nausea, and potential long-term toxic effects, particularly where compounds such as benzene are present. Methane (CH_4) recorded a mean concentration of 9.6 ± 1.7 ppm and was classified as having low direct AQI relevance. However, its presence serves as an indicator of petroleum hydrocarbon emissions and possible fugitive leakage from refinery operations. Although methane does not pose a major direct health risk at these concentrations, it reflects the occurrence of hydrocarbon-related emissions that may accompany other harmful pollutants. The health risk assessment demonstrates that the refinery environment in Eleme experiences poor ambient air quality, dominated by particulate matter pollution. The AQI results indicate that $PM_{2.5}$ (AQI = 286) and PM_{10} (AQI = 268) represent the most critical pollutants, falling within the Very Unhealthy category. These findings correspond with residents' perceptions, where 85.4% agreed or strongly agreed that the refinery is a source of air pollution, while 53.8% reported experiencing respiratory problems. The assessment therefore confirms that refinery-related emissions constitute significant environmental health concern, requiring continuous air quality monitoring, improved emission control technologies, and effective regulatory measures to protect communities surrounding the refinery environment.

Table 3: Spatial health risk implication based on distance from refinery

Distance from refinery	Pollution exposure level	Expected health risk
0–100 m	Very high	Severe risk due to elevated $PM_{2.5}$, PM_{10}, SO_2, NO_2, VOCs and combustion gases. Residents and workers may experience increased respiratory irritation and chronic exposure concerns.
101–200 m	High	Increased likelihood of respiratory symptoms and exposure-related discomfort.
201–300 m	Moderate to high	Continued exposure with reduced but still concerning pollutant levels.
301–400 m	Moderate	Lower exposure compared with closer zones but still affected by refinery emissions.
>400 m	Reduced but present	Pollutants remain above background levels, indicating wider dispersion of refinery influence.

Table 3 presents the spatial health risk implications of refinery-related air pollution based on distance from the refinery. The results demonstrate a clear relationship between proximity to the refinery and potential exposure risk, with pollution exposure levels reducing progressively as distance from the emission source increases. This pattern corresponds with the observed spatial distribution of measured pollutants, where concentrations of particulate matter and gaseous pollutants were highest within the closest sampling zones and declined with increasing distance. The 0–100 m distance zone was categorized as having a very high pollution exposure level, representing the area with the greatest potential health risk. Residents and workers within this zone are exposed to elevated concentrations of $PM_{2.5}$, PM_{10}, SO_2, NO_2, VOCs, and combustion-related gases released from refinery operations. Continuous exposure within this zone may increase the likelihood of respiratory irritation, asthma aggravation, reduced lung function, cardiovascular stress, and other chronic exposure concerns. The high-risk classification is supported by the measured pollutant concentrations, where the highest values for $PM_{2.5}$ (286.4 ± 32.8 µg/m³), PM_{10} (438.6 ± 46.5 µg/m³), SO_2 (215.2 ± 22.6 µg/m³), and NO_2 (185.6 ± 19.8 µg/m³) were recorded closest to the refinery. The 101–200 m zone was classified as having a high pollution exposure level. Although pollutant concentrations reduced compared with the immediate refinery zone, the levels remained elevated and capable of producing exposure-related health concerns. Individuals living or working within this distance range may continue to experience respiratory symptoms, discomfort from poor air quality, and increased vulnerability to pollution-related health effects due to repeated exposure. The 201–300 m zone was categorized as having a moderate to high exposure level, indicating that refinery emissions continue to influence air quality despite further distance from the source. The continued presence of pollutants within this zone suggests that atmospheric dispersion does not eliminate refinery impacts within the surrounding environment. Residents in this area may still experience exposure to reduced but concerning pollutant concentrations, particularly during periods of low wind speed or unfavourable atmospheric conditions that limit pollutant dilution. The 301–400 m zone recorded a moderate pollution exposure level, reflecting further reduction in pollutant concentrations due to atmospheric mixing, dilution, and deposition processes. However, the area remains affected by refinery emissions, indicating that the influence of industrial activities extends beyond the immediate operational boundary. Continued monitoring is therefore necessary to ensure that pollutant levels remain within acceptable environmental and health protection limits. The >400 m zone was classified as having reduced but present pollution exposure. Although this zone experienced the lowest pollutant concentrations, measured values remained above natural background conditions, demonstrating the wider dispersion of refinery emissions into surrounding communities. This indicates that refinery-related pollution is not limited to locations immediately adjacent to the facility but can influence air quality over a broader spatial area. The spatial health risk assessment indicates that distance from the refinery is an important determinant of pollution exposure and associated health risks. The gradual reduction in risk with increasing distance supports the findings of the ANOVA analysis, which showed significant differences in pollutant concentrations across distance categories ($p < 0.001$). The pattern also aligns with residents' perceptions, where a majority reported frequent observation of refinery emissions, including 71.9% who indicated that they could see gas flaring from their homes or business locations and 62.1% who reported noticing refinery pollution daily. The results emphasize the need for targeted environmental management strategies, particularly within high-exposure zones, including continuous air quality monitoring, emission reduction measures, health surveillance, and improved protection for communities located close to the refinery.

Perception of the Respondents of the Refinery being the Major Source of Pollution in the Study Area

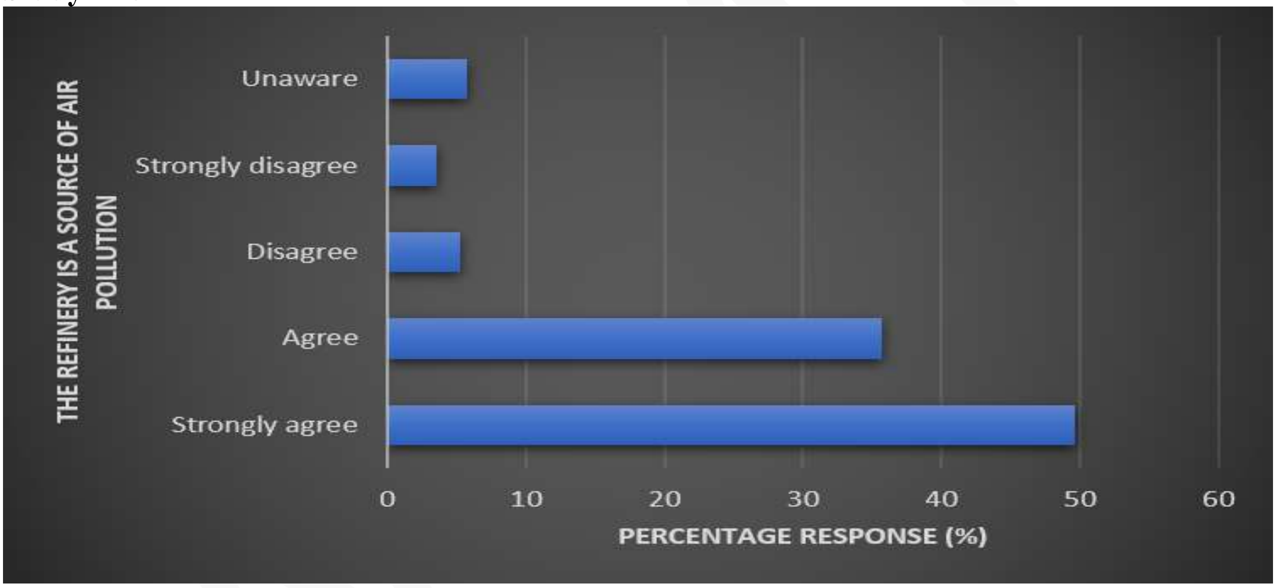

Figure 1: Perception of the Respondents of the Refinery being the Major Source of Pollution in the Study Area

Figure 1 shows respondents' perception of whether the refinery contributes to air pollution in the study area. The results reveal that 49.7% of respondents strongly agreed that the refinery is a source of air pollution, while 35.7% agreed. In contrast, 5.3% disagreed, 3.5% strongly disagreed, and 5.8% were unaware. The combined proportion of respondents who agreed or strongly agreed (85.4%) indicates a strong community perception that refinery activities contribute significantly to air quality deterioration. This perception corresponds with the measured pollutant concentrations, which showed elevated levels of particulate matter and gaseous pollutants within the refinery environment.

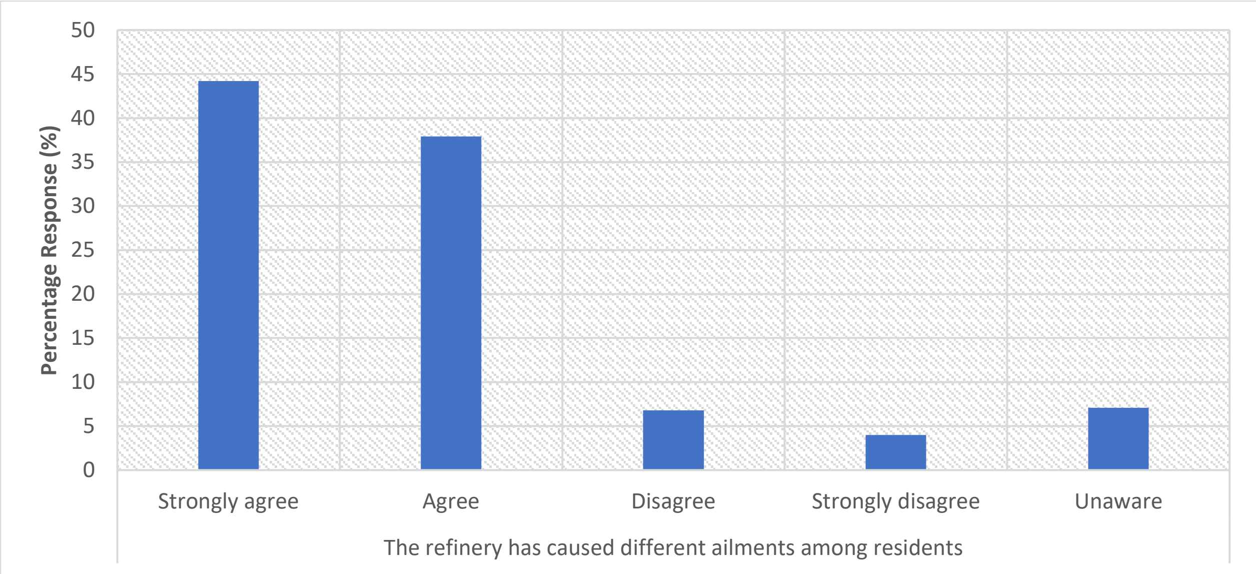

Figure 2: Perception of Respondents of the Pollutants from the Refinery Being a Major Cause of Diseases among the Locals

Figure 2 presents respondents' views on whether refinery activities have contributed to different ailments among residents. The findings show that 44.2% strongly agreed and 37.9% agreed that refinery operations have caused health problems within the community. Meanwhile, 6.8% disagreed, 4.0% strongly disagreed, and 7.1% were unaware. The high agreement level (82.1%) indicates widespread concern among residents regarding the possible health consequences of refinery-related pollution. This perception is consistent with the elevated concentrations of pollutants such as $PM_{2.5}$, PM_{10}, SO_2, and NO_2, which are associated with respiratory and cardiovascular health effects.

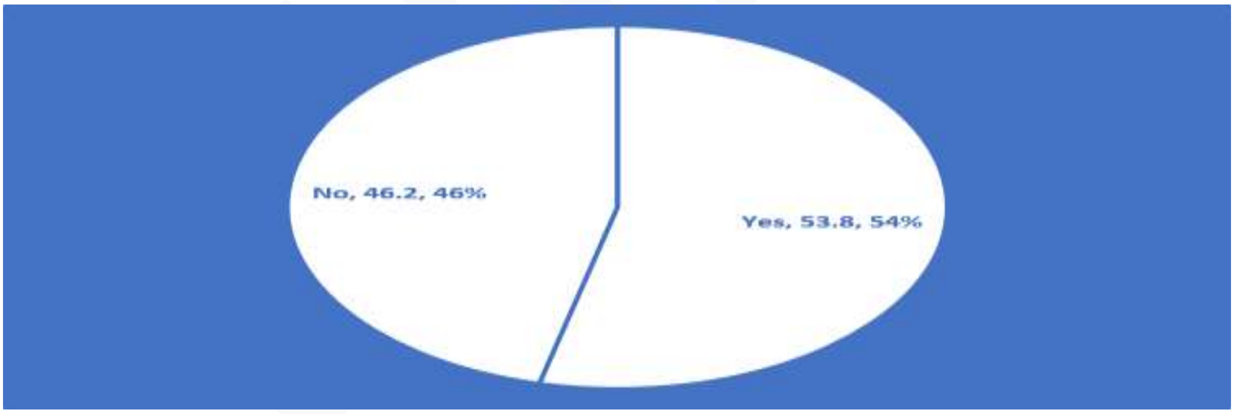

Figure 3: Experience of Respiratory Problems such as Asthma in the Area by Respondents

Figure 3 illustrates respondents' experiences of respiratory problems, including asthma. The result shows that 53.8% of respondents reported experiencing respiratory problems, while 46.2% indicated that they had not experienced such conditions. The finding suggests that respiratory symptoms represent an important health concern among residents of the refinery environment. The prevalence of reported respiratory problems may be linked to continuous exposure to elevated particulate matter and gaseous pollutants, particularly among individuals living and working close to emission sources.

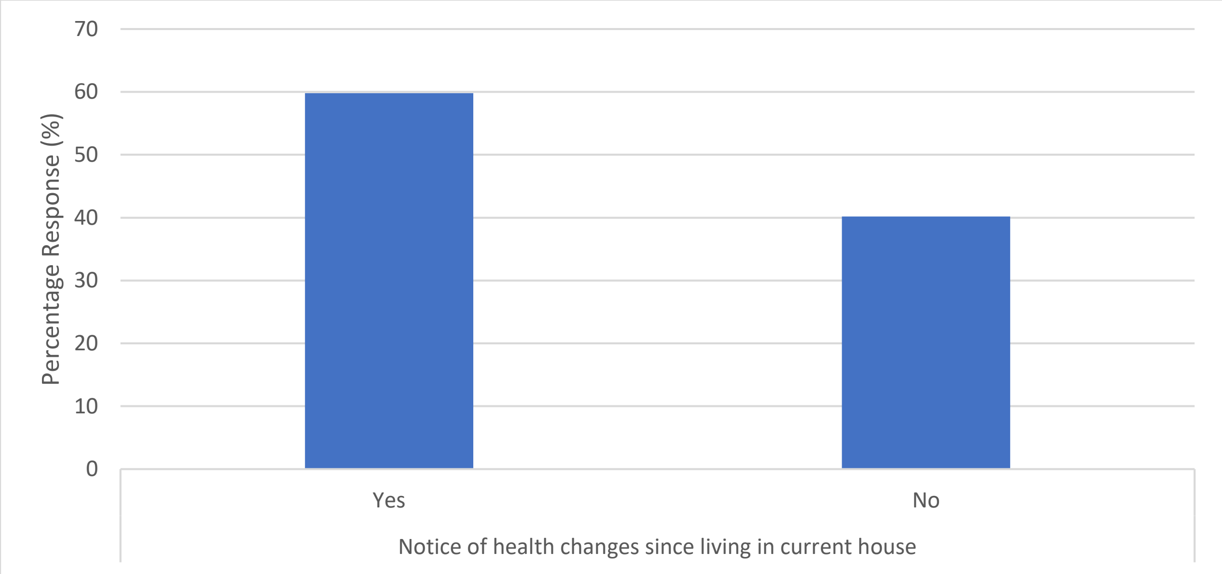

Figure 4: Notice of health changes since living in current house

Figure 4. presents whether respondents had noticed changes in their health since living in their current houses. The results indicate that 59.8% of respondents reported noticing health changes, while 40.2% reported no noticeable changes. The relatively high proportion of respondents reporting health changes suggests that prolonged residence within the refinery environment may influence residents' perception of pollution-related health effects. Long-term exposure to industrial emissions may contribute to gradual changes in respiratory health, general wellbeing, and environmental comfort.

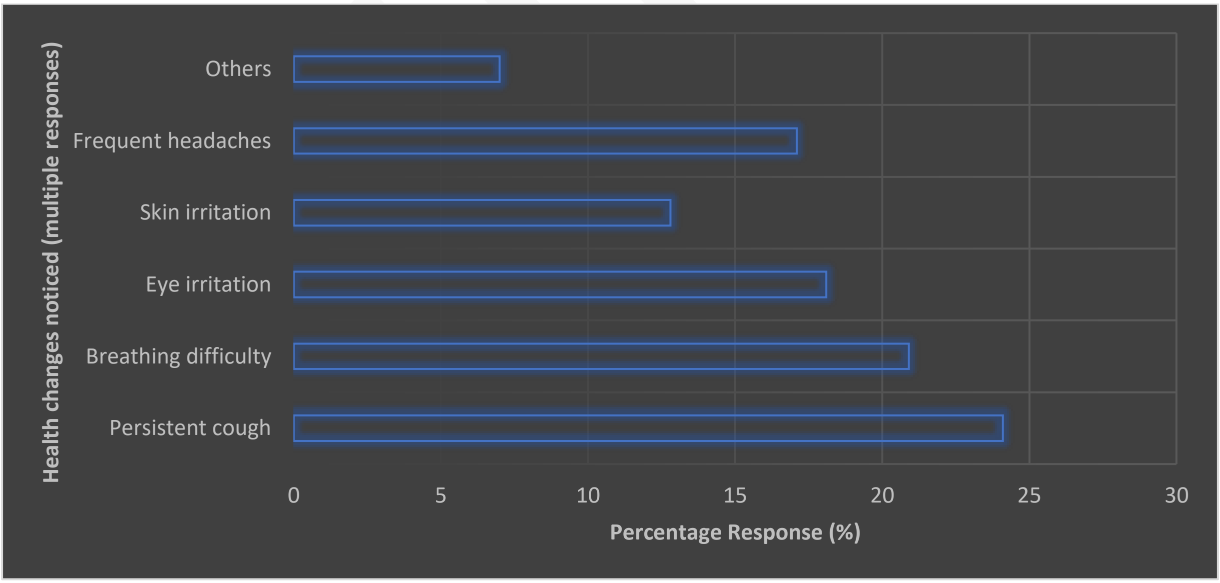

Figure 4: Health changes noticed (multiple responses)

Figure 4 presents the different health changes reported by respondents. The most frequently reported health concern was persistent cough (24.1%), followed by breathing difficulty (20.9%), eye irritation (18.1%), frequent headaches (17.1%), skin irritation (12.8%), and other symptoms (7.0%). The dominance of respiratory-related symptoms, particularly persistent cough and breathing difficulty, reflects possible exposure effects from airborne pollutants.

These reported symptoms correspond with the measured air quality results, where elevated particulate matter and gaseous pollutants were observed around the refinery environment.

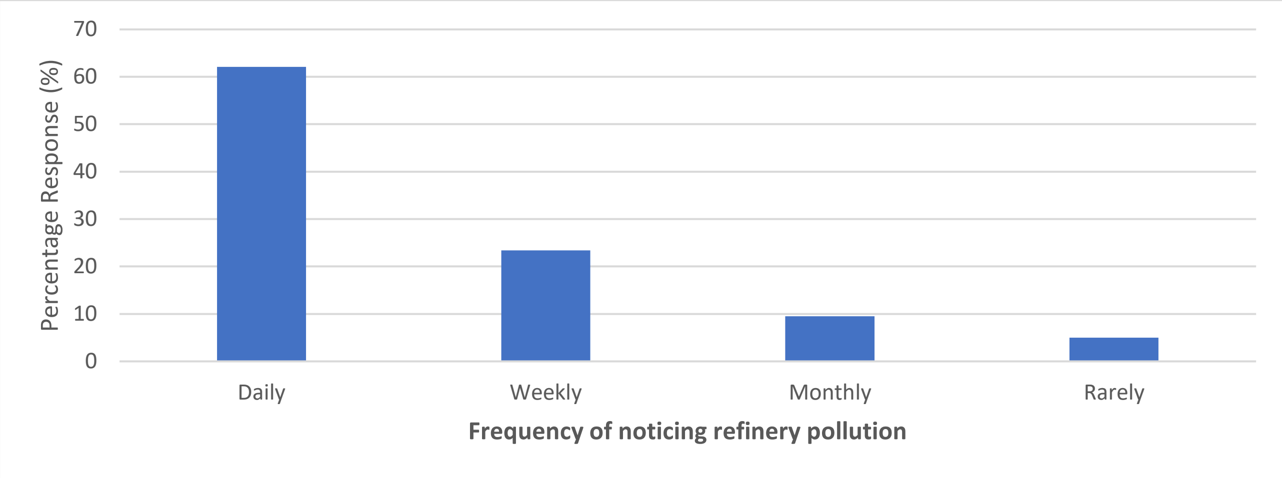

Figure 5: Frequency of noticing refinery pollution

Figure 5 presents how frequently respondents observe pollution from the refinery. The results show that 62.1% of respondents reported noticing refinery pollution daily, while 23.4% observed pollution weekly. Those who noticed pollution monthly accounted for 9.5%, whereas only 5.0% rarely observed refinery pollution. The dominance of daily observations indicates persistent exposure to refinery-related environmental disturbances. Frequent pollution observation may contribute to increased public concern and awareness regarding the impacts of refinery operations on ambient air quality.

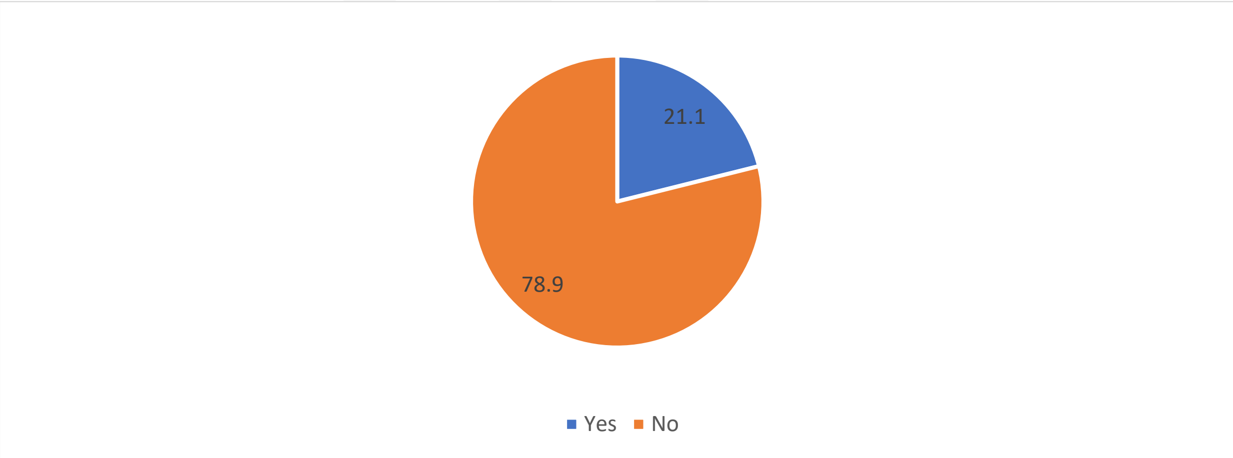

Figure 5: Use of protective nose mask during daily activities

Figure 5 shows whether respondents use protective nose masks during their daily activities. The result indicates that only 21.1% of respondents reported using nose masks, while 78.9% indicated that they do not. The low level of personal protective measure adoption suggests limited community preparedness for reducing exposure to polluted air. This may increase vulnerability, particularly among residents frequently exposed to refinery emissions during outdoor activities and occupational engagements.

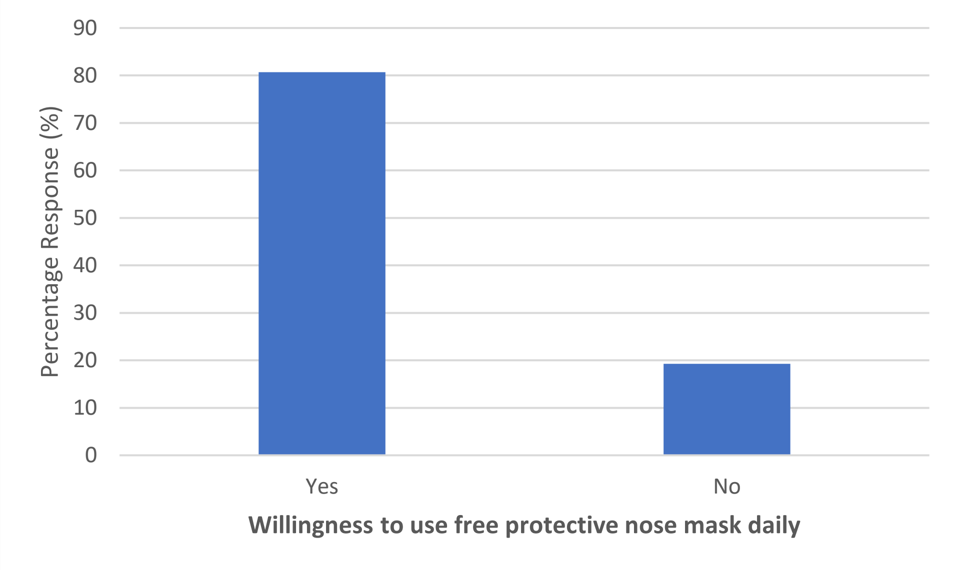

Figure 6 Willingness to use free protective nose mask daily

Figure 6 presents respondents' willingness to use free protective nose masks if provided. The findings show that 80.7% of respondents indicated willingness to use protective masks, while 19.3% were unwilling. The high willingness level suggests that residents recognize the importance of protective measures against air pollution exposure. The finding also indicates that providing affordable or free protective materials may improve community adaptation and reduce exposure risks.

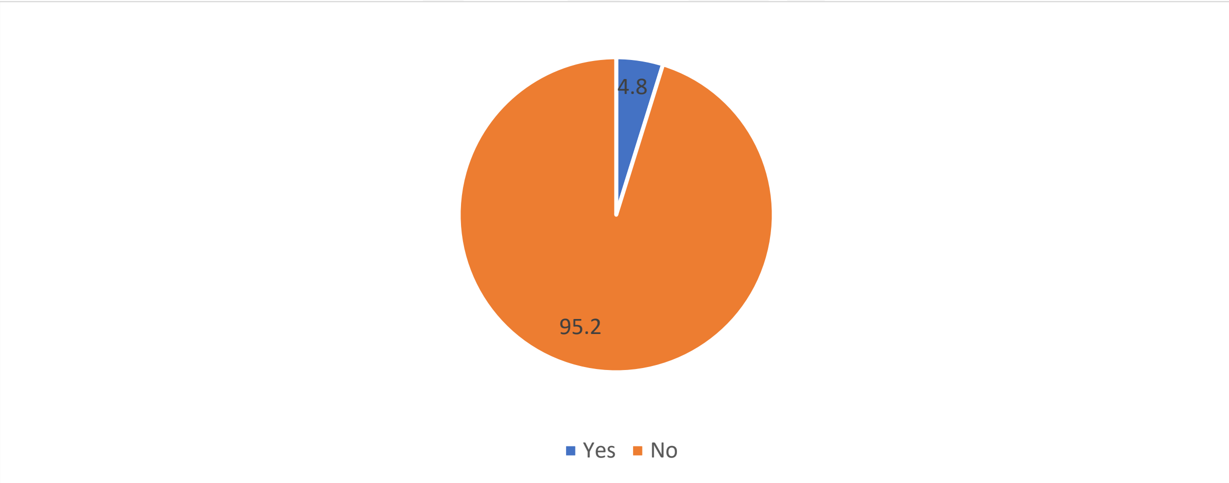

Figure 7: Received compensation due to air pollution exposure

Figure 7 presents whether respondents have received compensation because of exposure to air pollution. The results show that only 4.8% of respondents reported receiving compensation, while a substantial 95.2% indicated that they had not received any form of compensation. This finding highlight concerns regarding environmental justice and community support mechanisms in refinery-hosting areas. The lack of compensation may contribute to dissatisfaction among residents who perceive themselves as bearing the environmental and health burdens associated with refinery activities.

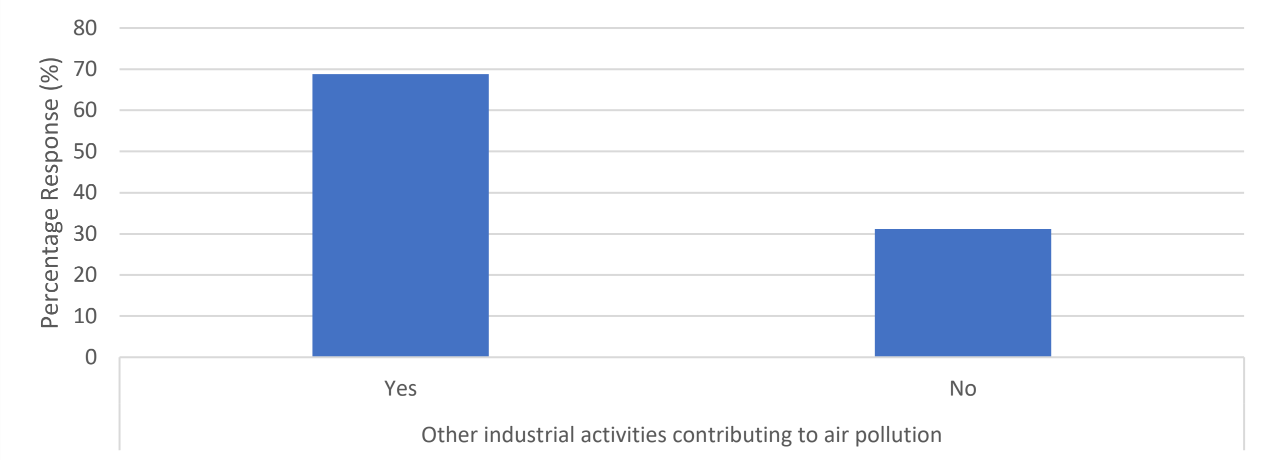

Figure 8: Other industrial activities contributing to air pollution

Figure 4.11 presents respondents' views on whether other industrial activities contribute to air pollution in the community. The results show that 68.8% of respondents agreed that other industrial activities contribute to air pollution, while 31.2% disagreed. This indicates that residents recognize that air quality problems may not originate solely from refinery operations but may also result from other industrial activities within the area. The finding reflects the industrial nature of Eleme and highlights the need for integrated pollution management involving all emission sources within the environment.

H_O2. The perception of the health effects of air pollution in the study area is not significantly different

Table 4: ANOVA summary testing the hypotheses 'there is no significant variation in ambient air quality (particulate matters) at different distances from the Port-Harcourt refinery'.

Particulate matter	n	df	0–100 m (Mean)	101–200 m (Mean)	201–300 m (Mean)	301–400 m (Mean)	>400 m (Mean)	F	p-value	Decision	Duncan Multiple Range Test
$PM_{2.5}$ (µg/m³)	90	4, 85	286.4±32.8	248.7±29.6	218.5±25.7	186.9±22.4	152.8±19.3	88.64	<0.001	Significant	A > B > C > D > E
PM_{10} (µg/m³)	90	4, 85	438.6±46.5	391.4±42.8	345.7±37.9	302.6±34.1	235.8±28.6	96.18	<0.001	Significant	A > B > C > D > E

Table 4 presents the one-way Analysis of Variance (ANOVA) results examining the spatial variation of particulate matter concentrations ($PM_{2.5}$ and PM_{10}) at different distances from the Port-Harcourt refinery. The hypothesis tested was that there is no significant variation in ambient air quality (particulate matter) at different distances from the refinery. The results indicate that both $PM_{2.5}$ and PM_{10} concentrations varied significantly across the five distance categories, demonstrating that proximity to the refinery has a significant influence on particulate pollution levels within the study area. The ANOVA result for $PM_{2.5}$ revealed a statistically significant difference among the sampling distances, with an F-value of 88.64 and p-value <0.001. The mean concentration was highest at the nearest sampling zone (0–100 m), with a value of 286.4 ± 32.8 µg/m³, and decreased consistently across the distance categories to 152.8 ± 19.3 µg/m³ beyond 400 m. The Duncan Multiple Range Test (DMRT) separated all five distance groups into distinct categories (A > B > C > D > E), indicating that each distance interval had significantly different $PM_{2.5}$ concentrations. This confirms that the immediate refinery environment experiences the greatest influence of fine particulate emissions. The significant variation observed in $PM_{2.5}$ concentrations can be attributed to the nature of refinery-related emission sources, including gas flaring, combustion processes, fuel burning, and industrial equipment operations. Fine particles generated from these activities can penetrate deep into the respiratory system and are associated with adverse health outcomes, particularly among individuals living and working close to emission sources. Although $PM_{2.5}$ concentrations reduced with increasing distance, the elevated values recorded beyond 400 m indicate that refinery emissions extend beyond the immediate operational area. Similarly, PM_{10} recorded significant spatial differences across the distance categories, with an F-value of 96.18 and p-value <0.001. The highest concentration was observed within the 0–100 m zone (438.6 ± 46.5 µg/m³), while the lowest concentration occurred beyond 400 m (235.8 ± 28.6 µg/m³). The DMRT result (A > B > C > D > E) confirms that the five distance zones differed significantly from one another. The higher F-value recorded for PM_{10} compared with $PM_{2.5}$ indicates a stronger spatial variation, suggesting that coarse particulate emissions are more concentrated around the refinery source. The observed PM_{10} pattern reflects contributions from both combustion and mechanical sources associated with refinery operations. Activities such as vehicular movement, road dust disturbance, transportation of petroleum products, industrial material handling, and construction activities may contribute significantly to coarse particle generation. The reduction in PM_{10} concentration with increasing distance reflects the influence of atmospheric dispersion, deposition, and dilution processes. The significant differences observed for both particulate fractions indicate that distance from the refinery is a major factor influencing ambient air quality. Since both pollutants recorded p-values less than 0.001, the null hypothesis stating that there is no significant variation in ambient air quality (particulate matter) at different distances from the Port-Harcourt refinery is rejected. Therefore, particulate matter concentrations vary significantly across different exposure zones, with locations closer to the refinery experiencing higher pollution levels. The findings are consistent with the measured gaseous pollutants, which also showed declining concentrations with increasing distance from the refinery. The results further support residents' perceptions of deteriorating air quality, as 71.9% of respondents reported observing gas flaring, while 62.1% indicated that they noticed refinery pollution daily. The elevated particulate concentrations near the refinery also provide a possible explanation for reported respiratory concerns among residents, where 53.8% acknowledged experiencing respiratory problems. The ANOVA results confirm that the refinery significantly influences particulate matter distribution within the study area. The strong distance decay pattern observed for $PM_{2.5}$ and PM_{10} highlights the need for effective particulate emission management, continuous air quality surveillance, and stronger regulatory measures to reduce exposure risks among communities surrounding the refinery.

Discussion of Findings

Exposure of Residents to Pollution Induced by the Port Harcourt Refinery

Demographic data show that individuals exposed to pollution due to the refinery are mainly male, actively employed, and have lived in the area for an extended period. The predominance of men (59.5%) and those in the 36–50 age group (37.2%) implies that many individuals are involved in outdoor jobs and activities, which heighten their chances of encountering environmental pollutants directly. Additionally, a significant number of respondents (34.2%) have resided in the area for more than 20 years, indicating a greater likelihood of experiencing ongoing exposure to emissions from the refinery over time. These outcomes are in line with the environmental exposure model, which asserts that both the length of residence and occupational activities greatly contribute to the cumulative impact of airborne pollutants (Brunekreef & Holgate, 2002). Likewise, research in industrial zones of developing nations has identified that long-term residents living near oil refineries face heightened exposure levels due to constant emissions and insufficient environmental regulations (Gobo et al., 2009; Ubani & Onyejekwe, 2013). This indicates that the community structure in the research area is particularly conducive for evaluating long-term exposure impacts, as residents possess characteristics of both prolonged residence and occupational exposure that heighten their susceptibility to pollution generated by the refinery.

Public Health Implications of Exposure to Refinery-Induced Air Pollution

The evaluation of air quality indicated alarmingly high levels of $PM_{2.5}$ (218.6 µg/m³) and PM_{10} (342.8 µg/m³), both categorized as "Very Unhealthy" according to AQI guidelines. The pronounced presence of fine and coarse particles signifies a serious deterioration in ambient air conditions. These particulates are recognized risk elements for respiratory and heart-related illnesses. The results are consistent with findings from the WHO, which state that prolonged exposure to particulate matter escalates the chances of asthma, chronic obstructive pulmonary disease (COPD), heart disease, and premature death (World Health Organization, 2021). Research in communities surrounding industrial sites has shown increased levels of particulate matter attributed to gas flaring and processes involving petroleum combustion, resulting in significant respiratory health consequences (Ismail & Umukoro, 2012; Njoku et al., 2016). Increased levels of SO_2, NO_2, and CO further substantiate the pollution associated with combustion typical of refinery settings. These gases are known to lead to airway inflammation, decrease lung performance, and escalate hospitalizations for respiratory issues (Dockery et al., 1993). The noted AQI readings exceeding 150 for most pollutants suggest that the area studied consistently faces air quality conditions detrimental to health. The spatial analysis also demonstrated a clear pattern of decrease with distance, as concentrations of pollutants were highest within 0–100 m of the refinery and diminished progressively with increased distance. This observation aligns with industrial emission dispersion models, indicating that pollutants diminish exponentially as one move further from the source of emissions (Seinfeld & Pandis, 2016). Studies conducted in Niger Delta refinery regions similarly corroborate that being near oil facilities significantly amplifies exposure to hazardous pollutants and related health dangers (Ajao & Anurigwo, 2002; Chinda & Braide, 2003).

Awareness and Perception of Residents on Air Quality and Public Health Implications

The analysis of perceptions indicated an exceptionally high degree of environmental consciousness among the participants, with 85.4% recognizing the refinery as a principal origin of air pollution. Furthermore, 82.1% contended that emissions from the refinery contribute to health issues within the local population, and 53.8% indicated that they had experienced respiratory symptoms. These observations are in accordance with environmental risk perception theory, which posits that residents living close to sources of industrial pollution often become more aware of environmental risks due to firsthand sensory and health experiences (Slovic, 1987). Comparable research conducted in Nigeria's oil-producing areas has shown a strong community awareness correlating refinery emission with respiratory conditions and environmental harm (Ezeh et al., 2017; Ubani & Onyejekwe, 2013). The high incidence of reported ailments like chronic coughs, difficulty in breathing, and eye irritation corresponds with epidemiological data that connects emissions from refineries to respiratory health issues (Pope & Dockery, 2006). Nevertheless, the fact that protective masks are rarely used (with 78.9% indicating non-use) shows a lack of adaptive behaviors despite the significant awareness, which highlights a disconnect between perception and protective measures that is often seen in industrial communities with limited resources (Olujimi et al., 2015). The statistic revealing that merely 4.8% of participants received compensation raises concerns regarding environmental justice, aligning with existing literature that suggests communities adjacent to oil refineries frequently endure unequal environmental challenges without sufficient remediation or compensation (Bullard, 2000).

Spatial Variation in Air Quality and Particulate Matter Distribution

The ANOVA findings indicated a significant statistical variation in the concentrations of $PM_{2.5}$ and PM_{10} across different distance categories ($p < 0.001$). The highest concentrations were observed at distances of 0–100 m, with levels consistently dropping as the distance from the refinery increased. The Duncan Multiple Range Test verified notable differences across all distance segments. This observed spatial trend is consistent with classical theories of atmospheric dispersion, which anticipate steep gradients in pollutant concentration surrounding specific industrial points (Seinfeld & Pandis, 2016). Similar observations have been made in refinery-host communities in the Niger Delta, where levels of particulates were significantly elevated close to emission points and diminished with distance due to processes of atmospheric dilution and deposition (Gobo et al., 2009; Ismail & Umukoro, 2012). The rejection of the null hypothesis indicates that industrial operations at the refinery substantially affect the distribution of ambient particulate matter. This assertion is also supported by research conducted by Njoku et al. (2016), which documented significant spatial variations in air quality in oil-producing areas, linking this to gas flaring and industrial combustion activities. Overall, the findings clearly illustrate that the Port Harcourt refinery plays a significant role in contributing to outdoor air pollution, presenting undeniable evidence of exposure, health implications, and spatial discrepancies. The results are strongly aligned with recognized environmental health research and empirical investigations from oil-rich regions, both globally and specifically within the Niger Delta, underscoring that closeness to refinery activities is a key factor influencing exposure risks and public health results.

Conclusion

This research focused on the exposure experienced by locals, implications for public health, awareness and perceptions related to air quality, and the geographic variability of particulate matter in connection to emissions from the Port Harcourt refinery. Results indicate that individuals residing in Eleme face chronic exposure to heightened levels of particulate matter and gaseous pollutants, specifically $PM_{2.5}$ and PM_{10}, with concentrations surpassing safe air quality limits and categorizing within unhealthy to very unhealthy ranges. Analysis of the respondents' demographics reveals that those most exposed tend to be economically active, long-term residents who are at an increased risk for cumulative health issues due to their enduring presence in the refinery-affected area. The findings also highlighted pronounced public health challenges arising from air pollution linked to the refinery. Elevated levels of $PM_{2.5}$, PM_{10}, SO_2, NO_2, CO, and VOCs were correlated with respiratory and cardiovascular hazards, including asthma, chronic cough, difficulties in breathing, and eye discomfort. This evidence underscores that air pollution in the area represents not just an environmental issue but a significant public health concern, particularly for vulnerable groups like children, elderly individuals, and those with pre-existing health conditions. Additionally, the findings indicated that residents possess a considerable level of awareness and perception regarding pollution from the refinery and its associated health effects. The majority of participants identified the refinery as a principal source of air contamination and connected it to the health issues within the community. Nonetheless, despite this awareness, the adoption of protective actions, such as wearing masks, remains quite low, indicating a disconnect between the understanding of risks and practical responses. The lack of compensation initiatives also raises concerns regarding environmental justice within the region. Geospatial analysis revealed notable differences in air quality based on distance from the refinery, with pollutant levels diminishing as distance increases. The ANOVA analysis corroborated this trend statistically, demonstrating that the proximity to the refinery significantly influences exposure levels. This spatial pattern reaffirms the finding that areas nearest to the refinery endure the greatest environmental and health challenges. The research concludes that emissions from the Port Harcourt refinery substantially compromise ambient air quality and present serious health hazards to the local populations. The comprehensive evidence from environmental data, statistical findings, and communal perceptions strongly supports the notion that refinery operations are a key contributor to air pollution in Eleme

Recommendations

i. Management of the refinery, alongside pertinent regulatory bodies, should implement more stringent emission control protocols. This should encompass the enhancement of flaring systems, the installation of sophisticated filtration technologies, and consistent environmental compliance evaluations to curtail both particulate and gaseous emissions at their source.

ii. Government and environmental protection organizations should set up ongoing air quality monitoring stations throughout Eleme and nearby areas to facilitate real-time data collection for early warnings, regulatory adherence, and public health strategy development.

iii. Community health initiatives ought to be enhanced by consistent health education for the public, supplying protective gear like masks, and creating specific medical monitoring programs for people residing in areas with high exposure levels, especially those located within 0–200 meters of the refinery.

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