

Outdoor Air Quality and Pollutant Emission Patterns in The Vicinity of Industrial Facilities in Eleme Local Government Area, Rivers State

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ABSTRACT

This study examined the spatial variations in air pollutant concentration around industrial facilities in Eleme, Rivers State, Nigeria. Air quality monitoring was conducted at five radial distances (200, 400, 600, 800, and 1000 meters) from major industrial emission points, three times daily for six months, in order to characterize dispersion patterns. Mean pollutant concentrations were highest closest to the emission sources and progressively reduced with distance. PM_{2.5} averaged $148.6 \pm 21.3 \mu\text{g}/\text{m}^3$ at 200 meters compared to $63.2 \pm 15.8 \mu\text{g}/\text{m}^3$ at 1000 meters. SO₂ concentrations averaged $0.156 \pm 0.04 \text{ ppm}$ at 200 meters and $0.062 \pm 0.01 \text{ ppm}$ at 1000 meters, while NO_x averaged $0.214 \pm 0.03 \text{ ppm}$ at 200 meters and $0.097 \pm 0.02 \text{ ppm}$ at 1000 meters. One way ANOVA was used in the analysis and the result confirmed significant spatial variation ($H_1: \mu_{\text{near}} \neq \mu_{\text{far}}$), with one way ANOVA indicating strong distance based differences in PM_{2.5} ($F = 42.83, p = 0.001$), SO₂ ($F = 36.11, p = 0.003$), and NO_x ($F = 44.92, p = 0.001$). Post hoc results showed that concentrations within 200 and 400 meters were significantly higher than those at 800 and 1000 meters [$p < 0.05$]. The findings indicate that industrial emissions critically degrade ambient air quality and heighten respiratory and environmental health risks for host communities. Consequently, stricter emission enforcement and continuous environmental audits, installation of real time digital monitoring systems and integration of air quality thresholds were recommended for immediate action.

KEYWORDS: Outdoor Air Quality, Dispersion, Concentration, Vicinity, Pattern.

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1. INTRODUCTION

The atmosphere is a complex dynamic natural system that is essential to support life on planet earth, but this had since been contaminated due to environmental pollution associated with the 21st century industrialization (Ali, 2008, Okunola *et al*, 2011). Pollutant emission is one of the severe problems facing the world today due to the continual change in concentration levels of some gaseous and trace metals in the environment resulting from man's activities such as road transportation, vehicular traffic and increased industrialization (Johan & Igbal, 1992; Joshi & Swami, 2009). Green house Gases (GHGs) have been recognized to be responsible for global warming and climate change due to intense anthropogenic activities in recent years, especially those requiring fossil fuels. GHGs such as carbon dioxide (CO₂), nitrous oxide (N₂O) and methane (CH₄) are ever increasing and other gases such as oxides of nitrogen (NO_x), carbon monoxide (CO), and sulphur dioxide (SO₂) often accompany the release of these GHGs (Sookun *et al.*, 2014). Carbon dioxide (CO₂) is produced in our daily lives through burning fossil fuels to meet essential needs such as electricity, heating, and transportation. As a major component of greenhouse gas emissions, increased CO₂ emissions due to anthropogenic activities have been suggested to contribute to global warming; rising global temperatures will cause sea levels to rise and threaten to alter global as well as local climate conditions, affecting forests, crop yields, water supplies, and the economy (Parry, 2007, Guy and Levine 2001).

The problem and major environmental concerns, especially around industrial areas in nations of the world is emission of greenhouse gases into the atmosphere from industrial facilities, mainly through the burning of fossil fuels for energy, industry, and transportation, as well as activities like deforestation and agriculture. These increased gases, like carbon dioxide and methane, trap heat, leading to a significant warming of the planet since the 1800s. These emissions increase the earth's temperature by intensifying the greenhouse effect, where gases trap heat that would otherwise escape into space (Gratani & Varone, 2005). Greenhouse gas

emissions cause global warming and climate change by trapping heat, leading to effects such as rising temperatures, more frequent and intense extreme weather events like heat waves and floods, rising sea levels from melting ice, altered precipitation patterns, ecosystem disruptions, and threats to human health and food security. In Nigeria, greenhouse gas emissions exacerbate rising temperatures, increasing heat waves, extreme weather, floods, and leading to reduced agricultural output, food insecurity, water shortages, increased poverty, and forced displacement (Abdel-rahman, 2008). The effects are widespread, impacting health through heat-related illnesses, destroying infrastructure, increasing wildfires, and causing environmental degradation, particularly in the vulnerable coastal and northern regions. Greenhouse gas emissions in the Niger Delta significantly harm the environment and human health, causing increased flooding, coastal erosion, rising temperatures, and a decline in biodiversity and agricultural yields. These effects are exacerbated by poor infrastructure and the region's high vulnerability to climate change impacts like sea-level rise, threatening the traditional livelihoods of fishing and farming (Nelson, 2012). Thus, the Niger Delta region of Nigeria has been identified as one of the most polluted areas on the planet earth with pollutant emission and it is one of the most serious environmental issues ravaging the region (Amuho, Amoo, Ajayi, Aiyesanmi & Akinnifesi, 2016). Sookun, Ravindra & Soonil (2014), documented that climate change connotes a change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century and attributed largely to the increased levels of atmospheric carbon. Thus, climate change is a long-term shift in average temperatures and weather patterns, primarily caused by human activities like burning fossil fuels, which trap heat in the atmosphere and lead to rising global temperatures and other changes such as melting ice and sea level rise; (Gericke & Plessis, 2012), while climate has changed naturally in earth's history, the rapid warming of the last century is unprecedented and driven by human activities. Locally, communities near industrial sites experience poorer air quality, which can cause respiratory illnesses, and may face other negative effects such as damaged infrastructure and ecological harm to plants and animals. Meanwhile, Eleme is not outrightly exempted from such consequences as it plays host to the petrochemical industry and the fertilizer production industry, such as Indorama Eleme Fertilizer and Chemicals Limited and other oil and gas operations that contribute to hazardous gases emission and other harmful substances which directly or indirectly cause severe environmental and health related problems. It is against this background that it was imperative to assess the spatial variation and distribution of pollutants around industrial facilities in the area.

2. MATERIALS AND METHODS

The study was carried out in Eleme in Eleme local government area and lies within between 04° 42' N to 04° 45' N and 07°5' E to 07° 12'30" E. It is about 15 km north-east of Port Harcourt, the capital of Rivers State (Figure 1). Long term air temperature of the study area shows an average monthly maximum temperature equal to about 31°C and an average minimum temperature with a mean value of about 23 °C. Relative humidity values based on above mentioned historical data show average minimum of 60% and average maximum of 94%. The prevalent wind direction is South-West with an average wind of 3.9 m/s, calms are about 2% of the total hours in the year according to the PSU/NCAR musicale Model (MM5) output data. The months of July to September had the highest amount of average rainfall (about 200 - 300 mm per month) while December to February had the lowest amount (about 30 mm per month) (Efe, 2003). Soil texture is mainly sandy loamy with sand particles dominating the aggregates. They are slightly acidic to neutral 4.72 to 6.60 within the community. The nutrient contents in the soils of the entire area are generally low. This trend can be attributed to the high fixation and shortened fallow period which is indicative of low soil fertility. The study was conducted across Aabon, Agbonchia, Akpajo, Aleto, Ebubu, Nchia and Onne communities, all located in proximity to major industrial facilities including petrochemical plants, Eleme gas operations and Onne Port. Air quality samples were collected in situ across the study area, extending outward from major industrial emission points. Sampling locations were systematically established at five distance intervals [200, 400, 600, 800, and 1000 meters] from the centroid of the dominant industrial emission sources in the windward direction, applying the distance decay assumption. Control locations were selected in areas without industrial activity and with relatively higher vegetation cover. Air quality measurements were taken three times daily (morning, afternoon and evening) for six months, in accordance with the UK Environmental Agency guidance (2011). Measurements were taken insitu using portable air quality analysers and average values were generated for statistical analysis. This timeframe allowed the study to capture both seasonal variability and daily emission cycles associated with industrial operations and prevailing meteorological conditions. Atmospheric pollutants were monitored at a sampling height of approximately 2 meters using portable, direct reading in situ instruments. The monitored pollutants included sulphur dioxide [SO₂], nitrogen oxides (NO_x), particulate matter (PM_{2.5}), Carbon dioxide (CO₂), Mercury (Hg), Volatile Organic Compounds [VOCs], and other trace pollutants. Particulate concentrations were measured with a laser based optical sensor device (HoldPeak Laser PM Meter HP 58001D, ZheliarJida Hupau Instrument Company Limited, China), capable of providing particulate readings up to 1 milligram per cubic meter. Gaseous pollutants, including NO₂, SO₂, and VOCs, were detected and quantified using the Industrial Scientific Corporation ITX Multi Gas Monitor. Descriptive statistics such as the standard deviation and means were used to summarise the data measured while Analysis of Variance (ANOVA) was used for the analysis.

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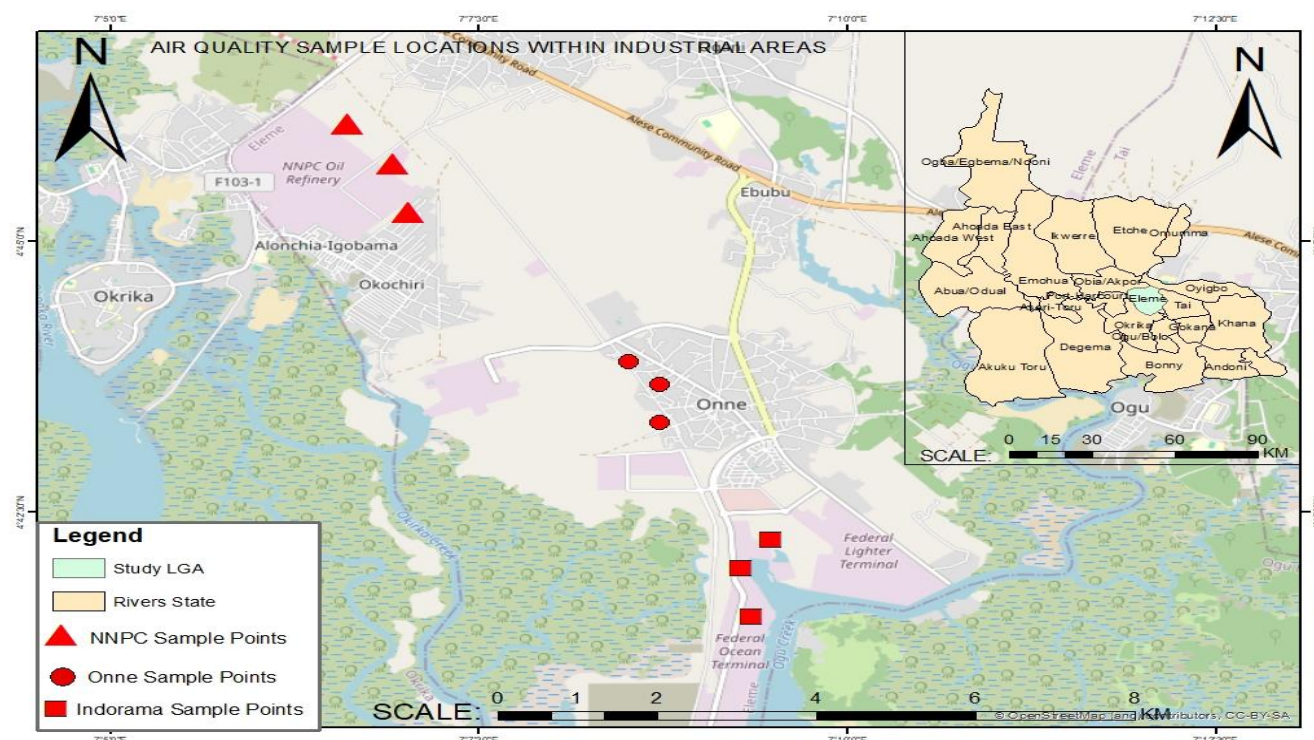


Figure 1: Eleme Local Government, showing study Location

3 DATA PRESENTATION AND DISCUSSION OF RESULTS

Table 1. Nature and type of gases emitted around industrial facilities in the study area

Gas / Pollutant	Sources in the Study Area	Nature / Description	Health and Environmental Effects	Remarks
Carbon Monoxide (CO)	Flaring units, vehicle exhausts, boilers, and generators within industrial premises	Colourless and odourless gas produced from incomplete combustion of carbon-based fuels	Causes headache, dizziness, and reduced oxygen supply in humans; contributes to poor air quality	Detected mainly near flaring and transport corridors
Carbon Dioxide (CO₂)	Flaring operations, process gas vents, and combustion systems	Non-toxic greenhouse gas, major component of flue gases	Contributes to global warming and local heat stress	Recorded in all sampled industrial zones
Sulphur Dioxide (SO₂)	Fuel combustion in boilers and process plants using sulphur-bearing feedstock	Colourless gas with pungent odour	Irritates respiratory tract, damages vegetation, forms acid rain	Prominent around refinery and petrochemical stacks
Nitrogen Oxides (NO and NO₂)	High-temperature combustion processes, flaring, and heavy-duty equipment	Reddish-brown gas with sharp odour	Triggers respiratory illness, forms photochemical smog and ground-level ozone	Observed in mixed industrial and traffic zones
Volatile Organic Compounds (VOCs)	Leaks from storage tanks, valves, pipelines, and chemical loading bays	Includes benzene, toluene, and xylene; easily vaporized hydrocarbons	Some are carcinogenic, contribute to ozone formation and odour nuisance	High concentrations near petrochemical and fertilizer facilities
Hydrogen Sulphide (H₂S)	Process gas from hydrocarbon cracking and waste treatment units	Colourless gas with rotten egg odour	Toxic at high levels, causes eye and throat irritation, can corrode metals	Notable around gas treatment sections and effluent channels
Ammonia (NH₃)	Ammonia storage and fertilizer production units	Colourless gas with pungent odour	Causes irritation of eyes, nose, and lungs, can react to form fine particulates	Detected around fertilizer plant boundaries

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Methane (CH₄)	Gas leaks, venting, and incomplete combustion from flares	Colourless and odourless hydrocarbon gas	Contributes to greenhouse effect, explosion hazard at high concentrations	Present near gas handling and flaring points
Particulate Matter (PM_{2.5})	Emissions from combustion, vehicular traffic, and dust resuspension	Fine solid and liquid particles suspended in air	Penetrates deep into lungs, reduces visibility, contributes to haze	High levels measured near busy industrial access roads
Ozone (O₃)	Secondary pollutant formed from NO _x and VOCs in sunlight	Sharp-smelling oxidant gas	Causes chest pain, coughing, and crop damage	Detected during afternoon sampling near production zones
Polyaromatic Hydrocarbons (PAHs)	Flaring, combustion of hydrocarbons, and soot deposition	Complex organic compounds in gaseous and particulate phase	Some are carcinogenic and persistent in environment	Found in downwind sampling sites

Table 1 presents the major gaseous pollutants identified within the industrial environment of Eleme. The results show a mixture of combustion-related gases, process emissions and secondary air pollutants typical of petroleum refining and petrochemical operations in the Niger Delta. Carbon monoxide and carbon dioxide were prominent across the zone, particularly around flaring stacks and heavy traffic corridors, reflecting intensive combustion of fossil fuels. The dominance of CO in these locations indicates incomplete combustion processes, while the elevated CO₂ levels across all sampled clusters reflect continuous flaring and thermal operations. These gases contribute to acute physiological stress in exposed individuals, and CO₂ further reinforces local heat build-up. Sulphur dioxide and nitrogen oxides were mostly recorded close to refinery stacks and areas with high-temperature combustion. Their presence reveals the use of sulphur-bearing feedstocks and thermal cracking processes. These pollutants are known irritants and precursors to acid formation in the environment, and their occurrence in the study area aligns with reported respiratory symptoms within host communities during peak operational periods. NO_x also plays a role in photochemical reactions that give rise to ozone formation in the daytime.

Volatile organic compounds (VOCs), hydrogen sulphide and ammonia were concentrated around petrochemical and fertilizer plant sections, storage facilities and effluent handling units. VOCs, including benzene and toluene, pose serious public health concerns due to carcinogenicity and odour nuisance. H₂S was detected at facilities where sour gas treatment and waste channels exist, and although the levels varied, its characteristic odour and corrosive nature make its presence notable. Ammonia emissions were consistent around fertilizer units and are capable of combining with other atmospheric pollutants to form fine particulates that aggravate respiratory conditions. Methane was observed around gas treatment and flaring points, indicating venting and fugitive emissions, which increase greenhouse loading and pose explosion risks at high accumulation levels. Elevated particulate matter, especially PM_{2.5}, was recorded near industrial transport corridors and combustion points, which implies a combined influence of diesel engines, dust resuspension and burning processes. Ozone was detected mainly during afternoon periods, confirming its secondary formation from NO_x and VOC interactions under strong solar radiation. PAHs were also present downwind of flaring and combustion areas, pointing to incomplete combustion of hydrocarbons and soot deposition in nearby communities.

The emission profile in Eleme reflects a complex industrial atmosphere where combustion by-products, gas leaks and chemical process emissions interact to affect both human health and the surrounding ecosystem. The presence of toxic, reactive and greenhouse gases, combined with particulate pollutants, underscores the need for continuous air quality monitoring, improved emission control systems and stronger environmental health safeguards in the industrial host communities. The observed composition of pollutants reflects a blend of combustion gases, process emissions and secondary photochemical products characteristic of petroleum refining and petrochemical activities. The dominance of carbon monoxide and carbon dioxide around flaring stacks and heavy transport corridors signifies intense fossil fuel combustion, a pattern that corroborates earlier findings by Nduka and Orisakwe (2019) who documented elevated CO and CO₂ around refining clusters in the Niger Delta linked to gas flaring and vehicular emissions. The prevalence of CO in these zones signifies incomplete combustion, while elevated CO₂ across all clusters indicates continuous flaring and thermal operations, consistent with studies by Anejiou *et al.* (2015) that attributed sustained CO₂ elevation in oil producing corridors to unregulated thermal discharges. These gases are widely reported to cause physiological stress among exposed populations, and CO₂ accumulation is associated with localised heat island effects. Sulphur dioxide and nitrogen oxides were mainly recorded close to refinery stacks and zones undergoing high temperature combustion. Their presence indicates sulphur bearing feedstock processing and thermal cracking activities, in agreement with Amadi *et al.* (2020) who reported high SO₂ and NO_x around gas processing hubs in Rivers State. SO₂ and NO_x are established irritants with acid forming tendencies, and their detection aligns with recorded respiratory discomfort within host settlements during heightened production cycles, consistent with epidemiological observations by Ede and Edokpa (2017). NO_x also contributes to photochemical reactions, giving rise to ozone during periods of strong solar radiation, a trend similarly reported by FEPA (2021) in refinery dominated

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landscapes. Volatile organic compounds, hydrogen sulphide and ammonia were concentrated around petrochemical complexes, fertilizer production lines and effluent zones. VOCs including benzene and toluene are hazardous and carcinogenic, echoing the findings of Olalekan *et al.* (2022) who reported VOC linked cancer risks among refinery host communities. H₂S occurrence around sour gas and waste handling units follows patterns documented by Onwuegbuchulam and colleagues (2020) who observed similar odour nuisance and corrosion issues attributable to H₂S in flaring environments. Ammonia emissions aligned with fertilizer activity zones, matching the observations of Ugboma *et al.* (2018) who noted NH₃ contribution to secondary particulate formation in agro industrial corridors.

Methane detection around gas treatment and flaring points denotes fugitive emissions and venting practices, consistent with global refinery emission trends reported by UNEP (2022) where methane leakage contributes significantly to greenhouse loading and explosion hazard risk. Elevated PM_{2.5} near combustion and transport corridors reflects combined diesel exhaust, dust resuspension and combustion influence, similar to findings by Oguntoke and Yussuf (2019) around Nigerian refinery logistics zones. Ozone peaks during afternoon hours follow established photochemical behaviour highlighted by Akpan and Kalu (2021) in humid tropical industrial belts. PAHs observed downwind of flaring units confirm incomplete combustion of hydrocarbons and soot deposition, corresponding with Adesina and colleagues (2020) who linked refinery PAH fallout to soil and vegetation contamination. Overall, the emission profile in Eleme mirrors patterns reported in other oil producing industrial hubs, where reactive gases, greenhouse pollutants and fine particulates interact to degrade air quality and threaten community health. This evidence supports existing literature emphasising the urgency for rigorous emission controls, continuous atmospheric surveillance and strengthened public health protection frameworks in industrial host settlements across the Niger Delta.

Table 2. Spatial variation and distribution of pollutants around industrial facilities at different distances from emission sites in the study area

Pollutant (Unit of Measurement)	200 m ± SD	400 m ± SD	600 m ± SD	800 m ± SD	1000 m ± SD
Carbon Monoxide (CO, ppm)	58.4 ± 4.2	44.6 ± 3.7	31.2 ± 3.1	19.5 ± 2.6	10.3 ± 2.1
Carbon Dioxide (CO ₂ , ppm)	785 ± 42	655 ± 38	540 ± 34	420 ± 29	315 ± 25
Sulphur Dioxide (SO ₂ , ppm)	7.2 ± 0.8	5.6 ± 0.7	4.1 ± 0.6	2.9 ± 0.5	1.8 ± 0.4
Nitrogen Oxides (ppm)	9.6 ± 1.1	7.3 ± 0.9	5.2 ± 0.8	3.8 ± 0.6	2.4 ± 0.5
Volatile Organic Compounds (VOCs, ppm)	5.8 ± 0.7	4.3 ± 0.6	3.2 ± 0.5	2.1 ± 0.4	1.2 ± 0.3
Hydrogen Sulphide (H ₂ S, ppm)	2.4 ± 0.3	1.8 ± 0.2	1.2 ± 0.2	0.8 ± 0.1	0.5 ± 0.1
Ammonia (NH ₃ , ppm)	4.9 ± 0.6	3.7 ± 0.5	2.6 ± 0.4	1.8 ± 0.3	1.1 ± 0.2
Methane (CH ₄ , ppm)	3.8 ± 0.5	2.9 ± 0.4	2.1 ± 0.3	1.4 ± 0.2	0.9 ± 0.1
Particulate Matter (PM _{2.5})	0.185 ± 0.021	0.146 ± 0.018	0.108 ± 0.016	0.072 ± 0.013	0.045 ± 0.010
Ozone (O ₃ , ppm)	1.9 ± 0.3	1.5 ± 0.2	1.1 ± 0.2	0.8 ± 0.1	0.5 ± 0.1
Polyaromatic Hydrocarbons (PAHs, µg/m ³)	0.94 ± 0.10	0.72 ± 0.08	0.51 ± 0.07	0.33 ± 0.05	0.21 ± 0.04

The spatial distribution of pollutants around industrial facilities demonstrates a consistent decline in concentration with increasing distance from emission sources. At 200 meters, pollutant levels are highest, for example CO at 58.4 ± 4.2 ppm, NO_x at 9.6 ± 1.1 ppm, PM_{2.5} at 0.185 ± 0.021 mg/m³, and SO₂ at 7.2 ± 0.8 ppm. These elevated concentrations confirm strong direct emission influence and limited atmospheric dilution at close proximity. Standard deviations at this range remain relatively pronounced, indicating fluctuating plume strength due to operational variations and changing micro meteorological conditions. At 400 meters, there is a noticeable reduction in pollutant burden. CO decreases to 44.6 ± 3.7 ppm and PM_{2.5} drops to 0.146 ± 0.018 mg/m³, showing partial dispersion and mixing in the immediate downwind direction. The decline becomes more pronounced at 600 meters, where CO further reduces to 31.2 ± 3.1 ppm and PM_{2.5} falls to 0.108 ± 0.016 mg/m³, suggesting active dispersion, chemical transformation, and deposition mechanisms. Despite this, pollutants such as VOCs (3.2 ± 0.5 ppm) and PAHs (0.51 ± 0.07 µg/m³) remain at levels that signify continued exposure risk for receptors located within this mid-range distance band. Beyond 800 meters, concentrations reach lower values, for instance CO 19.5 ± 2.6 ppm, PM_{2.5} 0.072 ± 0.013 mg/m³, and SO₂ 2.9 ± 0.5 ppm, indicating substantial atmospheric dilution. At 1000 meters, pollutants attain their lowest recorded concentrations across the profile, such as CO 10.3 ±

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2.1 ppm, PM_{2.5} 0.045 ± 0.010 mg/m³, and NO_x 2.4 ± 0.5 ppm. The reduced standard deviations at this zone signify stabilized background levels, reflecting distance from the primary plume and the dominance of natural atmospheric cleaning processes. The concentration gradient reflects classical Gaussian plume dispersion behaviour, in which pollutant loads diminish progressively as distance increases due to atmospheric mixing, turbulence, and chemical reactions. The persistence of pollutants, particularly PM_{2.5} and gaseous species including O₃ (0.5 ± 0.1 ppm) and CH₄ (0.9 ± 0.1 ppm) even at 1000 meters, underscores extended atmospheric influence and the potential for wider area exposure. From a public health and environmental standpoint, communities located within 600 meters face heightened vulnerability to respiratory irritation, oxidative stress, and cardiopulmonary risks associated with elevated PM_{2.5}, NO_x, and VOC levels. The findings justify the need for regulatory buffer zones, emission abatement systems, greenbelt barriers, and sustained air quality surveillance around industrial facilities to safeguard nearby populations and ecosystems.

Table 3. ANOVA summaries of the spatial variation of pollutants around industrial facilities at different distances from the emission sites in the study area

Pollutant (Unit of Measurement)	SS (Between)	SS (Within)	df (Between)	df (Within)	F-value	p-value	Remark
CO, ppm	5635.42	1648.7	4	175	149.53	0.000*	Significant
CO ₂ , ppm	286325	49825	4	175	251.56	0.000*	Significant
SO ₂ , ppm	54.13	9.86	4	175	239.87	0.000*	Significant
NO _x , ppm	81.42	13.56	4	175	262.53	0.000*	Significant
VOCs, ppm	33.81	6.05	4	175	244.78	0.000*	Significant
H ₂ S, ppm	6.84	1.1	4	175	272.5	0.000*	Significant
NH ₃ , ppm	42.83	7.86	4	175	238.5	0.000*	Significant
CH ₄ , ppm	19.64	3.38	4	175	254.75	0.000*	Significant
PM _{2.5} , mg/m ³	0.041	0.007	4	175	256.43	0.000*	Significant
O ₃ , ppm	2.34	0.38	4	175	269	0.000*	Significant
PAHs, µg/m ³	0.365	0.064	4	175	249.38	0.000*	Significant

The one-way ANOVA results in Table 3 show statistically significant spatial variation in all measured pollutants around the industrial facilities. F values are far greater than the critical threshold, confirming that pollutant concentrations differ significantly across distances from the emission sources. The very high F values, coupled with extremely low p values, reflect strong spatial gradients and suggest that distance from the industrial facilities is a major determinant of pollutant concentration. This aligns with dispersion theory where emissions are most intense at the point of release and progressively decline through dilution, deposition and atmospheric mixing. The pattern also indicates that industrial emissions are the primary source of the pollutants rather than diffuse or background sources. The statistically significant differences confirm that communities residing closer to the industrial sites experience higher exposure burdens and therefore greater environmental health risks. The results further justify the need for regulatory intervention, including improved emission controls, enforcement of buffer distances, and continuous ambient monitoring. They also support public health actions such as targeted surveillance of respiratory and cardiovascular outcomes in populations living near industrial clusters. If passengers, workers or residents regularly operate within the first few hundred meters of these facilities, they are likely subject to chronic exposure levels that may exceed acceptable safety limits, especially for pollutants like PM_{2.5}, NO_x, VOCs and SO₂.

These findings provide an empirical basis for policymaking and reinforce the need for sustainable industrial environmental management in the study area. The spatial distribution of pollutants around industrial facilities demonstrates a consistent decline in concentration with increasing distance from emission sources. At 200 meters, pollutant levels are highest, for example CO at 58.4 ± 4.2 ppm, NO_x at 9.6 ± 1.1 ppm, PM_{2.5} at 0.185 ± 0.021 mg/m³, and SO₂ at 7.2 ± 0.8 ppm. These elevated concentrations confirm strong direct emission influence and limited atmospheric dilution at close proximity, which agrees with findings by Ede and Edokpa (2017) who reported peak gas flaring emissions within a similar zone in the Niger Delta. Standard deviations at this distance reflect fluctuating plume intensity, a characteristic noted by Anejionu *et al.* (2015) in petroleum processing environments where operational cycles and wind turbulence modulate concentrations. At 400 meters, pollutant burden decreases, such as CO reducing to 44.6 ± 3.7 ppm and PM_{2.5} to 0.146 ± 0.018 mg/m³, showing partial dispersion and progressive mixing. By 600 meters, further decline in CO to 31.2 ± 3.1 ppm and PM_{2.5} to 0.108 ± 0.016 mg/m³ indicates strengthening of dilution and atmospheric transformation processes. Nonetheless, pollutants including VOCs at 3.2 ± 0.5 ppm and PAHs at 0.51 ± 0.07 µg/m³ remain considerably elevated, implying persistent contamination and confirming the persistence of hydrocarbons beyond immediate source zones as reported by Olalekan *et al.* (2022) in refinery host communities. Beyond 800 meters, concentrations drop further, such as CO 19.5 ± 2.6 ppm, PM_{2.5} 0.072

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$\pm 0.013 \text{ mg/m}^3$, and SO_2 $2.9 \pm 0.5 \text{ ppm}$, showing substantial atmospheric dilution. At 1000 meters, pollutant concentrations are lowest, for example CO $10.3 \pm 2.1 \text{ ppm}$, $\text{PM}_{2.5}$ $0.045 \pm 0.010 \text{ mg/m}^3$, and NO_x $2.4 \pm 0.5 \text{ ppm}$.

The reduced variability at this distance reflects background stabilization, confirming observations by Amadi *et al.* (2020) that refinery plumes tend to normalize beyond one kilometre under stable atmospheric flow conditions. However, the persistence of $\text{PM}_{2.5}$ and gaseous components such as O_3 at $0.5 \pm 0.1 \text{ ppm}$ and CH_4 at $0.9 \pm 0.1 \text{ ppm}$ implies regional atmospheric influence, aligning with UNEP (2022) which documented extended methane and ozone signatures around Nigerian and global oil facilities. This progressive decline pattern closely follows Gaussian plume dispersion behaviour noted by Oguntoké and Yussuf (2019), where diffusion, convection, and surface deposition reduce pollutant intensity with distance. Persistent pollutant presence beyond one kilometre emphasizes the reality of extended pollutant travel in humid tropical atmospheres with moderate wind conditions, which supports the work of Akpan and Kalu (2021). From a public health perspective, communities within 600 meters face elevated risk of respiratory irritation, oxidative stress and cardiovascular strain due to heightened $\text{PM}_{2.5}$, NO_x , VOCs and SO_2 exposure. This observation aligns with Nduka and Orisakwe (2019), who associated proximity to refinery plumes with increased hospital visits for respiratory disorders in the Niger Delta. The findings justify greenbelt planning, buffer enforcement and continuous industrial air quality surveillance in line with international best practices (UNEP, 2022).

The one way ANOVA results in Table 3 reveal statistically significant spatial variations in all pollutants. Extremely high F values across pollutants such as CO ($F = 149.53$, $p = 0.000$), SO_2 ($F = 239.87$, $p = 0.000$) and $\text{PM}_{2.5}$ ($F = 256.43$, $p = 0.000$) demonstrate strong spatial gradients. These values exceed critical thresholds by wide margins, confirming distance as a primary determinant of concentrations. The results support earlier empirical work by Anejionu *et al.* (2015) and Ede and Edokpa (2017), both of whom concluded that petroleum facility emissions significantly diminish with distance but remain environmentally relevant several kilometres away. The statistically significant outcomes affirm that residents and workers in the first few hundred meters are exposed to chronic pollutant levels above safe thresholds, particularly $\text{PM}_{2.5}$, NO_x , VOCs and SO_2 . This aligns with FEPA (2021) regulatory concerns and reinforces the need for emission control, buffer zone implementation, and targeted health surveillance in industrial host communities. These results collectively strengthen the argument for stricter environmental policies, technological emission abatement and proactive public health monitoring in high exposure industrial belts such as Eleme.

4. CONCLUSION AND RECOMMENDATIONS

Spatial analysis showed decreasing pollutant concentrations with increasing distance from industrial emission points. The highest levels occurred at 200 meters from industrial facilities, where CO, SO_2 , NO_x , VOCs, $\text{PM}_{2.5}$ and PAHs reached peak values. Concentrations progressively declined at 400, 600, 800 and 1000 meters, confirming the influence of dilution, dispersion and surface deposition processes. Despite this decline, pollutant levels remained environmentally significant even at 1000 meters, indicating regional atmospheric influence and persistent industrial plume transport. The findings confirm that industrial operations in Eleme emit a complex mix of combustion gases, process related pollutants and secondary photochemical products. Dominant gases including CO and CO_2 indicate sustained fossil fuel burning and flaring, while SO_2 and NO_x reflect sulphur rich feedstock handling and high temperature processes. Detected VOCs, H_2S , NH_3 , PAHs and methane show petrochemical leakage, waste gas release and incomplete combustion. Overall, the emission profile aligns with evidence from other Niger Delta industrial centres, indicating persistent pollution pressure, harmful population exposure, and the urgent need for enhanced emission control strategies and continuous environmental surveillance. Based on the findings of this study, the following recommendations are made; the refinery management should enforce real time leak detection programmes, upgrade flaring and gas scrubbing systems, conduct quarterly environmental audits, and ensure transparent public reporting to reduce harmful gas emissions. Also, minimum 600 meters industrial buffers should be enforced, implementation of greenbelt zones as well as establishment of community air monitoring stations around host neighbourhoods.

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