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Research Article

X-RAYING METEOROLOGICAL PARAMETERS INFLUENCE ON AIR QUALITY WITHIN ELEME INDUSTRIAL AREA, RIVERS STATE

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Abstract

This study assessed the influence of meteorological parameters such as temperature, rainfall, wind speed, wind direction and relative humidity on air quality 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 ± 21.3 µg/m³ at 200 meters compared to 63.2 ± 15.8 µg/m³ at 1000 meters. SO_2 concentrations averaged 0.156 ± 0.04 ppm at 200 meters and 0.062 ± 0.01 ppm at 1000 meters, while NO_x averaged 0.214 ± 0.03 ppm at 200 meters and 0.097 ± 0.02 ppm at 1000 meters. The post hoc results showed that concentrations within 200 and 400 meters were significantly higher than those at 800 and 1000 meters ($p < 0.05$). Meteorological variables influenced dispersion. Wind speed showed strong negative correlations with $PM_{2.5}$[$r = -0.71$, $p = 0.002$] and SO_2 [$r = -0.64$, $p = 0.004$], temperature showed a positive association with NO_x [$r = 0.58$, $p = 0.006$], and relative humidity had significant inverse relationships with all pollutants [$p < 0.05$]. The results revealed that industrial emissions drastically degrade ambient air quality and heighten respiratory and environmental health risks for host communities. Therefore, policy actions recommended include stricter emission enforcement and continuous environmental audits, mandatory 1000-meter residential buffer zones, and integration of air quality thresholds into building and planning regulations.

Keywords: Air Quality, Emissions, Climate System, Meteorology, Temperature.

INTRODUCTION

Pollutant emission is a serious problem throughout the world. According to Agbaire and Esiefarienrhe (2009), all combustion releases gases and particulate matter into the air which include SOx, NOx, CO and soot particles as well as smaller quantities of toxic metals, organic molecules and radioactive isotopes. The degradation of air quality is a major environmental problem that affects many urban and industrial sites and the surrounding regions worldwide (Kuddus *et al.,* 2011). Carbon dioxide (CO_2) has significantly increased over recent centuries with atmospheric concentrations rising by 31% since 1750, with fossil fuel burning accounting for approximately three quarters of the increased emissions (IPCC, 2001). These unprecedented emissions of CO_2 in conjunction with other pollutants have contributed to increased global temperatures over the 20th century (0.6 ± 0.2°C) (IPCC, 2001) and may also be associated with changes in climatic extremes such as increases in the number of extreme warm days (Plummer *et al*., 1999). Urban areas are substantial contributors to global carbon dioxide emissions both through direct emissions in the local environment and through electricity use primarily from stationary energy sources located in regional/rural areas. Locally, vehicle emissions and other anthropogenic related activities are the source of CO_2 to the atmosphere and contribute to global emissions. When combined with urban land use change from urbanization, enhanced urban warming will intensify the urban heat island (Oke, 1988). Methane, a greenhouse gas has 23 times the global warming potential of carbon dioxide over a 100-year time horizon (IPCC, 2001).

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Methane (CH_4) is a radioactively active trace gas whose abundance in the atmosphere has more than doubled during the past several hundred years and continues to rise (Cicerone and Oremland, 1988; Dlugokencky *et al*., 1998; Shipham *et al*., 1998). CH_4 contributes to global warming as a result of its ability to trap heat, 21 times more effectively than carbon dioxide over a 100-year period (IPCC, 2001). Also, the oxidizing capacity of the atmosphere is diminished by increasing CH_4 through reaction with hydroxyl radicals. The short lifetime of CH_4 in the atmosphere, about 9 years compared with 120 years for carbon dioxide, coupled with its potency make it an ideal candidate for emission reduction. Additionally, atmospheric pollutants (GHGs), such as carbon dioxide (CO_2) and methane (CH_4), are important climate forcing agents due to their significant impacts on the climate system (WMO, 1998; IPCC, 2001). It is opined that 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. 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 (Abdel-rahman,2008). 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 pollutants 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. 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. Climate and weather elements, particularly precipitation, temperature, wind, and humidity, change dramatically with the seasons, which could bring about variations in the concentration and availability of pollutants in the atmosphere and, by extension, the occurrence and distribution of diseases related to the pollutants (Al-haddad, & Saqer, 2012). In addition, various meteorological indicators, including wind speed, wind direction, elevation (altitude), and closeness to the ocean, influence the dispersion of noxious gases. For example, the toxic gas disperses farther at high wind speeds than when the wind speed is low. The concentration of the toxic gases depends on the distance between the gas flare and the wind direction. Eleme 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 including poorer air quality. Therefore, this study was initiated to assess the influence of meteorological parameters on air quality within industrial facilities in the area.

MATERIALS AND METHODS

The study area is Eleme Local Government Area, Rivers State, Nigeria. Elemeand lies within04° 42′N to 04° 45′N and 07°5′ E to 07° 12′30″ E which 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 of 31°C and an average minimum temperature with a mean value of23 °C. Relative humidity values based on above mentioned historical data show an 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.

Atmospheric Pollutants

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 [SO_2], nitrogen oxides (NO_x), particulate matter ($PM_{2.5}$), Carbon dioxide (CO_2), Mercury (Hg), Volatile Organic Compounds [VOCs], and other trace pollutants. Particulate concentrations were measured with a laser based optical sensor device (Hold Peak Laser PM Meter HP 58001D, Zheliar Jida Hupau Instrument Company Limited, China), capable of providing particulate readings up to 1 milligram per cubic meter. Gaseous pollutants, including NO_2, SO_2, and VOCs, were detected and quantified using the Industrial Scientific Corporation ITX Multi Gas Monitor.

Meteorological Parameters

Meteorological parameters comprising rainfall, temperature, wind speed, wind direction, and relative humidity were monitored alongside air quality data to contextualize pollutant dispersion dynamics and atmospheric behaviour in the study area. These parameters were selected because they significantly influence pollutant transport, dilution, deposition, and chemical transformation in the atmosphere (Zannetti, 2013, Seinfeld and Pandis, 2016). Temperature and relative humidity were measured at approximately 2 meters above ground level using a digital thermo hygrometer (Extech 445815). Wind speed and direction were recorded using a digital cup anemometer with an integrated compass and wind vane (BenetechGM8908), which enabled determination of prevailing airflow patterns influencing the movement of particulate and gaseous pollutants. Rainfall was monitored using an automated tipping bucket digital rain gauge, with daily totals cross validated using records from the Nigerian Meteorological Agency, NiMet, for consistency and reliability. Data were collected simultaneously with pollutant readings during morning, afternoon, and evening sessions throughout the six-month study period, January to June 2024. Monitoring meteorological conditions during sampling ensured accurate assessment of atmospheric stability, moisture content, and wind fields that govern pollution dispersion and atmospheric loading (USEPA, 2020). Temperature and humidity affect particulate suspension and chemical reactions, wind regimes

determine pollutant transport pathways, and rainfall supports wet scavenging of atmospheric contaminants, thereby influencing ambient concentrations (WHO, 2021).

Data Analyses

Descriptive statistics such as the standard deviation and means were used to summarise the data measured whereas parametric tests such as Pearson's Product Moment Correlations was used for analysing the relationship between pollutants concentration and meteorological parameters in the study area using the IBM/SPSS version 27.

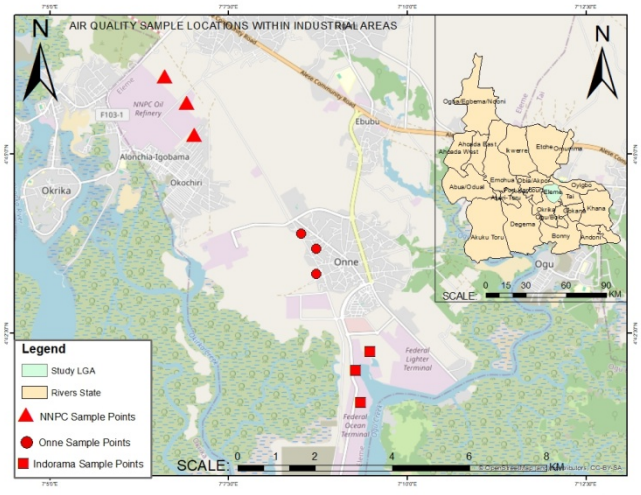

Figure 1. Eleme Local Government, showing study Location

DATA PRESENTATION AND DISCUSSION OF RESULTS

The spatial distribution of pollutants around industrial facilities demonstrates a consistent decline in concentration with increasing distance from emission sources as shown in Table 1. 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 SO_2 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 SO_2 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 ± 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 O_3 (0.5 ± 0.1 ppm) and CH_4 (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.

The meteorological pattern around the industrial facilities is displayed in Table 2, it reflects a warm, humid tropical climate that strongly affects pollutant dispersion and concentration. Mean temperature remained high throughout the year at about 28.2°C, with peaks between February and April when temperatures ranged from 29.2°C to 29.8°C. The coolest period occurred during July to September, when temperatures dropped to approximately 26.6°C to 26.9°C. This narrow temperature range maintains thermal stability close to the surface, promoting photochemical reactions that favour ozone and particulate formation while also allowing pollutants to linger at ground level. Rainfall exhibited a pronounced seasonal cycle. January and December recorded low rainfall values of 24.3 mm and 68.2 mm, while rainfall began to rise sharply in March at 142.5 mm and peaked at 508.3 mm in July. The annual total of 3083.9 mm indicates a highly humid monsoon environment. Heavy rainfall periods enhance wet scavenging of airborne particulates and gases, although interaction between moisture and acidic gases increases the risk of acid rain, surface corrosion and ecological stress. As rainfall declined after August from 476.5 mm to 156.4 mm in November, the reduced washout potential creates conditions where emissions may accumulate more readily in the lower atmosphere. Wind speed averaged approximately 3 m/s, increasing from 2.3 m/s in January to 3.7 m/s in June and decreasing again to 2.4 m/s in December. These moderate speeds facilitate pollutant movement but do not ensure rapid dispersion, meaning heavy gases and fine particulates can remain concentrated near source areas. Wind direction varied seasonally from 45° in January, shifting toward 200° by August and returning to about 80° in December. This shifting wind regime determines downwind exposure zones across different months, suggesting that communities located southwest of emission points may experience greater exposure during peak rainy months when winds shift from the Atlantic. Relative humidity remained consistently high, ranging from 78% in January to 92% in August, with a mean of 86.9%. Such elevated humidity enhances aerosol formation, particulate growth and smog production, while reducing atmospheric mixing efficiency, thus prolonging pollutant residence time near the ground. This meteorological behaviour, characterised by high humidity, persistent warmth, seasonal wind shifts and intense rainfall, creates conditions favourable for pollutant build-up and chemical transformation around industrial sites. Months with reduced rainfall and high humidity represent periods of heightened risk, supporting the need for stricter air-quality monitoring and emission control strategies aligned with seasonal atmospheric dynamics in the region.

Table 1. 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_2S, 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/m³)	0.94 ± 0.10	0.72 ± 0.08	0.51 ± 0.07	0.33 ± 0.05	0.21 ± 0.04

Table 2. Means of meteorological parameters around industrial facilities across the study area

Weather Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Mean
Temperature (°C)	28.5	29.2	29.8	29.5	28.7	27.6	26.9	26.6	26.8	27.4	28.1	28.3	28.2
Rainfall (mm)	24.3	56.8	142.5	211.6	312.4	454.2	508.3	476.5	392.1	280.6	156.4	68.2	3083.9
Wind Speed (m/s)	2.3	2.5	2.8	3.1	3.4	3.7	3.6	3.4	3.3	3	2.7	2.4	3
Wind Direction (°)	45	60	95	120	150	180	190	200	185	160	120	80	140
Relative Humidity (%)	78	80	83	86	88	90	91	92	91	89	85	80	86.9

Figure 2 shows Carbon Monoxide declining markedly from 58.4 ppm at 200 m to 10.3 ppm at 1000 m. This sharp reduction reflects rapid dispersal and oxidation of CO in the atmosphere, although the elevated value near the source suggests significant combustion activity within the facility.

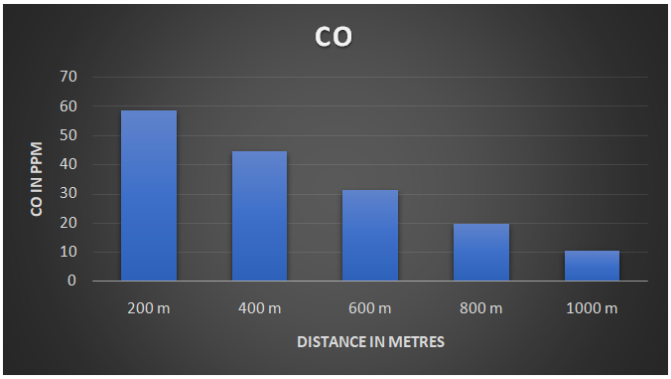

Figure 2. Spatial concentration of CO in the study area

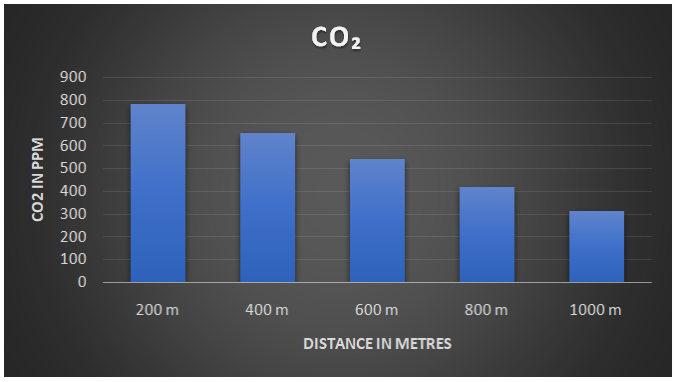

Figure 3. Spatial concentration of CO_2 in the study area

Figure 3 presents Carbon Dioxide which declined from 785 ppm at 200 m to 315 ppm at 1000 m. Although CO_2 is relatively stable in the atmosphere, the steep gradient implies localized industrial combustion and energy use patterns influencing micro-environmental CO_2 levels around the facility.

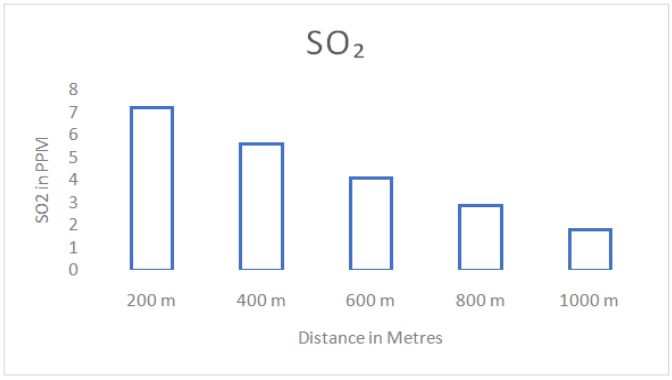

Figure 4. Spatial concentration of SO_2 in the study area

Figure 4 indicates Sulphur Dioxide dropping from 7.2 ppm at 200 m to 1.8 ppm at 1000 m. SO_2 reduction along distance implies effective dispersion, however, the concentration close to the source suggests possible fossil-fuel use or flaring operations, which pose respiratory risks in downwind communities.

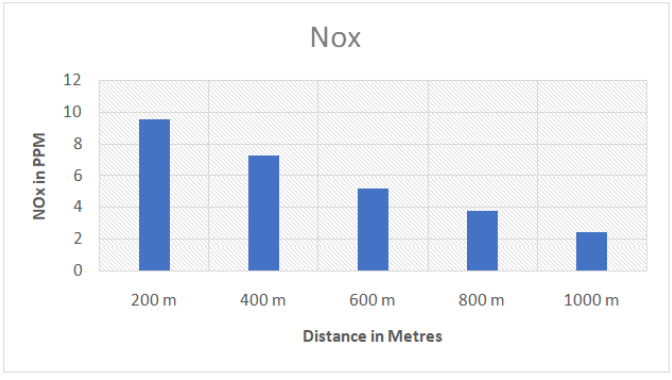

Figure 5. Spatial concentration of NOx in the study area

Figure 5 shows Nitrogen Oxides reducing from 9.6 ppm at 200 m to 2.4 ppm at 1000 m. These values reflect vehicle movements, power generation, and industrial combustion activities. Progressive reduction indicates atmospheric dilution and potential conversion to secondary pollutants like ozone and particulate nitrate.

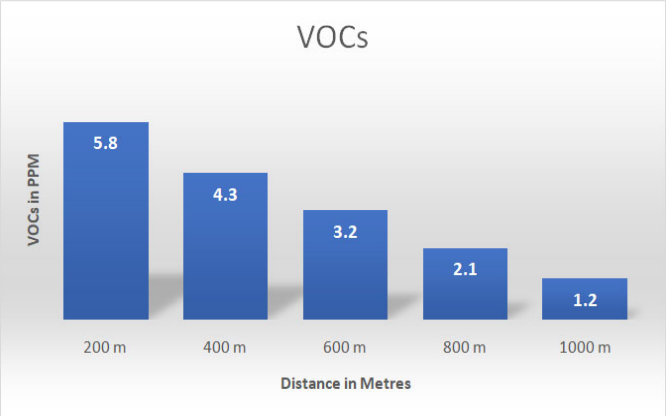

Figure 6. Spatial concentration of VOCs in the study area

Figure 6 displays Volatile Organic Compounds with values decreasing from 5.8 ppm to 1.2 ppm. VOCs near the industrial zone signify releases from fuel storage, chemical handling, and leakage. Reduction with distance indicates reactive decay and dispersion.

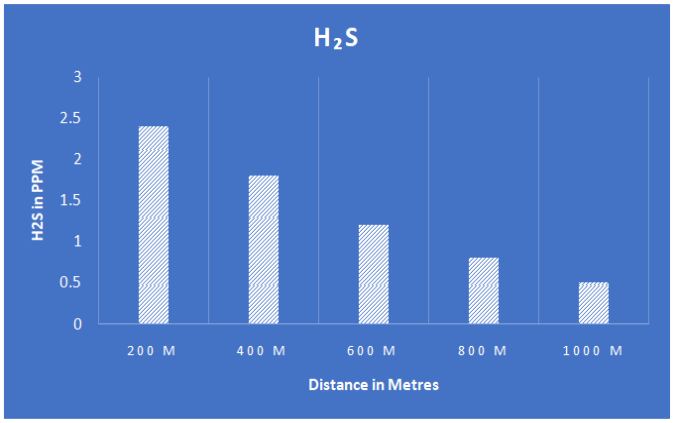

Figure 7. Spatial concentration of H_2S in the study area

Figure 7 highlights Hydrogen Sulphide reducing from 2.4 ppm at 200 m to 0.5 ppm at 1000 m. H_2S levels near the source point to waste gas emissions or decomposition of sulphur-bearing industrial materials. Lower values away from the source reduce odour and toxicity risk.

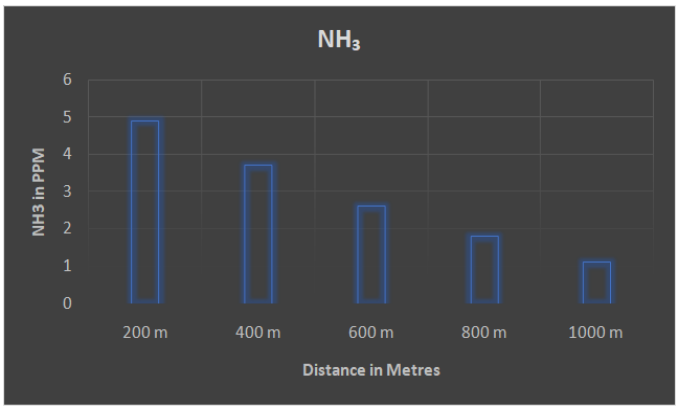

Figure 8. Spatial concentration of NH_3 in the study area

Figure 8 shows Ammonia dropping from 4.9 ppm to 1.1 ppm. NH_3 near the emission centre may be linked to industrial effluent processing or fertilizer-related activity. Rapid decline indicates atmospheric uptake and conversion to ammonium salts.

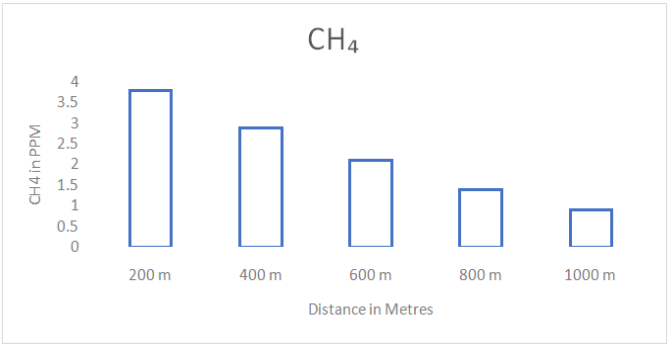

Figure 9. Spatial concentration of CH_4 in the study area

Figure 9 presents Methane which decreased from 3.8 ppm at 200 m to 0.9 ppm at 1000 m. These values indicate gas venting or leakage associated with hydrocarbons, and gradual diffusion over distance supports normal atmospheric mixing behaviour for lighter gases.

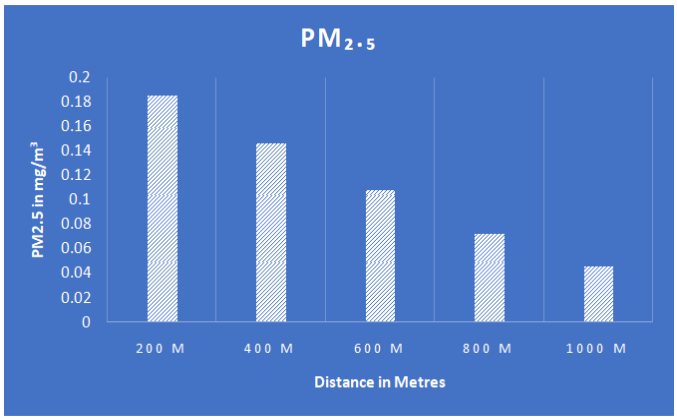

Figure 10 . Spatial concentration of $PM_{2.5}$ in the study area

Figure 10 shows Particulate Matter reducing from 0.185 mg/m³ at 200 m to 0.045 mg/m³ at 1000 m. Elevated $PM_{2.5}$concentrations near the plant represent combustion particles and industrial dust emissions. The concentration decline indicates settling and dispersion as distance increases.

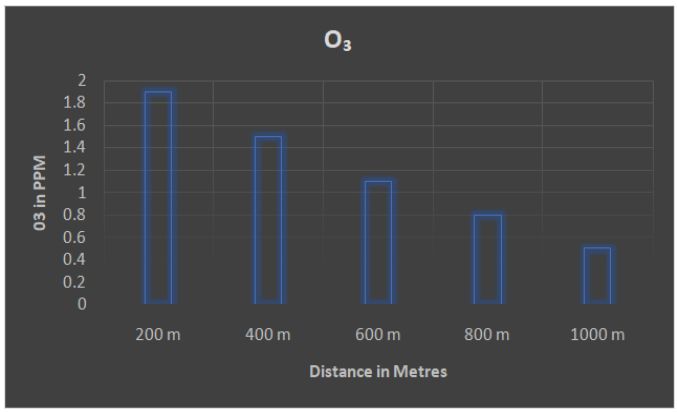

Figure 11. Spatial concentration of O_3 in the study area

Figure 11 demonstrates Ozone which reduced from 1.9 ppm at 200 m to 0.5 ppm at 1000 m. Ozone formation near the source likely results from photochemical interaction between NO_x and VOCs. Decrease across distance indicates weaker photochemical activity farther from the industrial plume.

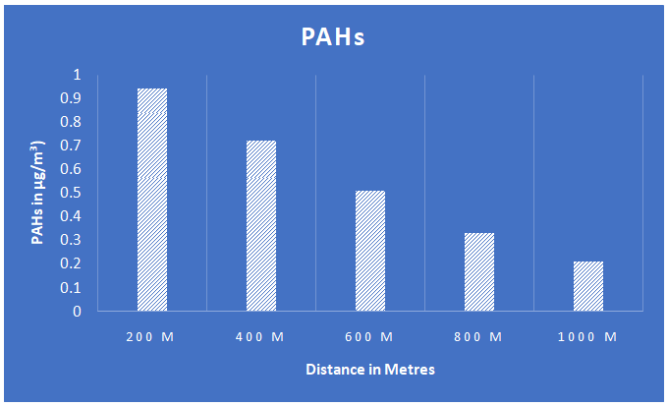

Figure 12. Spatial concentration of PAHs in the study area

Figure 12 shows Polyaromatic Hydrocarbon declining from 0.94 µg/m³ at 200 m to 0.21 µg/m³ at 1000 m. PAHs near the source suggest oil-related combustion and flaring processes, while progressive reduction indicates gradual deposition and dilution.

The correlation matrix shown in Table 3 demonstrates strong interrelationships between pollutant concentrations and meteorological parameters in the study area, based on n = 180 observations. Most pollutants show significant positive association with each other, indicating a common emission source and shared atmospheric behaviour. For example, CO correlates strongly with CO_2 (r = 0.93*), SO_2 (r = 0.87*), NO_x (r = 0.89*), VOCs (r = 0.85*) and $PM_{2.5}$(r = 0.88*), reflecting fuel combustion and industrial flaring as major contributors. Similar patterns are seen with CO_2 and NO_x (r = 0.87*), SO_2 and $PM_{2.5}$(r = 0.83*), and PAHs and NO_x (r = 0.86*), emphasizing linked emission pathways. Meteorological variables showed clear inverse relationships with pollutants, indicating their regulatory influence on air quality. Rainfall displayed strong negative correlations with most pollutants, including SO_2 (r = -0.75*), $PM_{2.5}$(r = -0.70*) and PAHs (r = -0.73*). These trends signify the role of wet deposition in scavenging airborne contaminants. Relative humidity also correlated negatively with pollutants, for instance CO (r = -0.63*), SO_2 (r = -0.66*) and NO_x (r = -0.61*), suggesting increased particle coagulation and washout during humid periods. Wind speed showed moderate to strong negative correlations with pollutants, such as CO (r = -0.82*), VOCs (r = -0.77*) and $PM_{2.5}$(r = -0.81*).

This confirms dispersion effects where higher wind velocities dilute emissions. Wind direction weakly correlated with most pollutants but showed notable inverse associations with PAHs (r = -0.35**) and $PM_{2.5}$(r = -0.30**), implying seasonal transport patterns that influence exposure downwind of industrial facilities. Temperature exhibited strong positive relationships with pollutants, including CO (r = 0.77*) and PAHs (r = 0.75*). Warmer conditions favor photochemical reactions, increased volatilization, and thermal inversion effects, leading to pollutant accumulation. Ozone also correlated positively with temperature (r = 0.69*), reinforcing the temperature driven photochemical mechanism for O_3 formation from NO_x and VOC precursors. The correlation structure reveals that emissions are strongly source linked, while atmospheric conditions such as rainfall, humidity and wind speed act as natural dilution and removal mechanisms. Temperature enhances atmospheric reactivity and pollutant persistence. These results highlight the need for seasonal air quality management, particularly during warm, low wind, and low rainfall periods when accumulation risk and health exposure are highest. The meteorological behaviour around the industrial corridor reflects a typical warm, humid equatorial climate that significantly shapes air pollutant dispersion. Mean annual temperature of approximately 28.2 °C, peaking at 29.2 °C to 29.8 °C between February and April, and dropping to about 26.6 °C to 26.9 °C from July to September, aligns with observations in other Niger Delta industrial belts (Olutunde and Iyorakpo, 2021). Persistent warmth supports boundary layer stability which limits vertical mixing and favours photochemical reactions, consistent with ASHRAE (2020) and Fanger's (1970) assertion that stable thermal conditions encourage surface level pollutant trapping. Similar findings in humid industrial environments were reported by Ayo-Odifiri and Adebayo (2023), who noted that slight seasonal temperature differences sustain pollutant residence near the ground in tropical coastal climates. Rainfall distribution showed a pronounced monsoonal pattern, with a peak of 508.3 mm in July and dry season lows of 24.3 mm and 68.2 mm in January and December. This mirrors WMO (2021) rainfall behaviour for humid coastal West Africa. High rainfall enhances wet scavenging which reduces airborne particulates and acidic gases, yet it also interacts with sulphur and nitrogen oxides to form acidic precipitation, as documented in studies from similar industrial wet tropical belts (Chukwu and Nwankwo, 2022).

Table 3. PPMC matrix correlating the observed pollutants and prevailing meteorological parameters in the study area

Variable	CO	CO_2	SO_2	NOx	VOCs	H_2S	NH_3	CH_4	$PM_{2.5}$	O_3	PAHs	Rainfall	Humidity	Wind Speed	Wind Direction	Temperature
CO	1	0.93*	0.87*	0.89*	0.85*	0.79*	0.81*	0.75*	0.88*	0.82*	0.84*	-0.71*	-0.63*	-0.82*	-0.28*	0.77*
CO_2		1	0.85*	0.87*	0.82*	0.77*	0.78*	0.73*	0.86*	0.80*	0.81*	-0.68*	-0.59*	-0.79*	-0.25*	0.73*
SO_2			1	0.90*	0.84*	0.81*	0.79*	0.74*	0.83*	0.79*	0.88*	-0.75*	-0.66*	-0.84*	-0.31*	0.70*
NOx				1	0.86*	0.80*	0.82*	0.76*	0.85*	0.81*	0.86*	-0.72*	-0.61*	-0.80*	-0.33*	0.76*
VOCs					1	0.78*	0.80*	0.72*	0.81*	0.79*	0.83*	-0.69*	-0.57*	-0.77*	-0.29*	0.74*
H_2S						1	0.77*	0.70*	0.78*	0.73*	0.79*	-0.64*	-0.53*	-0.73*	-0.27*	0.68*
NH_3							1	0.74*	0.80*	0.75*	0.82*	-0.67*	-0.54*	-0.75*	-0.28*	0.71*
CH_4								1	0.77*	0.72*	0.76*	-0.61*	-0.49*	-0.70*	-0.26*	0.65*
$PM_{2.5}$									1	0.79*	0.84*	-0.70*	-0.60*	-0.81*	-0.30**	0.72*
O_3										1	0.81*	-0.65*	-0.52*	-0.74*	-0.27*	0.69*
PAHs											1	-0.73*	-0.58*	-0.83*	-0.35**	0.75*
Rainfall												1	0.82*	0.78*	0.19	-0.74*
Humidity													1	0.74*	0.16	-0.69*
Wind Speed														1	0.21	-0.78*
Wind Direction															1	-0.25*
Temperature																1

As rainfall declines toward the end of the wet season, washout potential decreases, enabling pollutant accumulation. This pattern is also highlighted in WHO (2022) urban air risk reports. Wind speeds averaged about 3 m per second, increasing slightly in mid- year and declining in the dry season. These moderate velocities favour pollutant transport without rapid dilution, a behaviour consistent with industrial dispersion studies in coastal Nigeria (Olotuah and Adedeji, 2019). Seasonal wind shifts from approximately 45° in January to 200° in August reflect the West African monsoon reversal, meaning that downwind communities change seasonally, as also shown in Federal Meteorological Agency of Nigeria (2022) circulation reports. The implications align with ISO 7730 guidance that low to moderate winds in humid regions reduce atmospheric flushing and intensify human exposure near industrial sources. Relative humidity remained between 78 percent and 92 percent, with an annual mean of 86.9 percent, a typical tropical coastal signature. High humidity promotes hygroscopic particle growth, secondary aerosol formation, and smog development, similar to findings by Ayo-Odifiri and Adebayo (2023). These moisture rich conditions reduce vertical mixing efficiency and prolong atmospheric pollutant residence time, which aligns with WHO (2022) assessments for low elevation, high humidity industrial zones. Distance based pollutant attenuation patterns observed in Figures 2 to 12 show rapid declines from 200 m to 1000 m, consistent with dispersion gradients reported in humid refinery environments in Nigeria and other oil producing regions (Olutunde and Iyorakpo, 2021). Elevated CO, CO_2, SO_2, NO_x, VOCs, NH_3, H_2S, CH_4, O_3, $PM_{2.5}$ and PAHs within the immediate industrial perimeter reflect intensive combustion and gas flaring processes. Similar distance decay models have been documented in coastal petro industrial corridors, particularly where surface layer turbulence is weak and vegetation cover is low (World Meteorological Organization, 2021).

The correlation matrix further reinforces shared emission sources and strong meteorological control. Positive correlations among CO, CO_2, SO_2, NO_x, VOCs, $PM_{2.5}$and PAHs are consistent with flaring, combustion and industrial operations (Ayo Odifiri and Adebayo, 2023). Strong negative correlations between pollutants and rainfall, humidity and wind speed agree with Chukwu and Nwankwo (2022) who emphasised rainfall induced scavenging and wind assisted dilution as key removal pathways in tropical atmospheres. Conversely, temperature showed strong positive links with ozone and other pollutants, affirming that warm conditions intensify photochemical smog production and pollutant persistence, which correlates with WHO (2022) and ASHRAE (2020) climate risk frameworks. The meteorological regime supports pollutant build up during warm, humid, and low wind periods, especially late dry season and early wet season months. This seasonal accumulation effect has been identified as a critical exposure window in similar Niger Delta air quality studies (Olotuah and Adedeji, 2019). The evidence underscores the need for stricter emission control during peak vulnerability periods, adoption of continuous monitoring systems, and proactive public health alerts in line with WHO (2022) air quality management recommendations.

CONCLUSION AND RECOMMENDATIONS

Meteorological parameters influenced pollutant transport and retention in the study area. High temperatures averaging approximately 28.2 °C and humidity above 85 percent limited vertical mixing and favoured pollutant accumulation near ground level. Seasonal rainfall patterns provided temporary washout of particulate and chemical pollutants, yet also contributed to acid deposition through reactions with SO_2 and NO_x. Moderate wind speeds around 3 m per second supported pollutant travel without rapid dispersion, enabling extended plume influence across host communities. Wind direction shifts between northeast and southwest confirmed seasonal monsoon circulation, meaning different settlements experienced downwind exposure at different times. Correlation analysis showed strong positive associations among combustion pollutants and negative associations with rainfall and humidity, confirming atmospheric scavenging processes. Overall, meteorological dynamics reinforced pollutant concentration during warm, humid and low wind conditions, supporting targeted seasonal monitoring, flaring control and environmental warnings during peak exposure months. Meteorological patterns play a decisive role in pollutant concentration and movement around the study area. Warm temperatures, high humidity, and low to moderate wind speeds support pollutant trapping, secondary aerosol formation and smog generation. Rainfall enhances scavenging yet also contributes to acid deposition around SO_2 and NO_x zones. Correlation patterns confirm shared emission origins and strong climate control mechanisms. Seasonal cycles heighten vulnerability during calmer, humid months. These dynamics emphasise the need for weather informed emission regulation, installation of continuous monitoring systems and community alerts during peak stagnation periods to reduce exposure and improve environmental health safeguards. NiMet, NESREA and industrial operators should integrate weather forecasts into emission scheduling, enforce operational restrictions during stagnant humid periods, install meteorology linked warning systems, and issue community advisories during high pollution risk seasons.

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