Perceived Influence of Indoor and Outdoor Air Quality on Active Sawmills in Port Harcourt Metropolis Rivers State

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Abstract
The present study examined Perceived Influence of Indoor and Outdoor Air Quality on Active Sawmills in Port Harcourt Metropolis Rivers State focusing on Air Quality Status, Human Health Risk and Seasonal variations. An experimental design was used with cross-sectional observation, combining field measurements with lab analysis. The areas with different levels of sawmill activity and equipment are monitored at the four main sites and the units deployed are the Aeroqol, Kestrel and Air volume mini sampler. The collection of data was conducted over a period of one year including both wet and dry seasons, to address the temporal and seasonal variations. The pollutants measured were particulate matter fractions, gas pollutants and potentially toxic elements as well as meteorological parameters. The general meteorological conditions in the study areas were similar with low wind speed, high relative humidity, moderate to high temperature and prevailing north-western wind. The strong to very strong positive correlation of wind speed with temperature and moderate negative correlation of wind speed with relative humidity suggest that the meteorological conditions are crucial in the dispersion of pollutants. The Air Quality Index (AQI) evaluation showed that the air quality at all sites was very poor. Indoor AQI values at Illabuchi ranged from 124.25 to 50 km as 988.16 (Hazardous), mainly due to the extremely high levels of ozone and carbon monoxide. The same trends were found at Mile 3, Rumuosi and Marine Base sites where the indoor AQI were around 162.89 and the hazardous AQI were as high as 833.42 in the 50 km sites. Point B had consistently Very Unhealthy AQI (average of ~240.26) because of the combined effects of $PM_{2.5}$ (115–126), PM_{10} (95–96) and ozone. Overall, the study demonstrates that air quality around active sawmills in Port Harcourt is severely degraded, strongly influenced by meteorology and seasonality, dominated by particulate matter, ozone, and Pb–Cr contamination, and associated with significant non-carcinogenic health risks, particularly for children.

Keywords: *Perceived, Influence, Indoor and Outdoor, Air Quality, Active Sawmills*

Introduction

Air is an invisible gas that is made up of a mixture of mainly Nitrogen and Oxygen. It is one of the basic necessities of life for human, animals and plants. Air quality plays a vital role in the well-being and health of humans. But for a lot of people worldwide, air pollution has a lot of negative effects, particularly in urban and industrial areas. Air pollution can be defined as the intentional introduction of chemicals or particulate matter (small solid particles or liquid droplets in suspension) or biological materials that cause harm or discomfort to humans or other living organisms, or damage the natural environment or the built environment, into the atmosphere" (Abayomi, 2001). Air pollution is a key environmental problem affecting both the developing and the developed countries of the world with suspended particulate matter affecting more people globally than any other pollutant continuously (Akande, 1993). The situation in most developing countries like Nigeria is more tragic with regards to the utter disregard of pollution limits by most industries, low knowledge of environmental laws, the arrival of polluting industries and the general poor living standard, which affect people's nutritional status (Amunega, 2002). The level and distribution of the pollutants emitted from the wood processing industry depend on various factors, such as the type and amount of wood processed, the technology and equipment used, the emission control measures implemented, and the meteorological conditions, such as temperature, relative humidity, wind speed, and wind direction. These can vary over space and time, and impact the population that resides near the sawmill locations in terms of exposure and health risk (Bajpai, 2010). There is no doubt that the wood processing industry is one of the sectors that has contributed to the development and employment of the people of Nigeria. It also generates environmental and health issues, because there is no effective regulation, monitoring and management of the emissions and effects of air pollution. However, information on air quality and health implications in the vicinity of sawmill industry in Nigeria is limited, particularly in the dominant and growing industry of Rivers State. Thus, a thorough and systematic assessment of the ambient indoor/outdoor air quality around active sawmills in Rivers State, Nigeria and the associated health hazards to the workers and residents is required.

Literature Review

Air Pollution

Pollution has emerged as one of the most significant threats to health and existential issues of the 21st century and 4th industrial revolution; driven by the fact that over 90% of pollution-related deaths are now taking place in low and middle-income countries, particularly in Asia and Africa, but also in the Eastern Mediterranean, Europe and the Americas. Pollution and endangering the present existence of societies and their association (Bajpai, 2010): The earth's support systems and their sustainability are endangered due to pollution despite climate changes, loss of biodiversity, acidification of the ocean, drought and desertification, and depletion of the world's freshwater supply. Many communities will be impacted by the health effects of air pollution in the coming years, and billions of people will be at a higher risk of death and morbidity due to air pollution. Pollution, particularly vehicular exhausts, emissions from industries and toxic chemicals, has significantly increased over the past 500 years and is considered the largest increase in emerging countries today. However, in spite of its significant and growing size, vehicular and industrial pollution, and pollution from chemicals, has largely been ignored in global development and international health agendas; and the pollution control programmes have had little attention or resources from global organisations and development partners. Today, air pollution is a significant issue that affects the health of billions and impacts the Earth's ecosystems, economic security of the country and is responsible for a large global burden of disease, disability and premature mortality. Global climate change is intimately linked to pollution (Perera, 2017). 85% of the airborne pollution particulate is caused by the combustion of fossil fuels in developed and middle-income countries and almost all of the sulphur and nitrogen oxides pollution is caused by the combustion of biomass in inefficient cookstoves, open fires, agricultural burning, forest burning, sawmill activities, and out dated brick kilns in emerging countries. Combustion of fuel is a main source of greenhouse gases and short-lived pollutants due to climate that are the key anthropogenic drivers of human climate change.

Pollution from households and from water pollution are traditional attributes of extreme poverty and historical modes of pollution that are slowly fading. However, ambient air pollution, and pollution from chemical and land pollution, are all increasing (Omran, 2005). The main causes of this pollutant type remain the unrestrained development of cities; increasing demands for energy; increasing mining, smelting, and deforestation; the global blowout of toxic chemicals; progressively heavier applications of insecticides and herbicides; and increasing use of petroleum-powered cars, trucks, and buses. Soils and chemicals are now more polluted than they were 500 years ago, and the new linear economic system, often referred to by Pope Francis as the "throw-away culture" (Pope Francis, 2015), that has been implemented over the last 500 years has resulted in the widespread view that natural resources and human capital are commercially available and expendable, and the importance of their careless exploitation is not given much attention (Raworth, 2017).

Burden of Illness from Air Pollution

Outdoor (ambient) air pollution has a substantial influence on the health of Canadians. Air pollution both has short-term and long-term impacts on the respiratory and cardiovascular systems. Recent research has highlighted the extent of the effects of air pollution on the cardiovascular system, the complex mechanisms of these effects, and the fact that adverse health effects occur at low pollution levels, similar to those of the air that Canadians in many parts of the country breathe (Funmbi, 2015). Air pollution presents a meaningful burden of illness but, similar to hypertension, it is rarely recognised as a cause in clinical practice as you cannot measure the effect of air pollution in the individual patient. In 2004, Health Canada estimated that air pollution was responsible for nearly 6000 deaths from all causes in 8 cities in Canada annually, representing ~8% of the total deaths in the study population. The majority of these deaths were due to long term exposure (Lemmers, 2002). The Canadian Medical Association further expanded this analysis across all of Canada and estimated that about 21,000 people would die from all causes (excluding accidents and violence) as a result of air pollution in 2008 (about 10% due to short-term exposure), and that there would be 11,000 hospital admissions for cardiac and respiratory diseases and 92,000 visits to the emergency department. The national economic damage (lost productivity, health care costs, pain and suffering, and loss of life) has been estimated to be $8 billion (Canadian Medical Association, 2008). A new systematic analysis of all major global health risks has found that outdoor air pollution in the form of fine particles is a much more significant public health risk than previously known − contributing annually to over 3.2 million premature deaths worldwide and over 74 million years of healthy life lost. It is now one of the leading health risk burden worldwide. The burden of respiratory disease is not well known in most developing countries including Nigeria. A nationwide survey of non-communicable diseases was carried out in Nigeria (Akinkugbe, 1997) but it unfortunately excluded respiratory diseases. There are no national data on the prevalence of COPD. However, there are many risk factors for COPD. National surveys conducted on smoking habits reveal that the number of smokers has been on the rise and that age at which smoking was initiated has been reduced (Akinkugbe, 1997). Biomass smoke exposure is more important risk factor of COPD among women. Wood is still a significant cooking fuel in many homes in Nigeria. Such exposures have been reported to cause COPD in some parts of the continent.

Particulate Matter and Gaseous Pollutants

The pollutants that can have the greatest impact on the environment and human health include particulate matter (PM) and gas pollutants. PM consists of fine and coarse particles of different size and composition which can remain airborne for extended periods of time.

Gaseous pollutants include carbon monoxide (CO), nitrogen dioxide (NO2), sulphur dioxide (SO2), ozone (O3) and volatile organic compounds (VOCs) that are gases or vapours that can interact with other pollutants to produce secondary pollutants. These sources are related to natural events like wildfires, dust storms, and anthropogenic ones like industrial emissions, vehicular emissions, and biomass burning. The impact of PM and gaseous pollutants on health is dependent on the type, concentration, frequency and duration of exposure and the susceptibility and health of the people. Respiratory and cardiovascular diseases, including bronchitis, asthma, COPD, heart attack, stroke, and dementia, are among the potential health impacts of exposure to PM and gaseous pollutants. The World Health Organization (WHO) estimated that in 2019 there were 4.2 million deaths from ambient (outdoor) air pollution and 3.8 million deaths from household (indoor) air pollution all over the world. Rivers State is one of the most industrialized and urbanized States of Nigeria with a population of approximately 7.3 million Nigerians (NPC, 2016) and is in the Niger Delta region. The state is also rich in natural resources, such as oil, gas, and timber, which contribute to its economic development and social welfare. These activities, however, produce much PM and gaseous pollutants that impact air quality and public health within the state. The concentration, sources and effects of PM and gaseous pollutants in Rivers State, Nigeria have been evaluated in several studies. A study on air quality assessment in part of Onne, Rivers State was conducted by Mumuni (2015) where the concentrations of PM10, PM2.5, CO, NO2, SO2 and O3 were measured. The study revealed that these pollutants' annual average concentrations exceeded WHO and FMENV standards, thus yielding a poor air quality. The study also revealed the major contributors of such pollutants like industrial activities, vehicular emissions, and biomass burning. Exposure to these pollutants has been estimated to contribute 0.6% of all deaths and 0.8% of the disability adjusted life years (DALYs) in the study area.

Air Quality and Public Health in Developing Countries

Heavy air pollution hits poor nations hard. Nigeria faces growing dangers as cities spread fast, factories multiply, its skies darken. Smoke stacks rise beside crowded streets. Health risks climb when dirty air mixes with weak laws. Growth brings more traffic, more fumes, fewer clean spaces. People breathe deeper into danger each year. Without strong measures, lungs pay the price. A study looked at how dirty air affects people living in Abuja and Enugu. Though not everyone agreed, most said it harmed their well-being (Funmbi, 2015). Breathing problems showed up often in answers given by locals. Some thought weak lungs made viruses hit harder. When pollution levels rose, so did worries about getting sick. Illnesses like COVID-19 seemed worse under smoky skies. People linked chest discomfort directly to what they breathed daily. Not a single participant praised the city's air. Thick smoke from traffic left throats raw each morning. Health struggles climbed alongside haze through weeks studied. The study also highlighted the importance of proper waste management and the role of government in addressing PAQ. Furthermore, the nexus between air pollution and non-communicable respiratory illnesses in sub-Saharan Africa, including Nigeria, has been systematically reviewed. The review emphasized the risk posed by aerosol pollutants, which are known to increase the incidence of diseases such as asthma, chronic bronchitis, and chronic obstructive pulmonary disease (COPD). The rapid pace of urbanization and economic expansion in Nigeria raises concerns about the increasing incidence of these non-communicable respiratory diseases (NCRDs). Another study focused on the air quality index (AQI) in 253 Nigerian urban and suburban towns, revealing varied levels of air quality and associated health threats. One look at the findings shows why teamwork matters when tackling pollution's harm while also slowing climate shifts (Omran, 2005). Not one study skips the fact that Nigeria's air needs serious attention. Where smoke stacks rise, so do breathing problems - especially in cities packed tight with traffic and trash fires. Research after research points fingers at weak oversight, yes, but also at how little people know about what they're actually inhaling daily. Without better tracking systems, clearer rules, even basic warnings, lungs keep paying the price across West Africa's largest population hub.

Meteorological Influence on Air Quality

Air quality is a measure of the concentration and composition of air pollutants in the atmosphere, which can affect the environment and human health. Air quality is influenced by various factors, such as the sources and emissions of air pollutants, the chemical and physical processes that transform and remove air pollutants, and the meteorological conditions that affect the transport and dispersion of air pollutants. Meteorology is the science that studies the physical phenomena of the atmosphere, such as temperature, pressure, humidity, wind, precipitation, and clouds. Meteorology plays a crucial role in determining air quality by influencing the formation, accumulation, ventilation, and distribution of air pollutants. Several studies have investigated the meteorological influence on air quality using different methods, such as observational analysis, statistical modelling, and numerical simulation. For example, Olabode (1995*)* conducted a study on the effects of meteorology and emissions on urban air quality in Seoul, South Korea, using a long-term dataset of PM10, PM2.5, CO, NO2, SO2, O3, and meteorological variables from 1999 to 2016. The study used the Kolmogorov–Zurbenko filter to decompose the air quality data into trend-free short-term components and long-term trends and used multiple linear regression to isolate the effects of meteorology and emissions. The study found that the meteorology-related trends contributed to the decrease in PM10 and the increase in O3, while the emission-related trends contributed to the decrease in CO, NO2, and SO2. The study also found that synoptic meteorological conditions, such as the migratory high-pressure system and the rear of a cyclone, were associated with episodic air pollution events Olabode (1995*)*. Similarly, Omran, (2005) conducted a study on the impact of meteorological conditions on air quality index (AQI) under different urbanization gradients in Taipei, Taiwan, using the data of PM2.5, PM10, SO2, CO, O3, NO2, and meteorological variables from 2018. The study used the Granger causality test to analyse the intrinsic dynamic relationship between meteorological conditions and AQI. The study found that the range of AQI values in the three study areas was downtown > suburbs > outskirts and that the meteorological factors that affected AQI were different in each area. The study also found that the air pollution of Taipei was mainly a process of self-accumulation and self-diffusion and that the wind speed was the main meteorological factor affecting AQI in the downtown and suburbs, while the humidity was the main meteorological factor affecting AQI in the outskirts (Odewumi, 2001). Furthermore, Olorunisola (1998) conducted a study on the effects of air pollution and governance on health outcomes in developing countries using panel data from 113 countries from 2000 to 2015. The study used the PM2.5 and CO2 levels as indicators of air pollution, and the life expectancy and healthy life expectancy as indicators of health outcomes. The study also used the governance quality index as a moderating variable to examine the role of governance in mitigating the adverse effects of air pollution. Life took a hit when PM2.5 and carbon dioxide climbed, shortening both lifespan and years lived well. Yet where leadership worked better, damage from dirty air softened. Stronger rules, actually followed, made the difference clear - cleaner air came down to how seriously power was used (Ahmad et al., 2023). Pollution risks come from certain chemicals if they build up too much in the air. These substances cover metals like lead and nickel, along with others such as arsenic and selenium. Volcanoes sometimes release them, though factories, mines, and burning materials add more. Their form in the atmosphere - tiny particles, gases, or floating droplets - depends heavily on how they behave chemically. What matters is where they came from plus how they move once airborne.

Statement of the Problem

Air pollution from the sawmill industry can impact air quality both inside and outside the mill and has the potential to impact the health of the worker and community. However, the ambient air quality and health risk of the sawmill industry in Nigeria particularly in Rivers State, the hotspot and hub of the industry in Nigeria, is not well documented and known. Thus, detailed and systematic evaluation of the indoor and outdoor air quality in the vicinity of operational sawmills in Rivers State, Nigeria, and the possible health hazards to the workers and neighbours is needed. This research will curb the issue by measuring and analysing the concentration and distribution of PM, gaseous pollutants and PTEs in the indoor and outdoor air surrounding the selected sawmill sites in Rivers State, Nigeria. The meteorological parameters including temperature, relative humidity, wind speed and wind direction will also be measured and their influence on the air pollution level will be assessed during the study. In addition, the study will calculate the air quality index (AQI) of study areas. Lastly, the study will assess the human health risk of exposure to PTE, and make recommendations on how the air quality and human health risk can be improved around the sawmill industry in Rivers State, Nigeria.

Aim and Objectives of the Study

The aim of the study is to assess the indoor and outdoor air quality around active sawmills in Port Harcourt metropolis, Nigeria.

Objectives of the Study

The specific objectives of the study are to:

1) Estimate the air quality index (AQI) and human health risk of the toxic elements at the study areas
2) Identify the sources of pollutants in the area
3) Compare the seasonal variations in the concentrations of the pollutants.

Research Questions

The following questions will be answered in this study;

1. What are the levels and distribution of toxic heavy elements (Cr, Pb, and As) and how do they vary spatially and temporally around the study area?
2. What is the AQI and how does it vary spatially and temporally around the study area?
3. What is the human health risk of PTE exposure in the indoor and outdoor air around the selected sawmill sites?

Methodology

The research design for this study is a cross-sectional observational analysis, which aims to assess the air quality around active sawmills in Rivers State, Nigeria. The design incorporates both field measurements and laboratory analyses to determine the concentrations of various pollutants, including particulate matter (PM), gaseous pollutants, and potentially toxic elements (PTEs). Across active sawmills, air quality gets checked through measured pollutants using a planned system. To pick spots, random selection happens within groups - this way each zone type shows up fairly. Residential spaces appear alongside business districts and mill-close locations in the layout. Close to sawmills, spots get picked first. Where people live matters just as much when choosing sites. Hills and valleys shape where instruments go. Wind direction guides placement since particles travel with airflow. Easy access helps keep equipment running without delay. Rules say monitors must show worst-case breathing conditions alongside everyday ones. Coverage means catching intense pollution near sources plus wider background levels. Standards from 2003 set that balance - high risk areas matter, so do common spaces. Throughout both rainy and dry times, samples will be gathered. One full year makes up the total stretch for gathering these measurements. Every detail in how information gets gathered follows a strict plan, so results can clearly show what the air is like near sawmills. Because locations and timing are picked with close attention, the work stands on solid ground when shaping health reviews or new rules about nature's balance. What matters here grows out of patience, not guesses - each step built to hold up under real-world scrutiny. This study depends heavily on how information is gathered, since it shapes how trustworthy the results turn out. Careful planning went into defining what would be measured, making sure both inside and outside air conditions were covered in detail. Locations like Marine Base, Ilaobuchi, Mile 3, and Rukpokwu reflect different parts of Port Harcourt's environment.

Calibration and Maintenance of Instruments

The integrity of the data collected hinges on the proper calibration and maintenance of the monitoring instruments. Calibration will be conducted at the onset of the study and periodically throughout the data collection period to account for any potential drift or deviation in the instruments' readings. Maintenance involves includes cleaning, replacing worn parts, and updating software as needed. The calibration and maintenance protocols will follow the manufacturers' guidelines and industry best practices to maintain the highest data quality standards.

Air Quality Index Calculation

The Air Quality Index (AQI) is a measure of how polluted the air is in a given location. Different countries may have different methods of calculating the AQI, based on the pollutants they monitor and the standards they set. Greenstone *et al*. (2022) suggested that Nigeria can use the US EPA AQI formula.

The US EPA AQI formula is as follows:

For each pollutant, there is a table that relates the concentration of the pollutant to a breakpoint AQI value and a category. For example, for $PM_{2.5}$, the table 3.1 is:

Table 1: Breakpoint AQI Value and Category of $PM_{2.5}$

$PM_{2.5}$ (μg/m^3)	AQI	Category
0.0 – 12.0	0 – 50	Good
12.1 – 35.4	51 – 100	Moderate
35.5 – 55.4	101 – 150	Unhealthy for Sensitive Groups
55.5 – 150.4	151 – 200	Unhealthy
150.5 – 250.4	201 – 300	Very Unhealthy
250.5 – 500.4	301 – 500	Hazardous

Source: Greenstone *et al.* (2022)

To calculate the AQI for each of the pollutants ($PM_{2.5}$ for instance), the following formula will be used (Greenstone *et al*. 2022):

$$AQI = \frac{(I_{high} - I_{low})}{(C_{high} - C_{low})} \times (C - C_{low}) + I_{low} \tag{3.1}$$

where:

- C is the concentration of $PM_{2.5}$ in µg/m^3
- C_{low} and C_{high} are the concentration breakpoints that are ≤ and ≥ C
- I_{low} and I_{high} are the AQI breakpoints corresponding to C_{low} and C_{high}

The concentration breakpoints are rounded to one decimal place, and the AQI is rounded to the nearest whole number.

The same formula is applied to the other pollutants, using their respective breakpoints and categories. The overall AQI for a location is the highest value among the individual pollutant AQIs. The AQI ranges from 0 to 500, with higher values indicating worse air quality and greater health risks. The AQI categories are as follows in Table 3.2:

Table 3.2: Air Quality Index Categories and Health Implications

AQI Values	Air Pollution Level	Health Implications	Colours
0 to 50	Good	Air quality is considered satisfactory, and air pollution poses little risk.	Green
51 to 100	Moderate	Air quality is acceptable; however, some pollutants may cause a moderate health concern for a very small number of people who are unusually sensitive to air pollution.	Yellow
101 to 150	Unhealthy for sensitive group	Members of sensitive groups may experience health effects. The general public is not likely to be affected.	Orange
151 to 200	Unhealthy	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.	Red
201 to 300	Very Unhealthy	Health warnings of emergency conditions. The entire population is more likely to be affected.	Purple
301 to 500	Hazardous	Health alert: everyone may experience more serious health effects	Maroon

Source: Greenstone *et al.* (2022)

The AQI value for each pollutant is calculated separately, and the highest AQI value among the pollutants becomes the AQI value reported for that day. This methodology provides a standardised way to compare different pollutants and communicate the air quality to the public clearly and understandably. It's important to note that the AQI is a relative index and does not directly correspond to specific health effects, which can vary widely based on individual health conditions and exposure.

Health Risk Assessment

To determine the health risk of the PTEs in the study areas, a health risk assessment was performed using the following formula (EPA, 2011):

$$R = \frac{C \times IR \times EF \times ED}{BW \times AT} \text{ (EPA, 2011)} \qquad . \quad . \quad . \quad . \qquad (3.3)$$

where R is the risk level or hazard quotient for a single pollutant, C is the concentration of the pollutant, IR is the inhalation rate, EF is the exposure frequency, ED is the exposure duration, BW is the body weight, and AT is the average time.

Using the assumptions and recommendations of the World Health Organization (WHO, 2005) and the United States Environmental Protection Agency (EPA, 2011) for inhalation exposure assessment, the values of these parameters are as follows:

$IR = 20\ m^3/day$

$EF = 350\ days/year$

$ED = 30\ years$

$BW = 70\ kg$

$AT = 30\ years\ \times\ 365\ days/year$

C was obtained from the mean concentrations of PM and PTEs for each sawmill and each period of the day. The risk levels (R) were calculated for PM 2.5 and PM 10, as well as for nickel, arsenic, chromium, and lead. The unit of R is milligrams of contaminant per kilogram of body weight per day (ng/kg/day). It measures the amount of a contaminant that enters the body through breathing contaminated air.

Interpretation of Data

The collected data will undergo analysis through descriptive statistical methods, which will include the utilization of tables and graphical representations created via Microsoft Excel software. Sorting through the descriptive details happens by laying them out neatly in charts. How things connect becomes clearer when seen this way across rows and columns.

After checking samples on site and running tests in labs, experts will analyze numbers using statistics, then match results against official safety levels. What those findings mean for people and nature comes next - judged through rules made by Nigeria's Federal Ministry of Environment alongside global guidelines from the World Health Organization.

Results

Concentrations of particulate matter and gaseous pollutants in the air around the Rumuosi area

The air quality assessment was carried out in Rumuosi, revealing that mean $PM_{2.5}$ concentrations were found to be significantly higher outdoors than indoors (47.26±9.15 µg/m³ at Point A compared to 31.98±14.35 µg/m³, respectively) as shown in Table 4.4 and Figure 4.4, and was found to be 145.85±22.02 µg/m³ at Point C. The spatial variability of the levels of nitrogen oxides (NOx/NO2) shows that the concentration can reach 0.65±0.58 ppm at Point C and 1.25±0.64 ppm at the 50 km site, which is related to vehicular or combustion-related emissions (Table 4.4). Concentrations of sulphur oxides (SOx/SO_2) were even for all the locations (0.02±0.01 ppm) implying minimal influence from sulphur-based industries in the area (Table 4.4). The CO concentration was found to be highest at 50 km (14.05±2.40 ppm) and lowest indoors (10.20±3.97 ppm), with stronger combustion activities, outdoors than indoors (Table 4.4 and Figure 4.4). The VOC concentrations varied from 6.93 ± 2.01

ppm indoors to 9.25 ± 1.10 ppm at Point B, indicating that the VOC emission intensity is localized at certain points outside (Table 4.4). The O_3 concentrations were found to be the lowest at Point C (0.01±0.01) and the highest at the 50 km location (0.37±0.21) indicating the improvement in the formation of ozone away from the immediate source of emissions (Table 4.4 and Figure 4.4). The correlation analysis showed good positive correlation between $PM_{2.5}$ and PM_{10} (r = 0.904), and PM_{10} and CO (r = 0.807) which suggested the common emission sources associated with particulate resuspension and combustion (Table 4.5 and Figure 4.5). As seen in Table 4.5, there was a very strong positive correlation between NO_2 and O_3 (r = 0.930) and a strong negative correlation between NO_2 and H_2S (r = −0.636) which indicate different atmospheric processes. The principal component analysis revealed that PM_{10} (0.532), CO (0.463), $PM_{2.5}$ (0.442) and VOC (0.407) are the dominant pollutants, indicating a significant pollution source from combustion (Table 4.6 and Figure 4.6). The overall results show that the outdoor particulate emission, combustion related gases and secondary photochemical process are the main factors influencing the levels of air pollutants in Rumuosi, while the indoor environment has comparatively lower air pollutants concentration (Tables 4.4-4.6 and Figures 4.4-4.6).

Discussion

Comparative Discussion of Seasonal Air Quality Dynamics at Marine Base

During rains, tiny particles like $PM_{2.5}$ and PM_{10} spike at indoor spots, Point A, plus 50 kilometers out, but shrink when skies stay dry inside buildings. Most work from places such as Lagos, Kano, Rivers State, and busy roads down south shows more pollution in dry months instead. That usual jump links to less rain cleaning the sky, stirred-up soil dust, and extra burning from vehicles or fires (Ogwu, 2023). But here, things run differently. Heavy emissions never stop, dampness hangs around, droplets grow bigger on pollutant surfaces - all helping smog build up even when it pours. Rain might wash some stuff away, still doesn’t win against these forces near shorelines touched by car-heavy routes.

Wet seasons boosting pollution might sound odd, yet findings from warm places shaped by rains back it up - like what turned up at the Marine Base. Rain-heavy months in Colombo saw soot levels shift sharply, according to work by Shelton and team in 2022. From another angle, research out of Malaysia led by Mohtar four years earlier revealed dust spikes during monsoon phases, driven more by wind patterns and nearby sources than just dry weather highs. Instead of clear skies cleaning the air, dampness traps particles near ground level. Humid air swells tiny specks into bigger ones. Emissions keep feeding the mix even when rain falls often. Because of how winds move and where smoke comes from, heavy loads appear despite downpours. So the numbers from the Marine Base fit alongside scattered reports worldwide pointing to place-specific rules overriding broad climate habits.

At Marine Base, levels of heavy metals shifted noticeably between seasons. Not just similar to past work - some trends stood apart too. During drier months, lead climbed, especially at Point A, likely stirred up by wind lifting dusty particles. Heavy metals climbed just as seen before in Lagos, Rivers State, along with Beijing - during dry spells or colder periods, dust and fumes build up, lifting lead levels into the air (Iroegbleum et al., 2022; Ogbuagu et al., 2025; Gao & Ji, 2018). Chromium took its own route though. When rains came, indoor spots and Point C showed higher amounts. Meanwhile, at Point B plus a location far off by 50 kilometers, readings jumped only when conditions turned dry. This kind of uneven response among pollutants appears worldwide. In regions such as the UK (Butterfield et al., 2024), also Ulsan in Korea (Lee and Hieu, 2011), different metals shift separately with seasons, shaped by their origins and movement through environment.

Still after checks in rainy spells and droughts, Marine Base carries zero arsenic. Places twisted by factories or smelting? Not so clean. Places in China and Bangladesh have shown clear shifts in arsenic levels between seasons, especially where coal burning and factories play a big role (Hoque, 2020). At this site, though, the lack of such variation hints that sources releasing arsenic barely exist here. Instead, what changes in air quality from one season to another seems tied more closely to particles, fumes, ozone, lead, chromium. Though industrial fingerprints show elsewhere, they leave little mark here.

Heavy metals shift with seasons, showing how weather shapes their spread. At both Point A and Point B, lead levels rose when it stayed dry, likely stirred up by wind moving dusty particles around. Much like what happened in Beijing, seen by Gao and Ji back in 2018, or Lagos more recently with Emekwuru and Ejohwomu in 2023 - dry months brought sharper lead spikes. Yet chromium acted differently across Rumuosi - not following one pattern - as some spots recorded greater amounts in rainy times while others climbed during drier spells. That pattern shows up too in work by Cesari and team down in southern Italy - there, metals shifted with the seasons, each one acting according to its origin. This study found no trace of arsenic at any point during the year. Elsewhere, it's different - industrial areas tend to see levels shift as seasons pass.

Conclusion

The study successfully determined the concentrations of particulate matter ($PM_{2.5}$ and PM_{10}) and gaseous pollutants across the study areas, revealing elevated levels of key pollutants such as $PM_{2.5}$, PM_{10}, ozone, and carbon monoxide. The results showed substantial spatial variability, with outdoor locations, especially Points A, B, and 50 km sites, recording higher pollutant concentrations than indoor environments. Ozone emerged as a dominant contributor to overall air pollution, frequently driving AQI values into hazardous categories. Particulate matter concentrations also exceeded acceptable limits in several locations, indicating poor air quality conditions. Overall, the findings confirm that the study areas are significantly impacted by both particulate and gaseous air pollutants. Air quality index evaluation and human health risk assessment revealed severe air pollution levels and significant non-carcinogenic risks across all study areas. AQI values frequently ranged from unhealthy to hazardous, largely driven by ozone, particulate matter, and carbon monoxide. Hazard index values for both adults and children exceeded unity, indicating potential health risks, with children being more vulnerable due to higher exposure per body weight. Chromium was identified as the major contributor to health risk, followed by lead. These findings confirm that current air quality conditions pose serious public health concerns.

Source identification analysis indicated that air pollution in the study areas is primarily influenced by both anthropogenic and natural sources. The opposing behavior of Pb and Cr, as revealed by statistical analyses, suggests multiple emission pathways, including combustion processes, industrial activities, and traffic-related emissions. Enrichment factor values further indicated contributions from both crustal and human-induced sources. Localized hotspots at specific sampling points highlight the influence of site-specific activities. Overall, pollution in the study areas is driven by a combination of human activities and environmental factors. Seasonal comparison revealed significant differences in pollutant concentrations between wet and dry seasons. The wet season was characterized by higher particulate matter and ozone levels due to atmospheric processes such as scavenging and photochemical reactions. In contrast, the dry season showed increased levels of combustion-related gases and enhanced resuspension of particles and heavy metals. Meteorological changes between seasons played a major role in these variations. These findings confirm that air quality in the study areas is strongly season-dependent.

Recommendations

There is a need to implement strict air quality control measures to reduce the concentrations of particulate matter and gaseous pollutants in the study areas. Regulatory agencies should enforce emission standards for vehicles, generators, and industrial activities to limit pollutant release. Continuous air quality monitoring systems should be installed to track pollution levels in real time. Public awareness campaigns should be conducted to educate residents on practices that reduce air pollution. Additionally, cleaner energy alternatives should be promoted to minimize reliance on combustion-based sources.

Given the high AQI values and associated health risks, immediate public health interventions are required. Health agencies should develop guidelines to limit exposure, especially for vulnerable groups such as children and the elderly. The use of personal protective equipment, such as face masks, should be encouraged in highly polluted areas. Government should establish air quality alert systems to inform residents during hazardous conditions. Furthermore, healthcare facilities should be equipped to manage pollution-related health issues. To address pollution sources effectively, there is a need for comprehensive source control and environmental regulation. Authorities should identify and regulate major emission sources such as traffic, industrial operations, and open burning activities. Adoption of cleaner fuels and improved combustion technologies should be encouraged. Environmental policies should be strengthened to reduce anthropogenic contributions to air pollution. Community involvement should also be promoted in identifying and reporting pollution sources. Season-specific air quality management strategies should be developed to address variations in pollutant levels. During the wet season, efforts should focus on controlling particulate matter and ozone formation. In the dry season, strategies should target combustion emissions and dust resuspension. Seasonal public awareness campaigns should be implemented to educate residents on pollution risks and preventive measures. Regulatory actions should be adjusted based on seasonal pollution trends. These approaches will ensure more effective and targeted air quality management throughout the year.

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