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Investigating the Air Quality Parameters in Louisiana's Industrial Corridor: A Baton Rouge Case Study

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Abstract

In a local context, sustainable development entails utilizing the current resources—material and immaterial, measurable and immeasurable, popular and unpopular—of the community in a manner that avoids overexploitation and ensures intergenerational equity. This approach prioritizes the safety and health of local citizens, placing communal productivity above corporate profitability. This research aims to assess air quality surrounding 28 chemical industry sites in Baton Rouge, Louisiana, to understand the environmental and health impacts of industrial pollutants, with a focus on environmental justice. Air quality pollutants, including $PM_{2.5}$, PM_{10}, O_3, NO_2, CO, and SO_2, were monitored for 75 days during the Summer, using the BreezoMeter app. Python, Mapize, and QGIS software technologies were utilized for data analysis and visualization. Findings indicate a reduction in NO_2 and CO levels, compared to existing literature. However, the persistent challenge of particulate matter suggests areas for further environmental management efforts. Additionally, the research suggests a significant disparity in air pollution exposure, probably affecting marginalized communities. Although the nature of the study might not fully capture annual pollution trends, the findings highlight the urgent need for the chemical industry to adopt efficient production methods and for policymakers to enhance air quality standards and enforcement, particularly in pollution-sensitive areas. The disproportionate impact of air pollution on vulnerable communities calls for a more inclusive approach to environmental justice, ensuring equitable distribution of clean air benefits and community involvement in pollution management decisions.

Keywords

Air Quality Monitoring, Chemical Industry, Pollution, Environmental Justice, Health Implications, Particulate Matter, Case Study

1. Introduction

The escalating menace of air pollution constitutes a significant threat to public health, impacting over half of the global population with exposure exceeding the guidelines set by the World Health Organization (WHO), despite ongoing efforts to mitigate it in various nations (Shaddick et al., 2020; Turner et al., 2020). Air quality exerts diverse effects on health, ecosystems, heritage, and climate (Monks et al., 2009). Global mortality is significantly influenced by air pollution, leading to the loss of millions of healthy years of life. The adverse health impact is disproportionately borne by populations in numerous low- and middle-income countries, where the quality of air continues to degrade (WHO, 2021a)

Polluted air is recognized as a key factor contributing to various diseases among individuals, including cardiovascular and respiratory diseases, as well as lung cancer. The pollutants of primary concern include particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and carbon monoxide (CO), which are known to have severe health implications. Additionally, air pollution has detrimental effects on animals and contributes to the degradation of the plant environment (Almetwally et al., 2020). Beyond the immediate health effects, air pollution also has far-reaching consequences on climate and the environment. It contributes to global warming through the emission of greenhouse gases such as CO_2, methane (CH_4), and black carbon. The interaction between air pollutants and climate change can create feedback loops that exacerbate both issues. For example, increased temperatures can enhance the formation of ground-level ozone, while changes in climate can influence the dispersion and concentration of air pollutants.

The impact of air pollution is not uniformly distributed across the globe. Low- and middle-income countries often bear the brunt of air pollution due to rapid industrialization, urbanization, and less stringent environmental regulations. This leads to a significant public health burden, with higher rates of morbidity and mortality associated with air pollution-related diseases. Children, the elderly, and those with pre-existing health conditions are particularly vulnerable to the adverse effects of poor air quality. Efforts to combat air pollution have been ongoing at various levels, from international agreements like the Paris Agreement to national policies and local initiatives aimed at reducing emissions and improving air quality. The WHO has established Global Air Quality Guidelines to provide a framework for countries to develop and implement air quality standards. These guidelines aim to reduce the health burden of air pollution by setting targets for key pollutants, including $PM_{2.5}$, PM_{10}, NO_2, SO_2, O_3, and CO (WHO, 2021b).

In the United States, the Environmental Protection Agency (EPA) sets National Ambient Air Quality Standards (NAAQS) to protect public health and the environment. These standards are regularly reviewed and updated based on the latest scientific evidence. The primary standards are designed to protect human health, while secondary standards aim to prevent environmental and property damage. Despite these efforts, many urban areas continue to struggle with high levels of air pollution, often exceeding the recommended limits.

The disproportionate impact of air pollution on marginalized and vulnerable communities raises significant environmental justice concerns. These communities are often located near industrial sites and busy roads, exposing them to higher levels of pollutants. The concept of environmental justice emphasizes the fair treatment and meaningful involvement of all people, regardless of race, color, national origin, or income, in the development and enforcement of environmental policies (EPA, 2024b). Recent initiatives, such as the Justice40 Initiative in the United States, aim to address these disparities by ensuring that a significant portion of federal investments benefits disadvantaged communities.

As the world continues to urbanize and industrialize, addressing air pollution remains a critical challenge. This review paper aims to provide a comprehensive overview of the current state of knowledge on air pollution, its health and environmental impacts, and the measures being taken to mitigate its effects. The subsequent sections will delve into the specific pollutants of concern, the latest research findings, and the technological and policy advancements aimed at improving air quality globally.

Literature Review

Extensive evidence indicates that air pollution can have implications for human health, particularly demonstrating adverse effects on male fertility through a reduction in semen quality. Exposure to air pollution in Sao Paulo city in Brazil has been linked to a decline in female fertility, leading to an increased occurrence of implantation failures in mice exposed during the early stages (Mohallem et al., 2004). The continuously increasing presence of automobiles and industries contributes to the constant release of toxic gases such as SO_2, NO_x, and particulate matter into the atmosphere (Singh et al., 2022). This has adverse effects on both human health and plant productivity, ultimately resulting in ecosystem degradation and the loss of biodiversity (Saini et al., 2019).

Recent studies have provided further insights into the health impacts of air pollution. Yu et al. (2023) employed machine learning to model global daily ambient fine particulate matter ($PM_{2.5}$) concentrations, revealing the pervasive nature of unsafe air pollution levels worldwide. This study emphasizes the global scale of air pollution and underscores the necessity for international mitigation efforts. Similarly, Lelieveld et al. (2019) highlighted that air pollution is responsible for more than 8.8 million premature deaths annually, with fossil fuel-related pollution alone causing over 10 million deaths each year globally (Vohra et al., 2021). These findings align with Burnett et al. (2018), who introduced an updated risk assessment model showing increased mortality risks associated with $PM_{2.5}$ exposure, thereby stressing the importance of stringent air quality standards.

To support the application of recommendations from the WHO, the Global Air Quality Guidelines outlined the objectives and reasoning behind the quantitative air quality guidelines and interim permissible limits for six major air pollutants (Goshua et al., 2021): $PM_{2.5}$, PM_{10}, SO_2, NO_2, O_3, and CO. Similarly, the United States Environmental Protection Agency (U.S. EPA) recently revised the permissible limits set for these pollutants, presented in **Table 1**, where all except CO have both primary and secondary standards, at different averaging times and concentrations. The primary standard is aimed at protecting human health whereas the secondary standard is intended to protect the public welfare from any known or anticipated adverse effects. The guidelines provided by the WHO are also incorporated in **Table 1**.

Table 1. Permissible limits of ambient air pollutants. Adapted from the U.S. EPA (2024a) and WHO (2021a).

Pollutant	U.S. EPA			WHO	
	Standard	Averaging Time	Concentration	Averaging Time	Concentration
CO	Primary	8 hours	9000 ppb	24 hours	3500 ppb
		1 hour	35,000 ppb		
NO_2	Primary	1 hour	100 ppb	24 hours	13.3 ppb
	Primary and Secondary	1 year	53 ppb	1 year	5.3 ppb
SO_2	Primary	1 hour	75 ppb	24 hours	15.2 ppb
	Secondary	3 hours	500 ppb		
$PM_{2.5}$	Primary	1 year	9.0 μg/m^3	24 hours	15 μg/m^3
	Secondary	1 year	15.0 μg/m^3	1 year	5 μg/m^3
	Primary and Secondary	24 hours	35 μg/m^3		
PM_{10}	Primary and Secondary	24 hours	150 μg/m^3	24 hours	45 μg/m^3
				1 year	15 μg/m^3
O_3	Primary and Secondary	8 hours	70 ppb	8 hours	51 ppb

In urban industrial zones, the high concentration of facilities contributes to increased air pollution (He et al., 2019), a situation that is exacerbated when advanced technologies are deployed without achieving anticipated efficiency gains. This inefficiency often results in significant thermodynamic losses, such as excess heat release and energy waste, which have been linked to broader environmental issues like global warming and climate change (Awolesi et al., 2019).

A study by Al-Zboon (2021) reported PM_{10} concentrations in a cement industry in Riyadh, Saudi Arabia, surpassing the Organizational Safety and Health Administration (OSHA) guidelines, with the concentration of pollutants increasing with proximity to the plant site. The emissions hierarchy were arranged as follows: $PM_{10} > PM_{2.5} > CO_2 > O_3 > CO > VOCs > NO_x > SO_2 > H_2S$. The assessment of health risks revealed that the primary source contributing to the Hazard Quotient (HQ) is the dust generated by the cement plant, and the respiratory system emerged as the organ most significantly impacted by the emissions from the cement plant.

Since the current number of outdoor air quality monitoring sites is inadequate, relevant research suggests solutions involving the utilization of cost-effective equipment networking for gathering pollution data and precisely analyzing local monitoring information (Liu et al., 2020; Zhu et al., 2021). As a result, efficient technologies and instruments have been developed in recent years. For instance, Han et al. (2019) implemented a novel outdoor air quality monitoring system that enhances network arrangements with the Zigbee network tailored to factory settings and demonstrated its feasibility through preliminary testing. The system collected data on the six pollutants stated above, alongside temperature and humidity. The research adopted pollution traceability techniques to calculate dilution and diffusion coefficients, aiming for comprehensive city-wide pollution monitoring via local sites. Furthermore, the study employed an enhanced long short-term memory (LSTM) approach to predict urban air quality and found a strong correlation among $PM_{2.5}$, CO, and NO_2 levels. The results pointed to the manufacturing industry as the city's primary pollution source and concluded that integrating weather quality predictions to dynamically regulate production could significantly protect urban atmospheric environments. Similarly, an innovative microsensor platform that efficiently monitors activated carbon filters in real-time has been developed to provide valuable insights to uphold air quality and mitigate health risks (Cerro et al., 2018). Moreover, affordable monitors, like Knowing Our Ambient Local Air (KOALA), have proven to offer high performance and valuable long-term data for community air quality surveillance, although impacts by low temperature and high humidity have been reported (Liu et al., 2020; Pradhan et al., 2024).

The use of these monitors for air quality tracking is particularly advantageous for socially and economically marginalized groups in the United States, who are unevenly affected by inadequately studied air quality issues (Stewart et al., 2015), depriving them from environmental justice. According to the US EPA, Environmental Justice ensures that everyone, irrespective of their race, color, nationality, or income level, is treated fairly and involved significantly in the process of developing, implementing, and enforcing environmental laws, regulations, and policies (EPA, 2024b). Hence, the adoption of portable air quality monitors (or sensors) in environmental justice research could be attributed to their ability to evaluate pollution on a local scale, offering the potential to enhance spatial coverage (Hall et al., 2014).

Recently, the United States under the leadership of President Joe Biden through the EPA's Environmental Justice Thriving Communities Grantmaking program and the Community Change Grants, has earmarked substantial funding to confront environmental justice challenges (EPA, 2023a). The central aim is to empower marginalized communities that have historically borne the brunt of pollution and environmental harm. The programs are designed to lower barriers to federal funding, promote equal opportunity to clean air and water, and foster the development of healthy communities. The overarching goal is to ensure that these communities, which are often disadvantaged and overburdened by environmental issues, receive 40% of the benefits from federal investments in line with the Justice40 Initiative (EPA, 2023a).

Crucial components of the United Nations' Global Goals (Pradhan et al., 2017), otherwise referred to as Sustainable Development Goals (SDGs), supporting similar initiatives are Goal 11 (Sustainable Cities and Communities), Goal 13 (Climate Action), Goal 7 (Affordable and Clean Energy), and notably Goal 3 (Good Health and Well-being). For example, Goal 13's call for urgent action to combat climate change aligns with the administration's funding of community resilience projects, directly contributing to the health and well-being of the affected communities by reducing pollution and mitigating the impacts of climate change. Similarly, Goal 7's emphasis on affordable and clean energy is vital for ensuring that communities have access to sustainable energy sources, which reduces air pollution and associated health risks. Meanwhile, Goal 11's focus on making cities and human settlements inclusive, safe, resilient, and sustainable directly supports the objective of creating healthy living environments. Central to these efforts is Goal 3, which underscores the importance of ensuring healthy lives and promoting well-being for all at all ages, illustrating that health and well-being are fundamental outcomes that these initiatives strive to secure, reflecting their interdependence with environmental justice and sustainability.

In attaining these goals, the concept of thinking globally and acting locally is central. While the path to urbanization must consider society and sustainability, critical questions as to how global industries situated in local communities are affecting local environments are crucial for the attainment of the SDGs. Hence the need for research centered on the local environment, including impacts, tendencies, statuses, with constant monitoring and evaluation of environmental and health performance of citizens. In a local setting, sustainable development involves using current resources—both tangible and intangible, measurable and immeasurable, popular and unpopular—of local citizens without overexploitation. It ensures intergenerational equity, providing safety and health, while corporate profitability is not prioritized over communal productivity.

Gross Domestic Product is an important metric for assessing urbanization and development. In terms of GDP, Louisiana achieved a value of $219.1 billion in 2023, marking a significant growth of 18,400% compared to the figures from 2022 (IBIS World, 2024). About 87% of this revenue was generated by the industries ranking in decreasing order: Petroleum Refining, Oil Drilling & Gas Extraction and Plastic & Resin Manufacturing. The Baton Rouge Refinery, operated by ExxonMobil in Baton Rouge, Louisiana, stands as the state's largest refinery (Scott & Upton, 2019). It ranks as the fifth largest oil refinery in the United States and the thirteenth largest globally (Scott & Upton, 2019; Hemmerling et al., 2024).

Baton Rouge is the capital of Louisiana, located in the southeastern part of the state, and serves as a hub for various manufacturing and petrochemical industries in operation today. With a population of over 200,000 people (U.S. Census Bureau, 2024), the city is the seat and a subset of the East Baton Rouge Parish–with a population of about 500,000 people–which also comprises cities like Baker, Zachary, and Central.

In 2010, the Louisiana Department of Environmental Quality (LDEQ) released a report to the U.S. EPA that evaluated the existing Louisiana Ambient Air Quality Network and suggested modifications to align with data needs for air quality management while considering resource and financial limitations (EPA, 2020). The report focused on pollutants that exceeded or nearly exceeded standards in populated areas, and the adjustments included reducing monitoring for pollutants well within standards, merging sites to monitor various pollutants at fewer locations, and removing redundant monitors. The report laid the groundwork for improved air pollution control strategies and public information on air quality.

However, a regional news report in 2019 suggested that Baton Rouge received an "F" rating from the American Lung Association despite being compliant with federal air quality standards, positioning it among the most polluted cities in the U.S. with respect to O_3 levels (The Advocate, 2019). The persistent health risks, particularly for individuals with respiratory conditions like asthma exacerbating during the summer months when O_3 or smog levels increase, were also highlighted.

There is an 85-mile region in Louisiana, also known as the Cancer Alley, along the Mississippi River extending from Baton Rouge to New Orleans (see **Figure 1**). Over many years, this region has been burdened by pollution and issues of environmental injustice (Batiste, 2022). Thousands of contaminated sites (Superfund sites) resulting from hazardous waste being dumped, left exposed, or mismanaged by manufacturing facilities, processing plants, landfills, and mining sites, exist in the United States. In Cancer Alley, numerous petrochemical and industrial facilities have contaminated the air, water, and soil, resulting in adverse health effects among the residents (McCoy, 2021; Batiste, 2022). Moreover, proximity to pollution sources and major neurotoxin polluters have been reported to have negative effects on academic performance in East Baton Rouge (Lucier et al., 2011). Similarly, research conducted by Legot et al. (2012) revealed that the proximity to industrial pollutants in East Baton Rouge correlates with elevated incidences of neurodevelopmental diseases and childhood asthma, alongside higher rates of minority populations and poverty.

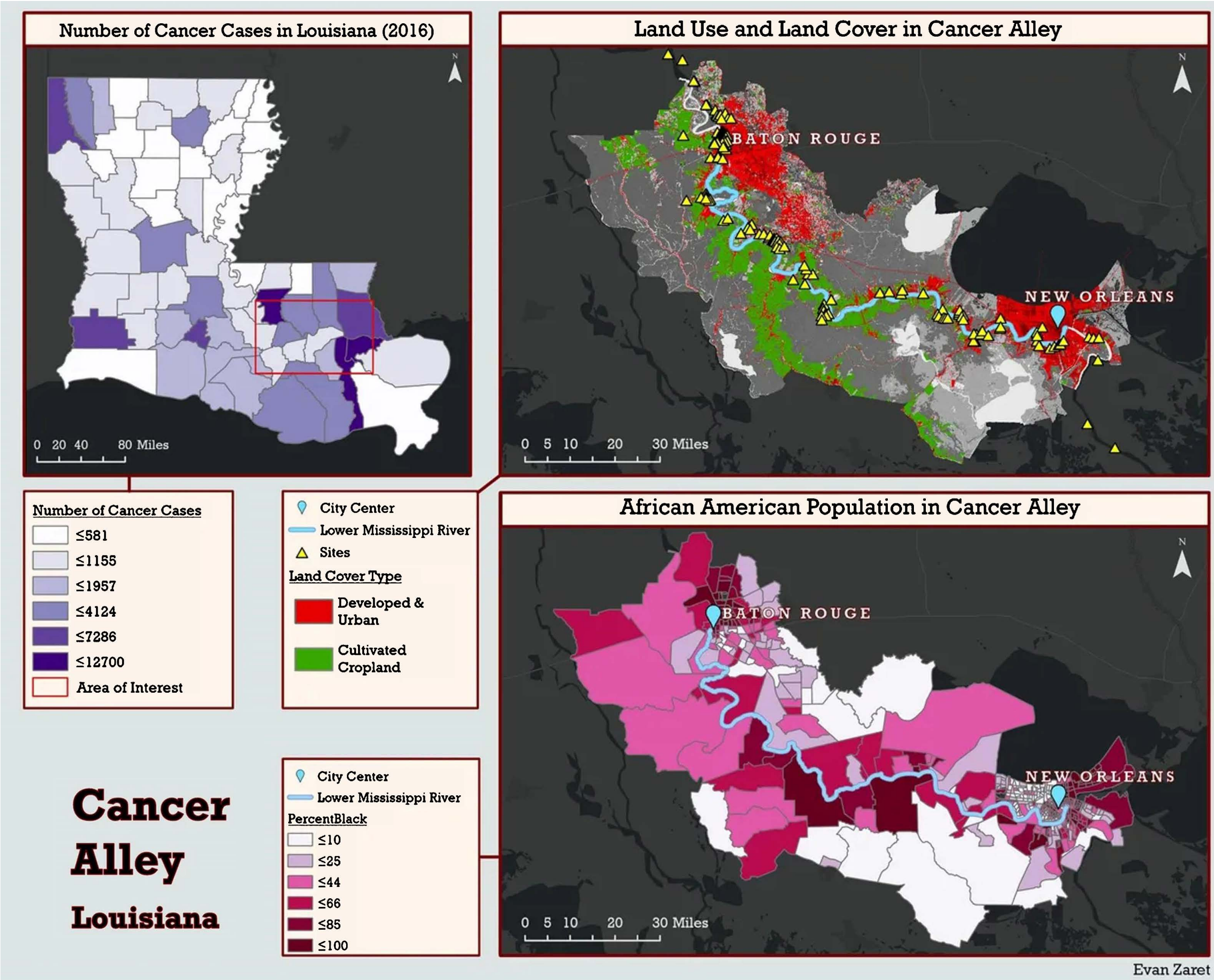

Figure 1. Maps depicting the interconnections between industrial land use, cancer cases, and the distribution of the African American population in the region, with legends located at the bottom left. Adapted from Sach Sustainability (2020).

Of all the minority groups, the Black communities within the industrialized region are the most adversely affected, and this may exacerbate pre-existing diseases in residents, as reported in recent studies. For instance, in a recent assessment exploring the relationship between air pollution, race, health, socioeconomic factors, and COVID-19 outcomes using longitudinal data on $PM_{2.5}$ concentrations, respiratory and immunological hazards from toxic air pollution, and emission changes, Terrell and James (2022) reveal that areas with higher air pollution burdens, significant Black populations, and increased unemployment rates experience higher COVID-19 death rates, independent of factors like diabetes, obesity, smoking, age, or poverty. The assessment also indicated a shift in the sources of $PM_{2.5}$, with industrial emissions remaining constant while vehicle emissions significantly declined. Despite a decrease in $PM_{2.5}$ levels from 2000 to 2015, a recent increase in south Louisiana correlates with rising industrial emissions (Terrell & James, 2022). Similarly, Fos et al. (2021) assessed the effects of long-term air pollution on the health of individuals in vulnerable communities in the Cancer Alley, expanding beyond the previously established link between air pollution and cancer risk. The study found high rates of premature death, more unhealthy mental health days, and higher COVID-19 death rates in the vulnerable communities, compared to others that are not, in the U.S., Louisiana, Harris County, Texas, Los Angeles County, and Philadelphia. Black individuals faced a risk 1.5% to 11.4% higher than their White counterparts.

These studies imply that there is a relationship between the location of industrial sites, the incidence of cancer, and the demographics of the population that could potentially be affected by environmental health risks associated with industrial pollution. A visualization of this relationship is provided in **Figure 1**. The top left map shows the number of cancer cases in Louisiana by parish in 2016. The top right map shows different types of land use such as city center, Mississippi River, industrial, developed area, cultivated crops, and other land. The industrial sites are marked in yellow and are prominently situated along the Mississippi River, indicating a possible link between industry and land use patterns. The bottom right map shows the distribution of the African American population within Cancer Alley. The shaded areas indicate where higher populations of African Americans live, with the shading intensifying where the population density increases.

Recently, the U.S. EPA declared that two locations in Baton Rouge be added to the latest revision of the Superfund National Priorities List (EPA, 2023b), suggesting its recognition of environmental injustices in relevant communities and the need for immediate intervention and remedial actions.

According to a more recent study carried out using GIS/remote sensing tools and air quality station data for East Baton Rouge, retrieved from the U.S. EPA, Frimpong et al. (2022) revealed that alterations in land use and land cover in East Baton Rouge have resulted in enhanced air quality within the last 30 years—with a decreasing concentration trend in CO, NO_2, and $PM_{2.5}$—due to factors such as less traffic, low industrial emissions, and clement meteorological conditions. However, the findings are limited to a geographic region (East Baton Rouge) and do not cover specific locations such as different industrial facilities or sites within the region.

Consequently, this study aims to investigate air quality in 28 chemical industry sites located in Baton Rouge and explore the potential consequences on the health and well-being of individuals living in proximity to these sites. Results from this study are important for four reasons: First, it will help provide evidence that suggests whether the air quality in the capital city is improving, offering a benchmark for environmental progress or decline over time. Second, it will inform targeted interventions and policy actions to mitigate adverse health impacts by identifying the extent of pollution and its sources. Third, the findings can enhance public awareness about the health risks associated with living near chemical industry sites, empowering communities with information to advocate for their health and safety. Fourth, the research could contribute to the broader discourse on environmental justice, highlighting disparities in exposure to pollution and prompting efforts to address these inequities at the local, state, and national levels.

The remainder of this paper is divided into four sections. Section **2** describes the methodology employed. Section **3** provides and discusses the results and their implications. Section **4** provides conclusions and future directions.

2. Methodology

Air quality pollutants in 28 chemical industry sites in Baton Rouge were monitored in the Summer of 2023, from June 21 to September 10, using the BreezoMeter app software. The software employs advanced models for air quality dispersion and rigorous accuracy analysis and validation techniques to ensure exceptional precision (Bhandari et al., 2022). It records and provides the concentrations of air quality pollutants hourly, alongside projections. For this study, data was retrieved at least once, daily, in real-time, mostly between 10 a.m. and 10 p.m., except for 7 days when data was not retrieved. The total number of days covered is 75. Pollutants surveyed include particulate matter ($PM_{2.5}$ and PM_{10}), CO, NO_2, SO_2 and O_3. Hygrothermal data were also retrieved. Python, QGIS, and Mapize were used for the analysis and visualization of data.

The study area map is provided in **Figure 2**. The left side of the Figure displays the map of Louisiana with its counties. On the right side is a detailed map

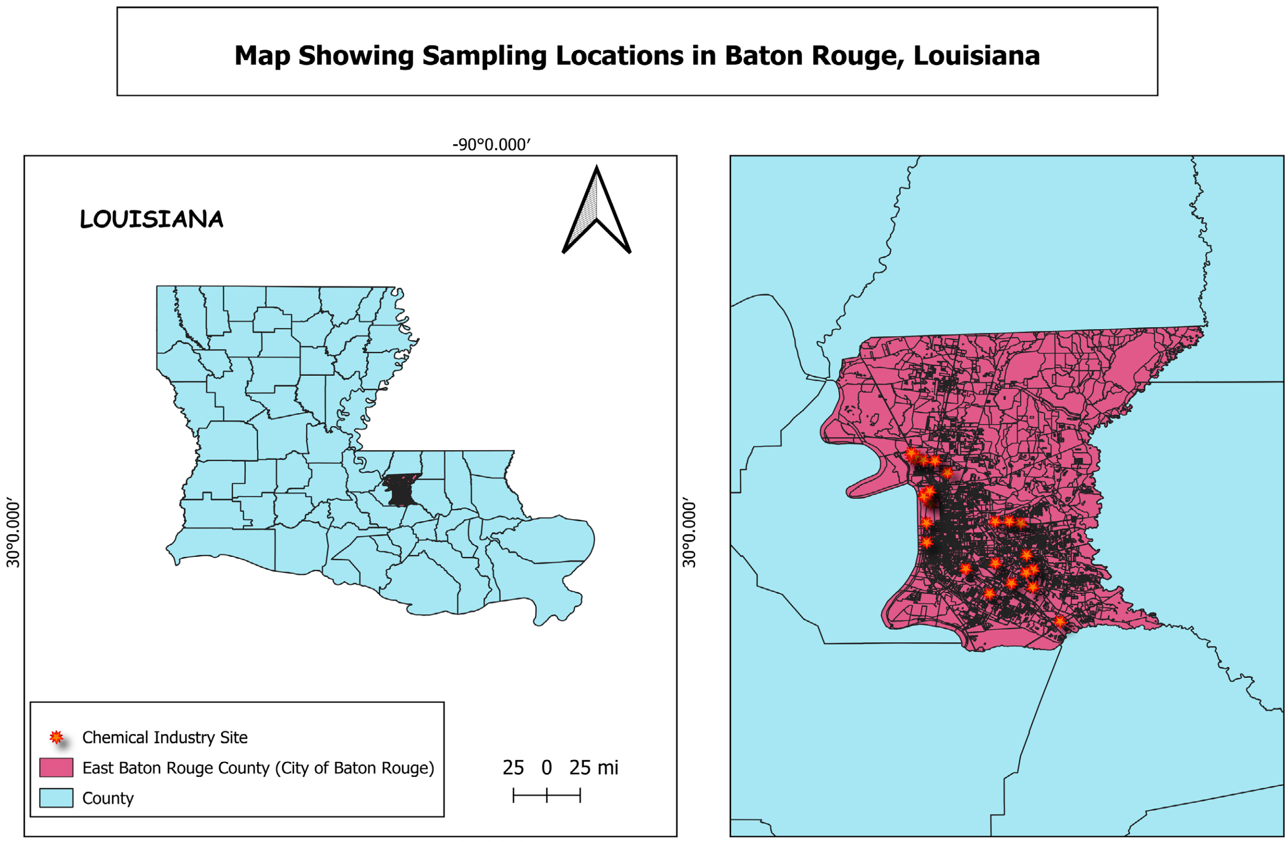

Figure 2. Distribution of 28 chemical industry sites across Baton Rouge City, within East Baton Rouge Parish, Louisiana.

of the East Baton Rouge County area, with specific points marked to represent chemical industry sites. Figure 3 shows a heat map overlaid on a road map of the Baton Rouge area, illustrating the distribution of the industrial sites being studied. The red and orange areas signal higher concentrations of these sites, particularly to the northwest and north of downtown Baton Rouge, indicating regions with potentially higher industrial activity. Table 2 provides an overview of the products and services associated with the study sites. The sites produce a range of items, from sulphuric acids, specialty chemicals, and plastics to more specific offerings like metallocene catalysts and aroma ingredients for food and fragrances. Some sites are involved in broader services, such as water treatment and oil and gas refining, or supply items for industries, including gases, welding products, and safety equipment. The table also indicates that one site is temporarily closed and highlights sites that handle petrochemical manufacturing, chemical distribution, and even logistics and transportation related to chemicals.

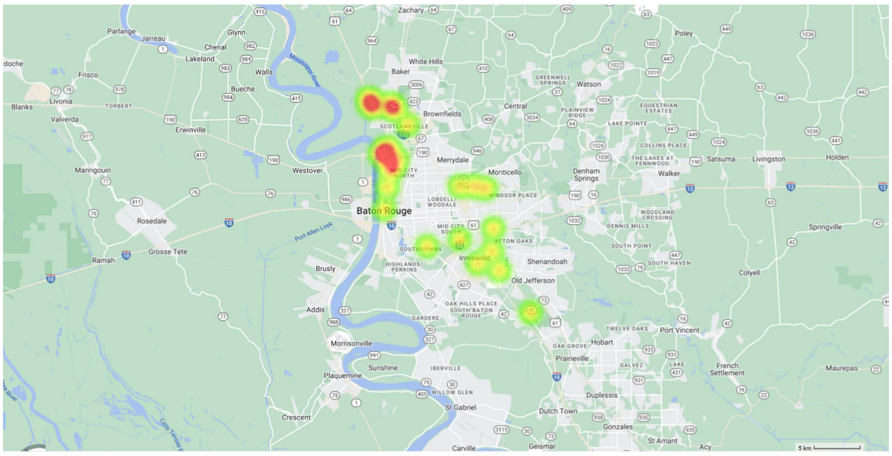

Figure 3. Heat Map showing chemical industry sites on a Baton Rouge Road map.

Table 2. Overview of the products and services associated with each of the 28 chemical industry sites in Baton Rouge.

ID	Associated Products/Services
Site 1	Sulphuric Acids
Site 2	Specialty Chemicals and Resins
Site 3	Specialty Materials
Site 4	Single Site Metallocene (Polyethylene) Catalysts, Catalyst Components including methylaluminoxane (MAO)
Site 5	Aroma Ingredients Used in Food, Flavoring and Fragrances
Site 6	Water Treatment; Oil and Gas Refining Adsorbents; Air Purification; Desiccants; Reactor Bed Supports; Catalyst Substrates and Supports
Site 7	Plastics
Site 8	Resin Finishing
Site 9	Specialty Chemical Products
Site 10	(Temporarily Closed)

Continued

Site 11	Gasses and gas equipment; Welding products and supplies; Industrial and construction supplies; Tools and hardware; Safety products
Site 12	Chemical Mobility (e.g. Cosmetics, Detergents, Solvents, Pharmaceuticals, Adhesives)
Site 13	Petrochemical Manufacturing
Site 14	Wholesale Chemicals
Site 15	Specialty Chemical Manufacturing (e.g. aluminum, sulfur, ammonia, and zirconium products)
Site 16	Manufacturing of Fine Chemicals as well as Laboratory Supplies and Equipment
Site 17	Cleaning Chemicals; Vapor Control Solutions; Pressure Washers; Tank Cleaning Equipment
Site 18	Logistics; Warehousing; Distribution of Specialty Chemicals including Acids, Amines, Ammonia, Antifoam, Glycols, Solvents, Powders, Powders, Filtration Chemicals
Site 19	Industrial Equipment Supplies
Site 20	Coalition of Chemical Manufacturers, Vendors and Suppliers
Site 21	Polypropylene Production
Site 22	Plastic Fabrication
Site 23	Petrochemicals
Site 24	Toll Processing; Contract Manufacturing; Warehousing; Transportation; Application Lab
Site 25	Instrumentation Products and Process Equipment.
Site 26	Hydroblasting; Vacuum Services; Hydro Excavation; Mechanical Services; Oil and Oily Water Recycling
Site 27	Manufacturing and Distribution of Laboratory Chemicals (e.g. Sugar)
Site 28	Supplier- Industrial and Medical Gases including oxygen, nitrogen, argon, hydrogen and carbon dioxide

3. Results and Discussion

3.1. Particulate Matter: $PM_{2.5}$ and PM_{10}

As illustrated in **Figure 4**, the mean concentration of $PM_{2.5}$ for most sites tend to cluster around 12.0 μg/m^3, with Site 27 registering the highest mean concentration at 19.6 μg/m^3. This occurs at a site where laboratory chemicals are manufactured and distributed. Although the mean concentration of 19.6 μg/m^3 falls below the primary and secondary standards of the U.S. EPA (see **Table 1**), if the value remained so throughout the year, it would exceed the primary standard, potentially necessitating action to reduce particulate matter levels to protect public health. Similarly, while the mean concentration is below the daily guideline of WHO (15 μg/m^3), the high standard deviation of about 9.2 μg/m^3 suggests that on certain days, the $PM_{2.5}$ concentration exceeded safe levels, likely influenced by the site's activities. Although Sites 9 and 25 rank closely to Site 27 with a mean concentration of 17.6 μg/m^3 and a standard deviation of 5.2 μg/m^3 and 6.1 μg/m^3 respectively, all sites exceed the annual mean primary standard of the U.S. EPA but below the daily mean. Given the potential health risks associated with $PM_{2.5}$, particularly in areas where chemical manufacturing occurs, it is important for the site to manage and monitor emissions to maintain air quality within safe limits consistently. Regular assessment and adherence to environmental regulations are crucial, especially in an area handling a mix of substances, including those as common as sugar, to ensure the health and safety of the local population and environment.

With a daily mean of 45 μg/m^3 and an annual mean of 15 μg/m^3, the WHO has more stringent guidelines for PM_{10} than the U.S. EPA. As illustrated in Figure 5, the mean concentrations of PM_{10} in all sites range from 17.8 - 39.3 μg/m^3, exceeding the annual mean value of the WHO guidelines. However, again, Site

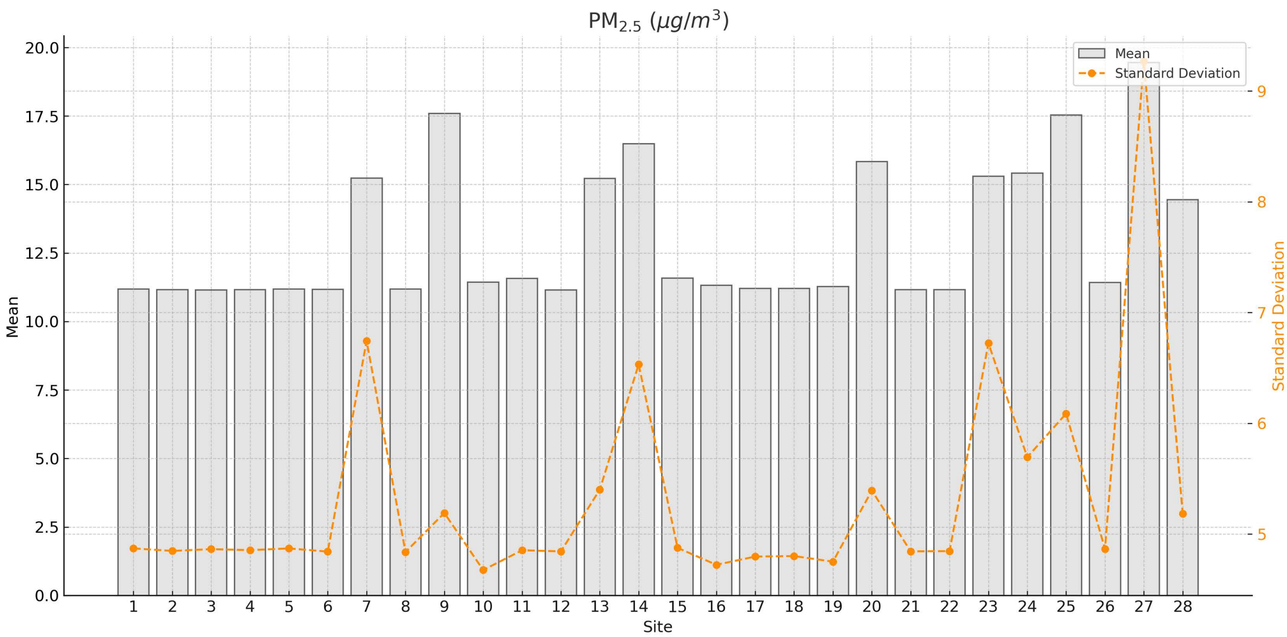

Figure 4. Mean $PM_{2.5}$ concentrations for Summer 2023 across 28 chemical industry sites in Baton Rouge.

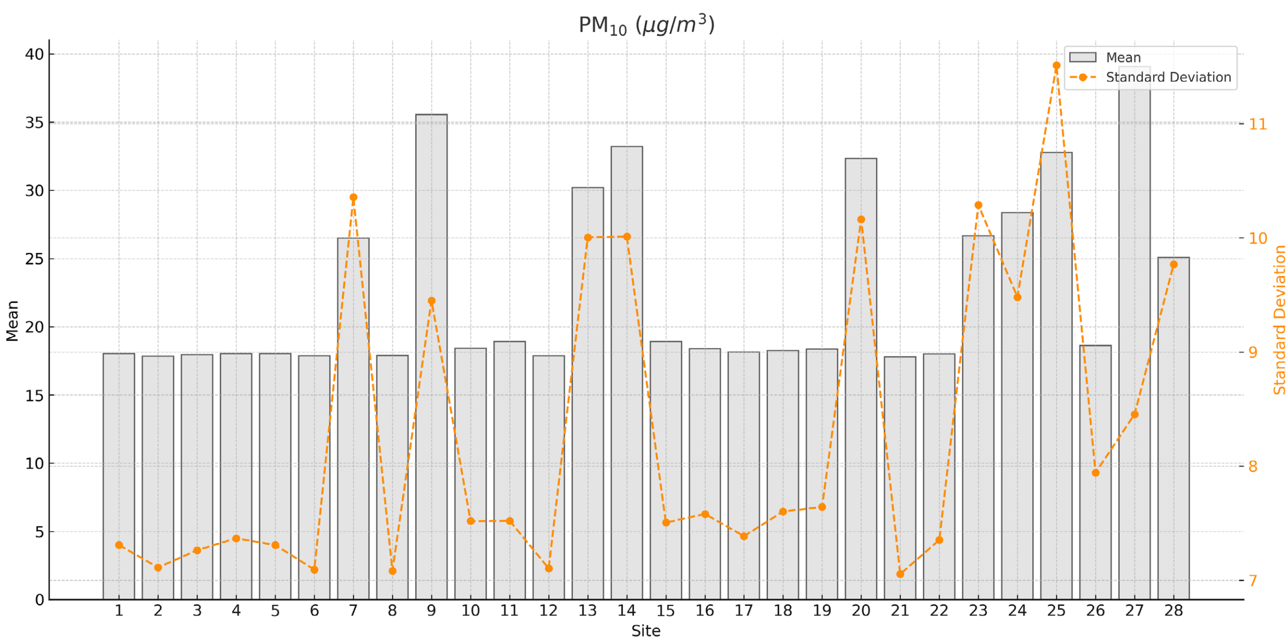

Figure 5. Mean PM_{10} concentrations for Summer 2023 across 28 chemical industry sites in Baton Rouge.

27 leads the rank with a particularly high concentration of 39.3 μg/m³. While the mean concentrations for all sites fall below the daily standards for WHO and the U.S. EPA (at 150 μg/m³), the range of standard deviations suggests that there are certain days with high spikes. For example, Sites 9 10, 14, 20, 25, 27 and 28 contain days exceeding the daily threshold. Like $PM_{2.5}$, this indicates a critical need for attention to air quality management at the sites to avoid any potential exceedances on a day-to-day basis. Complacency may exist adhering to U.S. EPA standards in lieu of the WHO's stricter guidelines, considering that the former rather than the latter is responsible for sanctioning organizations that are not compliant within the states. As a result, there exists a governance challenge in aligning local regulatory practices with global health recommendations. This further implies an underestimation of the public health risk.

3.2. Ozone (O_3)

The mean concentrations of O_3 for Sites 1-28 are all in the lower 30 ppb range, as depicted in **Figure 6**, and significantly below the EPA's limit of 70 ppb and WHO's limit of 51 ppb. This indicates that the mean O_3 levels at these sites are well within the recommended safety margin for air quality standards set by both regulatory bodies. However, it is important to note that these figures represent mean concentrations recorded once, daily, and repeatedly during the study, and compliance with the 8-hour standard specifically depends on those averages being maintained consistently throughout the day without exceeding 70 ppb. On three different days, the recorded concentration of O_3 exceeded this limit for most sites.

High O_3 concentrations, particularly at ground level, can have a range of harmful effects on human health, the environment, and materials. In terms of

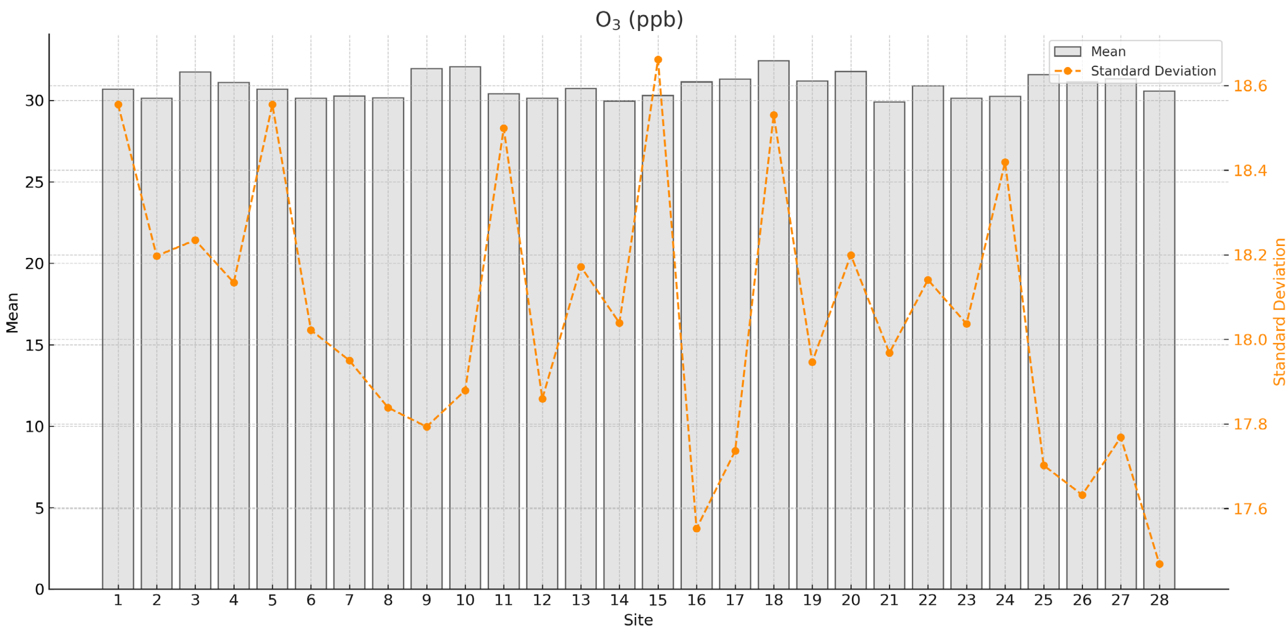

Figure 6. Mean O_3 concentrations for Summer 2023 across 28 chemical industry sites in Baton Rouge.

health, high levels of O_3 can result in or worsen respiratory problems such as bronchitis, emphysema, and asthma. Environmental effects and material damage include damage to vegetation, as O_3 can interfere with the ability of plants to reproduce and store food which can make them more susceptible to disease, insects, other pollutants, and harsh weather.

3.3. CO, SO_2 and NO_2

In Figure 7, the mean concentrations of CO in the chemical industry sites studied are within the range of 162 - 167 ppb which significantly falls below the WHO and the U.S. EPA guidelines provided in Table 1. Similarly, as illustrated in Figure 8, SO_2 levels fall below both guidelines. However, the mean NO_2 concentrations across Sites 1 - 28 show significant variation, with most sites reporting means well below the WHO's 24-hour guideline of 13.3 ppb and the annual guideline of 5.3 ppb. However, some sites exhibit notably higher mean concentrations that exceed these limits, especially Site 9 with a mean of 21.2 ppb and Site 27 with 17.3 ppb, which are significantly above both the 24-hour and annual WHO guidelines. Other sites with elevated means, such as Sites 7, 13, 14, 20 23 - 25, and 28, also stand out as potential areas of concern due to their higher NO_2 concentrations. These are depicted in Figure 9.

The standard deviation values indicate that while the mean concentrations at several sites may be compliant with the guidelines, there are still periods of time where the NO_2 levels spike above the recommended limits.

3.4. Hygrothermal Factors

As shown in Figure 10, the mean temperature values are relatively high, as expected for summer, averaging in the mid to upper 80˚F across all sites. The

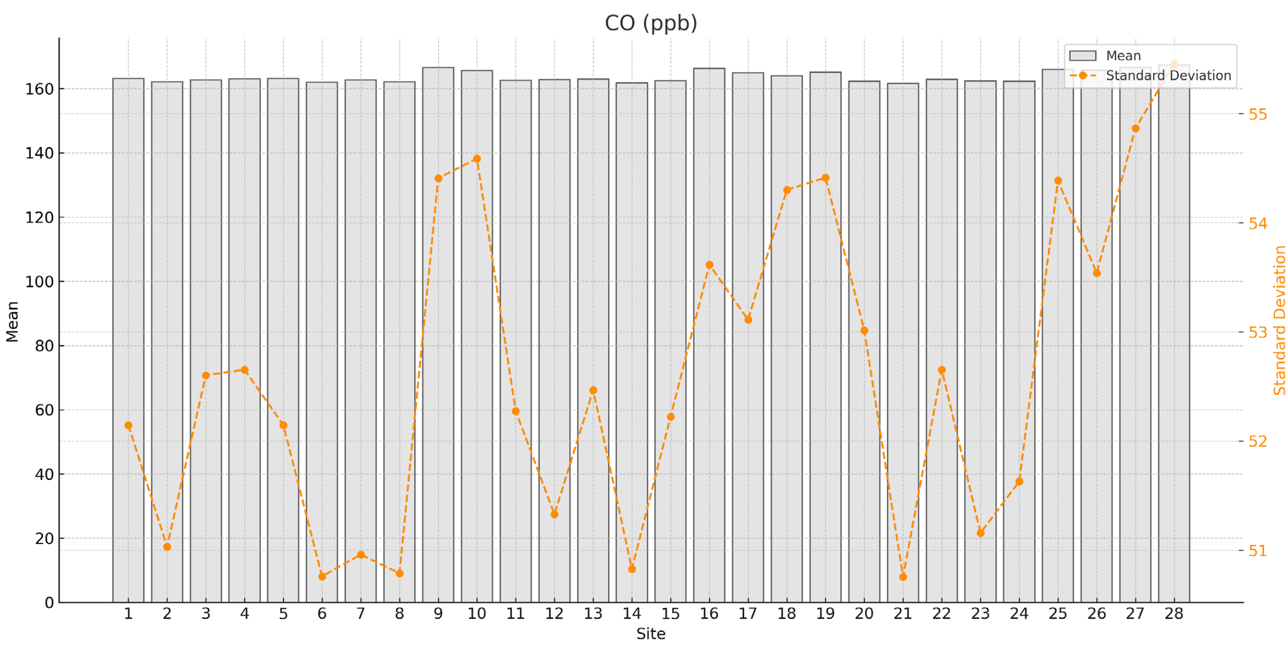

Figure 7. Mean CO concentrations for Summer 2023 across 28 chemical industry sites in Baton Rouge.

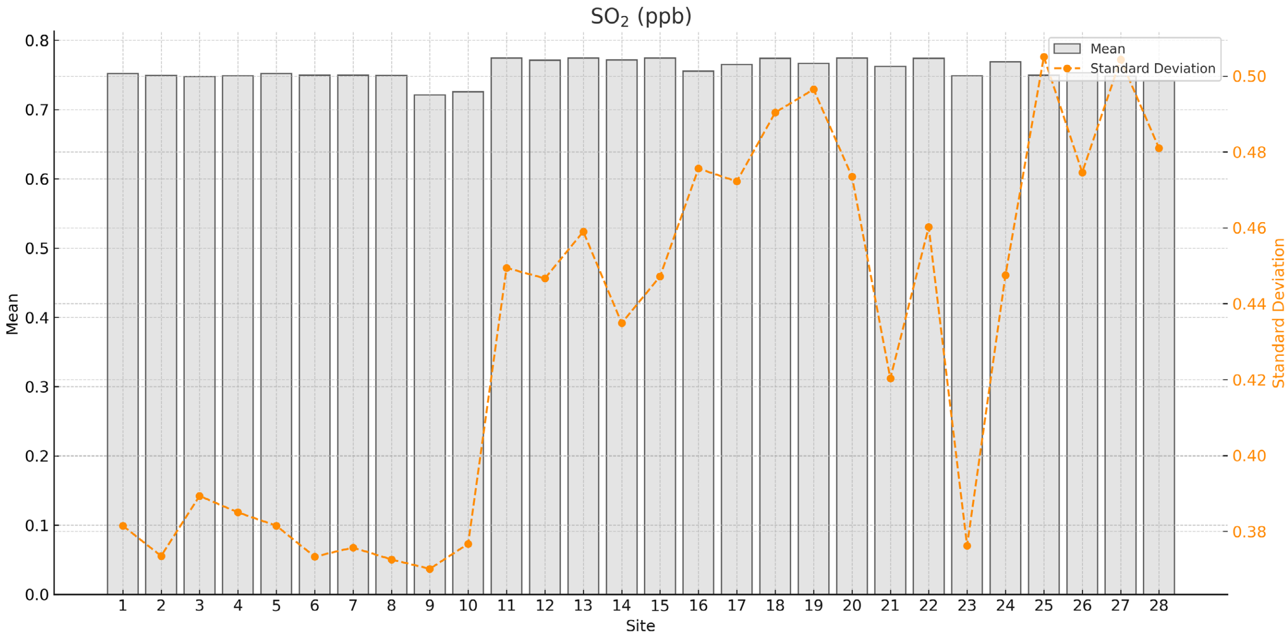

Figure 8. Mean SO_2 concentrations for Summer 2023 across 28 chemical industry sites in Baton Rouge.

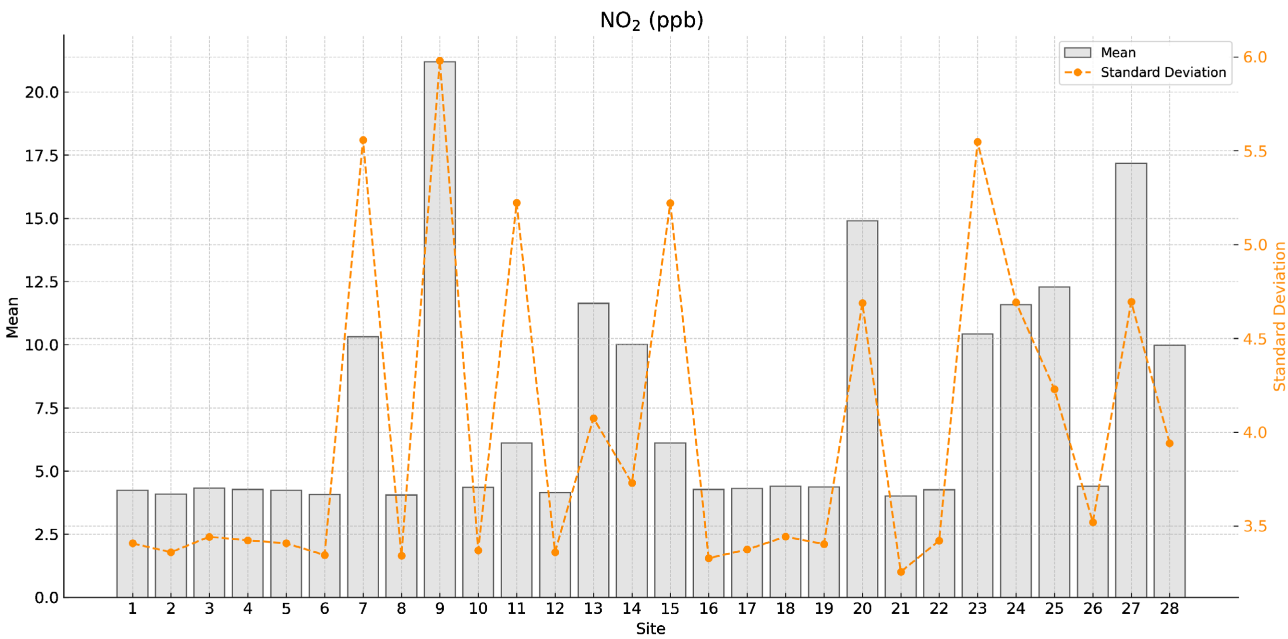

Figure 9. Mean NO_2 concentrations for Summer 2023 across 28 chemical industry sites in Baton Rouge.

standard deviations are moderate, indicating some variability in temperature but generally consistent with typical summer weather patterns. Humidity levels show more variation, with standard deviations around 16%, and mean values ranging mostly in the mid-60% to 70%. A few sites exhibit particularly high humidity levels (see **Figure 11**), which can impact the concentration of air pollutants.

High temperatures can increase the formation of ground-level O_3, a result of chemical reactions between oxides of nitrogen (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. Similarly, humidity can interact with

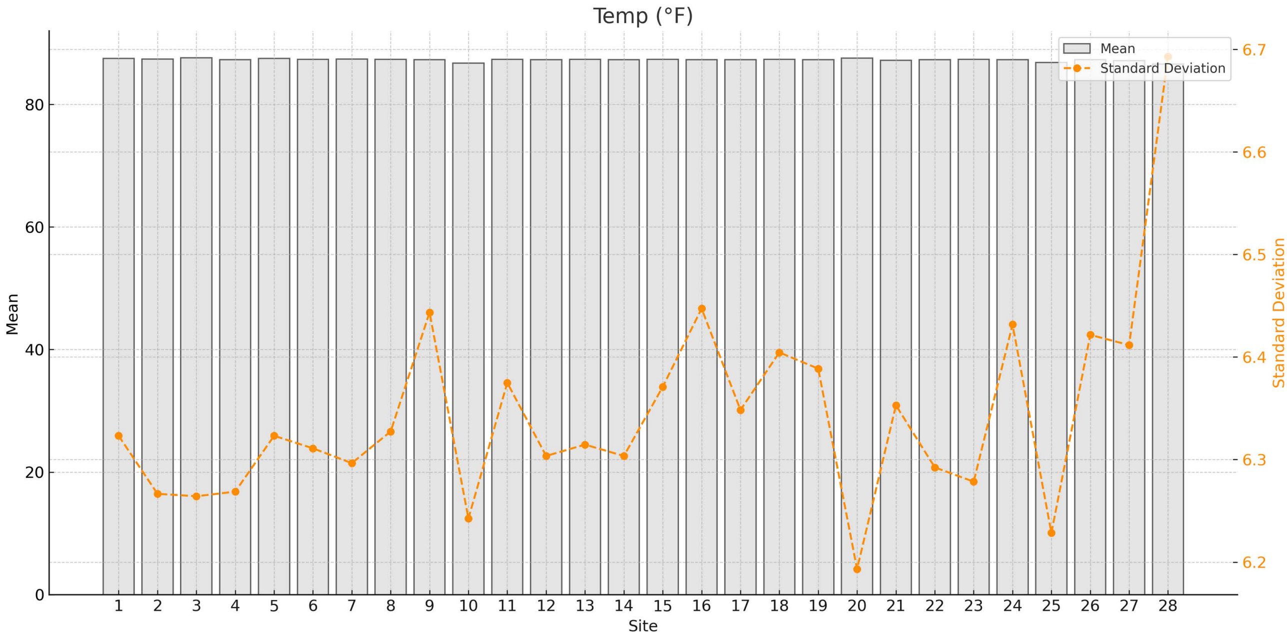

Figure 10. The mean temperature for Summer 2023 across 28 chemical industry sites in Baton Rouge.

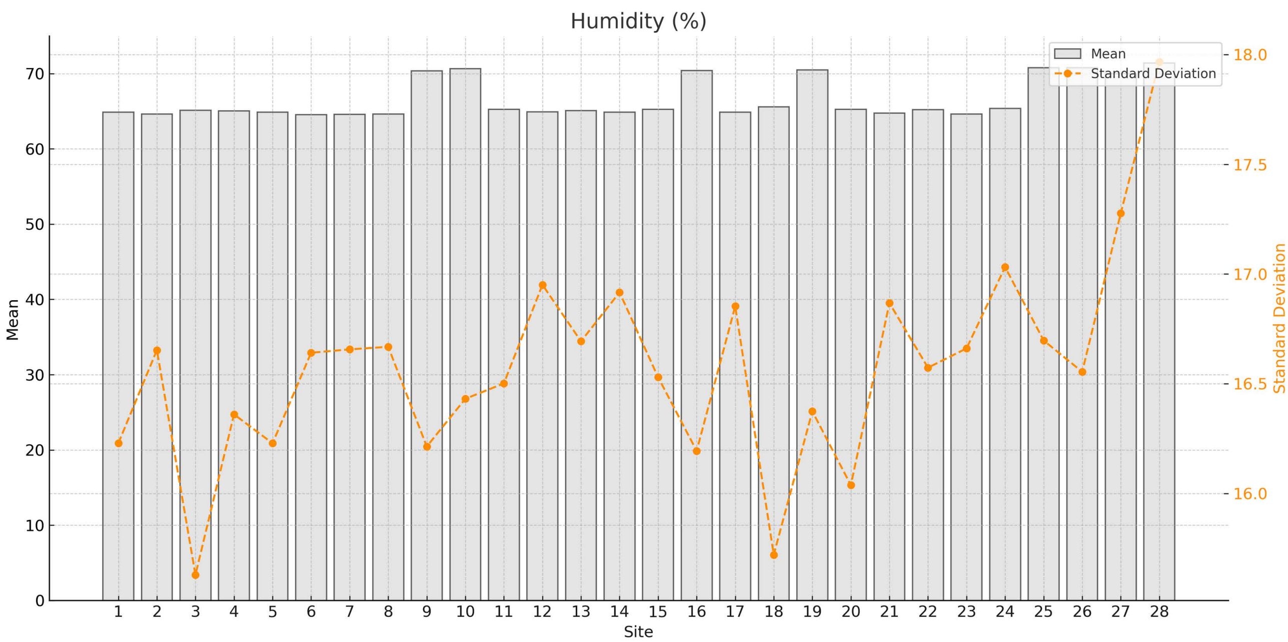

Figure 11. Mean humidity for Summer 2023 across 28 chemical industry sites in Baton Rouge.

pollutants to form secondary particulate matter and can also affect the dispersal and reaction rates of air pollutants.

3.5. Further Analysis and Discussion

The relationships between air pollutants and hygrothermal factors based on aggregated averages from all sites are illustrated in the correlation chart in Figure 12. The correlation analysis stems from averaging the average values of each parameter across all 28 industrial sites. Pollutants like NO_2, $PM_{2.5}$ and PM_{10}, show very high positive intercorrelations (>0.90). However, there is a negative correlation (−0.59) between CO and temperature. The former implies that common sources or conditions increase the three pollutants simultaneously or similar patterns of dispersion and behavior in the environment, whereas the latter relationship might be due to several factors, including but not limited to variations in emissions at different temperatures, changes in chemical reaction rates, or differences in the vertical mixing in the atmosphere that can disperse pollutants more effectively at higher temperatures.

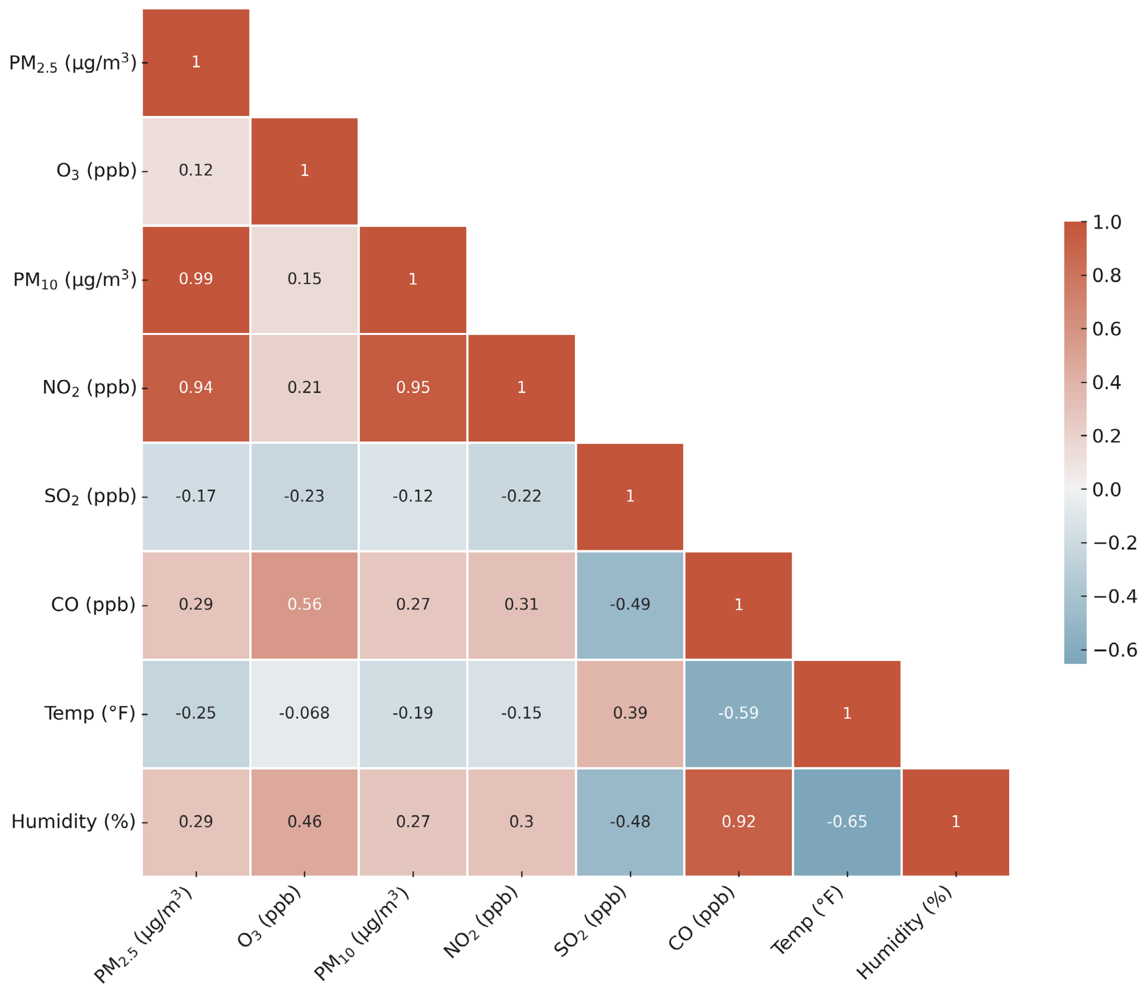

Figure 12. Correlation chart displaying the intercorrelation between aggregated averages of air pollutants and hygrothermal factors at chemical industry sites in Baton Rouge.

As depicted in **Figure 13**, a comparison is made between the results obtained from the current study and the longitudinal study of air quality in East Baton Rouge Parish by Frimpong et al. (2022) concerning three major air pollutants, namely CO, $PM_{2.5}$, and NO_2. The Figure indicates that there is a clear downward trend in NO_2 concentrations from Frimpong et al.'s 1991 observation through to the current study. This indicates an improvement in air quality concerning NO_2 levels over the years. Similarly, CO levels have also shown a drastic reduction

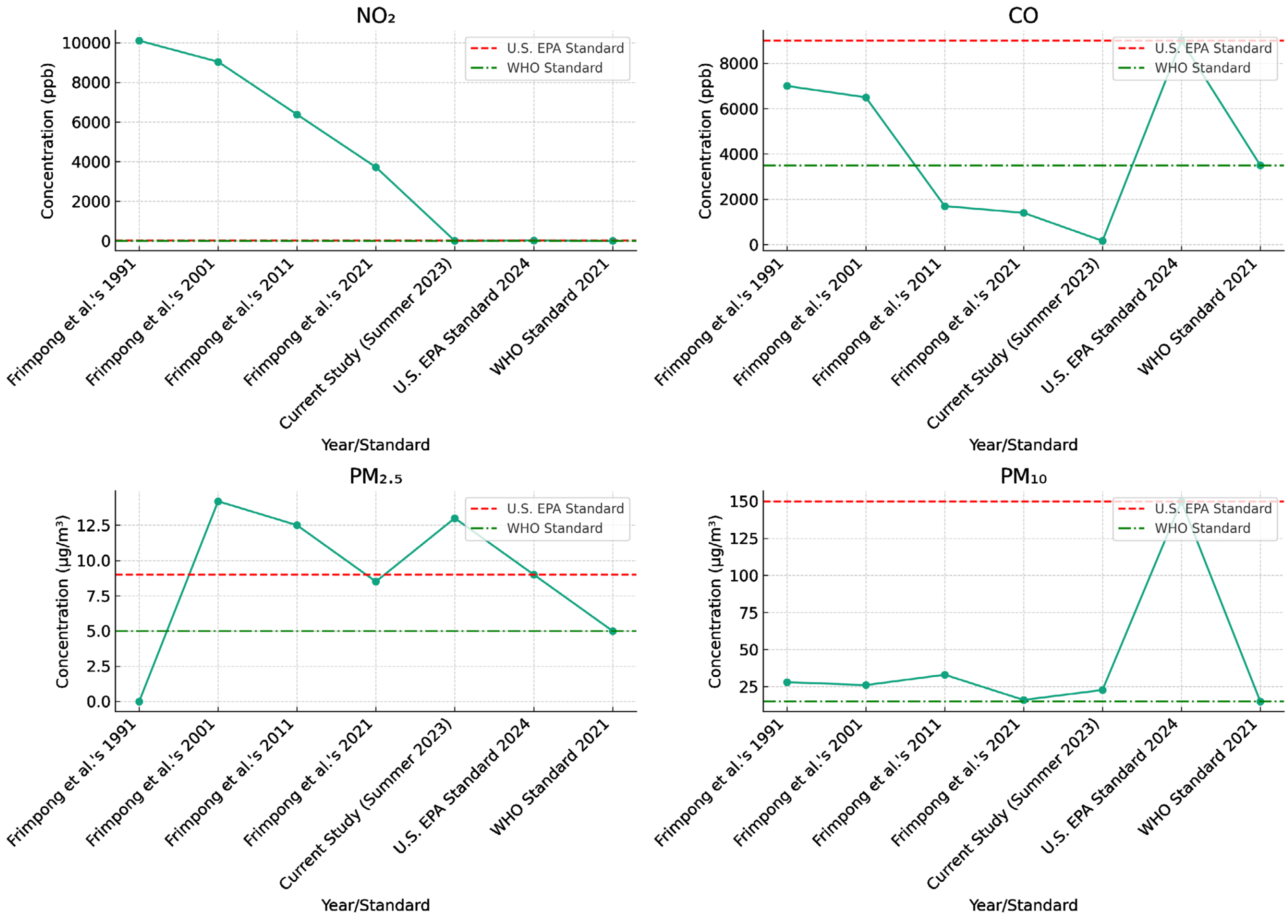

Figure 13. Plots comparing air pollutant levels from current and recent studies, alongside regulatory guidelines.

from earlier years to Frimpong et al.'s 2021 and further in the current study. However, $PM_{2.5}$ and PM_{10} levels have seen a slight increase in the current study compared to Frimpong et al.'s 2021. This indicates a minor setback in the reduction of fine particulate matter, which warrants attention for further analysis and action.

On the other hand, it is important to note that the values provided in Frimpong et al. (2022) are based on annual average of the years in comparison, particularly in East Baton Rouge which is a superset of Baton Rouge and other cities.

Meanwhile, the current study's finding is based on summer alone, and as a result, seasonal variations, such as increased energy usage for cooling, which can lead to higher emissions from power plants, and the photochemical generation of ozone and secondary particulates during warmer months, might have influenced the elevated $PM_{2.5}$ and PM_{10} levels observed. This seasonal disparity emphasizes the need for careful consideration when comparing these sets of data to ensure that like-for-like conditions are being evaluated.

Ambient air pollution is caused by several factors, such as natural phenomena, industrial processes, agricultural practices that are human-made, and vehicle emissions. Chemical companies that are engaged in transportation, waste management, energy production, and manufacturing processes are frequently linked to emissions of pollutants. For example, the levels of CO and NO_2 are influenced by emissions from combustion processes in power plants and industrial sites. Particulate matter, NO_2, and CO concentrations are significantly influenced by vehicle emissions (Festy, 1997; Bessagnet et al., 2022). Air pollution can be caused by agricultural practices that generate ammonia and methane (Munsif et al., 2021), such as raising cattle and applying fertilizer. In addition, high levels of pollution have the potential to disrupt ecosystems, and negatively impact wildlife populations. Acid rain, which can affect aquatic life and plant growth as well as change the quality of soil and water, is a result of sulfur dioxide emissions.

For both adults and children, exposure to high concentrations of $PM_{2.5}$, PM_{10}, O_3, NO_2, CO, and SO_2 can have detrimental effects on health. Particulates like $PM_{2.5}$ and PM_{10} can enter the respiratory system deeply, resulting in cardiovascular problems, respiratory disorders, and potentially early mortality (Basith et al., 2022; Wan Mahiyuddin et al., 2023). Meanwhile, lung inflammation and other respiratory ailments can be made worse by O_3 exposure (Wiegman et al., 2020). Although exposure to NO_2 has been associated with respiratory issues, especially in youngsters, and can eventually deteriorate lung function, high levels of CO can be fatal, producing headaches, dizziness, and disruption of oxygen transport in the blood. Similarly, exposure to SO_2 has the potential to worsen pre-existing respiratory disorders and irritate the respiratory tract (Lee et al., 2021).

These critical concentrations of the studied pollutants emphasize how important it is to address healthcare and environmental injustices in marginalized populations to reduce the incidence of serious illnesses like cancer (Wilson et al., 2014).

It takes a multifaceted strategy that includes public awareness efforts, technology improvements, and regulatory actions to address outdoor air pollution. Governments ought to impose more stringent emission standards on automobiles, factories, and other sources of pollution. Reducing emissions from industrial activities can be achieved by investing in renewable energy sources and implementing cleaner production practices. The risks to the individual are reduced in proportion to the extent of the intervention (Rose, 1985).

Meanwhile, industries can be encouraged to lessen their carbon footprint by implementing emissions trading programs and providing incentives for green activities. Programs for public education and awareness can encourage people to support clean air laws and make decisions that are ecologically friendly. Reducing outdoor air pollution requires corporate policies to incorporate environmental, social, and governance (ESG) factors. Industries should give priority to sustainability measures, such as cutting back on emissions of air pollutants, lowering emissions of greenhouse gases, and putting in place ethical waste management techniques (Prince et al., 2020).

Importantly, ESG factors should be incorporated by financial institutions and investors when making investment decisions, giving preference to industries that exhibit robust environmental stewardship procedures. To effectively tackle outdoor air pollution and advance sustainable development, cooperation between governments, corporations, and civil society is essential (Smith & Jacques, 2022).

4. Conclusions and Future Directions

This study evaluated air quality pollutants ($PM_{2.5}$, PM_{10}, O_3, NO_2, CO, and SO_2) across 28 chemical industry sites in the capital city of Louisiana during the summer of 2023. The answer to whether the air quality in Baton Rouge is improving is nuanced. Although, in the absence of fair comparison, findings suggest that the air quality in Baton Rouge is improving, particularly concerning NO_2 and CO levels, indicating effective measures and policies have been implemented to reduce these pollutants. However, the increase in $PM_{2.5}$ and PM_{10} levels, as observed in the most recent data, signals that challenges remain, particularly in controlling particulate matter pollution.

As previously stated, air quality data for the current study is based on data retrieved from chemical sampling sites and may not be sufficiently comparable to the whole of East Baton Rouge. Given that the distribution and density of sampling sites can significantly affect the perceived air quality in localized studies, we propose that the state of air quality in the overall industries in a locality, city, or state should be the baseline for generalizing and classifying the air quality in such places. Enforcing this as a policy will achieve various feats: Firstly, it ensures a more comprehensive and representative assessment of air quality, reducing biases introduced by limited or strategically placed sampling sites. Secondly, it facilitates targeted policy interventions by accurately identifying pollution hotspots and their sources within broader geographic areas. And finally, it encourages the implementation of more effective air quality management strategies that are tailored to the specific needs and challenges of the entire community, thereby ensuring that efforts to improve air quality are equitable and inclusive, ultimately leading to healthier living conditions for all residents.

Although certain sites were above at least one regulatory guideline for particulates, ozone, and NO_2, Site 27, a chemical industry site dealing in the manufacturing and distribution of manufacturing of lab chemicals shows dominance in exceedances.

Regulatory threshold exceedances pose a great impact on ecology and human health, and to mitigate these risks, the chemical industry must invest in massively inefficient technologies and sustainable energy sources, adopting cleaner production practices to reduce emissions from industrial activities.

The findings of this study, although centered on sites in Louisiana, have far-reaching impacts beyond this specific case study. The insights presented in this paper can significantly influence future research in the field, shape the perspectives of policymakers, and inform the strategies of environmental activists. Additionally, the results can guide business entities and individuals, especially those in vulnerable neighborhoods, in understanding and addressing air quality issues. Ultimately, the impact of these findings extends beyond the immediate context of Louisiana's capital city, offering valuable reference points for a wide range of stakeholders concerned with air quality.

However, we acknowledge a few limitations related to this study: Firstly, the reliance on data collected during a singular season may not capture variations in pollution levels over longer periods. Hence, there is a need for longitudinal monitoring. Additionally, while the study identifies associations between air quality parameters and chemical industry sites, further investigation is needed to establish causality and explore potential confounding factors. Moreover, the inability to assess individual exposure levels and health outcomes limits the ability to fully understand the impact of air pollution on affected populations. Therefore, future studies should cover this extensively.

Furthermore, championing campaigns to raise funds for the use of portable, low-cost monitoring devices for vulnerable groups would be beneficial to Baton Rouge society as well as scientific research, since more accurate and precise real-time data can be obtained as a result.

Despite these limitations, the findings of this study highlight the critical need for measures to mitigate air pollution from chemical industry sites and protect public health. Future research should aim to address these limitations and provide more comprehensive insights into the relationship between industrial activities and air quality.

Author Contributions

O.A. and P.G.O. conceived and designed the analysis. O.A. and O.K.A. extensively contributed to the literature review. O.A., P.G.O., and O.D.O. collected the data. O.A., P.G.O., F.G., and S.B.A. performed the analysis. O.A., P.G.O., F.G., O.D.O., S.B.A., O.K.A., A.O. and O.L. contributed to the writing, review, and editing of the final manuscript. The overall project was supervised by O.A.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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