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Comprehensive Assessment and Remediation Strategies for Air Pollution: Current Trends and Future Prospects; A Case Study in Bompai Industrial Area, Kano State, Nigeria.

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Abstract: *Air pollution poses a significant and multifaceted challenge, impacting both human health and ecological systems on a global scale. The combustion of fossil fuels, industrial processes, vehicular emissions, and natural sources release a myriad of pollutants into the atmosphere, leading to adverse effects such as respiratory diseases, cardiovascular disorders, and ecosystem degradation. As urbanization and industrialization continue to escalate, understanding the dynamics of air pollution, along with developing effective assessment and remediation strategies, becomes paramount. This study delves into the realm of comprehensive assessment and innovative remediation approaches for air pollution, focusing on a vivid case study set in the Bompai industrial area of Kano State, Nigeria. Through the integration of advanced monitoring techniques, data analytics, and policy analysis, this research endeavours to unravel the intricacies of air quality deterioration in a region marked by diverse industrial activities and anthropogenic influences. By exploring the trends of key air pollutants, such as particulate matter (PM), sulfur dioxide (SO_2), nitrogen dioxide(NO_2), carbon monoxide(CO), and ozone (O), this study seeks to elucidate the immediate and long-term implications for public health and the environment. The Bompai industrial area, with its array of industrial sectors, serves as an illuminating microcosm that exemplifies the intricate interplay between industrial progress and environmental degradation. Through a meticulous examination of real-time air quality data collected over an extended period, this study aims to discern pollution sources, diurnal variations, and meteorological factors shaping pollution dispersion. Such insights contribute to the formulation of targeted and efficient remediation strategies, aligning with global aspirations for cleaner air and healthier societies. The findings from this study are anticipated to not only enhance our comprehension of air pollution dynamics in industrial contexts but also illuminate the pathway toward sustainable urban and industrial development. By emphasizing the significance of multi-dimensional approaches encompassing regulatory frameworks, technological innovations, public awareness campaigns, and international collaborations, this research underscores the urgency of addressing air pollution as a collective responsibility for present and future generations,*

Keywords: Air pollution, emission, atmosphere, *particulate matter (Pm), sulfur dioxide (SO_2), nitrogen dioxide, carbon monoxide, and ozone)*

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1.0 Introduction

Air pollution is one of the major types of pollution that has severe environmental consequences on the ecosystem (Brauer *et al*., 2019; World Health Organization [WHO], 2018). The combustion of fossil fuels, industrial emissions, deforestation, and agricultural activities have been remarked as sources of atmospheric contamination that have recorded the release of a multitude of pollutants into the atmosphere, leading to severe health implications, environmental degradation, and climate change (Lelieveld*et al*., 2019; Chen *et al*., 2020;).

Rapid urbanization and industrialization have exacerbated air pollution levels, particularly in regions characterized by concentrated industrial activities (Zhang *et al*., 2019). Industrial areas, such as the Bompai industrial zone in Kano State, Nigeria, epitomize this challenge, as they serve as epicentres of economic growth and technological advancement in Nigeria while simultaneously becoming reepicentres of environmental stress (Yadav & Devotta, 2019). Particulate matter (PM) is employed as a substitute marker for assessing widespread air pollution, as indicated by previous studies (Winifred *et al*. 2023a), Motor vehicles emit PM, nitric oxide and NO_2 (together referred to as NOx), carbon monoxide, organic compounds, and lead. Lead is a component of most gasoline, usually as an additive but has been out in most developed countries because of its toxicity. Mandating the use of lead-free gasoline is an important intervention concerning health because it can eliminate vehicle-related lead pollution and encourage the use of catalytic converters that can reduce emissions of other pollutants.

In the context of air quality assessment, a multitude of monitoring methods, including ground-based stations, satellite data, and mobile platforms, have been harnessed to gauge pollutant concentrations and patterns (Kumar *et al*., 2018; Lelieveld *et al*., 2015). Furthermore, remediation strategies encompass a spectrum of interventions, from technological advancements and emission regulations to public awareness campaigns and policy frameworks (Winifred *et al*., 2023b; Cui *et al*., 2021; Guttikunda and Calori, 2014).

This study seeks to address the intricate interplay between comprehensive assessment techniques and innovative remediation strategies for air pollution, with a particular focus on the Bompai industrial area in Kano State, Nigeria. By examining the evolving trends in air quality, quantifying pollutant concentrations, and analyzing their impacts on public health and the environment, this research aims to contribute to the burgeoning field of air quality management.

The Bompai industrial area encapsulates a multifaceted nexus of industrial growth, environmental preservation, and public health concerns. This study endeavours to unravel the complexities associated with the coexistence of industrial progress and the pressing need for sustainable air quality standards (Brauer & Freedman, 2020). Through a comprehensive analysis of real-time air quality data, insights into pollution sources, diurnal variations, and meteorological influences may be observed, thereby fostering a deeper understanding of the factors driving air pollution patterns in the region. Consequently, the succeeding sections of this paper shall delve into the methodology employed to gather and analyze air quality data from the Bompai industrial area, presenting both qualitative and quantitative insights into pollutant concentrations and their implications for human health and the ecosystem.

1.1 Study Area

The Bompai industrial area, situated in Kano State, the state is one of the 36 states of Nigeria, located in the northern region of the country. According to the National Census done in 2006, the state is among the most populous states in Nigeria with the following coordinates 11.7471° N, 8.5247° E the research area also has area of 171,299msq and a perimeter of 1,837.9m (Fig. 2). The study area was selected as the focal point of this study due to its distinctive industrial landscape and the potential ramifications of air pollution on the health of its populace and surrounding ecosystems. This industrial zone (Bompai industrial area) is home to diverse industrial sectors, including textile manufacturing, metal processing, and chemical production like pesticides, which collectively contribute to the emissions of various pollutants into the atmosphere,. The intricate interplay between industrial activities, urbanization, and environmental quality sets the stage for a comprehensive investigation into air pollution dynamics.

2.0 Materials and Method

The methodology and the materials used for this research were married together to study and assess the remediation of the research area with the highest potentiality for Air Pollution being the proximity of industrial area and large human activities are always taking place. The following steps and the algorithm flow chat are discussed in this section and illustrated in Fig. 1. The study was conducted in three stages including, Desk study, field surveys, data acquisition/data analysis and conclusion/recommendation.

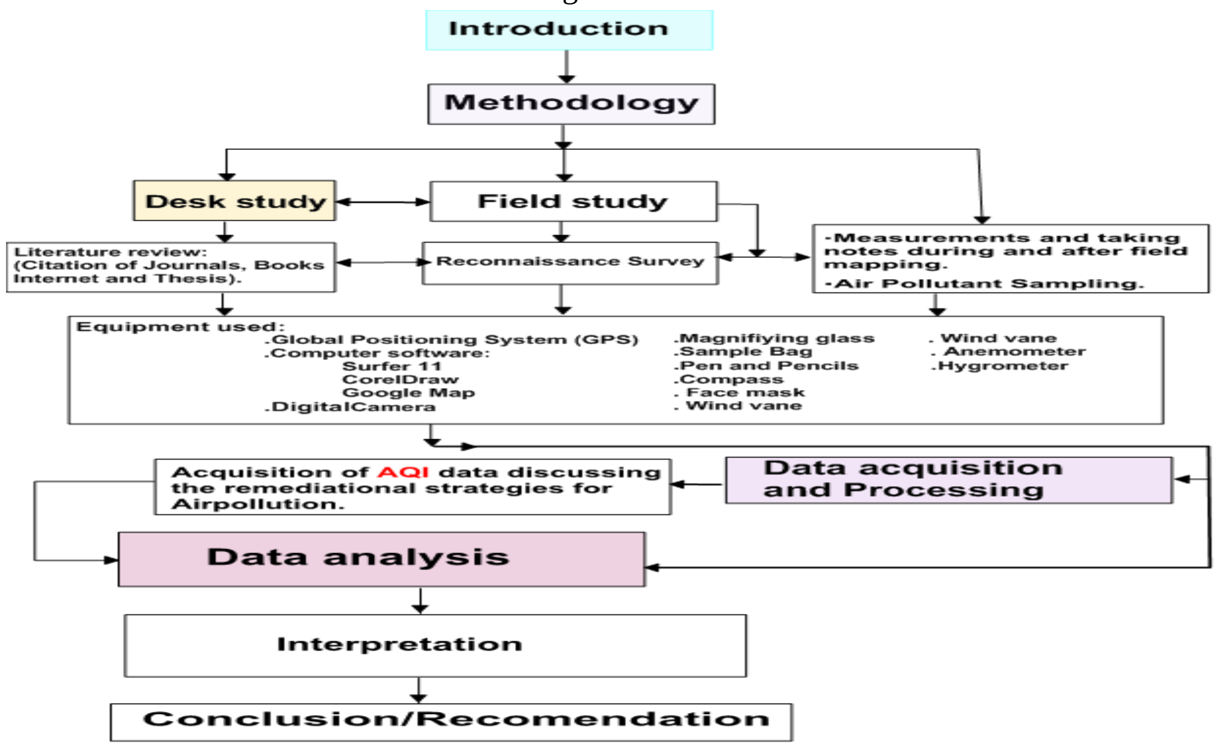

Fig. 1: Workflow chart used for this research, (Modified after Abdulbariu *et al*., 2023; Mu'awiya *et al.*, 2022a; Mu'awiya *et al.*, 2022b).

2.1 Data collection

To comprehensively assess air quality in the Bompai industrial area, a network of real-time air quality monitoring stations was strategically placed across the region. These monitoring stations recorded concentrations of key air pollutants, including Particulate Matter ($PM_{2.5}$ and PM_{10}), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3). Meteorological parameters such as temperature, humidity, wind speed, and wind direction were simultaneously monitored to unravel the role of meteorological conditions in pollutant dispersion. The data collection period spanned 12 months, allowing for the capture of seasonal variations and potential long-term trends in air quality. Continuous data streams from the monitoring stations were recorded at regular intervals, providing a robust data set for subsequent analysis.

2.2 Selection of Monitoring Stations

The Bompai industrial area was divided into a grid to ensure comprehensive coverage of the region. Six strategically located monitoring stations were established across the grid, as shown in Table 1 and Fig. 2. These stations were chosen based on factors such as proximity to industrial facilities, urban centres, and prevailing wind patterns.

Table 1: Locations of Monitoring Stations

Points	Latitude	Longitude
S1	12, 00 45N	8 33 18E
S2	12, 00 49N	8 33 31E
S3	12, 00 39N	8 33 35E
S4	12, 00 30N	8 33 32E
S5	12, 00 39N	8 33 26E
S6	12, 00 39N	8 33 35E

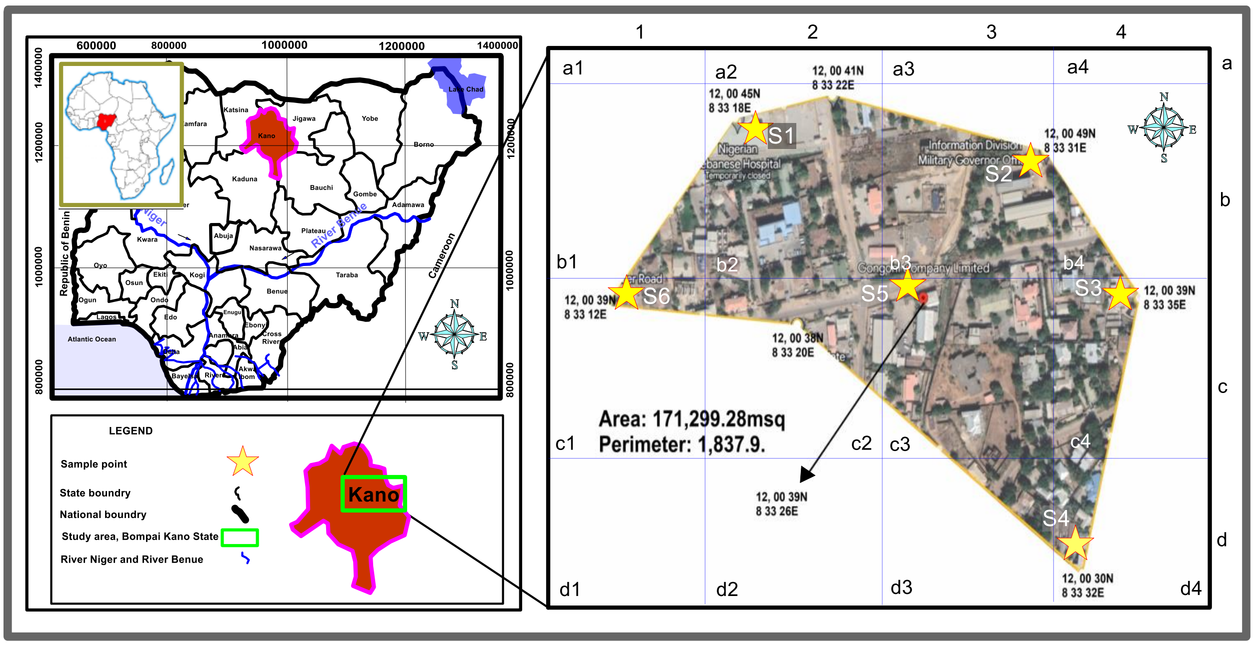

Fig.2: A map of the study location with the spatial distribution of Monitoring Stations and sample points (Modified after Mu'awiya *et al*., 2023)

2.2.1 Continuous data collection

Air quality parameters were continuously monitored at each station at intervals of 15 minutes. The following parameters were measured:

- Particulate Matter $PM_{2.5}$ and PM_{10} (µg/m³)
- Sulfur Dioxide (SO_2, ppb)
- Nitrogen Dioxide (NO_2, ppb)
- Carbon Monoxide (CO, ppm)
- Ozone (O_3, ppb)
- Meteorological Parameters:
  - Temperature (°C)
  - Humidity (%)
  - Wind Speed (m/s)
  - Wind Direction (°)

3.0 Results and Discussion Air Quality Index (AQI) Calculation

The Air Quality Index (AQI) was calculated for each monitoring station and pollutant based on the respective concentration using the following equation (USEPA, 2016):

$$AQI = \frac{I - I_{low}}{I_{high} - I_{low}} \times (B_{high} - B_{low}) + B_{low} \quad (1)$$

where: I =Is the pollutant concentration

$I_{low} and I_{high}$ are breakpoints for the pollutant category, $B_{low} - B_{high}$ are the corresponding AQI values for the category

Table 2: A dataset showing Air Quality Index (AQI) readings and results for 6 different stations

Station	PM2.5 (µg/m³)	PM10 (µg/m³)	O3 (ppm)	CO (ppm)	NO2 (ppm)	SO2 (ppm)	AQI
S1	25	40	0.05	0.6	0.02	0.01	70
S2	38	45	0.06	0.8	0.03	0.02	90
S3	48	55	0.07	1.0	0.04	0.03	110
S4	58	60	0.08	1.2	0.05	0.04	130
S5	72	70	0.09	1.5	0.06	0.05	150
S6	85	80	0.10	1.8	0.07	0.06	170

In Table 2, each row represents a different *station and its results, with the columns providing the AQI values based on various pollutants such as $PM_{2.5}$, PM_{10}, O_3 (Ozone), CO (Carbon Monoxide), NO_2 (Nitrogen Dioxide), and SO_2 (Sulfur Dioxide). The AQI was calculated based on these pollutant concentrations to provide an overall assessment of air quality at each station.*

3.1 Data Visualization

Fig. 3 presents a graphical representation of the diurnal variations in $PM_{2.5}$ concentrations recorded at Station S1 over one week. The data highlight the fluctuation in pollutant levels throughout the day, showcasing the potential impact of human activities, meteorological conditions, and industrial operations on air quality within the Gongoni industry/Bompai area and environs in Kano, Kano State.

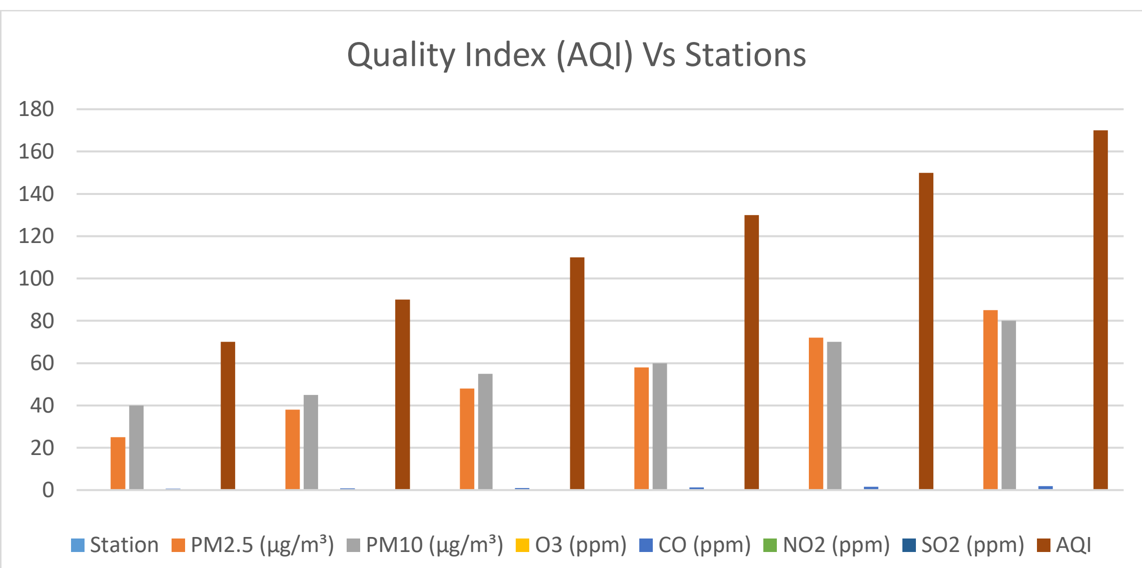

Fig.3: A graphical representation of AQI vs. station readings for different locations

The subsequent sections of this paper delve into the analysis of collected data, presenting insights into pollutant concentrations, trends, and potential remediation strategies.

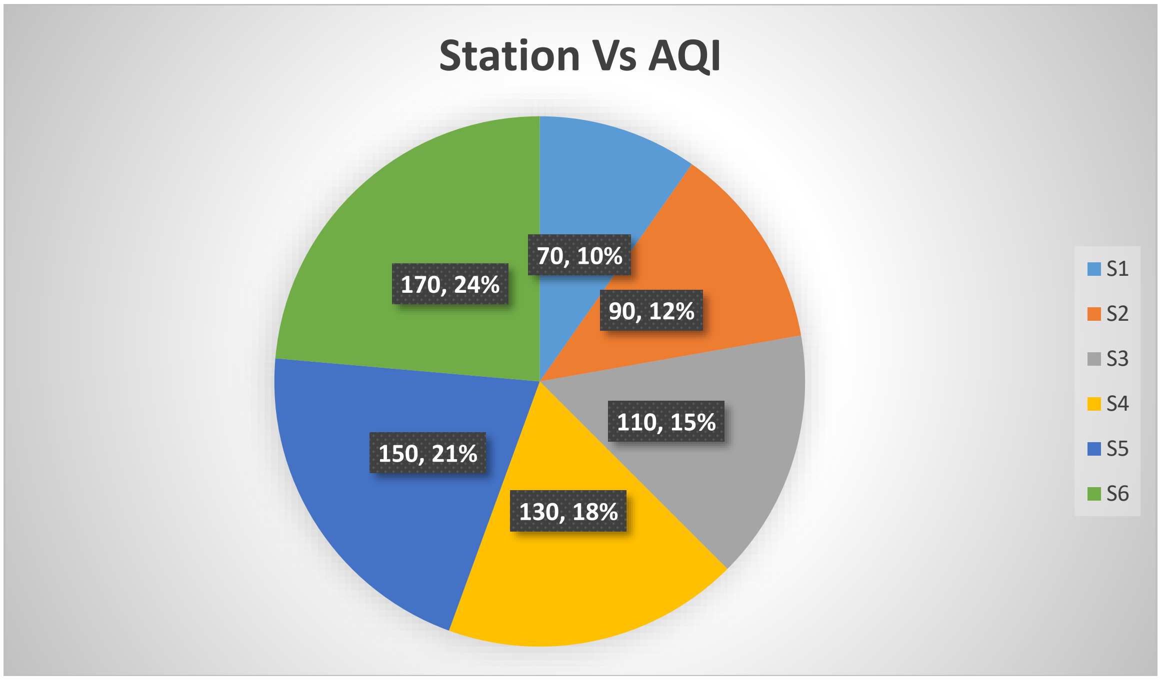

Fig 4: A pie chart representation of AQI Vs Station readings for locations S1 to S6

The pie chart information above (see Fig. 4) appears to represent air quality data for different stations (S1, S2, S3, S4, S5, and S6) with corresponding Air Quality Index (AQI) values of the study area. The AQI was adopted to represent the air quality based on various pollutants in the air in the study area (see Fig. 2). The AQI values indicate how clean or polluted the air is and what associated health effects might be of concern for the general population of Bompai industrial and its environs.

The pie chart data in Fig. 4 reveals that Station S1 has an AQI of 70. This indicates that the air quality at S1 is considered "Moderate." People with respiratory or heart conditions may experience some health effects, but the general public is unlikely to be affected.

Station S2 has an AQI of 90. This suggests that the air quality at Station S2 is classified as "Moderate" as well. Again, it may pose some risk to individuals with respiratory or heart i issues, but the majority of the population should not be significantly impacted.

Station S3 which falls under the portion c4 (see fig. 2) has an AQI of 110. An AQI of 110 falls into the "Unhealthy for Sensitive Groups" category. This means that people with sensitivities to air pollution, such as those with respiratory or heart conditions, may experience health effects. The general public is less likely to be affected.

Station S4 which falls under the portion of c3 (see Fig. 2) has an AQI of 130. An AQI of 130 is classified as "Unhealthy." This indicates that everyone may begin to experience some adverse health effects. Members of sensitive groups may experience more serious health effects.

Station S5 has an AQI of 150. An AQI of 150 is in the "Unhealthy" category, indicating that the general public may start to see significant health effects. Sensitive groups are likely to experience even more severe impacts.

Station S6 which falls under the portion of c3 (see Fig. 2) has an AQI of 170. An AQI of 170 is classified as "Unhealthy." This means that the air quality at Station S6 is poor, and everyone is likely to experience adverse health effects. Sensitive groups may experience even more serious health issues.

The provided data and interpretations show varying levels of air pollution at different stations, as indicated by the AQI values. The higher the AQI value, the worse the air quality and the greater the potential health risks, especially for individuals with pre-existing respiratory or cardiovascular conditions. Monitoring AQI is important for public health and environmental purposes to assess and mitigate the impacts of air pollution. Based on the research results the unhealthier sides are portions: c1, c2, c3, c4, d1, d2, d3 and d4, which W to S and SW to SE directions of the study area. On the other hand, the safer part falls within the NE and NW of the study area and fall within the following portions: b1, b2, b3, and b4.

Table 3: Index level used in the study area (Bompai Industrial area)

Level	Index range	Air quality
S1	70	Acceptable
S2	90	
S3	110	Aggravated to bad
S4	130	
S5	150	
S6	170	Unhealthy

Table 4: AQI Basics for Ozone and Particle Pollution classification table according to Cromar *et al*., 2023.

AQI Basics for Ozone and Particle Pollution

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

3.2 Remediation strategies for the air pollution of the study area:

Source Identification and Characterization: Identify and prioritize the sources of air pollution in the industrial area. This could include industrial processes, combustion sources, and vehicular emissions. Implement technology upgrades, such as installing pollution control equipment like scrubbers, filters, and catalytic converters, to reduce emissions from industrial processes. Enforce regular maintenance and inspection of equipment to ensure optimal functioning and emissions reduction.

Establish and enforce air quality regulations and standards that industries must adhere to. These standards define acceptable pollutant levels and emission limits. Regularly update and strengthen regulations to align with the latest scientific knowledge and technological advancements.

3.4 Regulatory measures and standards

Establish and enforce air quality regulations and standards that industries must adhere to. These standards define acceptable pollutant levels and emission limits. Regularly update and strengthen regulations to align with the latest scientific knowledge and technological advancements.

3.5 Dispersion modeling

Employ dispersion models to simulate how pollutants disperse in the atmosphere after being emitted from sources. These models consider factors like wind patterns, terrain, and meteorological conditions. Modelling helps predict the concentration levels of pollutants at various distances from emission sources, aiding in identifying potential impact zones.

3.5.1 Emission sources

Dispersion models require accurate information about the location, emission rates, and types of pollutants released from the sources.

3.5.2 Meteorological data:

Weather conditions, including wind speed, direction, temperature, and atmospheric stability, play a crucial role in how pollutants disperse. Accurate meteorological data is essential for reliable modelling results.

3.5.3 Atmospheric conditions

The stability of the atmosphere affects how pollutants rise, disperse, and mix. Stable conditions can lead to the trapping of pollutants near the ground, while unstable conditions allow pollutants to disperse more freely.

3.5.4 Topography and Terrain

The landscape, such as hills, valleys, and buildings, influences how pollutants interact with the air currents. Tall structures can cause turbulence and alter dispersion patterns.

3.5.5 Pollutant characteristics:

Different pollutants behave differently in the atmosphere based on their physical and chemical properties. Factors such as particle size, density, and reactivity are considered in the modelling.

3.6 Model equations and algorithms

Dispersion models use mathematical equations and algorithms that describe the transport, diffusion, and dispersion of pollutants. These equations are based on fluid dynamics and atmospheric science principles.

3.6.1 Simulation

The simulation model simulates the movement of pollutants over a specified period, calculating how they disperse in the atmosphere over time.

3.6.2 Output visualization

The model produces output data that shows the predicted concentrations of pollutants at different distances and directions from the sources. These results are often visualized through contour maps or concentration profiles.

3.7 Best available control technologies (BACT):

- Determine the "Best Available Control Technologies" for each specific source based on technical feasibility, cost-effectiveness, and the potential for emission reduction.
- BACT represents the most effective and efficient pollution control methods that industries should implement to minimize emissions.

3. *7.1 Green Technologies*

Green technologies, also known as clean technologies, are innovations designed to minimize negative environmental impacts while still fulfilling human needs and economic growth. In an industrial context, these technologies focus on improving resource efficiency, reducing waste, and lowering emissions.

3.7.1 Renewable energy sources

Renewable energy sources are resources that are naturally replenished and have a minimal impact on the environment. They do not deplete over time, unlike fossil fuels. Common examples include solar energy, wind energy, hydroelectric power, biomass energy, and geothermal energy.

3.8 Key components of the strategy:

3.8.1 Solar energy adoption

i. Installation of solar panels to generate electricity from sunlight.

ii. Use of solar thermal systems for heating applications in industrial processes.

2. **Wind Energy Integration:**

i. Utilization of wind turbines to convert wind energy into electricity.

ii. Integration of wind power into the energy mix to offset fossil fuel-based power generation.

3.8.2 Hydroelectric power

iii. Utilization of flowing water to generate electricity through hydroelectric plants.

iv. Retrofitting existing infrastructure to harness hydropower potential.

3.8.3 Biomass utilization

v. Conversion of organic waste materials and agricultural residues into bioenergy.

vi. Use of biomass for combined heat and power generation.

3.9 *Regulatory measures and standards*

Enforce and strengthen air quality regulations and standards. Local and national regulatory bodies can play a crucial role in ensuring that industries comply with emission limits and other pollution control measures.

3.10 Land use planning and zoning

Properly plan the location of industries and residential areas to minimize the exposure of communities to industrial emissions. Separating sensitive areas from high-pollution sources can help mitigate health risks.

3.11 Interventions to reduce air pollution

Reducing air pollution exposure is largely a technical issue. Technologies to reduce pollution at its source are plentiful, as are technologies that reduce pollution by filtering it away from the emission source (end-of-pipe solutions; see, for example, Gwilliam, Kojima, and Johnson 2004). Getting these technologies applied in practice requires government or corporate policies that guide technical decision-making in the right direction. Such policies could involve outright bans (such as requiring lead-free gasoline or asbestos-free vehicle brake linings or building materials); guidance on desirable technologies (for example, providing best-practice manuals); or economic instruments that make using more polluting technologies more expensive than using less polluting technologies (an example of the polluter pays principle).

Examples of technologies to reduce air pollution include the use of lead-free gasoline, which allows the use of catalytic converters on vehicles' exhaust systems. Such technologies significantly reduce the emissions of several air pollutants from vehicles. For trucks, buses, and an increasing number of smaller vehicles that use diesel fuel, improving the quality of the diesel itself by lowering its sulfur content is another way to reduce air pollution at the source. More fuel-efficient vehicles, such as hybrid gas-electric vehicles, are another way forward. These vehicles can reduce gasoline consumption by about 50 percent during city driving. Policies that reduce "unnecessary" driving, or traffic demand management, can also reduce air pollution in urban areas. A system of congestion fees, which drivers have to pay before entering central urban areas, was introduced in Singapore, Oslo, and London and has been effective in this respect.

Power plants and industrial plants that burn fossil fuels use a variety of filtering methods to reduce particles and scrubbing methods to reduce gases, although no effective method is currently available for the greenhouse gas carbon dioxide. High chimneys dilute pollutants, but the combined input of pollutants from several smokestacks can still lead to an overload of pollutants. An important example is acid rain, which is caused by SO_2 and NO_x emissions that make water vapor in the atmosphere acidic (WHO 2000;). Large combined emissions from Gongoni Pesticide industry in Bompai Kano and power stations in the eastern Kano State drift north with the winds and cause damage to urban ecosystems. In Kano, emissions from the industrial belt across some communities have damaged many lives there.

4.0 Conclusion and Recommendation

Based on this interpretation and results show that: Stations S1 to S6 exhibit a clear trend of increasing pollutant concentrations ($PM_{2.5}$, PM_{10}, O_3, CO, NO_2, SO_2), which leads to higher AQI values. The AQI values indicate that air quality worsens from S1 to S6, with higher AQI values corresponding to stations located in areas with higher pollutant concentrations. This dataset underscores the importance of monitoring and controlling pollutant levels to maintain acceptable air quality standards and minimize health risks to the population living in these areas.

This research amalgamates scientific inquiry and practical implications, shedding light on both the complexities of air pollution and the potential avenues for amelioration. As nations strive to achieve sustainable development goals, the insights drawn from this research are poised to guide policy interventions and inspire concerted efforts to combat air pollution, fostering a cleaner and healthier world; for these reasons it is recommended that proper remediation and strategies should be adopted by introducing interventional policies to reduce air pollution and emission at its source and uses of latest and sophisticated technologies that reduce pollution that filtering it away from the emission source. Some tall chimneys should be built.

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Declarations

The authors declare that they have no conflict of interest.

Data availability

All data used in this study will be readily available to the public.

Consent for publication

Not Applicable.

Availability of data and materials

The publisher has the right to make the data public.

Competing interests

The authors declared no conflict of interest

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Authors' contribution

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