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Systematic Review
Air Quality Challenges, Health Burden, Monitoring Technologies and Policy Responses in Low- and Middle-Income Countries: A Systematic Review with Perspectives from Nigeria

[1]Francis Olawale Abulude, [2]Julius Gbemiga Oyetunde and [3]Juliet Akudo Mbabie

[1]Environmental and Sustainable Research Group, Science and Education Development Institute, Akure, Ondo State, Nigeria
[2]Department of Chemical Sciences, Bamidele Olumilua University of Education, Science and Technology, Ikere-Ekiti, Ekiti State, Nigeria
[3]Chemistry Advanced Research Centre, Sheda Science and Technology Complex, Abuja, Nigeria

Abstract
One of the biggest threats to the environment and human health in the twenty-first century is still air pollution. This systematic review aimed to synthesize evidence on air quality challenges, health impacts, monitoring technologies and policy responses in low- and middle-income countries, with a particular focus on Nigeria. Significant differences in air quality monitoring capabilities still exist despite growing awareness, especially in Africa, where monitoring networks are still few. The years between 2014 and 2026 were the main focus of the search; PubMed, Scopus, Web of Science, ScienceDirect and Google Scholar databases were used, following the PRISMA 2020 framework. The main air contaminants, emission sources, health effects, monitoring methods and policy initiatives are all summarized in this overview. Emerging low-cost sensor technologies and their uses in environments with limited resources are given particular focus. Research shows that incorporating low-cost sensors, citizen science, satellite data and regulatory frameworks can significantly enhance air quality management. Through improved monitoring infrastructure, data-driven policy execution, public awareness and regional cooperation, the assessment also identifies the potential to increase Nigeria's air quality governance. The results add to the expanding conversation about environmental justice, public health protection and sustainable urban development in developing nations. Strengthening integrated monitoring systems, expanding low-cost sensing networks and enforcing evidence-based policies are essential for improving air quality and reducing pollution-related health burdens in LMICs.

Key words: Nigeria, low-cost sensors, public health, air pollution, $PM_{2.5}$ Governance of the environment

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Corresponding Author: Francis Olawale Abulude, Environmental and Sustainable Research Group, Science and Education Development Institute, Akure, Ondo State, Nigeria

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INTRODUCTION

In the twenty-first century, one of the most important environmental and public health issues is air quality[1]. The quality of the air people breathe is becoming more and more threatened by emissions from transportation systems, industrial operations, energy generation, agricultural practices and domestic fuel consumption as nations continue to urbanize and industrialize. Nowadays, air pollution is present in almost every part of the world and is a significant risk factor for illness, early death and a lower standard of living. Although the issue is widespread, low- and middle-income countries (LMICs) are disproportionately affected because of their rapid population growth, lax environmental regulations, inadequate monitoring infrastructure and pervasive reliance on polluting energy sources, all of which contribute to serious air quality problems[2].

Because it supplies oxygen for breathing and controls climatic processes, the atmosphere is an essential part of the Earth's life support system. However, the discharge of pollutants such as particulate matter (PM), nitrogen oxides (NOx), sulfur dioxide (SO_2), carbon monoxide (CO), volatile organic compounds (VOCs) and ground-level ozone (O_3)[3] has significantly changed the composition of the atmosphere due to human activity. These pollutants come from a variety of sources, such as automobiles, power plants, industrial processes, burning of biomass, incineration of garbage and cooking at home. Air quality standards are further deteriorating in many developing nations due to emissions from open garbage burning and informal economic activity[4].

Because fine particulate matter ($PM_{2.5}$) can enter the bloodstream and penetrate deeply into the respiratory system, it has garnered significant scientific attention among the many air contaminants. Respiratory conditions, cardiovascular ailments, neurological impairments, poor pregnancy outcomes and early mortality have all been associated with exposure to $PM_{2.5}$. According to estimates from the World Health Organization (WHO), both ambient and home air pollution are responsible for millions of deaths each year, making air pollution one of the major environmental determinants of health[5]. Long-term exposure to air pollution is linked to chronic illnesses, medical expenses and financial losses that jeopardize sustainable development initiatives, according to new research.

The burden of air pollution is not shared equally by all demographic groups. Pregnant women, older persons, urban dwellers, youngsters and people with pre-existing medical issues are especially susceptible to the negative effects of air pollution. Due to their developing immune systems and lungs, children are particularly vulnerable to respiratory infections and long-term health issues. Similarly, because they are closer to sources of pollution and have less access to healthcare services, low-income populations frequently have higher levels of exposure[6]. As a result, air pollution is now a social justice and equality issue in addition to an environmental one.

Alarming trends in the deterioration of air quality have been identified by recent global studies[7]. Many LMICs still have pollution levels that are higher than advised health-based norms, despite improvements in certain high-income nations brought about by strict environmental laws and technological developments. The WHO Global Air Quality Guidelines, which were published in 2021, drastically lowered the recommended exposure limits for main pollutants in response to mounting evidence that harmful health consequences might arise even at relatively low concentrations. The necessity of putting into practice efficient air quality management techniques globally is highlighted by these updated guidelines.

The problems of urbanization, climate change, energy access and sustainable development are all directly related to the problem of air pollution. Energy consumption, industrial growth and transportation demand have all increased as a result of the rapid urbanization of many emerging regions. Inadequate planning and infrastructure have frequently led to uncontrolled industrial emissions, clogged transportation networks and ineffective waste management systems. All of these elements work together to raise the concentrations of pollutants in metropolitan areas. Furthermore, a lot of air pollutants have origins in common with greenhouse gases, which opens up possibilities for integrated policies that address both mitigating climate change and improving air quality.

Over the past ten years, academics and policymakers in Africa have paid more attention to air pollution[8]. However, because long-term monitoring data is still scarce, there are still large knowledge gaps. Africa has comparatively few air quality monitoring networks as compared to Europe, North America and portions of Asia, which makes it challenging to precisely determine exposure levels and related health risks[9,10]. The creation of evidence-based environmental policies and initiatives has historically been hampered by this monitoring shortfall. However, by offering different methods for data collecting and analysis, current developments in low-cost sensing technologies, satellite remote sensing and atmospheric modeling have started to change air quality studies throughout the continent.

In the African environment, Nigeria is a particularly significant case study. Nigeria, the most populous nation in Africa and one of the biggest economies on the continent, is confronted with a number of environmental issues related to fast urbanization, industrialization, the expansion of transportation and energy instability. Particulate matter and gaseous pollutants are often found in high quantities in major cities like Lagos, Port Harcourt, Kano, Ibadan and Abuja. Vehicle emissions, industrial processes, petroleum refining, gas flaring, diesel generator use, burning of biomass and open waste burning are some of the sources of pollution. Urban air pollution is made worse by the widespread reliance on private electrical generators brought on by an unpredictable power supply.

Pollutant concentrations above WHO guidelines have been observed in a number of investigations carried out in Nigerian cities, raising concerns about possible public health repercussions[11,12]. Household air pollution is still a significant problem in addition to ambient air pollution, especially in rural and peri-urban areas where traditional biomass fuels are frequently used for heating and cooking. Limited monitoring infrastructure, disjointed regulatory frameworks and little public knowledge of the health consequences of poor air quality exacerbate these issues. As a result, thorough evaluations that summarize the available data and point the way toward more efficient air quality control are desperately needed.

Technological developments in monitoring have opened up new avenues for resolving some of these issues. The gold standard for assessing air contaminants is still traditional reference-grade monitoring stations, but their high acquisition and maintenance costs sometimes prevent deployment in environments with limited resources. Low-cost sensors have surfaced as viable substitutes in recent years that can support citizen science projects and increase monitoring coverage. These technologies provide previously unheard-of chances to produce high-resolution air quality data when paired with satellite observations and machine learning approaches, especially in areas with inadequate monitoring infrastructure.

As worries over air pollution have grown, policy measures have also changed[13]. To lower emissions and safeguard public health, governments, international organizations and environmental agencies have implemented several initiatives. These include waste management reforms, vehicle emissions standards, industrial restrictions, fuel quality improvements, renewable energy promotion and public awareness programs. However, due to variations in institutional frameworks, economic resources, governance capabilities and enforcement mechanisms, the efficacy of these initiatives varies widely across nations. It is crucial to comprehend these differences in order to determine optimal practices and guide the creation of future policies.

A thorough synthesis of current information is both pertinent and essential, given the growing acknowledgment of air pollution as a significant environmental and public health concern. There is a need for more comprehensive evaluations that incorporate these aspects into a single framework because previous studies have frequently concentrated on particular contaminants, geographical areas, health consequences, or monitoring techniques. Additionally, only a small number of systematic evaluations have highlighted the lessons learned from the Nigerian experience while specifically examining the particular opportunities and problems related to air quality management in LMICs[14,15].

Thus, with a focus on Nigeria in particular, this systematic review attempts to critically assess the present level of knowledge about air quality challenges, health impacts, monitoring technology and policy responses in low- and middle-income countries. In particular, this review aims to identify the major sources and emerging trends of air pollution, examine the documented health effects associated with pollutant exposure, assess both traditional and emerging technologies for air-quality monitoring, evaluate governance and policy responses aimed at improving air quality and identify key research gaps and future directions for sustainable air-quality management. This assessment supports ongoing initiatives to improve public health protection, increase environmental governance and encourage sustainable development in rapidly urbanizing areas by combining data from several disciplines.

Research questions: The following queries served as a guide for the review:

1. What are the main causes and patterns of air pollution in LMICs?
2. What health consequences are linked to ambient air pollution exposure?
3. Which monitoring tools are currently employed to evaluate the quality of the air?
4. In comparison to traditional monitoring systems, how successful are new low-cost sensor technologies?
5. What governance and policy measures have been put in place to deal with air pollution?
6. What can be learned to help Nigeria and other developing nations manage their air quality better?

MATERIALS AND METHODS

Review design: The Preferred Reporting Items for Systematic Reviews and Meta-Analyses[16] (PRISMA 2020) framework was used as the basis for this study's systematic review methodology. The systematic review approach was chosen because it offers a clear, exacting and repeatable process for locating, assessing and combining available data. A systematic review (publications between 2014 and 2026) provides an efficient way to incorporate findings from several domains into a cohesive body of knowledge, since air quality research is multidisciplinary and includes environmental science, public health, atmospheric chemistry, engineering and policy studies.

With special attention to data from Nigeria and other African nations, the evaluation concentrated on air quality issues, health consequences, monitoring technology and policy responses in Low- and Middle-Income Countries (LMICs). The evaluation aimed to evaluate new monitoring techniques, highlight significant trends in air pollution research and appraise policy initiatives intended to enhance air quality and safeguard public health.

Search strategy: Comprehensive searches in Scopus, Web of Science, PubMed, ScienceDirect and Google Scholar were used to find pertinent material. These databases were chosen due to their comprehensive coverage of public policy literature, atmospheric science, environmental engineering and environmental health. Peer-reviewed publications released between 2014 and 2026 were the main focus of the search. This time frame was chosen to document new advancements in health burden evaluations, policy interventions and air quality monitoring technologies.

The search method utilized to find pertinent material for the systematic review is shown in Table 1. The table shows that in order to guarantee thorough coverage of scientific evidence, several databases were searched. Large collections of peer-reviewed literature in environmental science, public health, atmospheric chemistry, engineering and policy studies can be found in Scopus, Web of Science, PubMed and ScienceDirect. Four theme categories were created using specific search terms.

Keywords for air quality: These words encompassed research on air pollution, such as keywords related to health: Air pollution, air quality, ambient pollution.

These terms focused on research examining the effects on health: Cardiovascular disease, respiratory illness and health burden.

Monitoring keywords: Studies concentrating on measurement technology were identified by these terms: Satellite monitoring, inexpensive sensors and air quality monitoring.

Keywords for policy: Governance and intervention research were the focus of these terms: Environmental governance and air quality policy.

Lastly, geographical keywords like "Africa", "Nigeria", "LMICs" and "developing countries" made sure that the evaluation included information pertinent to areas with inadequate monitoring systems and escalating pollution problems. To improve the overall quality and thoroughness of the evaluation, the search strategy was designed to maximize both sensitivity (collecting as many relevant studies as possible) and specificity (excluding irrelevant studies).

Inclusion and exclusion criteria: To ensure consistency and quality, predefined inclusion and exclusion criteria were established in Table 2.

Table 1: Search terms used

Theme	Search terms
Air quality	"air pollution" OR "air quality" OR "ambient pollution"
Health effects	"health burden" OR "respiratory disease" OR "cardiovascular disease"
Monitoring	"air quality monitoring" OR "low-cost sensors" OR "satellite monitoring"
Policy	"air quality policy" OR "environmental governance"
Geography	"Africa" OR "Nigeria" OR "developing countries" OR "LMICs"

Boolean operators (AND, OR) were applied to improve search sensitivity and specificity

Table 2: Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Peer-reviewed journal articles	Conference abstracts
English language publications	Non-English articles
Studies published between 2014 and 2026	Publications before 2014
Ambient air pollution studies	Indoor-only pollution studies
Human health, monitoring, or policy focus	Studies lacking relevance to the review objectives

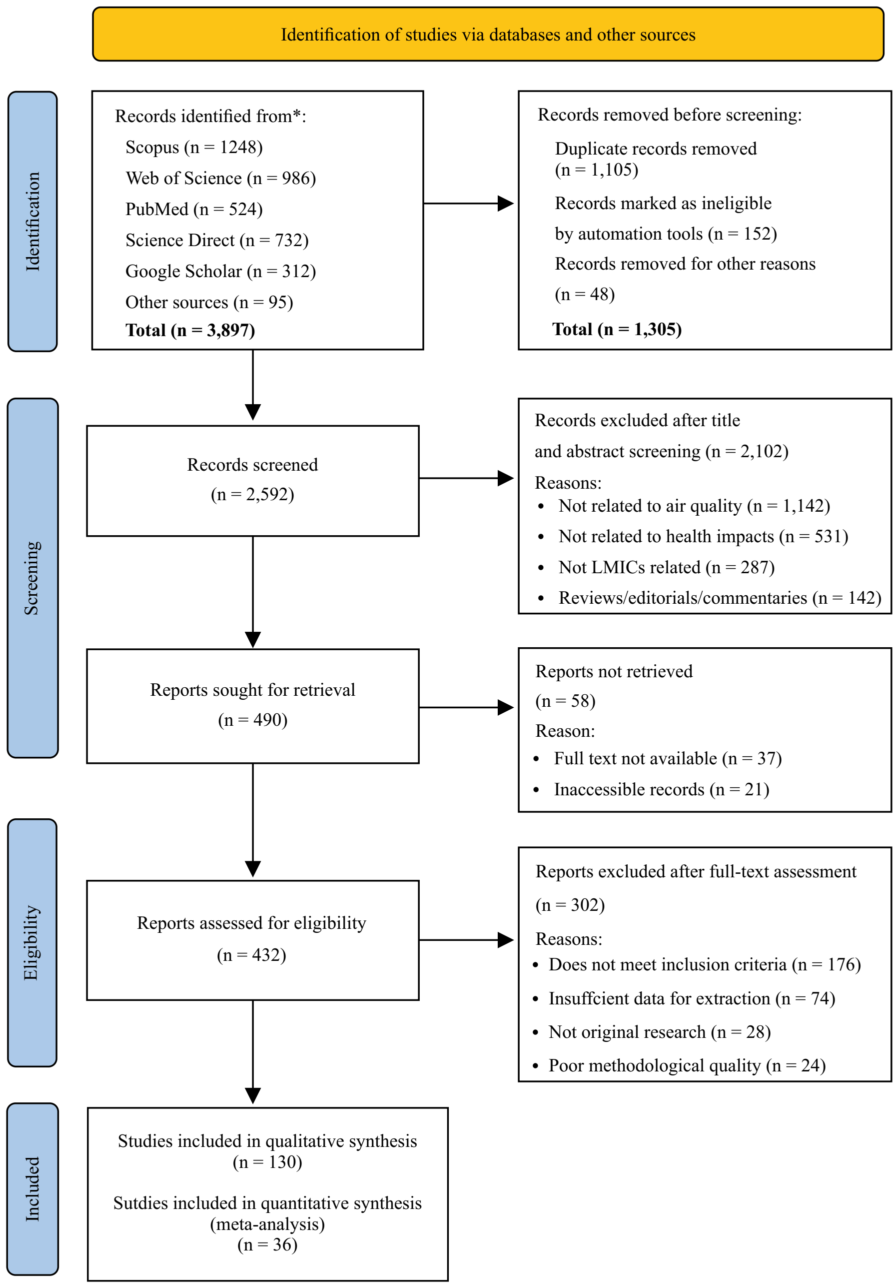

Fig. 1: PRISMA flow diagram of study selection process

Screening and selection process: Every record that was recovered was exported into a database for reference management. Duplicate records were found and eliminated. Relevance was assessed by screening abstracts and titles. After that, full-text publications were evaluated in relation to the inclusion criteria.

The methodical procedure utilized to find, filter, evaluate and choose studies for the review is depicted in Fig. 1. The PRISMA 2020 framework, which is widely acknowledged as the gold standard for reporting systematic reviews, is followed in this diagram. Four successive steps make up the figure.

Stage of identification: The total number of records obtained from significant scientific databases, including Scopus, Web of Science, PubMed, ScienceDirect, Google Scholar and others, is displayed in the first step. This phase guarantees clarity about the sources of the studies and shows the scope of the literature search.

Screening stage: The remaining papers were screened for titles and abstracts after duplicate records were eliminated.

Research was disregarded if it:

- Had nothing to do with the quality of the air
- Ignored the effects on health
- Were not carried out in LMICs
- Were review articles, editorials, or commentary pieces

This action significantly decreased the number of studies that needed in-depth evaluation.

Eligibility stage: Next, full-text copies of papers that might be pertinent were reviewed.

Articles were not included if:

- Complete texts were not accessible
- The methods were insufficient
- There wasn't enough data

Included stage: The number of papers included in the qualitative synthesis and, if relevant, the quantitative synthesis (meta-analysis) is presented in the final stage. Overall, Fig. 1 shows how the review process is transparent, rigorous and repeatable.

Quality assessment: The criteria used to assess methodological quality were modified from known standards for systematic reviews. Research was evaluated according to the following: All qualifying studies were subjected to a methodical quality evaluation procedure to guarantee that the conclusions of this review were founded on trustworthy and scientifically sound information. Evaluating the methodological rigor, validity, transparency and general trustworthiness of the research included in the evaluation was the assessment's main goal. Because studies differ greatly in terms of design, sample size, monitoring strategies, analytical techniques and reporting standards, quality assessment is a crucial part of systematic reviews. Weak or poorly constructed studies run the risk of influencing the review's overall conclusions if study quality is not assessed. Criteria derived from existing systematic review procedures and environmental health research frameworks were used to evaluate each chosen article. Six important domains were the focus of the evaluation.

Research design: The suitability of the research design was assessed. Because they offer more solid proof of exposure-response linkages, longitudinal studies, cohort studies, time-series analyses and well-structured observational studies were typically seen as more robust. Although cross-sectional studies were also included, their limitations in proving causal links led to a rigorous evaluation.

Sample size and study coverage: To produce more representative and trustworthy results, studies with bigger populations, more monitoring locations, or longer monitoring times were taken into consideration. To ascertain if the findings of small-scale studies could be applied to larger populations, they were thoroughly evaluated.

Air quality monitoring methodology: The techniques for measuring air contaminants received special attention. Research using calibrated low-cost sensors, satellite observations, reference-grade monitoring sites, or verified modeling techniques was deemed more robust than research using inadequately documented measuring techniques.

Exposure assessment procedures: The evaluation looked at how researchers calculated exposure to pollutants. Exposure assessment frameworks were typically thought to be stronger in studies that included continuous monitoring, human exposure assessments, geographic modeling, or satellite-ground data integration.

Statistical analysis: Additionally, the completeness of the reporting was evaluated. Articles were assessed according to how well they explained the study's goals, methods, monitoring tools, data processing techniques, constraints and conclusions. During the evidence synthesis process, articles that satisfied the majority of quality criteria were categorized as high-quality studies and given priority.

Data extraction and synthesis: The following information was taken from studies that qualified:

- The author or authors (Publication year)
- Study site
- Pollutants looked into
- The technology utilized for monitoring (Evaluation of health results)
- Important conclusions
- Implications for policy

To find recurrent themes and emergent patterns, a thematic synthesis approach was used. The results were divided into four major categories:

- Air pollution sources
- Effects on health
- Technologies for monitoring
- Reactions to government and policy

This method highlighted knowledge gaps that needed further research while facilitating comparative analysis across disciplines and geographical areas.

RESULTS AND DISCUSSION

Overview of included studies: Asia, Africa, Latin America, Europe and North America were among the many geographical regions represented in the final set of studies. Nonetheless, most of the research came from areas that are quickly urbanizing and where air pollution is still a significant environmental issue. The majority of research was on particulate matter ($PM_{2.5}$ and PM_{10}), which was followed by carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and ozone (O_3). The emphasis on integrated techniques that combine health assessments, exposure modeling and monitoring technologies has grown in recent publications.

MAJOR SOURCES OF AIR POLLUTION

Transportation, industrial operations, biomass combustion, energy production and garbage burning have all been repeatedly highlighted in the literature as the main causes of air pollution.

Transportation emissions: One of the biggest causes of urban air pollution in the world is still transportation. Elevated quantities of particulate matter and nitrogen oxides are caused by many factors, including rapid motorization, aging vehicle fleets, poor fuel quality and traffic congestion. Inadequate automobile pollution standards make these problems worse in many developing nations.

Industrial activities: Large amounts of particulate matter and gaseous pollutants are released by industrial processes such as manufacturing, mining, electricity generation, petrochemical refining and cement production. Localized pollution hotspots that impact nearby populations are often created by industrial clusters.

Biomass burning: In LMICs, burning biomass for agriculture, cooking and heating continues to be a significant source of emissions. Particularly in rural areas, domestic fuels including firewood, charcoal, crop wastes and animal dung are frequently utilized.

Open waste burning: In many cities with insufficient official waste management infrastructure, open burning of municipal rubbish is nevertheless common. Heavy metals, hazardous organic compounds and particulate matter are released into the atmosphere as a result of this technique.

In Low- and Middle-Income Countries (LMICs), air pollution originates from a wide range of anthropogenic and natural sources. Major contributors include household cooking with biomass fuels, open burning of solid waste and waste dumps, transportation and energy generation from coal, diesel and oil-fired power plants. Industrial activities and agricultural practices, including fertilizer application, soil tilling and manure management, also contribute substantially to air pollution. Natural sources, such as windblown dust, may further increase pollutant levels. However, the relative contribution of these sources varies by location and depends on factors such as the type of pollutant, seasonal and wind patterns, energy-use practices and the specific environmental and pollution characteristics of each region[17,18].

HEALTH EFFECTS OF AIR POLLUTION

Strong evidence connecting exposure to air pollution to negative health consequences was found in the examined literature (Table 3).

Respiratory diseases: The most commonly reported health consequences were respiratory conditions. Chronic obstructive pulmonary disease (COPD), bronchitis, asthma and decreased lung function have all been linked to long-term exposure to $PM_{2.5}$ and PM_{10}.

Cardiovascular diseases: Numerous epidemiological studies have shown correlations between air pollution and cardiovascular illnesses, including hypertension, stroke, ischemic heart disease and heart failure. Vascular dysfunction can be exacerbated by fine particles that enter the bloodstream and cause systemic inflammation.

Neurological and cognitive effects: Long-term exposure to air pollution may harm neurological outcomes, neurodegenerative illnesses and cognitive decline, according

Table 3: Health impacts associated with major air pollutants

Pollutant	Main sources	Biological mechanism	Reported health effects
$PM_{2.5}$	Vehicles, biomass burning and industry	Oxidative stress and inflammation	Asthma, COPD, stroke and cardiovascular diseases
PM_{10}	Dust, construction and industries	Respiratory irritation	Reduced lung function
NO_2	Vehicle combustion	Airway inflammation	Asthma aggravation, respiratory infections
SO_2	Fossil fuel combustion	Bronchial irritation	Respiratory symptoms
O_2	Atmospheric chemical reactions	Oxidative injury	Lung inflammation
CO_3	Incomplete combustion	Reduced oxygen transport	Cardiovascular stress

Table 4: Comparison of monitoring technologies

Technology	Accuracy	Cost	Coverage
Reference stations	Very high	High	Limited
Low-cost sensors	Moderate–high	Low	Extensive
Satellites	Moderate	Moderate	Regional-Global
Wearables	Moderate	Moderate	Personal

to new research. This field has drawn more scientific attention, despite the fact that research in this area is still comparatively small when compared to respiratory investigations.

Adverse pregnancy outcomes: Maternal exposure to air pollution has been linked in several studies to low birth weight, preterm birth and developmental issues.

AIR QUALITY MONITORING TECHNOLOGIES

A significant shift toward innovative monitoring approaches was observed over the review period (Table 4).

Conventional monitoring stations: Reference-grade stations are still necessary for regulatory compliance and continue to offer extremely accurate measurements[17]. However, the high cost of installation and operation restricts their deployment.

Low-cost sensors: Low-cost sensors have gained substantial popularity due to affordability, mobility and scalability. These devices enable vast monitoring networks and help with citizen science activities.

Satellite monitoring: In areas with little ground-based monitoring infrastructure, satellite observations have grown in importance due to their wide spatial coverage[18]. In order to enhance exposure assessment, remote sensing devices are now frequently combined with ground observations.

Wearable sensors: Wearable technology has grown in significance in environmental health research and provides potential for personal exposure monitoring.

The review's conclusions show that one of the biggest environmental risks to modern society is still air pollution. Pollutant concentrations in many urban and peri-urban areas continue to surpass international health-based guidelines despite significant technical advancements and governmental initiatives.

The disproportionate burden that low- and middle-income countries bear is one of the most striking findings from the evaluated literature. Pollution levels have increased in many cities due to rapid urbanization, industrial growth, population expansion and inadequate environmental infrastructure. These concerns are especially noticeable in Africa, where there are still few monitoring networks and insufficient enforcement of environmental legislation. The review emphasizes how transportation emissions account for the majority of urban pollution. Elevated PM_2 and NO_2 concentrations have been largely caused by aged fleets, rising car ownership and poor fuel quality. As a result, transportation-related interventions like improved public transit, pollution regulations and cleaner fuels continue to be essential parts of air quality management plans.

Another significant source of pollution has been identified as biomass combustion, especially in developing nations where energy poverty is still pervasive. Millions of homes are exposed to hazardous pollutants due to their reliance on conventional cooking fuels, which also adds to the burden of indoor and outdoor air pollution. Therefore, switching to greener energy sources promotes wider sustainability objectives and has major positive effects on public health. The review provides additional evidence of the significant health consequences linked to exposure to air pollution. Although respiratory disorders continue to be among the most often reported consequences, there is growing evidence that pollution impacts several organ systems, such as the neurological and cardiovascular systems. These results highlight the necessity of considering air pollution as a significant public health concern requiring multidisciplinary solutions rather than just an environmental problem.

Table 5: Comparison of air quality management approaches in selected African Countries

Country	Major challenge	Monitoring approach	Policy response
South Africa	Industrial emissions, coal combustion	Extensive monitoring network	National Ambient Air Quality Standards[27]
Nigeria	Transport emissions, generators, waste burning	Limited stations + emerging sensors	Regulatory strengthening required[28]
Kenya	Urban transport emissions	Sensor networks and modelling	Nairobi clean air initiatives[29]
Ghana	Traffic and household pollution	Monitoring stations and research networks	Urban pollution control programmes[30]
Ethiopia	Biomass combustion, transport	Research-based monitoring	Clean cooking initiatives[31]

The quick development of inexpensive air quality monitoring devices is one particularly promising trend noted in the literature[19,20]. Due to the high expense of traditional technology, many African nations have historically lacked sufficient monitoring networks. Opportunities to increase monitoring coverage, enhance data availability and promote community involvement have been made possible by the development of reasonably priced sensors. These technologies can significantly enhance knowledge of pollution dynamics when combined with machine learning methods and satellite observations.

Nigeria serves as a prime example of the difficulties and possibilities involved in managing air quality in emerging nations. Transportation, industrial processes, diesel generators, gas flaring, burning of biomass and waste disposal methods continue to cause pollution in major cities. Simultaneously, new research projects that make use of inexpensive sensors and satellite data show interesting paths for enhancing monitoring capabilities and bolstering evidence-based policymaking[21]. Regional differences in policy responses continue to be significant. Regulatory enforcement, technical innovation, monitoring infrastructure and public awareness campaigns are typically combined in nations that have effectively improved air quality. On the other hand, areas with little institutional capacity frequently find it difficult to convert environmental laws into quantifiable improvements in air quality. This implies that to achieve sustainable results, good administration is just as crucial as technological innovation.

Several research gaps were also noted in the review. There are still few long-term exposure studies in many developing nations, especially in Africa[22,23]. More integration of socioeconomic analysis, atmospheric modeling, remote sensing and epidemiological research is required. Given their similar emission sources and overlapping policy implications, future research should also look into how air pollution and climate change interact. Overall, the data suggest that governments, researchers, business players, civil society organizations and local communities must work together to achieve significant changes in air quality[24]. Significant health, economic and environmental benefits are anticipated from investments in clean energy technology, environmental education, sustainable transportation systems and monitoring infrastructure. Achieving sustainable development goals and raising the standard of living for quickly expanding urban populations depend on such actions.

AIR QUALITY IN AFRICA AND NIGERIA: EVIDENCE, CHALLENGES and EMERGING OPPORTUNITIES

Air quality challenges across Africa: One of Africa's biggest environmental and public health issues is air pollution. In many African cities, rapid urbanization, industrial development, population increase, transportation expansion and rising energy demands have all contributed to declining air quality (Table 5). Large portions of Africa are still under-monitored, which limits knowledge of pollution dynamics and related health hazards, in contrast to many industrialized regions where comprehensive monitoring networks allow evidence-based policy actions. There is a distinct mix of anthropogenic and natural emission sources in the African continent. Seasonal wildfires, wind-blown particles and Saharan desert dust are examples of natural sources. Vehicle emissions, industrial processes, burning of biomass, combustion of domestic fuels, power generation and open waste burning are examples of anthropogenic sources. These sources frequently interact to create complicated pollution mixtures that change over time and space. According to recent research, urban air pollution levels in several African cities routinely surpass WHO-recommended standards for $PM_{2.5}$ and PM_{10}[25,26]. Concerns about respiratory ailments, cardiovascular conditions, decreased productivity, medical expenses and early death have been raised by these elevated concentrations. However, the scarcity of long-term monitoring data means that there are still a lot of unknowns. Air quality assessment has improved throughout the continent in recent years thanks to the use of inexpensive sensors, satellite-based data and atmospheric modeling tools[11,17]. Researchers are now able to determine pollution hotspots, calculate population exposure and assess response tactics thanks to these technologies. However, establishing sustainable monitoring systems that can assist environmental governance and public health protection still requires significant investments.

Table 6: Summary of selected air quality studies in Nigeria

Author(s)	Location	Pollutants investigated	Methodology	Major findings
Eze *et al.*[35]	Nigeria	$PM_{2.5}$, PM_{10}	Epidemiological assessment	Demonstrated associations between particulate exposure and health risks
Akinlade *et al.*[36]	Southwestern Nigeria	PM, gaseous pollutants	Ambient monitoring	Reported elevated particulate concentrations in urban environments
Rafiee *et al.*[32]	Lagos	$PM_{2.5}$, PM_{10}	Air monitoring	Identified traffic and industrial activities as major contributors
Ede and Edokpa[37]	Niger delta	Atmospheric pollutants	Environmental assessment	Highlighted impacts of petroleum-related activities
Jekayinfa *et al.*[38]	Nigeria	Household emissions	Indoor exposure assessment	Identified biomass fuels as important pollution sources
Sidibe *et al.*[39]	African cities	PM exposure	Exposure modelling	Demonstrated urban pollution-health relationships
Saetae *et al.*[40]	Multiple locations	$PM_{2.5}$	Low-cost sensor monitoring	Demonstrated feasibility of affordable monitoring approaches

Table 7: Major sources of air pollution in selected Nigerian cities

City	Dominant sources
Lagos	Transportation, industry, generators
Port harcourt	Petroleum activities, soot, gas flaring
Abuja	Traffic, construction, generators
Kano	Industry, traffic, biomass, dust
Ibadan	Traffic, waste burning and domestic fuels
Akure	Traffic, domestic combustion, generators

Air pollution in Nigeria: Nigeria's massive population, quickly increasing urban centers, increased industrial operations and ongoing energy issues make it one of the most significant case studies in African air quality studies (Table 6). Growing environmental challenges, many of which have a direct impact on ambient air quality, have coincided with the nation’s economic expansion.

Nigeria’s main sources of pollution include:

- Transportation by road
- Electricity generators that run on diesel
- Industrial operations

Petroleum refining activities

- The flaring of gas

Burning biomass

- Burning agricultural residue
- Burning and disposing of garbage openly

Due to economic activity and population density, urban regions typically have the greatest pollution levels[32]. Transportation emissions, industrial growth and energy generation are major issues for Lagos, Port Harcourt, Kano, Ibadan, Abuja and other quickly growing cities (Table 7). Particular consideration should be given to the extensive use of diesel generators. Due to frequent disruptions in the electrical supply, homes, companies and institutions have become largely dependent on private generators, resulting in significant emissions of carbon monoxide, sulfur dioxide, nitrogen oxides and particulate matter. This phenomenon sets Nigeria apart from many other nations and poses a serious threat to public health and the environment.

EVIDENCE FROM MAJOR NIGERIAN CITIES

Lagos: Nigeria’s commercial hub, Lagos, is one of Africa’s fastest-growing megacities. Air pollution is greatly increased by the city’s dense population, vast transit system, ports, industrial facilities and energy needs. Particulate matter and gaseous pollutants are frequently found in high concentrations, especially in industrial areas and traffic corridors, according to studies. One of the biggest causes of urban pollution is still traffic congestion. Combined, heavy-duty vehicles, commercial buses, motorbikes and individual cars produce significant amounts of $PM_{2.5}$, PM_{10}, NO_2 and CO. Pollutant concentrations in nearby towns are further increased by port operations and industrial developments.

Port harcourt: In the Niger Delta, Port Harcourt is a significant petroleum-producing metropolis. Due to reports of black soot incidents during the previous ten years, the city’s air quality issues have garnered significant national and international attention.

Among the possible sources of contamination are:

- The refining of petroleum
- Illegal refining of crude oil
- The flaring of gas
- Emissions from industry
- Transportation-related activities

Research has connected Port Harcourt's high particle concentrations to worse environmental quality and more respiratory complaints.

Abuja: Abuja, the capital of Nigeria, has seen tremendous urbanization and population increase. Despite being thought of as less dirty than Lagos or Port Harcourt, the air quality has gotten worse due to increased vehicle traffic, development and energy use. Traffic-related pollutants are rapidly contributing to ambient pollution levels, according to monitoring studies[33].

Kano: One of the biggest business hubs in Northern Nigeria is Kano. Local air pollution is mostly caused by desert dust, vehicle emissions, industrial processes and the burning of biomass. Due to its position, the city is especially vulnerable to periodic dust transport events related to the Harmattan season, which frequently cause excessive particle concentrations.

Ibadan: Transportation, garbage burning, industrial operations and household energy consumption all contribute to pollution in Ibadan. Concerns about exposure to particulate matter and gaseous pollutants have grown as a result of rapid urbanization and insufficient waste management systems.

Akure: Elevated $PM_{2.5}$ concentrations have been found in residential, business and institutional settings in Akure, according to recent studies[34]. The growing usage of inexpensive sensors has enhanced knowledge of the dynamics of local air quality and brought attention to the necessity of ongoing monitoring initiatives.

Emerging opportunities for air quality management in Nigeria: There are numerous chances to enhance air quality management despite major obstacles.

- **Growth of monitoring networks:** Affordable options for expanding the coverage of spatial monitoring are offered by low-cost sensors. While lowering operating costs, integration with reference-grade devices can enhance data quality
- **Monitoring via satellite:** For areas without considerable monitoring infrastructure, satellite products provide useful information. Pollution forecasting and exposure assessment can be improved by combining satellite data with ground measurements
- **Initiatives for citizen science:** Participation of the community in air quality monitoring can promote environmental stewardship and raise public awareness
- **Transition to clean energy:** Emissions from generators and the burning of biomass might be significantly decreased by expanding access to cleaner cooking fuels and renewable energy technology
- **Data-based governance:** Geographic Information Systems (GIS), machine learning models and real-time monitoring systems can all help with evidence-based environmental decision-making

POLICY IMPLICATIONS, RECOMMENDATIONS AND CONCLUSION

Policy implications: The results of this comprehensive research have significant ramifications for public health policy, sustainable development planning and environmental governance. Air pollution needs to be acknowledged as a multidisciplinary problem that impacts social well-being, economic productivity, health and climate resilience rather than just being seen as an environmental problem[41,42]. Evidence shows that the burden of disease and healthcare costs are greatly increased by poor air quality. As a result, investments in improving air quality ought to be considered investments in both national development and public health. Reducing mortality, increasing worker productivity, lowering healthcare expenses and improving the general quality of life are all possible outcomes of effective air quality management. The assessment emphasizes even more how crucial it is to incorporate air quality concerns into urban planning procedures. The effects on the environment and human health should be explicitly taken into account when designing waste management policies, transportation systems, industrial development and energy infrastructure.

RECOMMENDATIONS

Strengthen air quality monitoring infrastructure: National monitoring networks should be expanded by governments using a combination of low-cost sensors that have been calibrated and reference-grade stations. For well-informed policy development and evaluation, trustworthy monitoring data are crucial.

Create extensive air quality guidelines: While taking into account regional environmental and socioeconomic factors, national air quality rules should be in conformity with WHO guidelines.

- **Encourage cleaner transportation systems:** The following should be encouraged by policy:
  - The growth of public transportation
  - The use of greener car technologies
  - Higher-quality fuel: Programs for vehicle maintenance and inspection
- **Increase the adoption of renewable energy:** Investing more in renewable energy systems, such as solar, wind and hybrid technologies, is necessary to lessen reliance on diesel generators and biomass fuels
- **Enhance systems for waste management:** Improving collection, recycling and waste treatment facilities should be a top priority to end open waste burning
- **Increase public knowledge:** Programs for environmental education should inform people about the dangers air pollution poses to their health and promote changes in behavior that lower emissions
- **Encourage multidisciplinary research:** To enable comprehensive solutions, future research should incorporate viewpoints from environmental science, epidemiology, engineering, economics and public policy
- **Boost regional cooperation:** Coordinated monitoring programs, data exchange and policy harmonization can help African nations, which share many common air quality issues

RESEARCH GAPS AND FUTURE DIRECTIONS

A number of significant research gaps were found. First, there are still few long-term exposure studies in many developing nations. To fully comprehend the long-term health effects of exposure to air pollution, more long-term studies are required. Second, low-cost sensors must be better calibrated and validated in a variety of climates, especially tropical ones. Third, future research ought to look into how air pollution and climate change interact. Integrated mitigation measures may result in significant co-benefits because many pollutants share emission sources with greenhouse gases. Fourth, there should be more focus on studies on vulnerable groups, such as low-income communities, pregnant women, elderly persons and children. Lastly, an interesting topic for further research is the use of big data analytics, machine learning and artificial intelligence in air quality predictions.

CONCLUSION

With a focus on Nigeria specifically, this systematic review looked at monitoring technology, health effects, air quality issues and policy responses in low- and middle-income nations. The data shows that vehicle emissions, industrial processes, biomass combustion, energy production and garbage burning continue to be the main causes of air pollution, which poses a serious threat to the environment and human health. Strong correlations between exposure to air pollution and negative respiratory, cardiovascular, neurological and developmental consequences are confirmed by the review. Vulnerable communities are disproportionately affected by these health effects, which also greatly increase the burden of sickness in the country.

In areas with inadequate monitoring infrastructure, new prospects for enhancing air quality assessment have been made possible by advancements in monitoring technologies, particularly low-cost sensors, satellite observations, wearable technology and data analytics. These developments are especially pertinent to African nations, where there are still few traditional monitoring networks. Nigeria is a prime example of the difficulties and possibilities related to managing air quality in developing nations that are quickly urbanizing. Air quality is still being deteriorated by transportation emissions, diesel generators, industrial processes and the burning of biomass, but new monitoring programs and increased policy interest lay the groundwork for future advancements.

In the end, governments, scholars, businesses, communities and international organizations must work together to achieve cleaner air. Significant health, economic and environmental advantages can be obtained via investments in monitoring infrastructure, clean energy technology, sustainable transportation systems, environmental education and evidence-based policies. In order to promote sustainable development, safeguard public health and guarantee a healthy future for current and future generations, such activities are crucial.

REFERENCES

1. Tavella, R.A., F.M.R. da Silva Jr., M.A. Santos, S.G.E.K. Miraglia and R.D.P. Filho, 2025. A review of air pollution from petroleum refining and petrochemical industrial complexes: Sources, key pollutants, health impacts, and challenges. ChemEngineering, Vol. 9. 10.3390/chemengineering9010013.
2. Schoch, M., C.F. de Lauriere and T. Bernauer, 2026. Large gaps in monitoring urban air pollution in low- and middle-income countries associated with economic conditions and political institutions. PLoS ONE, Vol. 21. 10.1371/journal.pone.0321358.

3. Chen, Y., Y. Dai, J. Qian, Y. Si and F. Chen *et al*., 2025. Potential impact of air pollution on polycystic ovary syndrome incidence: A global analysis of 171 countries and regions from 1990 to 2021. J. Ovarian Res., Vol. 18. 10.1186/s13048-025-01777-1.
4. Ramadan, B.S., I. Rachman and T. Matsumoto, 2022. Activity and emission inventory of open waste burning at the household level in developing countries: A case study of Semarang City. J. Mater. Cycles Waste Manage., 24: 1194-1204.
5. Katz, M.A., M.Y.R. Castro, N. Seyidov, M.T. Herdman and S. Mehdiyev *et al*., 2023. The effectiveness of primary series CoronaVac vaccine in preventing COVID-19 illness: A prospective cohort study among healthcare workers in Azerbaijan, May-November 2021. Influenza Respir. Viruses, Vol. 17. 10.1111/irv.13147.
6. Rentschler, J. and N. Leonova, 2023. Global air pollution exposure and poverty. Nat. Commun., Vol. 14. 10.1038/s41467-023-39797-4.
7. Wolf, M.J., D.C. Esty, H. Kim, M.L. Bell and S. Brigham *et al*., 2022. New insights for tracking global and local trends in exposure to air pollutants. Environ. Sci. Technol., 56: 3984-3996.
8. Matthaios, V.N., D. Pope, P. Koutrakis, C.O. Olopade and C.M. North, 2025. The struggle against air pollution in African megacities and the hidden problems for the estimation of the burden of disease. Global Challenges, Vol. 9. 10.1002/gch2.202500108.
9. Brauer, M., M. Amann, R.T. Burnett, A. Cohen and F. Dentener *et al*., 2012. Exposure assessment for estimation of the global burden of disease attributable to outdoor air pollution. Environ. Sci. Technol., 46: 652-660.
10. Patil, P. and P. Agrawal, 2026. AI assessment of health risk based on air pollution: An epidemiological review. Environ. Sci. Eur., Vol. 38. 10.1186/s12302-026-01349-0.
11. Abulude, F.O., A.A. Okunola and A. Inobeme, 2026. Evaluation of $PM_{2.5}$ Air Quality at the University of Lagos, Nigeria: Source Attribution, Toxicity Potential, and Adherence to National and International Guidelines. In: Air Pollution-Emerging Contaminants and Control Strategies, Noreña, H.A.S., J.G. Ronderos-Lara and J.K. Summers (Eds.) IntechOpen, London, United Kingdom, ISBN: 978-1-83635-702-5.
12. Olise, F.S., 2025. Bridging data gaps in Nigerian air pollution: Coverage, infrastructural challenges, and public health implications. Environ. Sci. Pollut. Res., 32: 23331-23350.
13. Jafari, A.J., E. Charkhloo and H. Pasalari, 2021. Urban air pollution control policies and strategies: A systematic review. J. Environ. Health Sci. Eng., 19: 1911-1940.
14. Atuyambe, L.M., R.E. Arku, N. Naidoo, T. Kapwata and K.P. Asante *et al*., 2024. The health impacts of air pollution in the context of changing climate in Africa: A narrative review with recommendations for action. Ann. Global Health, Vol. 90. 10.5334/aogh.4527.
15. Niyi-Odumosu, F., O.B. Ozoh, V.O. Ope, B.M. Ale, O. Akinnola, A. Iseolorunkanmi and D. Adeloye, 2025. Exploring the impact of climate change on respiratory health in Nigeria: A scoping review of current research, government policies and programs. Clim. Change, Vol. 178. 10.1007/s10584-025-03880-0.
16. Page, M.J., D. Moher, P.M. Bossuyt, I. Boutron and T.C. Hoffmann *et al*., 2021. PRISMA 2020 explanation and elaboration: Updated guidance and exemplars for reporting systematic reviews. BMJ, Vol. 372. 10.1136/bmj.n160.
17. McDuffie, E.E., R.V. Martin, J.V. Spadaro, R. Burnett and S.J. Smith *et al*., 2021. Source sector and fuel contributions to ambient $PM_{2.5}$ and attributable mortality across multiple spatial scales. Nat. Commun., Vol. 12. 10.1038/s41467-021-23853-y.
18. Shaddick, G., M.L. Thomas, P. Mudu, G. Ruggeri and S. Gumy, 2020. Half the world's population are exposed to increasing air pollution. npj Clim. Atmos. Sci., Vol. 3. 10.1038/s41612-020-0124-2.
19. El Arfaoui, A., M. El Khaili, I. Chakir, O. Arif, H. Nhaila, I. Essamlali and M. Tabaa, 2026. Towards improving air quality monitoring using fixed and mobile stations: Case of Mohammedia city. Sustainability, Vol. 18. 10.3390/su18062944.
20. Khreis, H., J. Johnson, K. Jack, B. Dadashova and E.S. Park, 2022. Evaluating the performance of low-cost air quality monitors in Dallas, Texas. Int. J. Environ. Res. Public Health, Vol. 19. 10.3390/ijerph19031647.
21. Ahmed, T., L. Creedon and S.S. Gharbia, 2023. Low-cost sensors for monitoring coastal climate hazards: A systematic review and meta-analysis. Sensors, Vol. 23. 10.3390/s23031717.
22. Jafta, N., B. Shezi, M. Buthelezi, S. Muteti-Fana and R.N. Naidoo, 2025. Household air pollution and respiratory health in Africa: Persistent risk and unchanged health burdens. Curr. Opin. Pulm. Med., 31: 89-97.
23. Frazenburg, C., M.M. Sepadi and M. Chitakira, 2025. Investigating the disproportionate impacts of air pollution on vulnerable populations in South Africa: A systematic review. Atmosphere, Vol. 16. 10.3390/atmos16010049.
24. WHO, 2021. WHO Global Air Quality Guidelines: Particulate Matter ($PM_{2.5}$ and PM_{10}) , Ozone, Nitrogen Dioxide, Sulfur Dioxide and Carbon Monoxide. World Health Organization, Geneva, Switzerland, ISBN-9789240034228, Pages: 273.
25. Ngutuka, M.K., F. Bangelesa, D.M. Matondo, L. Aketi and B.O. Kabengele *et al*., 2026. Urban air pollution, green space, and pneumonia risk: A spatial analysis across health zones in Kinshasa, Democratic Republic of Congo. BMC Public Health, Vol. 26. 10.1186/s12889-026-26318-3.
26. Ngutuka, M.K., D.M. Matondo, F. Bangelesa, B.P. Kianu and B.O. Kabengele *et al*., 2025. Short-term effects of $PM_{2.5}$ exposure and cardiorespiratory health risks in a Sub-Saharan African urban setting. Discover Atmos., Vol. 3. 10.1007/s44292-025-00068-0.

27. Simelane, S.P. and K.E. Langerman, 2024. The sensitivity of health impact assessments of $PM_{2.5}$ from South African coal-fired power stations. Air Qual. Atmos. Health, 17: 325-340.
28. Orie, C.J., 2023. Sensor technologies perception for intelligent vehicle movement systems on Nigeria road network. Colloquium, 10: 194-208.
29. de Xun Chua, S., O. Oguge, C.A. Oliewo, R. Sserunjogi and D. Okure *et al*., 2025. East African city centers show lower $PM_{2.5}$ levels than their suburbs. Environ. Sci. Technol. Lett., 12: 1169-1176.
30. Adjei-Mantey, K., K. Matsumoto, Y. Shigetomi, Y. Yamamoto and T. Nakayama, 2023. Factors affecting household air pollutants in West Africa: Evidence from Ghana and Nigeria. Energy Sustainable Dev., Vol. 76. 10.1016/j.esd.2023.101288.
31. Benti, N.E., G.S. Gurmesa, T. Argaw, A.B. Aneseyee and S. Gunta *et al*., 2021. The current status, challenges and prospects of using biomass energy in Ethiopia. Biotechnol. Biofuels, Vol. 14. 10.1186/s13068-021-02060-3.
32. Rafiee, M. and M. Jahangiri-Rad, 2015. Steps towards mitigation of air pollutants as a key for sustainable development I.C. Ecologia, 5: 31-42.
33. Abulude, F.O., K.M. Arifalo, A. Adamu, A.M. Kenni, A. Akinnusotu, S.D. Oluwagbayide and S. Acha, 2022. Indoor air quality ($PM_{2.5}$ and PM_{10}) and toxicity potential at a commercial environment in Akure, Nigeria. Environ. Sci. Proc., Vol. 24. 10.3390/ECERPH-4-13103.
34. Ezeigwe, N.M., E.D. Adinma, E.L. Okobia and S. Schwander, 2024. Characterization and quantification of vehicular emissions in Abuja municipality-implications for public health. Niger. Med. J. 65: 276-291.
35. Eze, I.C., E. Schaffner, E. Fischer, T. Schikowski and M. Adam *et al*., 2014. Long-term air pollution exposure and diabetes in a population-based Swiss cohort. Environ. Int., 70: 95-105.
36. Akinlade, G.O., H.B. Olaniyi, F.S. Olise, O.K. Owoade, S.M. Almeida, M. Almeida-Silva and P.K. Hopke, 2015. Spatial and temporal variations of the particulate size distribution and chemical composition over Ibadan, Nigeria. Environ. Monit. Assess., Vol. 187. 10.1007/s10661-015-4755-4.
37. Ede, P.N. and D.O. Edokpa, 2015. Regional air quality of the Nigeria's Niger Delta. Open J. Air Pollut., 4: 7-15.
38. Jekayinfa, S.O., J.I. Orisaleye and R. Pecenka, 2020. An assessment of potential resources for biomass energy in Nigeria. Resources, Vol. 9. 10.3390/resources9080092.
39. Sidibe, A., Y. Sakamoto, K. Murano, O.A. Koita, I. Traore, Y. Dansoko and Y. Kajii, 2022. Personal exposure to fine particles ($PM_{2.5}$) in Northwest Africa: Case of the urban city of Bamako in Mali. Int. J. Environ. Res. Public Health, Vol. 19. 10.3390/ijerph19010611.
40. Saetae, S., F.O. Abulude, M.M. Ndamitso, A. Akinnusotu and S.D. Oluwagbayide *et al*., 2024. Multi-year continuous observations of ambient $PM_{2.5}$ at six sites in Akure, Southwestern Nigeria. Atmosphere, Vol. 15. 10.3390/atmos15070867.
41. Suriano, D., F.O. Abulude and M. Penza, 2025. The use of low-cost gas sensors for air quality monitoring with smartphone technology: A preliminary study. Chemosensors, Vol. 13. 10.3390/chemosensors13050189.
42. Mbabie, J.A. and F.O. Abulude, 2026. Air quality, physical activity, and sustainable urban health: Implications for physical education, sports participation, and social equity. ASEAN J. Phys. Educ. Sport Sci., 5: 75-92.