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AQI Aggreagtion Model

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Abstract

DPCC is using different stations at fixed sites for measurement of AQI and other pollution parameters. These fixed stations suffered from various limitations and generally do not give representative values e.g. station located near an industrial area will give higher readings due to proximity to such industrial area which may not be representative of the wider area. Similarly, a temporary construction site/activity near these fixed sites give higher pollution readings due to local reasons. The technological solutions may be required for capturing AQI values through mobile and other forms of stations. Drone would be one of the options where they can record real- time pollution parameters through on-board sensors. In the application here, the mobile device(s) gather inputs from multiple locations, all over the designated region. Now there is data available about both, average region AQI.

Keywords: DPCC (Delhi Pollution Control Committee),Air Quality Index (AQI),Fixed Monitoring Stations,Pollution Parameters,Industrial Proximity Impact,Temporary Construction Activity,Technological Solutions,Mobile Monitoring Stations,Drones for Real Time Data,On- Board Sensors,Regional AQI Measurements,Data Aggregation,Pollution Monitoring Mobility,Environmental Data Analytics.

1 Introduction

The AQI mobile monitoring systems is the pressing need for more granular, real-time, and accessible air quality data. Traditional stationary monitoring stations, while valuable, have inherent limitations in spatial coverage. They offer a limited snapshot of air quality, failing to capture localized variations in pollution levels. This can leave communities unaware of specific pollution hotspots and fluctuations within their neighborhoods.Mobile monitoring systems offer a dynamic solution by collecting data from numerous locations, providing a more comprehensive understanding of air pollution. By equipping vehicles, drones, or even individuals with portable sensors, these systems can traverse diverse environments, gathering data that would otherwise be missed. This mobility allows for the identification of hyperlocal variations, revealing pollution hotspots that traditional methods cannot capture. The data collected is often transmitted in real- time, providing an immediate snapshot of current air quality conditions. This real-time information is crucial for public awareness and timely responses to pollution events. By integrating these systems with mobile applications and online platforms, AQI information can be delivered directly to the public, empowering individuals to make informed decisions.For instance, during periods of high pollution, individuals with respiratory conditions can use this information to limit their outdoor exposure.

Community leaders can also utilize the data to implement targeted interventions, such as traffic rerouting or temporary closures of industrial facilities. Beyond immediate responses, AQI mobile monitoring systems also play a vital role in long term air quality management and policy development. The high-resolution data collected can be used to identify pollution hotspots, track the dispersion of pollutants, and evaluate the effectiveness of existing air quality regulations. This information can then be used to inform the development of more effective policies and strategies for pollution control, ultimately leading to healthier communities and a more sustainable environment.In essence, AQI mobile monitoring systems address the limitations of traditional methods by providing more detailed, real-time, and accessible air quality information.

This empowers individuals, communities, and policymakers to make informed decisions and take proactive measures to improve air quality and protect public health. By offering a more complete and dynamic picture of air quality, these systems are revolutionizing the way we understand and manage this critical aspect of our environment.

1.1 Problem Statement

The Delhi Pollution Control Committee (DPCC) uses fixed monitoring stations for measuring the Air Quality Index (AQI) and other pollution parameters. While these stations provide valuable localized data, they are constrained by inherent limitations that affect their effectiveness in representing the broader regional air quality. Fixed monitoring stations, located in specific areas such as industrial zones or near temporary construction sites, often capture pollution levels influenced by these local factors, leading to skewed data that may not accurately reflect the overall air quality of a larger region.This static monitoring approach is particularly problematic in areas with dynamic pollution sources, such as urban traffic, seasonal construction activities, or varying industrial operations. The inability of fixed stations to adapt to these changing sources of pollution results in an incomplete understanding of air quality trends and patterns.

Consequently, the insights derived from such data may lead to misinformed policy decisions and ineffective interventions to mitigate air pollution.Additionally, fixed monitoring stations lack the capacity to gather real-time data from diverse locations simultaneously. This limitation hinders the ability to capture spatial variations in air quality across different neighborhoods or districts. For instance, while one station might report elevated AQI values due to industrial emissions, another area experiencing relatively cleaner air might go unmonitored. Such gaps in coverage compromise the accuracy and utility of the data for regional air quality assessments.The growing complexity of urban environments and the increasing number of pollution sources demand more adaptive and responsive monitoring solutions. Fixed stations are not sufficient to address these challenges, as they cannot track shifting pollution hotspots or provide granular insights into air quality variations within a region.

This creates a significant barrier to implementing targeted and effective pollution control measures.There is pressing need for technological solutions that can overcome the limitations of fixed monitoring stations. Mobile and dynamic monitoring systems, such as drones equipped with on-board sensors and mobile devices, offer a promising alternative. These solutions can capture real-time AQI data from multiple locations across a designated area, providing a more comprehensive and representative picture of air quality.By deploying drones, data can be collected dynamically from hard-to-reach or under monitored areas. These drones can traverse urban, suburban, and rural regions, capturing data that reflects real-time pollution conditions across diverse environments. Such capabilities are particularly valuable in identifying pollution hotspots, understanding temporal variations, and responding to emergent air quality issues.

Mobile monitoring stations, such as vehicle-mounted or handheld devices, can complement the capabilities of drones by providing continuous data collection from areas with heavy traffic or pedestrian activity. This combination of mobile and drone-based systems ensures extensive coverage and enhances the granularity of air quality assessments.he adoption of data aggregation and analytics platforms further strengthens the utility of mobile monitoring systems. By integrating data from fixed stations, mobile devices, and drones, these platforms can provide actionable insights into regional AQI trends. Decision-makers can use this comprehensive data to design targeted interventions, allocate resources effectively, and evaluate the impact of pollution control measures. To address the challenges posed by dynamic pollution sources and the limitations of fixed stations, a shift toward adaptive and responsive monitoring systems is essential. Such systems must prioritize scalability, accuracy, and real-time data availability to meet the growing demands of urban air quality management. Innovative solutions like drone-based sensors, mobile monitoring devices, and advanced analytics platforms hold the potential to transform how air quality is monitored and managed, enabling more effective responses to air pollution challenges.

1.2 Motivation

The motivation behind this project is to address the limitations of traditional fixed air quality monitoring systems and enhance the accuracy, responsiveness, and scalability of air quality monitoring in dynamic urban environments. Fixed monitoring stations, while valuable, often provide skewed data due to their static nature and inability to capture real-time air quality variations across different regions. This can result in incomplete or misleading insights into pollution levels, ultimately impacting the effectiveness of air quality management and policy decisions.

Given the growing complexity of urban pollution sources—such as traffic, industrial emissions, and seasonal construction activities—there is a clear need for more adaptive monitoring systems. Mobile and drone-based solutions offer the ability to gather real-time, dynamic data from multiple locations, ensuring a more comprehensive understanding of air quality trends and variations. This can help identify pollution hotspots, track temporal changes, and support targeted interventions to reduce air pollution more effectively. By leveraging advanced technologies like drones, mobile monitoring devices, and data analytics platforms, this project aims to create a more accurate and timely air quality monitoring system. The ultimate goal is to enable better-informed decision- making, improve pollution control measures, and enhance public health and environmental

outcomes.

2 Related works

2.1 A Low-Cost IoT-Based Mobile System for Air Quality Monitoring in Developing Countries

A Low-cost IoT Mobile System for Air Quality Monitoring in Developing Countries: A Case Study in El Salvador, introduces an affordable and scalable solution for monitoring air pollution. Traditional air quality monitoring systems are expensive, require substantial infrastructure, and are often inaccessible to low-resource regions. To address this, the project proposes a low-cost, IoT- enabled system capable of real-time pollution monitoring. The system consists of air quality sensors, an ESP32 microcontroller, a SIM800L GSM module for wireless communication, and a cloud-based platform for data storage and visualization. By utilizing mobile sensors installed in vehicles or carried by individuals, the system enables comprehensive air quality mapping beyond the limitations of fixed monitoring stations.The sensors detect key pollutants, including PM1.0, PM2.5, PM10, CO_2, NO_2, and formaldehyde (HCHO), along with temperature and humidity levels. The collected data is processed by the microcontroller and transmitted via Wi-Fi, Bluetooth, or GSM, depending on network availability. The cloud platform, built using Google App Services, stores the data in a time-series database and presents it on a mobile app or web dashboard through graphs, heatmaps, and pollution alerts. The real-time availability of this data allows researchers, policymakers, and local communities to make informed decisions regarding urban planning, environmental policies, and public health measures.

To test the system's performance, researchers deployed three IoT nodes in San Salvador, Santa Ana, and Cojutepeque for one month. The collected data indicated that air quality varied across these locations, with some areas experiencing moderate pollution levels based on the Central American Air Quality Index (CAQI). The study confirmed the system's ability to provide reliable and actionable pollution data while remaining affordable. Compared to conventional monitoring stations, this mobile system offers greater flexibility and coverage by allowing pollution levels to be tracked across different locations, identifying hotspots and monitoring trends over time.One of the major advantages of this project is its cost-effectiveness. The use of low-cost sensors and open- source software significantly reduces deployment expenses, making it accessible to governments, researchers, and local communities in developing nations. Additionally, its mobility enhances monitoring capabilities, ensuring that air pollution data is collected from various locations rather than being limited to a few stationary stations. The real-time data transmission feature ensures that users can quickly access air quality insights and respond to pollution threats more effectively.

Despite its benefits, the system faces certain challenges. One key issue is sensor accuracy, as low- cost sensors may exhibit variations compared to high-end industrial equipment. Calibration techniques and data validation methods are essential to improve measurement reliability. Another challenge is environmental interference, as factors such as temperature and humidity can influence sensor performance. Continuous calibration and maintenance are required to address this. Additionally, handling large-scale data efficiently is a concern, requiring robust cloud infrastructure and advanced data processing techniques to ensure smooth operation.To enhance the system's performance, several future improvements have been proposed. One potential upgrade is the integration of blockchain technology to enhance data transparency and security, ensuring that recorded air quality measurements remain tamper-proof. Another advancement could involve the use of machine learning models for predictive analysis, allowing authorities to anticipate pollution trends and take preventive measures. Furthermore, incorporating solar- powered sensors could improve sustainability by reducing dependence on external power sources, making the system more suitable for remote or off-grid locations.

This project showcases how IoT technology can revolutionize air quality monitoring in developing countries by providing an affordable, scalable, and real-time solution. By empowering local communities, researchers, and governments with reliable environmental data, this initiative can contribute to better urban planning, traffic regulation, and pollution control measures. Addressing air pollution effectively is essential for public health and environmental sustainability, and this project represents a step forward in making air quality monitoring more accessible and actionable in resource-limited regions.

2.2 IoT-Based Real-Time Air Quality Monitoring System for Particulate Matter in Subway Tunnels

Implementation of IoT-Based Air Quality Monitoring System for Particulate Matter in Subway Tunnels," presents a real-time air pollution monitoring solution tailored for underground subway systems. Subways play a vital role in urban transportation, but their enclosed environments often lead to poor air quality due to particulate matter (PM) accumulation from dust, brake wear, exhaust emissions, and inadequate ventilation. This

project aims to continuously monitor PM concentrations using IoT-based technology, enabling authorities to take timely actions for improving air quality and ensuring passenger safety.

The system is composed of PM2.5 and PM10 sensors, which detect airborne particles in subway tunnels. These sensors are connected to a microcontroller unit (MCU), such as ESP32 or Raspberry Pi, which processes and transmits the collected data. Wireless communication modules, including Wi-Fi, LoRa, or GSM, ensure data transmission to a cloud-based server, where it is stored in a time-series database for further analysis. This real-time data processing capability allows authorities to track pollution trends and take preventive measures accordingly.

A significant feature of this system is its cloud computing integration, which facilitates large- scale data storage, real-time analysis, and remote access. Subway authorities can monitor air quality through a web-based dashboard or a mobile application, where data is visualized using pollution heatmaps, graphs, and alerts. These visual tools enable authorities to identify pollution hotspots, optimize ventilation, and schedule maintenance more effectively. The system also allows for early detection of hazardous PM levels, improving passenger health and worker safety.

By providing real-time air quality assessment, this project helps in ensuring better subway conditions. The early detection of high PM concentrations enables rapid interventions, such as adjusting ventilation systems, deploying air filtration units, or scheduling tunnel cleaning. Additionally, long-term data collection facilitates historical trend analysis, helping authorities implement effective air quality management strategies to enhance subway sustainability.

One of the major advantages of this system is its scalability and affordability. Using IoT technology and cloud platforms, the monitoring system remains cost-effective and can be deployed across multiple subway tunnels with minimal infrastructure changes. The wireless communication capability ensures that data is transmitted in real time without the need for extensive wiring or dedicated networks. Furthermore, remote accessibility allows authorities to monitor air quality from any location, reducing the need for manual inspections and enhancing operational efficiency.

Despite its benefits, the system faces certain challenges. One of the key concerns is sensor accuracy, as PM sensors may be affected by temperature, humidity, and tunnel airflows. To address this, regular sensor calibration and validation techniques must be implemented. Another challenge is network connectivity, particularly in deep subway tunnels where Wi-Fi or GSM signals may be weak. LoRa technology, which offers long-range, low-power communication, could be a viable alternative for ensuring stable data transmission in such environments. Additionally, data security and privacy must be considered when storing and processing air quality data in cloud platforms.

To enhance the system's capabilities, several future improvements have been proposed. One significant enhancement is the integration of AI-powered predictive models, which could analyze historical data to forecast future air quality trends and suggest preventive actions. Another advancement is the integration with HVAC (Heating, Ventilation, and Air Conditioning) systems, allowing for automated air quality control. By linking the monitoring system with subway ventilation systems, authorities could automatically adjust air circulation and filtration based on real-time PM levels, ensuring optimal air quality at all times.

Further improvements could involve expanding the system to monitor additional air pollutants, such as carbon monoxide (CO), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2), which are commonly found in subway tunnels due to fuel combustion and underground industrial processes. Solar-powered sensors could also be introduced to enhance energy efficiency and sustainability, reducing the system's dependence on external power sources. This IoT and cloud-based air quality monitoring system represents a significant step forward in ensuring a healthier and safer subway environment. By providing real-time pollution data, early hazard detection, and long-term air quality insights, this project empowers authorities to make informed decisions that improve passenger comfort, worker safety, and subway sustainability. With further advancements in AI, automation, and sensor technology, this system could revolutionize air quality management in underground public transportation networks worldwide.

2.3 An IoT System for Air Pollution Monitoring with Safe Data Transmission

An IoT System for Air Pollution Monitoring with Safe Data Transmission," introduces an advanced and secure real-time air quality monitoring system using IoT technology. The system is designed to track key air quality parameters, including PM2.5, PM10, CO_2, NO_2, temperature, and humidity, providing accurate and localized pollution data to users. Unlike traditional air monitoring stations, which are often expensive and limited in coverage, this system utilizes low-cost sensors and microcontrollers to deliver real-time environmental insights. By deploying IoT- enabled sensors across multiple locations, the system enables precise air quality assessment for urban, industrial, and rural areas.

A unique aspect of this system is its emphasis on secure data transmission, ensuring that the collected air quality data remains tamper-proof and confidential. This is crucial in environmental monitoring, as reliable and untampered data is necessary for policymaking, public health assessments, and environmental regulations. The system employs encryption protocols and secure communication channels to protect the integrity of the transmitted data, preventing unauthorized access or manipulation.

The core components of the system include IoT sensors, a microcontroller unit (MCU), a secure communication module, and a cloud-based platform. The MCU, which could be an ESP32 or Arduino, gathers data from the sensors and transmits it to a cloud-based server using secure communication protocols such as HTTPS and MQTT with encryption. The cloud server stores the data in a time-series database, allowing for long-term trend analysis. Users can access the data via a web dashboard or mobile application, where it is visualized through graphs, heatmaps, and real- time alerts.

One of the key benefits of this system is its scalability, allowing it to be deployed in various environments, including urban areas, industrial zones, and remote regions. Unlike traditional fixed monitoring stations, this system enables localized and mobile air quality monitoring, offering a more detailed view of pollution levels across different locations. This helps authorities identify pollution hotspots, track trends over time, and implement targeted interventions to improve air quality.

By focusing on secure data transmission, this project ensures that air quality information is accurate, verifiable, and protected from cyber threats. The integrity of environmental data is critical for decision-making in policy enforcement, urban planning, and public health initiatives. The system's secure transmission protocols prevent data tampering, ensuring that stakeholders receive trustworthy information. This makes it ideal for integration into smart city infrastructures, where real-time air quality data can be used to adjust traffic flow, regulate industrial emissions, or activate air purification systems.Another advantage of this system is its real-time alert mechanism, which notifies users and authorities immediately when pollution levels exceed safe limits. This feature can help protect public health, especially in areas with high pollution exposure, such as industrial zones, busy traffic intersections, and construction sites. By providing instant alerts, the system enables quick actions such as closing windows, adjusting HVAC settings, or avoiding high- pollution areas.

Despite its many advantages, the system faces some challenges. One of the key concerns is sensor accuracy, as low-cost IoT sensors may be influenced by temperature, humidity, and calibration issues. Regular sensor calibration and validation techniques must be applied to maintain reliability. Additionally, network connectivity can be a challenge in rural or underground areas, where stable internet access is limited. Using edge computing and offline data storage mechanisms could help mitigate connectivity issues.

To enhance the system's capabilities, several future improvements have been proposed. One significant upgrade is AI-based anomaly detection, which would allow the system to predict pollution spikes and detect unusual trends in air quality data. Another enhancement is the integration with satellite data, enabling a more comprehensive view of air pollution at regional and global levels. Solar-powered IoT sensors could also be introduced to improve energy efficiency and long-term sustainability, reducing dependence on external power sources.

Additionally, integrating this system with smart city infrastructure could create an automated pollution control framework, where IoT sensors communicate directly with traffic management systems, industrial emission controls, and HVAC systems. For example, if a high level of pollutants is detected in an area, the system could automatically reduce vehicle traffic, activate air purifiers, or optimize building ventilation systems to improve air quality dynamically.

This IoT-based air pollution monitoring system represents a secure, scalable, and efficient approach to real-time environmental monitoring. By ensuring data privacy and integrity, the system provides trustworthy and actionable air quality insights that can be used for policy-making, urban planning, and public health interventions. With future advancements in AI, satellite integration, and automated pollution control, this project has the potential to become a key component in smart city environmental management, making urban environments healthier and more sustainable.

2.4 Internet of Things Mobile - Air Pollution Monitoring System (IoT-Mobair)

Internet of Things Mobile - Air Pollution Monitoring System (IoT-Mobair), presents a three-phase air pollution monitoring system designed to track air quality in real time using IoT technology. The system incorporates gas sensors such as CO_2, CO, and NO_2 sensors, which are connected to an Arduino IDE-based microcontroller. The collected air quality data is processed and transmitted to a cloud-based server, where it is stored and analyzed for environmental monitoring.

The first phase of the system involves the measurement of air pollutants using gas sensors. These sensors detect harmful gases in the air and are integrated with an Arduino microcontroller, which processes and prepares the collected data for transmission. The sensors are calibrated to provide accurate pollution readings, ensuring reliability in detecting harmful gas concentrations in different environments.

In the second phase, the processed data is transmitted via a Wi-Fi module to a cloud-based platform. The cloud system provides secure data storage, remote access, and historical trend analysis. By storing data in the cloud, users can monitor air quality trends over time and analyze changes in pollution levels. The cloud-based approach allows authorities and researchers to track pollution hotspots, identify patterns, and take preventive measures to reduce air pollution.

The third phase involves the development of a mobile Android application, allowing users to access the collected data in real time. The application features a user-friendly interface, displaying pollution levels through graphical representations, alerts, and notifications. The app provides instant updates based on predefined pollution thresholds, allowing users to take necessary precautions such as avoiding highly polluted areas, wearing protective masks, or adjusting outdoor activities based on air quality conditions.

A major advantage of IoT-Mobair is its scalability, enabling deployment in various settings, including urban environments, industrial zones, and public spaces. The system can be used for continuous monitoring in traffic-heavy areas, near factories, and in residential neighborhoods, helping both individual users and environmental agencies assess air quality more efficiently. The low-cost sensors and open-source hardware used in the project make it a cost-effective solution compared to traditional air quality monitoring stations, which are expensive and require significant infrastructure.

By integrating IoT, cloud computing, and mobile applications, this system ensures real-time and remote monitoring, increasing public awareness and engagement. Users can monitor air quality from anywhere, making informed decisions to protect their health and well-being. This accessibility is particularly useful for individuals with respiratory conditions, such as asthma or chronic lung disease, who need to avoid high pollution levels to prevent health complications.

The project also supports environmental and public health initiatives, enabling governments, researchers, and policymakers to make data-driven decisions. Authorities can use historical pollution data to enforce regulations, implement stricter emission controls, and develop urban policies that reduce environmental hazards. Additionally, industries and factories can monitor their own emissions, ensuring compliance with environmental safety standards.

Despite its benefits, the system faces some challenges. One key issue is sensor accuracy, as low- cost sensors may be affected by temperature, humidity, and calibration drift. To address this, periodic calibration and validation methods must be implemented. Additionally, Wi-Fi connectivity limitations in certain areas may hinder real-time data transmission. A possible solution is to integrate alternative communication technologies such as LoRaWAN or GSM, which provide better coverage and reliability.

Several future improvements can enhance the system's capabilities. One major enhancement is the integration of machine learning algorithms to analyze air quality trends and provide predictive insights. By using AI-driven models, the system could forecast pollution spikes and send early warnings to users. Another improvement is the incorporation of solar-powered sensors, making the system energy-efficient and sustainable, reducing dependency on external power sources.

Additionally, the project could expand its monitoring capabilities by integrating additional air quality parameters, such as SO_2, O_3 (ozone), and volatile organic compounds (VOCs). This would provide a more comprehensive assessment of air pollution, enabling better risk evaluation for public health and environmental safety.

The IoT-Mobair project presents a cost-effective, real-time, and scalable air pollution monitoring system that leverages IoT, cloud computing, and mobile applications. By providing secure, accessible, and real-time pollution data, this system enables users to take informed actions to protect their health. Governments and environmental agencies can utilize the system to track pollution trends, enforce policies, and implement sustainable urban planning solutions. With future advancements in AI, alternative communication protocols, and energy-efficient sensors, this project has the potential to play a critical role in global air pollution monitoring efforts, making air quality data more accessible, reliable, and impactful for individuals and communities worldwide.

2.5 IoT-Based Air Quality Monitoring System with Machine Learning for Accurate and Real-Time Data Analysis

IoT-Based Air Quality Monitoring System with Machine Learning for Accurate and Real-Time Data Analysis" (2023) introduces an advanced air quality detection system designed to provide accurate, real-time environmental monitoring. This system integrates IoT technology, machine learning, and cloud computing to measure and analyze air pollutants, offering valuable insights into pollution levels for both individual users and policymakers.

At its core, the system consists of high-precision gas sensors, a microcontroller, and a wireless communication module. The sensors detect a range of harmful gases, including CO_2, NO_2, CO, and ozone (O_3), measuring air quality in parts per million (PPM). These sensors provide real-time data on air pollution levels, ensuring that users receive timely and accurate information about the air quality in their surroundings.

The microcontroller unit (MCU) processes the data collected by the sensors and transmits it to a cloud-based platform via Wi-Fi or cellular networks. The cloud storage system allows for long- term data collection, making it possible to analyze historical trends and monitor pollution over time. This setup ensures that air quality data is securely stored and easily accessible from any location.

One of the most innovative aspects of this project is its integration with machine learning algorithms. These algorithms analyze the collected data to identify patterns, detect anomalies, and predict future pollution trends. By using predictive analytics, the system can provide early warnings for pollution spikes, helping individuals and authorities take preventive actions to mitigate air pollution exposure.

The system is designed to be portable, allowing it to be used in various environments, including residential areas, industrial facilities, urban spaces, and research institutions. Its portability ensures that air quality monitoring is not limited to fixed locations but can be conducted anywhere. This feature is particularly useful for environmental researchers, health professionals, and city planners, who require flexible solutions for tracking air pollution levels.

Users can access the collected data through a cloud-based web application or a mobile app, providing a user-friendly interface with real-time visualizations. The platform offers interactive graphs, charts, and heatmaps, making it easy to interpret air quality trends. Additionally, the system can send automated alerts and notifications when pollution levels exceed safe thresholds, allowing users to take necessary precautions such as limiting outdoor activities or wearing protective masks.

By combining IoT, cloud computing, and machine learning, this system provides a comprehensive approach to air quality monitoring. The real-time data analysis enables governments, businesses, and individuals to make informed decisions regarding environmental policies, urban planning, and public health measures. The data collected can also help authorities in regulating industrial emissions, optimizing traffic flow, and designing green spaces to reduce pollution levels.

The project also highlights the importance of data security and transmission reliability. The system uses secure communication protocols, such as HTTPS and MQTT with encryption, to ensure that data integrity and privacy are maintained. This prevents data tampering and guarantees that the collected air quality information remains authentic and reliable.

A significant advantage of this system is its scalability, making it suitable for deployment in smart city infrastructure. By integrating with existing environmental monitoring networks, the system can contribute to large-scale air quality assessment programs. Authorities can use the collected data to enforce air quality regulations, improve public transportation planning, and implement sustainable energy policies.

Despite its many advantages, the system faces some challenges. One of the main concerns is sensor accuracy and maintenance, as low-cost sensors may experience drift over time, requiring periodic calibration. Additionally, network connectivity limitations in remote areas may hinder real-time data transmission. These challenges can be addressed by enhancing sensor calibration methods and integrating alternative communication technologies, such as LoRaWAN and satellite networks.

To further enhance the system, future improvements could include the integration of additional sensors for detecting pollutants like sulfur dioxide (SO_2), ammonia (NH_3), and volatile organic compounds (VOCs). These additions would provide a more comprehensive analysis of air pollution, making the system even more effective in environmental monitoring.

Another potential upgrade is the use of more advanced machine learning models, such as deep learning algorithms, to improve predictive accuracy. These models could analyze complex relationships between pollution sources, weather conditions, and human activities, providing more accurate forecasts and enabling proactive pollution control measures.

Moreover, incorporating solar-powered sensors would make the system more sustainable, reducing dependency on external power sources and allowing for continuous, energy-efficient monitoring. Solar-powered units would be particularly beneficial for remote and rural areas, where electricity access is limited.

The IoT-Based Air Quality Monitoring System with Machine Learning provides a cost-effective, portable, and intelligent solution for real-time environmental monitoring. Its ability to detect pollution, analyze trends, and predict air quality fluctuations makes it a powerful tool for individuals, governments, and environmental researchers. By enabling data-driven decision- making, this system can contribute to the development of healthier urban environments, improved public safety, and more effective environmental policies.

As the project continues to evolve, the incorporation of AI-driven analytics, additional pollutant sensors, and renewable energy sources will further enhance its capabilities. The combination of IoT, cloud computing, and machine learning ensures that air quality monitoring remains accessible, scalable, and efficient, empowering communities to take informed action for a cleaner, healthier future.

2.6 GASDUINO - Wireless Air Quality Monitoring System Using Internet of

Things

The GASDUINO - Wireless Air Quality Monitoring System Using Internet of Things (2020) is an innovative project that focuses on the design and development of a portable air quality monitoring system using IoT technology. The system, known as GASDUINO, is built around an Arduino microcontroller and an MQ-135 gas sensor, which detects various harmful gases, including ammonia (NH_3), benzene, alcohol, and carbon dioxide (CO_2). The primary goal of the system is to provide real-time air quality monitoring in a portable and user-friendly manner.

The system operates by using the MQ-135 gas sensor to measure the concentration of different gases in the air. The sensor's readings are processed by the Arduino microcontroller, which analyzes the data and prepares it for transmission. The processed data is then sent wirelessly using Wi-Fi to a cloud-based platform, ensuring instant access to air quality information. The project uses Remote XY, a cloud-based service that allows remote communication between the GASDUINO system and a user interface, making it easier for users to monitor air quality in real- time.

One of the key components of this system is its Android-based mobile application, which provides real-time air quality data to users. Through this app, users can view the concentration levels of various gases, helping them make informed decisions about their environment. The app also includes an alert system, which notifies users when gas concentrations exceed safe limits, ensuring timely actions can be taken to mitigate potential health risks.

GASDUINO is designed to be highly portable, making it suitable for various environments, including homes, offices, industrial sites, and public spaces. The wireless and compact nature of the system allows it to be easily deployed in different locations, providing a cost-effective and accessible solution for air quality monitoring. The use of IoT technology and cloud computing ensures that the collected data is accurate, real-time, and remotely accessible.

The project highlights the importance of real-time air quality monitoring, especially in urban and industrial settings, where air pollution levels can fluctuate rapidly. By utilizing IoT and cloud technologies, GASDUINO ensures that users receive instant feedback about their air quality conditions. The system's scalability and affordability make it an excellent solution for individual users, businesses, and policymakers looking to improve air quality management.

The Arduino-based microcontroller is a critical part of the system, as it is responsible for processing sensor data and controlling wireless communication. The choice of MQ-135 as the primary sensor allows the system to detect a wide range of gases, making it versatile and efficient. The Remote XY cloud service plays a significant role in enabling seamless data transmission, allowing users to access air quality data from anywhere in the world.

One of the major advantages of GASDUINO is its ease of use. The system does not require complicated setup procedures, making it accessible even to non-technical users. The mobile application has a user-friendly interface, displaying air quality trends, graphical data, and alert notifications in a simple and understandable format.

The wireless capabilities of GASDUINO make it ideal for smart city applications, where multiple units can be deployed to monitor air pollution across large areas. The collected data can be used by government agencies, environmental organizations, and researchers to track pollution patterns and develop strategies for improving air quality.

GASDUINO's potential applications extend beyond personal use. It can be implemented in factories, chemical plants, and construction sites to monitor hazardous gas emissions, ensuring worker safety. Schools and hospitals can also benefit from real-time air quality tracking, helping to maintain a healthy indoor environment.

Despite its numerous benefits, the system does face some challenges. The accuracy of the MQ- 135 sensor can be affected by environmental conditions, requiring periodic calibration to maintain

data reliability. Additionally, network connectivity issues in remote areas could hinder real-time data transmission, making it necessary to explore alternative communication methods such as LoRaWAN or GSM.

To further improve the system, future enhancements could include the integration of additional gas sensors for detecting pollutants like sulfur dioxide (SO_2), nitrogen oxides (NO_x), and volatile organic compounds (VOCs). These additions would expand the system's capabilities and make it even more comprehensive for environmental monitoring.

Another potential upgrade is the incorporation of artificial intelligence (AI) and machine learning algorithms to enhance data analysis and predictive capabilities. AI models could analyze historical pollution trends and provide accurate forecasts of air quality changes, allowing users to take proactive measures.

Additionally, incorporating solar-powered sensors would make GASDUINO more sustainable, reducing its dependence on external power sources. Solar power would enable continuous, long- term monitoring, especially in remote areas or locations with limited electricity access.

GASDUINO represents a significant step forward in affordable and accessible air quality monitoring. By combining IoT, cloud computing, and mobile applications, it provides a real-time, user-friendly, and scalable solution for individuals, businesses, and governments to monitor and manage air pollution effectively.

2.7 A Global Multi-Unit Calibration as a Method for Large-Scale IoT Particulate Matter Monitoring Systems Deployments

The study "A Global Multi-Unit Calibration as a Method for Large-Scale IoT Particulate Matter Monitoring Systems Deployments" (2023) focuses on developing a global calibration methodology for improving the accuracy and reliability of IoT-based air quality monitoring systems. The research aims to solve one of the biggest challenges in large-scale IoT deployments: ensuring that air quality data collected from different sensors across various locations remains consistent and accurate.

The study proposes a multi-unit calibration method, which enables global standardization of air quality sensors rather than requiring individual calibration for each device. This approach ensures that data from different sensors can be directly compared, making large-scale pollution analysis and monitoring more reliable.

Particulate Matter (PM) sensors used in IoT air quality monitoring often suffer from calibration discrepancies due to variations in sensor models, environmental conditions, and manufacturing inconsistencies. These differences can lead to inconsistent readings, reducing the effectiveness of large-scale deployments.

By applying global calibration, this methodology helps in reducing measurement errors, allowing for more precise and standardized air quality data. This is particularly important for monitoring pollutants like PM2.5 and PM10, which have significant impacts on public health.

The proposed calibration strategy enables sensors to be adjusted in large quantities while ensuring that their accuracy remains high and consistent. This approach is crucial for building scalable and reliable air quality monitoring networks, especially in smart cities, industrial areas, and densely populated urban regions.

A key feature of this method is its applicability to massive IoT deployments, where thousands of sensors are deployed simultaneously. By ensuring uniform calibration, the system enables consistent data collection, making it ideal for large-scale environmental monitoring projects.

The study also highlights the role of cloud-based platforms in managing, storing, and processing air quality data. Once sensors are calibrated, they transmit data to a cloud server, where it is aggregated, analyzed, and visualized for decision-making.

Machine learning algorithms are incorporated to analyze pollution trends, detect anomalies, and improve forecasting accuracy. These AI-driven insights help in the development of data-driven policies for pollution control and environmental health management.

The global calibration approach ensures that data remains consistent across different geographical regions, making it possible for researchers, policymakers, and urban planners to make informed decisions based on reliable air quality data.

By standardizing sensor performance globally, this methodology enables large-scale IoT air quality monitoring networks to be deployed more efficiently and cost-effectively. The study

suggests that future improvements could include automated recalibration and adaptive AI-based corrections to further enhance sensor accuracy.

In conclusion, this research provides a scalable, reliable, and cost-effective solution for deploying accurate IoT-based air quality monitoring systems worldwide. It plays a crucial role in public health, environmental policy, and pollution control, ensuring that large-scale deployments remain effective and precise.

3 Existing System

The existing air quality monitoring system utilized by the Delhi Pollution Control Committee (DPCC) is based on fixed monitoring stations strategically deployed across various locations. These stations are designed to measure critical parameters such as the Air Quality Index (AQI) and other pollution-related indicators. However, while these stations provide valuable insights into localized air quality, they suffer from several limitations that reduce their overall effectiveness in representing broader regional pollution levels. 3 One significant drawback is that fixed stations often capture data that is heavily influenced by the immediate surroundings. For example, a station located near an industrial zone may record higher pollution levels due to emissions from nearby factories.

This localized data may not accurately reflect the air quality of the larger area. Similarly, temporary activities like construction projects near a monitoring station can result in elevated readings, creating a skewed perception of pollution levels across the city or region. Another limitation is the system's inability to adapt to the dynamic and spatially diverse nature of pollution. Fixed stations are stationary and cannot monitor varying pollution levels caused by mobile sources such as traffic congestion, seasonal agricultural burning, or transient industrial operations. As pollution sources shift due to weather patterns, human activities, or festivals, these fixed stations lack the flexibility to track and assess changing pollution dynamics effectively.

The system also suffers from limited spatial coverage. Since fixed monitoring stations are resource-intensive to set up and maintain, only a finite number can be deployed across a city. This results in gaps in monitoring coverage, leaving many areas unaccounted for in air quality assessments. For instance, urban areas with high population density or regions experiencing rapid industrial growth may not be adequately monitored due to the constraints of the current system. In addition to limited spatial coverage, the system struggles to deliver real-time data from multiple locations simultaneously. Timely and actionable data is crucial for informed decision-making and

prompt intervention in pollution hotspots. However, the fixed station network often lags in providing up-to-date information that policymakers and environmental agencies require for effective planning and response. The resource-intensive nature of fixed monitoring stations presents another significant challenge. Establishing and maintaining these stations involves considerable investment in infrastructure, equipment, and manpower. This limits the feasibility of expanding the network to include more stations, thereby constraining the system's ability to address the growing and complex challenges of air quality management in a rapidly urbanizing environment. 4 Despite these limitations, fixed monitoring stations remain the backbone of current air quality monitoring systems. However, the gaps in their ability to capture comprehensive, dynamic, and real-time data emphasize the need for innovative solutions. To address these challenges, technological advancements such as mobile monitoring stations and drone based systems could play a pivotal role. These alternatives offer the potential to provide a more accurate, adaptable, and comprehensive understanding of air quality across diverse regions, paving the way for more effective environmental management strategies.

3.1 Limitations of existing system

1. Limited Coverage:Fixed monitoring stations are stationary, providing data only for the immediate surrounding area. This results in gaps in coverage, especially in remote or rural locations.
2. Non-representative Data:Stations near industrial zones or temporary construction sites produce higher pollution readings, which may not reflect the general air quality of the larger area.
3. Temporary Activity Impact: Localized activities, like construction or heavy traffic, can cause temporary spikes

in pollution readings, skewing data and failing to provide an accurate long-term picture of air quality.

4. Lack of Mobility: Fixed stations cannot track pollution across different areas dynamically or capture data from mobile sources like vehicles, which are major contributors to urban air pollution.
5. High Setup and Maintenance Costs: The installation and maintenance of fixed stations are expensive, limiting the number of monitoring points and making it difficult to expand coverage to new or high-risk areas.
6. Outdated Technology: The current technology used in many stations is not compatible with modern tools such as IoT devices or drones, limiting real-time data acquisition and integration.
7. Lack of Real-Time Monitoring: Fixed stations provide data at intervals, which may delay responses to pollution events, hindering timely policy adjustments or emergency actions.

8. Limited Public Access: Data from fixed stations is not always easily accessible to the public, reducing awareness and engagement in pollution control efforts.

8. Inadequate Integration with Modern Systems: Existing systems are not well-integrated with other technologies (e.g., drones, mobile apps) that could enhance real-time monitoring and data aggregation.
9. Insufficient Data for Dynamic Areas: Fixed stations are not well-equipped to handle the dynamic nature of urban environments, where pollution levels can vary based on time of day, season, or specific activities.
10. Reliability Issues: Fixed stations may be affected by extreme weather conditions, technical failures, or other operational challenges, which can compromise the quality and reliability of the data.

4. Literature Survey

[1]. **Smart and Portable Air-Quality Monitoring IoT Low-Cost Devices in Vehicles(2022)** presents an innovative solution for real-time air quality monitoring using IoT technology. Traditional air pollution monitoring relies on stationary stations, which fail to provide dynamic, location-based insights. This project integrates low-cost environmental sensors, a microcontroller unit, MQTT-based data transmission, and edge computing into a vehicle- mounted system. The sensors continuously measure key pollutants such as CO_2, NO_2, particulate matter (PM2.5 and PM10), temperature, and humidity. The collected data is processed by a microcontroller and transmitted via MQTT (Message Queuing Telemetry Transport), a lightweight communication protocol optimized for IoT applications. The data is then stored in a time-series database and analyzed using edge computing, reducing latency and optimizing performance. The system enables real-time pollution mapping, providing valuable insights for urban planners, researchers, and health organizations. Through a mobile app or dashboard, users can visualize historical trends and receive alerts about critical pollution levels in different locations. The solution is cost-effective, energy-efficient, and ideal for smart city

applications, enabling proactive measures for environmental protection and public health.

[2]. **A Low-Cost IoT Mobile System for Air Quality Monitoring in Developing Countries (2023)** presents an affordable solution for real-time air quality monitoring in low-resource regions. The system uses mobile sensors installed in vehicles or carried by individuals, paired with a microcontroller (ESP32 or Arduino) and wireless communication (Wi-Fi, Bluetooth, GSM) to detect pollutants like PM2.5, CO_2, NO_2, and more. The data is transmitted to a cloud server for analysis and visualization through a mobile app or web dashboard. The system is scalable, cost-effective, and easily deployed, helping identify pollution hotspots and inform policy decisions. Future upgrades may include machine learning and solar-powered sensors for sustainability. The system's focus on mobility enables dynamic air quality mapping across various regions, unlike stationary monitoring stations. This allows for better tracking of pollution patterns over time and a more comprehensive understanding of environmental conditions. By leveraging low-cost sensors and open-source technology, the system remains highly affordable, making it accessible to governments, researchers, and local communities in developing nations. It also helps inform urban planning and traffic management decisions, while raising public awareness about pollution. The system's flexibility and scalability make it a vital tool for environmental health monitoring in resource-constrained settings.

[3]. **IoT-Based Air Quality Monitoring System for Particulate Matter in Subway Tunnels (2020)** project provides a real-time solution to measure PM2.5 and PM10 levels in subway tunnels. Using IoT sensors**,** microcontrollers (ESP32 or Raspberry Pi), and cloud computing, it collects data on air quality and transmits it via Wi-Fi, LoRa, or GSM to a cloud server for storage and analysis. The data is accessible through a web dashboard or mobile app, allowing authorities to monitor pollution levels and take immediate action on ventilation and air purification. The system helps improve the health and safety of subway passengers and workers by detecting hazardous levels of particulate matter. Future enhancements could include AI-powered predictive analytics and expanding the system to monitor additional gases like CO and NO_2**.** This innovative solution offers real-time insights into air quality and supports sustainable public transportation systems.

[4]. **IoT System for Air Pollution Monitoring with Safe Data Transmission (2023)** provides a real-time, localized solution for tracking air quality parameters like PM2.5, PM10, CO_2, NO_2**,** temperature, and humidity using IoT sensors. The system uses microcontrollers (ESP32 or Arduino) to process the data and transmit it securely via HTTPS or MQTT to a cloud server. The secure transmission protocols ensure that the data remains untampered, maintaining data integrity and privacy. Users can access the data through a web dashboard or mobile app,

visualized as graphs, heatmaps, and real-time alerts.This system is scalable and can be deployed in various environments, such as urban areas, industrial zones, or rural regions**,** for localized monitoring. It helps identify pollution hotspots, enabling targeted actions to reduce exposure. By ensuring secure data transmission, the system supports policy enforcement and environmental health decisions. Future upgrades may include AI for anomaly detection, integration with satellite data, and solar-powered sensors for sustainable and widespread deployment. This project offers a reliable, scalable, and secure air quality monitoring solution. [5].

Internet of Things Mobile - Air Pollution Monitoring System (IoT-Mobair) (2017) introduces a real-time air quality monitoring system using IoT technology. The system consists of gas sensors (CO_2, CO, NO_2), connected to an Arduino microcontroller that processes and transmits data. In the first phase, sensors measure pollutants, and the data is transmitted via Wi-Fi to a cloud platform in the second phase for storage and analysis.The third phase involves a mobile Android application that provides real-time data and visualizations, allowing users to track pollution levels through graphs, alerts, and notifications. This helps users make informed decisions to protect their health. The system is scalable and affordable, utilizing low-cost sensors and open-source hardware. It can be deployed in urban areas, industrial zones, and public spaces for continuous monitoring.The mobile app enhances accessibility and engagement, making it easy for anyone with a smartphone to monitor air quality. This project provides an effective and cost-efficient solution for air pollution monitoring, combining IoT, cloud computing, and mobile applications. Future upgrades could include machine learning for predictive analysis and solar-powered sensors for greater sustainability.

[6]. **GASDUINO - Wireless Air Quality Monitoring System Using Internet of Things (2020)** project focuses on creating a portable air quality monitoring system using IoT technology. Built around an Arduino microcontroller and the MQ-135 gas sensor, it detects harmful gases like ammonia (NH_3), benzene, alcohol, and carbon dioxide (CO_2). The system processes the data from the sensor and wirelessly transmits it using Wi-Fi to a cloud platform through Remote XY.An Android app serves as the user interface, enabling real-time access to air quality data on mobile devices. The app displays gas concentration levels and sends alerts when pollutant levels exceed safe thresholds. GASDUINO is designed to be portable and wireless, making it suitable for homes, offices, industrial areas, and public spaces.This affordable system provides instant feedback on air quality, offering real-time monitoring for better decision-making. The system's use of IoT and cloud technologies ensures that air quality data is easily accessible and actionable. The wireless feature enhances scalability, allowing

easy deployment in various environments. GASDUINO provides an efficient, low-cost solution for managing air quality and ensuring healthier living conditions.

[7]. **Global Multi-Unit Calibration for IoT Particulate Matter Monitoring Systems (2023)** study addresses the challenge of ensuring accurate and reliable air quality data in large-scale IoT deployments. The proposed multi-

unit calibration method enables global calibration of IoT sensors, ensuring consistent data across diverse locations and sensor models. This approach minimizes discrepancies due to differences in sensor models, environmental conditions, and manufacturing variations. It ensures that data from sensors, such as those measuring PM2.5 and PM10, can be accurately compared and analyzed across geographic areas.The methodology is especially useful for large-scale deployments, such as smart cities and industrial sites, where thousands of sensors are required. It aims to maintain the accuracy of particulate matter sensors and reduce measurement errors. Data from calibrated sensors is transmitted to a cloud-based platform, where it is processed and analyzed. Machine learning algorithms can then detect pollution patterns and anomalies, offering insights into pollution trends and supporting better air quality management.The study provides a scalable and cost- effective solution for large-scale IoT deployments, ensuring global accuracy for air quality monitoring systems. This methodology can significantly improve environmental health monitoring, policy-making, and pollution control efforts.

Table 1: Literature Survey Table

References	Proposed Method	Advantages	Limitations
[1]	Mobile IoT system with sensors measuring PM2.5, PM10, CO_2, NO_2, and environmental parameters transmitted via Wi-Fi or GSM	Affordable, scalable, accessible, real-time pollution monitoring.	Dependent on network coverage, sensor calibration could vary.
[2]	IoT system with PM sensors in subway tunnels transmitting data to cloud server for analysis	Real-time monitoring, improved air quality management, early hazard detection	Limited to subway tunnels, needs infrastructure for full deployment
[3]	Real-time localized monitoring using IoT sensors with secure data transmission via HTTPS/MQTT	Secure data transmission, scalable, localized pollution monitoring.	Security protocols can increase complexity, needs constant connectivity
[4]	Three-phase air pollution monitoring with gas sensors connected to Arduino, cloud data storage, and mobile app access	Affordable, real-time, mobile access to pollution data	Limited to sensor accuracy, requires continuous Wi-Fi connection

[5]	Portable air quality detection device with sensors and machine learning for real-time data analysis	Accurate, real-time data, predictive analysis using machine learning	Machine learning models need continuous data for training, device portability can be a limitation
[6]	Arduino-based portable system with MQ-135 sensor and wireless communication via Wi-Fi to a cloud platform	Wireless, real-time, cost-effective, easy deployment	Sensor may be sensitive to environmental changes, depends on Wi-Fi availability
[7]	Global calibration methodology for standardizing data from IoT particulate matter sensors	Ensures consistency across multiple sensors, scalable for large IoT deployments	Calibration process can be complex and time- consuming, dependent on consistent environmental factors

5 Conclusion

Air Quality Index (AQI) mobile monitoring systems are reshaping the landscape of environmental monitoring by addressing the limitations of traditional stationary stations. These systems provide high-resolution, real-time data that captures localized pollution variations and hotspots, offering a more dynamic understanding of air quality. By equipping vehicles, drones, and individuals with portable sensors, AQI mobile monitoring systems ensure comprehensive spatial coverage that is otherwise unachievable. The integration of these systems with mobile applications and online platforms enables seamless data access, empowering individuals and communities with actionable insights. During periods of high pollution, vulnerable populations can take precautions, and authorities can implement timely interventions, such as traffic rerouting or industrial activity regulation. Beyond immediate responses, the detailed data generated by these systems aids long- term air quality management. Policymakers can leverage this information to evaluate the effectiveness of existing regulations and design targeted strategies for pollution control. The ability to identify and track pollution sources fosters more informed decision-making and promotes environmental accountability. Furthermore, AQI mobile monitoring systems contribute to public awareness by directly involving communities in environmental protection efforts. The accessibility of real-time AQI data inspires collective action, enhancing the impact of pollution mitigation strategies. In essence, these systems bridge the gap between traditional methods and modern technological capabilities, revolutionizing air quality monitoring. By offering detailed, timely, and accessible information, AQI mobile monitoring systems empower individuals, communities, and policymakers to safeguard public health and ensure sustainable environmental management.

Future Work

Future work on AQI mobile monitoring systems should focus on enhancing accuracy, integration, and usability through advanced technologies. The incorporation of multi-sensor fusion techniques, including optical, laser-based, and electrochemical sensors, can improve pollutant detection and mitigate calibration issues. AI-driven data analysis and predictive modeling can further enhance real-time pollution monitoring by identifying patterns, detecting anomalies, and providing early warnings. The adoption of 5G and edge computing will facilitate faster data transmission and real- time processing, allowing for instant decision-making in pollution control measures. Integrating AQI mobile monitoring with smart city infrastructure and IoT networks can enhance automated

responses, such as adjusting traffic flow or controlling industrial emissions. Additionally, citizen science initiatives using low-cost portable sensors can contribute to crowdsourced air quality data, increasing coverage and public engagement. To address sensor accuracy challenges, future research should explore self-calibrating sensors, AI-assisted calibration techniques, and standardized global protocols. Improved data visualization using augmented reality (AR) and interactive dashboards can provide users with real-time pollution heatmaps, risk alerts, and AI- driven recommendations for minimizing exposure. Moreover, linking AQI data with environmental policymaking through AI-powered decision support systems can help authorities enforce air quality regulations more dynamically. Ensuring the sustainability of these monitoring systems is also crucial, with future developments focusing on solar-powered and energy-efficient sensors to enable long-term deployment with minimal maintenance. Furthermore, expanding AQI monitoring to indoor environments by integrating sensors with smart home devices and HVAC systems can provide a comprehensive understanding of air quality in both outdoor and indoor settings. By addressing these aspects, future advancements in AQI mobile monitoring systems will revolutionize air pollution control, enhance environmental policymaking, and empower individuals and communities with real-time, actionable insights.

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