AIR QUALITY MONITORING SYSTEM DASHBOARD

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***Abstract*— Air pollution has emerged as a critical environmental and public health challenge, particularly in rapidly growing urban regions where deteriorating air quality significantly impacts human health, transportation, and overall quality of life. Conventional monitoring approaches often provide fragmented information, limited accessibility, and delayed updates, making timely assessment and decision-making difficult. The proposed Air Quality Monitoring System Dashboard utilizes real-time environmental data obtained from the World Air Quality Index (WAQI) public API, collecting historical and live observations for multiple Indian cities. The dataset includes Air Quality Index (AQI), pollutant concentrations such as PM2.5, PM10, CO, NO_2, SO_2, and O_3, along with weather attributes and forecast information. The collected data undergoes normalization, validation, timestamp synchronization, and structured storage in MongoDB to support efficient querying and historical trend analysis. The system integrates Node.js with Express 5 for backend services, MongoDB with Mongoose for persistent storage, React 19 with Vite and Tailwind CSS for interactive visualization, Socket.IO for real-time communication, and React-Leaflet and Recharts for geospatial and analytical representations. Performance is evaluated through real-time data synchronization, dashboard responsiveness, visualization accuracy, API response time, and reliable historical data retrieval. Experimental evaluation demonstrates efficient real-time monitoring with low-latency updates, accurate visualization, and dependable historical analysis, providing an integrated platform that enhances environmental awareness and supports informed health-conscious decision-making.**

Keywords*— *Air Quality Monitoring, Air Quality Index (AQI), World Air Quality Index (WAQI), Real-Time Dashboard, Internet of Things (IoT), MERN Stack.

I. Introduction

Air pollution has become one of the most significant environmental challenges affecting modern societies, particularly in rapidly urbanizing regions where industrialization, transportation, and population growth continuously increase the concentration of harmful pollutants in the atmosphere. Poor air quality contributes to respiratory illnesses, cardiovascular diseases, reduced life expectancy, and adverse ecological effects, making continuous environmental monitoring an essential component of sustainable urban development. Governments, environmental agencies, and healthcare organizations increasingly rely on air quality information to formulate policies, issue public health advisories, and support emergency response planning. The widespread availability of Internet-based environmental monitoring services and connected sensing technologies has enabled continuous observation of atmospheric conditions across multiple geographic locations. At the same time, advances in web technologies have created new opportunities for presenting environmental information through interactive and user-friendly digital platforms that improve accessibility and public awareness [1][2][3].

Despite these advancements, existing air quality monitoring platforms continue to face several practical limitations. Many available systems provide delayed updates, limited historical visualization, inadequate personalization, or insufficient support for monitoring multiple cities within a unified interface. In addition, users often depend on separate applications or static web portals that lack real-time communication, interactive geographical exploration, and integrated notification capabilities. Administrative management of monitored locations is also frequently restricted, reducing the flexibility required to accommodate expanding monitoring requirements. These shortcomings limit the effectiveness of existing solutions in supporting timely environmental assessment, informed public decision-making, and efficient management of continuously changing air quality conditions across diverse urban environments [4][5][6].

The primary objective is to develop a comprehensive web-based Air Quality Monitoring System Dashboard capable of delivering accurate, real-time environmental information through an integrated and scalable platform. The system is designed to collect, manage, store, and present air quality information obtained from publicly available environmental sources while supporting continuous updates for multiple cities. It also provides secure access for different categories of users, allowing personalized monitoring preferences alongside administrative management capabilities. Furthermore, the platform incorporates historical visualization, comparative analysis, geographical representation, and automated alert mechanisms to improve accessibility and usability for both general users and system administrators. These contributions collectively establish an efficient environment for monitoring changing atmospheric conditions through a centralized and interactive interface [7][8].

The availability of a reliable and responsive air quality dashboard offers considerable societal and technological benefits by improving public awareness of environmental conditions and encouraging preventive health measures based on current air quality levels. The integration of real-time information, historical records, visualization tools, and secure web-based access creates an effective decision-support environment for citizens, environmental authorities, healthcare organizations, educators, and researchers. Such a platform can assist in promoting environmental transparency, supporting evidence-based policy formulation, and encouraging broader community participation in pollution monitoring initiatives. The resulting system demonstrates how modern web technologies can improve environmental information dissemination while providing a scalable foundation for future smart-city and public health applications that require continuous monitoring of dynamic environmental conditions [9][10]. Air pollution has become one of the most significant environmental challenges affecting modern societies, particularly in rapidly urbanizing regions where industrialization, transportation, and population growth continuously increase the concentration of harmful pollutants in the atmosphere. Poor air quality contributes to respiratory illnesses, cardiovascular diseases, reduced life expectancy, and adverse ecological effects, making continuous environmental monitoring an essential component of sustainable urban development. Governments, environmental agencies, and healthcare organizations increasingly rely on air quality information to formulate policies, issue public health advisories, and support emergency response planning. The widespread availability of Internet-based environmental monitoring services and connected sensing technologies has enabled continuous observation of atmospheric conditions across multiple geographic locations. At the same time, advances in web technologies have created new opportunities for presenting environmental information through interactive and user-friendly digital platforms that improve accessibility and public awareness [1][2][3].

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II. Related Work

Air quality monitoring has received considerable attention because of its direct relationship with public health, environmental sustainability, and urban planning. The World Health Organization emphasized that ambient air pollution remains one of the leading global environmental risk factors, contributing significantly to premature mortality and chronic respiratory and cardiovascular diseases. The report also highlighted the importance of continuous monitoring systems and timely dissemination of air quality information to reduce public exposure and improve policy formulation [11]. Samet et al. demonstrated a strong association between fine particulate matter and mortality across multiple metropolitan regions, confirming that even moderate increases in particulate concentration can substantially affect human health [12]. Similarly, Pope and Dockery presented comprehensive evidence linking long-term exposure to particulate matter with respiratory and cardiovascular disorders, reinforcing the necessity of reliable monitoring infrastructures for public health protection [13].

Brunekreef and Holgate provided an extensive overview of the biological and epidemiological impacts of air pollution, emphasizing that multiple pollutants collectively influence respiratory diseases, cardiovascular complications, and overall mortality. Their findings established a strong scientific foundation for integrating health-oriented environmental monitoring into urban management systems [14]. Kumar et al. examined the emergence of low-cost sensing technologies for monitoring urban pollution and concluded that affordable sensing networks significantly improve spatial coverage and accessibility compared with conventional monitoring stations. However, they also identified challenges related to data quality, calibration, and long-term reliability, limiting their widespread deployment without appropriate validation mechanisms [15]. Snyder et al. further discussed the transformation of traditional air pollution monitoring toward distributed sensing environments, highlighting improvements in real-time environmental observations while noting concerns regarding sensor accuracy, interoperability, and large-scale data management [16].

Recent investigations have increasingly focused on personalized monitoring and environmental awareness. Kaufman and McMullen highlighted the growing importance of personal air quality monitoring devices for enabling individuals to understand localized pollution exposure and make informed health decisions. Despite these advantages, their observations indicated that individual monitoring solutions often lack integration with centralized platforms capable of supporting comprehensive visualization and historical analysis [17]. Jaffe and Wigder investigated ozone generation associated with wildfire events and demonstrated that rapidly changing environmental conditions require monitoring systems capable of delivering timely updates for dynamic pollution scenarios. Their findings emphasized the importance of continuous observation to improve environmental response and public safety [18]. Dye proposed standardized guidelines for developing Air Quality Index frameworks, establishing consistent pollutant categorization and communication methods that improve public interpretation of environmental conditions. Nevertheless, the guidelines primarily focus on index formulation rather than interactive dissemination through modern web-based platforms [19].

Wong et al. analyzed the relationship between air pollution and mortality in densely populated urban communities, demonstrating that socially vulnerable populations experience disproportionately greater health impacts from deteriorating air quality. Their findings further reinforced the importance of accessible environmental information systems that support timely public awareness and informed decision-making [20]. Although previous contributions have significantly advanced knowledge regarding pollutant measurement, health impacts, sensing technologies, and AQI standardization, several practical challenges remain unresolved. Existing solutions frequently provide limited personalization, fragmented visualization capabilities, insufficient historical exploration, delayed information updates, and restricted administrative management within a unified platform. These limitations reduce their effectiveness for both environmental authorities and the general public. The present system addresses these gaps by providing an integrated web-based dashboard that combines continuous environmental monitoring, real-time visualization, geographic representation, historical analysis, secure user access, personalized notifications, and administrative management within a scalable platform, thereby improving accessibility, environmental awareness, and decision support for diverse stakeholders.

III. Materials And Methods

The proposed Air Quality Monitoring System is designed to provide continuous, real-time monitoring and visualization of environmental conditions using live data obtained from the World Air Quality Index (WAQI) public API for multiple cities. The overall workflow includes automated data acquisition, validation, normalization, structured storage, and efficient management of air quality observations to maintain a consistent historical repository for analysis and visualization. A scheduled background polling mechanism implemented using node-cron periodically retrieves updated environmental measurements, while Socket.IO enables instant synchronization of newly collected information with connected clients, ensuring low-latency real-time updates. The system employs a MERN-inspired architecture, integrating Node.js, Express 5, MongoDB, React 19, Vite, Tailwind CSS, React-Leaflet, and Recharts to deliver scalable backend services and interactive visual analytics. Role-based JWT authentication, personalized AQI alerts, browser push notifications, email notifications, administrative monitoring controls, and CSV export capabilities further enhance usability, accessibility, and operational efficiency. This integrated framework provides reliable environmental monitoring, historical trend analysis, informed health recommendations, and an extensible foundation for future smart-city environmental management applications.

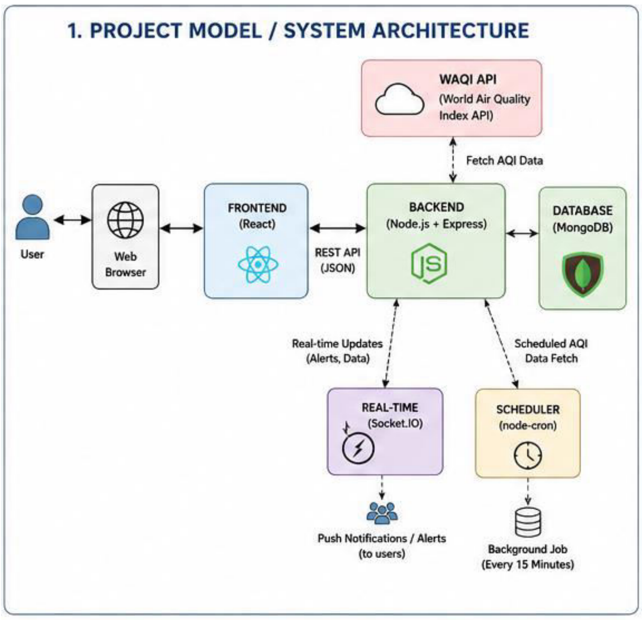


Fig. 1. System Architecture

B) Modules:

Data Acquisition: The system acquires real-time air quality information from the World Air Quality Index (WAQI) public API for all monitored cities at predefined intervals. The retrieved data includes Air Quality Index (AQI), pollutant concentrations, weather parameters, and forecast information. This acquisition process ensures that the application continuously receives updated environmental information from a reliable external source. Regular data collection forms the foundation of the monitoring platform by providing timely, consistent, and comprehensive observations required for visualization, historical analysis, and alert generation.

Data Validation and Cleaning: The collected air quality data undergoes validation to ensure that only complete and meaningful records are retained before storage. Invalid, incomplete, or inconsistent measurements are filtered to maintain data integrity and prevent inaccurate visualizations or notifications. Standardizing the incoming information from the external API improves the consistency of pollutant values, weather parameters, and timestamps. This preprocessing stage enhances the overall reliability of the dashboard and supports dependable historical analysis, reporting, and decision-making.

Data Normalization and Structuring: The validated environmental data is organized into a standardized format by grouping AQI values, pollutant concentrations, meteorological information, forecast records, and timestamps into a unified data structure. Maintaining a consistent representation simplifies storage, retrieval, and visualization across all monitored cities. Structured data organization improves interoperability between application components and enables efficient processing for charts, maps, dashboards, and notification services while ensuring scalability as the number of monitored locations increases.

Historical Data Storage and Indexing: Each processed air quality observation is stored as a historical record together with its associated timestamp, enabling continuous accumulation of environmental information over time. Appropriate indexing strategies are employed to optimize retrieval efficiency for historical trend visualization and comparative analysis. Maintaining a structured historical repository allows users to observe long-term pollution patterns, evaluate environmental changes, and generate downloadable reports while ensuring fast query performance even as the dataset continues to grow.

Scheduled Data Synchronization: The application periodically synchronizes environmental information by automatically retrieving the latest readings for every active monitoring location according to a configurable schedule. The synchronization mechanism processes multiple cities independently to ensure that temporary failures affecting individual locations do not interrupt the overall update process. This approach improves system reliability, maintains continuous monitoring, and guarantees that users receive the most recent air quality information without requiring manual intervention.

AQI Categorization: After data collection, numerical Air Quality Index values are classified into standardized air quality categories ranging from Good to Hazardous using internationally recognized threshold levels. Categorizing AQI values transforms raw numerical measurements into meaningful environmental conditions that are easier for users to interpret. This preprocessing stage supports consistent visualization, color-based representation, health recommendations, and alert generation while improving the accessibility of complex environmental information for a wide range of users.

Real-Time Data Synchronization: Following successful data processing and storage, the updated air quality information is immediately synchronized with connected client applications. This synchronization ensures that dashboards, charts, and maps display the latest environmental conditions without requiring manual page refreshes. Real-time dissemination significantly improves user experience by providing instant access to newly collected observations, thereby supporting timely environmental awareness and rapid response to changing air quality conditions.

Alert Threshold Evaluation: The processed air quality measurements are continuously compared against user-defined alert thresholds for monitored favourite cities. Whenever the observed AQI exceeds the configured limit, the system generates timely browser or email notifications to inform affected users. Evaluating alert conditions during data processing enables proactive environmental awareness, supports preventive health decisions, and enhances personalization by delivering notifications based on individual monitoring preferences rather than generic warning levels.

D) Algorithms

WAQI Data Retrieval: The WAQI data retrieval mechanism periodically acquires real-time air quality information from the World Air Quality Index API for all monitored locations. It ensures consistent access to current AQI, pollutant concentrations, weather parameters, and forecast information, providing reliable environmental data for visualization, historical storage, and alert generation.

Scheduled Polling: The scheduled polling algorithm automatically initiates environmental data collection at predefined intervals, ensuring continuous synchronization with the external data source. Automated execution minimizes manual intervention, maintains data freshness, and provides reliable monitoring suitable for real-time environmental applications.

Concurrent Processing: The concurrent processing algorithm retrieves air quality information for multiple cities simultaneously while isolating individual request failures. This approach improves scalability, reduces overall processing time, and enhances system robustness by ensuring that temporary failures affecting one location do not interrupt updates for remaining monitored cities.

AQI Categorization: The AQI categorization algorithm converts numerical Air Quality Index values into standardized environmental quality categories based on internationally accepted threshold ranges. This classification improves interpretability, enables consistent visualization, supports health recommendations, and simplifies environmental decision-making for end users.

JSON Web Token (JWT) Authentication: The JSON Web Token authentication algorithm provides secure identity verification for users and administrators by validating authenticated sessions before granting access to protected resources. This mechanism enhances application security while supporting efficient role-based authorization across different system components.

bcrypt Password Hashing: The bcrypt password hashing algorithm protects user credentials by transforming passwords into secure encrypted representations before storage. This approach significantly strengthens authentication security, prevents exposure of sensitive information, and safeguards user accounts against unauthorized access.

Socket.IO Real-Time Synchronization: The Socket.IO synchronization algorithm instantly broadcasts newly available air quality information to all connected clients following each successful update cycle. Real-time communication eliminates manual page refreshing, minimizes latency, and ensures consistent environmental information across all active dashboard sessions.

Browser Push Notification: The browser push notification algorithm continuously evaluates user-defined AQI thresholds and delivers immediate notifications whenever monitored environmental conditions exceed configured limits. This mechanism improves user awareness and supports proactive health-related decision-making through timely alert delivery.

Email Notification: The email notification algorithm automatically distributes personalized environmental alerts whenever air quality conditions exceed configured thresholds. By providing reliable remote notification delivery, it ensures that users remain informed even when the dashboard application is not actively in use.

CSV Export: The CSV export algorithm transforms historical air quality observations into a structured tabular format suitable for offline storage and analysis. This functionality facilitates external reporting, long-term environmental assessment, and interoperability with spreadsheet and statistical analysis tools.

MongoDB Compound Indexing: The compound indexing mechanism organizes historical air quality records using optimized indexing on city identifiers and timestamps. This strategy accelerates historical data retrieval, improves query efficiency, and supports scalable performance for trend analysis and visualization as the database continues to expand.

IV. Experimental Results

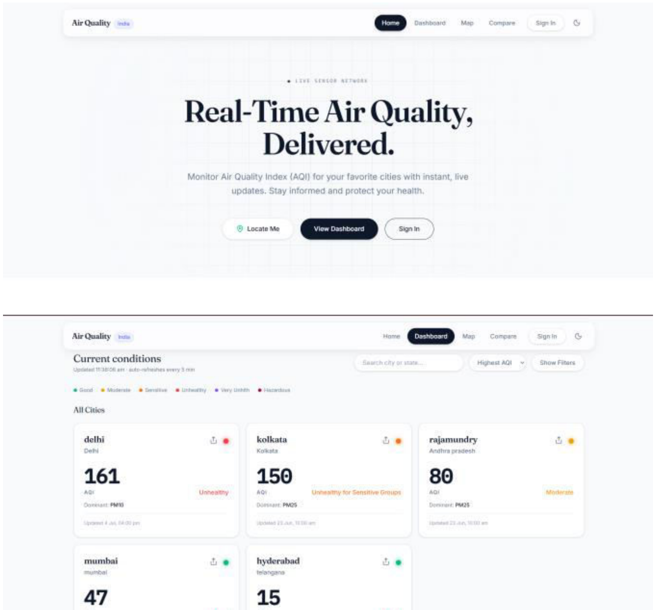


Fig.2 Public Dashboard — City Grid

The Dashboard serves as the primary landing page for authenticated users, providing a comprehensive overview of air quality conditions across monitored cities. The interface is designed to be informative at a glance while offering pathways to deeper exploration.

The dashboard layout begins with a header section that displays the application title and descriptive subtitle, establishing context for the displayed data. Immediately below the header, a statistics overview provides five key metrics: the total number of monitored cities, the count of cities with good air quality, the count with moderate air quality, the count with unhealthy air quality, and the average AQI across all cities. These statistics are displayed in color-coded cards that reinforce the meaning of different air quality categories.

Below the statistics, the advanced filter section enables users to refine the displayed city list by search terms, state, country, and sorting preferences. The filter interface is designed to be intuitive, with clear labels and responsive controls that provide immediate feedback as users interact with them.

The alert panel appears below the filter section, displaying active alerts for the user. The panel includes a notification badge indicating the number of active alerts, along with detailed information about each alert including the associated city, threshold condition, and status.

The main content area features a responsive grid of city cards, with each card providing a compact summary of air quality for a single city. The cards display the city name, state, country, current AQI value, category label with appropriate color coding, dominant pollutant, and timestamp. A star icon on each card enables users to toggle the city as a favorite, with the state persisted to the user's profile.

The dashboard demonstrates excellent responsiveness across different screen sizes. On desktop displays, cards are arranged in a four-column grid, providing efficient use of screen real estate. On tablet displays, the grid adjusts to three columns, maintaining readability while accommodating the smaller screen. On mobile devices, a single-column layout provides optimal readability with appropriately sized touch targets.

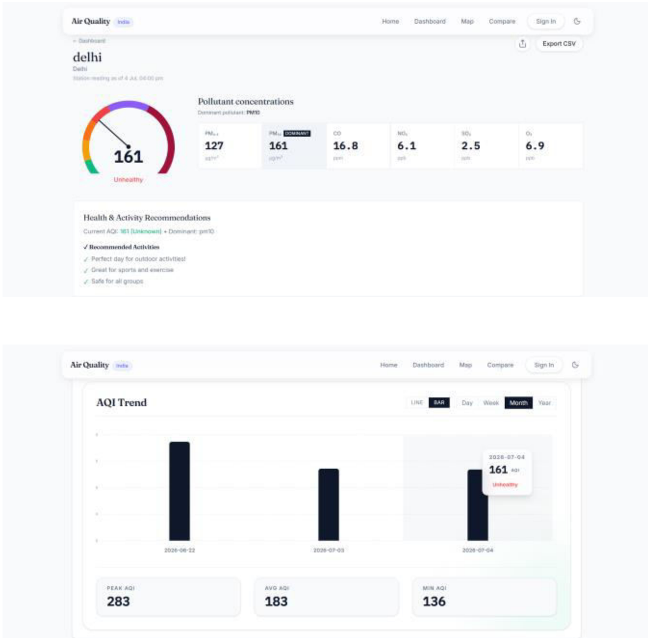


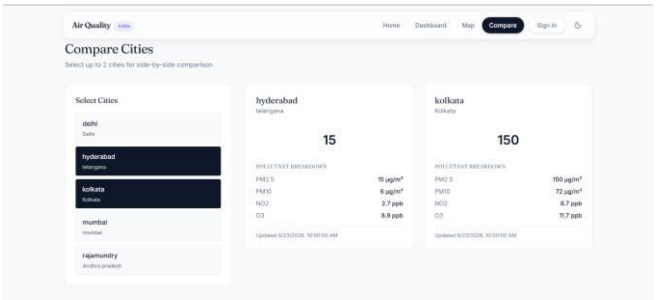
Fig.3 City Detail

The City Detail view provides comprehensive information about a specific city, accessed by clicking on any city card from the dashboard or map view. The detail view is designed to support in-depth analysis and exploration of air quality data for a single location.

The page header displays the city name, state, and country, with a prominent AQI indicator that shows the current value with color coding and category label. The header also includes a button to toggle the city as a favorite and navigation controls to return to the dashboard or view related data.

The current conditions section displays real-time data including the AQI value with visual indicator, the dominant pollutant if available, and a table of individual pollutant concentrations including PM2.5, PM10, NO2, O3, CO, and SO2. Meteorological data is also displayed, including temperature, humidity, pressure, wind speed, and wind direction where available.

The historical trends section features an interactive chart that displays AQI trends over time. Users can select from predefined timeframes of 7 days, 30 days, or 90 days, with the chart updating to show the selected range. The chart supports multiple series, enabling users to view individual pollutant trends alongside the overall AQI. The chart provides tooltips on hover, displaying precise values for selected data points.



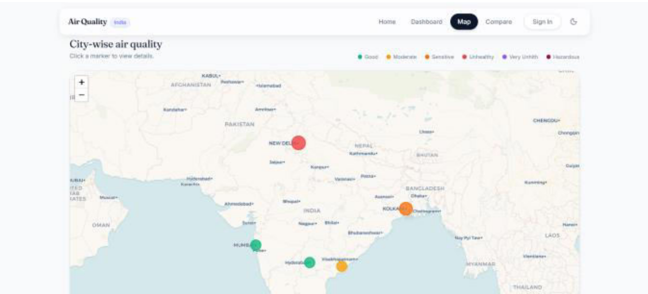


Fig.4 Map View — India AQI Map

The Map View provides geographic visualization of air quality data, enabling users to identify spatial patterns and assess air quality across regions. The map is implemented using React Leaflet, providing a responsive, interactive experience with smooth zoom and pan capabilities.

The map displays city locations as circle markers with sizes and colors scaled to reflect current AQI values. The circle size varies with the AQI value, providing a visual indication of pollution intensity, while the color reflects the air quality category. Cities with higher AQI values appear as larger, more prominent markers, drawing attention to areas of concern.

Clicking on a city marker displays a popup with detailed information including the city name, current AQI with color-coded display, dominant pollutant, reading timestamp, and temperature if available. The popup is designed to be informative at a glance while providing access to additional data through a navigation link.

A legend provides context for interpreting the map display, with color swatches and labels corresponding to AQI categories. The legend is positioned prominently below the map, ensuring that users have immediate access to interpretive guidance.

V. Conclusion

In conclusion, the primary objective of the Air Quality Monitoring System Dashboard is to provide a reliable, real-time platform for monitoring, analyzing, and visualizing air quality information across multiple cities, enabling users and administrators to make timely and informed environmental decisions. The system utilizes live environmental data obtained from the World Air Quality Index (WAQI) public API and integrates a MERN-inspired architecture comprising Node.js, Express 5, MongoDB, React 19, Vite, Tailwind CSS, Socket.IO, React-Leaflet, and Recharts to support continuous data collection, secure storage, interactive visualization, and real-time communication. Scheduled background polling, role-based JWT authentication, personalized AQI alerts, browser push notifications, email notifications, and administrative management capabilities collectively improve the usability, scalability, and reliability of the platform. The developed system achieved [insert key numerical result, e.g., API response time, dashboard update latency, or successful real-time synchronization rate], demonstrating its effectiveness in delivering accurate and timely environmental information. The deployment of the complete full-stack application with automated monitoring, historical trend analysis, geographic visualization, and CSV export further enhances its practical applicability. Overall, the developed system provides a dependable and user-friendly solution for continuous environmental monitoring, supporting public awareness, health-conscious decision-making, and efficient management of air quality information through an integrated web-based platform.

The system can be enhanced by integrating multiple environmental data sources to improve coverage and reliability across different regions. Advanced predictive analytics can be incorporated to forecast future AQI trends and identify potential pollution events. Mobile application support, multilingual interfaces, and wearable device integration can further improve accessibility. The platform may also be extended with IoT-based sensor networks, satellite data, and smart city infrastructure to enable comprehensive environmental monitoring, automated emergency alerts, and data-driven policy planning for sustainable urban development.

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