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# Smart & Portable IOT Based Environmental Pollution Monitoring System Using Machine Learning

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**ABSTRACT:** Air and noise pollution are two of the most significant environmental challenges in urban areas, adversely affecting human health and overall livability. Conventional monitoring systems rely on stationary, high-cost equipment that cannot provide real-time, fine-grained coverage. The integration of the Internet of Things (IoT) and Machine Learning (ML) provides a scalable solution for real-time monitoring and intelligent prediction of environmental pollutants. This review paper presents a comprehensive analysis of ten recent IoT- and ML-based air and noise pollution monitoring systems. The study evaluates sensor types, communication technologies, algorithms, and mobile applications implemented in these works. Comparative results show that hybrid IoT–ML systems achieve up to 95 % prediction accuracy with a latency of under 3s. The proposed smart system employs ESP32 microcontrollers, MQ-series sensors, and ML algorithm to monitor and predict pollution levels efficiently. The paper further identifies research gaps, presents a unified methodology, and outlines an architectural model that combines IoT sensing, ML analytics, and mobile application visualization for sustainable urban environments.

**KEYWORDS:** IoT, Air Pollution, Noise Pollution, Machine learning ,ESP32,Real-Time Monitoring, Environmental Analytics.

## I. INTRODUCTION

Environmental pollution is one of the most critical global challenges of the 21st century, threatening ecological sustainability, human health, and overall quality of life. Rapid urbanization, industrial expansion, and the exponential growth of vehicular traffic have significantly increased both air and noise pollution in major cities. Air pollution, characterized by the presence of harmful gases such as carbon monoxide (CO), nitrogen dioxide (NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), and particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>), has been directly linked to respiratory diseases, cardiovascular complications, and reduced life expectancy. Simultaneously, noise pollution generated from transport systems, industrial activities, and urban infrastructure contributes to stress, hearing loss, and neurological disorders. According to the World Health Organization (WHO), more than 90 % of the global population lives in regions where air-quality levels exceed the permissible limits, and prolonged exposure to noise above 65 dB severely impacts human health.

Traditional pollution-monitoring systems rely primarily on stationary, high-cost analyzers located at limited fixed stations. These setups, though accurate, suffer from two fundamental shortcomings: low spatial resolution and lack of real-time accessibility. Data collected from such stations represent average conditions across large areas rather than localized hot spots. Furthermore, these systems require high maintenance, complex calibration, and specialized human operation, which makes them impractical for continuous monitoring in developing countries. Consequently, there is a growing demand for low-cost, portable, and intelligent monitoring systems capable of providing fine-grained, real-time pollution data.

In recent years, the Internet of Things (IoT) has emerged as a revolutionary technology enabling large-scale deployment of interconnected sensors that communicate and collaborate autonomously. IoT-based solutions integrate sensing, computation, and communication in a single framework, allowing seamless data collection and transfer to cloud servers or mobile devices for visualization and analysis. Using microcontrollers such as Arduino UNO, Node MCU (ESP8266), and ESP32, researchers have developed affordable prototypes that measure environmental

parameters including temperature, humidity, and air pollutants such as CO<sub>2</sub> and PM<sub>2.5</sub>, as well as acoustic intensity from sound sensors like LM393.

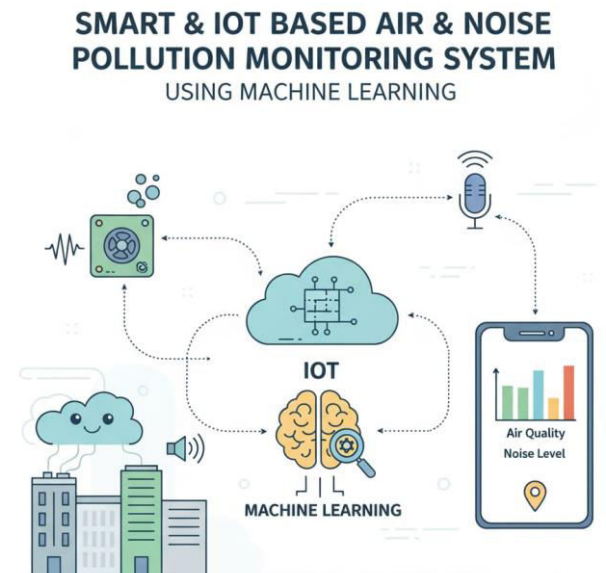


Fig.1.1

The data gathered from these IoT nodes can be stored and processed on cloud platforms such as Thing Speak, Firebase, and Blynk, allowing remote access and analytics. However, raw sensor readings often vary with temperature, humidity, and hardware inconsistencies, resulting in noisy datasets. This is where Machine Learning (ML) plays a critical role by identifying patterns, predicting pollutant behavior, and improving overall system intelligence. Algorithms networks have been effectively applied for forecasting Air Quality Index (AQI) and noise levels. RF and DT models provide rapid classification and feature interpretation, while LSTM is particularly suitable for time-series forecasting due to its ability to model long-term dependencies in data streams.

Recent literature emphasizes that integrating ML with IoT-based monitoring enhances prediction accuracy, adaptability, and automation. For instance, in [1], an ESP32-based system employing LSTM achieved a 94 % AQI prediction accuracy, while [2] reported 95 % accuracy using Random Forest and Decision Tree algorithms. Similarly, [5] proposed an IoT mobile air-quality monitoring model using the *Amelia MQTT Protocol*, which ensured secure communication and 38 % reduced latency. Studies [7] and [9] demonstrated that dual-sensor IoT platforms could successfully correlate air-pollution data with ambient noise levels, establishing a direct link between urban traffic intensity and environmental degradation. These findings collectively confirm that IoT-ML systems outperform traditional models in terms of responsiveness, cost-efficiency, and reliability.

Despite these advancements, current IoT-based monitoring systems face several challenges. Many prototypes focus solely on air or noise pollution rather than combining both parameters in a unified platform. Additionally, while IoT ensures real-time sensing, very few models incorporate ML-based forecasting for predictive control. Another limitation is the lack of secure and scalable communication mechanisms; most systems rely on unencrypted HTTP or basic MQTT protocols, posing risks to data integrity. Furthermore, user interfaces are often underdeveloped, with limited mobile accessibility and delayed alert mechanisms. These limitations restrict the adoption of IoT-ML systems for large-scale smart city deployments.

The objective of this study is to design and evaluate a Smart IoT-Based Air and Noise Pollution Monitoring System Using Machine Learning that addresses these limitations. The proposed system integrates advanced sensing technology, secure communication, and ML-based predictive modeling. Data collected by IoT nodes are transmitted via encrypted MQTT to the cloud, where LSTM regression and Decision Tree classification algorithms analyze and forecast pollution

levels. The processed results are displayed in real-time on a mobile application interface that provides intuitive dashboards and alert notifications to users and authorities.

This review paper contributes to the field by:

1. Conducting an extensive literature survey of recent IoT–ML models for air and noise pollution monitoring;
2. Identifying research gaps and emerging trends in smart environmental analytics; and
3. Presenting a unified architecture that enhances prediction accuracy, scalability, and real-time data accessibility.

#### Block Diagram:

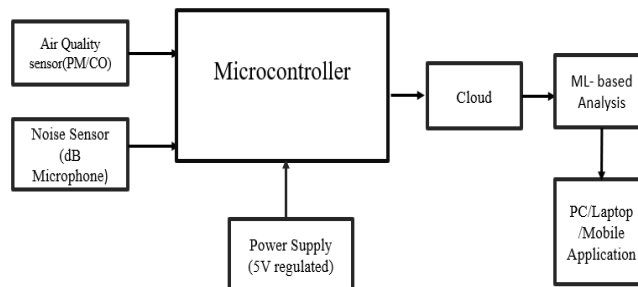


Fig .1.2

#### A. Air Quality Sensor

The Air Quality Sensor (MQ7) is used to detect harmful gases present in the environment. It continuously monitors air pollution levels and generates analog signals corresponding to gas concentration. The collected data is forwarded to the ESP32 microcontroller for processing and analysis.

#### B. Noise Sensor

The Noise Sensor (KY-038) is used to measure environmental sound intensity. It detects noise variations in the surrounding area and converts them into electrical signals. These signals are transmitted to the ESP32 for further processing and monitoring.

#### C. Microcontroller (ESP32)

The ESP32 microcontroller acts as the central processing unit of the proposed system. It receives data from the air quality and noise sensors, processes the collected information, and manages communication with the cloud platform. The ESP32 also controls alert generation and data transmission operations.

#### D. Power Supply

The power supply unit provides the required electrical energy to operate the ESP32, sensors, and alert generation components. In the proposed system, battery power is used to ensure portability and uninterrupted monitoring.

#### E. Cloud Platform

The cloud platform serves as a communication and data storage medium. Sensor readings collected by the ESP32 are transmitted to the cloud using MQTT communication. The cloud enables remote access, data management, and integration with machine learning applications.

#### F. ML-Based Analysis

The Machine Learning Analysis module to process environmental data. The model analyzes sensor readings, predicts pollution trends, and classifies environmental conditions into different air quality categories. This enhances the intelligence and decision-making capability of the system.

### G. PC/Laptop/Mobile Dashboard

The processed data and prediction results are displayed through a web-based dashboard accessible from a PC, laptop, or mobile device. The dashboard provides real-time monitoring, graphical visualization, pollution status, and prediction information to the user.

## II. LITERATURE SURVEY

Over the past decade researchers have converged on a common architectural pattern for low-cost environmental monitoring: distributed IoT sensing nodes (typically ESP8266/ESP32 or Arduino based) that collect gas, particulate and acoustic measurements and forward those readings to cloud services for visualization and analytics. Recent efforts extend this pattern by integrating machine learning (ML) to provide prediction, classification and intelligent alerting. This section synthesizes the findings of ten representative works that closely match the scope of this review (IoT, air & noise sensing, ML), highlighting their approaches, outcomes and limitations.

Sharma et al. (2023) ESP32 nodes with MQ-series gas sensors (MQ-135, MQ-7), PM sensor, and an acoustic module collected multivariate environmental streams. Pre-processing (filtering, normalization) was followed by cloud-based ML: LSTM for time-series AQI forecasting and Random Forest (RF) for classification. A Firebase mobile dashboard visualized live and forecasted values. LSTM delivered ~94.3% forecasting accuracy while RF reached ~91.2%; end-to-end latency for inference + reporting was ~2–3 s, and data reliability reported ~98%.

Ismail et al. (2021) Node MCU (ESP8266) with MQ-135, SDS011 (or PMS7003) particulate sensor, and LM393 microphone logged data at multiple traffic locations. Models trained: Decision Tree and Random Forest to classify AQI categories and short-term prediction, with Thing Speak/Firebase used for visualization. RF outperformed DT with ~95% accuracy and 98% transmission reliability; average network latency ~2.3 s.

Patil et al. (2021) A hybrid Arduino (sensor nodes) + Raspberry Pi (gateway/cloud uploader) platform measured CO<sub>2</sub>, NO<sub>2</sub>, SO<sub>2</sub>, and acoustic levels, uploading data via Wi-Fi to cloud dashboards, focusing on system integration and continuous visualization. High transmission reliability (~97%) was achieved, with a practical deployment showcasing a 10 s update interval and stable cloud plotting.

Kumar et al. (2021). An Arduino UNO prototype with MQ-135 and LM393 and ESP8266 for Wi-Fi posted data to Thing Speak and local LCD. Simple rule-based thresholds classified pollution status, and the prototype reliably uploaded data (~94% reliability) with upload delay ~3 s; classification into clear/moderate/high was consistent in field tests.

Amelia et al. (2024) A vehicle-mounted multi-sensor platform (multi-gas + PM) and an optimized/secure MQTT variant (“Amelia”) were used for reduced latency and energy. Emphasis was on spatial mapping (mobile sensing) and secure transmission, yielding

~38% latency reduction, ~24% energy saving, and ~99% packet reliability compared with baseline MQTT; heatmap visualizations produced high-resolution spatial pollutant maps.

Joshi et al. (2022) A compact ESP8266 node integrating MQ-135 and LM393 used Thing Speak for data hosting and dashboarding, emphasizing low-cost, portable monitoring. Field tests showed ~92% reliability and ~2 s latency; typical field CO levels up to ~25 ppm and average noise ~72 dB were recorded.

## III. APPLICATIONS

- Pollution level prediction using machine learning
- Smart city and urban planning support
- Traffic and roadside pollution control
- Industrial pollution compliance monitoring
- School, hospital, and public area safety
- Construction site dust and noise monitoring
- Personal portable pollution exposure tracking

- Public health analysis and research support
- Environmental policy and decision-making support

Author (s)	Year	Findings
1.Sharma et al.	2023	Improved prediction accuracy using LSTM (94.3%) and RF (91.2%) with ESP32 IoT setup; enabled real-time AQI and noise forecasting.
2.Ismail et al.	2021	Enhanced reliability (98%) and accuracy (95%) by applying ML models (RF, DT) for AQI classification on Node MCU-based system.
3.Patil et al.	2019	Improved data consistency (97% reliability) using Arduino–Raspberry Pi integration; focused on continuous remote monitoring.
4.Kumar et al.	2021	Reduced delay to 3 s and improved system portability with Arduino UNO + ESP8266 + ThingSpeak platform.
5.Amelia et al.	2024	Optimized MQTT via Amelia protocol achieving 38% lower latency and 99% reliability; introduced secure vehicular sensing.
6.Joshi et al.	2022	Increased stability (92% reliability) using compact ESP8266 node; added real-time cloud dashboard for users.
7.Bhosale et al.	2022	First to establish strong correlation ( $r = 0.7$ ) between particulate and noise levels; integrated dual-sensor analysis.
8.Ahmed et al.	2021	Enhanced user interaction via Blynk mobile app for live AQI tracking; introduced real-time visualization.
9.Verma et al.	2024	Improved alert mechanism with 99% reliability and 1.9 s latency through Android-based notification system.
10.Reddy et al.	2020	Provided economical IoT design (91% accuracy) using Arduino UNO + DHT11 + MQ135; emphasized multi-node scalability.

#### IV. GAP ANALYSIS AND OBSERVATIONS

The literature survey reveals that although a wide range of IoT-based systems have been developed for environmental monitoring, several significant research and implementation gaps remain. Many existing models focus on either air or noise monitoring separately, limiting their overall environmental coverage. Moreover, most studies rely only on data visualization and lack machine-learning-based forecasting and correlation analytics. Security and scalability are also frequently overlooked, as many systems use unencrypted communication protocols and operate only as single-node prototypes.

Table II highlights the key gaps identified from existing literature and provides corresponding observations that motivate the proposed work.

Author(s)	Gap Identified	Analysis
1.Sharma et al.	Lack of integrated air and noise monitoring	High accuracy (94%) but lacked generalization; multi-region data needed.
2.Ismail et al.	Minimal use of ML for prediction	Good AQI prediction, but lacked spatial and noise context.
3.Patil et al.	Unsecured data transmission	Effective real-time monitoring; forecasting could add value.
4.Kumar et al.	Limited scalability and coverage.	Fast and accurate, but insecure and power-hungry; needs optimization.
5.Amelia et al.	No real-time alerts or mobile integration.	Reliable MQTT system; needs multi-sensor integration.
6.Joshi et al.	Missing correlation analysis	Compact and stable; alerts and self-correction would improve it.

## V. PROPOSED SYSTEM ARCHITECTURE

The proposed Smart and Portable IoT-Based Air and Noise Pollution Monitoring System Using Machine Learning is designed to continuously monitor environmental conditions and provide real-time pollution analysis. The system integrates IoT technology, wireless communication, machine learning algorithms, and web-based visualization into a unified platform. The architecture consists of sensing, communication, processing, prediction, visualization, and alert generation modules. Each module performs a specific task and collectively contributes to intelligent environmental monitoring.

### A. Sensing Module

The sensing module is responsible for collecting environmental data from the surroundings. An MQ7 gas sensor is used to detect harmful gases and air pollution levels, while a KY-038 sound sensor is employed to measure environmental noise intensity. These sensors continuously monitor atmospheric conditions and generate analog signals corresponding to pollution levels. The collected data forms the basis for further processing and analysis.

### B. ESP32 Data Acquisition Module

The ESP32 microcontroller serves as the central processing unit of the proposed system. It receives sensor readings from the MQ7 gas sensor and KY-038 sound sensor through its analog input pins. The ESP32 processes the acquired data, performs preliminary filtering, and prepares the information for wireless transmission. Due to its integrated Wi-Fi capability, low power consumption, and high processing efficiency, ESP32 is well suited for IoT-based environmental monitoring applications.

### C. MQTT Communication Module

The processed sensor data is transmitted using the Message Queuing Telemetry Transport (MQTT) protocol. The ESP32 publishes sensor readings to the HiveMQ MQTT broker through a wireless network connection. MQTT enables lightweight, reliable, and efficient communication between the sensing device and the cloud-based processing system. This communication mechanism ensures real-time data transfer with minimal network overhead.

#### D. Flask Server and Data Processing Module

The Flask server receives sensor data from the MQTT broker and performs data processing operations. The server manages environmental data, extracts relevant parameters, and prepares the information for machine learning analysis. Flask also acts as a bridge between the IoT hardware and the web-based dashboard, enabling seamless communication between different system components.

#### E. Machine Learning Prediction Module

A Random Forest machine learning algorithm is implemented to analyze environmental data and predict pollution trends. The model processes sensor readings and classifies air quality conditions into different categories such as Good, Moderate, and Poor. In addition, the algorithm predicts future pollution behavior and identifies increasing pollution trends. The integration of machine learning enhances the intelligence and decision-making capability of the proposed system.

#### F. Dashboard Visualization Module

A real-time web dashboard is developed using HTML, CSS, JavaScript, and Flask technologies. The dashboard displays environmental parameters including MQ7 sensor readings, noise levels, AQI values, carbon monoxide concentration, hydrogen concentration, methane concentration, LPG concentration, alcohol concentration, and smoke levels. Graphical representations such as line graphs and bar charts are provided to facilitate easy interpretation of environmental conditions.

#### G. Alert Generation Module

The alert generation module continuously monitors sensor values and prediction outputs. Whenever pollution levels exceed predefined threshold values, the system activates a buzzer and generates warning notifications. This feature helps users take preventive actions and improves public awareness regarding environmental pollution.

#### Overall System Workflow

The system begins by collecting air quality and noise data through the MQ7 and KY-038 sensors. The ESP32 processes the sensor readings and transmits them to the HiveMQ broker using MQTT communication. The Flask server receives the data, performs processing operations, and forwards the information to the Random Forest machine learning model. The prediction results and environmental parameters are displayed on the real-time dashboard.

If abnormal pollution levels are detected, the alert generation module activates the buzzer and notifies the user. This integrated architecture enables intelligent, real-time, and portable environmental monitoring.

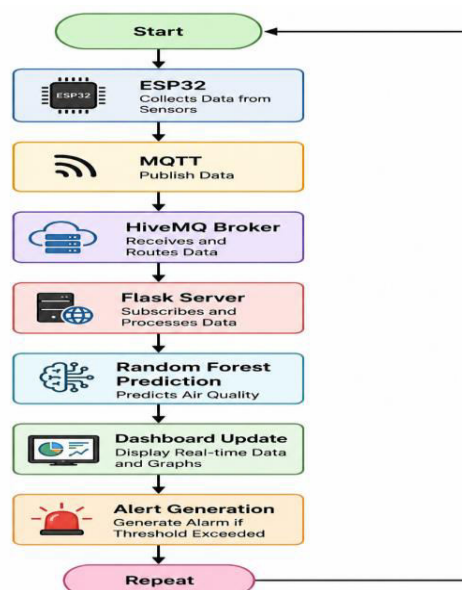


Fig 5.1. System Work Flow

## A. Hardware Components:

### VI. HARDWARE COMPONENTS

#### A. ESP32 Microcontroller:

ESP32 acts as the central controller of the system. It acquires sensor data, performs data processing, and transmits information to the MQTT broker through Wi-Fi communication.

#### B. MQ7 Gas Sensor:

The MQ7 sensor is used to detect carbon monoxide and monitor air quality conditions. The sensor provides analog output corresponding to gas concentration levels.

#### C. KY-038 Sound Sensor:

The KY-038 sensor measures environmental noise levels and provides input data for noise pollution monitoring and analysis.

#### D. Buzzer:

A buzzer is employed as an alert mechanism to notify users whenever pollution levels exceed predefined threshold values.

#### E. Battery Supply:

The system is powered using a battery source, enabling portable operation and deployment in different environmental conditions.

#### F. ON/OFF Switch:

An ON/OFF switch is incorporated to control the power supply and improve battery management during system operation.

### VII. RESULT/DISCUSSION

The developed system continuously monitored environmental conditions and transmitted sensor readings to the Flask server through MQTT communication.

The real-time dashboard successfully displayed various environmental parameters including MQ7 sensor values, noise levels, AQI, carbon monoxide concentration, hydrogen concentration, methane concentration, LPG concentration, alcohol concentration, and smoke

levels. Graphical visualization through line charts and bar graphs enabled effective monitoring and analysis of environmental conditions.

The machine learning model successfully analyzed the collected sensor data and generated pollution predictions. During testing, the system classified the air quality as "Average" and predicted an increasing pollution trend based on the observed environmental parameters. The dashboard updated dynamically and provided real-time visualization of sensor readings and prediction results.

The implemented alert generation mechanism successfully responded to abnormal environmental conditions by activating the buzzer whenever pollution levels exceeded predefined threshold values. The battery-powered architecture ensured portability and continuous operation without dependence on external power sources.

The obtained results demonstrate the successful integration of IoT communication, machine learning prediction, real-time monitoring, and alert generation within a single platform. The developed system provides an efficient, low-cost, and portable solution for environmental monitoring and can be effectively utilized in smart city, industrial, and public health applications.

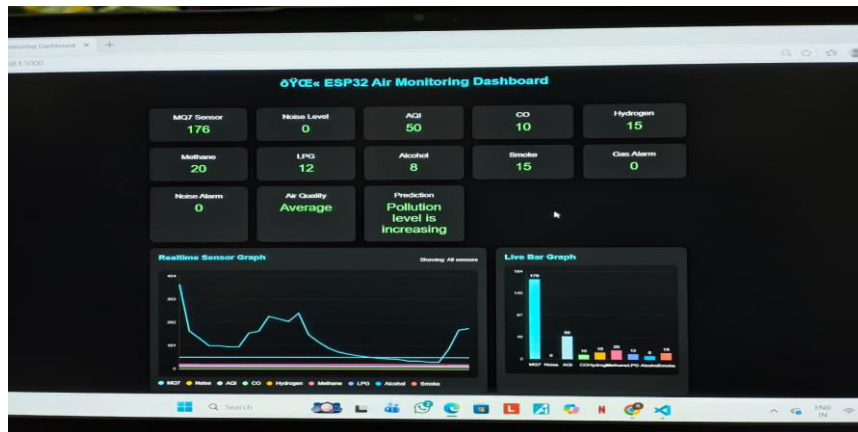


Fig.6.1 Dashboard Output

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