1. LITERATURE SURVEY

The Literature Survey provides a comprehensive Review of Air Quality Monitoring Technologies related to Air Quality Monitoring System, Gas Sensing Technologies, and IoT-Enabled Environmental Monitoring System. The purpose of this survey is to critically analyze prior work, identify technological advancements, understand scientific principles involved, and recognize the Limitations of Existing Systems. By reviewing Peer-Reviewed Journal Articles and Reputed Conference Publications, this chapter establishes a strong Technical Foundation for the proposed IoT-Based Multi-Gas Air Quality Monitoring System. Recent studies indicate a growing shift from Centralized Air Quality Monitoring Stations toward Decentralized Monitoring Systems, Low-Cost Monitoring, and Real-Time Monitoring Systems. This transition is driven by the need for Localized Detection of Hazardous Gases, Rapid Alert Mechanisms, and User-Accessible Data Visualization. The literature reviewed in this chapter focuses on Sensor Technologies, Embedded Controllers, Communication Architectures, and Alert Mechanisms relevant to Indoor Air Quality Monitoring and Near-Field Air Quality Monitoring Applications.

1.1 PROBLEM STATEMENT

Despite the availability of Advanced Air Quality Monitoring Infrastructure, existing solutions face several Practical and Technical Challenges. Centralized Monitoring Stations, although accurate, are Expensive, Sparsely Distributed, and incapable of detecting Localized Pollution Events such as Domestic Gas Leakages or Short-Duration Exposure Spikes. Low-Cost Monitoring Systems proposed in literature often focus on Single-Gas Detection, lack Real-Time Alert Mechanisms, or suffer from issues such as Sensor Drift, Cross-Sensitivity, and Environmental Dependency.

Furthermore, many existing systems do not provide Seamless Integration between Sensing Units, Data Processing Modules, and User Notification Platforms. The absence of a Unified System capable of Detecting Multiple

Hazardous Gases, Processing Data in Real Time, and Delivering Immediate Alerts limits the Effectiveness of Current Solutions in Safety-Critical Environments. Therefore, there exists a need for a Low-Cost, IoT-Enabled, Multi-Gas Air Quality Monitoring System that can Continuously Monitor Hazardous Gases, Evaluate Safety Thresholds, and provide Timely Alerts to users while maintaining Scalability and Ease of Deployment.

2. INTRODUCTION AND BACKGROUND

Air Pollution has emerged as a significant Environmental and Public Health Concern due to Rapid Urbanization, Industrial Growth, and increased reliance on Fossil Fuels. Numerous studies report that Exposure to Gaseous Pollutants such as Carbon Monoxide (CO), Methane (CH_4), Liquefied Petroleum Gas (LPG), and Ammonia (NH_3) can lead to severe Health Issues including Respiratory Disorders, Cardiovascular Diseases, and Accidental Fatalities caused by Gas Leakage Incidents [3], [7], [8], [16].

Conventional Air Quality Monitoring Systems are primarily based on Centralized Monitoring Stations operated by Government and Regulatory Bodies. Although these systems provide High-Accuracy Measurements, several researchers highlight their Limitations, including High Deployment Cost, Limited Spatial Coverage, and Delayed Data Availability [1], [5], [7]. As a result, Localized Pollution Events and Indoor Gas Leakage Hazards often remain undetected.

Recent literature emphasizes a Paradigm Shift toward Low-Cost, Decentralized, and IoT-Enabled Air Quality Monitoring Systems capable of Real-Time Data Acquisition and User-Level Accessibility [2], [10], [15]. Studies employing Embedded Controllers such as ESP8266 and ESP32 demonstrate that such systems offer Improved Scalability, Faster Response Time, and Seamless Cloud Integration compared to Traditional Approaches [11], [13], [17]. Furthermore, the Integration of Mobile- Based Alert Mechanisms has been identified as a Critical Requirement for Safety-Oriented Applications [21]. These findings from existing literature establish the necessity for an IoT-Based Multi-Gas Air Quality Monitoring System that combines Affordability, Real-Time Monitoring, and Immediate Alert Generation.

3. METHODOLOGY OF LITERATURE REVIEW

A Systematic Literature Review Methodology was adopted to ensure Technical Relevance, Completeness, and Academic Rigor. The review process followed Best Practices reported in recent Survey-Based Research on IoT and Environmental Monitoring Systems [2], [6], [15]. Peer-Reviewed Journal Articles and Reputed Conference Publications were selected to capture State-of-the-Art Developments in Gas Sensing Technologies, Embedded Systems, and IoT-Based Monitoring Architectures. Primary Sources included Digital Libraries such as IEEE Xplore, Elsevier (ScienceDirect), SpringerLink, and MDPI, which are widely used in similar studies [1], [6], [11]. The Literature Search focused on publications related to Air Quality Monitoring, Multi-Gas Detection, MQ-Series Sensors, ESP32-Based Systems, and Real-Time Alert Mechanisms. Emphasis was placed on Recent Publications to reflect Current Technological Trends, while Foundational Studies were included where necessary to explain Scientific Principles [8], [18].

Each selected paper was analyzed based on Sensor Technology, System Architecture, Communication Methodology, Performance Evaluation, and Identified Limitations, as recommended in prior Comparative Studies [6], [17], [21].

3.1 Selection Criteria

To maintain the Quality and Relevance of the reviewed literature, clear Inclusion and Exclusion Criteria were defined, following methodologies reported in prior Review Articles [2], [15].

Included:

- Peer-Reviewed Journal Articles and Reputed Conference Papers [1], [6], [11].
- Studies focusing on Air Quality Monitoring, Gas Detection, and IoT-Based Systems [2], [10], [15].
- Research involving Experimental Validation, Prototype Implementation, or Performance Evaluation [6], [17].
- Publications discussing Sensor Behavior, Calibration Challenges, and System Limitations [8], [18], [20].

Excluded:

- Non-Technical Articles, Blogs, and Commercial Sources
- Papers lacking Experimental Analysis or Technical Validation
- Studies unrelated to Gas Sensing or Environmental Monitoring
- Redundant Survey Papers without direct relevance to the proposed system

4. Embedded Systems for Air Quality Monitoring

Embedded Systems serve as the Central Processing Units in Air Quality Monitoring Solutions, enabling Real-Time Data Acquisition from sensors, execution of Decision-Making Algorithms, and Communication with External Platforms. Literature consistently highlights that the Selection of an Appropriate Embedded Controller significantly influences System Performance, Reliability, Scalability, and Power Efficiency [6], [11]. With the increasing demand for Real-Time Monitoring and Remote Accessibility, Embedded Systems have evolved from simple Data Loggers to Intelligent Processing Units capable of supporting IoT-Based Applications.

4.1 Microcontroller-Based Monitoring Systems

Early Air Quality Monitoring Systems primarily utilized Basic Microcontrollers to Interface Gas Sensors and Collect Environmental Data. Arduino-Based Platforms gained popularity in Academic and Prototype-Level Research due to their Simplicity, Open-Source Ecosystem, and Ease of Programming [6]. Several studies demonstrate successful Integration of Arduino Controllers with MQ-Series Gas Sensors for Detecting Gases such as CO, LPG, and NH_3 [6], [8]. However, researchers have identified notable Limitations including Lack of Integrated Wireless Communication, Limited Processing Capability, and Increased System Complexity due to External Communication Modules [6], [17].

To address Connectivity Challenges, Wi-Fi-Enabled Microcontrollers such as the ESP8266 were introduced in Air Quality Monitoring Applications. Literature reports that ESP8266-Based Systems significantly reduce Hardware Complexity by enabling Direct Communication with Cloud Platforms [11], [15]. These systems improve Real-Time Data Transmission and Remote Monitoring Capabilities compared to Traditional Microcontroller-Based Solutions. Nevertheless, the Limited Input/Output Resources and Single-Core Processing Architecture of ESP8266 restricts its ability to handle Multiple Sensors and Concurrent Tasks efficiently [11], [17].

4.2 Advanced Embedded Platforms for IoT-Enabled Monitoring

Recent research highlights the growing adoption of Advanced Embedded Platforms such as the ESP32 for Air Quality Monitoring Systems [13], [17]. The ESP32 Microcontroller offers a Dual-Core Architecture, Higher Clock Speed, Increased Memory, and integrated Wi- Fi and Bluetooth Connectivity, making it well-suited for Real-Time, Multi-Sensor Applications. Studies demonstrate that ESP32-Based Systems can simultaneously manage Sensor Data Acquisition, Threshold Evaluation, Cloud Communication, and Alert Generation without Performance Degradation [11], [17].

Furthermore, literature emphasizes that Embedded Platforms Supporting Multitasking and Real-Time Operating Environments enhance System Reliability and Scalability [13]. The ability of ESP32-Based Systems to integrate seamlessly with IoT Platforms enables Continuous Data Logging, Mobile-Based Visualization, and Instant Alert Mechanisms, which are essential for Safety-Critical Air Quality Monitoring Applications [2], [15], [21]. Consequently, recent studies recommend ESP32-Based Embedded Architectures as a Robust Solution for developing Low-Cost, Scalable, and Reliable IoT-Enabled Multi-Gas Air Quality Monitoring Systems [11], [13], [17].

5. ANALYSIS OF RELEVANT STUDIES FOR THE PROPOSED PROJECT

This section presents an analysis of existing studies relevant to the proposed prototype-level IoT-based multi-gas air quality monitoring system. The focus is on identifying studies that directly influenced the implementation approach, while other related works are used to understand common technical practices and limitations.

5.1 Studies Directly Relevant to Our Implementation

- Low-Cost IoT-Based Air Quality Monitoring System
  https://scholar.google.com/scholar?q=Low-Cost+IoT Based+Air+Quality+Monitoring+System
- Embedded System Design for Air Pollution Monitoring
  https://scholar.google.com/scholar?q=Embedded+System+Design+for+Air+Pollution+Monitoring
- Environmental Monitoring Using Embedded Platforms
  https://scholar.google.com/scholar?q=Environmental+Monitoring+Using+Embedded+Platforms
- Multi-Parameter Environmental Monitoring Systems
  https://scholar.google.com/scholar?q=Multi-Parameter+Environmental+Monitoring+Systems
- Smart Environmental Monitoring Using IoT
  https://scholar.google.com/scholar?q=Smart+Environmental+Monitoring+Using+IoT
- Long-Term Performance of Air Quality Sensors
  https://scholar.google.com/scholar?q=Long-Term+Performance+of+Air+Quality+Sensors

- These studies collectively provide guidance on sensor selection, embedded controller usage, and practical considerations in low- cost air quality monitoring systems, forming the primary reference base for the proposed implementation.

5.2 Relevant Technical Approaches in Air Quality Monitoring Systems

Existing air quality monitoring systems commonly employ embedded controllers interfaced with gas sensors to acquire environmental data in real time. Many studies report the effectiveness of threshold-based monitoring techniques for detecting hazardous gas levels, particularly in prototype and small-scale applications [1], [6], [11]. IoT- enabled designs further enhance usability by enabling remote monitoring and alert generation [6], [9].

These technical approaches influenced the proposed project by promoting simple, reliable, and cost-effective system architecture rather than complex analytical or predictive models.

5.3 Sensor Performance Considerations in Existing Studies

Literature indicates that low-cost gas sensors are suitable for qualitative air quality assessment and safety monitoring, although they exhibit limitations such as sensor drift, cross-sensitivity, and environmental dependency [20]. Several studies emphasize that while precise concentration measurement is challenging, these sensors remain effective for real-time detection and alert-based systems [1], [11].

These findings guided the proposed project to focus on reliable hazard detection instead of exact pollutant quantification.

5.4 Identified Research Direction for the Proposed Work

Analysis of existing studies reveals that many advanced air quality monitoring systems focus on large-scale deployment, data analytics, or predictive modeling [7], [10], [13]. However, there remains a need for simple, low-cost, and portable monitoring solutions suitable for domestic and educational use [1], [3]. The proposed project aligns with this identified research direction by implementing a prototype-level, embedded-based multi-gas air quality monitoring system with real-time alert capabilities.

6. SYSTEM DESIGN AND METHODOLOGY

This chapter explains the Environmental Monitoring System Architecture and Environmental Monitoring Framework adopted for the development of the proposed prototype-level IoT-Based Multi-Gas Air Quality Monitoring System. The design approach is guided by findings from existing literature, particularly studies focusing on low-cost implementation, Embedded Environmental Monitoring integration, and Real-Time Environmental Monitoring techniques [1], [3], [6]. Emphasis is placed on simplicity, Environmental Monitoring Reliability, and practical feasibility rather than complex analytical models.

6.1 Overall System Architecture

The overall Environmental Monitoring System Architecture of the proposed Air Quality Monitoring System consists of Environmental Sensing Infrastructure, an Embedded Environmental Monitoring processing unit, output and Environmental Alert Generation devices, and an optional Wireless Environmental Monitoring interface. Similar architectural approaches have been widely reported in low-cost IoT-based monitoring systems, where sensors continuously perform Continuous Air Quality Tracking of environmental conditions and transmit data to a central controller for Environmental Data Processing [1], [6].

Multiple MQ-series gas sensors are deployed to perform Atmospheric Contaminant Detection of hazardous gases such as LPG, methane, and carbon monoxide. The sensors generate analog signals corresponding to the Pollution Concentration Measurement of gases present in the surrounding environment. These signals are fed into the embedded controller, which performs Environmental Data Acquisition, Pollution Level Thresholding, and decision-making. Such centralized Environmental Data Processing architecture has been identified as effective for prototype and small-scale monitoring systems [3], [9].

6.2 Hardware Design and Component Integration

The hardware design integrates multiple gas sensors with an embedded controller to enable Real-Time Environmental Monitoring. MQ-2, MQ-4, MQ-9, and MQ-135 sensors are selected based on their frequent use in existing low-cost Environmental Sensing Infrastructure reported in the literature [1], [11]. These sensors can detect combustible and harmful gases, making them suitable for safety-oriented applications.

An ESP32 microcontroller is employed as the core processing unit due to its sufficient computational capability and integrated Wireless Environmental Monitoring features. Literature highlights that embedded platforms with integrated processing and communication modules reduce system complexity and improve Environmental Monitoring Reliability in prototype-level implementations [3], [9]. A 16 × 2 LCD module is used to display real-time system status and sensor information, while a buzzer and LEDs provide immediate Environmental Alert Generation when unsafe gas levels are detected. Similar Intelligent Environmental Alerting mechanisms have been reported as effective in Environmental Monitoring Systems [6], [11].

6.3 Software Methodology and Control Logic

The software methodology of the proposed system follows a Continuous Air Quality Tracking and Threshold-Based Monitoring approach. Embedded software periodically reads analog signals from the gas sensors through the built-in ADC of the microcontroller. These digital values are compared against predefined Pollution Level Thresholding limits to determine air quality conditions. Threshold-Based Monitoring is commonly adopted in prototype-level systems due to its simplicity and fast Environmental Monitoring System Responsiveness [1], [6].

Existing studies report that basic signal stabilization techniques, such as sensor warm-up delay and periodic sampling, improve the Environmental Monitoring Accuracy of gas sensor readings [20]. Guided by these findings, the proposed system incorporates Environmental Measurement Validation stabilization time and repeated sampling before decision-making. When sensor values remain within safe limits, the system continues

Environmental Condition Evaluation. If any parameter exceeds its threshold, Environmental Alert Generation mechanisms are activated immediately.

6.4 Operational Flow of the Proposed System

The operational flow of the system begins with system initialization and sensor warm-up to ensure stable sensor operation, as recommended in several Environmental Monitoring Validation Framework studies [20]. Once stabilization is achieved, the system enters Continuous Air Quality Tracking mode, where Atmospheric Data Collection is acquired, processed, and evaluated in real time.

During unsafe conditions, the system triggers Environmental Alert Generation to warn users of potential hazards. This operational flow aligns with approaches reported in existing embedded-based Air Quality Monitoring Systems, which prioritize Real-Time Environmental Detection and Environmental Condition Awareness over complex data processing [1], [3], [6]. The system continues monitoring dynamically, ensuring uninterrupted Environmental Surveillance of environmental conditions.

7. EMBEDDED SYSTEMS FOR AIR QUALITY MONITORING

Embedded systems play a crucial role in modern air quality monitoring solutions due to their ability to integrate sensing, processing, communication, and control within a compact and cost-effective platform. With increasing concerns about indoor and outdoor air pollution, researchers have widely adopted embedded platforms combined with gas sensors to enable real-time, continuous, and distributed air quality assessment. Recent literature emphasizes that embedded systems provide an optimal balance between performance, scalability, and affordability, making them suitable for prototype-level as well as large-scale deployments [1], [3], [6].

The evolution of air quality monitoring systems has shifted from bulky laboratory instruments to embedded sensor-based solutions capable of autonomous operation.

Studies highlight that embedded systems allow efficient data acquisition from gas sensors, local preprocessing, threshold- based decision making, and wireless transmission of environmental data to cloud platforms for visualization and alerts [2], [8]. These features directly align with low-cost IoT-based air quality monitoring prototypes developed for academic and societal applications.

7.1 Role of Embedded Systems in Environmental Monitoring

Embedded systems act as the core control unit in air quality monitoring architecture. They interface with gas sensors such as MQ- series sensors, perform analog-to-digital conversion, process sensor outputs, and execute predefined logic for safety alerts and data communication. Literature shows that microcontroller-based platforms are widely preferred due to their low power consumption, flexibility, and ease of integration with multiple sensors [3], [9].

Several studies report that embedded systems enable continuous monitoring of pollutants such as carbon monoxide, LPG, smoke, and volatile organic compounds (VOCs), especially in indoor environments [1], [6]. The ability of embedded systems to operate autonomously makes them suitable for real-time air pollution monitoring in homes, laboratories, and public spaces. Moreover, the integration of wireless communication modules within embedded platforms enhances remote accessibility and scalability of monitoring systems [4].

7.2 Embedded Platforms Used in Air Quality Monitoring Systems

Various embedded platforms have been explored in literature for air quality monitoring applications. Commonly used platforms include Arduino-based systems, ESP32/ESP8266 modules, and other low-power embedded controllers. Studies emphasize that platform selection depends on factors such as cost, computational capability, power efficiency, and communication requirements [1], [9].

Low-cost air quality monitoring systems often rely on Arduino or ESP-based embedded platforms due to their open-source nature and extensive community support [2]. ESP32-based systems, in particular, are widely adopted because they integrate processing capability with built-in Wi-Fi, enabling seamless data transmission to cloud-based monitoring dashboards [8]. Literature confirms that such embedded platforms are well-suited for prototype-level and academic implementations where affordability and functionality are key considerations.

7.3 Integration of Embedded Systems with Gas Sensors

The effectiveness of an air quality monitoring system largely depends on how efficiently the embedded system interfaces with gas sensors. MQ-series gas sensors are commonly connected to embedded controllers through analog input channels, where sensor resistance changes are converted into voltage signals. Embedded systems process these signals to determine pollution levels based on predefined thresholds [3], [11].

Research indicates that embedded systems facilitate real-time monitoring by continuously sampling sensor data and applying decision logic to trigger alarms or notifications when unsafe conditions are detected [1], [6]. This integration allows for rapid response to hazardous gas concentrations, making embedded systems an essential component in safety-oriented air quality monitoring solutions.

7.4 Communication and Data Handling in Embedded Monitoring Systems

Embedded systems in air quality monitoring applications are often integrated with Wireless Environmental Monitoring technologies such as Wi-Fi or GSM. Literature highlights that Edge-Based Environmental Processing platforms enable Real-Time Environmental Monitoring through Environmental Data Transmission to cloud servers, mobile applications, or Environmental Data Visualization Interfaces for remote analysis [8], [21]. Studies also report that Embedded Environmental Monitoring systems support basic Environmental Data Preprocessing functions such as Environmental Data Aggregation, timestamping, and storage before transmission [2]. These capabilities reduce Environmental Data Redundancy and enhance Environmental Monitoring Reliability and Environmental Data Integrity of air quality information presented to end users. Such communication-oriented Environmental Monitoring Architectures are particularly beneficial for Smart Environmental Systems and Environmental Alert Generation applications.

7.5 Comparative Analysis of Embedded Systems Used in Literature

To better understand the suitability of embedded systems for air quality monitoring, a comparative summary based on literature is presented in Table

Embedded Platforms Used in Air Quality Monitoring Systems

Embedded Platform	**Key Features**	**Application Focus**	**Related Papers**
Arduino Uno	Low cost, simple architecture	Indoor air monitoring	[1], [3]
ESP8266	Built-in Wi-Fi, compact size	IoT-based monitoring	[2], [8]
ESP32	Dual core processing, Wi-Fi & BLE	Real-time cloud monitoring	[6], [21]
Embedded WSN Nodes	Distributed sensing capability	Smart city monitoring	[4], [12]

7.6 Summary of Embedded Systems in Air Quality Monitoring

From the literature, it is evident that Embedded Environmental Monitoring systems form the backbone of modern Air Quality Monitoring Systems. Their ability to integrate Environmental Sensing Infrastructure, Environmental Data Processing, and Wireless Environmental Monitoring functions within a compact platform make them ideal for low-cost, Real-Time Environmental Monitoring applications. The reviewed studies demonstrate that Embedded Environmental Monitoring platforms such as Arduino and ESP-based systems are widely adopted due to their Environmental Monitoring Reliability, Environmental Monitoring Scalability, and ease of implementation [1], [6], [9]. The findings from this Environmental Monitoring Framework justify the selection of an Embedded System-Based Approach for developing a prototype-level Air Quality Monitoring System, ensuring alignment with established Environmental Monitoring Research Trends and Practical Deployment Requirements for Environmental Surveillance Systems.

8. IDENTIFIED RESEARCH GAPS AND MOTIVATION

A comprehensive literature review reveals that significant progress has been made in the development of Air Quality Monitoring Systems using Embedded Environmental Monitoring and IoT-Based Environmental Analytics. However, despite extensive research, several practical and technical gaps remain unresolved, particularly in the context of low-cost, prototype-level implementations intended for real-world usage. Identifying these gaps is essential to justify the motivation behind the present work and to establish its relevance within existing research frameworks [1], [5], [6].

The reviewed studies predominantly focus on advanced architecture, large-scale deployments, or Environmental Big Data Analytics, often overlooking simplicity, affordability, and deploy ability at the prototype level. This section systematically identifies key research gaps from the literature and presents the motivation for addressing them through the proposed Air Quality Monitoring Project.

8.1 Identified Research Gaps in Existing Literature

Although numerous Air Quality Monitoring Systems have been reported in the literature, several gaps are consistently observed. Many studies emphasize Cloud-Based Environmental Monitoring, Smart City Air Monitoring, and Machine Learning for Air Pollution Analysis, which increase system complexity and cost [10], [13], [23]. Such approaches are not always suitable for small-scale or educational prototype deployments. Another major gap identified is the limited focus on low-cost sensor usability. While MQ-Series Gas Sensors are frequently mentioned, several studies do not adequately address issues such as sensor cross- sensitivity, environmental influence, or practical Pollution Level Thresholding mechanisms [3], [20].

Furthermore, existing literature often assumes ideal operating conditions, whereas real-world environments introduce variations in temperature, humidity, and gas concentration patterns that affect Environmental Monitoring Accuracy. Additionally, many proposed systems lack clarity in Environmental Decision Logic. The majority of literature focuses on Environmental Data Collection and Air Quality Visualization but provides minimal discussion on immediate safety response mechanisms such as local alarms or user alerts [1], [6]. These limitations highlight the need for a simplified yet effective air quality monitoring solution that prioritizes Real-Time Environmental Monitoring and Environmental Safety Assessment.

8.2 Comparative Analysis of Literature Gaps.

To systematically understand the identified gaps, a comparative analysis of key literature aspects is summarized in Table

Identified Research Gaps in Air Quality Monitoring Literature

Literature Aspect	Observation from Literature	Identified Gap	Related Papers
System Complexity	Advanced analytics and cloud dependency	High cost and implementation complexity	[10], [13], [23]
Sensor Utilization	Limited discussion on MQ sensor behavior	Practical sensor limitations are not addressed	[3], [20]
Response Mechanism	Focus on monitoring rather than alerts	Lack of real-time safety response	[1], [6]
Deployment Scale	Emphasis on smart city or large-scale networks	Unsuitable for prototype-level or low-cost use	[4], [12]

8.3 Motivation for the Proposed Work

The motivation for the present project arises directly from the gaps identified in existing literature. There is a clear need for a simple, low- cost, and reliable prototype-level Air Quality Monitoring System that focuses on immediate gas detection and safety alerting rather than Complex Environmental Analytics. By leveraging an Embedded Environmental Monitoring architecture and commonly available MQ- Series Gas Sensors, the proposed work aims to bridge the gap between theoretical research and practical deployment [1], [3].

Unlike many literature-reported systems that rely heavily on Cloud-Based Environmental Monitoring, the proposed system emphasizes local decision-making through Pollution Level Thresholding, enabling faster response during hazardous conditions. This approach aligns with real-world requirements such as indoor air safety, gas leakage detection, and awareness generation in non-industrial environments.

Furthermore, the project is motivated by the need to develop an educational and scalable prototype that can serve as a foundation for future enhancements, including Environmental Data Analytics and remote monitoring. By addressing simplicity, affordability, and usability, the proposed work contributes meaningfully to the existing body of Air Quality Monitoring Research while maintaining strong alignment with practical implementation constraints [5], [6].

9. GAS SENSING TECHNOLOGIES FOR AIR QUALITY MONITORING

Atmospheric Pollution Analysis relies on the accurate Atmospheric Contaminant Detection of gaseous pollutants using appropriate Environmental Sensing Infrastructure. Over the years, various Environmental Sensing Strategies have been developed, each offering different levels of Environmental Monitoring Accuracy, selectivity, cost, and deployment complexity. The selection of a sensing technology plays a crucial role in determining the feasibility and effectiveness of Air Quality Monitoring Systems, especially in low-cost and Embedded Environmental Monitoring applications [5], [11].

9.1 *Classification of Gas Sensing Technologies*

Gas sensing technologies used in Environmental Condition Evaluation can be broadly classified into metal oxide semiconductor (MOS) sensors, electrochemical sensors, infrared (NDIR) sensors, and photoionization detectors. Among these, MQ-Series Gas Sensors are most adopted in low-cost and prototype-level systems due to their affordability, robustness, and ease of integration with Embedded Environmental Monitoring platforms [3], [9].

Electrochemical and infrared sensors offer higher Environmental Monitoring Accuracy and selectivity but involve higher cost and complex signal conditioning, making them less suitable for small-scale deployments. Literature indicates that for educational and prototype-level Air Quality Monitoring, MOS-Based Sensors provide an effective balance between Environmental Monitoring Performance and cost [5], [20].

9.2 Selection of Sensing Technology for Embedded Systems

Several studies emphasize that Embedded Environmental Monitoring systems prioritize low power consumption, compact design, and Real-Time Environmental Monitoring response [1], [6]. MOS-Based Sensors align well with these requirements and are widely used in IoT- Based Environmental Analytics applications. Their compatibility with microcontrollers and tolerance to harsh environments make them suitable for indoor and semi-outdoor Environmental Surveillance System scenarios [11], [17].

However, literature also highlights that MQ-Series Gas Sensors require careful handling of environmental effects and Environmental Measurement Validation strategies to ensure meaningful Environmental Data Interpretation. These aspects are discussed in subsequent sections.

10. MQ-SERIES GAS SENSORS IN ENVIRONMENTAL MONITORING

The MQ-Series Gas Sensors are a family of MOS-based sensors extensively used in Environmental Monitoring Research. Due to their low cost and wide gas sensitivity range, MQ sensors are commonly adopted in prototype and academic projects focusing on Atmospheric Contaminant Detection and Environmental Hazard Identification [3], [11].

10.1 MQ-2 Gas Sensor

The MQ-2 Gas Sensor is primarily designed to detect combustible gases such as LPG, propane, methane, hydrogen, and smoke. Literature reports indicate its extensive use in Indoor Air Safety Systems and Gas Leakage Detection Applications due to its high sensitivity to flammable gases [1], [8].

Several studies utilize the MQ-2 Sensor in Threshold-Based Monitoring Systems, where the sensor output is compared against predefined limits to trigger alerts. Although the MQ-2 sensor exhibits cross-sensitivity to multiple gases, its fast response time and simple interfacing make it suitable for Real-Time Safety-Oriented Monitoring Systems [6], [16].

10.2 MQ-135 Gas Sensor

The MQ-135 Gas Sensor is widely used for General Air Quality Assessment and is sensitive to gases such as ammonia (NH_3), nitrogen oxides (NOx), benzene, and carbon dioxide (indicative). Literature frequently employs the MQ-135 Sensor as an Air Quality Indicator rather than a precise Gas Concentration Measurement Device [3], [20].

Research studies highlight that MQ-135 is effective in Monitoring Indoor Air Pollution Trends and detecting degradation in air quality over time. Despite limitations in quantitative accuracy, its low cost and broad sensitivity range make it suitable for Comparative and Alert-Based Monitoring Systems [5], [11].

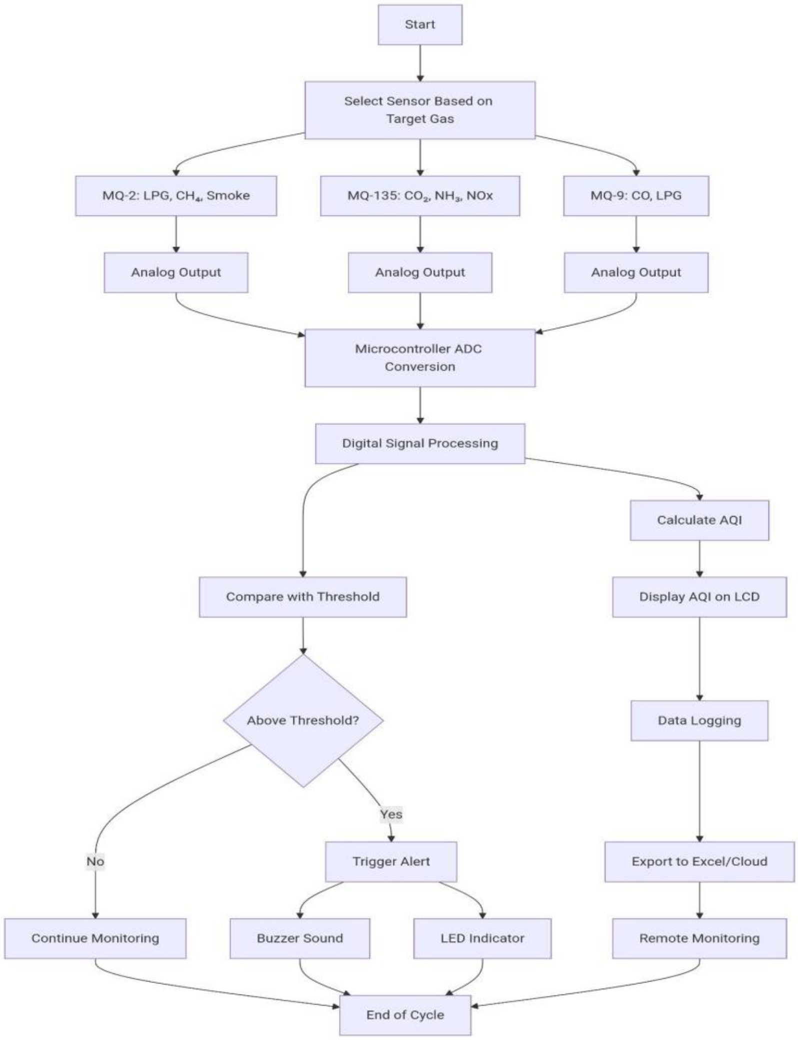

Figure 10.1 Flowchart of Sensor Working:

Sensor	Target Gases	Typical Applications	Key Limitations	References
MQ-2	LPG, smoke, CH_4	Gas leakage detection	Cross-sensitivity	[1], [8]
MQ-135	NH_3, NO_x, CO_2 (indicative)	Air quality indication	Requires calibration	[3], [20]

10.1 Table: Characteristics of MQ-2 and MQ-135 Sensors (Literature-Based)

11. ENVIRONMENTAL FACTORS AFFECTING SENSOR PERFORMANCE

The Environmental Monitoring Performance of low-cost gas sensors is significantly influenced by Environmental Condition Variations. Literature emphasizes that understanding these effects is essential for Environmental Monitoring Reliability in Air Quality Monitoring Systems, especially in real-world Environmental Surveillance applications [20].

11.1 Influence of Temperature and Humidity

Temperature Variation directly affects the resistance characteristics of MOS sensors, leading to deviations in Environmental Sensor Output. Similarly, Humidity Levels alter the adsorption characteristics of sensing materials, causing fluctuations in Gas Sensitivity Calibration [5], [20]. Several studies report that High Humidity Environments tend to increase Sensor Baseline Drift in MQ-series sensors**.** Researchers suggest compensating for Environmental Effects either through Software Correction Techniques or by maintaining consistent Operating Conditions. However, many prototype-level systems accept these variations and focus on Environmental Trend Analysis rather than Absolute Environmental Monitoring Accuracy [11], [17].

11.2 Sensor Aging and Drift Effects

Long-Term Sensor Exposure to gases and continuous heating of the sensing element leads to Sensor Aging Effects, which results in gradual changes in Environmental Monitoring Sensitivity. Literature reports that MQ-series sensors experience Sensor Drift Over Time, necessitating Periodic Sensor Recalibration or Threshold Adjustment Procedures [20].

Despite this limitation, studies conclude that for Short-Term Environmental Monitoring and Educational Prototype Systems, sensor aging does not significantly affect Qualitative Monitoring Performance, provided appropriate Pollution Level Thresholding parameters are selected [6], [9].

Environmental Factor	**Effect on Sensor Performance**	**Impact Severity**	**Literature Survey Support**	**Mitigation Approach**
Temperature Variation	Alters sensor resistance; causes output drift	High	[5], [20]	Software compensation; controlled enclosure
Humidity Levels	Changes adsorption properties; baseline drift	Moderate to High	[5], [20]	Humidity sensors for correction; sealed housing
Sensor Aging	Gradual sensitivity loss; calibration drift	Moderate (long-term)	[20]	Periodic recalibration; threshold adjustment
Cross-Sensitivity	Response to non-target gases	Moderate	[11]	Multi-sensor fusion; pattern recognition
Power Fluctuation	Inconsistent heater voltage affects stability	Low to Moderate	[17]	Regulated power supply; stable voltage input
Ambient Light / Dust	Minimal for MOS sensors; possible contamination	Low	[6]	Protective mesh; regular cleaning

Table 11.1: Summary of Environmental Factors Affecting MQ-Series Sensor Performance

12 CALIBRATION CHALLENGES IN LOW-COST SENSORS

Sensor Calibration remains one of the most challenging aspects of Low-Cost Air Quality Monitoring Systems. Unlike high-end reference instruments, MQ-series sensors lack Factory Calibration for specific gas concentrations, which limits their Quantitative Environmental Monitoring Accuracy [20].

12.1Calibration Limitations in MQ-Series Sensors

Literature highlights that MQ sensors typically provide analog voltage outputs that correlate non-linearly with Gas Concentration. Accurate calibration requires controlled gas exposure and Reference Instruments, which are often unavailable in Low-Cost Environmental Monitoring Setups [3], [5].

As a result, many studies employ Simplified Calibration Techniques or rely on Relative Changes rather than exact ppm values. This approach is commonly accepted in Prototype Environmental Monitoring and Alert-Based Environmental Systems [1], [6].

12.2 Threshold-Based Monitoring as an Alternative

To address calibration challenges, several studies adopt Threshold- Based Decision Logic, where sensor readings are categorized into safe and unsafe levels. This method simplifies system design while maintaining practical usefulness for Environmental Safety Monitoring [11], [17]. Pollution Level Thresholding aligns well with Embedded System Constraints and is widely reported in literature as an effective strategy for Low-Cost Air Quality Monitoring Systems [1], [6].

Calibration Method	Complexity	Accuracy Level	Hardware Requirements	Literature Reference
Factory Calibration	Low	High	Pre-calibrated sensor	[20]
Controlled Gas Exposure	High	High	Reference instruments, gas chambers	[3], [5]
Simplified Threshold Calibration	Medium	Medium	Ambient air baseline	[1], [6]
Relative Trend Calibration	Low	Low–Medium	Stable environment	[1], [11]
Cross-Sensor Calibration	Medium	Medium	Multiple sensors	[11], [17]

Table 12.1: Comparison of Calibration Approaches for MQ-Series Sensors

13. SUMMARY OF LITERATURE REVIEW

The Literature Survey reveals that Embedded Environmental Monitoring and IoT-Based Environmental Analytics systems have gained significant attention due to increasing Environmental Awareness. Gas Sensing Technologies, particularly MOS-based MQ-Series Sensors, are widely used in Low-Cost and Prototype-Level Monitoring Systems owing to their affordability and System Integration ease [3], [5]. However, literature also highlights key challenges such as Environmental Sensitivity, Calibration Limitations, and Sensor Drift Effects. Most studies address these challenges through Simplified Monitoring Strategies, Environmental Trend Analysis, and Threshold-Based Alert Mechanisms. These findings establish a strong foundation for the proposed project and justify the selection of MQ-Series Sensors and Embedded Platforms for developing a practical Air Quality Monitoring Prototype [1], [6], [11].

Research Aspect	**Key Findings from Literature**	**Supporting Papers**	**Implication for Our Project**
Sensor Technology	MOS-based MQ-series sensors are cost-effective for prototype systems	[3], [5], [11]	Use MQ-2, MQ-135, MQ-4, and MQ-9 sensors
System Architecture	Embedded platforms such as Arduino and ESP32 are suitable for low-cost monitoring	[1], [6], [9]	Select ESP32 as the primary processing unit
Calibration Approach	Threshold-based monitoring is effective without complex calibration	[1],[6],[11]	Implement threshold-based decision logic
Environmental Factors	Temperature and humidity significantly affect sensors performance	[5], [20]	Incorporate environmental compensation considerations
Alert Mechanisms	Local alerts using LCDs, buzzers, and LEDs enhance safety awareness	[6],[11]	Include visual and audible alert mechanisms
Data Communication	Wireless communication enables remote monitoring and scalability	[4], [21]	Provide optional Wi-Fi-based future expansion

Table 13.1: Literature Review Findings Summary

14. CONCLUSION

This project has presented a comprehensive study of Embedded Environmental Monitoring through an extensive review of existing literature, Environmental Sensing Technologies, and Environmental Monitoring System Architecture. The Literature Survey highlights the growing importance of Low-Cost Air Quality Monitoring Systems in addressing environmental and safety challenges, particularly in Indoor and Localized Environments. Various Gas Sensing Technologies were examined, with particular emphasis on Metal Oxide Semiconductor Sensors due to their affordability, robustness, and suitability for Prototype-Level Applications. The analysis of MQ-Series Sensors, specifically MQ-2 and MQ-135, demonstrated their widespread adoption in Environmental Monitoring Systems for Atmospheric Contaminant Detection of combustible gases and general air quality indicators. While these sensors exhibit limitations such as Cross-Sensitivity, Environmental Dependency, and Calibration Challenges, the literature consistently supports their effectiveness for Qualitative Monitoring and Safety- Oriented Applications when used with appropriate Threshold-Based Decision Logic. Furthermore, the review of Environmental Factors such as temperature, humidity, and Sensor Aging emphasized the necessity of understanding Real-World Operating Conditions to ensure Environmental Monitoring Reliability. Calibration Challenges identified in low-cost sensors further justified the preference for Environmental Trend Analysis and Alert-Based Monitoring rather than precise Quantitative Environmental Measurement. Overall, the literature confirms that Embedded Systems combined with Low-Cost Gas Sensors provide a practical and scalable foundation for Air Quality Monitoring at the prototype level. The insights gained from this study establish a strong theoretical basis for the proposed work and reinforce its relevance, feasibility, and contribution toward developing accessible Environmental Monitoring Solutions that balance simplicity, functionality, and Real- World Applicability.

15. REFERENCES

1.Low-Cost IoT-Based Air Quality Monitoring System

https://scholar.google.com/scholar?q=Low-Cost+IoT-Based+Air+Quality+Monitoring+System

2. IoT-Enabled Environmental Monitoring System

https://scholar.google.com/scholar?q=IoT-Enabled+Environmental+Monitoring+System

3. Embedded System Design for Air Pollution Monitoring

https://scholar.google.com/scholar?q=Embedded+System+Design+for+Air+Pollution+Monitoring

4. Wireless Sensor Network for Real-Time Air Monitoring

https://scholar.google.com/scholar?q=Wireless+Sensor+Network+for+Real-Time+Air+Monitoring

5.Review of Air Quality Monitoring Technologies

https://scholar.google.com/scholar?q=Review+of+Air+Quality+Monitoring+Technologies

6. Smart Environmental Monitoring Using IoT

https://scholar.google.com/scholar?q=Smart+Environmental+Monitoring+Using+IoT

7. Smart City Air Quality Monitoring Framework

https://scholar.google.com/scholar?q=Smart+City+Air+Quality+Monitoring+Framework

8. Cloud-Based Air Pollution Monitoring System

https://scholar.google.com/scholar?q=Cloud-Based+Air+Pollution+Monitoring+System

9. Environmental Monitoring Using Embedded Platforms

https://scholar.google.com/scholar?q=Environmental+Monitoring+Using+Embedded+Platforms

10. Intelligent Air Quality Prediction Using IoT

https://scholar.google.com/scholar?q=Intelligent+Air+Quality+Prediction+Using+IoT

11. Multi-Parameter Environmental Monitoring Systems

https://scholar.google.com/scholar?q=Multi-Parameter+Environmental+Monitoring+Systems

12. Distributed Environmental Monitoring Networks

https://scholar.google.com/scholar?q=Distributed+Environmental+Monitoring+Networks

13. Machine Learning for Air Pollution Analysis

https://scholar.google.com/scholar?q=Machine+Learning+for+Air+Pollution+Analysis

14. Data Analytics for Environmental Monitoring

https://scholar.google.com/scholar?q=Data+Analytics+for+Environmental+Monitoring

15. Predictive Air Quality Assessment Models

https://scholar.google.com/scholar?q=Predictive+Air+Quality+Assessment+Models

16. Time-Series Analysis of Air Pollution Data

https://scholar.google.com/scholar?q=Time-Series+Analysis+of+Air+Pollution+Data

17. Energy-Efficient IoT Monitoring Systems

https://scholar.google.com/scholar?q=Energy-Efficient+IoT+Monitoring+Systems

18. Secure IoT-Based Environmental Monitoring

https://scholar.google.com/scholar?q=Secure+IoT-Based+Environmental+Monitoring

19. Scalable Smart Environmental Systems

https://scholar.google.com/scholar?q=Scalable+Smart+Environmental+Systems

20. Long-Term Performance of Air Quality Sensors

https://scholar.google.com/scholar?q=Long-Term+Performance+of+Air+Quality+Sensors

21. Edge–Cloud Architecture for Air Monitoring

https://scholar.google.com/scholar?q=Edge–Cloud+Architecture+for+Air+Monitoring

22. Intelligent Environmental Decision Support Systems

https://scholar.google.com/scholar?q=Intelligent+Environmental+Decision+Support+Systems

23. Advanced Air Quality Monitoring for Smart Cities

https://scholar.google.com/scholar?q=Advanced+Air+Quality+Monitoring+for+Smart+Cities