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Manhole Management System: IoT-Powered Solution for Safety and Efficiency

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Abstract

The Manhole Management System is an IoT-based solution designed to enhance safety and efficiency in manhole monitoring. Real-time monitoring is crucial due to risks such as hazardous gas accumulation, flooding and overheating. This project integrates IoT technologies to monitor air quality, water levels and temperature using the MQ-135 gas sensor, HC-SR04 ultrasonic sensor and LM35 temperature sensor with connected to an ESP32 microcontroller. When hazardous conditions are detected, the system transmits real-time alerts to a Telegram application by enabling maintenance workers or authorities to respond immediately. The system demonstrates effective sensor integration, data processing and alerting with LEDs providing visual indicators and Telegram notifications ensuring timely warnings. So, the result confirm the system's ability to accurately detect hazards, improving safety and supporting efficient manhole management.

1. Introduction

Modern society depends heavily on urban infrastructure to supporting essential services and ensuring the safety and convenience of daily life. Manholes are essential access points for underground systems like communication networks, utilities and drainage systems. However, their management often poses safety hazards such as gas leaks, water overflow and overheating, which leading to accidents, operational disruptions and costly maintenance. Traditional inspection are time-consuming and frequently fail to detect hazards promptly. Manhole management can be improved by utilizing the Internet of Things (IoT), which allows for real-time monitoring and enhancing productivity and safety.

The potential of sensors and microcontrollers for hazard detection and real-time communication is highlighted by scientific research on IoT applications in infrastructure management. Although studies have shown that gas, ultrasonic and temperature sensors are effective, but many implementation are limited to monitoring specific parameters or lack integrated alert system. This highlights a research gap in developing a comprehensive solution for continuous monitoring, alerting and data driven decision making in manhole management.

This study seeks to answer: "How can IoT technology improve safety and efficiency in manhole management?" So, that a smart IoT-based system, integrating sensors for gas, water level and temperature monitoring with real-time alerts via Telegram can effectively address existing challenges. By ensuring continuous monitoring and timely intervention. The system is expected to improve safety, reduce risks and support sustainable urban infrastructure.

2. Literature Review

The literature review for the Manhole Management System: IoT Powered Solution for Safety and Efficiency explores the adoption of IoT-based systems for monitoring and managing manholes. IoT technologies including sensors, processors and communication mechanisms, enable automated monitoring of conditions such as water levels, gas presence and temperature. The main objectives are to implement an IoT-based system for proactive monitoring, integrate sensors for real-time condition detection and alert mechanisms and prevent urban hazards by ensuring timely maintenance and intervention.

In addition, by combining IoT devices with real-time data transmission, this system empowers authorities and maintenance workers to respond immediately, maintaining manhole conditions, preventing accidents and enhancing public safety[1]. So, the reviews examines exisiting research, identifying gaps further investigation and providing a foundation for deploying IoT-powered manhole management solutions. This approach supports improvements and enhances the efficiency or urban infrastructure systems.

So, he development of smart manhole systems has been explored in various studies, each contributing valuable insights into IoT-based solutions for urban infrastructure management. These studies emphasizes the improtance of integrating IoT technologies to enhance monitoring, safety and efficiency. The research aims to collect and analyze existing findings to establish a foudation for the proposed manhole management system. The important studies consist of:

- Towards a Fully Automated Monitoring System for Manhole Cover: Smart Cities and IoT Application [2]
- Centralized Drainage System Detection and Monitoring using IoT[3]
- Smart Manhole Managing and Monitoring System using IoT [4]
- Manhole Intrusion Detection System with Notifications Stages [5]
- IoT Device for Sewage Gas Monitoring and Alert System [6]
- On a Working Monitoring System of Manhole Wells Based on Technology of Internet of Things [7]

3. Methodology

The Manhole Management System: IoT Powered Solutions for Safety and Efficiency addresses common issues in manholes such as gas leaks, flooding and high temperature by leveraging IoT technology. The system enables real-time monitoring of manhole conditions with alerts sent via a communication module and visual indicators activated LEDs. The notifications are delivered through the Telegram application, allowing authorities to assess the manhole's current state promptly. This approach enhances efficiency, improves safety for workers and the public and helps prevent unwanted incidents.

3.1 System Block Diagram

This project uses IoT technology to increase efficiency and safety while addressing frequent manhole issues including gas leaks, flooding and high temperatures. The system is built around the ESP32 microcontroller and integrates the MQ-135 gas sensor, HC-SR04 ultrasonic sensor and LM35 temperature sensor to monitor real-time conditions inside the manhole. LEDs indicators serve as visual alerts when hazards are detected and notifications are sent via the Telegram app as a communication module. By enabling continuous monitoring and timely alerts, this system enhancee safety for both workers and the public while reducing the risk of accidents. Fig. 1 shows the project's working principle by focusing on the components that are utilized to keep the system functioning.

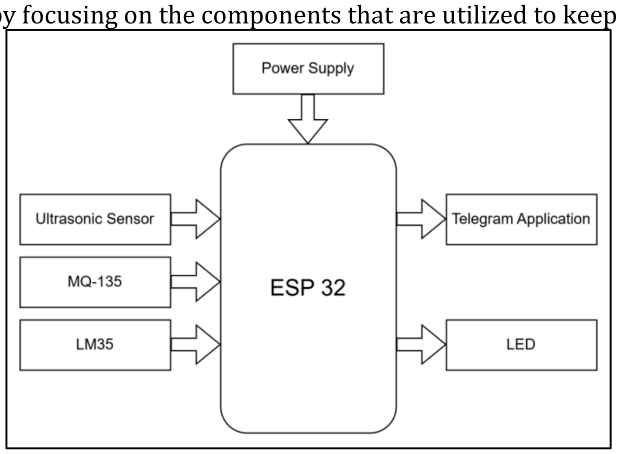


Fig. 1: Block Diagram of the system

The system is powered by solar panel, converting sunlight into electricity to operate the ESP32 microcontroller, sensors and LEDs by making ideal for rural manholes while promoting sustainability [8]. ESP32 is microcontroller unit (MCU) can be used to connect to other devices through Bluetooth and Wi-Fi [9]. So,ESP32 main role for this systems acts as control unit for three main sensor with data processing. The MQ-135 gas sensor used to measure, detect and keep monitoring of gases including smoke, carbon dioxide and other hazardous gases. Some of gases in the air can detected and their concentration measured with a gas sensor. [9] A 100 ppm threshold are specified for MQ-135 gas sensor in this project. The HC-SR04 ultrasonic sensor generates high frequency sound waves that are inaudible to humans and these sound waves go towards the target within the manhole and bounce back when they hit the water surface. Ultrasonic sensor is crucial to monitor water levels and help to wastewater's safety and efficiency from overflows. The LM35 temperatre sensor are high precision integrated circuit with linearly propotional output voltage based on Celcius [10]. So, these sensor used in the system for monitoring temperature in detecting any overheating due to breakdown or external factors. The ESP32 processes data from the MQ-135 gas sensor, HC-SR04 ultrasonic sensor and LM35 temperature sensor to monitori air quality, water levels and temperature. It activates LEDs and sends real-time alerts via Telegram when thresholds are exceeded or no threshold detected for knows manhole conditons for every 60seconds.

3.2 System Flowchart

Fig. 2 was highlighted the process of monitoring air quality, water levels and temperature inside the manhole. The system initializes Wi-Fi and sets up LEDs as visual indicator for alerts. Sensors collect data with the MQ-135, ultrasonics sensor and the LM35. The system evaluates the conditions against set thresholds. If the air quality exceeds 100ppm, the red activates and a Telegram alert warns of potential gas leaks. If water levels fall below 20cm, the green LED turns on and a Telegram alert notifies about possible overflow risks. For temperature above 37°C, the yellow LED lights up, and a Telegram alert highlights overheating risks. If no thresholds are breached, the system provides real-time updates via Telegram. The monitoring cycle will repeats every two seconds to ensure consistent updates about manhole conditions.

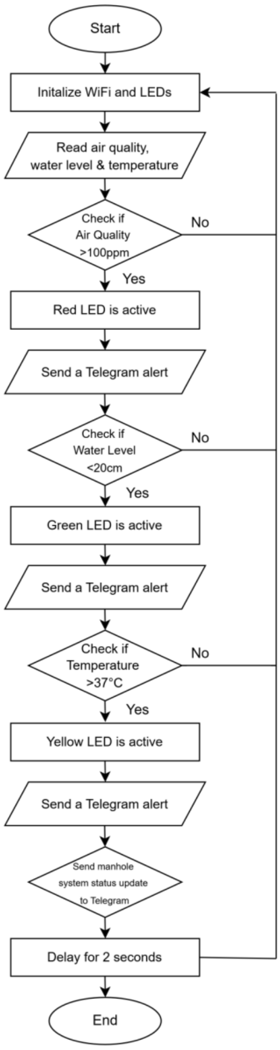


***Fig. 2*:** System Flowchart

4. Result and Discussion

This chapter shows the result and discussion of the Manhole Management System to enhance safety and efficiency. The system communicates through network sensors with an ESP32 microcontroller and Telegram application to allow the real-time monitoring.

4.1 Capability Sensors for Real-Time Detection

4.1.1 MQ-135 (Gas Sensor)

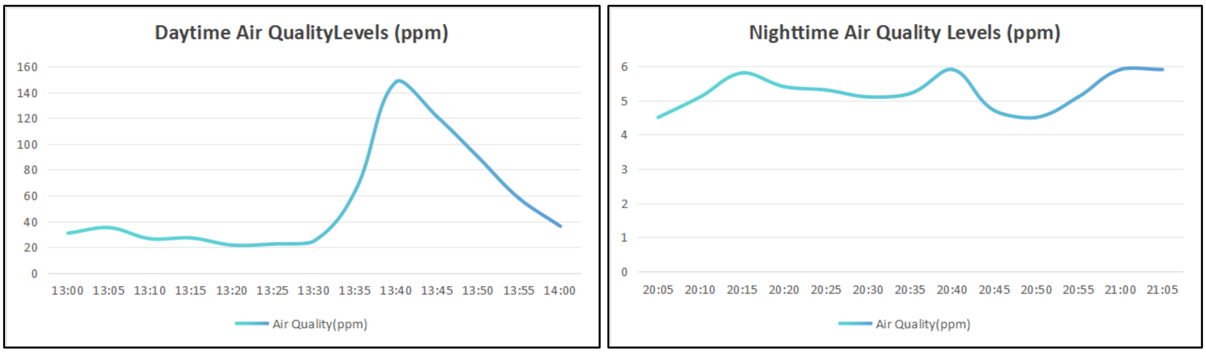
Table 1: Daytime air quality readings(ppm)

Timestamp	Air Quality (ppm)	LED Status	Notes
13:00	30.7	OFF	
13:05	35	OFF	
13:10	26.4	OFF	
13:15	27	OFF	
13:20	21.5	OFF	
13:25	22.3	OFF	
13:30	24.7	OFF	
13:35	63.4	OFF	
13:40	148.3	ON	Telegram sent alert
13:45	121.1	ON	Telegram sent alert
13:50	89.7	OFF	
13:55	57.6	OFF	
14:00	36.1	OFF	

Table 2: Nighttime air quality readings(ppm)

Timestamp	Air Quality (ppm)	LED Status	Notes
20:05	4.5	OFF	
20:10	5.1	OFF	
20:15	5.8	OFF	
20:20	5.4	OFF	
20:25	5.3	OFF	
20:30	5.1	OFF	
20:35	5.2	OFF	
20:40	5.9	OFF	
20:45	4.7	OFF	
20:50	4.5	OFF	

20:55	5.1	OFF
21:00	5.9	OFF
21:05	5.9	OFF



(a) (b)

Fig. 3: Graph for Air Quality Levels(ppm) (a)Daytime (b)Nighttime

Table 1 and 2 demonstrates differences in air quality between daytime and nighttime conditions. During the day, air quality levels ranged from 21.5 ppm to 148.3 ppm with spikes at 13:40 (148.3ppm) and 13:45(121.1ppm) exceeding threshold. These triggered LED indicators and Telegram alerts by suggesting possible minor gas leaks due to operational or environmental factors. A night, readings were consistently low ranging between 4.5 ppm and 5.9 ppm likely due to reduced activity near manholes and indicating decreased risk.

Fig 3 (a). shows daytimme air quality peaking at 145 ppm at 13:55 before gradually stabilizing by 14:00. In contrast, Fig 3 (b) depicts stable nighttime air quality with minor fluctuations between 5 and 6 ppm over an hour. These results highlights significant differences in air quality patterns, emphasizing effectiveness of the system in detecting real-time changes and the need for further research to optimize its performance.

4.1.2 LM35 (Temperature Sensor)

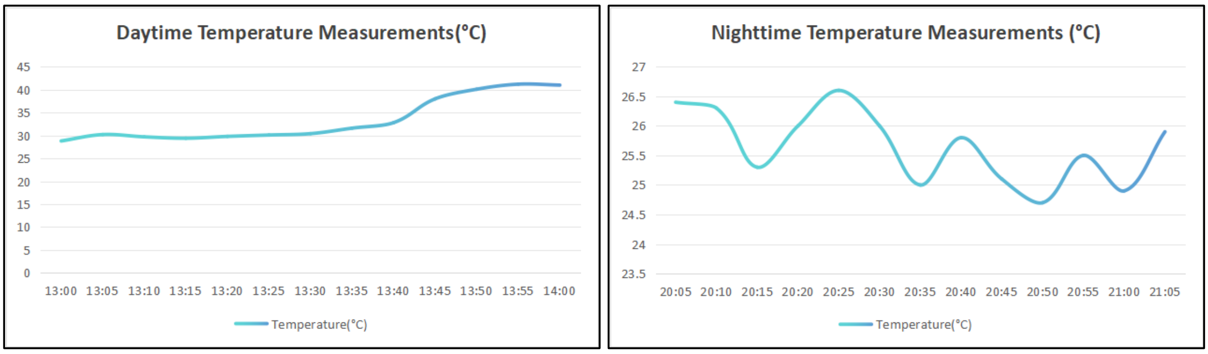
Table 3: Daytime Temperature Mesurements(°C)

Timestamp	**Temperature (°C)**	**LED Status**	**Notes**
13:00	28.8	OFF	
13:05	30.2	OFF	
13:10	29.7	OFF	
13:15	29.4	OFF	
13:20	29.8	OFF	
13:25	30.1	OFF	
13:30	30.4	OFF	
13:35	31.6	OFF	
13:40	32.8	OFF	
13:45	38	ON	Telegram sent alert
13:50	40.1	ON	Telegram sent alert
13:55	41.2	ON	Telegram sent alert
14:00	41	ON	Telegram sent alert

Table 4: Nighttime Temperature Measurement(°C)

Timestamp	**Temperature (°C)**	**LED Status**	**Notes**
20:05	26.4	OFF	
20:10	26.3	OFF	
20:15	25.3	OFF	
20:20	26	OFF	
20:25	26.6	OFF	
20:30	26	OFF	

20:35	25	OFF	
20:40	25.8	OFF	
20:45	25.1	OFF	
20:50	24.7	OFF	
20:55	25.5	OFF	
21:00	24.9	OFF	
21:05	25.9	OFF	



(a) (b)

Fig. 4: Graph for Temperature Measurement(°C) (a)Daytime (b)Nighttime

Table 3 and 4 highlight the temperature variations in the manhole during day and night. Daytime temperature ranged from 28.8°C to 41.1°C with critical threshold of 38°C breached at 13:45. The peak temperature of 41.2°C at 13:55 suggest potential overheating due to external heat or manhole activities. Nighttime temperatures remained steady and lower, ranging from 24.7°C to 26.6°C, with no threshold breaches likely due to reduced activity and ambient heat.

Fig.4 (a) shows a steady daytime temperature increase from 29°C at 13:00 to 41°C, exceeding the critical threshold, while nighttime measurements, as depicted in the graph were stable between 24°C and 26°C. These findings emphasize the system's effectiveness in detecting overheating hazards during the day and the need further investigation into potential causes such as ventilation issues or external heat sources.

4.1.3 HC-SR04 (Ultrasonic Sensor)

Table 5: Water Level readings (cm)

Timestamp	Temperature (°C)	LED Status	Notes
21:30	33	OFF	
21:35	28	OFF	
21:40	14	ON	Telegram sent alert
21:45	17	ON	Telegram sent alert
21:50	15	ON	Telegram sent alert
21:55	17	ON	Telegram sent alert
22:00	18	ON	Telegram sent alert
22:05	14	ON	Telegram sent alert
22:10	23	OFF	
22:15	23	OFF	
22:20	23	OFF	
22:25	24	OFF	

22:30	23	OFF

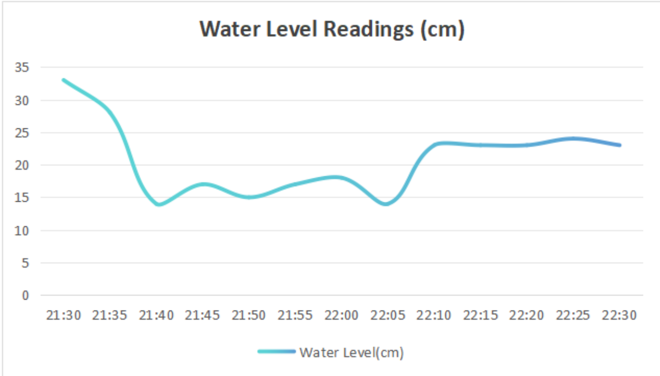


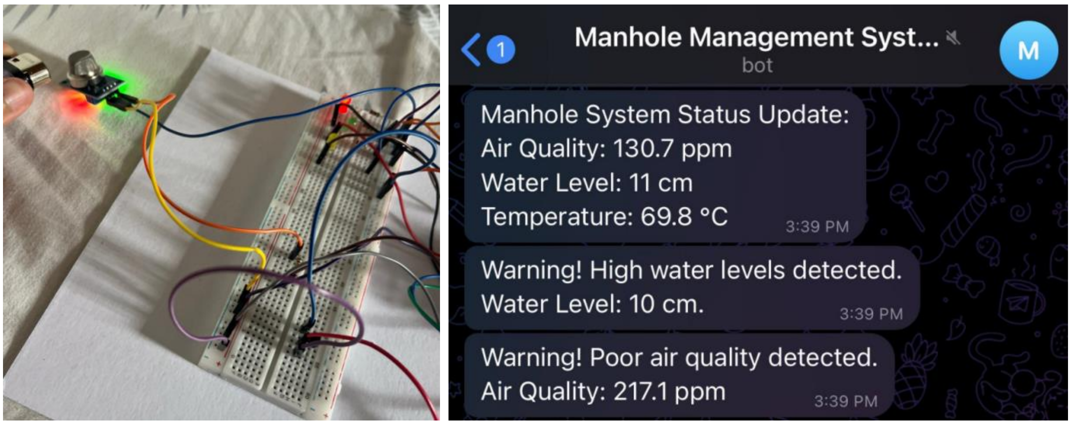
Fig. 5: Graph for Water Level Readings (cm)

Table 5 shows water level variations detected by the ultrasonic sensor, revealing potential overflow issues. Water levels fell below the 20 cm threshold, reaching a low of 14 cm between 21:40 and 22:05. This triggered LEd indicators and Telegram alerts to notify maintenance workers and authorities. The critical levels persisted for 25 minutes, possibly indicating drainage issues or high inflow. Afterward, water levels stabilized between 23 cm and 24 cm with no further alerts.

Fig.5 shows water levels decreasing from 33 cm to 14 cm between 21:30 and 22:05, fluctuating before stabilizing at 23 cm by 22:10. These results demonstrate the system's capability for timely detection and response to hazardous water levels. Further investigation into factors such as blockages or rainfall is recommended to enhance monitoring and system performance.

4.2 Manhole Monitoring for Threshold Identification

4.2.1 MQ-135



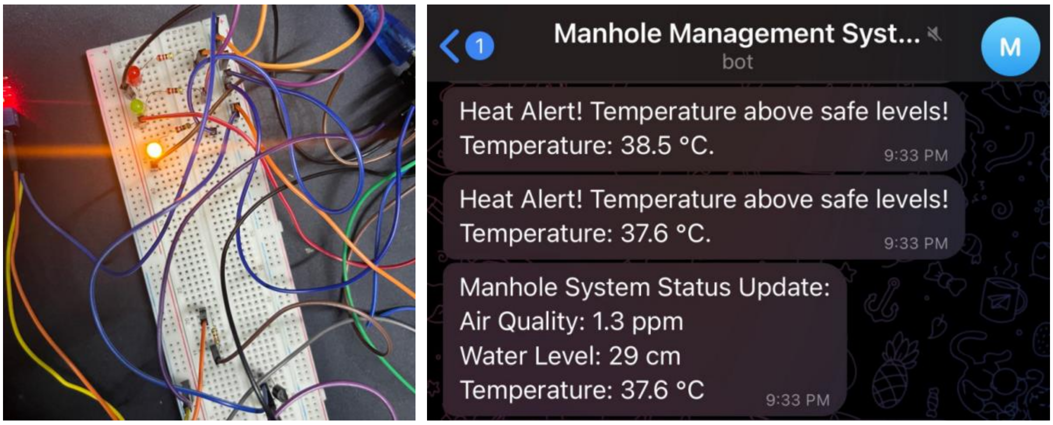
(a) (b)

Fig. 6: (a) Red LED activated when air quality threshold reached (b) Real-time alerts when air quality triggering

The MQ-135 gas sensor in the manhole management system detects and responds to hazardous gas concentrations effectively. During a demonstration Fig. 6 (a), it detected toxic gas from a lighter and activated the red LED when the concentration exceeded the threshold, shows its real-time detection capability.

As shown in Fig.6 (b), the system sends status updates when conditions are normal and alerts when thresholds are breached. For instance, at 130.7 ppm and reported normal air quality but at 217.1 ppm, it issued a "Warning! Poor ai quality detected" alert via Telegram. This ensure quick responses to hazards, enhancing safety and effective manhole management.

4.2.2 LM35 (Temperature Sensor)

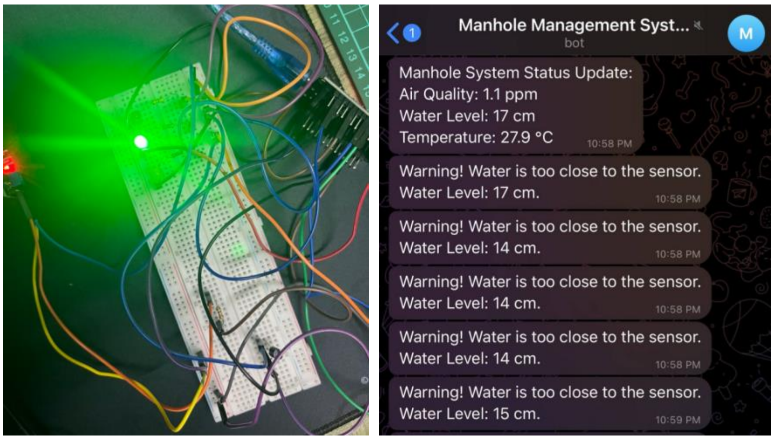


(a) (b)

Fig. 7: (a)Yellow LED activated when overheating threshold reached (b) Real-time for temperature sensors reached threshold

The LM35 temperature sensor in the manhole management system detects overheatinng by monitoring temperature breaches above 37°C threshold. When the temperature exceeds this limit in Fig.7 (a), a yellow LED activates, signaling a potential overheating issues inside the manhole. Fig 7 (b) shows real-time notifications are sent via Telegram such as "Heat Alert! Temperature above safe levels!" at 38.5°C and 37.6°C. This provides accurate, real-time monitoring for maintenance workers or authorities. By integrating the LM35 sensor with visual and real-time alerts, the system ensures timely detection and response.

4.2.3 HC-SR04 Ultrasonic Sensor



(a) (b)

Fig. 8: (a) Green LED activated when overheating threshold reached (b) Real-time for ultrasonic sensors reached threshold

The HC-SR04 ultrasonic sensor in the manhole management system monitors water levels to detect potential flooding or overflow situations. The threshold is set at 20 cm, and when water level exceed this limit as showns in Fig. 8 (a), the green LED activates is signaling dangerously high water levels. Real-time alerts are sent via Telegram was shown in Fig. 8 (b) such as "Warning! Water is to close to the sensor" when levels reach 17 cm, 14 cm and 15 cm. This ensures maintenance workers or authorities are promptly informed to take action.

4.3 Sensor Measured vs Actual Value for Each Sensor

4.3.1 MQ-135 (Gas Sensor)

Table 6: Sensor measured vs Actual Value for MQ-135 (Daytime)

Timestamp	Measured Air Quality(ppm)	Actual Air Quality(ppm)
13:00	30.7	54
13:15	27	54
13:30	24.7	53
13:45	121.1	53

14:00	36.1	52

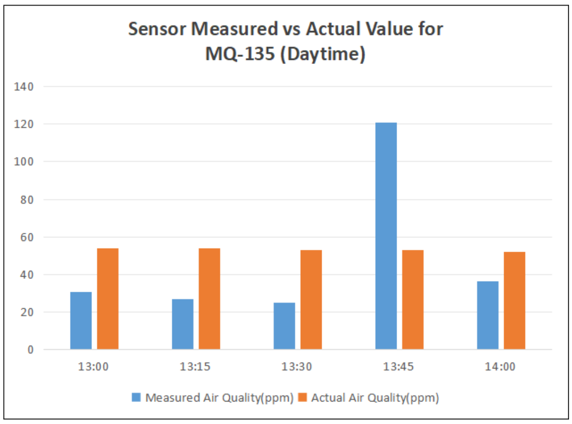


Fig. 9: Graph for Sensor Measured vs Actual Value for MQ-135 (Daytime)

The MQ-135 sensor readings highlighted significant differences compared to real air quality from the waqi.info website as shown in Table 6 and Fig. 9. At 13:00, the sensor recorded 30.7 ppm but the real value is 54 ppm. At 13:45, the sensor showed 121.1 ppm, while the real value was 53 ppm. These differences might happen because the sensor was not calibrated or because things like temperature, sunlight or humidity affected it. To make the sensor more accurate, the sensor should be calibrated with known gas values, placed in a shaded area to reduce heat and sunlight effects and use simple data processing methods like averaging to smooth out the readings.

Table 7: Sensor Measured vs Actual Value for MQ-135 (Nighttime)

Timestamp	Measured Air Quality(ppm)	Actual Air Quality(ppm)
20:05	4.5	46
20:20	5.4	44
20:35	5.3	44
20:50	4.5	44
21:05	5.9	43

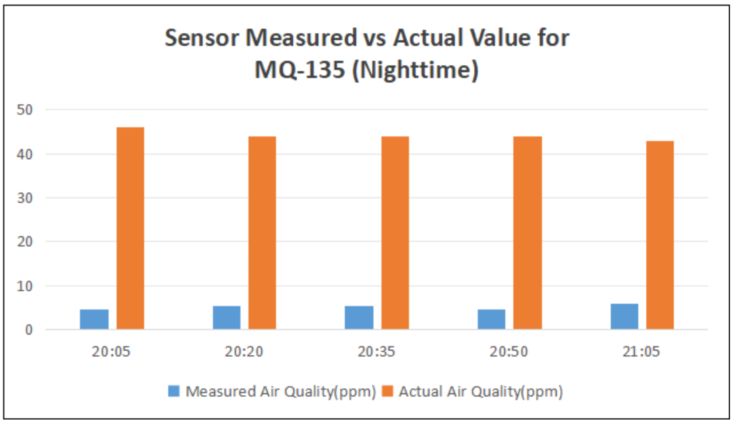


Fig. 10: Graph for Sensor Measured vs Actual Value for MQ-135 (Nighttime)

Table 7 highlights the differences between the MQ-135 sensor readings and actual nighttime air quality values. At 20:05, the sensor measured 4.5 ppm while the actual for real-time air quality monitoring website was 46 ppm. The actual values gradually decreased from 46 ppm at 20:05 to 43 ppm at 21:05, while the sensor readings remained low by ranging between 4.5 ppm and 5.9 ppm. Fig.10 illustrates this difference, which suggest the sensor is not measuring air quality correctly at night. This may be due to calibration problems or lower accuracy in nighttime conditions such as cooler temperature or lower humidity. The sensor readings stay within a small range even if they are wrong, which shows it is not very sensitive to changes air quality.

To fix this, the sensor needs to be calibrated to match real values. Testing it in stable nighttime conditions and using a correction factor can help make it more accurate. These steps will improve the MQ-135 sensor's ability to measure air quality at night.

4.3.2 LM35 (Temperature Sensor)

Table 8: Sensor Measured vs Actual Value for LM35 (Daytime)

Timestamp	Measured Temperature(°C)	Actual Temperature(°C)
13:00	28.8	30
13:15	29.4	31
13:30	30.4	32
13:45	38	30
14:00	41	31

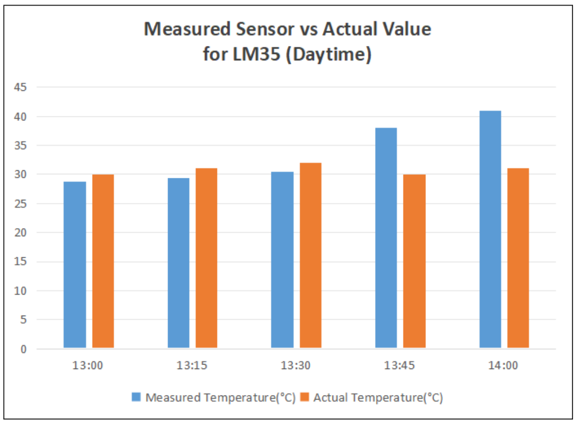


Fig. 11: Graph for Sensor Measured vs Actual Value for LM35 (Daytime)

Table 8 compares LM35 sensor reading to actual temperature values during the day. At 13:00, the actual temperature from a weather application was 30°C, while the sensor recorded 28.8°C. Initially, the sensor followed the actual trend but later showed lrger differences as shown in Fig. 11. By 14:00, the sensor recorded 41°C, while the actual temperature was 31°C. This indicates the LM35 sensor may have accuracy issues, especially at higher temperature due to calibration errors, overheating or exposure to sunlight.

Table 9: Sensor Measured vs Actual Value for LM35 (Nighttime)

Timestamp	Measured Temperature(°C)	Actual Temperature(°C)
20:05	26.4	26
20:20	26	26
20:35	25	26
20:50	24.7	25
21:05	25.9	25

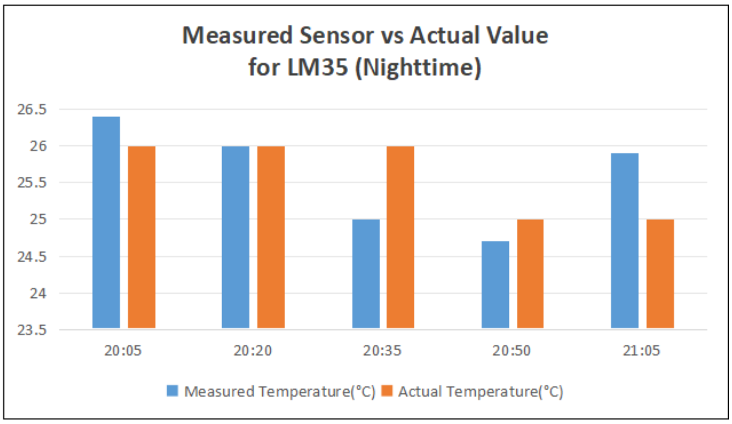


Fig. 12: Graph for Sensor Measured vs Actual Value for LM35 (Nighttime)

Table 9 and Fig. 12 show that the LM35 sensor's nighttime temperature readings closely match actual values. At 20:05, the sensor measured 26.4°C, while the actual temperature from a weather app was 26°C. Similarly, at 20:50, the sensor recorded 24.7°C compared to an actual temperature of 25°C and at 21:05, the sensor mesured 25.9°C while the actual was 25°C. The small differences indicate that the LM35 sensor performs well at night, providng accurate reading with only minor differences due possible calibration or environmental factors. The LM35 sensor delivers reliable nighttime temperature readings with minimal adjustment needed.

4.3.3 HC-SR04 (Ultrasonic Sensor)

Table 10: Sensor Measured vs Actual Value for HC-SR04

Timestamp	Measured Water Level(cm)	Actual Water Level (cm)
21:30	33	34
21:45	17	17
22:00	18	17
22:15	23	24
22:30	23	23

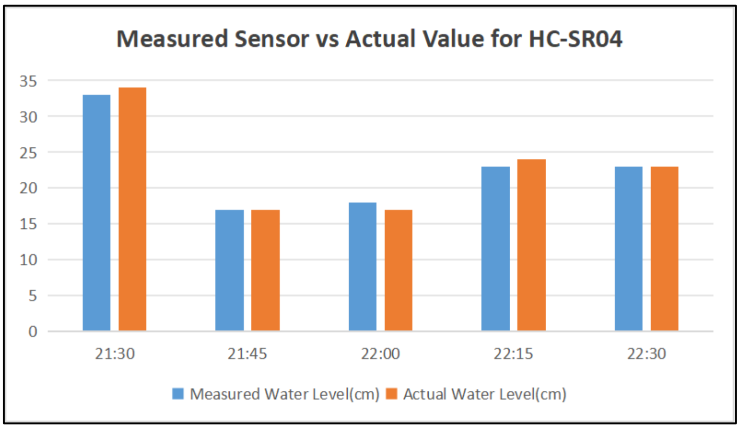


Fig. 13: Graph for Sensor Measured vs Actual Value for HC-SR04

Table 10 shows that the HC-SR04 ultrasonic sensor gives readings close to actual water levels with small differences. At 21:30, the sensor measured 33 cm compared to the actual 34 cm. At 21:45 and 22:30, the sensor readings matched the actual values of 17 cm and 23 cm. Small differences occurred, like at 22:00, where the sensor recorded 18 cm instead of 17 cm and at 22:15, where it measured 23 cm instead of 24 cm. Actual water levels were measured manually with measuring tape, which my have caused small errors. Environmental factors like rippless or uneven water surfaces could also affect sensor accuracy.

Recalibrating the sensor and reducing distrubances can improve accuracy. Automating the measurement process instead of using a measuring tape could further reduce errors. So, the sensor provides reliable readings with minor adjustments needed.

4.4 Real-time Alerts Via Telegram Application

The manhole management system uses the Telegram application to send real-time alerts and updates to ensuring maintenance workers or authorities are quickly informed about manhole conditions.

The system has two main functions which is threshold alerts and regular update about manhole condition as shown in Fig. 14. For example, the MQ-135 gas sensor sends a "Warning! Poor air quality detected", the HC-SR04 ultrasonic sensor alerts "Warning! Water is too close to the sensor" and the LM35 temperature sensor issues a "Heat Alert! Temperature above safe levels."

The regular updates are sent every 60 seconds, showing current air quality, water levels and temperature readings, even when conditions are normal. For instance, the system may report air quality at 654.7 ppm, water level at 0 cm and temperature at 40.5°C. An immediate alerts are sent when threshold are exceeded such as air quality reaching 234.2 ppm or temperature rising above 39.7°C.

So, the real-time monitoring and alert system support quick decision-making and enables proactive maintenance to prevent potential hazards.

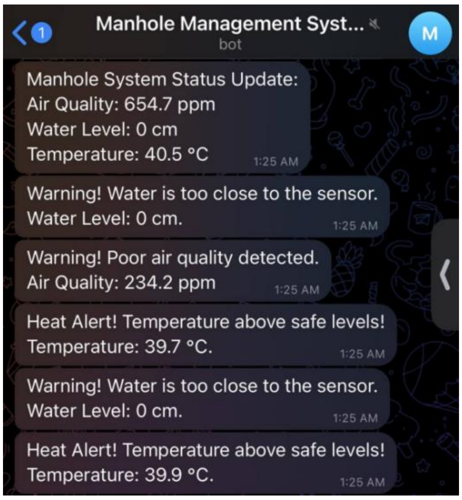


Fig. 14: Real-time alert via Telegram application

5. Conclusion

The Manhole Management System demonstrates strong potential for improving safety and efficiency. By using real-time sensor data, the system can quickly detect gas leaks, flooding and temperature spikes, enabling faster responses and proactive maintenance. This helps optimize resources and reduce downtime.

However, some challenges need attention. Issues like network stability , sensor sentivity and Wi-Fi coverage could affect system performance. Poor Wi-Fi coverage may disrupt communication between devices and the central system. Environmental factors like temperature changes or pests might cause inaccurate readings or damage sensors. In addition, connecting many system at once could lead to network instability.

Then, to addressing the challenges will enhance the system's reliability, accuracy and adaptability to different environments, making it a more effective solution for managing manhole conditions.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

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This guide contains examples of common types of APA Style references. Section numbers indicate where to find the examples in the Publication Manual of the American Psychological Association (7th ed.).

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