iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: IV Month of publication: April 2026

DOI: https://doi.org/10.22214/ijraset.2026.79186

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue IV Apr 2026- Available at www.ijraset.com

Real-Time Urban Manhole Monitoring Using IoT and LoRa

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Abstract: Manholes are n important element of drainage and sanitation systems in an everevolving urban landscape. However, they are faced with issues of toxic gas buildup, flooding and displaced covers. Traditional means of monitoring manholes consist of manual inspections; extremely time consuming and unsafe for the Inspector.
To solve this problem, a Real-Time Urban Manhole Monitoring System was created using an Arduino UNO and IoT functionality, which includes several Sensors such as the MQ-135 Gas Sensor, HC-SR04 Ultrasonic for detecting the water level in the manhole, Mercury Tilt Sensor for displacement of the manhole cover, and the DHT11 Sensor for temperature and humidity readings.
The Below sensor data is transmitted to the cloud via a LoRaWAN communication module operating at 433 MHz, which provides long-range communication and bypasses the limitations of traditional GSM systems.
The sensor data is sent to the ThingSpeak cloud platform for real-time monitoring, while an emergency alert is sent via WhatsApp using the Twilio API. A Node.js web dashboard provides municipal authorities with a real-time monitoring solution for their city's manhole status, allowing them to identify hazardous situations and improve the safety of urban infrastructure.
Keywords: Urban Manhole Monitoring, Internet of Things (IoT), Arduino UNO, LoRa WAN Communication, MQ-135 Gas Sensor, HC-SR04 Ultrasonic Sensor, DHT11 Sensor, ThingSpeak Cloud, WhatsApp Alert System, Smart City Infrastructure.

I. INTRODUCTION

Underground drainage systems and manholes are important components of sanitation and stormwater management in modern expanding cities. Unfortunately, the importance of these components is often overlooked until an emergency situation arises due to toxic gases accumulating, flooding occurring quickly, or displaced manhole covers causing an unsafe situation for both the public and maintenance workers alike. Harmful gases such as hydrogen sulfide (H_2S), methane (CH_4), and carbon monoxide (CO) can accumulate inside manholes without warning, making manual inspections very dangerous for maintenance workers.

In most municipalities, monitoring of drainage systems is accomplished through periodic manual inspections of workers; however, this method is time-consuming and workers are at risk of entering into hazardous areas with no foreknowledge of the conditions present in the manhole. As cities continue to expand, a need for improved methods of monitoring important infrastructure exists.

This project addresses this need by developing a Real-Time Urban Manhole Monitoring System using the Internet of Things (IoT) technology. The system consists of an Arduino UNO and multiple sensors that measure gas levels, water levels, temperature, humidity, and location of the manhole cover. The system uses LoRa WAN for data communication rather than conventional GSM communications due to the long-range and reliable data transfer achievable with LoRa WAN technology. Data is uploaded on a continual basis from the monitoring of manholes to the ThingSpeak cloud platform for real-time monitoring, and in the event a manhole experiences an emergency, an alert can be generated via a WhatsApp bot using Twilio API.

Furthermore, a Node.js based web dashboard will be created to easily allow authorities to view the conditions at the various manhole locations so that they may be able to identify potential issues quickly and take appropriate action.

II. LITERATURE SURVEY

The application of the Internet of Things (IoT) to monitor urban stormwater drainage systems has recently been examined by multiple researchers in order to provide improved safety of underground infrastructure. Existing papers demonstrate the development of systems based on the use of IoT by using combinations of sensors, microcontrollers and wireless communication to detect dangerous circumstances inside manholes and to provide early warning alerts for those conditions.

The initial examples of IoT-based monitoring systems used to monitor drainage for environmental conditions and focus on reducing energy consumption have previously been documented [1].

In general these designs have greatly improved the efficiency of drainage monitoring by allowing the monitoring of many different environmental conditions, but they still have limitations on the number of variables measured and do not provide overall monitoring of gas concentration levels, water levels and help verify structural changes.

Many researchers have proposed manhole monitoring systems that monitor the condition of manholes ultimately developing intelligent IoT-based monitoring systems for smart cities that use NB-IoT (narrow band internet of things) based wireless communications [2]. Unfortunately, most systems that use NB-IoT cost far more to deploy than do non-NB-IoT systems because they rely on using cellular networks which incur significant costs.

Other researchers are developing monitoring technologies that rely on NodeMCU modules, GPS units, gas sensors and ultrasonic sensors to help monitor the condition of manholes in real-time [3]. However, the use of WiFi for these monitoring systems provides poor performance for monitoring conditions below ground as WiFi signals generally have very poor coverage in below ground environments.

Several researchers have recently investigated the use of LoRa (long-range) communications for monitoring manholes. LoRa provides extended ranges with improved communications response times with respect to existing wireless monitoring systems [4]. In addition, many monitoring systems use machine learning to enhance the reliability of the monitoring system, however, this poses the potential for increased complexity of both hardware and the overall system.

Despite the significant progress that has been achieved, many existing systems still continue to experience technical difficulties with gas sensors (MQ2) in high humidity conditions and unreliable cellular GSM communications for monitoring conditions below ground [8]. The project proposes the use of an MQ-135 gas sensor to deal with some of the challenges encountered in high humidity environments and LoRa WAN communication technology for long-distance reliable communications, as well as cloud-based monitoring and management of the system via web-based dashboard to create a real-time monitoring and management system for this particular application.

The table below lists all of the various hardware components utilized in the Urban Manhole Monitoring System and provides the specifications and descriptions.

TABLE I. Hardware Components and Specifications

No.	Component	Spec.	Description
No.	Component	Specification	Purpose
1	Arduino UNO	ATmega328P MCU	Central controller that reads sensors and manages system operation
2	MQ-135 Gas Sensor	Air quality sensor	Detects toxic gases inside the manhole
3	HC-SR04 Ultrasonic Sensor	2–400 cm range	Measures water level distance
4	Water Level Sensor	Analog detection module	Identifies flooding or water presence
5	DHT11 Sensor	Temp & Humidity sensor	Monitors environmental conditions
6	Tilt Sensor	Mercury/Ball switch	Detects manhole cover displacement
7	LoRa SX1278 Module	433 MHz communication	Long-range wireless data transmission
8	Breadboard & Jumper Wires	Prototyping hardware	Circuit connections between components
9	Power Supply	Battery/Adapter	Provides power to the system

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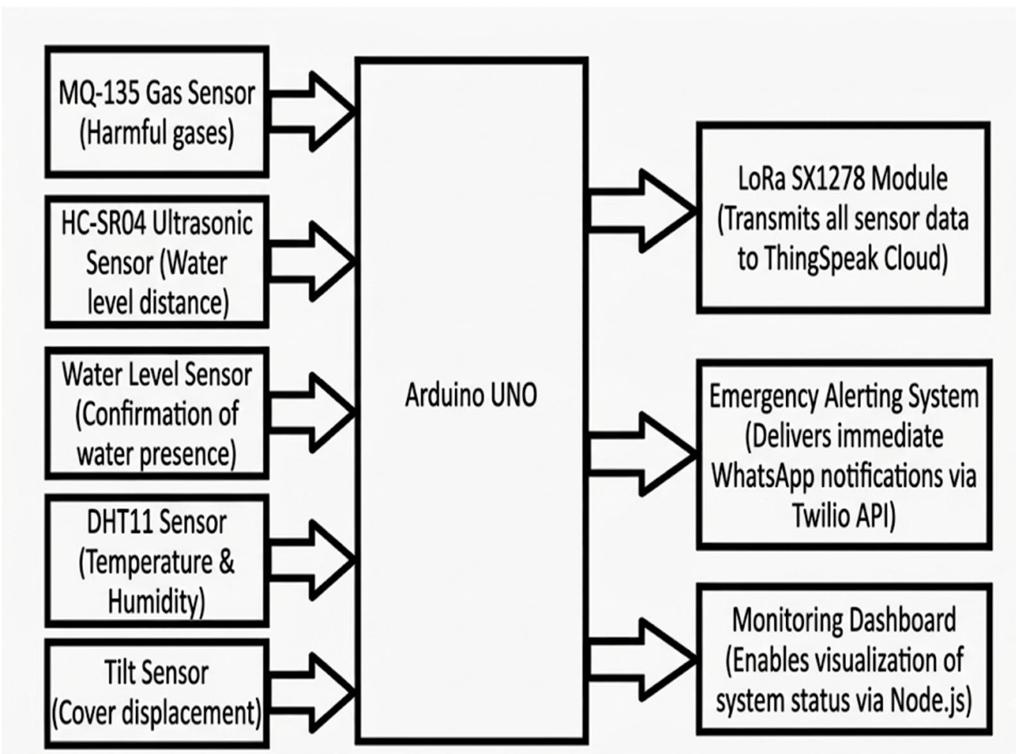
III. IMPLEMENTATION

A Real-Time Manhole Monitoring System is proposed for use in Urban Areas. The monitoring system is intended to monitor underground manholes with the help of multiple sensors and an Arduino UNO microcontroller. This monitoring system would include sensors that measure gas levels, detecting hazardous levels of gases with the help of an MQ-135 gas sensor. The monitoring system also includes a measure of water levels in the manhole. The HC-SR04 Ultrasonic Distance Sensor measures the water levels, allowing for early identification of flooding risks. The monitoring system will include several levels of security to ensure that flooding will not be an issue by also including a water level sensor for verification of water levels as well as the DHT11 humidity/temperature sensor to monitor internal humidity and temperature of the drainage chamber. Each manhole will have a tilt sensor to detect if a manhole cover has moved or has been displaced.

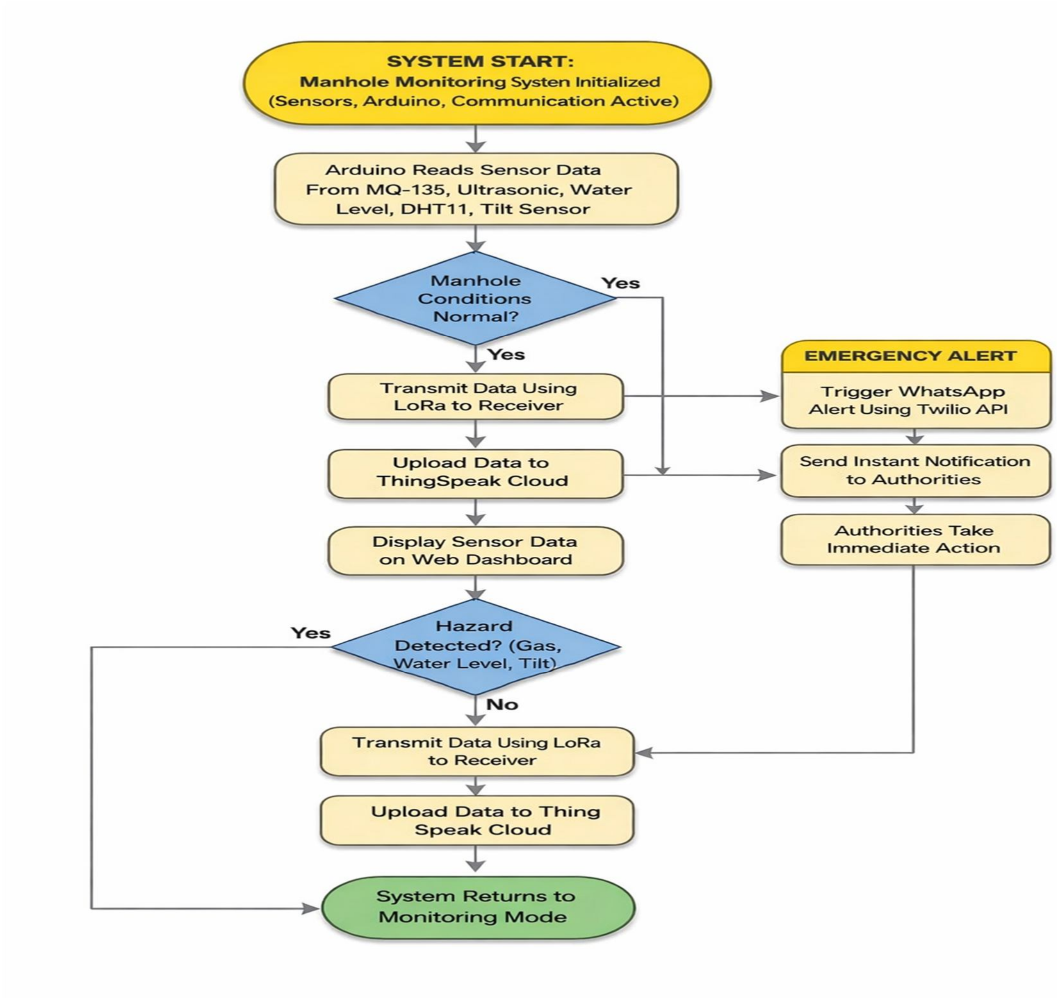
The Arduino UNO will continually monitor each of the above-mentioned sensors by continuously reading from each of them and will compare the results from each sensor with acceptable safety ranges. If the system detects any abnormal condition (e.g., gas leakage from manhole and/or high water levels in the manhole) it will immediately send an alert.

The monitoring system will utilize a LoRa SX1278 module for long-distance wireless communication with the system. Communication will continue to work even in underground situations where cellular reception is degraded. The sensor's data will also be uploaded to a cloud system called "ThingSpeak" for real-time monitoring. Should an emergency occur, alerts will be sent through an integrated WhatsApp notification system, using the Twilio API, and authorities can view each manhole's status on a Node.js web-based dashboard to monitor their overall condition and respond to any potential hazards quickly.



Flow Chart

Here is how a proposed Real-Time Urban Manhole Monitoring System works according to its process flow diagram. The Arduino UNO continuously monitors its sensors inside a manhole environment; this includes an MQ-135 gas sensor, HC-SR04 ultrasonic sensor, water level sensor, DHT11 sensor, and tilt sensor. These five types of sensors collect and transmit relevant data that the Arduino will process by verifying if the values are still within acceptable levels. If they are not based on abnormal conditions (e.g., accumulations due to toxic gases or excessive rising water levels), this information will be transmitted via the LoRa SX1278 module; the system updates the cloud-based application with this new information and sends a WhatsApp alert to the appropriate authorities for them to take an action before an_incident_occurs.



IV. RESULTS AND ANALYSIS

A. *Serial Monitor Screenshot Example*

Received Data: 350,280,310,36.0,68.0,10,1,YELLOW
MQ4: 350
MQ135: 280
Water Level: 310
Temperature: 36.0°C
Humidity: 68%
Distance: 10 cm
Tilt: 1
Status: YELLOW

WARNING: Monitor Manhole Conditions

B. *Software Implementation*

When the Real-Time Urban Manhole Monitoring System is powered on, it will automatically run without the need for human intervention after it initializes and powers up the Arduino UNO board that will begin taking readings from any sensors found in the manhole environment continuously. The parameters monitored through some of the sensors include: gas concentration, water level, temperature, humidity, and the position of the manhole cover.

While operating normally, the system will remain in a monitoring state; all sensor readings will be processed and transmitted at regular intervals to the LoRa SX1278 communication module on an ongoing basis. The uploaded information is available via the ThingSpeak cloud platform and can be viewed online in real-time via the monitoring dashboard.

If any abnormal conditions are detected, such as the presence of toxic gases or an abrupt increase in the water level and/or the dislocation of the manhole cover, the system will warn users immediately. This information is communicated through the communication module, and an alert is issued immediately through the Twilio API to the WhatsApp alert system. This provides the responsible authorities with the ability to quickly identify and respond to the issue and prevent any potential harm from occurring.

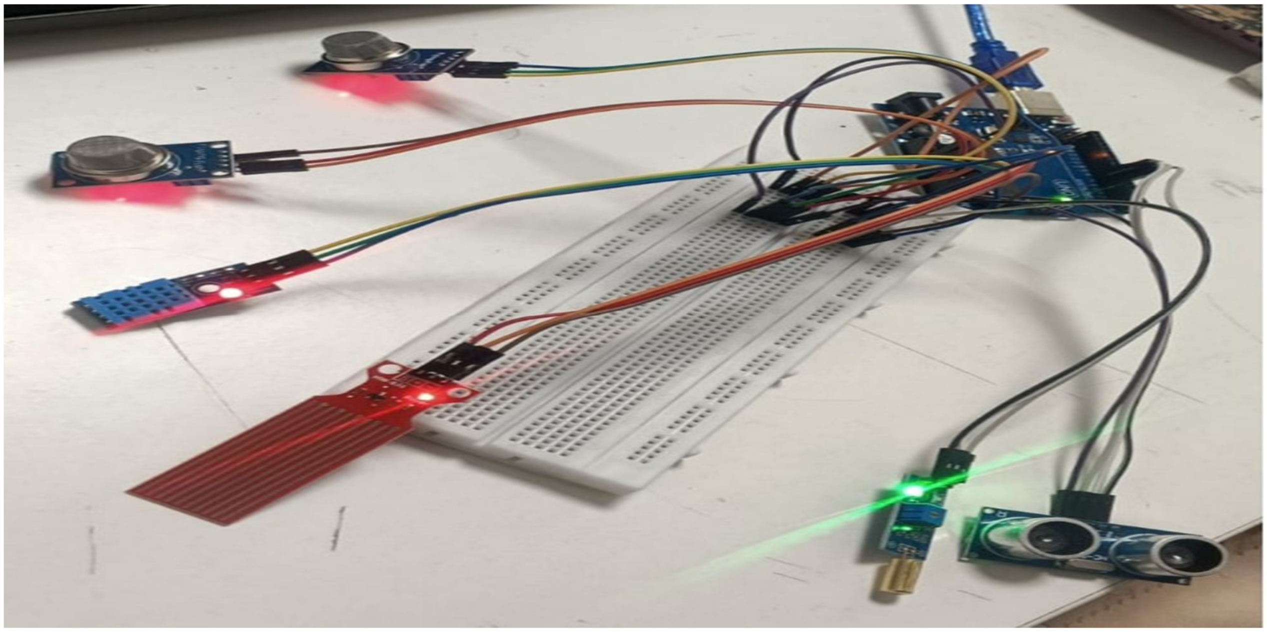
The software implementation provides continuous monitoring, reliable communication, and fast alert generation leading to an effective solution to improve the safety and management of urban drainage infrastructure.

C. *Hardware Implementation*

The Real-Time Urban Manhole Monitoring System is built around a hardware configuration, where the primary controller used to coordinate all of the various components is the Arduino UNO. Additionally, the MCU will be interfaced with several ancillary sensors that will permit monitoring of the conditions (environmental or structural) underground in manholes.

The core hardware components for the system will include an MQ-135 gas sensor to detect the presence of hazardous gases, an HC-SR04 ultrasonic sensor and a water level sensor to measure the level of water, a DHT-11 sensor for measuring temperature and humidity, and a tilt switch to detect any displacement or lifting of the manhole cover from its original position. These sensors will be connected to the Arduino UNO to allow for continuous collection and processing of data from each sensor.

Whenever the Arduino UNO detects any abnormal conditions, such as the detection of hazardous gas, a high water level, or a tilting manhole cover, it will send output through the LoRa SX1278 Communication Module. Once the data is sent to the Cloud Monitoring Platform, an alert notification will be sent to the monitoring platform. The hardware implementation will allow for long-range reliability of data transmission and real-time monitoring of urban sewage drainage infrastructure.



The primary goal of this proposed Urban Manhole Monitoring System in Real Time offers a way to increase safety/monitoring of urban drainage infrastructure through continuous indicators of unsafe conditions (hazardous) within manholes. This system incorporates the use of an Arduino UNO as its master controller for gathering data collected from a variety of Sensors to monitor Gas levels, water level, temperature, humidity, and the cover position of manholes.

For example, gas sensors like the MQ-135, ultrasonic sensors like the HC-SR04, water level sensors, temperature/humidity sensors like the DHT11, and tilt sensors all coupled together can allow the detection of abnormal conditions such as gas accumulation, flooding, or tilted cover. Once an abnormal condition has been detected, the system will transmit the information via a LoRa communication module to the monitoring platform and provides an alert notification through a WhatsApp alert system.

This proposed system is reliable, cost efficient, and very appropriate for real time monitoring of infrastructures. Reducing manual inspection and providing early alerts for potential hazards increases the safety of workers and improves response time by the authorities.

1) Impact on Urban Maintenance: The system greatly enhances urban operations by allowing maintenance to know of any hazards in manholes ahead of time. These alerts immediately alert workers to problems, enabling them to remediate the problem before it causes any serious incidents. Automating the monitoring process also decreases the number of manual inspections that must be done regularly, which increases both worker safety and efficiency in terms of time and use of resources.
2) Limitations and Challenges: The testing of the system revealed a number of issues, but the system was able to perform well overall. However, there are a few limitations associated with the system that must be addressed. Among these limitations is the constraints imposed by LoRa communications on its total payload size when transmitting data over a wide range of distances; where the likelihood of signal interference could occur due to high levels of urbanisation within very closely spaced buildings. Additionally, the installation of LoRa networks will typically require custom-built gateways, which will add to the overall complexity of large-scale deployment.
3) Future Improvements: Improvements for the Future will consist of the addition of Artificial Intelligence (AI) to analyse sensor data over time and to find patterns or trends in manhole condition. This will allow maintenance to be done on a preventive basis and for authorities to anticipate failures before they happen. Improvements may also consist of increased use of more sophisticated sensors as well as integrating with smart city infrastructure platforms so that monitoring, data analytics and/or even automatic decision making, are enhanced.

V. CONCLUSION

Real-Time Monitoring of Manholes in an Urban Environment is a possible option to help manage an urban drainage system and keep them safe. The Real-Time monitoring system uses Arduino Uno and sensors to monitor different variables including gas levels in the manhole, water level, temperature, humidity and location of the manhole cover enabling it to collect and review data from a safety perspective and help identify hazardous situations (toxic gas build-up, flooding or movement of the manhole cover).

LoRa communication helps the proposed system transmit data over long distances and in an environment where communication is impossible. This will aid in keeping the maintenance staff and authorities safe. The proposed system is a feasible model because of its reliability and cost-effectiveness. But it is important that the proposed system can withstand the different types of environmental elements and the payload attached to the LoRa. The proposed hardware must also be made water resistant. There is a need for another improvement on the proposed system in the future through AI technology that can provide analysis of data, making the system more intelligent. Through the analysis of patterns, this will help ensure the safety of the smart city. The Real-Time Urban Manhole Monitoring System is a possible solution for the management and safety of urban drainage infrastructure. Implementation of the proposed system will be accomplished using numerous sensors attached to an Arduino Uno, which will allow for the monitoring of critical parameters such as gas concentrations, water levels, temperature, humidity, and the location/removal of the manhole cover. This will allow the system to monitor and analyze the data in real-time while monitoring for any possible issues such as hazardous accumulation of toxic gas, flooding, and the movement of the manhole cover.

The system proposed can use the LoRa technology for ensuring data transmission capacity over a long distance and in other situations where conventional means of communication may not be available. For instance, this can assist with the safety of personnel, including agency personnel and maintenance personnel. This system is also practicable as it offers a viable and cost-effective option. Nevertheless, the LoRa payload and the environmental conditions of the hardware used with the proposed system will have to be considered for the design. In addition, the hardware will have to be shielded from water. In future iterations of the proposed system, advancement in Artificial Intelligence (AI) will help to increase the intelligence of the system through pattern analysis and ensure the safety of the smart city overall.

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