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Sub Surface Soil Washout Risk Detection System Using IoT Application

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ABSTRACT: Water wastage and natural hazards such as landslides pose significant challenges to infrastructure, environmental sustainability, and human safety. This project proposes an integrated Internet of Things (IoT)-based monitoring system designed to address both smart water pipeline management and landslide detection. The system utilizes multiple sensors, including water flow sensors based on the Hall Effect principle and turbidity sensors, to monitor water flow and quality within pipelines, thereby enabling the detection of leakages and contamination. Simultaneously, environmental sensors are deployed to monitor parameters such as soil stability and precipitation for early landslide detection. A NodeMCU microcontroller is used as the core processing unit due to its efficiency and support for IoT applications, enabling real-time data acquisition and transmission. The collected data is uploaded to a cloud platform, such as ThingSpeak, for storage, analysis, and visualization. This allows continuous remote monitoring and timely decision-making.

The proposed system provides accurate, real-time insights into water usage and environmental risks, contributing to efficient water management and improved disaster preparedness. Experimental observations indicate that the system enhances early warning capabilities, reduces water wastage, and supports effective risk management strategies.

KEYWORDS: IOT, Smart Monitoring System, Water Flow Sensor, Landslide Detection, Cloud Computing, Node MCU

I. INTRODUCTION

In recent years, rapid urbanization and the expansion of underground infrastructure have significantly increased the dependence on pipeline networks for water distribution in urban areas. These pipelines play a vital role in supplying water for domestic, industrial, and municipal purposes. However, due to aging infrastructure, inadequate maintenance, and environmental factors, pipeline leakage has become a major concern. Since these pipelines are located below the ground surface, leakages are often difficult to detect at an early stage and may remain unnoticed for long durations. Continuous leakage results in the seepage of water into the surrounding soil, which gradually increases the soil moisture content and reduces its strength and stability.

From a geotechnical perspective, soil strength depends on cohesion and internal friction, both of which are adversely affected by excess water. As a result, prolonged leakage can lead to subsurface soil washout, where soil particles are displaced by flowing water, creating underground voids. These voids weaken the load-bearing capacity of the ground, leading to surface deformation, cracks, road subsidence, and even sudden collapse or sinkhole formation. Such incidents pose serious threats to public safety, infrastructure, and economic stability.

Existing detection techniques, such as acoustic monitoring and ground-penetrating radar, are often costly and not suitable for continuous real-time monitoring. Therefore, there is a need for a cost-effective and efficient system that can detect leakage at an early stage. In this context, the present project proposes a Subsurface Soil Washout Risk Early Detection System using a multi-sensor approach. The system integrates soil moisture, ultrasonic, and temperature sensors with a microcontroller to provide real-time monitoring and early warning. The primary objective is to detect

early-stage soil weakening and prevent potential failures, contributing to safer and more sustainable infrastructure management.

- Can be used in urban water pipeline systems.
- Helps in preventing road collapse and sinkholes.
- Applicable in smart city infrastructure.
- Can be extended for large-scale monitoring systems.
- Useful for municipal corporations and construction industries.

II. LITERATURE SURVEY

- **Patil et al., “Landslide Detection and Alert System Using IoT,” 2020.**

This paper proposes an IoT-based system for real-time landslide detection using soil moisture, tilt, and vibration sensors. Data is processed using Arduino and transmitted through ESP modules. Alerts are generated when threshold values are exceeded. The system improves early warning capability and is suitable for high-risk areas.

- **Vrba et al., “Use of Remote Sensing for Identification and Description of Subsurface Drainage System Condition,” 2018.**

This study uses remote sensing techniques to detect subsurface drainage systems using indicators like soil moisture and vegetation. RS data combined with GIS allows large-scale analysis. Infrared and aerial imagery were found effective, though accuracy depends on environmental conditions.

- **Zhang et al., “Development and Application of an IoT-Based System for Soil Water Status Monitoring,” 2019.**

This paper presents a low-cost IoT system to monitor soil water parameters such as moisture and hydraulic conductivity. Data is transmitted via ESP32 and visualized on cloud platforms. The system performs comparably to traditional methods and supports long-term monitoring.

- **Kumar et al., “Underground Drainage Monitoring System Using IoT,” 2021.**

This paper presents an IoT-based system for monitoring urban drainage systems. Flow sensors detect blockages, leaks, and abnormal sewage flow. NodeMCU sends data to the cloud via Wi-Fi.

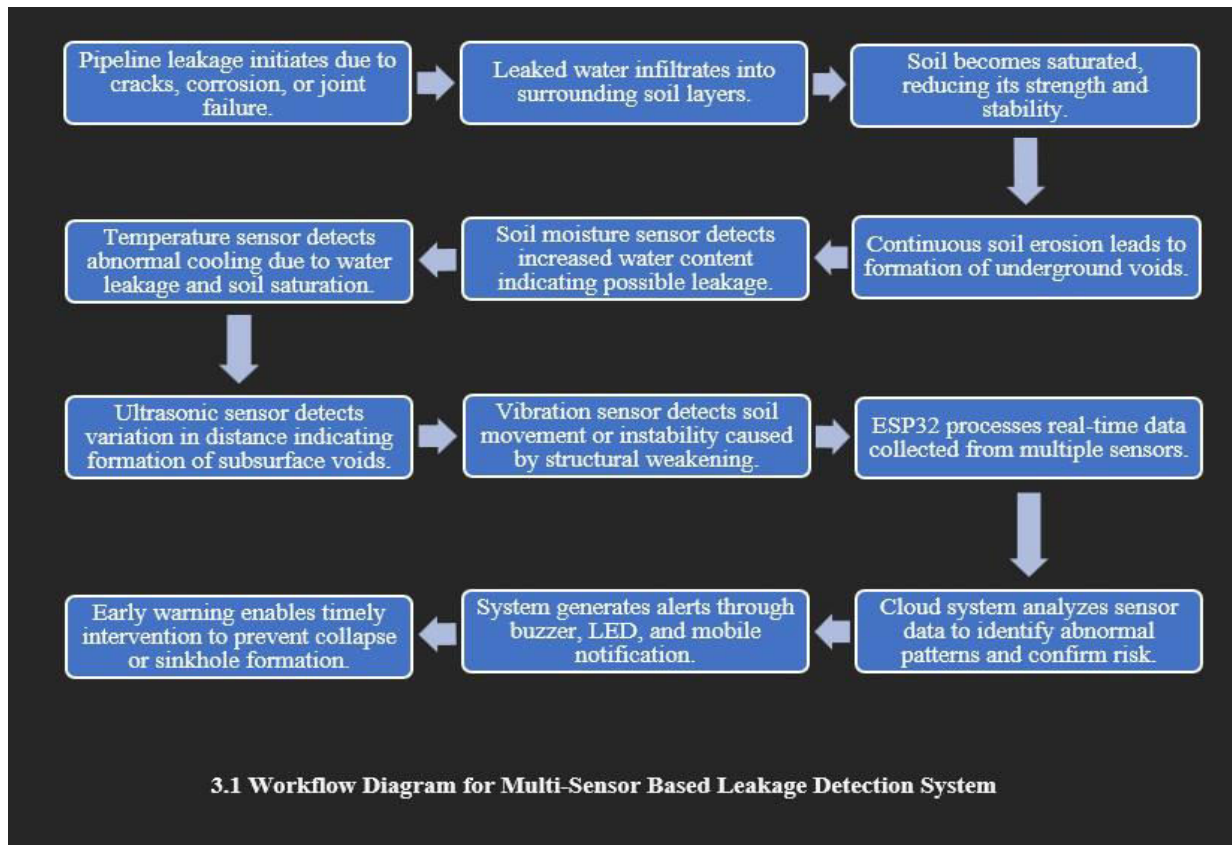
Users receive alerts through applications and notifications. It helps locate exact blockage points quickly. Improves efficiency over manual drainage monitoring. Supports smart city infrastructure management.

- **Sharma et al., “Soil Monitoring Using IoT Technology,” 2020.**

This paper focuses on IoT-based smart agriculture systems. Sensors monitor soil moisture, temperature, humidity, and water levels. Raspberry Pi processes data and automates irrigation. AI and automation improve decision-making and efficiency. Reduces water wastage and manual labour.

Enhances crop productivity and resource utilization. Supports precision farming and remote monitoring.

III. METHODOLOGY



3.1 Workflow Diagram for Multi-Sensor Based Leakage Detection System

1. Soil Moisture Sensor Detects the Moisture

The soil moisture sensor is placed near the pipeline and continuously measures the water content in soil. When leakage occurs, moisture increases and crosses a threshold, indicating possible soil saturation and washout risk.

2. Temperature Sensor Detects the Drop in Temperature

The temperature sensor monitors soil temperature. Leakage water causes a slight drop in temperature, which supports detection of abnormal conditions.

3. Ultrasonic Sensor Detects the Increase in Distance

The ultrasonic sensor measures the distance from sensor to ground surface. Due to soil weakening, surface sagging occurs, increasing the measured distance.

4. ESP32 Processes Data Received from Sensors

ESP32 collects data from all sensors and compares it with predefined threshold values to identify leakage and washout conditions.

5. The Processed Data is Sent to the Cloud

The ESP32 transmits data to a cloud platform for real-time monitoring and analysis.

6. Alert is Generated

When sensor values exceed threshold limits, the system generates an alert through LED or buzzer to indicate risk.

3.1 SENSOR SPECIFICATIONS

Sr. No.	Sensor Name	Working Principle	Range	Purpose
1	Soil Moisture	Measures electrical conductivity	0 – 4095 (ADC)	Detects water content in soil
2	Ultrasonic Sensor	Uses sound waves (echo principle)	2 – 400 cm	Detects surface deformation
3	Temperature Sensor	Measures thermal variation	-10°C to 85°C	Detects temperature changes
4	Vibration Sensor	Detects mechanical vibration/shock	Digital (HIGH/LOW)	Detects ground disturbance/instability

IV. EXPERIMENTAL RESULTS

4.1 Working Principle

- **Pipe leakage is created in a layered soil model**

The experiment begins by introducing a controlled pipe leakage within a precisely layered soil model (consisting of gravel, sand, and topsoil). This setup replicates the complex underground conditions of municipal infrastructure, allowing for the study of how pressurized water interacts with different soil densities.

- **Leakage makes soil wet and unstable.**

As water escapes the pipeline, it infiltrates the surrounding pores, significantly increasing the soil's degree of saturation. This process not only makes the soil wet.

- **Moisture sensor detects water increase.**

The embedded soil moisture sensor continuously monitors the dielectric constant of the surrounding medium. Upon leakage, the sensor detects a rapid spike in water content rising from a baseline state (approx. 46%) to near-saturation levels (approx. 95%). This provides the primary evidence of a breach in the pipeline's integrity.

- **Vibration sensor detects soil instability.**

Parallel to the moisture spike, the vibration sensor identifies the mechanical energy released by the leaking fluid. Turbulent flow at the leak site and the physical shifting of unstable soil particles generate specific micro-vibrations. Detecting these signals allows the system to distinguish between a minor leak and a high-energy rupture.

- **ESP32 processes data and triggers alert.**

The ESP32 microcontroller serves as the system's brain, simultaneously processing the incoming analog and digital signals from the sensor array. Using predefined threshold logic, the ESP32 filters out environmental noise and confirms a "leakage state" only when the data from multiple sensors correlates. Once confirmed, it triggers an immediate visual or remote IoT alert.

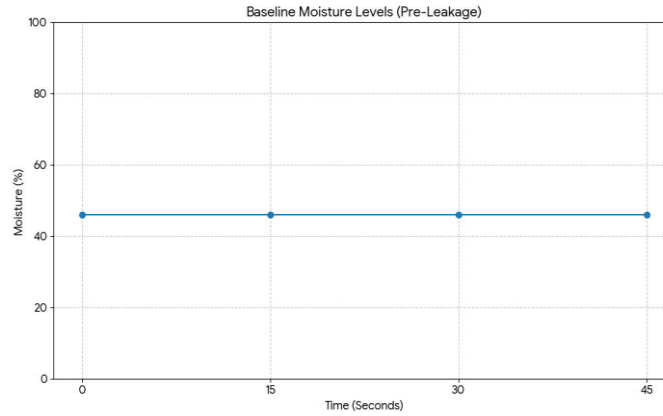
- **Enables early detection to prevent major damage.**

When water leaks from the pipe, it spreads into the surrounding soil. This increases soil moisture, which is detected by the moisture sensor. As moisture increases, soil strength decreases, indicating washout risk. The ultrasonic sensor detects any surface changes such as sagging. The system provides early warning based on sensor data

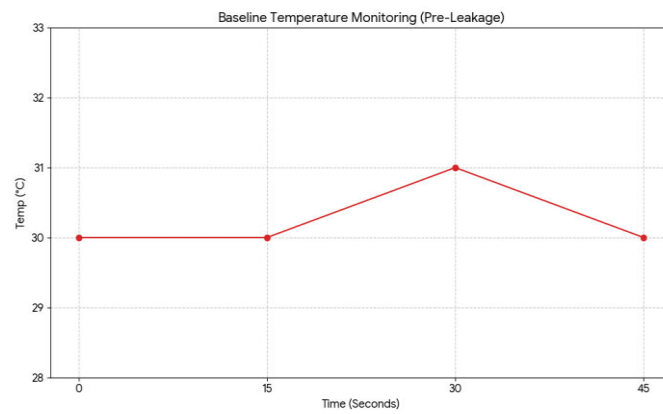
4.2 Observation Tables

Sr No	Time (Seconds)	Soil Moisture (%)	Temperature (°C)	Ultrasonic (Distance cm)	Vibration
1	0	46	30	3	N/A
2	15	46	30	3	N/A
3	30	46	31	3	N/A
4	45	46	30	3	N/A

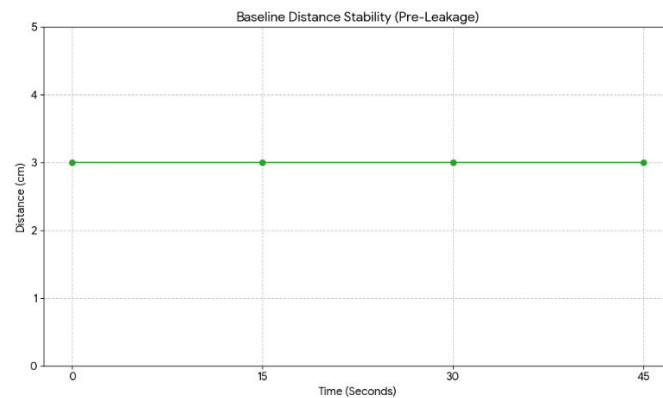
Table 4.1: Baseline Sensor Readings under Normal Operating Conditions



Graph 4.1 Moisture Level (Before Leakage)

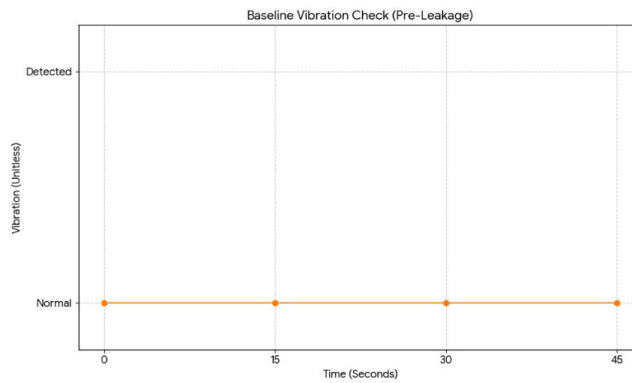


Graph 4.2 Temperatue Level (Before Leakage)



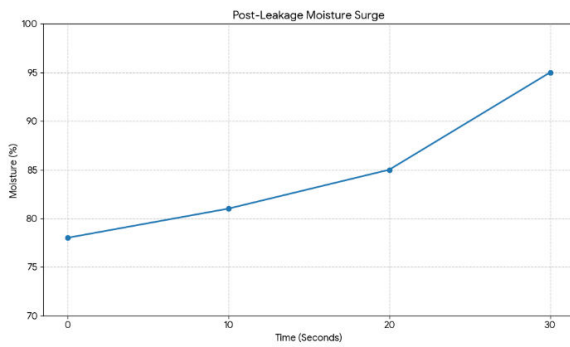
Graph 4.3 Distane Measurnment (Before Leakage)

Sr No	Time (Seconds)	Soil Moisture (%)	Temperature (°C)	Ultrasonic (Distance cm)	Vibration
1	0	78	30	3	N/A
2	10	81	29	3	N/A
3	20	85	28	3.5	N/A
4	30	95	27	4	YES

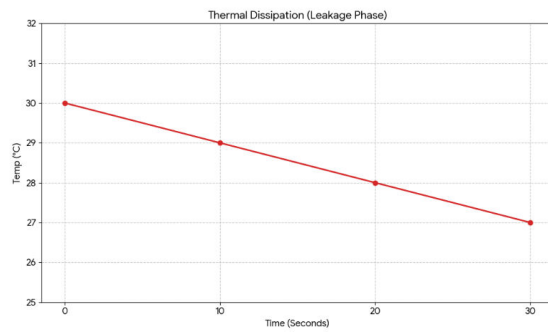


Graph 4.4 Vibration Detection (Before Leakage)

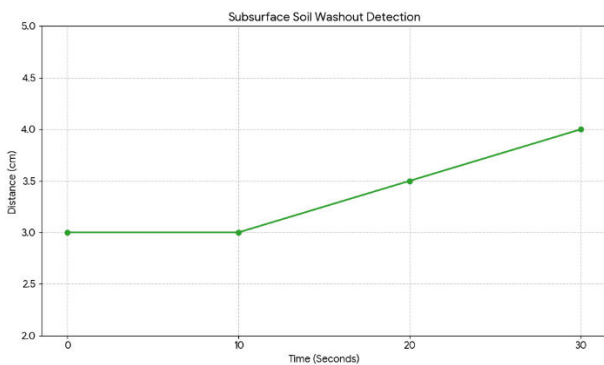
Table 4.2: Sensor Response and Data Trends During Active Leakage Simulation



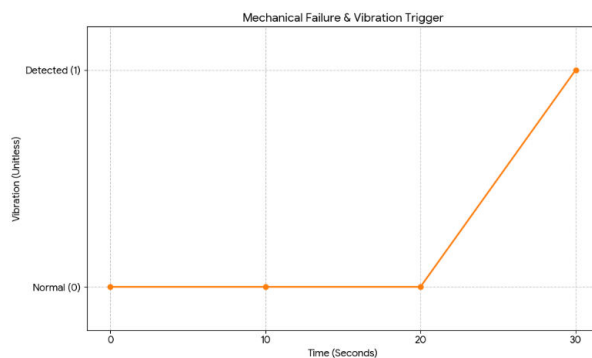
Graph 4.5 Moisture Level (After Leakage)



Graph 4.6 Temperature Level (After Leakage)



Graph 4.8 Distance Measurement (After Leakage)



Graph 4.9 Vibration Detection (After Leakage)

4.3 Outcome Discussion

A. Moisture Dynamics and Soil Saturation

In the normal state, moisture was maintained at a steady 46%, which is ideal for soil stability. Upon leakage, the moisture surged to 95% within 30 seconds. This indicates that the soil has reached its **field capacity** and is moving toward a state of total saturation.

B. Thermal Dissipation

The drop from 30 Degree Celsius to 27 degree Celsius is a critical indicator. In fluid dynamics, this is often caused by the **Joule-Thomson effect** (cooling due to rapid pressure drops) or simply the endothermic nature of water spreading through a warmer medium. This thermal "dip" provides a secondary confirmation that the moisture increase is due to a fluid leak and not a sensor malfunction.

C. Physical Displacement (Ultrasonic)

The Ultrasonic sensor recorded a distance increase from 3 cm to 4 cm. This suggests **subsidence** or soil erosion the physical displacement of material caused by the force of the leaking fluid. The Vibration trigger at 30 sec confirms a "High-Energy Event," such as a pipe rupture or the onset of turbulent flow.

D. Mechanical Kinetic Energy (Vibration Sensor)

The Vibration sensor transitioned from a **static baseline (N/A or 0)** to an **active detection state (YES or 1)** at the 30-second mark. In underground pipeline monitoring, vibration is the most immediate indicator of a mechanical breach.

V. CONCLUSION

This research project aimed to develop a robust, multi-sensor approach to pipeline monitoring. Based on the experimental results, the following conclusions are drawn regarding the project objectives.

- ✓ The system detected leakage within 30 seconds. Soil moisture increased from 46% to 78% and temperature dropped by 1°C. This shows the system can identify leakage before visible damage occurs.
- ✓ The soil moisture sensor provided continuous and accurate readings. The value increased from 46% to 95%, clearly showing the transition from normal condition to leakage condition.
- ✓ The ultrasonic sensor detected an increase in distance from 3 cm to 4 cm. This indicates soil displacement and helps in identifying washout risk before surface failure.
- ✓ The system uses simple and low-cost sensors such as moisture, temperature, ultrasonic, and vibration sensors. It provides accurate results without using expensive equipment.
- ✓ The vibration sensor activated when moisture reached a high level. This provides a clear early warning signal that can help prevent structural damage.
- ✓ The system successfully collected and organized sensor data over time. This data can be sent to the cloud for real-time monitoring and alert generation.

The results confirm that the proposed system successfully detects pipeline leakage and identifies soil washout risk at an early stage. The use of multiple sensors improves accuracy and provides a reliable warning system. The system is cost-effective and suitable for practical applications.

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