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Integrated Environmental Pollution Monitoring and Prediction Platform

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ABSTRACT

Air, water, and soil pollution are rising sharply across rural, urban and industrial regions, yet the systems used to track them remain fragmented, sparse, and reactive rather than predictive. This paper presents the Integrated Environmental Pollution Monitoring and Prediction Platform (IEPMP), a system that combines IoT-based multi-media sensing with machine learning to give both a real-time picture of environmental conditions and a short-term forecast of how they are likely to change.

The proposed system captures air, water, and soil parameters using low-cost sensors, transmits them through Wi-Fi-enabled microcontrollers to a cloud backend, and applies regression and instance-based learning models to forecast near-term pollution levels. It presents essential information such as pollutant concentration, safety status, predicted trend, and location through a simple, colour-coded dashboard.

The system aims to reduce the response gap between when pollution occurs and when it is acted upon, by combining continuous sensing with predictive alerts. It also provides a foundation for further features such as cross-media correlation analysis, deep learning-based forecasting, and city-wide scalability to improve environmental management efficiency.

Keywords: Environmental Pollution, IoT Sensing, Air Quality, Water Quality, Soil Health, Machine Learning, Pollution Prediction, Decision Support.

1. Introduction

Rapid industrialization, rural and urban growth have placed increasing strain on air, water, and soil quality, with pollution now recognized as a major factor affecting public health and ecosystem stability. Environmental agencies often face difficulty responding to pollution events in time because monitoring infrastructure is thin, unevenly distributed, and slow to report results.

Existing monitoring systems typically track a single pollution domain, such as air or water alone, and provide only descriptive readings of present or past conditions. They do not support predictive decision-making, such as forecasting when a location is likely to cross a safety threshold, and this limits the ability of authorities to intervene before a pollution event becomes severe.

To address these challenges, the proposed system introduces an integrated pollution monitoring and prediction solution that combines air, water, and soil sensing with machine learning-based forecasting. It identifies developing pollution trends, issues early alerts, and continuously updates its dashboard as new sensor data arrives. The system also features a simple, accessible interface intended for use by municipal authorities, researchers, and the general public.

2. Literature Review

2.1 Title of the Paper: A Complete Air Pollution Monitoring and Prediction Framework

Authors and Year: J. Kalajdjieski, K. Trivodaliev, G. Mirceva, S. Kalajdziski, and S. Gievska — 2023

This paper proposes encoder-decoder deep learning architectures with attention mechanisms to forecast particulate matter levels in a way that generalizes across locations and seasons. It further introduces adversarial data-augmentation techniques to compensate for missing sensor readings caused by device faults or connectivity loss. The work focuses solely on air pollution and does not consider water or soil quality parameters.

2.2 Title of the Paper: *Industrial Environmental Pollution Monitoring and Prediction Analysis Using IoT and Machine Learning*

Authors and Year: M. Sowmiya and P. Sowmiya - 2023

This paper presents a two-device IoT architecture for real-time monitoring of gases and particulate matter in industrial settings, paired with an LSTM model to forecast when air-quality safety limits are likely to be exceeded. The system performs well for its intended industrial-air use case but is not designed to integrate other pollution media such as water or soil.

2.3 Title of the Paper: *IoT Based Air Pollution Monitoring & Prediction System*

Authors and Year: M. Rakib, S. Haq, M. I. Hossain, and T. Rahman — 2022

This paper combines a four-sensor IoT device with an ARIMA forecasting model to predict next-day pollutant levels and Air Quality Index values, reporting mean absolute percentage errors generally below 11 percent. The approach demonstrates strong short-term forecasting accuracy for air pollutants but does not extend to multi-domain environmental monitoring.

2.4 Title of the Paper: *Water Quality Index Prediction System Using IoT Enabled Sensor Suite and Machine Learning*

Authors and Year: A. Johar, S. A. Lahari, and P. RN — 2023

This paper measures pH, dissolved oxygen, conductivity, turbidity, and temperature through an IoT sensor suite and applies the Canadian Water Quality Index alongside LSTM and neural-network models to estimate water safety against WHO and CPCB benchmarks. The system is effective for water-quality prediction but operates independently of air or soil monitoring systems.

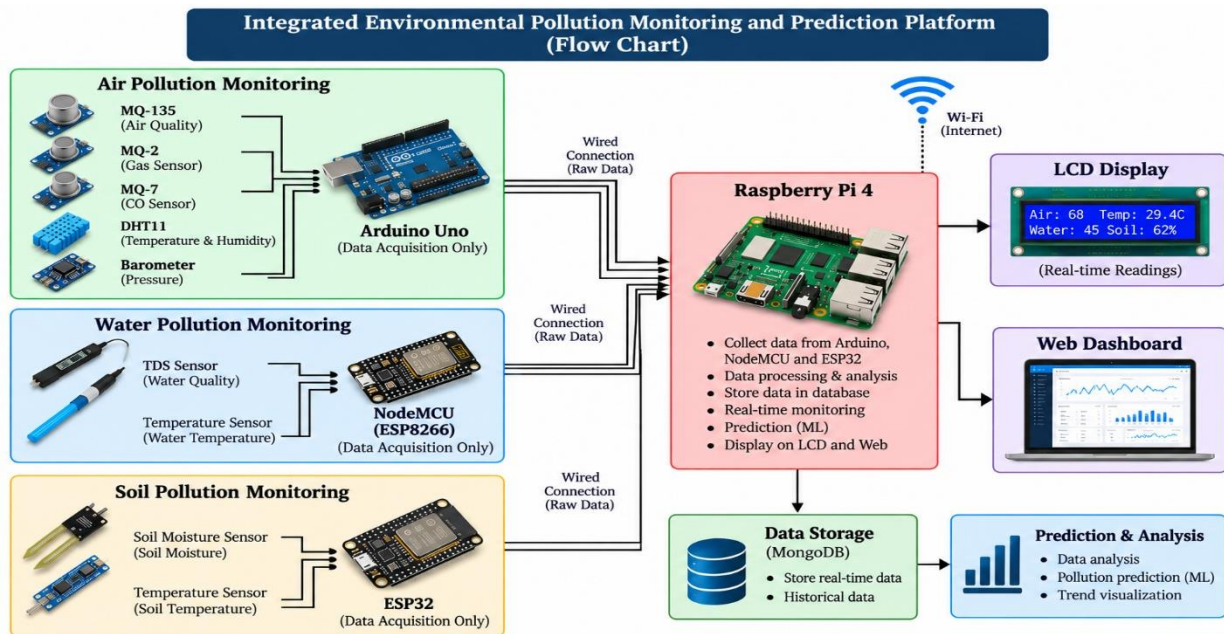
2.5 Title of the Paper: *Toward Design of Internet of Things and Machine Learning-Enabled Frameworks for Analysis and Prediction of Water Quality*

Authors and Year: M. A. Rahu, A. F. Chandio, K. Aurangzeb, S. Karim, M. Alhussein, and M. S. Anwar — 2023

This paper compares several regression models (LSTM, SVR, MLP, NARNet) and classification models (SVM, XGBoost, Decision Trees, Random Forest) for predicting the Water Quality Index and Water Quality Class from canal sensor data, finding that MLP achieved the lowest prediction error among regressors. While thorough in its model comparison, the study remains confined to the water domain.

3. Research Methodology

- **Data Collection:** Environmental data is collected using sensors placed in different locations. These sensors measure parameters such as: Air quality (CO, CO₂, PM2.5, PM10), Temperature, humidity and Noise levels. These readings provide the basic data required for monitoring environmental conditions.
- **Data Transmission:** The collected data is sent from sensors to the system using communication technologies like: Wi-Fi, GSM / IoT modules. This enables the sensor readings to reach the processing or storage platform in real time.
- **Cloud Storage:** The transmitted data is stored in cloud platforms or databases. Cloud storage helps in: Storing large amounts of data, Easy access from anywhere, Data security and backup.
- **Data Processing:** The stored data is cleaned and processed to remove errors or noise. This step includes: Filtering unwanted data, Organizing data for analysis. The processed data is then organized into a suitable format for machine learning analysis.
- **Prediction:** Machine Learning algorithms are used to predict future pollution levels based on past data. The model used is Random Forest. This helps provide an early indication of possible environmental changes.
- **Visualization:** The processed data and predictions are shown using: Graphs and charts, Dashboards. Visualization makes it easier to understand changes and trends in environmental parameters. Users can monitor the system and interpret the results more easily.
- **Alert System:** When pollution levels exceed safe limits, the system generates alerts. Alerts are sent through: Notifications.



4. Objectives of the Study

1. Real-Times Pollution Monitoring
2. Pollution Prediction Using Machine Learning
3. Early Warning and Alert System
4. Data Visualization and Reporting
5. Real-Time Soil Moisture and Temperature Monitoring

5. Result and Discussion

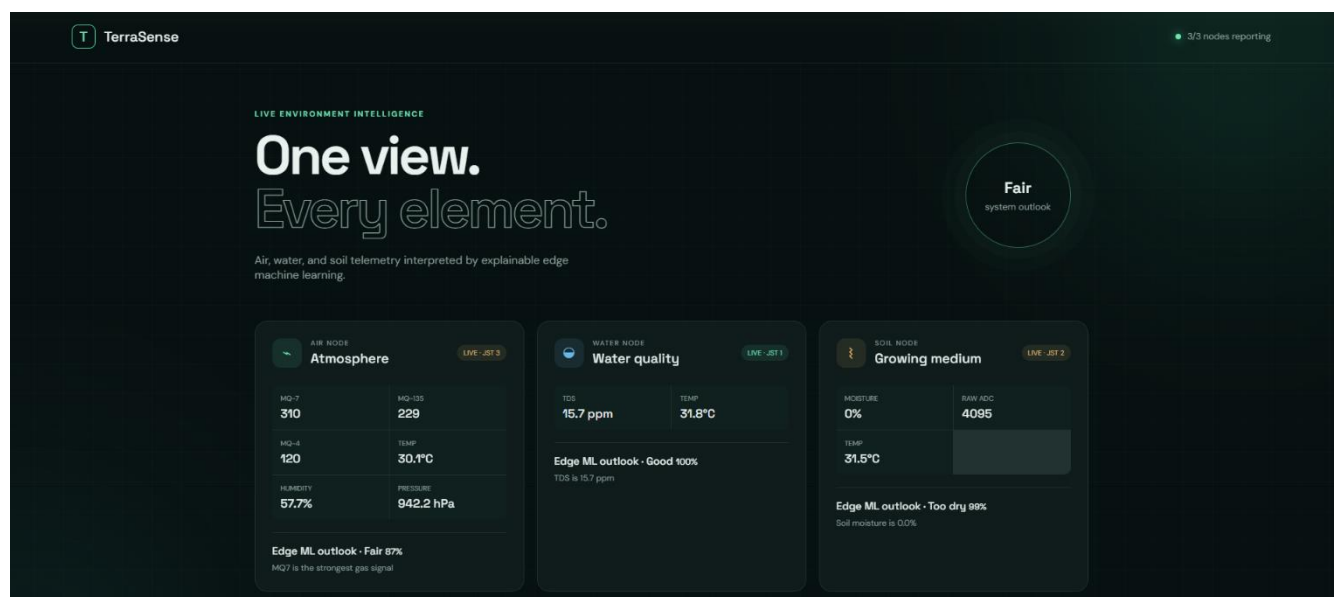


Fig 5.1 Live Environmental Status Dashboard

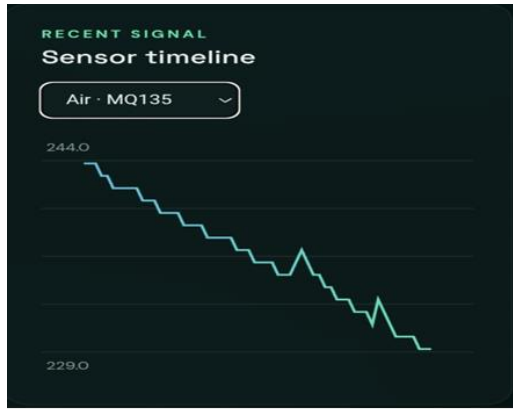


Fig 5.2 Atmospheric Gas Monitoring Trends

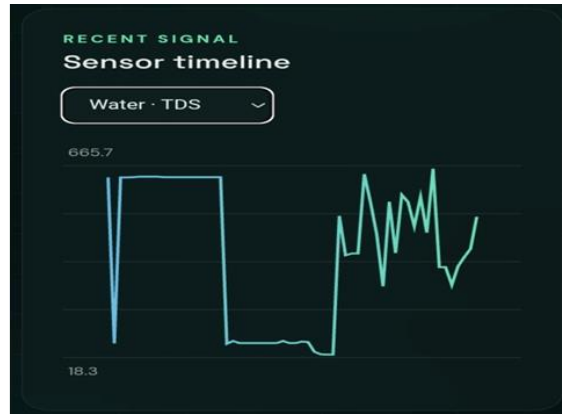


Fig 5.3 Real-Time Water Purity Monitoring



Fig 5.4 Soil Moisture Monitoring Timeline

The experimental evaluation confirms that the proposed IoT-based environmental monitoring system is capable of continuously acquiring, visualizing, and interpreting environmental sensor data using Raspberry Pi and Edge Machine Learning. The system successfully identified different soil-moisture conditions, distinguishing dry conditions at approximately 11% moisture from good conditions in the range of approximately 29–42%. The soil-temperature readings remained stable at around 27.3°C, while the MQ135 produced continuously varying raw ADC measurements, demonstrating real-time sensor acquisition. The integration of sensor timelines and Random-Forest-based Edge-ML classification provides an interpretable and responsive approach for environmental condition monitoring. These results demonstrate the practical feasibility of combining IoT sensing and Edge ML for real-time environmental monitoring and decision support.

The soil-moisture experiments produced different operating conditions. The system recorded moisture levels of 11.1%, 11.4%, 28.8%, 32.0%, and 42.4%. At 11.1–11.4%, the Edge-ML system classified the soil condition as “Too dry,” whereas readings of 28.8–42.4% were classified as “Good.” This demonstrates that the system can distinguish between different soil-moisture conditions and provide an interpretable condition assessment.

6. Conclusion

The proposed IoT and Edge Machine Learning-based environmental monitoring system successfully demonstrates real-time monitoring and intelligent interpretation of environmental parameters using sensors and a Raspberry Pi. The system continuously collects sensor data, processes the readings at the edge, and presents the results through a user-friendly monitoring dashboard.

Overall, the developed system provides a low-cost, real-time, and intelligent approach to environmental monitoring. By combining IoT sensing, data visualization, and Edge ML, it can support timely identification of changing environmental conditions and provide useful information for monitoring and decision-making. Future work can focus on sensor calibration, larger real-world datasets, improved ML validation, additional environmental parameters, and automated alerts or control mechanisms to further enhance the reliability and scalability of the proposed system.

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