



Smart Village Automation Using IoT

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Abstract: Water is one of the most crucial resources of a village, but its availability and demand is majorly calculated manually, thereby leading to delayed decision-making and poor planning. Smart Village Automation Using IoT is a low-cost solution which leverages the power of the Internet Of Things and Machine Learning to manage the water distribution of rural areas and village services [1] [2]. An ultrasonic sensor is used to calculate the water level of the storage tank, which is then transmitted via Wi-Fi (MQTT) to an application server which validates the data and stores it in a MongoDB database. The Python FastAPI server is used to host the machine learning models; a demand prediction model that predicts the demand based on water level, temperature, rainfall, population, date-time and water used, and a Random Forest Regressor model which classifies between normal consumption and leakage/theft. The citizen and moderator portals built using React allow users to view water-related information, government schemes, complaints, and Razorpay payment integration. The complaint management system escalates unaddressed complaints to the relevant authority after 25 days of creation. In the leakage/theft model, the pressure has a feature importance of 48.3%, followed by the actual consumption at 26.8%, flow rate at 18.1%, and expected consumption at 6.8%. The low-cost implementation has only one hardware sensor, the ultrasonic sensor, but factors like high implementation cost, lack of technical know-how, connectivity issues, training data, and maintenance can affect the adoption rate. Future improvements include the addition of more sensors and tanks, better training data, deploying the application on mobile and cloud platforms and exploring other avenues of Smart Village such as agricultural support and waste management.

Keywords: IoT, Smart Village, Machine Learning, Water Distribution, Water Demand Prediction, Leakage Detection, ESP32, Ultrasonic Sensor

I. INTRODUCTION

Efficient management of natural resources is central to rural development, and water is one of the most important resources of a village community. Monitoring its availability and demand is therefore central to effective water management. Traditional approaches to monitoring water levels and planning water usage rely mostly on manual observation, which makes it difficult for administrators to obtain precise and timely information about the available water resources.

Internet of Things (IoT) provides a practical way to close this information gap by connecting low-cost sensors and microcontrollers to web-based services [1] [2]. Smart village initiatives apply such technologies to basic rural services so that routine tasks can be monitored and automated with less manual effort [2] [3]

This paper presents “Smart Village Automation Using IoT,” a system that focuses primarily on smart water management. An ultrasonic water-level sensor connected to an ESP32 microcontroller measures the distance between the sensor and the water surface of a tank, and this distance is converted into a water-level percentage. The reading is relayed through IoT communication to a web-based application in which the current water level can be monitored.

The system also includes Machine Learning (ML) for water-demand prediction. With the current water-level reading in combination with historical data and other relevant parameters, it predicts future demand, which helps the administrator to anticipate the expected water requirement and to plan and manage the available resources. A separate ML model identifies patterns related to normal water usage, leakage or possible theft.



The system has two types of users— Citizen and Admin. Using the web application, citizens can:

- Monitor the current water level and the predicted water-demand information
- Check the available government schemes
- Raise complaints related to village services, such as land-tax bills
- Track complaint status, view bills and make digital payments

The Admin has access to a management dashboard in which the administrator can monitor the current water level, view water-demand predictions, manage citizen complaints and provide information related to government schemes.

The system is designed with minimal hardware. The ultrasonic water-level sensor is the only physical sensor used for real-time water monitoring; other water-related parameters such as flow rate are not measured with additional hardware, which keeps the implementation cost low. The project focuses on water-level monitoring and water-demand prediction while still delivering valuable citizen services.

The objective of this work is to develop a practical and cost-effective smart water management system for rural communities that improves water-level monitoring, predicts water demand, supports better water-management decisions, and provides citizen services such as government scheme information and complaint submission. By combining IoT-based real-time monitoring, ML-based prediction, database management and a web dashboard, the system has as a result of giving the administrator a centralized view of water availability and expected demand.

II. RELATED WORK

The conceptualization of the proposed system draws on three intersecting areas of research: (i) smart villages and the use of IoT in rural settings, (ii) IoT-based water-level monitoring and water metering with Machine Learning, and (iii) ML-based leakage identification for water conservation.

A. Smart Villages and IoT in Rural Areas

Cvar et al. compared the use of IoT technology in smart cities and smart villages, discussing their similarities, differences and future prospects [2]. Emerllahu and Bogataj reviewed the literature on smart villages as infrastructure of rural areas and set out a research agenda for the field [3]. These studies position IoT as an enabling technology for rural development and motivate a village-scale platform that starts from one essential service.

B. IoT-Based Water Monitoring and Metering

Malche and Maheshwary presented an IoT-based water-level monitoring system for a smart village, which directly addresses the problem of observing water availability without manual checks [1]. Jamadarkhani et al. reported IoT-enabled smart water metering that uses multi-sensor data and Machine Learning techniques [4]. Together with other recent studies that apply IoT and ML to water-demand forecasting and decision support, this work highlights the role of real-time data in efficient water management.

C. Machine Learning for Leakage Identification

Liu et al. studied how Machine Learning can enhance leakage identification and water resource conservation in order to improve the operational efficiency of a water supply network [5]. Following this direction, the proposed system includes a Random Forest model [6] that classifies water usage as normal, leakage or theft from flow rate, pressure, expected usage and actual usage.

D. Positioning of the Proposed System

The proposed system brings these directions together in a single platform. It combines real-time tank-level monitoring with an ultrasonic sensor and ESP32, ML-based demand prediction and leakage/theft detection, and citizen-facing services such as government schemes, complaints, bills and payments, while keeping the hardware requirement to a single sensor. Table I maps the reviewed literature to the corresponding parts of the system.



TABLE I
MAPPING OF LITERATURE TO THE PROPOSED SYSTEM

Reference	Focus	Contribution to Proposed System
[1]	IoT-based water level monitoring for a smart village	Supports the IoT tank-level monitoring module of the proposed system
[2]	IoT in smart cities and smart villages	Frames the IoT-based rural service platform and its future prospects
[3]	Smart villages as infrastructure of rural areas (literature review)	Supports an integrated, extensible village platform
[4]	IoT-enabled smart water metering with multi-sensor data and ML	Guides the combination of sensor data with ML for water management
[5]	ML-enhanced leakage identification in water supply networks	Guides the leakage and theft detection model
[6]	Random Forest algorithm	Provides the algorithmic basis of the normal/leak/theft classifier
[7]	MQTT messaging protocol	Provides lightweight sensor-to-backend communication

III. PROBLEM STATEMENT

Water availability in a village depends on how well administrators can see how much water is stored and how much will be needed. When this information is collected by manual observation, it is often imprecise and arrives late, so planning of water distribution is reactive and abnormal usage such as leakage or theft may remain unnoticed.

The same dependence on manual follow-up affects village services. Complaints about services such as land-tax bills, information on government schemes and bill payments are not connected to one another, and unresolved complaints require continuous manual monitoring to prevent them from being forgotten. Solutions that depend on many different sensors are, in addition, costly for rural communities.

Problem Statement: “Village administrators rely on manual observation to know how much water is available and how much will be needed, which leaves them without timely and accurate information for planning water distribution, detecting abnormal usage, or responding to citizens' service requests. Therefore, a low-cost, web-based platform is required that monitors the tank water level in real time using IoT, predicts water demand and detects leakage or theft using Machine Learning, and gives citizens and administrators a single channel for water information, government schemes, complaints, bills and payments.”

Key Challenges Addressed by the Proposed System:

- Manual Monitoring: Replaces manual observation of water levels with real-time sensor readings.
- Delayed Information: Gives administrators the current water level on a live dashboard instead of periodic manual reports.
- Unplanned Distribution: Predicts water demand so that the expected requirement can be planned in advance.
- Water Loss: Identifies patterns of normal usage, leakage and possible theft.
- High Hardware Cost: Uses a single ultrasonic sensor as the only physical sensor, keeping implementation cost low.
- Complaint Delays: Automatically escalates complaints unresolved for more than 25 days to the next level of authority.
- Fragmented Services: Unifies water information, government schemes, complaints, bills and payments in one web platform.
- Role-Specific Access: Provides separate Citizen and Admin interfaces with secure login and role-based access.



IV. PROPOSED SYSTEM AND METHODOLOGY

The proposed solution replaces manual observation with a modular system that combines IoT sensing, web technologies, database management and Machine Learning. Its workflow follows the stages described below, from data acquisition at the water tank to visualization on the user dashboards.

A. Data Acquisition

The process begins with data acquisition. An ultrasonic sensor connected to an ESP32 measures the water level of the tank in real time. The sensor measures the distance between itself and the water surface, and this distance is converted into the corresponding water-level percentage. The ESP32 sends the collected readings through Wi-Fi to the backend system using the MQTT protocol [7].

B. Data Transmission, Processing and Storage

The Node.js and Express backend receives the water-level readings from the MQTT broker, validates and processes them, and stores them in MongoDB. HTTP-based communication and simulation endpoints are also available for testing and for generating sample water-related data when the physical sensor is not in use. The database maintains user accounts, complaints, water readings, bills, payments and prediction-related information, so that the frontend and backend services can securely store and retrieve data whenever required.

C. Machine Learning Module

The Node.js backend communicates with a Python FastAPI service that loads the trained ML models. The water-demand prediction model uses available parameters such as water level, temperature, rainfall, population, date/time and water usage to predict future water demand. A separate Random Forest model [6] identifies patterns related to normal water usage, leakage or possible theft from the available usage-related inputs.

D. Automation and Digital Services

Complaint handling is automated. When a citizen submits a complaint, it is stored in the database and becomes available to the administrator, who can update its status and escalate it if it remains unresolved. A scheduled cron job checks the complaint records automatically, and complaints that remain unresolved for more than 25 days are escalated to the next level of authority, which reduces the need for continuous manual monitoring. For payments, citizens can view their available bills and initiate payment through the Razorpay integration, while payment information is maintained in the database.

E. User Interaction and Visualization

The user interaction layer is developed using React and Vite and provides separate role-based interfaces for citizens and administrators. Citizens can register and log in, submit complaints, track complaint status, view services and bills, make payments and monitor water information. Administrators can manage complaints, monitor water data, view predictions and manage administrative information. The live water-level value from the ultrasonic sensor is presented together with prediction and water-management information, and charts and dashboard components help administrators understand the current water situation.

F. Operational Workflow

- Citizen Operations: Citizens register and log in through secure, role-based access, monitor water-level and demand information, view government schemes, submit complaints, track their status and pay bills online.
- Administrator Operations: Administrators monitor the live water level, review demand predictions and usage analysis, manage and escalate complaints, and provide information related to government schemes.
- Backend Sequence: The ESP32 sends the tank reading over MQTT; the backend validates and stores it; the FastAPI service provides demand predictions and usage classification; the results are served to the dashboards; and the scheduled job escalates overdue complaints.

V. SYSTEM DESIGN

The Smart Village Water Management System's design follows a microservice architectural style that employs IoT, backend, database, and machine learning services to build the web application for managing water resources in a village. The system design isolates the components' concerns to offer flexibility and ease while maintaining and upgrading the services.



The IoT layer consists of the ESP32 microcontroller and the ultrasonic sensor that capture the water level percentage and transmit the data to the backend through MQTT. The Node.js and Express backend serve as the system's engine and store all the data in the MongoDB database. The FastAPI, which runs on Python, is the machine learning part of the backend that hosts the models for predicting water demand and classifying water usage data. Finally, the React application, which uses the Vite framework, serves as the user interface for the citizens and the administrators to access the required water services such as the complaint escalation, water bill, and payment systems. In addition, the system escalates all the unresolved complaints to the next level after twenty-five days. Table II below shows the technologies used in the system.

TABLE II
LAYER-WISE TECHNOLOGY OF THE PROPOSED SYSTEM

Layer	Technology	Function
IoT Layer	ESP32, ultrasonic sensor, Wi-Fi, MQTT	Measures the tank water level and transmits it to the backend
Backend Layer	Node.js, Express.js	Handles APIs, authentication, complaints, bills, payments and water readings
Database Layer	MongoDB	Stores users, complaints, water readings, bills, payments and prediction data
ML Layer	Python, FastAPI, Random Forest	Predicts water demand; identifies normal usage, leakage and theft
Automation Layer	Scheduled cron job	Escalates complaints unresolved for more than 25 days
Payment Layer	Razorpay API	Processes digital bill payments
Frontend Layer	React, Vite	Role-based Citizen and Admin dashboards with charts and live monitoring

VI. ARCHITECTURE

The system's operational process consists of a chain that takes the sensor reading of the water tank to the user's dashboard and automates the concerned village services. Figure 1 below shows the system's data flow:

- Sensing and Transmission: The ultrasonic sensor measures the distance to the water surface, which is converted into a water-level percentage; the ESP32 sends the readings over Wi-Fi to the backend using MQTT.
- Sensing and Transmitting: The ultrasonic sensor captures the distance, which is converted to the percentage of water in the tank. The ESP32 microcontroller transmits the obtained data to the backend via Wi-Fi using the MQTT protocol.
- Backend: The Node.js and Express backend handles the data from the MQTT broker, saves it in the MongoDB database, and serves the web application.
- Machine Learning: The backend communicates with the Python FastAPI, which houses the machine learning models. The models perform the prediction task and provide the water demand forecast and classification of the data as normal, leakage, or theft.
- Visualizing and Automating: The React dashboard displays the water percentage, machine learning results, complaints, and bills while automating the complaint escalation and bill payment processes using the scheduled tasks and Razorpay API.

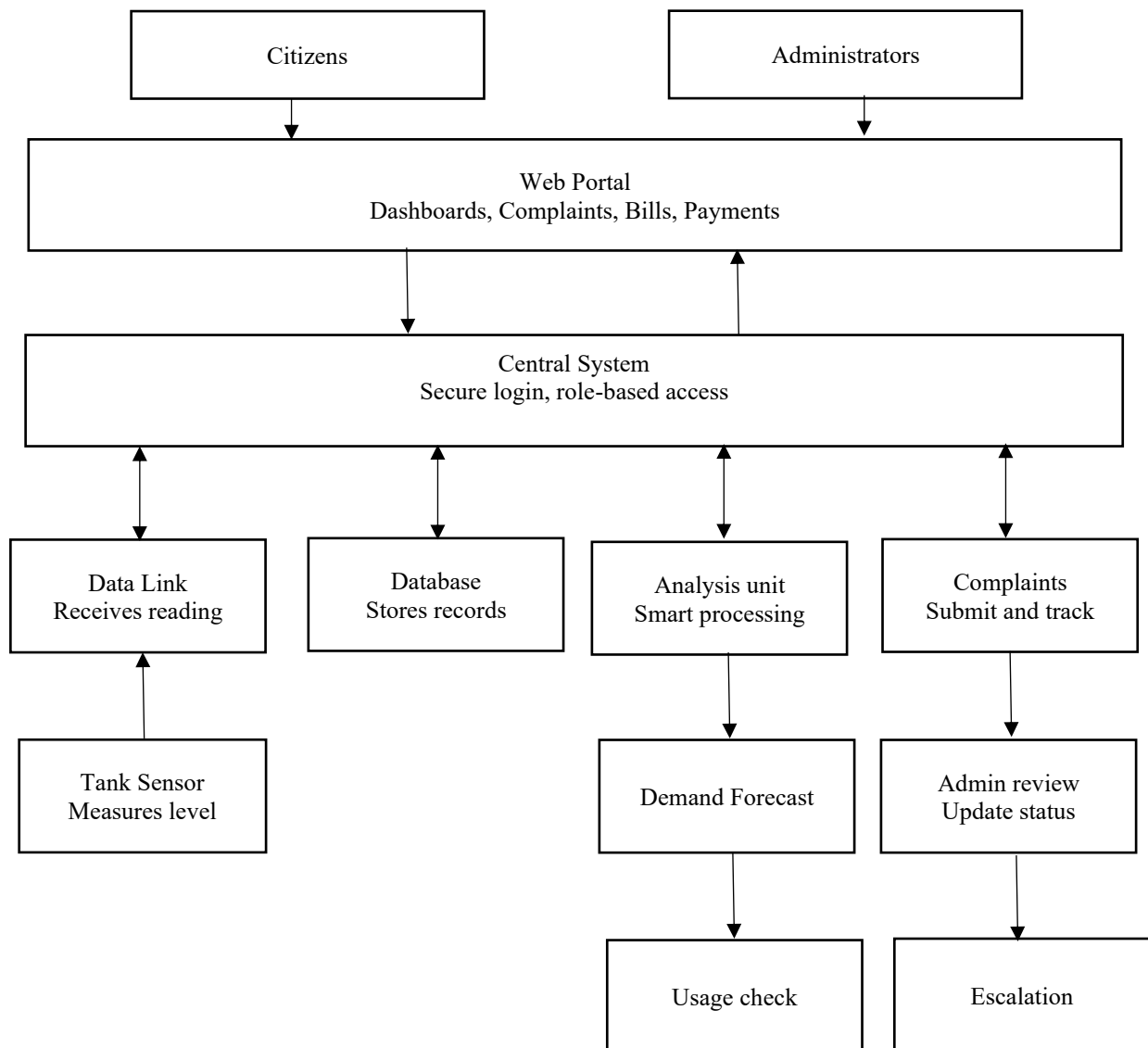


Fig. 1 System Architecture of the Smart Village Water Management System

VII. RESULTS

The proposed architecture was implemented as a prototype of the Smart Village Water Management System. This section summarizes the behaviour of the implemented modules and the outcome of the leakage and theft detection model.

A. IoT Water-Level Monitoring

The IoT module collects water-level data using the ultrasonic sensor and relays it through MQTT, so that the latest water level is displayed on the dashboard. When the physical sensor is not in use, the simulation endpoints supply sample readings for testing.

B. Water-Demand Prediction

The ML module predicts water demand from the volume of water available, weather, usage and other variables, and provides administrators with projections of the expected water requirement for planning and distribution.

C. Leakage and Theft Detection

The Random Forest-based module analyzes flow rate, pressure, expected usage and actual usage to identify normal, leak and theft conditions. As shown in Fig. 2 and Table III, pressure has the highest influence on the model (48.3%), followed



by actual usage (26.8%), flow rate (18.1%) and expected usage (6.8%). Pressure and actual usage together account for about three quarters of the total importance. Overall, the results demonstrate that the proposed model can analyze water-flow parameters and support automated detection of abnormal water usage.

In the current prototype only the ultrasonic sensor is a physical sensor, so flow rate, pressure and valve conditions can be simulated when additional sensors are not available. The values in Table III describe how the trained model weighs its inputs and are not accuracy measures; validation with field data remains part of future work.

TABLE III
FEATURE IMPORTANCE OF THE LEAKAGE AND THEFT DETECTION MODEL

Rank	Input Feature	Relative Importance (%)
1	Pressure	48.3
2	Actual usage	26.8
3	Flow rate	18.1
4	Expected usage	6.8

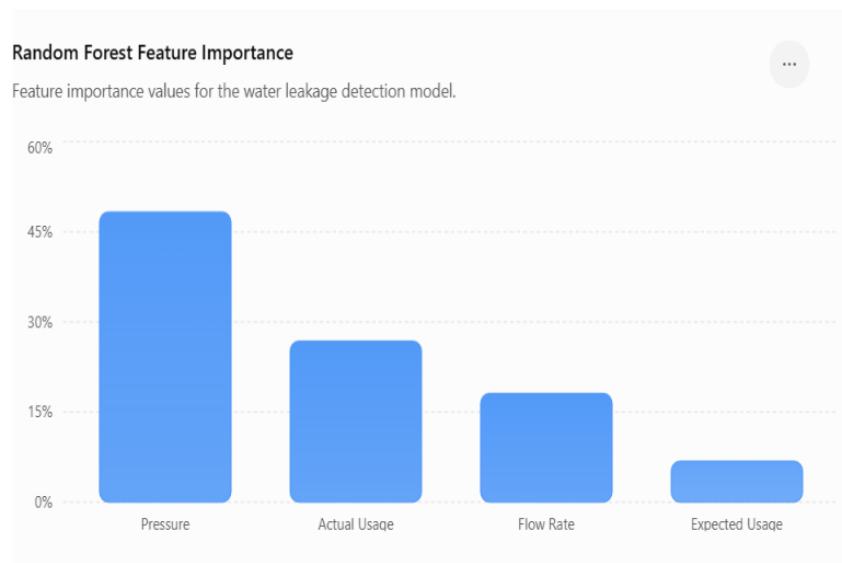


Fig. 2 Random Forest Feature Importance for the Water Leakage Detection Model

D. Citizen Services and Automation

Citizens and administrators use separate role-based dashboards for water information, complaints, bills and government schemes. Automatic complaint escalation after 25 days reduces manual effort and improves accountability, and bill payments are processed through the Razorpay integration. Some testing or demonstration responses of the payment module may use sample data, depending on the availability of the external service.

VIII. FEASIBILITY ANALYSIS AND DISCUSSION

A. Technical Feasibility

The system uses a modern, modular and widely supported software stack. The frontend is built with React and Vite, the backend runs on Node.js and Express.js, data is stored in MongoDB, and the ML models are served through a Python FastAPI service. Sensing relies on an ESP32 microcontroller and an ultrasonic sensor communicating over Wi-Fi with MQTT [7]. The separation of the IoT, backend, database and ML layers allows individual parts to be upgraded without redesigning the whole system.

B. Economic Feasibility

Because the ultrasonic sensor is the only physical sensor required, the hardware cost remains low; other parameters such as flow rate are not measured with additional hardware sensors and can be simulated when needed. The use of freely



available web frameworks further reduces development cost, which makes the system suitable for village administrations with limited budgets.

C. Operational Feasibility

Role-based Citizen and Admin dashboards give each user the required services through a single web interface. Automatic complaint escalation and scheduled jobs reduce the need for continuous manual monitoring, and the centralized dashboard lets administrators see water availability and expected demand together.

D. Challenges and Limitations

Several challenges may affect adoption of the system: implementation cost, limited technical knowledge, network connectivity, availability of reliable training data for the ML models, and maintenance requirements. In addition, the prototype currently monitors a single tank. Appropriate planning, training and infrastructure are needed to address these challenges.

E. Expected Outcomes

The system is expected to support efficient water management, reduce unnecessary water usage, speed up monitoring and improve accountability in complaint handling, thereby contributing to sustainable resource utilization and digital transformation in rural communities.

IX. CONCLUSION AND FUTURE SCOPE

This paper presented Smart Village Automation Using IoT, an integrated Smart Village Water Management System for efficient water monitoring and village service management. By combining IoT, web technologies, Machine Learning and automation, the system monitors real-time water levels using an ESP32 and an ultrasonic sensor, and provides water-demand prediction and leakage/theft detection through trained ML models. The key contributions of this work are: a low-cost IoT water-level monitoring module; an ML layer for demand prediction and abnormal-usage detection; a centralized, role-based dashboard through which citizens and administrators access water information, complaints, bills and digital services; and automatic complaint escalation that reduces manual effort and improves accountability.

Subsequent development will focus on the following directions:

- Adding more real-time water sensors and monitoring multiple village water tanks for better water-availability information.
- Training the ML models on a larger amount of real-time data to predict water demand and detect theft and leakage more accurately, with in-depth analysis of water-usage trends.
- Extending the platform to other smart village elements such as agriculture and waste management.
- Turning the application into a mobile app and connecting it to cloud systems for better scalability and easier use by citizens and government officials.
- Adding more IoT devices and automated controllers to build a more extensive and intelligent water-distribution network.

In summation, this work shows that the integration of real-time IoT data, Machine Learning and a web-based platform supports better water management, faster monitoring and more efficient smart village services, and offers a practical, low-cost starting point for the digital transformation of rural communities.

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