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HydroWatch: IoT Based Water Quality Monitoring System

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[1] ***Abstract*—Stagnant water storages are dangerous as they are highly vulnerable to contamination and microbe growth thus requiring constant checkups to prevent public health concerns as around 250 people fell ill in a society of Greater Noida and several deaths in Rajouri due to contamination in water tanks. HydroWatch presents a Water Quality Monitoring system designed to safeguard public health by continuously analyzing stagnant water in storage tanks, detecting anomalies, and ensuring prompt notification to the authorities. The solution works using a clear methodology: first, small sensors collect the data, and then smart computer programs check it. First, data is collected using a small, battery-friendly computer connected to sensors put straight into the water tank. These sensors measure four important things: Total Dissolved Solids (TDS), Temperature, pH, and Turbidity. Next, the data travels wirelessly to a database. The system uses Machine Learning, smart computer programs to study data. When an anomaly is found, the system automatically sends a warning and a report. The water quality data can be seen on a website dashboard. Only authorized people can see this information using a secure login (token-based authentication). The solution prevents waterborne diseases and allows clean and usable water usage among communities. HydroWatch ensures immediate anomaly detection and guarantees robust public health protection through secure, real-time alerting.**

Index Terms— ESP32, pH sensor, TDS sensor, turbidity sensor, temperature sensor, Google Firebase, React JS, Node JS, JWT, Tailwind CSS, IoT, CPS

I. INTRODUCTION

MONITORING water quality is essential for maintaining public health and environmental safety. However, traditional methods still depend on manual sampling and laboratory analysis, which are slow, expensive, and unable to provide continuous updates. Stagnant water—commonly found in tanks, reservoirs, or storage units—poses an even greater challenge, as the lack of circulation allows bacteria, algae, and sediments to build up over time. Reports from several cities have shown that contaminated storage water has led to serious health problems, including outbreaks of cholera and typhoid. These incidents underline the urgent need for automated, affordable, and continuous monitoring systems.

The Internet of Things (IoT) offers an effective solution by linking multiple sensors through wireless networks and cloud-based platforms. When combined with Artificial Intelligence (AI) and Machine Learning (ML), IoT systems can go beyond simple monitoring to actively analyse data and predict anomalies in environmental conditions.
The **HydroWatch** system was developed to meet these needs by combining hardware sensors, cloud databases,

machine learning algorithms, and a secure web dashboard. Its main objectives are:

1) To design a low-cost, automated, and scalable IoT-based system for monitoring stagnant water.
2) To apply ML algorithms that identify patterns and detect irregularities in water quality data.
3) To build a secure and user-friendly web interface for visualizing real-time data.
4) To send instant email alerts whenever unsafe water conditions are detected or predicted.

By integrating these technologies, HydroWatch transforms traditional monitoring into an intelligent, real-time, and predictive water management system that enhances both safety and efficiency.

II. Literature Review

In recent years, numerous IoT-based water quality systems have emerged, yet many of them focus on flowing water systems such as municipal pipelines or rivers. These models often overlook stagnant environments where contamination risk is highest.

Nayan et al. (2021) proposed a sensor-based IoT model to measure physical parameters like pH and TDS using Arduino and ESP8266 modules. However, it lacked intelligent analytics and secure data handling. Kumar and Patel (2021) demonstrated that AI-enhanced IoT architectures significantly improved response time and data accuracy but required substantial hardware resources. Later, Kumar et al. (2024) introduced a hybrid AI-IoT framework for leakage detection, revealing that ML integration drastically improves operational reliability.

Despite these contributions, limited focus has been placed on real-time alert systems or secure dashboards that facilitate decision-making for stored water. HydroWatch addresses this gap by introducing automated email notifications and multi-layer authentication, ensuring that only verified personnel can access sensitive water quality data.

III. Methodology

A. System Overview

HydroWatch follows a four-tier system architecture consisting of sensing, transmission, processing, and visualization layers. Each layer is designed for modularity, allowing future scalability or component upgrades without system overhaul.

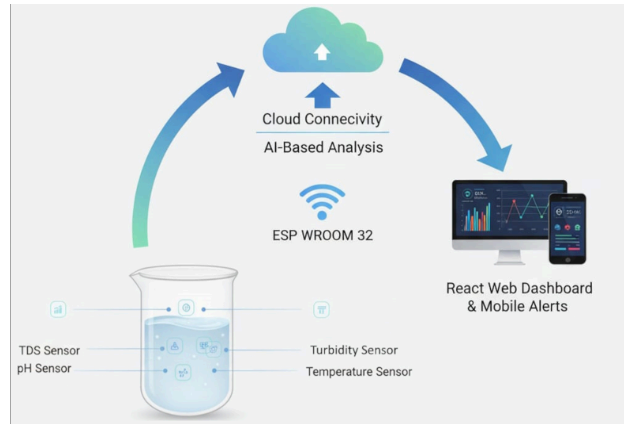

Fig. 1. System architecture of HydroWatch

B. Hardware Configuration

At the foundation of HydroWatch lies the ESP WROOM 32 microcontroller, chosen for its cost efficiency, low power consumption, and integrated WiFi and Bluetooth capabilities. It serves as the bridge between sensors and the cloud infrastructure.

The sensors connected to it include:

1) pH Sensor: Determines acidity or alkalinity.
2) TDS Sensor: Measures dissolved solids in ppm.
3) Turbidity Sensor: Detects suspended particles, indicating water clarity.
4) Temperature Sensor: Monitors thermal variation, crucial for detecting bacterial growth conditions.

All sensors are submerged in the water storage tank, and readings are taken every 10 seconds. The data is filtered, formatted, and wirelessly sent to the Firebase database for analysis.

C. Software Stack and Data Processing

The backend of HydroWatch is powered by Node.js and Express.js, responsible for API management, data routing, and real-time synchronization with Firebase. Nodemailer.js is integrated to generate and send instant email notifications when water parameters exceed defined thresholds. For example, if the turbidity level rises above 5 NTU or the pH drops below 6.5, a detailed email containing the alert message, timestamp, and parameter report is automatically sent to users and authorities.
The frontend is implemented using React.js, which allows modular component-based UI design. Chart.js provides dynamic graph visualization, showing continuous trends of pH, TDS, temperature, and turbidity over time. Tailwind CSS enhances user experience through responsive design and clean styling.

Security is ensured using JWT (JSON Web Token) for session management and OAuth for third-party secure authentication. This ensures that only verified users—such as water quality officers, administrators, or residents—can access the web dashboard.

D. Workflow

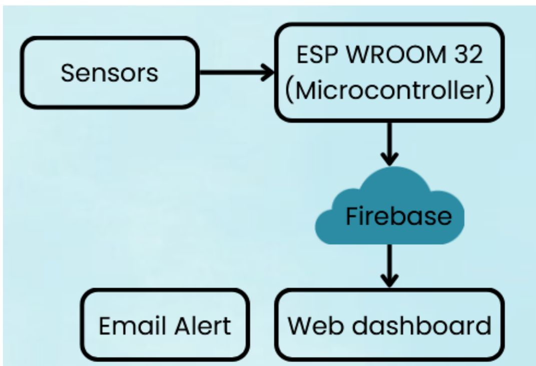

Fig. 2. HydroWatch workflow illustrating the stages of the flow of data

The workflow of the system goes through several stages to retrieve, store and analyze data.

1) Data Collection: Sensors record raw readings periodically.

2) Data Transmission: The ESP32 sends the readings to Firebase through WiFi connectivity.

3) Cloud Storage: Firebase stores and organizes data in real time, accessible to both backend and frontend services.

4) Data Processing: The backend validates sensor data, checks against threshold limits, and performs ML-based predictions.

5) ML Analysis: Using a statistical anomaly detection model classifies potential contamination risks.

6) User Notification: If anomalies are detected or predicted, Nodemailer sends automated emails to registered users.

7) Visualization: The frontend dashboard updates dynamically, marking alerts in red and generating trend graphs using Chart.js.

This continuous workflow ensures that even minor variations in water quality are detected early, allowing preventive measures before contamination becomes critical.

E. Machine Learning Integration

HydroWatch uses a combination of supervised learning and statistical modelling for anomaly detection. The model continuously learns from historical sensor readings to establish adaptive thresholds. With each iteration, prediction accuracy improves, allowing the system to identify patterns that precede contamination events, such as a consistent decline in pH coupled with increased turbidity.

The ML model runs on the backend, hosted on a cloud environment linked to Firebase. It can predict upcoming unsafe conditions with high reliability and trigger both dashboard warnings and email notifications pre-emptively.

IV. Result and Findings

HydroWatch was tested over a period of two weeks with dummy values and from a liter tank of water under controlled conditions. The sensors collected readings every 10 seconds, generating over 1,000 data samples.

TABLE I
SAMPLE WATER READINGS

Parameter	Safe Range	Detected Value	Alert Status
pH	6.5 – 8.5	5.9	Alert
TDS (ppm)	<500	680	Alert
Turbidity (NTU)	<5	8.2	Alert
Temperature (°C)	25 – 35	31	Normal

HydroWatch achieved an accuracy of 98.5% in anomaly detection and was able to issue email alerts within 8–10 seconds of detecting irregularities. Firebase's real-time data synchronization ensured all dashboard users viewed updated readings simultaneously. The React dashboard displayed clear visual trends and automatically highlighted critical readings in alert colors.

V. Discussion and Analysis

The results confirm that HydroWatch provides accurate, reliable, and responsive monitoring for stagnant water systems. Compared to manual testing, which may take hours or days, HydroWatch can identify unsafe conditions in seconds.

The integration of Node.js and Express.js for backend processing ensures scalability and event-driven data handling, while Nodemailer.js automates critical communications. The combination of React.js, Chart.js, and Tailwind CSS allows the dashboard to deliver real-time analytics in an aesthetically minimal yet highly functional layout.

The inclusion of JWT and OAuth authentication ensures strong data protection; a feature often absent in other IoT prototypes. Minor limitations, such as periodic sensor recalibration and reliance on internet connectivity, can be addressed with GSM modules and offline data buffering.

VI. Conclusion

HydroWatch demonstrates the combination of IoT and AI integration in environmental monitoring, specifically for stagnant water systems prone to contamination. The system offers a full-stack, end-to-end solution that bridges hardware sensing with intelligent data analytics and automated communication.

By integrating ESP32 hardware, Firebase cloud infrastructure, and a robust software ecosystem—Node.js, Express.js, React.js, Chart.js, Tailwind CSS, JWT, and OAuth—HydroWatch ensures secure, real-time, and predictive water quality monitoring. The automated email alert system via Nodemailer adds an immediate response layer, ensuring timely awareness among users and authorities.

Future versions of HydroWatch can integrate mobile app compatibility, GSM connectivity, and bacterial sensors for even deeper analysis. Its modular and scalable design makes it suitable for large-scale applications in smart cities, residential complexes, and municipal water systems. HydroWatch represents a critical step toward intelligent, data-driven water management, ensuring clean and safe water for communities everywhere.

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