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Grey Water Management :- Leveraging IoT For Sustainable Water Reuse

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Abstract This research addresses the escalating issue of water scarcity, particularly in densely populated regions where traditional water sources are increasingly compromised by pollution and overuse. Currently, water quality is typically monitored only at centralized infrastructure points such as water treatment plants and reservoirs [17]. Grey water—wastewater generated from domestic activities such as washing and bathing—remains a largely untapped resource that, if treated appropriately, can significantly reduce the demand for freshwater. This project presents an IoT-based grey water quality monitoring system designed to enable real-time assessment and promote the safe reuse of grey water. The system employs a suite of sensors to measure critical water quality parameters, including pH, temperature, turbidity, water level, total dissolved solids (TDS), and gas concentrations. These sensors are interfaced with an ESP32 microcontroller, which transmits collected data to the ThingSpeak cloud platform for real-time visualization and analysis. Based on predefined thresholds, the system classifies water as either Safe for Cultivation or Not Safe for Cultivation. Experimental validation confirms the system's effectiveness in monitoring water quality, demonstrating its potential in advancing sustainable water management practices. The proposed device can be adapted to monitor water quality for various water-sensitive applications [3]. By offering a cost-effective, scalable, and automated solution, this project supports efficient grey water reuse across agricultural, landscaping, and urban sectors, thereby contributing to broader global water conservation efforts. Water scarcity has emerged as one of the most critical global challenges of the 21st century, exacerbated by rapid urbanization, climate change, and the overexploitation of freshwater resources. In many urban and peri-urban areas, traditional sources such as rivers, lakes, and groundwater are becoming increasingly unreliable due to contamination and depletion. In such a context, alternative water sources like grey water hold immense potential for supplementing the existing supply. However, the lack of real-time monitoring and quality assessment mechanisms has hindered the safe and effective reuse of grey water.The proposed IoT-based grey water monitoring system bridges this gap by providing a smart and automated approach to evaluate the usability of domestic wastewater. By leveraging an ESP32 microcontroller and a suite of environmental sensors, the system performs real-time acquisition of key water quality metrics. These include pH, which indicates acidity or alkalinity; temperature, which affects biological activity; turbidity, which reflects water clarity; TDS, a measure of dissolved substances; gas detection, for identifying harmful compounds; and water level, for volumetric tracking. All readings are continuously uploaded to the ThingSpeak cloud platform, enabling seamless remote access, visualization, and analysis through IoT dashboards and automated alerts.A significant feature of the system is its decision-making capability based on threshold classification. By comparing sensor readings with predefined safety limits aligned with agricultural and environmental standards, the system categorizes the water as Safe for Cultivation or Not Safe for Cultivation. This binary classification aids farmers, gardeners, and urban planners in making informed decisions about water reuse without the need for laboratory testing.Beyond its core functionality, the system offers scalability and adaptability. It can be deployed in residential complexes, commercial buildings, agricultural fields, and urban landscapes to promote localized water recycling. The use of low-cost components and open-source platforms ensures affordability and accessibility, especially in resource-constrained settings. Moreover, the modular architecture allows future integration with machine learning algorithms to enable predictive analytics and anomaly detection in water quality trends.

Keywords: Grey Water Management, Water Quality Monitoring, IoT-Based System, Smart Water Management, ESP32 Microcontroller, ThingSpeak Cloud Platform, Water Conservation, Real-Time Data Acquisition.

1. INTRODUCTION

Water scarcity is an increasingly urgent global concern, driven by population growth, industrial expansion, urbanization, and climate change. Effective management of existing water resources is therefore critical to achieving sustainability. In this context, Water Distribution Systems (WDSs) must evolve to include intelligent monitoring mechanisms. The integration of Internet of Things (IoT) technology into WDSs presents a transformative opportunity. By deploying distributed sensor nodes across the network, authorities can track water quality and system performance in real-time, enabling timely interventions and efficient maintenance In many developing nations like India, the need for water conservation is particularly acute. Groundwater levels are depleting at alarming rates, and surface water bodies are increasingly contaminated. Grey water, which consists of relatively clean wastewater generated from household activities like bathing, washing, and laundry, constitutes a considerable portion of domestic wastewater. Along with harvested rainwater, grey water offers an underutilized opportunity for reuse in non-potable applications such as agriculture, landscaping, toilet flushing, and industrial cooling. However, traditional grey water recycling methods are typically manual, costly, and lack adaptability to varying water quality standards.This project proposes a smart grey water monitoring system leveraging IoT to address these limitations. The system architecture includes an ESP32-CAM microcontroller, which serves dual roles: it controls the data acquisition process and functions as an optical sensor to assess turbidity through image analysis techniques. Supplementary sensors are employed to measure other crucial parameters, including pH (to gauge acidity or alkalinity), temperature, TDS (to quantify dissolved substances), and gas concentration (using the MQ2 sensor to detect flammable and toxic gases). Additionally, a rainfall detection sensor is integrated to monitor seasonal water availability, aiding in decision-making for irrigation and storage management All sensory data are transmitted wirelessly via the ESP32 module to ThingSpeak, a cloud-based platform that supports real-time data visualization, logging, and analytics. This data is further used to classify the water based on predefined thresholds as either Safe or Not Safe for Reuse, primarily in cultivation and landscaping scenarios. The cloud platform can also trigger alerts and provide insights via graphical dashboards, enabling users—whether farmers, municipal officials, or urban planners—to make informed decisions without needing physical water sampling.The implementation of such a cost-effective, wireless, and autonomous monitoring system has several key benefits:

Real-Time Decision Making: Live data transmission and cloud processing enable users to respond quickly to water quality fluctuations.

Resource Optimization: By identifying reuse opportunities, the system reduces reliance on potable water supplies.

Scalability: The modular design allows the system to be scaled across households, agricultural fields, or even entire municipalities.

Environmental Impact: Efficient reuse of grey water reduces freshwater extraction, lowers energy consumption for water treatment, and contributes to climate resilience.

Furthermore, the ESP32-CAM's camera module can be utilized to integrate machine learning techniques, such as image-based turbidity detection using convolutional neural networks (CNNs), enabling more accurate classification in future enhancements. The combination of IoT, cloud computing, and potential AI integration makes this system highly adaptable for future smart city infrastructure.In conclusion, this IoT-based grey water monitoring system aligns with the principles of sustainable development, offering a viable technological solution to tackle water scarcity through efficient grey water reuse. Its integration into urban and rural water management frameworks can contribute significantly to environmental sustainability, economic viability, and public health protection.

2. LITERATURE SURVEY

Water scarcity has become a severe global challenge, prompting the development of sustainable water management systems. Grey water reuse has emerged as a potential solution to address non-potable water needs such as irrigation, toilet flushing, and landscaping. In this context, numerous researchers have explored various aspects of grey water management, monitoring technologies, and IoT-based systems.Elhegazy and Eid [1] presented a comprehensive review of grey water management technologies and trends from the 2000s to 2020s, highlighting the transition from traditional systems to intelligent, automated methods. Liu et al. [2] proposed a multi-region blue/grey water management system for the Yangtze River Economic Belt, emphasizing the need for regional integration in water planning strategies.In industrial applications, Gupta et al. [3] designed a low-cost IoT-based automatic water quality monitoring system tailored for textile industries. Their system demonstrates the effectiveness of real-time data acquisition in reducing pollution and optimizing water reuse. Similarly, Abdalla et al. [4] conducted an eco-efficiency analysis of combined grey and black water systems, concluding that integrated approaches provide superior resource utilization.Research by Moparthi et al. [5] and Prashanth et al. [6] addressed energy efficiency in sensor networks, which is crucial for sustainable deployment of IoT systems in water quality monitoring. Moparthi et al. [7] further explored image-based disease detection in plants, indirectly supporting the use of grey water in agriculture through monitoring techniques.Chandalwar et al. [8] proposed a generic IoT-based water quality monitoring system incorporating sensors for real-time analysis, aligning with the needs of grey water reuse. Earlier work by Ghunmi et al. [9] reviewed grey water treatment systems, identifying limitations in scalability, labor requirements, and lack of automation.In terms of technological advancement, Khaled et al. [10] developed an IoT-enabled turbidity detection system, using embedded sensors and cloud integration. Their system ensures real-time water quality insights and can be extended for domestic and agricultural applications.Collectively, the literature reflects a shift towards intelligent, IoT-enabled frameworks for water quality assessment. These solutions are increasingly addressing the limitations of traditional grey water reuse systems by providing real-time monitoring, data analytics, and scalable infrastructures for sustainable water management.

In the realm of smart sensing, researchers like Abbas et al. [11] have explored IoT retrofitting in developing regions to improve water usage comfort and efficiency. Their system, ASHRAY, demonstrated the practicality of data-driven retrofits in enhancing water resource management. Cattai et al. [12] proposed GraphSmart, a graph-based technique for green and accurate water monitoring in IoT environments, which offers improved scalability and reliability across urban infrastructure. Seckler et al. [13] provided one of the earliest projections on global water scarcity in the 21st century, reinforcing the urgency of adopting modern solutions such as grey water recycling. Trust management in IoT-based drinking water systems, as explored by Aiche et al. [14], emphasizes the importance of data integrity and reliability in mission-critical water treatment applications.Liu et al. [15] presented a comprehensive global assessment of water scarcity, identifying trends in water stress across continents and advocating for the incorporation of smart technologies for demand-side management. Similarly, Charan et al. [16] developed a domestic water recharge system that leverages IoT to automate rainwater harvesting and recharge processes.Real-time water quality monitoring has been a recurring focus, as evidenced in the work of Azida Abu Bakar et al. [17], who developed a sensor calibration system to enhance accuracy and long-term reliability. These improvements are essential for systems deployed in diverse environmental conditions. Aiche et al. [18] further explored safety optimization techniques in IoT water plants, identifying vulnerabilities and proposing robust solutions to safeguard public health. Truong et al. [19] introduced an IoT-based open ditch drainage monitoring system that integrates water level sensors and cloud analysis to mitigate flooding risks, supporting urban resilience strategies. Wanjiru and Xia [20] proposed an energy-water co-optimization framework for residential buildings, where grey water recycling plays a key role in minimizing overall resource consumption.In the agricultural domain, Sulaiman et al. [21] investigated the viability of using grey water in vegetated wall agro-systems. Their research validated the agronomic and environmental benefits of recycling household water. Nuthalapati et al. [22] proposed a LoRaWAN-enabled water quality monitoring system suitable for metropolitan cities, offering low-power and long-range communication capabilities essential for scalable IoT deployments.Ngo Ho et al. [23] offered a practical methodology for grey water reuse in household irrigation, bridging the gap between theoretical research and community-scale applications. Mohanasundaram et al. [24] demonstrated a mobile application-supported water monitoring system that provides real-time feedback, promoting public engagement and awareness.Zulkifli et al. [25] introduced spectroscopy-integrated IoT methods for detecting specific pollutants at household points-of-use, signifying a new wave of precision water quality assessment. Finally, Taouraout et al. [26] explored smart city applications for recycling treated grey water in urban green spaces, showcasing the potential of grey water systems to contribute to sustainable urban development.This comprehensive literature review clearly illustrates the evolving landscape of IoT-enabled grey water management systems, ranging from sensor technologies and data analytics to cloud platforms and real-time monitoring applications. The review highlights the interdisciplinary nature of this field, blending environmental engineering, IoT systems, cloud computing, and sustainable development, thus laying a strong foundation for the development of advanced, automated grey water reuse systems tailored for both rural and urban applications.

3. PROPOSED SYSTEM

The proposed system is an IoT-based grey water monitoring and analysis platform designed toevaluate the reusability of wastewater for irrigation and other non-potable applications. It combines real-time sensing, cloud-based data analytics, and user-friendly visualization to support sustainable water reuse practices.

1. System Architecture

The system comprises the following components:

Sensing Layer:

pH Sensor: Measures the acidity or alkalinity of the water.

TDS Sensor: Measures the total dissolved solids to evaluate salinity.

Temperature Sensor (DS18B20): Monitors water temperature, which affects plant growth.

Gas Sensor (MQ Series): Detects volatile gases or pollutants indicating contamination.

Turbidity Sensor: Assesses water clarity to detect suspended particles.

Microcontroller Unit (MCU):

ESP32 or Arduino UNO with Wi-Fi module: Acts as the central node to collect sensor data and transmit it wirelessly to the cloud platform.

Cloud Platform:

ThingSpeak: A real-time data visualization and storage platform. It receives sensor data through HTTP or MQTT and plots it for analysis. It also hosts classification logic to display whether the water is safe or not.

User Interface:

Web Dashboard or Mobile View (ThingView App): Enables users to monitor live parameters, receive alerts, and view historical trends for better decision-making.

1. **Water Sample Collection**: Grey water is introduced to the sensing unit.

2. **Data Acquisition**: Sensors measure relevant parameters and send analog/digital signals to the MCU.

3. **Data Processing**: The microcontroller digitizes and organizes the readings.

4. **Cloud Communication**: Processed data is uploaded to the ThingSpeak server using Wi-Fi.

5. **Analysis & Visualization**: ThingSpeak plots the real-time data, performs threshold checks, and classifies the water as "Safe" or "Not Safe."

6. **User Feedback**: Results are displayed to users via a dashboard, with potential alerts (email/SMS) for unsafe water.

.Key Features of the Proposed System

- **Real-Time Monitoring**
- **Low-Cost and Scalable**
- **Modular Sensor Integration**
- **Cloud-Based Visualization & Alerts**
- **Sustainable & Eco-Friendly**

1. System Overview

The system integrates sensor-based water quality analysis, microcontroller-based data acquisition, wireless communication, cloud data analytics, and user interface components. It operates autonomously to collect, analyze, and transmit key grey water parameters, enabling real-time decision-making regarding water usability.

2. System Architecture

a. Hardware Layer:

Sensing Unit:

pH Sensor (e.g., SEN0161-V2) – For measuring the acidity/alkalinity of grey water.

TDS Sensor (e.g., Gravity TDS Meter) – Detects the concentration of dissolved solids, indicating salinity and potential contamination.

- Temperature Sensor (DS18B20) – Measures water temperature, vital for microbial growth and plant health
- .Turbidity Sensor (e.g., SEN0189) – Measures water clarity to detect particulate matter.
- Gas Sensor (MQ135 or MQ2) – Detects harmful gases such as ammonia or method.

RESULT & DISCUSSION

The experimentation phase was critical to validate the effectiveness of the IoT-based grey water monitoring system in real-world scenarios. The system was evaluated based on key water quality parameters—Temperature, TDS (Total Dissolved Solids), pH, Gas Presence, and Turbidity—across four distinct water samples. These experiments demonstrate the robustness, limitations, and practical implications of the proposed system.

Performance Analysis Across Samples

Experiment 1 (Alkaline Water):

The system flagged this water sample as unsafe due to a very high pH (12) and elevated TDS (1205 ppm), exceeding the permissible cultivation threshold. The low temperature (10°C) could also impede seed germination and plant metabolism. Despite the absence of gas and low turbidity, the chemical imbalance rendered it unsuitable for reuse in agriculture. This confirms the system's sensitivity in identifying pH anomalies.

Experiment 2 (Tap Water):

This served as a baseline or control sample. All parameters fell within the acceptable range: pH at 7 (neutral), TDS at 400 ppm (well below the 800 ppm limit), and no gas detection. The temperature (33°C) was conducive for most crop types, indicating ideal growing conditions. The system accurately identified this sample as safe, validating its core functionality under normal conditions.

Experiment 3 (Acidic Water):

This sample presented extremely low pH (2.5) and high TDS (1638 ppm). Additionally, gas was detected, likely from chemical reactions or biological decomposition, indicating volatile compounds in the water. Although the sample was clear in turbidity, the combination of acidity, gas emission, and dissolved solids led to a correctly classified unsafe result. This shows that the gas sensor and TDS module contribute crucially to the decision-making process.

Experiment 4 (Clean Water Sample):

This sample recorded optimal values across all parameters, such as pH of 7, TDS of 785 ppm, and temperature of 20°C, leading to a safe for cultivation verdict. The results confirm the system's accuracy in detecting ideal water quality, reinforcing its utility in determining reusability with minimal processing.

Trend and Pattern Recognition

A clear trend was observed: pH and TDS were the most influential indicators in determining water safety. Both alkaline and acidic extremes directly resulted in a "Not Safe" classification. Interestingly, turbidity had no significant effect, as all samples were visually clear, but this may not always hold true in more contaminated environments. The presence of gas correlated strongly with water toxicity, underscoring the need for gas sensors in real-time assessments.

IoT System Efficacy

The integration with the ThingSpeak platform proved invaluable. Data collected was not only visualized in real-time but also stored for longitudinal analysis, allowing for historical trend comparisons. The system's ability to issue immediate classification messages on water safety supports field applications where rapid decisions are necessary.

Additionally, the modular sensor-based architecture enabled isolated fault diagnosis. For example, anomalies in pH or TDS could be quickly traced back to specific sensor behavior, aiding maintenance.

Application Potential

The results establish the viability of deploying this system in agricultural fields, nurseries, urban green spaces, and rooftop gardens, especially in regions with water scarcity. Since tap water and treated clean water passed the test, reuse of household wastewater (post minimal treatment) could serve as a viable alternative to fresh water in irrigation and landscaping.

Moreover, the real-time capabilities allow local authorities or users to continuously monitor community water systems, aiding in predictive maintenance and resource optimization.

CONCLUSION

Water is one of the most vital elements for livelihood but at the same time, it is polluted by different kinds of fastest-growing industries like textiles, leather, sugar and many more [3]. In conclusion, the Grey Water Management :- Leveraging IoT for Sustainable Water Reuse works effectively. This project successfully developed an IoT-based grey water quality monitoring system that enables real-time assessment of water safety for cultivation. By integrating sensors to measure key parameters such as pH, TDS, temperature, turbidity, and gas levels, the system provides a cost-effective and scalable solution for sustainable water reuse. The experimental results demonstrated the system's accuracy and efficiency in classifying water samples as either Safe for Cultivation or Not Safe for Cultivation based on predefined thresholds. The use of ThingSpeak for cloud-based data visualization further enhances real-time monitoring and decision-making.

Despite some challenges and limitations, such as sensor calibration issues, reliance on internet connectivity, and the exclusion of microbial contamination monitoring, the project presents a promising approach to water conservation. With future enhancements, including automated filtration, machine learning-based anomaly detection, and expanded contamination monitoring, the system can be widely adopted for applications in agriculture, landscaping, urban wastewater management, and industrial water recycling. There has been an attempt that has been made to build a system that is capable of preserving the ground water by harvesting the rain water and re-using the grey water made available from every household. [16]. Ultimately, this project contributes to addressing global water scarcity issues by promoting the safe and efficient reuse of grey water through innovative IoT technology.

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