Predicting Groundwater Levels Using Borehole Data for Sustainable Management Systems

Vinayak khot
Computer Science and Engineering
KLS VDIT
Haliyal, India
vinnukhot78@gmail.com

Mallikarjun Waghamodi
Computer Science and Engineering
KLS VDIT
Haliyal, India
puneetwaghamodi@gmail.com

Rahul lad
Computer Science and Engineering
KLS VDIT
Haliyal, India
rahullad0307@gmail.com

Dr. Venkatesh Shankar
Professor and Head of the Department
Computer Science and Engineering
KLS VDIT
Haliyal, India
vss@klsvdit.edu.in

Abstract

Groundwater depletion presents a major obstacle to achieving sustainable agriculture, especially in areas such as Karnataka, India. Conventional groundwater monitoring techniques tend to be manual, sporadic, and do not support real-time data integration, which often results in inefficient management of water resources. This project introduces an affordable IoT-based system designed for continuous monitoring and management of groundwater levels. By leveraging ESP8266 microcontrollers, the system combines soil moisture sensors with ultrasonic water level sensors to gather up-to-date information on soil moisture and water availability. The data is transmitted over Wi-Fi to the Blynk IoT cloud platform, enabling users to remotely monitor and control the system through a user-friendly mobile application. Furthermore, the integration of weather information via APIs supports predictive analytics, assisting in more informed irrigation and water management decisions. The automation of pump control based on sensor readings and weather forecasts helps maximize water efficiency, reduce over-extraction, and support sustainable groundwater practices. This solution is designed to be scalable and easily accessible, providing farmers and stakeholders with an effective tool to improve the sustainability of water resources in agriculture.

I. INTRODUCTION

Groundwater serves as a vital resource for agriculture, drinking, and industrial uses, particularly in areas like Karnataka, India. However, excessive extraction combined with the lack of real-time monitoring Existing systems have posed significant challenges to achieving sustainable water management. Conventional techniques for groundwater monitoring are often inefficient and outdated often manual, intermittent, and lack real-time data processing, limiting their effectiveness in guiding water conservation efforts The rise of the Internet of Things (IoT) presents a potential breakthrough solution to these challenges. By utilizing IoT-based sensors such as soil moisture detectors and ultrasonic water level sensors, real-time information on groundwater and soil conditions can be gathered. When these sensors are paired with microcontrollers like the ESP8266 and connected to cloud-based platforms These technologies facilitate real-time data gathering and evaluation. Additionally, the integration of weather data via APIs can improve the system's predictive accuracy, facilitating more informed and proactive water management decisions.

Although While these technologies provide notable benefits, there remains a shortage of integrated systems, comprehensive systems for real-time groundwater monitoring and management. Developing an effective and sustainable solution requires addressing challenges such as data accuracy, scalability of the system, energy efficiency, and user-friendly design. This project focuses on creating an IoT-based groundwater monitoring solution that employs ESP8266 microcontrollers along with soil moisture and ultrasonic water level sensors, combined with weather data obtained via API integration. The system aims to deliver continuous data collection, analysis, and visualization to support Environmentally responsible water management approaches, especially in the agricultural sector.

II. LITERATURE SURVEY

- **Espinoza Ortiz, M.; Apún Molina, J.P.; Belmonte Jiménez, S.I.; et al.** developed an economical IoT system for real-time monitoring of piezometric levels and groundwater temperature, as detailed in Sensors, 2023 (DOI: 10.3390/s23239364). The device employs ESP8266 microcontrollers combined with pressure transducers to gather continuous data, which is sent every 15 minutes using the MQTT protocol to a cloud-based server. This information is accessible through an interactive web dashboard for easy visualization. **Impact:** The study validates the practicality of implementing cost-effective, real-time groundwater monitoring solutions in rural regions, thereby promoting sustainable management of wate resources**.**

- **Deshpande, G.; Goswami, M.; Kolhe, J.; et al.** developed Cost-effective IoT-based solution for tracking soil moisture levels. and temperature, as presented in their 2022 arXiv preprint (DOI: arXiv:2206.07488). The system utilizes Raspberry Pi along with IoT technologies to collect and transmit data, offering real-time visualization through a mobile app to support better irrigation management. **Impact:** This work emphasizes the benefits Utilizing IoT platforms in conjunction with soil moisture monitoring can significantly optimize water consumption in agricultural activities.

- **Borah, S.; Kumar, R.; Mukherjee, S**. detailed the design and testing of an economical System based on a capacitive sensor for detecting soil moisture levels aimed at IoT-enabled agricultural applications, as published in the Journal of Computing and digital technologies Management, 2023 (DOI:10.22059/jitm.2023.91570). This system accurately measures soil moisture levels across various soil types, improving the precision of irrigation scheduling. **Impact:** The research offers an affordable and Dependable instrument for evaluating soil moisture levels, supporting more efficient water use and promoting sustainability in agricultural water management.

- **Shafira, A.; Nugraha, S.; Suhendra, T.** developed an IoT-enabled soil moisture monitoring system powered by solar energy, targeting urban horticulture, as detailed Presented at the First International Conference Proceedings on Sustainable Engineering Development and Technological Innovation, 2022 (DOI: 10.4108/eai.11-10-2022.2326280). The system uses ESP-WROOM-32 microcontrollers to provide reliable and sustainable monitoring of soil moisture levels. **Impact:** This research highlights the successful combination of renewable solar power with IoT technology to promote sustainable and energy-efficient practices in urban agriculture.

- **Kuindra, I**.; and co-authors developed an IoT-driven system for soil moisture monitoring and forecasting Applying linear regression methods, along with a case study focusing on Vinca plants. Published in the Journal of Intelligent Software Systems in 2023 (DOI: 10.26798/jiss. v2i1.929), the system gathers moisture data through NodeMCU ESP8266 microcontrollers and displays the information on Google Data Studio dashboards for easy visualization. **Impact:** This work emphasizes the role of predictive analytics in soil moisture management, facilitating timely and efficient irrigation planning.

.III. METHODOLOGY

1.Site Selection and Borehole Setup

- Choose Monitoring Locations: Determine sites through analysis of hydrogeological conditions, land usage, and water requirements.
- Drill Boreholes: Establish boreholes fitted with sensors to measure groundwater levels at different depths.
- Deploy Multilevel Monitoring Systems: Utilize multilevel setups to collect depth-specific data, essential for assessing vertical changes within aquifers.

2.Data Collection

- Acquire Continuous Time-Series Data: Continuously monitor and record groundwater levels, precipitation, temperature, and extraction rates.
- Maintain Data Accuracy**:** Calibrate sensors periodically and perform validation checks to ensure data reliability.
- Integrate Remote Sensing**:** Utilize satellite imagery and data to complement on-ground measurements, particularly in hard-to-access locations.

3**.** Data Preprocessing

- Address Incomplete Data: Use advanced imputation methods, For example, using Generative Adversarial Network models. (GANs), to estimate and fill missing values in the dataset.

- Standardize Inputs: Normalize the data to ensure consistent scaling, which aids in effective model training and faster convergence.

- Select Relevant: Features Use methods such as Principal Component Analysis (PCA) for reducing dimensionality to pinpoint the most important variables that significantly impact groundwater levels.

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4.Model Development

- Select Suitable Modeling Techniques: Choose prediction models that align with the structure and nature of the data. For time-series forecasting, models like Long Short-Term Memory (LSTM) networks are particularly effective.

- Parameter Optimization: Enhance model efficiency by fine-tuning Variables adjusted through optimization techniques like the Lion Algorithm.

- Model Evaluation: Divide the dataset into training and testing portions to assess model accuracy and ensure it generalizes well, avoiding overfitting.

5.Forecasting and Scenario Evaluation

- Predict Groundwater Trends: Apply trained models to estimate future groundwater levels under varying conditions, such as changes in precipitation and water extraction rates.

- Evaluate Uncertainty: Measure and analyze the degree of uncertainty in predictions to support risk assessment and guide informed decision-making.

. 6. Integration with Water Management.

- Design Decision-Support Interfaces: Build intuitive tools that allow stakeholders to view forecasts and utilize insights for strategic planning.

- Adopt Flexible Management Strategies: Modify groundwater extraction practices dynamically in response to predictive model outputs to promote long-term sustainability.

- Foster Stakeholder Involvement: Collaborate with local communities, regulatory bodies.

IV. DISCUSSION

Forecasting groundwater levels using borehole data Is essential in sustainable water management, particularly in areas like Karnataka, India, where groundwater is a key water source. This approach combines borehole-based monitoring, advanced data analysis, and Utilizing artificial intelligence methods to promote responsible groundwater usage.

The process begins with carefully selecting monitoring locations based on factors such as hydrogeological characteristics, land use, and regional water needs. Boreholes are then installed and outfitted with sensors to measure groundwater levels at different depths. Multilevel sensor setups are used to capture depth-specific data, which is important for understanding vertical changes within aquifers.

Data collection includes gathering continuous time-series information on groundwater fluctuations, precipitation, temperature, and water extraction rates. Maintaining data accuracy requires routine sensor calibration and data validation Technologies for remote sensing, such as satellite-based systems imagery, can further enhance the dataset, especially in less accessible areas.

During preprocessing, gaps in the data are filled using imputation methods such as Generative Adversarial Networks (GANs). Data is then normalized to improve training efficiency, and dimensionality reduction tools such as Principal Component Analysis (PCA) are applied to isolate the most impactful variables affecting groundwater levels.

Model development focuses on choosing predictive techniques that align with the nature of the data. Long Short-Term Memory (LSTM) networks are particularly well-suited for forecasting time-series data, while optimization strategies Optimization methods like the Lion Algorithm may be utilized to fine-tune model parameters and improve accuracy. To ensure model reliability and avoid overfitting Separating the dataset into distinct training and testing portions is crucial for validation purposes

During the prediction and scenario evaluation phase, the trained models are used to estimate future groundwater levels under varying conditions, such as shifts in rainfall or groundwater extraction rates. Evaluating the degree of uncertainty in these predictions is vital for supporting effective risk analysis and water management decisions.

In the implementation stage, predictive insights Are integrated within resource management frameworks. This involves designing interactive decision-support tools with user-friendly interfaces for end-users, adjusting water usage policies based on forecast outputs, and involving all relevant stakeholders—such as local communities, regulators, and water authorities—in the design and operational processes.

This integrated methodology combines on-site data collection, robust data preprocessing, and machine learning to deliver accurate groundwater level forecasts. By embedding these predictive capabilities into water management systems, stakeholders are empowered to make evidence-based decisions that promote the sustainable utilization of groundwater resources.

V. RESULTS

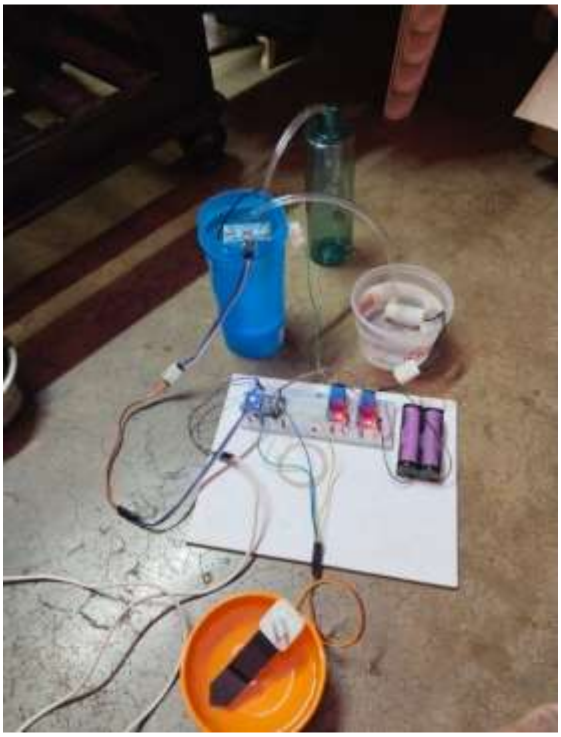

Fig 1: Groundwater level prediction using sustainable management system process

1. NodeMCU ESP8266 – Serves as the central microcontroller, handling data processing and Wi-Fi communication.

2. Capacitive Soil Moisture Sensor – Detects and measures the moisture content in the soil.

3. Ultrasonic Sensor (HC-SR04**)** – Calculates the water level in the storage tank.

4. 2-Channel Relay Module – Manages control of two independent water pumps.

5. Water Pumps – One is used for irrigation, and the other for transferring water between containers.

6. Battery Pack – Provides portable power to the entire system.

7. Tubes and Containers – Used for water transport and storage.

8. Breadboard and Jumper Wires – Facilitate the electrical connections within the circuit.

Software & Platforms

- Arduino IDE – Used to write and upload code to the NodeMCU.

- Google Sheets with Apps Script – Enables real-time data logging in the cloud.

- IFTTT or Webhooks – Integrates data communication over Wi-Fi to log and trigger events.

System Workflow

1. The soil moisture sensor periodically checks the current moisture level in the soil.

2. The ultrasonic sensor measures the water height in the tank and translates the value into millilitres.

3. Every 10 seconds, data including time, temperature, weather conditions, soil moisture, and water level is logged to Google Sheets.

4. The system operates based on preset thresholds:

5. The data logs confirm that the pump activates appropriately when low moisture is detected and water is available.

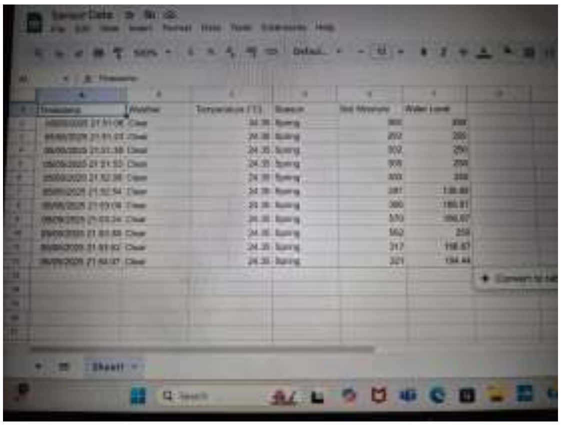

Fig 2: Real Time updated Sensor Data

The smart irrigation system functions independently by combining real-time environmental sensing with automated water management. It employs a NodeMCU ESP8266 microcontroller Linked with a capacitive sensor for soil moisture measurement and an ultrasonic sensor for data collection. The soil moisture sensor provides ongoing monitoring of soil dryness, while the ultrasonic sensor measures the water level in the reservoir by detecting the distance to the water surface. These measurements are processed by the NodeMCU and transmitted every 10 seconds to a Google Sheet through Wi-Fi, Utilizing cloud platforms such as Google Apps Script or Webhooks.

The system uses set threshold values to determine irrigation needs. As an example, when soil moisture drops below a specific level (such as 300) and the water volume exceeds a minimum amount (e.g., 150 mL), the NodeMCU activates a relay to switch on the water pump. The pump runs until the soil moisture reaches an optimal range or the water supply falls below a safe limit. This method enhances water efficiency by applying irrigation solely when required minimizing waste and manual intervention. Continuous data logging to Google Sheets creates a clear and accessible record of system operations, enabling users to monitor environmental conditions and the system's responses over time.

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