

Groundwater Management Using IoT, Technology, Machine Learning, And Civil Engineering Approach

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Abstract. Groundwater is vital to industry, agriculture, and drinking water production. A growing amount of groundwater needs to be managed effectively because of the effects of climate change and growing demand. Conventional methods frequently prove inadequate for managing groundwater and tackling these issues. This study investigates how to use machine learning, Internet of Things (IoT) technologies, and civil engineering to create a more reliable and effective groundwater management strategy and Infrastructure in our environments. Real-time monitoring capabilities offered by IoT technology allow for ongoing data collection on groundwater levels, quality, and usage. Machine learning algorithms can use this data to forecast future patterns and anomalies, providing an initiative-taking groundwater management tool. Civil engineering solutions like artificial recharge and sophisticated irrigation systems are crucial for sustainable usage and replenishment. This paper thoroughly analyzes current developments in various domains and suggests a synergistic framework to improve groundwater management by fusing machine learning, IoT, and civil engineering. According to our research, integrating these technologies can maximize groundwater resource utilization, raise aquifer sustainability, and increase the accuracy of groundwater monitoring and forecasting. The suggested framework offers a comprehensive and innovative technological solution to overcome the shortcomings of current groundwater management techniques. Future

research should concentrate on improving integrated systems and investigating their applications across various geographical and climatic contexts to ensure the sustainable management of groundwater resources globally.

Keywords: Management of groundwater; The Internet of Things; Monitoring in real time; Machine learning; Civil engineering; Optimization of water resources; Adaptation to climate change.

INTRODUCTION

As the primary water source for industrial processes, agricultural irrigation, and home use, groundwater is crucial to the world's water supply. The sustainable management of groundwater resources is not without its difficulties, though. Water availability and soil stability are threatened by over-extraction, which occurs when water is taken out more quickly than can be naturally supplied in our environments. Over-extraction depletes aquifers and causes water tables to drop. Pollutants, including nitrates, heavy metals, and organic compounds, contaminate groundwater through industrial discharges, inappropriate waste management, and agricultural runoff. These contaminants pose a significant health concern and need expensive cleanup. The effects of climate change further complicate groundwater management because of changes in precipitation patterns, droughts, and rising temperatures, which impact recharge rates and water availability. Conventional groundwater management techniques are frequently reactive and unable to provide real-time data and predicted insights since they depend on sporadic manual measurements and past consumption trends. This shortcoming hampers timely decision-making and resource conservation.

On the other hand, new prospects for improving groundwater management are presented by incorporating contemporary technologies. Using sensor networks, the Internet of Things (IoT) makes it possible to continuously monitor groundwater levels, quality, and usage in real time. This process generates high-resolution data, which can then be sent to centralized systems. Machine learning advances provide robust instruments to analyze this data, spot trends, forecast future conditions, and maximize water use. In addition, advances in irrigation technology and artificial recharge methods made possible by civil engineering advances support groundwater replenishment and sustainable use. Together, these developments in engineering and technology provide a more accurate and efficient way to

manage groundwater resources, overcoming the drawbacks of conventional approaches and opening the door to long-term sustainable water management strategies in the face of rising demand and climate change.

Objectives: 1) To assess the current state of groundwater management-related IoT, machine learning, and civil engineering.

2) To develop a comprehensive framework for better using these technologies in groundwater management, forecasting, and monitoring.

METHOD

Data Acquisition and Monitoring. A significant development in groundwater monitoring is the installation of Internet of Things (IoT) sensors in wells, boreholes, and aquifers; this allows for real-time data collection and analysis, which is essential for sustainable resource management. These sensors make continuous monitoring of groundwater levels, pH, electrical conductivity, temperature, precipitation, and other relevant environmental data possible. The gathered data is wirelessly transferred to centralized servers and thoroughly analyzed to quickly identify patterns, irregularities, and contamination occurrences. This strategy improves early warning systems for deteriorating groundwater quality and supports initiative-taking decision-making for distributing and protecting water resources. Technology integration supports efficient policy creation and resource planning to reduce environmental effects and guarantee long-term groundwater sustainability. It is consistent with the concepts of adaptive management.

Remote Sensing and Satellite Imagery. Monitoring a range of environmental factors, including changes in land use, the health of the vegetation, and surface water dynamics, is aided by satellite imaging and remote sensing technologies. According to authors [1], these technologies provide broad regional coverage that enhances comprehensive groundwater management by supplementing the localized data from IoT sen-

sors. Large-scale land modifications, such as urban sprawl, deforestation, and agricultural practices, can be observed by satellite photography. Furthermore, remote sensing techniques yield significant insights into vegetation conditions, including identifying stress indicators and biomass changes that can impact groundwater recharge rates. Additionally, by combining satellite and remote sensing data with IoT measurements, stakeholders can achieve a more robust and nuanced approach to monitoring groundwater resources and developing sustainable management strategies. These technologies also make it easier to monitor surface water dynamics, such as river flow patterns, lake levels, and water body extents, which contributes to a holistic understanding of hydrological processes.

Data Processing and Analysis. Regression models and neural networks are two examples of machine learning methods that are increasingly important for evaluating historical and current groundwater data. These models can create forecasting tools for recharge rates, groundwater levels, and sources of contamination. With their ability to simulate intricate nonlinear interactions, neural networks have proven useful in research projects like Singh's [2] prediction of semi-arid regions' groundwater levels. Because of their ease of use and interpretability, regression models such as multiple linear regression (MLR) are also widely utilized [3], for instance, MLR, to assess the influence of environmental factors on groundwater recharge in West Bengal, India.

Data analytics methods are used concurrently to manage massive amounts of heterogeneous data from satellites and Internet of Things sensors. Among these methods are data fusion approaches, which combine several data sources to improve decision-making. For example, authors [4] combined satellite and ground-based data to enhance groundwater recharge predictions, resulting in more accurate forecasting models; this demonstrates how data fusion incorporates data from multiple sensors and sources to understand groundwater systems comprehensively. Ultimately, this connection supports more sustainable groundwater management by enabling accurate and real-time monitoring.

Authors [5], in their review of groundwater pollution detection techniques, state that big data analytics aids in identifying patterns and anomalies, which can be crucial for the early detection

of contamination sources. Thus, combining big data analytics and machine learning offers solid tools for improving groundwater research and management, enabling more accurate forecasts and informed decision-making.

Artificial Recharge and Infrastructure Development. With artificial recharge techniques like infiltration basins, recharge wells, and percolation ponds, civil engineering techniques are essential to improving natural groundwater replenishment. These techniques are intended to speed up the natural recharge processes by allowing surface water to seep into the groundwater system. For example, authors [6] highlight the significance of such Infrastructure in groundwater management by discussing creative designs for recharge wells that improve sustainability and efficiency. Optimizing water availability also depends on the planning and upkeep of Infrastructure such as reservoirs, aqueducts, and dams, which control surface water flows. These buildings aid in managing water distribution, lessening droughts' effects, and guaranteeing a steady water supply for various applications.

Water conservation technologies are crucial for cutting down on water waste and decreasing reliance on groundwater resources at the same time. Effective irrigation methods, such as drip irrigation and precision agriculture, reduce water losses from evaporation and runoff. This guarantees that water is delivered directly to the plant roots. For instance, studies have demonstrated that drip irrigation systems increase the water use efficiency of agricultural activities. [7]. Additionally, water recycling facilities are essential for cleaning and repurposing wastewater for uses other than drinking, which helps to preserve fresh water supplies and lessens the strain on groundwater resources [8]. Designing a sustainable water management system that improves groundwater recharge, maximizes surface water use, and lowers overall water consumption by fusing these civil engineering methods with water conservation technologies is feasible.

Decision Support System and Stakeholder Engagement. Groundwater management requires Integrated Decision Support Systems (DSS), which use machine learning and analytics from IoT data to guide decision-making. These technologies enable initiative-taking and educated management of groundwater resources by providing stakeholders and policymakers with sophisticated visualizations, scenario simula-

tions, and thorough risk assessments. DSS, for instance, can use real-time data from the Internet of Things sensors to track groundwater quality and levels, forecast trends, and assess the effects of various management approaches. The system's predictive skills are improved using machine learning algorithms, which offer precise forecasts and highlight hazards [9].

Furthermore, community involvement and stakeholder engagement are essential to effectively executing groundwater management programs. Organizing community discussions, stakeholder workshops, and educational initiatives promotes active community participation in management initiatives and increases public understanding of groundwater conservation techniques. By including stakeholders, decision-making processes are made to consider their expertise and concerns, which promotes a sense of ownership and dedication to sustainable groundwater management. To effectively address local needs and preferences, authors [9] emphasize the significance of incorporating varied community members in groundwater management while discussing techniques and obstacles in stakeholder involvement. A comprehensive and inclusive groundwater management approach that improves resilience and sustainability may be developed by integrating robust stakeholder engagement techniques with the technological advantages of DSS.

RESULTS AND DISCUSSION

Case Study 1. Monitoring in Real Time in California [10]. An Internet of Things-based groundwater monitoring system was put in place in California to address the problems of over-extraction and depletion. This system made real-time data on groundwater levels and quality available, essential for better decision-making and efficient regulation enforcement. The system uses Internet of Things (IoT) sensors to monitor groundwater conditions and provide stakeholders with up-to-date information continuously.

Furthermore, researchers analyzed this data and used machine learning models to predict future patterns, allowing for proactive management techniques. Because of these predictive abilities, managers more sustainably manage groundwater resources by foreseeing potential problems and taking action to prevent further depletion. This example of how technology can improve en-

vironmental management methods is the integration of advanced analytics with real-time monitoring.



A LevelSender telemetry system installed within a 2" monitoring well with the antenna on the outside of the enclosure to increase data transmission.

Figure 1 – Real-time groundwater monitoring



Figure 2 – The telemetry graph of the real-time capture of groundwater

Case Study 2. Indian Predictive Analytics. In India, a project combining IoT sensors and machine learning algorithms to monitor and predict groundwater levels in agricultural regions. This system provided farmers with real-time data, helping them optimize irrigation schedules, reduce water usage, and improve crop yields. In addition, engineers used civil engineering techniques to construct recharge wells, enhancing groundwater replenishment by allowing more efficient water infiltration. This integrated approach conserved water, supported sustainable agricultural practices, and improved water management.

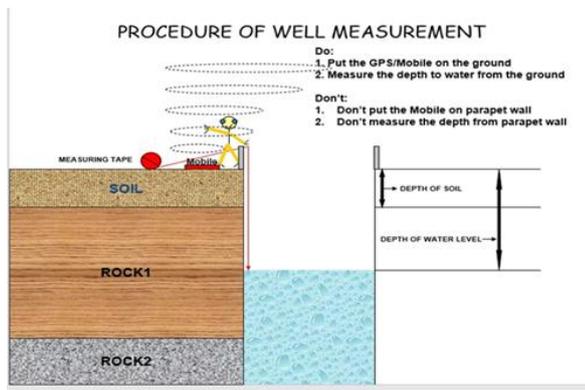


Figure 3 – The procedures for groundwater in real-time

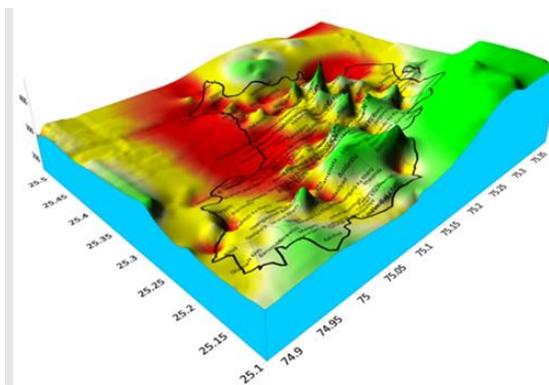


Figure 4 –A predictor sample of a water recharge of groundwater

CONCLUSIONS

In conclusion, a revolutionary strategy that tackles the pressing issues of sustainability and water shortages is merging IoT, innovative technology, machine learning, and civil engineering with groundwater management. IoT devices make it easier to collect and monitor data in real time, giving researchers a more detailed understanding of groundwater dynamics. By analyzing this data, machine learning models improve decision-making processes by optimizing water management techniques and producing predictive in-

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sights. To ensure the efficient use and replenishment of groundwater resources, advancements in civil engineering facilitate the building of sustainable irrigation networks and artificial recharge systems. By embracing these technologies, we can achieve a sustainable balance between groundwater use and replenishment, ensuring long-term water security for future generations in the face of increasing environmental and societal pressures. This interdisciplinary constructive collaboration enhances the efficiency and accuracy of groundwater management and promotes initiative-taking measures to prevent over-extraction and contamination.

Experts advise developing and using comprehensive frameworks incorporating IoT, technology, machine learning, and civil engineering to promote groundwater management. To enable continuous, real-time data collection, policymakers and stakeholders should invest in deploying IoT sensors and smart devices throughout crucial groundwater basins. Researchers must improve data analytics and machine learning algorithms to deliver precise predictions and valuable insights that facilitate accurate decision-making. Designing and constructing resilient Infrastructure, such as effective irrigation systems and recharging wells suited to the local environment, requires close coordination with civil engineers. The efficacy of these technologies will also be increased by supporting multidisciplinary research and development and by giving professionals in these disciplines training and education. Finally, encouraging community involvement and knowledge of sustainable groundwater practices will guarantee the accomplishment and durability of these projects, supporting an equitable and sustainable groundwater management system.

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