

Leveraging Deep Learning and Cloud Computing for Water Usage Optimization in Agriculture: A Study

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Abstract

Water scarcity and inefficient irrigation practices are significant challenges in modern agriculture. This research investigates how deep learning and cloud computing can be combined to enhance water efficiency in agricultural practices. Leveraging advancements in deep learning and cloud computing, researchers have developed innovative solutions for optimizing water usage. This review examines the state-of-the-art methodologies, technologies, and applications in smart irrigation systems. It explores how deep learning models and cloud platforms are transforming agricultural water management by enabling predictive analytics, real-time monitoring, and adaptive control mechanisms. Running deep learning models on the cloud can be energy-intensive. Future studies should explore energy-efficient AI models and sustainable cloud computing solutions. Obtaining accurate, real-time agricultural data continues to be a significant challenge. Future studies should prioritize creating improved data collection methods and incorporating a wider range of datasets. The study also highlights key challenges and future directions for integrating these technologies into large-scale agricultural practices.

Keywords: Deep learning, cloud computing, agriculture, water usage, PVC

INTRODUCTION

Freshwater scarcity poses a significant issue, particularly in Mediterranean and South Asian nations like India. Within Europe, Mediterranean countries are especially susceptible to droughts [1]. Studies have highlighted a connection between climate policies and water management strategies. Various factors, including sector-specific water demands and the effects of specific temperature increases on water availability, can influence water management. Climate change and its consequences consistently

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appear as key topics in research related to water resources and agriculture. The potential impacts of global warming have led to the consideration of adopting adaptation measures in the water sector to ensure water supplies for food production and the population, and to protect ecosystems [2]. In addition, the safety of water consumed by humans and returned to the environment must also be guaranteed. Potential risks of climate change include increased water scarcity, deterioration of water quality, increased salinization of water and soil, loss of biodiversity, increased need for irrigation, and potential costs for emergency and remedial measures. For these reasons, there has been an increase in studies aimed at reducing water consumption in irrigation processes. Several studies suggest adopting social, economic, and climate-related policy actions, along with embracing

technological advancements, to enhance water management. Agriculture plays a vital role in the economies of these nations, making efficient water resource management essential for the sustainability of this sector. In India, 10% of the land area is covered under rice fields [3]. Furthermore, 20% of India's population lives below the poverty line and 15% is food insecure. Therefore, a reduction in food output impacts not only the general population but also the overall economy. The 2002 monsoon season was the driest in the last 130 years. This led to a decline in rice production due to freshwater shortages. The Standardized Precipitation Evapotranspiration Index (SPEI) was utilized to identify drought conditions resulting from irregularities in surface water levels. These indices, along with information collected from sensors monitoring the environment, soil, and water, can be used to determine the current water status and the ability to meet the total demand for freshwater. Resource-rich countries have already implemented water management and water reuse systems to optimize water use and reduce the environmental impact of using large amounts of water. However, some countries may find these solutions too costly. Commercially available sensors for agricultural and irrigation systems are so expensive that it is not feasible for small farmers to implement this kind of system on their own farms. Today, manufacturers provide affordable sensors that can be integrated with nodes to create economical systems for managing irrigation and monitoring agricultural activities.

Furthermore, due to the growing interest in low-cost sensors for tracking agriculture and water, new affordable sensors are being proposed in researches which include a leaf water strain tracking sensor [4], Examples include a multi-level soil moisture sensor made from copper jewelry wire, positioned next to a PVC pipe [5], a water salinity monitoring sensor made by using copper coils [6], and a water turbidity sensor that utilizes colored and infrared LED emitters and receivers [7]. Due to the current advances in sensors for the implementation of irrigation structures for agriculture and the evolution of WSN and IoT technology that may be implemented within the improvement of those structures, we present a survey aimed at summarizing the current state of the art in smart irrigation systems. This survey aims to provide an overview of the current state of research on irrigation systems. It will identify the key parameters monitored within these systems, including water quantity and quality, soil properties, climatic factors, and fertilizer application. We will offer an outline of the maximum applied nodes and Wi-Fi technology employed to enforce WSN and IoT based smart irrigation structures. Lastly, we are able to find out the demanding situations and the exceptional practices for the implementation of sensor-based smart irrigation structures. Several researchers have conducted studies centered on irrigation systems, water management, or precision agriculture technologies. However, the existing alternative surveys on smart irrigation structures analyzed pretty some papers [8], yet they do not provide an in-depth evaluation of the state of the art work regarding irrigation structures. Others are focused on particular factors concerning irrigation which include software program for irrigation structures [9], pivot-middle particular irrigation structures or irrigation structures for greenhouses. Lastly, there are surveys that concentrate on precision agriculture [10], crop tracking and the agro-commercial and environmental fields of agriculture [11] that touch upon irrigation agriculture. This survey provides an overview of the latest developments in irrigation systems, along with the sensors and actuators employed in their implementation. Furthermore, we primarily discuss the most commonly applied nodes and the Wi-Fi technology employed for the communication and transmission of the records accrued via sensors. This way, with this study we cope with the cutting-edge gap in literature with a survey that offers an outline of IoT-primarily based smart irrigation structures.

Importance of Reviewing Deep Learning and Cloud Computing in Smart Irrigation

Rather than focusing on broader challenges such as water scarcity and climate change, this study emphasizes the role of deep learning and cloud computing in smart irrigation [12, 13]. These technologies enable:

- *Precision irrigation*: Ensuring that crops receive water at optimal levels without wastage.
- *Real-time decision making*: Leveraging AI-driven insights to adjust irrigation schedules dynamically.
- *Scalability and accessibility*: Cloud-based solutions can be deployed across different farm sizes, benefiting both small and large-scale agricultural practices.

- *Resource efficiency*: Smart irrigation systems optimize water use while minimizing operational costs and human intervention.

Smart Irrigation Techniques

A review of smart irrigation techniques is essential to:

- *Identify existing challenges*: Understanding the limitations of current irrigation systems and areas where deep learning and cloud computing can improve efficiency.
- *Compare technological approaches*: Evaluating different machine learning models, IoT integration strategies, and cloud-based architectures to determine the most effective solutions.
- *Enhance agricultural sustainability*: Assessing how smart irrigation contributes to water conservation and long-term agricultural sustainability.
- *Guide future research*: Providing insights into emerging trends, gaps in knowledge, and innovative solutions that can enhance the effectiveness of smart irrigation systems.
- *Facilitate adoption*: Helping policymakers, researchers, and farmers make informed decisions about implementing advanced irrigation technologies in diverse agricultural settings.

LITERATURE REVIEW

Hamdoon *et al.* [1]

Mostly, clean water is utilized in agriculture. There has been a consistent interest in developing systems and solutions that rationalize water resources in agriculture without reducing productivity. In contrast, the solutions should enhance manufacturing whilst using much less water. On the opposite hand, The Internet of Things is a distinguished latest generation that offers diverse answers in lots of disciplines, such as agriculture and irrigation. This study presents an IoT-based architecture for smart irrigation by developing a prototype that includes a controller unit, sensors, and water pumps. These systems monitor the soil's irrigation needs and decide the proper quantity of water based on the sensor data. As those values are brought through cloud computing to a user's cellular app, irrigation can be monitored and managed from a couple of angles. This incorporates guide irrigation mode and automated irrigation mode and determines the proper quantity of irrigation based on sensor inputs.

Rabak *et al.* [2]

The expansion of precision agriculture technology from industrial agriculture to domestic gardening is exceptionally important because of its financial and fitness benefits, brought through a brand new manner of crop production. Additionally, it gives physiological and psychological benefits to the gardeners. The soil degradation and lack of awareness among gardeners regarding soil properties and the chemical composition of irrigation water results in much less domestic crop production. In this work, we proposed a brand new linked sensor machine wherein smart watering can connect with a Wi-Fi sensor community for soil evaluation at the side of the homes of water. The soil conditions were measured using thick film pH and moisture sensors. The pH sensor shows a sensitivity of 53 ± 2 mV/pH when using a RuO₂ vs. Ag/AgCl electrode, and 42 ± 1.26 mV/pH with a RuO₂ vs. carbon electrode, within the pH range of 3 to 8.

Depending at the soil properties, the sensor-integrated watering can automatically create an appropriate pH solution by mixing the alkaline/acidic solutions stored in separate containers within the watering can. This prepared pH controlled water is then applied into the plants by the user. Online tracking of both soil and irrigation water chemical content help the gardener to develop vegetation sustainably.

Dhanaraju *et al.* [3]

Smart farming is an improvement that has emphasized the use of information and communication in machinery, gadgets, and sensors in community-based hi-tech farm management cycles. Emerging technologies, including the Internet of Things (IoT) and cloud computing, are anticipated to drive growth and accelerate the adoption of robotics and artificial intelligence in agriculture. Such ground-

breaking shifts are disrupting modern-day agriculture approaches, while also presenting several challenges. This paper investigates the tools and equipment used in packages of Wi-Fi sensors in IoT agriculture, and the expected demanding situations confronted whilst merging generation with traditional farming activities. Furthermore, this technical know-how is beneficial to growers for the duration of crop intervals from sowing to harvest; and it's applications in packaging and delivery are also investigated.

Sadri et al. [4]

Cloud Computing, the most important computing and storage tool in the Internet of Things (IoT), still faces various challenges. Removing IoT endpoints from the cloud platform can cause serious problems in real-time applications such as disaster management, healthcare applications, etc. To solve these problems, Fog Computing is a new platform with special capabilities to perform the important tasks of IoT data management and real-time application management. Data management for IoT with Fog Computing is crucial to reduce the latency of real-time IoT applications, which is necessary to achieve more specialized knowledge and smarter decision-making. Minimizing the volume of data transmitted to the cloud layer is a key challenge in managing data on fog computing platforms. In this article, to select and investigate the studies on data size reduction in fog computing, a systematic literature review (SLR) process was applied to understand and classify the different topics and related approaches in this field. Furthermore, published studies in the field of edge computing that came closer to our goal were also considered. This study aims to categorize and examine research on data reduction (FDR) conducted between 2016 and 2022. It introduces an approach-based taxonomy that organizes the topics and methodologies found in the selected articles. The taxonomy includes areas such as data filtering, compression, aggregation, prediction, pattern recognition, general faceting, and related techniques. Additionally, the study highlights unresolved issues in FDR and outlines key challenges for future research.

Bouali et al. [5]

Water is becoming increasingly scarce. Unrestricted management and extensive use of fossil fuels in groundwater pumping for irrigation are exacerbating global warming and damaging the environment. Given the rapid population growth and the associated increase in food demand, optimal utilization of groundwater and energy is becoming essential and vital for sustainable agriculture. In this context, smart agriculture (SA) has emerged as a promising field leveraging ICT (Information and Communication Technology) to optimize resource utilization and simultaneously increase crop yields. This paper presents a comprehensive SA solution with a focus on cost-effectiveness. Commercial solutions are expensive and therefore prohibitive for small and medium-sized farmers. Our solution revolves around three main axes: 1. Smart water meters promote optimal groundwater usage and conservation through real-time data collection and monitoring using a cloud-based Internet of Things (IoT) system. 2. Renewable energy integration reduces dependency on fossil fuels for groundwater extraction and promotes energy-efficient agriculture. 3. Smart irrigation promotes the cultivation of good quality and quantity of crops without damaging the soil and groundwater ecosystem. We implemented and evaluated our solution in actual smart farm test environments. The findings indicate that using our SA system led to a reduction in water usage by as much as 71.8% compared to conventional irrigation methods. Additionally, our solution is open source, making it readily accessible and adaptable for other researchers to support the development of cloud-based platforms focused on utilizing groundwater resources, particularly in arid and sub-Saharan regions.

Friha et al. [6]

Water is becoming increasingly scarce. The unmonitored control and the enormous use of fossil fuels for ground water pumping in irrigation exacerbate global warming and harm the environment. Along with the rapid populace increase and the concomitant demand for food, most effective utilization of water-desk and electricity is turning into a ought to and integral for sustainable agriculture. In this context, Smart Agriculture (SA) is emerging as a promising field that utilizes Information and

Communication Technology (ICT) to enhance resource efficiency and boost crop yields. This paper presents a practical SA solution focused on cost-effectiveness. Commercial solutions are expensive and as a result often inaccessible to small and medium farmers. Our solution revolves round three primary axes: 1. Smart water metering encourages efficient water usage and supports its conservation at the consumer level (a.k.a., groundwater) through real-time records series and tracking the use of a Cloud-based IoT (Internet of Things) machine; 2. Renewable-Energy integration promotes electricity generation in green agriculture by lowering reliance on fossil fuels in water-desk pumping, and 3 Smart irrigation aims to promote high-quality and high-yield crop production without harming the soil and the water-desk ecosystems. Our solution has been deployed and examined in an actual-international Smart Farm testbed. The outcomes have proven that the adoption of our SA machine reduces the quantity of water consumption (with a conventional irrigation machine) by as much as 71.8%. Finally, our solution is open-source and may be easily adopted and adapted by other researchers to support the development of a dedicated Cloud-based platform for water-desk utilization, mainly in arid and sub-Saharan countries.

García *et al.* [7]

This paper offers a complete assessment of rising technology for the internet of things (IoT) based smart agriculture. We begin by summarizing the existing surveys and describing emergent technology for the rural IoT, along with unmanned aerial vehicles, Wi-Fi technology, open-source IoT platforms, software defined networking (SDN), network function virtualization (NFV) technology, cloud/fog computing, and middleware platforms. We additionally offer a category of IoT packages for smart agriculture into seven categories: smart monitoring, smart water management, agrochemical applications, disease control, smart harvesting, supply chain management, and smart agricultural practices. In addition, we provide a taxonomy and a side-by-side comparison of the latest techniques of supply chain control based on blockchain technology in agricultural IoTs. Furthermore, we showcase actual tasks that use many of the aforementioned technologies, which reveal their exceptional overall performance withinside the discipline of smart agriculture. Finally, we highlight open research challenges and discuss possible future research directions for agricultural IoTs.

Nawandar *et al.* [8]

In countries with water scarcity, water management is of utmost importance. It also affects agriculture, since large amounts of water are used for this purpose. The possible effects of global warming have prompted the exploration of water adaptation strategies to secure water availability for both food production and consumption. As a result, there has been a growing interest in researching methods to conserve water in irrigation processes. Traditional commercial sensors used in agricultural irrigation systems are often highly priced, making them inaccessible to small-scale farmers. Fortunately, recent advancements have enabled the production of low-cost sensors that can be integrated with nodes to build budget-friendly systems for irrigation management and agricultural monitoring. With the rapid development of IoT and wireless sensor network (WSN) technologies applicable to such systems, this survey aims to present a comprehensive overview of the current landscape of smart irrigation solutions. It outlines the key parameters monitored in irrigation, including water quantity and quality, soil conditions, and climatic factors. Additionally, it reviews the most commonly used nodes and wireless communication technologies. Finally, the paper addresses the challenges faced and outlines best practices for deploying sensor-based irrigation systems effectively.

Kamienski *et al.* [9]

Agriculture contributes significantly to the Indian economy and most people depend on it for their livelihood. Hence, water is a critical resource that must be protected with modern technologies. IoT is not only fundamental for Industry 4.0 but also opens its possibilities for smart agriculture. This study aims to design an affordable and intelligent system for efficient smart irrigation. The use of IoT allows the devices used in the system to communicate and connect autonomously, with features such as managed mode for user interaction, one-time setup to predict irrigation schedules, neural decision

making for intelligent assistance, and remote monitoring of data. An exemplary crop trial field was selected to demonstrate the results of the proposed system including irrigation scheduling, decision making by neural network, remote data display, etc. The neural network provides the devices with the required intelligence to consider the current sensor inputs and mask the watering schedule for efficient irrigation. The system utilizes MQTT and HTTP protocols to keep users informed about crop conditions, even from distant locations. Its smart features, affordability, and portability make it highly effective and adaptable for use in farms, greenhouses, and similar environments. Efficient freshwater management through precision irrigation plays a key role in boosting crop production, cutting expenses, and promoting environmental sustainability. With the help of technology, water can be delivered to plants in precisely the right amounts they require.

del Pozo et al. [10]

The Internet of Things (IoT) is the obvious choice for smart water management applications, but the integration of different technologies required for seamless operation in practice is not yet fully completed. The SWAMP project takes a practical approach through four pilot initiatives in Brazil and Europe, aiming to create an IoT-driven smart water management platform for precision agriculture irrigation. This paper outlines the SWAMP system's architecture, platform design, and deployment, emphasizing the platform's ability to be replicated. It also provides a performance evaluation of the FIWARE components integrated into the system, addressing scalability, which is a key challenge in IoT applications. Results show that it can provide sufficient performance for the SWAMP pilot, but to achieve higher scalability with fewer computational resources, specially designed configurations and redesign of some components are required.

RESEARCH GAPS

Despite advancements in smart irrigation techniques, several research gaps remain unaddressed:

- *Limited data availability:* Many regions lack access to high-quality, real-time agricultural data, making it challenging to develop robust machine learning models.
- *Scalability issues:* While cloud-based systems provide efficient processing, small-scale farmers often lack the infrastructure or resources to implement such solutions.
- *Model generalization:* Current deep learning models are typically trained on limited datasets, which restricts their capability to perform well across varying climate and soil conditions.
- *Integration of IoT and edge computing:* Many smart irrigation systems rely on cloud computing, but edge computing can offer faster and more localized decision-making. Further research is needed to optimize hybrid cloud-edge architectures.
- *Energy consumption:* Running AI models on cloud platforms requires significant energy. There is a need for more energy-efficient deep learning architectures tailored for agricultural applications.
- *Farmer adoption and usability:* Many farmers lack the technical expertise to use AI-driven smart irrigation systems effectively. Research should focus on designing user-friendly interfaces and training programs to enhance adoption.
- *Long-term impact assessment:* There is limited research on the long-term impact of AI-based irrigation systems on soil health, crop yield, and water conservation.

DEEP LEARNING

Deep learning, a branch of machine learning, concentrates on classification problems and utilizes evolutionary algorithms [14]. Learning in this domain is typically categorized into three types: supervised, semi-supervised, and unsupervised learning. Various deep learning structures, such as fully connected networks, recurrent neural networks (RNNs), and artificial neural networks (ANNs), have been applied across multiple fields, including artificial intelligence, computer vision, data analytics, social media filtering, computational linguistics and biology, drug discovery, and information retrieval [15]. The concept of ANNs is inspired by the knowledge processing and decentralized nature of biological systems, although there are notable differences from the human brain. For instance, neural

networks function in a symbolic and static manner, whereas biological brains operate dynamically and analogically.

The term "deep learning" stems from the use of multiple layers within the neural network architecture. Earlier studies found that a simple linear perceptron could not serve as a universal classifier, while a network with a nonlinear input layer and one wide hidden layer could [9]. Modern deep learning uses multiple layers of limited size to balance functionality, optimization, and theoretical generality. These architectures often diverge from traditional connectionist models for improved performance, interpretability, and training efficiency, which accounts for their structured and adaptable design [16].

Most contemporary deep learning approaches emphasize machine learning applications, particularly convolutional neural networks (CNNs). These models may also involve structured propositional expressions or latent variables arranged in deep generative models such as deep belief networks and deep Boltzmann machines. Each layer within a deep learning model learns to transform input data into progressively more abstract representations. For example, in image recognition, the raw input may be pixel data; the first layer might identify edges, the second layer might recognize patterns of edges, the third could detect facial features like eyes and noses, and the final layer might identify the presence of a face. Significantly, the model can automatically determine which features to associate with each layer.

The phrase "deep learning" specifically references the number of transformation layers data passes through. Deep learning models often have a high credit assignment path (CAP) depth [5], which refers to the chain of transitions from input to output. CAPs help define potential causal links between the input and the result. In feedforward networks, CAP depth is equal to the number of hidden layers plus one. For recurrent neural networks (RNNs), where signals may circulate through the same layer repeatedly, the CAP depth can theoretically be infinite. While there is no universally defined depth that separates shallow from deep learning, it is generally accepted that a CAP depth of more than two qualifies as deep learning. A CAP depth of two is already sufficient to approximate any function, making it a universal approximator [7].

METHODOLOGY

Data Collection and Integration

- *Sensor network*: Deploy a network of soil moisture sensors, weather sensors, and environmental monitoring devices across agricultural fields. These sensors will collect data on soil moisture levels, ambient temperature, rainfall, wind speed, and solar radiation, which are critical for determining irrigation needs.
- *External data*: In addition to sensor data, weather forecasts, satellite imagery (such as NDVI for crop health), and historical data on soil types and crop growth will be integrated into the system. This information will help create a detailed understanding of the agricultural environment.
- *Data preprocessing*: Raw data will undergo cleaning and preprocessing to address missing entries, reduce noise, and normalize values. Additionally, time-series sensor data will be synchronized to ensure consistency.

Cloud Infrastructure Configuration

- *Cloud platform*: The system will leverage cloud services such as AWS, Google Cloud, or Microsoft Azure for data storage, processing, and analysis. These platforms offer scalable storage, computing power, and access to machine learning tools and APIs for training and deploying models.
- *Data integration*: All gathered data, including sensor outputs, weather information, and satellite images, will be consolidated and stored in cloud-based databases like AWS S3 or Google Cloud Storage. The cloud infrastructure will allow for easy access to data by stakeholders for analysis and decision-making.

- *Real-time processing:* Using cloud computing resources, data will be processed in real-time to facilitate immediate decision-making for irrigation schedules. The cloud system will enable centralized monitoring and control over the entire irrigation network.

Deep Learning Model Development

Model architecture: The core of the proposed methodology is the development of deep learning models capable of predicting irrigation requirements based on real-time environmental and soil data. The models will include:

- *Convolutional neural networks (CNNs)* for analyzing spatial data, such as satellite images or NDVI maps, to assess crop health and water stress.
- *Recurrent neural networks (RNNs)*, especially Long Short-Term Memory (LSTM) models, are used to process time-series data such as weather predictions and soil moisture readings, enabling accurate forecasting of future water needs.
- *Multimodal hybrid models:* A combination of CNN and LSTM models will be used to predict irrigation needs by considering both spatial (crop health, satellite images) and temporal (weather, soil moisture) factors.
- *Model evaluation:* The model's effectiveness will be tested using an independent validation dataset to verify its capability to handle new, unseen data. Evaluation metrics like Mean Absolute Error (MAE), Root Mean Squared Error (RMSE), and R^2 will be employed to measure the accuracy of its predictions.

CONCLUSION

Deep learning and cloud computing have revolutionized water usage optimization in agriculture, offering a pathway to more sustainable and efficient practices. While challenges remain, the rapid advancements in these fields hold promise for addressing global water scarcity and enhancing agricultural productivity. Ongoing research and technological advancements, along with favorable policies, are essential for unlocking the complete benefits of these innovations.

FUTURE DIRECTIONS

Integration of Emerging Technologies

Combining deep learning and cloud computing with edge computing, blockchain, and reinforcement learning can further enhance system efficiency and security.

Weather-Resilient Irrigation Models

Developing models that adapt to climate variability will be crucial for ensuring sustainable water management.

Affordable Solutions for Small Farmers

Research should focus on cost-effective systems tailored to the needs of small-scale farmers, including offline and edge based solutions.

Policy and Framework Development

Governments and organizations should establish policies and frameworks to promote the adoption of these technologies, ensuring equitable access and support.

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