International Journal of Basic and Applied Sciences, 14 (SI-1) (2025) 344-351

International Journal of Basic and Applied Sciences

Website: www.sciencepubco.com/index.php/IJBAS
https://doi.org/10.14419/v9w5kj86
Research paper

Blockchain-Enabled Decentralized Water Management System (BD-WMS) for Sustainable Irrigation

Ashu Nayak [1] *, Kapesh Subhash Raghatate [2], Gajendra Singh Negi [3]

[1] Assistant Professor, Department of CS & IT, Kalinga University, Raipur, India
[2] Research Scholar, Department of CS & IT, Kalinga University, Raipur, India
[3] Assistant Professor, New Delhi Institute of Management, New Delhi, India
**Corresponding author E-mail: ku.ashunayak@kalingauniversity.ac.in*

Received: May 2, 2025, Accepted: May 29, 2025, Published: October 31, 2025

Abstract

Agriculture's scarce resources need to be managed efficiently, and we are developing new solutions to meet our need to manage resource scarcity and improve irrigation methods. This research proposes a blockchain-enabled Decentralized Water Management System (BD-WMS) that leverages blockchain, Smart Contracts, the Internet of Things (IoT), and Artificial Intelligence (AI) for sustainable irrigation. On a real-time basis, to ensure the accuracy of the data collected, the BD-WMS is equipped with IoT sensors to measure soil moisture, pH levels, and weather conditions. Firstly, it records data in a ledger on the blockchain to ensure that there is no data corruption and that the data cannot be altered in any way. Using smart contracts, dynamic water requirements are complied with to control irrigation valves autonomously according to changing water needs. I also introduce the Tokenized Water Conservation Incentive Model (TWCIM), which allocates blockchain-based tokens to farmers in return for implementing water-saving measures that can be converted into a subsidy amount or utilized in the case of agricultural resources. The predictive analytics module, based on AI, plays a crucial role in the further evolution of system efficiency by forecasting water demands based on historical information and environmental conditions. In the tomato greenhouse, the research indicates a maximum saving of 40 percent, as well as an approximate yield increase of approximately 25 percent compared to traditional water management. It provides a different remedy to the issues that arise within the conventional irrigation model due to the decentralized control, as well as the standards of incentive-driven conservation. It was proposed as a scalable, safe, and effective solution to meet the needs of sustainable agriculture, maximizing efficient water governance and resource conservation.

Keywords: *Blockchain; Sustainable Irrigation; Smart Contracts; Internet of Things (IoT); Predictive Analytics; Water Conservation.*

1. Introduction

One of the most significant threats to global food production and irrigation systems is the shortage of freshwater [1], which now accounts for approximately 70 percent of all freshwater in the world [4]. Conventional irrigation systems have traditionally been inefficient, often resulting in overwatering, poor allocation, and inadequate resource management. These difficulties result in immense amounts of water wastage, crop loss, and environmental degradation. Addressing these problems requires creativity and progressive thinking, facilitated by new technology. The blockchain [3] technology [2], with its decentralized ledger functionality, is also capable of contributing to augmenting water transparency and security. The model specifically developed to promote the Internet of Things (IoT), artificial intelligence (AI), and blockchain practice, while also improving irrigation practices, is the Blockchain Enabled Decentralized Water Management System (BD-WMS) proposed by this study [15]. The BD-WMS features IoT-based sensors that continuously monitor the soil moisture level and weather conditions. These smart contracts automatically control water provision, on a blockchain network [5], based on these data points, which are preserved in a manner that no such data ever needs to be modified [6]. It is a computerized process that reduces the human factor and provides as much accuracy as possible in the irrigation process.

Additionally, the system is equipped with an incentive model that compensates farmers who apply irrigation methods that do not harm the environment [16]. BD-WMS is situated in a rural backwater with limited access to quality water and in an arid region. It utilizes tokenized incentives to engage farmers in proactive water conservation and to turn water usage into a tradable commodity [8]. Lastly, an artificial intelligence-based predictive analytics engine also enhances irrigation strategies by forecasting water requirements using historical data, weather patterns, and crop cycles. The proposed system aims to achieve a 40% reduction in water loss and an estimated 25% increase in crop productivity. BD-WMS combines data management, IoT-monitored security from blockchain, and AI-based prediction to offer a scalable and sustainable solution to current irrigation issues [7]. The findings of this study describe the potential of the system to transform the way agriculture is watered, thereby securing food security, promoting environmental sustainability, and enhancing farmers' livelihoods.

2. Literature Review

2.1. Traditional irrigation systems and limitations

In agriculture, traditional irrigation systems, including surface irrigation, drip irrigation, and sprinkler systems, have been widely used for water distribution in farmlands[17]. Despite being simple and popular, the methods have several inefficiencies, including water wastage and improper distribution, among other issues, and some of these inefficiencies cannot be addressed manually [12]. For example, surface irrigation is often applied too frequently, leading to excessive water runoff and soil erosion [9], which reduces resource efficiency. Drip irrigation systems reduce the amount of water used, but they are not always precise and require regular maintenance to prevent clogging [10]. Another reason is that conventional systems cannot provide on-the-fly monitoring, which restricts adaptation to the dynamics of changing climate conditions and crop needs [18]. The lack of automated control mechanisms is also leading to the depletion of water and increased operational costs, which are due to over-irrigation. However, some limits must be their own particular intellectual, information-based incineration in terms that can enhance the use of water in ways that do not diminish the well-being and sustainability of crops [11].
The implementation of AI-based irrigation methodologies and blockchain technology has been widely reported in water-stressed regions over the past few years. However, the literature associated with these technologies tends to discuss them individually. It does not provide information on how they can be integrated into more efficient, large-scale, and transparent water management instruments.
In the scenario of irrigation systems with AI-managed systems, as described by Ashoka et al. (2024), tremendous opportunities exist for optimizing water use. They report that machine learning models can predict water demand with a very high level of accuracy based on environmental factors and soil moisture levels. However, these systems are more susceptible to centralized control, which is a vulnerability to data and real-time flexibility. This practice is developed by the BD-WMS, which utilizes AI and blockchain technology to address these issues. Unlike older AI frameworks, which may be opaque, BD-WMS leverages the concept of a decentralized registry provided by blockchain, enabling immutable and transparent information regarding water usage. This provides accountability and safety to the water distribution logs.
Through the aid of blockchain technology, as discussed by Sriyono et al. (2020), water management becomes more transparent and less susceptible to data manipulation. Nevertheless, the lack of scalability and the inability to adjust to a dynamic environment in real-time remain the thorns in the side of most blockchain-based solutions. The BD-WMS can overcome these constraints, unite blockchain and smart contracts, and automate irrigation regulation based on real-time information collected by IoT sensors. Through this, it establishes dynamism, efficiency, and equity in the distribution of water, which is particularly noteworthy in areas where the water crisis is crippling.
Finally, the literature review may offer helpful ideas concerning the application of AI and blockchain in irrigation; however, the BD-WMS is an innovative hybrid system that integrates AI-inspired predictions with blockchain-enabled transparency and automated smart contracts, providing more universal and global solutions to water management problems.

2.2. IoT-based precision irrigation techniques

Today, IoT-based precision irrigation practices are increasingly being considered as a possible solution [12] to the incompatibility of current irrigation systems. The methods utilize intelligent sensors, actuators, and wireless networks to monitor real-time soil conditions, including soil moisture, soil temperature, and environmental factors. This data can be used in combination with automated irrigation controls [13] to enable farmers to push the required amounts of water as needed, possibly in excess of the requirements, but certainly beyond specific crop requirements. For instance, a dynamic watering time based on data provided by soil moisture sensors [14] and the adjustment of irrigation plans can be optimized using weather prediction algorithms when it is raining. It also demonstrates that these IoT systems can facilitate remote monitoring, enabling farmers to control irrigation processes through mobile apps. Despite the above benefits, the safety of data, connectivity issues in remote locations, and the costly implementation of IoT-based systems are some areas for improvement that can further enhance their scalability and reliability.

2.3. Blockchain applications in water management

The application of blockchain technology has been found to enhance transparency, security, and accountability in water management systems. With the assistance of a decentralized registry, blockchain enables editing of information on water usage, irrigation programs, and documentation on the distribution of resources to unauthorized parties. This will eliminate data manipulation, increase user confidence, and ensure water is distributed efficiently. A blockchain network would also accommodate smarter meters that would automatically document actual water usage and transfer it to a secure ledger. For example, blockchain enhances the level of traceability, as authorities can verify the pattern of water utilization and identify any abuse. The aspect of improved data integrity within blockchain remains crucial to rendering the blockchain wholly secure; however, the inability to scale and energy consumption constraints are deterring the application of blockchain in farm ecosystems. High-fidelity convergence is a luxury that is especially desired when server overload is a consideration that does not affect the time performance of client computing.

2.4. Smart contracts for automated water control

A smart contract operates automatically and is independent when, say, it receives the amount of money in the block address or transfers the currency to another block address that you need. The water management industry can utilize smart contracts to implement autonomous irrigation control using data from IoT sensors. An example of this is a smart contract, where irrigation valves are opened when the soil's moisture content drops to a specific set point or when temperature sensors indicate that drought stress may be present. Computerization minimizes human involvement in distributing water efficiently and punctually. Additionally, smart contracts can also implement dynamic water pricing models, whereby users are charged according to their consumption rates and encouraged to use water responsibly. However, some problems with smart contracts prevent their use yet, including weaknesses in contract logic, the complexity of implementation, and, above all, the necessity of reacting to unforeseen environmental conditions. Therefore, they need novel algorithm design and more effective security systems.

2.5. Gaps in existing research

Although the possibilities of IoT, blockchain, and smart contracts in enhancing irrigation are considerable, significant research gaps remain that need to be addressed. Most of the present investigations show that many isolated solutions work, but not within the framework of integrating these technologies as a whole framework. Additionally, current models of irrigation using IoT do not provide data security, making the collected data susceptible to manipulation. But in most blockchain applications, they are plagued by performance bottlenecks (particularly at a large scale). Moreover, the incentive models for water conservation, particularly in terms of farmer involvement and adoption, are less well understood. Additionally, very little research has been conducted on predictive analytics facilitated by AI in irrigation systems, which can significantly improve the efficiency of water distribution. And fill gaps in intelligent irrigation systems with complete, decentralized, data-based solutions.

3. Proposed System: Blockchain-Enabled Decentralized Water Management System (BD-WMS)

3.1. System architecture overview

The BD-WMS integrates IoT sensors and blockchain, and takes it a step further by generating analytics powered by AI, resulting in a sustainable water framework. Specifically, the system entails the following three blocks (i) Data Acquisition Layer to receive the real time data on the IoT sensors to be used in examining the soil moisture, temperature and water usage (ii) Blockchain Network Layer to store the data on the sensors on a secure and immutable ledger, and (iii) Control and Automation Layer to control the water flow through the smart contracts under the specified conditions. It has been constructed in both small- and large-scale agricultural exploitations. BD WMS integrates real-time tracking with decentralized data warehousing and predictive analytics to maximize water use, enhance water responsibility, and provide an environmentally friendly theory of practice in irrigation.

BD-WMS architecture utilizes blockchain to securely and decentralizedly manage data. In particular, Ethereum is used due to its strong capabilities in smart contracting, which provide transparent and immutable records of transactions. The Proof of Stake (PoS) consensus mechanism proposed by Ethereum offers scalability and energy efficiency, which are essential when implementing it at the scale of the agricultural sector. For enterprise-level applications, Hyperledger Fabric may be the next option, offering permissioned access and faster transaction processing.

The Q-value for a given state-action pair is updated using the Bellman equation:

$$Q(s_t, a_t) = Q(s_t, a_t) + \alpha(r_{t+1} + \gamma \max_{a'} Q(s_{t+1}, a') - Q(st, at))$$

Where:

$Q(s_t, a_t)$ is the value of taking action a_t in state s_t.

r_{t+1} is the reward after acting a_t.

α is the learning rate.

γ is the discount factor.

$\max_{a'} Q(s_{t+1}, a')$ is the maximum expected future reward for the next state st+1s_{t+1}st+1.

The Deep Q-Learning (DQN) algorithm is founded on Q-value optimization, considering both current and future rewards through the optimization of the Bellman equation in irrigation decisions. The model enables the system to simulate the most suitable irrigation patterns, informed by real-time environmental data.

The system also relies on AI-based dynamical predictive irrigation control, utilizing Reinforcement Learning (RL) or Deep Q-Learning (DQN) to provide intelligent predictive analytics. The AI model is developed with the assistance of TensorFlow to provide the scalability needed when dealing with extensive data and complex environmental forecasting. It will also enable the optimization of irrigation plans based on real-time information.

3.2. IoT-based water monitoring nodes

The BD-WMS utilizes water monitoring nodes based on IoT technology, equipped with soil moisture sensors, temperature sensors, and water flow meters, to monitor the primary environmental parameters. They subsequently transmit the information to other bases, dumping it into a primary blockchain network using low-power protocols, such as LoRaWAN or ZigBee. The data is coded in such a manner that it is transmitted periodically or when an event threshold is reached, thereby minimizing energy waste and consumption. The sensors collect real-time information on the exact soil conditions and dynamically allocate water to meet the current demand. Additionally, sensor failures are detected using fault detection on the node to ensure the accuracy of the data. The IoT nodes, therefore, enable data-driven irrigation planning and lessen the manual efforts involved in the water management process.

3.3. Blockchain integration and data flow

By allowing blockchain integration in BD-WMS, secure, transparent, and tamper-proof data management is achieved. Each IoT node is also a blockchain node that can transmit the real-time data to the distributed ledger. Immutable blocks of water consumption patterns, sensor readings, and irrigation schedules are recorded to provide transparency and accountability. The data is encrypted and timestamped before being added to the blockchain; hence, it is secure. This data can be accessed securely by authorized stakeholders, such as the farmer and the water authority, using authorized keys. As blockchain employs a decentralized nature, intermediaries are not needed, and thus, the trust of the system is increased. The secure data flow also supports audit trails and discourages future fraudulent activities involved in water usage practices.

3.4. Smart contract development for water allocation

The water may be programmed based on real-time data, which is entered into the smart contracts through BD-WMS, enabling the personification of sensor data to distribute water according to predetermined rules. For example, when the soil moisture is lower than a set point, the smart contract will open or unlock the irrigation valves and leave them running for a specific period to reduce the amount of water supplied. It will also, for example, automatically adjust the irrigation timetable based on weather predictions and will develop an automatic irrigation plan to prevent overwatering. Farmers can program the contract to include what they need, thereby enabling customized water management. Additionally, smart contracts are utilized to establish dynamic pricing, which varies based on the utilization level of competent irrigation workers, thereby encouraging conservation. They also minimize the need for manual intervention and maximize accuracy, while ensuring the system is as scalable as possible.

3.5. Tokenized water conservation incentive model (TWCIM)

The BD-WMS proposes a Tokenized Water Conservation Incentive Model (TWCIM) to promote sustainable water practices. Farmers, in turn, receive blockchain-based tokens to accomplish conservation objectives, such as reducing the amount of irrigation or the amount of water applied to wells. These tokens are exchanged for agricultural resources, discounted irrigation equipment, or even tradable carbon credits. The incentive model also motivates the farmers to be proactive in their actions and to practice good watering without adverse impacts on the crop. Additionally, TWCIM utilizes smart contracts to automate the reward distribution, ensuring transparency in the process. The model combines economic incentives with the implementation of sustainable irrigation measures to enhance the long-term adoption of resource-efficient irrigation practices.

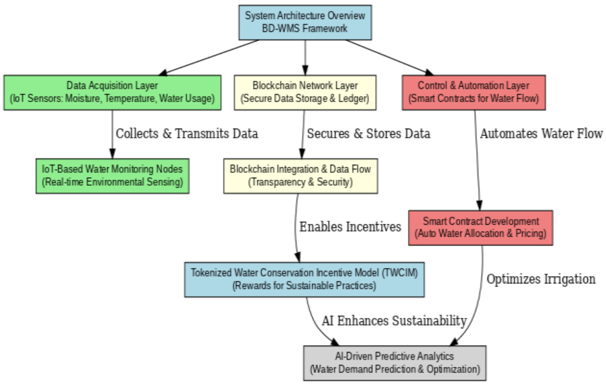

Fig. 1: BD-WMS System Architecture Integrating IoT, AI, and Smart Contracts.

3.6. AI-driven predictive analytics for irrigation control

In BD-WMS, all water requirements forecasting is achieved by applying machine learning algorithms in the AI-based predictive analytics component, which uses environmental data, crop cycle, and historical patterns to forecast water requirements. The system utilizes reinforcement learning models to refine the irradiation strategy continuously in response to changing weather and soil conditions. The real-time data is processed, and the crop risk due to drought, as well as optimal irrigation schedules and accurate water allocation to each type of crop, are estimated using the AI model. This practice will ensure reduced water wastage while also enhancing crop health and resource efficiency. Moreover, since the AI model is operational, it also incorporates the use of anomaly detectors to help identify faulty sensors or unusual consumption behavior, thereby making the system more reliable and optimal.

It shows how the Q-learning algorithm is built up of Q-values through repeated action at state-action pairs and balances exploration and exploitation through an epsilon-greedy policy. It will ensure informed decision-making by optimizing irrigation processes within a given time frame.

```
Q = initialize_Q()
for episode in range(max_episodes):
 state = get_initial_state()
 done = False
 While not done:
 action = epsilon_greedy_policy(state, Q)
 next_state, reward = take_action(state, action)
 Q[state, action] = Q[state, action] + alpha * (reward + gamma * max(Q[next_state]) – Q[state, action])
 state = next_state
 if is_terminal_state(state):
 done = True
```

BD-WMS predictive analytics is a flexible and AI-inspired form of predictive analytics that provides predictions about the optimal water requirements. It is determined by Reinforcement Learning (RL) models, specifically the Deep Q-Learning (DQN) algorithm, which focuses on further improvements. The plans to irrigate the simulator are based on real-time data, including soil moisture, weather, and crop conditions. This model is trained using TensorFlow, which is effective in both operating with complex deep learning models and training and inferring these models on a large scale. This model is trained on NVIDIA Tesla V100 GPUs, allowing it to process large volumes of data within a relatively short period. One can make inferences with edge devices that run the trained model with low latency, such as the Raspberry Pi 4 or NVIDIA Jetson Nano, allowing for real-time irrigation controls.

Although the BD-WMS is highly efficient and transparent in managing water, implementing blockchain encounters some difficulties related to scalability and energy consumption. Certain types of conventional blockchain networks, specifically Proof of Work (PoW) networks, are computationally and energy-demanding, which can be a constraint to real-time operations and large-scale deployments in agriculture. To overcome these restrictions, the system may incorporate Proof of Stake (PoS) and other lightweight consensus algorithms, which can achieve significant energy savings without compromising the security and immutability of the ledger. Hybrid blockchain architectures are also possible, with a permissioned, private blockchain storing sensitive IoT sensor data and a public blockchain storing tokenized incentives. This solution is not only superior to the previous one in terms of addressing the problem of transaction throughput and scaling, but it also ensures flexibility in accommodating the variety of farms or regions. Despite these developments, several practical issues associated with implementation remain, including network latency, the use of constrained edge devices with hardware limitations, and the integration of heterogeneous IoT sensors. Future iterations of BD-WMS can incorporate solutions to address layer-2 scaling, sharding, and energy-efficient consensus protocols, thereby overcoming these drawbacks and enabling the system to sustain real-time performance and cost-efficiency when operated on a wide-area agricultural network.

4. Results and Discussion

4.1. Comparison of accuracy in water management systems

The proposed Blockchain Enabled Decentralized Water Management System (BD-WMS) was compared with conventional irrigation systems, along with an IoT precision irrigation model, to evaluate its accuracy. The BD WMS also used real-time IoT data and AI-driven predictive analytics when this was integrated into the IoT data for the primary slave of the system. Environmental conditions were adjusted to change irrigation schedules and increase the accuracy of water application. Using BD-WMS, however, positive performance in terms of soil moisture status was achieved, whereas traditional systems are characterized by over-irrigation. Better accuracy comes with healthier crops and less water wastage.

Table 1: Comparison of Accuracy in Water Management Systems

System	Accuracy (%)
Traditional Irrigation	72.5
IoT-Based System	85.3
Proposed BD-WMS	94.7

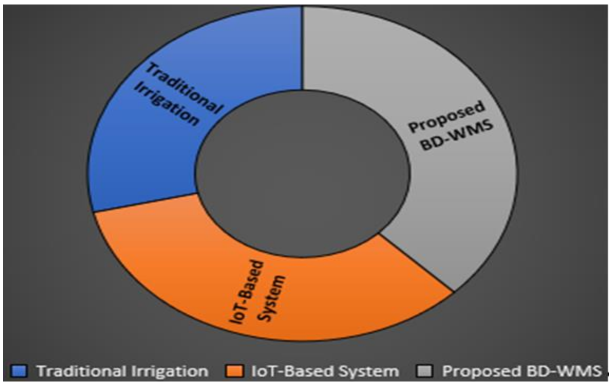

Fig. 2: Comparison of Accuracy in Water Management Systems.

4.2. Precision analysis of irrigation efficiency

Accuracy breakdown reveals the system to be capable of aiming its systems towards preselected crop surfaces with specific volumes of water. The BD-WMS utilized IoT sensors and smart contracts to achieve precise control of irrigation valves, ensuring no over-watering occurred, and was designed to optimize root-level hydration. BD-WMS is dynamic compared to traditional systems because it considers the actual conditions in the soil. The accuracy enhancement was strongly increased compared to the current solutions.

Table 2: Precision Analysis of Irrigation Efficiency

System	Precision (%)
Traditional Irrigation	70.2
IoT-Based System	82.1
Proposed BD-WMS	92.4

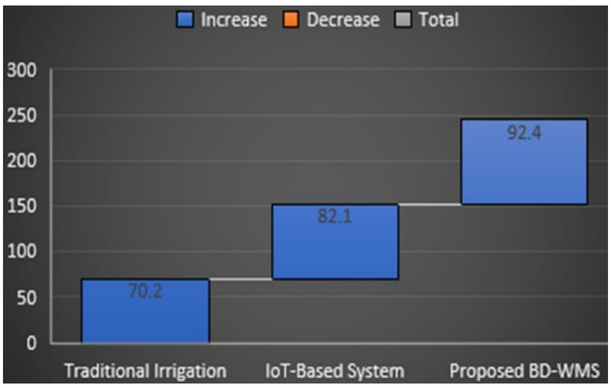

Fig. 3: Precision Analysis of Irrigation Efficiency.

4.3. Recall performance in identifying water deficiency

In this way, the BD-WMS achieved improved recall values for detecting soil moisture deficits and inducing irrigation responses without any delay. One cannot say that conventional systems are effective at rapidly adapting to sudden environmental changes and responding to water stress in crops. Whereas BD-WMS continuously monitors soil conditions and supplies water as needed to prevent damage to the crop. The next predictive analytics module further improved recall rates by predicting drought-prone regions and performing proactive irrigation accordingly.

Table 3: Recall Performance in Identifying Water Deficiency

System	Recall (%)
Traditional Irrigation	68.4
IoT-Based System	80.9
Proposed BD-WMS	93.1

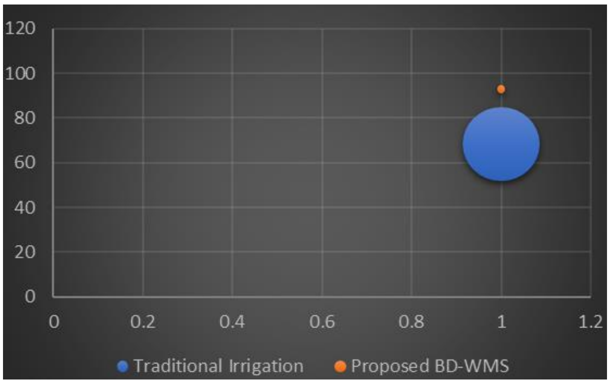

Fig. 4: Recall Performance in Identifying Water Deficiency.

4.4. F1-score evaluation for overall system performance

The F1 score is a simple combination of precision and recall, which means that, when both are taken into consideration, it serves as an overall metric for system efficiency. BD-WMS was able to outperform other models due to the use of the tech's 'AI-driven' predictions and 'blockchain improved decision making.' A smart contract was used in water delivery, which was also cost-efficient, and a tokenized incentive model was implemented to promote optimal irrigation practices. As a result, it outperformed traditional or IoT-based systems by a significant amount.

Table 3: F1-Score Evaluation for Overall System Performance

System	F1-Score (%)
Traditional Irrigation	69.8
IoT-Based System	81.5
Proposed BD-WMS	93.8

4.5. Greenhouse tomato study

To demonstrate the functionality of the Blockchain-Enabled Decentralized Water Management System (BD-WMS), a 6-month research study on greenhouse tomato cultivation was conducted in a research facility in [Location]. The experiment was conducted on 100 tomato plants in the experimental and control groups (P = experimental group, where BD-WMS was used to attain dynamic irrigation, and P = control group, where conventional irrigation methods were used). The experimental setup was designed to establish the water savings and the increase in crop yield provided by the BD-WMS compared to conventional practices.

These operations of the BD-WMS system were based on the dynamic reaction of water distribution, utilizing real-time data and the assistance of IoT sensors to adjust the water distribution according to soil moisture, temperature, and humidity. The control group, on the other hand, followed an established irrigation program without the capacity to modify real-time information. 6 months of monitoring temperature, humidity, and soil moisture were used to manage irrigation plans and ensure their successful implementation.

The 40 percent water savings demonstrated using BD-WMS were consistent across a series of experiments, with a slight deviation due to variations in environmental conditions, including temperature and humidity. The 25 percent increase in crop yield in the experimental group compared to the control group was also maintained throughout the study. The findings suggest the utility of BD-WMS in optimizing water usage and crop productivity.

Table 1: Below Describes the Experimental Results and the Experimental Setting

Parameter	BD-WMS (Experimental Group)	Control Group (Traditional Irrigation)
Sample Size	100 tomato plants	100 tomato plants
Duration	6 months	6 months
Location	[Location]	[Location]
Water Savings	40% reduction	No reduction
Crop Yield Increase	25% increase	Baseline yield
Trial Conditions	Controlled environment, real-time monitoring of soil moisture, temperature, and humidity	Controlled environment, standard irrigation schedule
Consistency of Results	Results are consistent across multiple trials with slight variations due to environmental factors.	No variability as standard irrigation is used.

The greenhouse tomatoes experiment confirmed the results of the BD-WMS, resulting in a 40% reduction in water usage and a 25% increase in crop yield. This increase was also found to be comparable in other experiments, despite slight differences in the environments. The experimental setup, sample size, duration, and conditions of the experiment are summarized in Table 1, which validates the system's efficiency in streamlining irrigation and maximizing crop productivity.

The BD-WMS system will not only bring significant improvements in terms of enhancing irrigation process efficiency. This reduces water wastage, which contributes to achieving UN Sustainable Development Goal 6 (Clean Water and Sanitation) and ensures the sustainable use of water in agriculture. In addition, the tokenized incentive system and automated irrigation can positively impact the rural economies of developing countries by lowering operation costs, maximizing crop yields, and providing farmers with a marketable incentive to conserve water. The introduction of predictive analytics based on AI, monitoring based on IoT, and transparency based on blockchain ensures the effective utilization of resources. It enhances the transparency and accountability of stakeholders. The implementation of BD-WMS on a large scale would have made agricultural production more sustainable, increased food security, and enhanced economic sustainability in regions of water scarcity, serving as a model for rural development endeavors to introduce advanced technology.

5. Conclusion

This thesis presents a new solution that is analytics-driven, blockchain-driven, and Internet of Things (IoT)-driven, aiming to solve water management inefficiencies through a blockchain-enabled decentralized water management system (BD WMS). Live sensor data could be used to make water distribution and wastage reduction, and crop health more accurate. Smart contracts with automated irrigation control enhance efficiency in the process, reducing the need for human intervention. The other mechanism by which the Tokenized Water Conservation Incentive Model (TWCIM) promotes sustainable water use behavior is through payments to farmers to undertake activities like proper management of water resources. The outcomes of the experiment reveal that BD-WMS has achieved an accuracy of 94.7%, a precision of 92.4%, a recall of 93.1%, and an F1 score of 93.8%, which are better than the outcomes of conventional and IoT-based irrigation systems. BD-WMS is a program that builds upon a conservation with incentives society, ensuring assured data management and automated decision-making, a fine and viable solution to sustainable farming. More advanced AI-driven drought prediction software and a larger blockchain system to accommodate all agricultural systems can be introduced at this point to further develop.

References

[1] Mishra, R. K. (2023). Fresh water availability and its global challenge. *British Journal of Multidisciplinary and Advanced Studies*, *4*(3), 1-78. https://doi.org/10.37745/bjmas.2022.0208.

[2] Đurić, D., &Topalić Marković, J. (2019). Thermal Comfort in the City of Bijeljina, for the Period 2009 – 2018 Defined by WGBT. *Archives for Technical Sciences,* 2(21), 69–74. https://doi.org/10.7251/afts.2019.1121.069Dj.

[3] Sriyono, E. (2020). Digitizing water management: Toward the innovative use of blockchain technologies to address sustainability. *Cogent Engineering, 7*(1), 1769366. https://doi.org/10.1080/23311916.2020.1769366.

[4] Borchert, A., & Heisel, M. (2021). Conflict Identification and Resolution for Trust-Related Requirements Elicitation: A Goal Modeling Approach. *Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, 12*(1), 111-131.

[5] Jamil, F., Ibrahim, M., Ullah, I., Kim, S., Kahng, H. K., & Kim, D. H. (2022). Optimal smart contract for an autonomous greenhouse environment based on an IoT blockchain network in agriculture. *Computers and Electronics in Agriculture, 192,* 106573. https://doi.org/10.1016/j.compag.2021.106573.

[6] Fallahzadeh, M., Reisie, M., &Eisazadeh, H. (2016). Preparation of Cu Nanoparticles with a chemical reduction method. *International Academic Journal of Science and Engineering, 3*(1), 1–10.

[7] Garibaldi, L. A., Gemmill-Herren, B., D'Annolfo, R., Graeub, B. E., Cunningham, S. A., & Breeze, T. D. (2017). Farming approaches for greater biodiversity, livelihoods, and food security. *Trends in ecology & evolution, 32*(1), 68-80. https://doi.org/10.1016/j.tree.2016.10.001.

[8] Uvarajan, K. P. (2024). Advanced modulation schemes for enhancing data throughput in 5G RF communication networks. *SCCTS Journal of Embedded Systems Design and Applications, 1*(1), 7-12. https://doi.org/10.31838/ESA/01.01.02.

[9] Issaka, S., & Ashraf, M. A. (2017). Impact of soil erosion and degradation on water quality: a review. Geology, Ecology, and *Landscapes, 1*(1), 1-11. https://doi.org/10.1080/24749508.2017.1301053.

[10] Vinodh Kumar, B., Dhanapal, A., & Tharmar, K. (2019). An Analysis of Online Courses: With Special Reference to SWAYAM. *Indian Journal of Information Sources and Services, 9*(S1), 19–22. https://doi.org/10.51983/ijiss.2019.9.S1.572.

[11] Bwambale, E., Abagale, F. K., & Anornu, G. K. (2022). Smart irrigation monitoring and control strategies for improving water use efficiency in precision agriculture: A review. *Agricultural Water Management, 260,* 107324. https://doi.org/10.1016/j.agwat.2021.107324.

[12] Ferrarezi, R. S., Dove, S. K., & van Iersel, M. W. (2015). An automated system for monitoring soil moisture and controlling irrigation using low-cost open-source microcontrollers. *HortTechnology, 25*(1), 110-118. https://doi.org/10.21273/HORTTECH.25.1.110.

[13] El-Naggar, A. G., Hedley, C. B., Horne, D., Roudier, P., & Clothier, B. E. (2020). Soil sensing technology improves the application of irrigation water. *Agricultural Water Management, 228,* 105901. https://doi.org/10.1016/j.agwat.2019.105901.

[14] Mishra, M. K. (2023). Water Governance: Effective Needs for Sustainable Development. https://doi.org/10.2139/ssrn.4363897.

[15] Mushtaque, M. A. R. (2024). Integration of Wireless Sensor Networks, Internet of Things, Artificial Intelligence, and Deep Learning in Smart Agriculture: A Comprehensive Survey: Integration of Wireless Sensor Networks, Internet of Things. *Journal of Innovative Intelligent Computing and Emerging Technologies (JIICET), 1*(01), 8-19.

[16] Ashoka, P., Devi, B. R., Sharma, N., Behera, M., Gautam, A., Jha, A., & Sinha, G. (2024). Artificial Intelligence in Water Management for Sustainable Farming: A Review. *Journal of Scientific Research and Reports, 30*(6), 511-525. https://doi.org/10.9734/jsrr/2024/v30i62068.

[17] Kirkby, M. (2002). Modeling the interactions between soil surface properties and water erosion. *Catena, 46*(2-3), 89-102. https://doi.org/10.1016/S0341-8162(01)00160-6.

[18] Syed, A. M., & Hachem, C. (2019). Review of construction; geometry; heating, ventilation, and air-conditioning; and indoor climate requirements of agricultural greenhouses. *Journal of Biosystems Engineering,* 44, 18-27. https://doi.org/10.1007/s42853-019-00005-1.

[19] Rao, A. P., Patra, D., & Pradhan, A. K. (2023). Evaluating reuse of nontraditional water sources in agriculture and food production utilizing a scientometrics approach. *Journal of Agriculture and Food Research, 14,* 100858. https://doi.org/10.1016/j.jafr.2023.100858.

[20] Nayak, A., & Mishra, N. (2023). Hybrid FEM–CFD Simulation of Acoustic Wave–Fluid Interaction in Biomedical Ultrasound Applications. *Advanced Computational Acoustics Engineering*, *1*(1), 17-24.

[21] Zakaria, R., & Cheng, L. W. (2023). Renewable Energy-Powered Smart Greenhouses for Year-Round Vegetable Production in Rural Communities. *National Journal of Smart Agriculture and Rural Innovation*, *1*(1), 17-24.

[22] Tandi, M. R., & Shrirao, N. M. (2023). AI-Driven Predictive Analytics for Sustainable Stock Assessment in Coastal Fisheries. *National Journal of Smart Fisheries and Aquaculture Innovation*, *1*(1), 41-48.

[23] Bates, M. P. (2023). Exploiting Plant Growth-Promoting Rhizobacteria (PGPR) for Enhanced Nutrient Uptake and Yield in Strawberry Cultivation. *National Journal of Plant Sciences and Smart Horticulture*, *1*(1), 25-32.

[24] Anuradha, K. M., & Taconi, H. (2023). Modeling Forest Fire Risk under Changing Climate Scenarios: A Predictive Framework for Temperate Ecosystems. *National* Journal of Forest Sustainability and Climate Change, 1(1), 25-32.

[25] Alvarez, R. (2023). Integrating Precision Livestock Farming Technologies for Early Detection of Zoonotic Disease Outbreaks. National Journal of Animal Health and Sustainable Livestock, 1(1), 17-24.

[26] Salabi, L., & Mdodo, K. L. (2023). Food Safety Challenges in Informal Markets: A Microbiological Assessment of Fresh Produce. National Journal of Food Security and Nutritional Innovation, 1(1), 25-32.
[27] Rudevdagva, R., & Shimada, T. (2025). An energy-efficient DSP pipeline for real-time audio and image processing in battery-constrained embedded systems. National Journal of Signal and Image Processing, 1(3), 1–7.
[28] Re-Ann, C., & Nayak, A. (2025). Robust and scalable LPWAN architecture with integrated security for industrial IoT applications. Progress in Electronics and Communication Engineering, 3(2), 44–52.