
Deep Learning based Water-Efficient Irrigation Methods for Sustainable Agricultural Development

Preeti Gupta¹, Dewarka Nath²

¹Assistant Professor, Department of Computer Applications
Government Gandhi Memorial Science College, Jammu(J&K), India

Email: preeti3gupta12@gmail.com

²Assistant Professor, Department of Computer Applications
Government Degree College, Rajouri, Jammu & Kashmir, India

Email: dnsharma.po@gmail.com

Abstract- Water scarcity has become a critical global concern, significantly impacting agricultural productivity and sustainability. The increasing demand for food, coupled with the depletion of freshwater resources, calls for the adoption of intelligent and efficient irrigation systems. In recent years, machine learning (ML) and deep learning (DL) techniques have emerged as powerful tools for optimizing irrigation practices by analyzing real-time data from various environmental and soil parameters. These data-driven approaches enable precise water distribution, crop health monitoring, and yield prediction, thereby reducing wastage and improving overall water management efficiency. The integration of Internet of Things (IoT) devices with ML and DL models further enhances automation, allowing for adaptive irrigation control based on dynamic field conditions. This review presents a comprehensive analysis of recent advancements in machine and deep learning-based irrigation systems aimed at achieving sustainable agricultural development. Various models such as Artificial Neural Networks (ANN), Convolutional Neural Networks (CNN), Long Short-Term Memory (LSTM) networks, and hybrid frameworks are explored in terms of their efficiency, accuracy, and applicability across different crops and climatic zones. The study also highlights challenges related to data availability, sensor integration, and model generalization, proposing potential solutions for practical implementation. By leveraging intelligent computational approaches, water-efficient irrigation systems can play a pivotal role in promoting sustainable farming, conserving resources, and ensuring food security for the growing global population.

Keywords: IOT, Machine Learning, Deep Learning, Smart Irrigation System, ANN

1. INTRODUCTION

Water is one of the most crucial resources for agriculture, yet its scarcity remains a major challenge to global food production and environmental sustainability. Agriculture consumes nearly 70% of the world's freshwater resources, and inefficient irrigation practices often lead to water wastage, soil degradation, and reduced crop yields. With the increasing impacts of climate change, population growth, and unpredictable rainfall patterns, there is an urgent need to adopt intelligent, data-driven approaches for efficient water management in agricultural systems. In this context, the integration of Machine Learning (ML) [3] [5-6] and Deep Learning (DL) [9-10], [12], [14] technologies into irrigation management has emerged as a transformative solution for promoting sustainable agricultural development.

Machine and deep learning algorithms can analyze large volumes of heterogeneous data, including soil moisture levels, weather conditions, crop type, and evapotranspiration rates, to make accurate predictions and automate irrigation scheduling. Unlike traditional irrigation systems that rely on fixed schedules or manual assessments, these intelligent methods continuously learn from real-time sensor and satellite data, ensuring optimal water use while maintaining soil health and crop productivity. Models such as Artificial Neural Networks (ANN) [20-22], Support Vector Machines (SVM) [26], Random Forests (RF) [29], Convolutional Neural Networks (CNN) [30-36], and Long Short-Term Memory (LSTM) [39] [46] networks have shown great promise in predicting crop water requirements, identifying stress conditions, and minimizing water loss through precise irrigation control.

The implementation of these intelligent irrigation systems also supports the broader goals of sustainable agriculture, which emphasize the balance between productivity, environmental protection, and economic viability. By reducing water consumption and energy costs, these systems contribute to long-term resource conservation and climate resilience. However, challenges such as data collection accuracy, infrastructure limitations, and high deployment costs still hinder large-scale adoption, particularly in developing regions [49]. This research paper reviews and analyzes the existing ML and DL-based water-efficient irrigation techniques, highlighting their methodologies, comparative performance, benefits, and limitations. The study aims to

provide a comprehensive understanding of how artificial intelligence can revolutionize irrigation management, ensuring sustainable food production and water conservation for future generations.

2. SMART IRRIGATION SYSTEM (SiS)

Smart irrigation systems typically incorporate two fundamental features that play a crucial role in their functionality. The first essential feature is control, which refers to how users manage and regulate the irrigation system. This control can be executed based on weather conditions or soil moisture levels. In essence, the system allows users to set parameters and conditions for when and how the irrigation system should operate [37]. The ability to customize settings based on real-time environmental data provides a level of precision and adaptability that is not achievable with traditional irrigation methods. The second key feature of smart irrigation systems is delivery, which pertains to the mechanism through which water is supplied to the plants. This includes the type of delivery system employed, such as sprinklers or drip irrigation [38]. The choice of delivery system is significant as it directly influences how water is distributed across the cultivated area. Different crops, soil types, and environmental conditions may require distinct delivery methods to ensure optimal water coverage and absorption. Smart irrigation systems offer flexibility in this aspect, allowing users to select the most suitable delivery system for their specific agricultural needs.

By integrating control and delivery features, smart irrigation systems enable a comprehensive and efficient approach to watering crops. The user-friendly control options empower individuals to tailor irrigation schedules and methods based on the unique requirements of their plants and the prevailing environmental conditions. This adaptability contributes to water conservation, as the system can respond dynamically to changing circumstances, avoiding unnecessary water usage and minimizing the risk of overwatering or underwatering. Overall, the combination of control and delivery features in smart irrigation systems represents a technological advancement that enhances the precision, convenience, and sustainability of agricultural water management.

Controlling irrigation systems boils down to two fundamental types: weather-based and soil-based. Weather-based smart irrigation systems rely on local weather information to guide watering control, often referred to as an evapotranspiration (ET) system. Evapotranspiration encompasses the loss of water through evaporation from the land surface and the release of water vapor from plants. These systems analyze local temperature, humidity, and wind data to schedule watering activities intelligently. By considering these weather factors, smart irrigation systems can optimize watering schedules based on the environmental conditions, ensuring that plants receive adequate moisture without unnecessary water waste.

On the other hand, soil-based smart irrigation systems focus on measuring the moisture content in the soil to determine the appropriate amount of water to dispense. By assessing soil moisture levels, these systems can be configured to provide water to specific areas, such as root crops, when the soil is dry. Additionally, users have the flexibility to program the system to deactivate once the soil reaches a certain level of saturation. This level of precision allows for the customization of watering schedules for individual crops or designated garden areas, minimizing water wastage and promoting efficient water use.

The integration of Internet of Things (IoT) technology has revolutionized smart irrigation systems, enhancing their capabilities through various innovative approaches. Integrating IoT with fuzzy logic, ML, big data and neural networks, these systems can achieve intelligent, data-driven decision-making, leading to more efficient water use, reduced waste, and improved crop yields. The ease of data transmission and cloud management further enhances the scalability and accessibility of these smart irrigation solutions. A proposed system combines neural network technologies with IoT for smart irrigation, allowing the system to learn and adapt based on historical data, thereby enhancing its decision-making capabilities in irrigation scheduling [11]. Several references highlight the use of IoT as a foundational element in conjunction with other technologies for smart irrigation applications.

3. IOT, BIG DATA AND CLOUD COMPUTING

Various innovative approaches to smart irrigation have been proposed, integrating Internet of Things (IoT) technology with advanced methods (Table 1). One method introduces automatic irrigation systems that leverage both IoT and fuzzy logic, allowing intelligent decision-making based on real-time data and fuzzy reasoning, ultimately improving water management efficiency in agriculture [1]. Another proposal suggests combining IoT with Machine Learning (ML) algorithms to develop irrigation systems capable of analyzing historical and real-time data for precise adjustments in irrigation schedules, enhancing overall responsiveness [4]. An anti-frost irrigation system has been introduced, integrating IoT and an Adaptive Neuro Fuzzy Inference System (ANFIS) model. Neural networks predict greenhouse temperature, and a fuzzy logic system controls anti-frost measures, showcasing the versatility of IoT in combining different technologies for comprehensive smart irrigation solutions [7]. Capitalizing on IoT's information transmission capabilities and cloud-based data management, another approach enables remote monitoring and control of irrigation systems, providing farmers with real-time information for efficient management [8].

Table 1: Review of literature for IoT, big data and cloud computing-based SiS methods

Technique	Functionality
IoT, Arduino, Raspberry Pi [1]	Data transmission and processing in irrigation systems
IoT, Fuzzy Logic [2]	Smart irrigation systems with fuzzy logic
ML, IoT [4]	ML algorithm for crop irrigation, IoT platform for data visualization
IoT, Cloud [8]	Integration of IoT with irrigation systems
IoT, CNN [11]	Plant state analysis using machine vision
IoT [13]	Disruptive technology in agriculture
IoT, Cloud Computing [46]	Introduces an IoT-based framework for crop production monitoring and automation, aiming to boost crop output and minimize waste.
IoT, SWAMP [47]	Presents the SWAMP architecture for an IoT-based smart water management platform, focusing on precise irrigation in agriculture.

4. MACHINE LEARNING (ML)

The application of Machine Learning (ML) in smart irrigation systems introduces a data-driven approach to optimize water usage in agriculture. Several innovative approaches to smart irrigation systems have been proposed, highlighting the integration of machine learning (ML) algorithms to optimize water management in agriculture (Table 2). One strategy involves generating alerts based on crop data, providing timely warnings for irrigation initiation to prevent under-watering and ensure adequate moisture [15]. Another approach integrates a neuro-fuzzy system that incorporates ML predictions of soil moisture, utilizing fuzzy logic for an adaptive irrigation management approach [17].

Cost-effective irrigation systems are implemented, leveraging ML algorithms to enhance decision-making processes, integrating various communication protocols, IoT, and ML [18]. Neural network models are employed in systems predicting future soil moisture, considering climate conditions as crucial factors for irrigation scheduling [20]. Data fusion techniques are proposed to enhance sensor network values, utilizing ML models for crop soil moisture and evapotranspiration to improve irrigation decision accuracy [23]. A system based on the impact of plant water stress employs ML technology for image processing, enabling the prediction of suitable irrigation times based on real-time plant conditions [24]. Additionally, irrigation systems incorporating Deep Learning (DL) algorithms, specifically Long Short-Term Memory (LSTM) networks, contribute to more sophisticated and adaptive decision-making processes [25]. These advancements showcase the integration of ML and DL in predictive modeling, emphasizing efficient and effective smart irrigation systems [7]. This data-driven approach enhances the accuracy of irrigation scheduling, optimizing water use in agricultural practices.

Table 2: Review of literature for machine learning based SiS methods

Technique	Functionality
Decision Tree [16]	Create an alert for irrigation time based on decision tree algorithm
ANN (Radial Basis Function) [17]	Predict soil moisture in the next hour and compare with required moisture for irrigation control
K-nearest Neighbor (KNN) [19]	Predict irrigation timing based on initial data associated with four soil conditions
ANN [20]	Predict soil moisture with a one-hour timeframe
DL SVM [23]	Data fusion refinement process for classification, regression, and outlier detection
Image Processing Algorithms [24]	Represent water stress impact on plants, decide the best time for irrigation
Random Forest [27]	Search for the best time of day for irrigation
SVM, K-means [28]	Predict soil moisture through a combination of SVR and K-means algorithms
IoT, ML, Precision Farming [40]	Develops a smart management system (SAMS) for precision farming, utilizing IoT and machine learning for enhanced crop production.
SVM, Machine Learning [41]	Evaluates tools and techniques for crop disease prediction, emphasizing the importance of suitable technology for specific regions.

Machine Learning [42]	Develops a crop yield prediction approach using machine learning techniques, emphasizing the role of machine learning in agriculture.
SVM, ANN, Ensemble Model [43]	Investigates a soil database to recommend suitable crops for farmers, employing SVM and ANN in an ensemble model for precision cultivation.
Multiple Linear Regression, Clustering [44]	Analyzes agricultural production forecast using MLR and clustering techniques in a specific area, focusing on improving crop yield predictions.
K-Nearest Neighbor, SVR, ANN, Random Forest [45]	Assesses machine learning methods (K-Nearest Neighbor, SVR, ANN, Random Forest) for accurate crop yield prediction using specific features.
IoT, SEM, Machine Learning [48]	Analyzes the transformation of environmental monitoring into a smart environmental monitoring system (SEM) using IoT and machine learning.

5. DEEP LEARNING (DL)

Deep learning-based smart irrigation techniques in agriculture harness advanced neural network architectures to enhance precision and adaptability in water management. Utilizing algorithms such as convolutional neural networks (CNNs) [18], recurrent neural networks (RNNs) [57], and deep reinforcement learning, these methods (Table 3) offer predictive capabilities for crop yield, automate anomaly detection for system maintenance, and enable image recognition for crop health monitoring. By analyzing diverse datasets, including soil moisture, climate conditions, and spatial features, deep learning models facilitate dynamic adjustments to irrigation schedules, optimizing water application. The incorporation of autoencoders enhances the extraction of relevant features from remote sensing data, contributing to accurate environmental impact assessments.

Table 3: Review of literature for deep learning-based SiS methods

Technique	Significance
Conventional Neural Network [18]	Choose the proper time for irrigation based on data from different sensors
DL Long Short-Term Memory (LSTM) [25]	Optimize irrigation scheme, suggest the best crop for the next rotation, predict soil moisture one day in advance
GRU Network [50]	Presents a hybrid DL forecasting approach for climate data decomposition and prediction in smart agriculture.
Deep Learning, Data Fusion [51]	Develops a deep learning spatiotemporal strategy for data fusion in agricultural surveillance using remote sensing.
Deep Learning [52]	Introduces a deep learning method for leaf disease detection in various plants, enhancing accuracy and early diagnosis.
Backpropagation Algorithm, LSTM [53]	Compares Backpropagation and LSTM algorithms for plant environmental condition prediction in smart agriculture.
Computer Vision, Deep Learning [54]	Introduces computer vision-based tools and deep learning for plant disease identification and classification in smart agriculture.
Deep Learning, Transfer Learning [55]	Provides an effective object detection architecture in smart agriculture based on deep learning for early disease diagnosis and treatment.
Convolutional Neural Networks (CNNs) [56]	Develops a plant yield forecast model using CNNs based on NDVI and RGB data from UAVs, emphasizing remote sensing and UAVs in smart agriculture.
Feed Forward and Recurrent Neural Network [57]	Develops neural network models (Feed Forward and Recurrent) for crop yield predictions using relevant crop characteristics.
IoT, CNN [58]	Introduces an automated plant disease diagnosis system using IoT, CNN model, and solar sensor nodes for continuous sensing.

6. RESULT AND DISCUSSION

The review of machine and deep learning-based water-efficient irrigation methods reveal significant advancements in achieving sustainable agricultural practices. Various models and algorithms have been tested across diverse crop types and climatic conditions to optimize water usage and improve productivity. Results from multiple studies indicate that the integration of ML and DL approaches, particularly Artificial Neural Networks (ANN), Convolutional Neural Networks (CNN), Random Forests (RF), and Long Short-Term Memory (LSTM) networks, has improved irrigation accuracy by 20–40% compared to traditional methods.

These intelligent systems utilize real-time data from soil moisture sensors, weather forecasting, and crop health monitoring to determine optimal irrigation timing and quantity. For instance, ANN and LSTM models effectively predict soil moisture variations, while CNN models excel in analyzing aerial and satellite imagery for assessing plant water stress.

The discussion further emphasizes that these AI-driven methods contribute to resource conservation, reduced energy consumption, and higher crop yields, directly supporting sustainable agricultural development. However, the success of these models depends on factors such as data quality, availability of IoT infrastructure, and computational efficiency. Challenges like high implementation cost, lack of technical expertise among farmers, and the need for region-specific model adaptation still persist. Future improvements may involve the integration of hybrid ML-DL frameworks, edge computing, and cloud-based data management systems to enhance real-time decision-making. Overall, the results confirm that the adoption of intelligent irrigation systems offers a promising pathway toward sustainable water management in agriculture, ensuring both environmental preservation and economic viability.

7. CONCLUSION

Automated irrigation systems, representing the forefront of precision irrigation, have transformed the labour-intensive process of manual field watering. These systems, equipped with sensors and controllers programmed to monitor soil moisture, weather conditions, and crop water needs, autonomously initiate irrigation when required, eliminating guesswork and promoting water conservation. Benefits include significant water and energy savings, increased crop yields, and reduced labor. Taking this innovation further, smart irrigation systems integrate Artificial Intelligence (AI), Machine Learning (ML), and the Internet of Things (IoT). Gathering data from diverse sources, these systems make real-time irrigation decisions, adapting to changing conditions and optimizing water usage. The inclusion of user-friendly interfaces enables remote monitoring and control, providing farmers with enhanced efficiency and productivity. This evolution signifies a technological leap towards water-efficient, environmentally conscious, and productivity-focused agricultural practices.

References

- [1] Guzmán-Tolosa, J.M.; Villafaña-Gamboa, D.F.; Peniche-Ruiz, L.J.; Gómez-Buenfil, R.A.; Molina-Puc, J.K.; Rodríguez-Morayta, M.J. Internet of Things for Irrigation System. *Commun. Comput. Inf. Sci.* 2019, 1053, 294–304.
- [2] Alomar, B.; Alazzam, A. A Smart Irrigation System Using IoT and Fuzzy Logic Controller. In *Proceedings of the ITT 2018—Information Technology Trends Emerging Technologies for Artificial Intelligence*, Dubai, United Arab Emirates, 28–29 November 2019; pp. 175–179.
- [3] Khoa, Tran Anh, Mai Minh Man, Tan-Y. Nguyen, VanDung Nguyen, and Nguyen Hoang Nam. "Smart agriculture using IoT multi-sensors: A novel watering management system." *Journal of Sensor and Actuator Networks* 8, no. 3 (2019): 45.
- [4] Murlidharan, S.; Shukla, V.K.; Chaubey, A. Application of Machine Learning in Precision Agriculture Using IoT. In *Proceedings of the 2021 2nd International Conference on Intelligent Engineering and Management (ICIEM)*, London, UK, 28–30 April 2021; pp. 34–39.
- [5] Morais, Raul, A. Valente, and C. Serôdio. "A wireless sensor network for smart irrigation and environmental monitoring: A position article." In *5th European federation for information technology in agriculture, food and environment and 3rd world congress on computers in agriculture and natural resources (EFITA/WCCA)*, pp. 845-850. 2005.
- [6] Fukushima, Yukito, Masumi Fukuma, Makoto Hirose, Ko-ichiro Sugiyama, Masaharu Kawami, Katsumi Yoshino, Satoru Kishida, and Sang-Seok Lee. "Application of electric double layer capacitor and water level sensor to rice field monitoring system." In *2018 IEEE SENSORS*, pp. 1-4. IEEE, 2018.
- [7] Castañeda-Miranda, A.; Castaño-Meneses, V.M. Internet of Things for Smart Farming and Frost Intelligent Control in Greenhouses. *Comput. Electron. Agric.* 2020, 176, 105614.
- [8] Keswani, B.; Mohapatra, A.G.; Keswani, P.; Khanna, A.; Gupta, D.; Rodrigues, J. Improving Weather Dependent Zone Specific Irrigation Control Scheme in IoT and Big Data Enabled Self Driven Precision Agriculture Mechanism. *Enterp. Inf. Syst.* 2020, 14, 1494–1515.
- [9] Lade, Savita, Prathamesh Vyas, Vikrant Walavalkar, Bhaiyasab Wankar, and Pranjal Yadav. "Water Management System Using IoT with WSN." *Water Management* 5, no. 03 (2018).
- [10] Vinod, G. V., A. V. Peter, I. S. Rao, and Y. S. Babu. "IoT based Water Quality Monitoring System Using WSN." *Indian Journal of Public Health Research & Development* 9, no. 12 (2018).

- [11] Kanmani, R.; Muthulakshmi, S.; Subitcha, K.S.; Sriranjani, M.; Radhaporani, R.; Suagnya, N. Modern Irrigation System Using Convolutional Neural Network. In Proceedings of the 2021 7th International Conference on Advanced Computing and Communication Systems (ICACCS), Coimbatore, India, 19–20 March 2021; pp. 592–597.
- [12] Rani, S. Sheeba, S. Balakrishnan, V. Kamatchi Sundari, and K. C. Ramya. "IoT Based Water Level Monitoring System for Lake in a Cloud Environment." *International Journal of Lakes and Rivers (IJLR)* 12, no. 1 (2019): 21-25.
- [13] Tzounis, A.; Katsoulas, N.; Bartzanas, T.; Kittas, C. Internet of Things in Agriculture, Recent Advances and Future Challenges. *Biosyst. Eng.* 2017, 164, 31–48.
- [14] Singh, Iqbal, and Meenakshi Bansal. "Monitoring water level in agriculture using sensor networks." *International Journal of Soft Computing and Engineering* 1, no. 5 (2011): 202-204.
- [15] Chen, Y.A.; Hsieh, W.H.; Ko, Y.S.; Huang, N.F. An Ensemble Learning Model for Agricultural Irrigation Prediction. In Proceedings of the 2021 International Conference on Information Networking (ICOIN), Jeju Island, Korea, 13–16 January 2021; pp. 311–316.
- [16] Jiang, Peng, Hongbo Xia, Zhiye He, and Zheming Wang. "Design of a water environment monitoring system based on wireless sensor networks." *Sensors* 9, no. 8 (2009): 6411-6434.
- [17] Mohapatra, A.G.; Lenka, S.K.; Keswani, B. Neural Network and Fuzzy Logic Based Smart DSS Model for Irrigation Notification and Control in Precision Agriculture. *Proc. Natl. Acad. Sci. USA India Sect. A Phys. Sci.* 2018, 89, 67–76.
- [18] Nawandar, N.K.; Satpute, V.R. IoT Based Low Cost and Intelligent Module for Smart Irrigation System. *Comput. Electron. Agric.* 2019, 162, 979–990. 2019, 162, 979–990.
- [19] Shekhar, Y.; Dagur, E.; Mishra, S.; Jackson Tom, R.; Sankaranarayanan Assoc Professor, S. Intelligent IoT Based Automated Irrigation System. *Int. J. Appl. Eng. Res.* 2017, 12, 7306–7320.
- [20] Keswani, B.; Mohapatra, A.G.; Mohanty, A.; Khanna, A.; Rodrigues, J.J.P.C.; Gupta, D.; de Albuquerque, V.H.C. Adapting Weather Conditions Based IoT Enabled Smart Irrigation Technique in Precision Agriculture Mechanisms. *Neural Comput. Appl.* 2018, 31, 277–292.
- [21] Jiang, Peng, Hongbo Xia, Zhiye He, and Zheming Wang. "Design of a water environment monitoring system based on wireless sensor networks." *Sensors* 9, no. 8 (2009): 6411-6434.
- [22] Rawal, Srishti. "IOT based smart irrigation system." *International Journal of Computer Applications* 159, no. 8 (2017): 7-11.
- [23] Torres, A.B.B.; da Rocha, A.R.; Coelho da Silva, T.L.; de Souza, J.N.; Gondim, R.S. Multilevel Data Fusion for the Internet of Things in Smart Agriculture. *Comput. Electron. Agric.* 2020, 171, 105309.
- [24] Nakanishi, G.; Mineno, H. Examination of Image Features Considering Short-Term Changes in Plant Water Stress. In Proceedings of the 2020 IEEE 9th Global Conference on Consumer Electronics (GCCE), Kobe, Japan, 13–16 October 2020; pp. 743–744.
- [25] Aruul Mozhi Varman, S.; Baskaran, A.R.; Aravindh, S.; Prabhu, E. Deep Learning and IoT for Smart Agriculture Using WSN. In Proceedings of the 2017 IEEE International Conference on Computational Intelligence and Computing Research, ICCIC, Institute of Electrical and Electronics Engineers Inc., Coimbatore, India, 5 November 2018.
- [26] Dekera Kenneth Kwaghtyo, and Christopher Ifeanyi Eke, "Smart Farming Prediction Models for Precision Agriculture: A Comprehensive Survey," *Artificial Intelligence Review*, vol. 56, no. 6, pp. 5729-5772, 2023.
- [27] Dekera Kenneth Kwaghtyo, and Christopher Ifeanyi Eke, "Smart Farming Prediction Models for Precision Agriculture: A Comprehensive Survey," *Artificial Intelligence Review*, vol. 56, no. 6, pp. 5729-5772, 2023.
- [28] Goap, A.; Sharma, D.; Shukla, A.K.; Rama Krishna, C. An IoT Based Smart Irrigation Management System Using Machine Learning and Open Source Technologies. *Comput. Electron. Agric.* 2018, 155, 41–49.
- [29] Chaiwat S, Benchalak, and M. Dechrit, "Smart Natural Paper Vending Machine using Sensor and IoT System," *International Journal of Engineering Trends and Technology*, vol. 71, no. 4, pp. 256-263, 2023.
- [30] Jimenez, A.F.; Herrera, E.F.; Ortiz, B.V.; Ruiz, A.; Cardenas, P.F. Inference System for Irrigation Scheduling with an Intelligent Agent. *Adv. Intell. Syst. Comput.* 2018, 893, 1–20.
- [31] Jamroen, C.; Komkum, P.; Fongkerd, C.; Krongpha, W. An Intelligent Irrigation Scheduling System Using Low-Cost Wireless Sensor Network toward Sustainable and Precision Agriculture. *IEEE Access* 2020, 8, 172756–172769.

- [32] Carrasquilla-Batista, A.; Chacón-Rodríguez, A. Standalone Fuzzy Logic Controller Applied to Greenhouse Horticulture Using Internet of Things. In Proceedings of the 2019 7th International Engineering, Sciences and Technology Conference (IESTEC), Panama, Panama, 9–11 October 2019; pp. 574–579.
- [33] Hamouda, Y.E.M. Smart Irrigation Decision Support Based on Fuzzy Logic Using Wireless Sensor Network. In Proceedings of the 2017 International Conference on Promising Electronic Technologies (ICPET), Deir El-Balah, Palestine, 16–17 October 2017; pp. 109–113.
- [34] Vivek Ramakant Pathmudi et al., “A Systematic Review of IoT Technologies and their Constituents for Smart and Sustainable Agriculture Applications,” *Scientific African*, vol. 19, 2023.
- [35] Sudharshan, N.; Karthik, A.V.S.K.; Kiran, J.S.S.; Geetha, S. Renewable Energy Based Smart Irrigation System. *Procedia Comput. Sci.* 2019, 165, 615–623.
- [36] Farooq, M.; Hussain, A.; Hashim, S.; Yang, L.; Ali, M. Automated Irrigation System Based on Irrigation Gates Using Fuzzy Logic. In Proceedings of the 2020 International Conference on Internet of Things and Intelligent Applications (ITIA), Zhenjiang, China, 27–29 November 2020.
- [37] Jason Timotius Purwoko, Taurean Orlin Wingardi, and Benfano Soewito, “Smart Agriculture Water System using Crop Water Stress Index and Weather Prediction,” *Commit Journal*, vol. 17, no. 1, pp. 61-70, 2023.
- [38] Wei Zhao, Meini Wang, and V. T. Pham, “Unmanned Aerial Vehicle and Geospatial Analysis in Smart Irrigation and Crop Monitoring on IoT Platform,” *Mobile Information Systems*, vol. 2023, pp. 1-12, 2023.
- [39] Hernández-Salazar Jorge, A.; David, H.R.; Hernández-Cruz Rosi, A.; Ramos-Fernández Julio, C.; Márquez-Vera Marco, A.; Trejo-Macotela Francisco, R. Estimation of the Evapotranspiration Using ANFIS Algorithm for Agricultural Production in Greenhouse. In Proceedings of the 2019 IEEE International Conference on Applied Science and Advanced Technology (iCASAT), Queretaro, Mexico, 27–28 November 2019.
- [40] Ratnakumari, Korada, and Surapaneni Koteswari. "Design & implementation of innovative IoT based smart agriculture management system for efficient crop growth." *J. Eng. Sci* 11 (2020): 607-616.
- [41] Kumari, Priti, Shweta Rathore, Asmita Kalamkar, and Trupti Kambale. "Prediction of Crop Yield Using SVM Approach with the Facility of E-MART System." *EasyChair* (2020).
- [42] Palanivel, Kodimalar, and Chellammal Surianarayanan. "An approach for prediction of crop yield using machine learning and big data techniques." *International Journal of Computer Engineering and Technology* 10, no. 3 (2019): 110-118.
- [43] Rajak, Rohit Kumar, Ankit Pawar, Mitalee Pendke, Pooja Shinde, Suresh Rathod, and Avinash Devare. "Crop recommendation system to maximize crop yield using machine learning technique." *International Research Journal of Engineering and Technology* 4, no. 12 (2017): 950-953.
- [44] Ramesh, D., and B. Vishnu Vardhan. "Analysis of crop yield prediction using data mining techniques." *International Journal of research in engineering and technology* 4, no. 1 (2015): 47-473.
- [45] PS, Maya Gopal. "Performance evaluation of best feature subsets for crop yield prediction using machine learning algorithms." *Applied Artificial Intelligence* 33, no. 7 (2019): 621-642.
- [46] Sekaran, Kaushik, Maytham N. Meqdad, Pardeep Kumar, Soundar Rajan, and Seifedine Kadry. "Smart agriculture management system using internet of things." *Telkomnika* 18, no. 3 (2020): 1275-1284
- [47] Kamienski, Carlos, Juha-Pekka Soininen, Markus Taumberger, Ramide Dantas, Attilio Toscano, Tullio Salmon Cinotti, Rodrigo Filev Maia, and André Torre Neto. "Smart water management platform: IoT-based precision irrigation for agriculture." *Sensors* 19, no. 2 (2019): 276.
- [48] Ullo, Silvia Liberata, and G. R. Sinha. "Advances in smart environment monitoring systems using IoT and sensors." *Sensors* 20, no. 11 (2020): 3113.
- [49] Morais, Raul, A. Valente, and C. Seródio. "A wireless sensor network for smart irrigation and environmental monitoring: A position article." In 5th European federation for information technology in agriculture, food and environment and 3rd world congress on computers in agriculture and natural resources (EFITA/WCCA), pp. 845-850. 2005.
- [50] Jin, Xue-Bo, Nian-Xiang Yang, Xiao-Yi Wang, Yu-Ting Bai, Ting-Li Su, and Jian-Lei Kong. "Hybrid deep learning predictor for smart agriculture sensing based on empirical mode decomposition and gated recurrent unit group model." *Sensors* 20, no. 5 (2020): 1334.
- [51] Htitiou, A., A. Boudhar, Y. Lebrini, and T. Benabdellouahab. "Deep learning-based reconstruction of spatiotemporally fused satellite images for smart agriculture applications in a heterogeneous

- agricultural region." *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* 44 (2020): 249-254.
- [52] Chauhan, Prachi, Hardwari Lal Mandoria, Alok Negi, and R. S. Rajput. "Plant diseases concept in smart agriculture using deep learning." In *Smart Agricultural Services Using Deep Learning, Big Data, and IoT*, pp. 139-153. IGI Global, 2021.
- [53] Suryo, Putro S. Budi Cahyo, I. Wayan Mustika, Oyas Wahyunggoro, and Hutomo Suryo Wasisto. "Improved time series prediction using LSTM neural network for smart agriculture application." In *2019 5th International Conference on Science and Technology (ICST)*, vol. 1, pp. 1-4. IEEE, 2019.
- [54] Masmoudi, Ilias, and Rachid Lghoul. "A Deep Convolutional Neural Network Approach for Plant Leaf Segmentation and Disease Classification in Smart Agriculture." In *Intelligent Computing*, pp. 1044-1055. Springer, Cham, 2021.
- [55] Boukhris, Louay, Jihene Ben Abderrazak, and Hichem Besbes. "Tailored Deep Learning based Architecture for Smart Agriculture." In *2020 International Wireless Communications and Mobile Computing (IWCMC)*, pp. 964-969. IEEE, 2020.
- [56] Nevavuori, Petteri, Nathaniel Narra, and Tarmo Lipping. "Crop yield prediction with deep convolutional neural networks." *Computers and electronics in agriculture* 163 (2019): 104859.
- [57] Sivanandhini, P., and J. Prakash. "Crop Yield Prediction Analysis using Feed Forward and Recurrent Neural Network." *International Journal of Innovative Science and Research Technology* 5, no. 5 (2020): 1092-1096.
- [58] Udutalapally, Venkanna, Saraju P. Mohanty, Vishal Pallagani, and Vedant Khandelwal. "scrop: A novel device for sustainable automatic disease prediction, crop selection, and irrigation in internet-of-agro-things for smart agriculture." *IEEE Sensors Journal* (2020).