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**REVIEW**

# Applications of Artificial Intelligence in Precision Irrigation

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## ABSTRACT

This paper provides an overview of the various applications of Artificial Intelligence (AI) in precision irrigation. It covers key research areas, methodologies, challenges, and future prospects in the field. The methodology is based on exploring how AI technologies are being used to optimize water management in agriculture and examines the growing body of research on the application of AI in irrigation systems. Deep investigation was conducted to explore how AI technologies can enhance water management in agriculture, leading to improved water management and crop yield in addition to resource efficiency. The paper discusses AI-based methods for monitoring soil conditions, weather forecasting, and real-time decision-making in irrigation. However, integration of AI systems with existing irrigation infrastructure and farming practices can be challenging, requiring significant investment in hardware and software.

***Keywords:*** Artificial Intelligence (AI); Irrigation; Agriculture; Data.

## 1. Introduction

Agriculture is the backbone of economies around the world. However, it faces significant challenges due to climate change, water scarcity, and the need for sustainable resource management [1]. Artificial Intelligence (AI) has emerged as a transformative technology in addressing these challenges, particularly in the domain of irrigation [2]. AI techniques are being harnessed to optimize water management, conserve resources, and enhance crop productivity in an era

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when the need for sustainable agriculture is more pressing than ever [3].

In a world where water scarcity is becoming increasingly prevalent due to population growth and climate change, conserving water for agriculture is essential [4]. Irrigation water management is a cornerstone of sustainable agriculture. It supports the long-term viability of farming systems, maintains soil health, and minimizes environmental degradation [5,6]. Efficient irrigation ensures that water is used optimally, reducing water wastage and conserving this valuable resource [7]. Climate change is affecting rainfall patterns and increasing the frequency of droughts. Efficient irrigation practices can help agriculture adapt to these changes by providing a consistent and reliable source of water, mitigating the negative impact of climate change [8].

However, traditional irrigation methods come with various challenges that affect the efficiency and sustainability of agricultural systems. Inefficient water use such as surface and flood irrigation, are often inefficient in distributing water uniformly across fields [9]. The uncontrolled flow of water in traditional systems can lead to soil erosion, which degrades soil quality and reduces agricultural productivity [10]. Moreover, traditional irrigation often consumes large volumes of water, leading to competition for limited water resources. This competition can result in water scarcity, especially in regions facing droughts or increased water demand [11,12].

Against this backdrop, the integration of AI technologies emerges as a transformative force, offering novel solutions to longstanding challenges. Through harnessing real-time data through sensor technologies, employing predictive analytics using machine learning algorithms, and implementing precision irrigation through automated systems, AI stands poised to revolutionize how we manage water resources in agriculture [13].

In this context, the aim of this paper is to underscore the pivotal role that Artificial Intelligence (AI) plays in revolutionizing irrigation management, with a focus on its profound importance and far-reaching impacts. Additionally, it will address potential challenges and considerations associated with the adoption of AI in irrigation, while also outlining future trends and opportunities for further research and development. Ultimately, this paper seeks to contribute to the discourse on the nexus between AI and irrigation management, highlighting the imperative of embracing technological advancements for a more sustainable and productive agricultural future.

## 2. AI techniques in irrigation

Artificial Intelligence (AI) encompasses various techniques that have found application in irrigation systems. Machine learning, deep learning, fuzzy logic, and expert systems are some of the core AI techniques leveraged to optimize irrigation processes (see **Figure 1**).

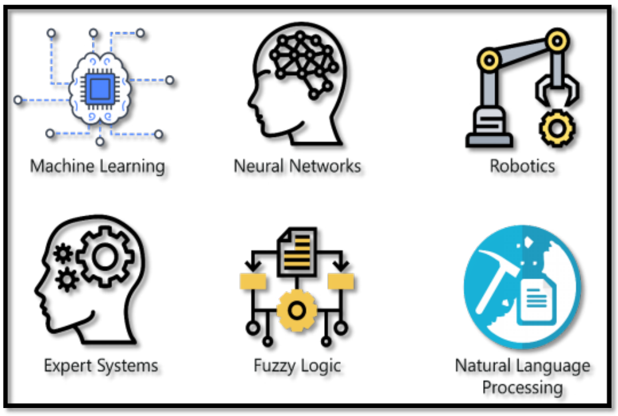


**Figure 1.** Types of artificial intelligence [14].

Artificial Intelligence techniques leverage advanced algorithms and data analysis to enhance efficiency, reduce water wastage, and improve overall agricultural productivity. The most commonly AI techniques employed in irrigation are:

### 2.1 Machine learning

Machine learning models, such as decision trees, random forests, and support vector machines, are employed to predict soil moisture levels and determine optimal irrigation schedules. These models learn from historical data, taking into account factors like weather conditions, soil types, and crop characteristics [15].

### 2.2 Deep learning

Neural networks, a subset of deep learning, are used for image recognition and interpretation in precision agriculture. Drones equipped with cameras and AI-driven algorithms can assess crop health and water stress, aiding in targeted irrigation [13].

### 2.3 Fuzzy logic

Fuzzy logic is employed to handle uncertainty in irrigation decision-making. It allows for a more nuanced approach, considering imprecise data. For instance, it can help adjust irrigation in response to uncertain weather forecasts [16].

### 2.4 Expert systems

Expert systems combine human knowledge and AI algorithms to provide irrigation recommendations [17]. These systems are particularly useful for small-scale farmers who may not have extensive technical knowledge [18].

The subsequent sections will delve into the practical application of Artificial Intelligence (AI) techniques across various domains related to irrigation management, including Weather Forecasting, Soil Moisture Monitoring, Crop Health Monitoring, and Decision Support Systems.

## 3. Weather forecasting

AI-driven weather forecasting models have gained significant attention in recent years for their ability to provide accurate and precise weather predictions, which can be used to optimize irrigation scheduling [19]. In this section, we will review several studies that focus on AI-driven weather forecasting models for precise irrigation timing.

Munoth, Goyal, and Tiwari [20] examined the existing literature on AI-driven weather forecasting models for precise irrigation timing. The authors analyze the performance of various AI models, including neural networks, support vector machines, and decision trees, in predicting weather parameters such as temperature, humidity, and wind speed. They also evaluate the impact of these models on crop yields and water consumption. The review finds that AI-driven weather forecasting models can significantly improve irrigation scheduling, leading to better crop health and yield, and reduced water consumption. Alibabaei, Gaspar, and Lima [21] proposed a deep learning model for crop yield prediction and irrigation scheduling. The model uses satellite data and weather data to predict crop yields and optimize irrigation schedules. The authors evaluate the performance of the model using a case study of corn crops in South Korea. They find that the deep learning model can accurately predict crop yields and reduce water consumption by up to 20%.

Moreover, Shaikh et al. [22] proposed an AI-driven irrigation scheduling system using machine learning and weather forecasting. The system uses historical weather data and soil moisture data to predict crop water requirements and optimize irrigation schedules. The authors evaluate the performance of the system using a case study of wheat crops in Saudi Arabia. They find that the AI-driven system can reduce water consumption by up to 30%.

Overall, these studies demonstrate the potential of AI-driven weather forecasting models for precise irrigation timing in agriculture, leading to significant water savings while maintaining crop yield and promoting sustainable agriculture practices.

## 4. Soil moisture monitoring

Several studies demonstrate the potential of AI-based soil moisture monitoring and management systems for improving crop yield, reducing water usage, and promoting sustainable agriculture.

Sinwar et al. [23] proposed an AI-based soil moisture monitoring and management system for irrigation optimization. The system uses a combination of sensors and machine learning algorithms to monitor soil moisture levels and optimize irrigation schedules based on crop water requirements. The study shows that the AI-based system can reduce water consumption by up to 30% compared to traditional irrigation methods.

Patrizi et al. [24] demonstrates the use of deep learning algorithms for soil moisture monitoring and crop yield prediction. The system uses a Convolutional Neural Network (CNN) to analyze multispectral remote sensing data and predict soil moisture levels. The study shows that the CNN model can accurately predict soil moisture levels and crop yields, and can be used to optimize irrigation schedules and crop management.

Dubois, Teytaud, and Verel [25] proposed a machine learning approach for soil moisture monitoring and management in agriculture. The system uses a decision tree algorithm to analyze soil moisture data and predict crop water requirements. The study shows that the machine learning algorithm can accurately predict soil moisture levels.

In the domain of Decision Support Systems (DSS), the reliance on external technologies like Soil Monitoring is pivotal for its effective functioning. Soil Monitoring serves as a foundational component that provides essential data inputs required for informed decision-making processes within agricultural contexts. Through continuously assessing soil moisture levels, nutrient composition, and other critical parameters, Soil Monitoring systems offer real-time insights into environmental conditions, thereby enabling DSS to generate more accurate and contextually relevant recommendations [26]. For instance, knowledge of soil moisture levels can inform irrigation scheduling, crop selection, and fertilizer application strategies, ultimately optimizing resource utilization and maximizing yield. Similarly, in environmental management, such data can facilitate early detection of drought conditions, leading to timely interventions and mitigation measures [27].

In conclusion, the integration of AI in soil moisture monitoring and management systems presents a transformative opportunity for irrigation management. The potential benefits, including increased crop yield, reduced water usage, and support for sustainable farming practices, highlight the positive impact that AI technologies can have on the future of agriculture.

## 5. Crop health monitoring

There have been several studies conducted on the use of AI solutions for monitoring crop health and stress. Nguyen et al. [28] used deep learning algorithms to analyze multispectral imagery of crops and detect stress and diseases. The results showed that the proposed method could accurately detect stress and diseases in crops. Zamani et al. [29] used machine vision techniques to detect and segment diseased leaves in rice crops. The results showed that the proposed method could accurately detect diseased leaves in rice crops, which could help farmers to take early action to prevent crop damage.

Virnodkar et al. [30] used deep learning algorithms to classify crop stress levels in remote sensing imagery. The results showed that the proposed method could accurately classify crop stress levels and could be used to monitor crop health in real-time. Harakannanavar et al. [31] compared deep learning and traditional computer vision methods for crop stress detection. The results showed that deep learning methods could effectively detect crop stress, with higher accuracy than traditional methods. Gao et al. [32] provided an overview of the use of deep learning for crop stress detection in plants. The authors discuss the challenges and opportunities of using deep learning for crop stress detection and provide recommendations for future research.

These studies demonstrate the potential of AI solutions for monitoring crop health and stress. Through using deep learning and machine vision techniques to analyze data from multispectral imagery, satellite imagery, and other sources, researchers can accurately detect. This information can help farmers to take action to prevent or mitigate the effects of crop stress, and can ultimately lead to higher yields and profits.

## 6. Decision support systems

AI-based decision support systems for irrigation management have gained significant attention in recent years. These systems use various AI techniques to analyze data from sensors, meteorological stations, and other sources to optimize irrigation management. Yousaf et al. [33] proposed an AI-based decision support system for irrigation management. The system used data from soil moisture sensors, weather stations, and crop models to optimize irrigation schedules. The results showed that the proposed system could reduce water use and improve crop yield. Mohapatra and Lenka [34] proposed a hybrid decision support system for irrigation management using deep learning and fuzzy logic. The system used data from soil moisture sensors, weather stations, and crop models to optimize irrigation schedules. The results showed that the proposed system could reduce water use and improve crop yield.

Pierre et al. [35] proposed an AI-based decision support system for real-time irrigation management. The system used data from soil moisture sensors, weather stations, and crop models to optimize irrigation schedules. The results showed that the proposed system could reduce water use and improve crop yield. Sinwar et al. [23] proposed an AI-based decision support system for irrigation management in precision agriculture. The system used data from soil moisture sensors, weather stations, and crop models to optimize irrigation schedules. The results showed that the proposed system could reduce water use and improve crop yield. For more details, see **Figure 2** below.

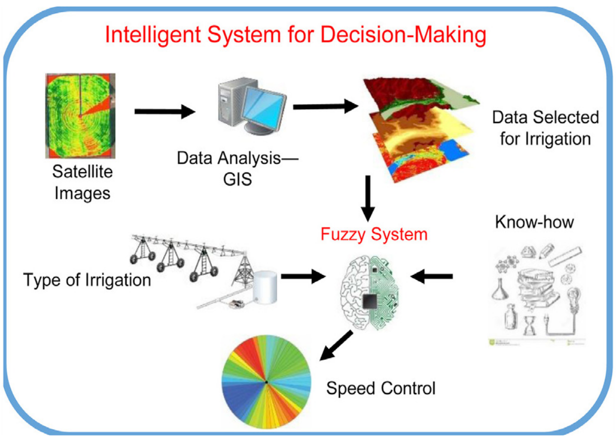


**Figure 2**. Structure for the strategy of the intelligent irrigation system [36].

There are a number of studies that discuss AI-based decision support systems for irrigation management [23,37–40]. These studies show that AI-based decision support systems can be a valuable tool for irrigation management. AI can be used to collect and analyze data on soil moisture, weather conditions, and crop growth, and to make real-time decisions about how to irrigate crops. This information can help farmers to improve irrigation efficiency, reduce the risk of waterlogging and soil salinization, and increase crop yields. These studies have found that AI can be used to improve irrigation efficiency and water use, reduce the risk of waterlogging and soil salinization, and increase crop yields.

## 7. Benefits of AI techniques in irrigation

Several studies were done to determine the advantages that AI technology can provide to irrigation. Bwambale, Abagale, and Anornu [41] provided an overview of the literature on AI-based irrigation management. The authors discuss the benefits of using AI techniques to optimize irrigation schedules, reduce water use, and improve crop yield. Moreover, Talaviya et al. [3] summarized the benefits of AI techniques in irrigation management. The authors discuss the advantages of using AI to optimize irrigation schedules, reduce water use, and improve crop yield. Qazi, Khawaja, and Farooq [42] provided an overview of recent advances in AI-based irrigation management. The authors discuss the benefits of using AI techniques to optimize irrigation schedules, reduce water use, and improve crop yield.

Yousaf et al. [33] discussed the benefits of AI-based decision support systems in irrigation management. The authors highlight the advantages of using these systems to optimize irrigation schedules, reduce water use, and improve crop yield. Parra et al. [43] investigated the impact of AI techniques in irrigation management in a citrus orchard. The results showed that the use of AI techniques could reduce water use, improve crop yield, and reduce the cost of irrigation.

These studies highlight the potential benefits of AI techniques in irrigation management. Overall, AI techniques can provide a number of benefits for irrigation, including, but not limited, to the following:

- Enhanced water management: AI-based irrigation systems provide real-time monitoring of soil moisture, weather conditions, and crop health. By analyzing these data, AI can optimize irrigation schedules, reducing water wastage and ensuring that crops receive the right amount of water. This information can help farmers to improve the efficiency of their irrigation systems and reduce the risk of crop damage.

- Increased crop yields: AI can be used to optimize irrigation schedules, which can lead to improved crop yields. AI can also enable precision farming, allowing for site-specific irrigation and fertilization. This targeted approach enhances crop quality and yield while minimizing resource inputs.
- Improved soil management: AI can be used to monitor soil moisture and drainage conditions, and to make adjustments to irrigation schedules as needed. This can help to prevent waterlogging and soil salinization, which can damage crops and reduce yields.
- Cost Reduction: Efficient water use and resource management result in cost savings for farmers. Through reducing water and energy consumption, AI techniques in irrigation contribute to economic sustainability in agriculture.
- Sustainability: Sustainable farming practices are crucial for preserving the environment. AI-driven irrigation reduces the ecological footprint of agriculture by preventing over-irrigation and minimizing chemical usage.

From the above points, AI technology provides several clear advantages over traditional methods in irrigation management. It excels in precision and efficiency by analyzing extensive datasets from sources like soil sensors and weather forecasts, enabling real-time adjustments to irrigation schedules based on specific crop needs. Unlike conventional approaches reliant on fixed schedules, AI's predictive capabilities allow proactive decision-making, anticipating future water requirements and mitigating risks such as drought or excess rainfall. AI's adaptability to changing environmental conditions ensures optimal crop conditions throughout the season, integrating diverse data sets comprehensively for holistic insights into field conditions and crop health. Moreover, while initial costs may be higher, AI-driven systems offer long-term cost savings through reduced water and energy consumption, promoting sustainable agricultural practices.

## 8. Discussion

The application of AI technology in irrigation management has been extensively studied and has shown significant potential for enhancing efficiency, conserving water, and improving crop yield.

From the 1990s to the 2020s, AI application in irrigation has evolved significantly. It began with experimental use for automated scheduling and progressed through the integration of remote sensing, GIS, and IoT technologies. Machine learning models optimized water usage based on real-time data, while advancements in drone technology enhanced crop monitoring. Recent years have seen AI-driven predictive analytics and the development of autonomous irrigation systems, highlighting AI's role in enhancing agricultural sustainability and productivity through efficient water management and adaptive control (see **Table 1** below).

**Table 1.** Summary of the major developments in AI application in irrigation from the 1990s to the 2020s.

| Year Range | AI Application in irrigation |
|---|---|
| 1990s | Initial research on AI-driven irrigation systems, primarily using rule-based expert systems and fuzzy logic. |
| Early 2000s | Advancements in machine learning algorithms led to their incorporation in irrigation systems, improving water use efficiency and crop yields. |
| Late 2000s | Introduction of IoT devices and sensor networks, enabling real-time data collection and analysis for precision irrigation. |
| Early 2010s | Deep learning algorithms started being applied to irrigation systems, further enhancing predictive capabilities. |
| Mid 2010s | Integration of satellite imagery and drone technology for large-scale irrigation monitoring and management. |
| Late 2010s | Emergence of smart irrigation systems using AI for automated decision-making and optimized water distribution. |
| 2020s | Emphasis on sustainable agriculture with AI-powered irrigation, focusing on water conservation and climate resilience. |

Multiple studies mention that AI technologies offer a range of benefits, including improved water-use efficiency, enhanced crop productivity, cost savings, and increased resilience to environmental challenges [33,42]. One key advantage of AI-based irrigation management is its ability to optimize irrigation schedules based on real-time data and environmental factors. Thus, by leveraging AI algorithms, irrigation systems can adapt to changing conditions such as weather patterns, soil moisture levels, and crop water requirements, thereby ensuring that water is applied precisely when and where it is needed most. This targeted approach not only minimizes water wastage but also maximizes the effectiveness of irrigation, leading to improved crop health and yield.

Moreover, AI techniques enable proactive decision-making in irrigation management by providing predictive insights and recommendations. Through analyzing historical data and patterns, AI-driven decision support systems can anticipate future water requirements and suggest optimal irrigation strategies accordingly. This predictive capability not only improves water-use efficiency but also helps farmers mitigate risks associated with water scarcity or excess, ultimately enhancing overall farm profitability.

However, several challenges must be addressed for successful implementation of AI technology into irrigation management. These include ensuring the availability and quality of data, integrating AI systems with existing farm infrastructure, managing the initial costs of implementation, providing adequate technical training and support, optimizing energy usage, enhancing algorithm robustness and adaptability, and addressing regulatory and ethical considerations [23]. Thus, by overcoming these obstacles through collaborative efforts and technological innovation, the application of AI in irrigation management can contribute to more sustainable and productive agricultural practices, benefiting both farmers and the environment.

## 9. Conclusions

In conclusion, the literature review provides an overview of the current state of research in AI-based irrigation and serves as a foundation for understanding the advancements and challenges in this rapidly evolving field. This literature review has demonstrated the significant potential of AI techniques in optimizing irrigation schedules, reducing water use, and improving crop yield. Several studies have highlighted the benefits of using AI techniques, such as machine learning, deep learning, and fuzzy logic, to analyze data from various sources, such as soil moisture sensors, weather stations, and satellite imagery. AI's ability to analyze real-time data from multiple sources allows for adaptive responses to changing environmental conditions, thereby optimizing water use and minimizing waste. However, several challenges persist, including issues with data quality and availability, the complexity of integrating AI systems with existing agricultural infrastructure, and the initial investment costs involved. Furthermore, the scalability and reliability of AI models in diverse agricultural settings require ongoing advancements in algorithm development and sensor technologies. Addressing these challenges will be crucial for maximizing the full potential of AI technologies and ensuring sustainable agricultural practices.

Overall, the literature has shown that AI techniques have great potential to revolutionize irrigation management, and further research is needed to fully realize this potential. It is important to continue to develop and refine AI-based irrigation management systems, and to address the challenges and future directions in order to maximize their effectiveness and ensure their long-term sustainability.

The use of AI techniques in irrigation has the potential to revolutionize the way farmers manage their crops and will play an increasingly important role in irrigation management. This technology has the potential to help farmers conserve water, improve crop yields, and reduce the risk of crop damage. While AI techniques in irrigation offer promising solutions, several challenges need to be addressed. Data quality, scalability, and the need for accessible technology in developing regions are some of the key challenges.

In the latest technology research literature from 2023 to 2024, significant advancements have continued to shape AI applications in irrigation. Researchers have focused on enhancing the precision and efficiency of irrigation systems through advanced machine learning algorithms and AI-driven optimization techniques. Additionally, emerging technologies such as blockchain and edge computing have been investigated for their potential to further optimize irrigation management by improving data integrity and processing efficiency in decentralized systems.

Future research should focus on integrating AI with Internet of Things (IoT) technologies for more comprehensive and real-time data collection. Additionally, AI can be utilized to predict long-term climate trends, helping farmers adapt to changing conditions [44]. One of the biggest challenges is the need for large amounts of data. AI algorithms require a lot of data in order to learn and make accurate predictions. This data can be difficult to collect, especially for small-scale farmers. In addition, the data that is available is often not always accurate or complete. Another challenge is the need for specialized expertise. AI techniques can be complex and require a high level of expertise to develop and implement. This expertise is not always available to farmers, especially in developing countries.

Key recommendations to overcome these challenges include enhancing data quality through diverse and representative datasets, and prioritizing transparency and interpretability in AI systems. Additionally, it was advised to establish robust regulatory frameworks that ensure ethical AI development and deployment. These measures aim to address challenges such as algorithmic bias, data privacy concerns, and the interpretability of AI decisions effectively.

Finally, there is the need for AI techniques to be continuously updated. The agricultural environment is constantly changing, and AI algorithms need to be able to adapt to these changes in order to remain effective. This can be a time-consuming and costly process.

## Author Contributions

The first author entails conceptualizing the study, designing its framework, and drafting the manuscript. The second and third authors contribute significantly to the technical aspects of the research and are involved in revising the study.

## Conflict of Interest

The authors declare that they have no conflicts of interests.

## Data Availability Statement

The data that support the findings of this study are available on request.

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## References

[1] Branca, G., Chileshe, P. Climate change mitigation in the East and Southern Africa region: An economic case for the agriculture, forestry and land use sector. IFAD Research Series 92. Rome: IFAD.

[2] Collins, C., Dennehy, D., Conboy, K., et al., 2021. Artificial intelligence in information systems research: A systematic literature review and research agenda. International Journal of Information Management. 60, 102383. DOI: https://doi.org/10.1016/j.ijinfomgt.2021.102383

[3] Talaviya, T., Shah, D., Patel, N., et al., 2020. Implementation of artificial intelligence in agriculture for optimisation of irrigation and application of pesticides and herbicides. Artificial Intelligence in Agriculture. 4, 58–73. DOI: https://doi.org/10.1016/j.aiia.2020.04.002

[4] Pérez-Blanco, C.D., Hrast-Essenfelder, A., Perry, C., 2020. Irrigation technology and water conservation: A review of the theory and evidence. Review of Environmental Economics and Policy. 14(2), 216–239. DOI: https://doi.org/10.1093/reep/reaa004

[5] Bijekar, S., Padariya, H.D., Yadav, V.K., et al., 2022. The state of the art and emerging trends in the wastewater treatment in developing nations. Water. 14(16), 2537.
DOI: https://doi.org/10.3390/w14162537

[6] Schoengold, K., Zilberman, D., 2007. Chapter 58 The economics of water, irrigation, and development. Handbook of Agricultural Economics. 3, 2933–2977.
DOI: https://doi.org/10.1016/S1574-0072(06)03058-1

[7] Wang, X., Zhang, J., Shahid, S., et al., 2014. Adaptation to climate change impacts on water demand. Mitigation and Adaptation Strategies for Global Change. 21(1), 81–99.
DOI: https://doi.org/10.1007/s11027-014-9571-6

[8] Oweis, T., Hachum, A., 2006. Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. Agricultural Water Management. 80(1–3), 57–73.
DOI: https://doi.org/10.1016/j.agwat.2005.07.004

[9] Kumar, S., Meena, R.S., Jhariya, M.K., 2020. Resources use efficiency in agriculture. Springer: Singapore.
DOI: https://doi.org/10.1007/978-981-15-6953-1

[10] Koluvek, P.K., Tanji, K.K., Trout, T.J., 1993. Overview of soil erosion from irrigation. Journal of Irrigation and Drainage Engineering. 119(6), 929–946.
DOI: https://doi.org/10.1061/(ASCE)0733-9437(1993)119:6(929)

[11] Solomon, K.H., Burt, C.M., 1999. Irrigation sagacity: A measure of prudent water use. Irrigation Science. 18(3), 135–140.
DOI: https://doi.org/10.1007/s002710050054

[12] Jamali, M., Soufizadeh, S., Yeganeh, B., et al., 2021. A comparative study of irrigation techniques for energy flow and greenhouse gas (GHG) emissions in wheat agroecosystems under contrasting environments in south of Iran. Renewable and Sustainable Energy Reviews. 139, 110704.
DOI: https://doi.org/10.1016/j.rser.2021.110704

[13] Magomadov, V.S., 2019. Deep learning and its role in smart agriculture. Journal of Physics: Conference Series. 1399(4), 044109.
DOI: https://doi.org/10.1088/1742-6596/1399/4/044109

[14] Understanding Different Types of Artificial Intelligence with Examples [Internet]. Edureka; 2023 [cited 2023 Nov 20]. Available from: https://www.edureka.co/blog/types-of-artificial-intelligence/

[15] Kingston, G.B., Dandy, G.C., Maier, H.R., 2008. Review of artificial intelligence techniques and their applications to hydrological modeling and water resources management. Part 1—imulation. Water Resources Research Progress. Nova Science Publishers: New York, USA. pp. 67–99.

[16] Applied Technologies, 2020. Communications in computer and information science. Springer International Publishing: Switzerland.
DOI: https://doi.org/10.1007/978-3-030-42520-3

[17] Blessy, J.A., Kumar, A. (editors), 2021. Smart irrigation system techniques using artificial intelligence and IoT. 2021 Third International Conference on Intelligent Communication Technologies and Virtual Mobile Networks (ICICV); 2021 Feb 04–06; Tirunelveli, India. USA: IEEE. p. 1355–1359.

[18] Anil Chougule, M., Mashalkar, A.S., 2022. A comprehensive review of agriculture irrigation using artificial intelligence for crop production. Computational Intelligence in Manufacturing. 187–200.
DOI: https://doi.org/10.1016/b978-0-323-91854-1.00002-9

[19] Guravaiah, K., Raju, S.S. (editors), 2020. e-Agriculture: Irrigation system based on weather forecasting. 2020 IEEE 15th International Conference on Industrial and Information Systems (ICIIS); 2020 Nov 26–28; RUPNAGAR, India. p. 617–622.
DOI: https://doi.org/10.1109/ICIIS51140.2020.9342739

[20] Sensor Based Irrigation System: A review

[Internet] [cited 2016 Apr 30]. Available from: https://www.researchgate.net/publication/303842913_Sensor_based_Irrigation_System_A_Review

[21] Alibabaei, K., Gaspar, P.D., Lima, T.M., 2021. Crop yield estimation using deep learning based on climate big data and irrigation scheduling. Energies. 14(11), 3004. DOI: https://doi.org/10.3390/en14113004

[22] Shaikh, F.K., Memon, M.A., Mahoto, N.A., et al., 2022. Artificial intelligence best practices in smart agriculture. IEEE Micro. 42(1), 17–24. DOI: https://doi.org/10.1109/mm.2021.3121279

[23] Pattnaik, P.K., Kumar, R., Pal, S., 2020. Internet of things and analytics for agriculture, Volume 2. Studies in Big Data. Springer: Singapore. DOI: https://doi.org/10.1007/978-981-15-0663-5

[24] Patrizi, G., Bartolini, A., Ciani, L., et al., 2022. A virtual soil moisture sensor for smart farming using deep learning. IEEE Transactions on Instrumentation and Measurement. 71, 1–11. DOI: https://doi.org/10.1109/tim.2022.3196446

[25] Dubois, A., Teytaud, F., Verel, S., 2021. Short term soil moisture forecasts for potato crop farming: A machine learning approach. Computers and Electronics in Agriculture. 180, 105902. DOI: https://doi.org/10.1016/j.compag.2020.105902

[26] Canillas, E.C., Salokhe, V.M., 2002. A decision support system for compaction assessment in agricultural soils. Soil Tillage Research. 65(2), 221–230. DOI: https://doi.org/10.1016/S0167-1987(02)00002-8

[27] De la Rosa, D., Mayol, F., Diaz-Pereira, E., et al., 2004. A land evaluation decision support system (MicroLEIS DSS) for agricultural soil protection. Environmental Modelling & Software. 19(10), 929–942. DOI: https://doi.org/10.1016/j.envsoft.2003.10.006

[28] Nguyen, T.T., Hoang, T.D., Pham, M.T., et al., 2020. Monitoring agriculture areas with satellite images and deep learning. Applied Soft Computing. 95, 106565. DOI: https://doi.org/10.1016/j.asoc.2020.106565

[29] Zamani, A.S., Anand, L., Rane, K.P., et al., 2022. Performance of machine learning and image processing in plant leaf disease detection. Journal of Food Quality. 1–7. DOI: https://doi.org/10.1155/2022/1598796

[30] Virnodkar, S.S., Pachghare, V.K., Patil, V.C., et al., 2020. Remote sensing and machine learning for crop water stress determination in various crops: A critical review. Precision Agriculture. 21(5), 1121–1155. DOI: https://doi.org/10.1007/s11119-020-09711-9

[31] Harakannanavar, S.S., Rudagi, J.M., Puranikmath, V.I., et al., 2022. Plant leaf disease detection using computer vision and machine learning algorithms. Global Transitions Proceedings. 3(1), 305–310. DOI: https://doi.org/10.1016/j.gltp.2022.03.016

[32] Gao, Z., Luo, Z., Zhang, W., et al., 2020. Deep learning application in plant stress imaging: A Review. AgriEngineering. 2(3), 430–446. DOI: https://doi.org/10.3390/agriengineering2030029

[33] Yousaf, A., Kayvanfar, V., Mazzoni, A., et al., 2023. Artificial intelligence-based decision support systems in smart agriculture: Bibliometric analysis for operational insights and future directions. Frontiers in Sustainable Food Systems. 6. DOI: https://doi.org/10.3389/fsufs.2022.1053921

[34] Mohapatra, A.G., Lenka, S.K., 2016. Hybrid decision support system using PLSR-fuzzy model for GSM-based site-specific irrigation notification and control in precision agriculture. International Journal of Intelligent Systems Technologies and Applications. 15(1), 4. DOI: https://doi.org/10.1504/ijista.2016.076101

[35] Pierre, N., Ishimwe Viviane, I.V., Lambert, U., et al., 2023. AI-based real-time weather condi-

tion prediction with optimized agricultural resources. European Journal of Technology. 7(2), 36–49.
DOI: https://doi.org/10.47672/ejt.1496

[36] Mendes, W.R., Araújo, F.M.U., Dutta, R., et al., 2019. Fuzzy control system for variable rate irrigation using remote sensing. Expert Systems with Applications. 124, 13–24.
DOI: https://doi.org/10.1016/j.eswa.2019.01.043

[37] Srivastava, A., Maity, R., 2023. Assessing the potential of AI–ML in urban climate change adaptation and sustainable development. Sustainability. 15(23), 16461.
DOI: https://doi.org/10.3390/su152316461

[38] Bruggeman, A. (editor), 2016. The future of sustainable irrigation management in Europe. ENORASIS Conference Abstracts: 27 Nov 2014; IRLA2014 International Symposium; Patras, Greece. p. 1–13.

[39] Bashir, B.A., 2007. Remote sensing derived crop coefficient for estimating crop water requirements for irrigated sorghum in the Gezira Scheme, Sudan. Journal of Environmental Informatics. 10(1), 47–54.
DOI: https://doi.org/10.3808/jei.200700099

[40] Bashir, M.A., Hata, T., Tanakamaru, H., et al., 2008. Satellite-based energy balance model to estimate seasonal evapotranspiration for irrigated sorghum: a case study from the Gezira scheme, Sudan. Hydrology and Earth System Sciences. 12(4), 1129–1139.
DOI: https://doi.org/10.5194/hess-12-1129-2008

[41] 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.
DOI: https://doi.org/10.1016/j.agwat.2021.107324

[42] Qazi, S., Khawaja, B.A., Farooq, Q.U., 2022. IoT-Equipped and AI-Enabled next generation smart agriculture: A critical review, current challenges and future trends. IEEE Access. 10, 21219–21235.
DOI: https://doi.org/10.1109/access.2022.3152544

[43] Parra, L., Botella-Campos, M., Puerto, H., et al., 2020. Evaluating irrigation efficiency with performance indicators: A case study of citrus in the east of Spain. Agronomy. 10(9), 1359.
DOI: https://doi.org/10.3390/agronomy10091359

[44] Obaideen, K., Yousef, B.A.A., AlMallahi, M.N., et al., 2022. An overview of smart irrigation systems using IoT. Energy Nexus. 7, 100124.
DOI: https://doi.org/10.1016/j.nexus.2022.100124