



# Enhancing Agricultural Sustainability Through IoT-Based Smart Irrigation Systems: A Review of Soil Monitoring, Water Management, and Technological Integration

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**Abstract.** Agriculture plays a crucial role in the economy, yet traditional irrigation systems often demonstrate inefficiencies in water usage and control. For centuries, conventional agriculture has been a cornerstone of development globally. This research introduces a novel approach utilizing machine learning algorithms to enhance smart agriculture through an IoT-based smart irrigation system. The new systems should consist of a network of sensors and actuators to collect vital soil data, such as moisture, temperature, and humidity. By integrating artificial intelligence techniques, particularly machine learning strategies, the smart irrigation system aims to effectively control, monitor, and automate irrigation processes. The key objective of such a system should be to continuously assess soil moisture content during varying conditions, ensuring optimal irrigation management for sustainable agricultural practices.

**Keywords:** Smart Irrigation, Machine Learning, Internet of things

## 1 Introduction

Agriculture is one of the largest sources of livelihood in India, and with it, the demand for fresh water used in irrigation continues to rise. Currently, agriculture accounts for 83% of India's total water consumption, but unplanned water usage often leads to significant wastage. To address this, agriculture is increasingly moving towards precision and smart farming techniques powered by Artificial Intelligence (AI). Precision Agriculture, often referred to as "smart agriculture," is a technology-driven approach that monitors, analyses, and responds to variations within the same environment to optimize crop health. For healthy crops, it is essential to manage resources like water, sunlight, and nutrients effectively. According to the World Bank, agriculture will require 70% of global freshwater resources, underscoring the importance of optimizing water usage in agricultural practices.

The researchers play a very important role in the development of agriculture 4.0 based on the smart System iot based model machine learning artificial intelligence. This type of highly efficient technology was introduced in agriculture for high productivity efficiency and the help in high quality production of farmers. Day by Day research in the field of smart irrigation agriculture and water management is increasing (Fig. 1) because this field is the most demanding and developing field in the current scenario.

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Because the need to the water sustainability and food productivity are should be balanced in our zone For sustainable economic develop and increasing in employment that’s why research in the field of Agriculture is increasing day by day.

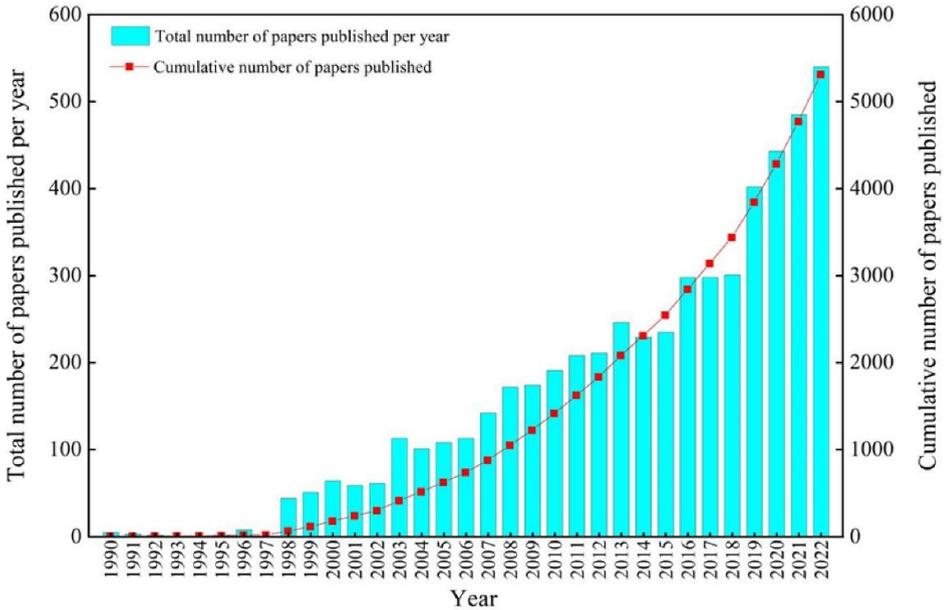


Fig. 1. Graph Representing Research Paper Publication from 1990 to 2022

**Comprehensive Review of Methods**

Effective monitoring of soil moisture and weather conditions is crucial for efficient irrigation, IoT and Wireless Sensor Networks (WSN) are used for real-time monitoring of these parameters, Soil moisture sensors measure the water content in the root zone to determine irrigation needs Weather monitoring sensors provide data on various factors like humidity, air temperature, and wind speed, there should an integrated system which combines IOT and ML techniques together otherwise it will be difficult to manage such system separately, the integration of wireless sensors networks will enable farmers to automate irrigation system through web services and real-time data processing. They use a data set for smart irrigation system to monitor irrigation properly with the help of sensors and data set on observation (Fig. 2).

Data Ranges and its Labels			
Soil Moisture (%)	Temperature (°C)	Humidity (%)	Class
<30	>45	<30	Highly Needed (4)
30-45	35-45	35-45	Needed (3)
46-60	25-34	46-60	Average (2)
61-80	20-24	61-80	Not Needed (1)
80-100	<20	>80	Highly Not Needed (0)

**Figure 2** Dataset descriptions

**Fig. 2.** Dataset Description

Choosing the suitable Machine Learning models is essential; neural networks are recommended for their reliability with noisy data, robust generalization, learning capacity, and adaptability. Support Vector Machines (SVM) are favored for their exceptional capability to manage redundant features and high dimensionality, while Random Forest (RF) techniques have demonstrated effectiveness in handling diverse datasets with varying characteristics.

## 2 Literature Review

Youness Tace et al proposed an innovative approach to address water scarcity in agriculture by developing a smart irrigation system based on IoT and machine learning. Their model aims to reduce water consumption while enhancing crop productivity, aligning with Agriculture 4.0 principles. This system utilizes environmental sensors (measuring soil humidity, temperature, and rainfall) to gather real-time data, enabling precise, data-driven irrigation decisions. Machine learning algorithms, such as K-Nearest Neighbors (KNN), Logistic Regression, Neural Networks, SVM, and Naïve Bayes, were evaluated, with KNN achieving the highest accuracy at 98.3% and an RMSE of 0.12. The system integrates with a web platform, allowing farmers to monitor sensor data and model predictions for improved irrigation efficiency. This solution illustrates how AI and IoT can modernize agriculture by optimizing resource usage and supporting sustainable farming practice

David Vallejo-Gómez et al. conducted a systematic review of existing smart irrigation systems, focusing on systems that integrate artificial intelligence techniques

for urban and rural soil crops. Their review utilized a modified PRISMA 2020 approach, with search equations and screening processes that filtered 170 relevant articles. A detailed analysis using VantagePoint software enabled the identification of 50 key articles, which were reviewed for insights on the current state and adaptability of smart irrigation in agriculture. Their findings provide a comprehensive overview of smart irrigation technologies, using IoT and machine learning, and offer valuable information on approaches that can enhance automation in both rural and urban agriculture settings. This review is intended to benefit researchers and the general public by presenting AI-driven advancements in agricultural practices and opportunities for future development in automated irrigation systems.

Khaled Obaideen et al. examined the role of smart irrigation systems that use IoT technology in supporting sustainable agriculture and addressing global water efficiency challenges. Their study aligns with the United Nations' Sustainable Development Goal (SDG) 6, particularly Target 6.4, which emphasizes water-use efficiency. This review focuses on automated irrigation systems that leverage IoT and sensory technologies, facilitating improved soil and weather monitoring, resource conservation, and reduced environmental impact. Through qualitative analysis and secondary data, they discuss how sensory systems enable farmers to understand crop requirements better and reduce water usage. By advancing the automation of irrigation, this research highlights potential benefits and challenges, offering insights that can guide both researchers and farmers toward more effective and sustainable irrigation practices. This study underscores the importance of continuous research to enhance agricultural efficiency and reduce costs while supporting global sustainability goals.

Abiadi Younes et al. conducted a systematic literature review on the application of machine learning (ML) techniques in smart irrigation systems (SIS), highlighting their potential to enhance irrigation control, monitoring, and automation. Their review analyzed 55 studies from 2017 to 2023, identifying nine prevalent ML models and evaluating them based on technique type, estimation accuracy, model comparison, and estimation context. Findings suggest that ML-based SIS outperform traditional approaches by providing better prediction accuracy and resource efficiency. However, despite these advancements, ML applications in SIS remain limited, with challenges such as achieving generalizable results and addressing implementation issues. This review offers guidelines for researchers and practitioners, identifying key contributions and challenges in advancing ML-enabled irrigation solutions for improved agricultural sustainability and efficiency.

### **2.1 Gaps Identified**

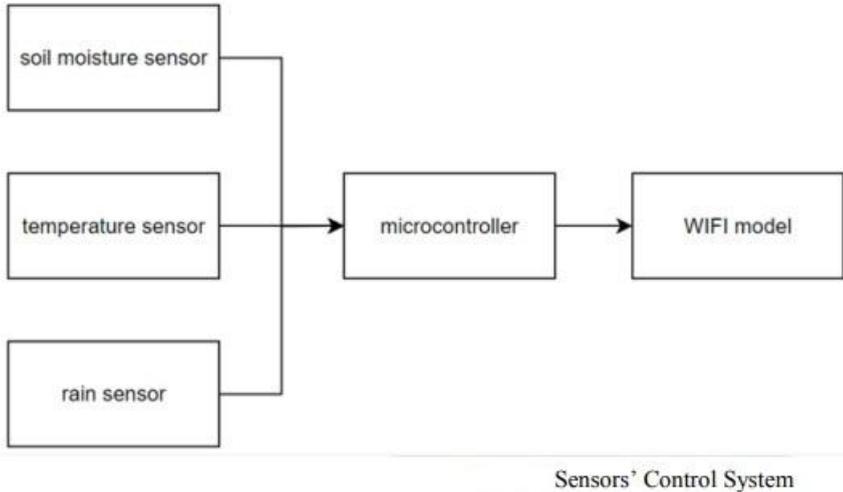
Gaps Identified are shown in Table 1

**Table 1.** Gaps Identified

References	Gap Identified	Description
[1] [4] [7] [12]	Friendly,	the system and users can easily use the system.
[4] [5] [10] [14] [17]	Security	The paper doesn't address potential security concerns related to data collection and control of irrigation systems.
[8] [9] [11] [12] [17]	Integrated Development Adaptability	All these different technologies like AI, ML and IoT must be developed in a integrated manner for comprehensive agricultural solutions
[2] [14] [15] [16] [18]	Current models require large datasets to train machine learning algorithms effectively. Limited sensor data can hinder the model's performance.	All these different technologies like AI, ML and IoT must be developed in a integrated manner for comprehensive agricultural solutions
[3] [13] [15] Data Dependent		
Not User	To use such complex AI models and Iot devices, farmers need a user-friendly interface which hides all complexities of	

### 3 Comparative Analysis and Limitations

1. According to paper [19] IoT applications use a variety of sensors to collect data in current time. Farmers use linked sensors to examine soil conditions and track crop health and get information to water supply schedule. They develop the model those work like using sensor collect details of soil moistures', temperature and wind speed according to this information they send data wirelessly to using WIFI module to the microcontroller to analyse data set (Fig. 3).



**Fig. 3.** Sensor Control System

Limitations of the model is they farmers required a high Budget to implement this system, and according to the paper the sensor required WIFI module to transfer the data of soil to the microcontroller for analysing that's why farmer required Wi-fi connection Internet connectivity good electricity connection.

Comparatively to the other research paper this paper providing the complete model which help farmer for smart irrigation system but it highly expensive comparison to other models and farmers required more understanding to handle this model like understanding of how to operate the microcontroller how to maintain the sensor regular maintenance of the sensors etc.

2. According to paper [20] To achieve effective farming and high productivity need to do farming Using developing technology like machine learning, artificial intelligence to deploy automated irrigation system analyzing soil condition, To effective water resource utilisation.

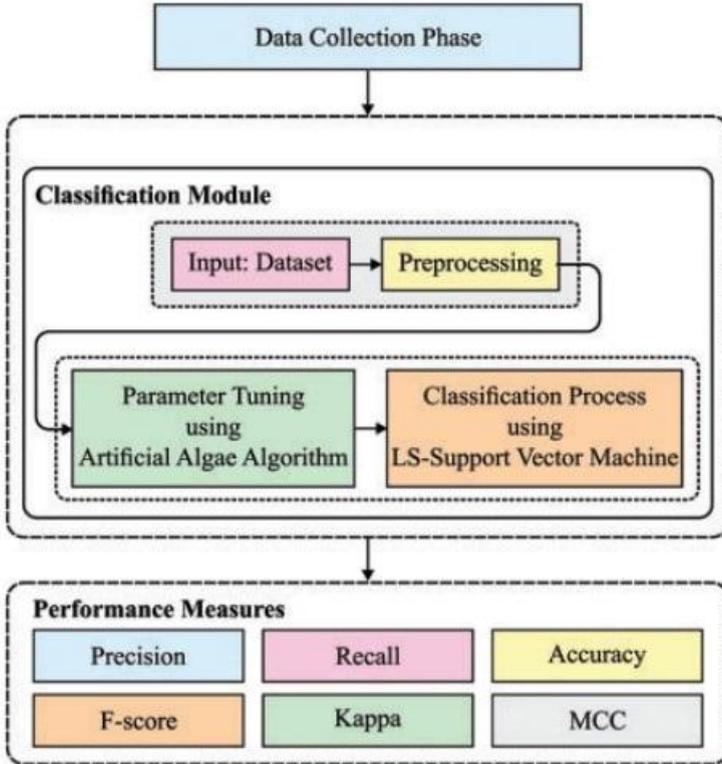
The IoT ML-SIS technique is designed to monitor farmland parameters and make informed irrigation decisions. Additionally, the Artificial Algae Algorithm (AAA) combined with the Least Squares-Support Vector Machine (LS-SVM) model is utilized for classification to assess irrigation requirements.

This model is structured with four fundamental layers: the perception layer, application layer, processing layer, and transport layer.

The perception layer, also referred to as the physical layer, functions as a data-collecting sensor. It measures factors such as temperature, soil moisture, and air humidity.

The transport layer facilitates the transfer of collected data from the perception layer to the processing layer using networks like LAN, wireless, 2G, or 3G.

The processing layer analyses, stores, and processes the vast amounts of data received from the transport layer.



### Overall process of IoTML-SIS model

Fig. 4. Overall Process of IoTML-SIS model

The IoT ML-SIS technique aims to monitor various parameters of farmland and make well-informed irrigation decisions (Fig. 4). To support this, the Artificial Algae Algorithm (AAA) is integrated with the Least Squares-Support Vector Machine (LS-SVM) model, which is used for classifying and determining irrigation needs. The system is organized into four primary layers: the perception layer, application layer, processing layer, and transport layer.

The perception layer, also known as the physical layer, serves as a sensor for data collection, monitoring variables such as temperature, soil moisture, and air humidity. The transport layer enables the transmission of this collected data to the processing layer

through networks like LAN, wireless systems, 2G, or 3G. Finally, the processing layer is responsible for analyzing, storing, and handling the large volume of data it receives from the transport layer.

Limitations: But as comparatively other models they model have the complexity in model because they use the heavy load algorithm to implement this module like LS-SVM and AAA, which have a limitations LS-SVM Is highly complex to work on last dataset because This holding linear equation for finding best solution which become very complex. And this algorithm is very sensitive and noise effective a small change or noise affect this algorithm to change in the result. This algorithm generally based on the selection of Karnal which may affect the result or solution small change in kernel affect the result, this model and the algorithm not suitable for the sudden change in the weather to handle this condition. The model which implements on this algorithm which required high resource for work.

3. According to author [21] Traditional agriculture has been the pillar of development on the planet for centuries. But with exponential population growth and increasing demand, farmers will need water to irrigate the land to meet this demand , Agriculture 4.0 or precision agriculture is a technology of agricultural supervision that detects, calculates, and reacts to inconsistencies within the same environment and other environmental yields, they compare many previous supervised based machines learning based algorithm used in agriculture technology 4.0 for efficient irrigation, water management and high efficiency (Fig. 5)..

**Table 1.** Previous work on supervised machine learning models.

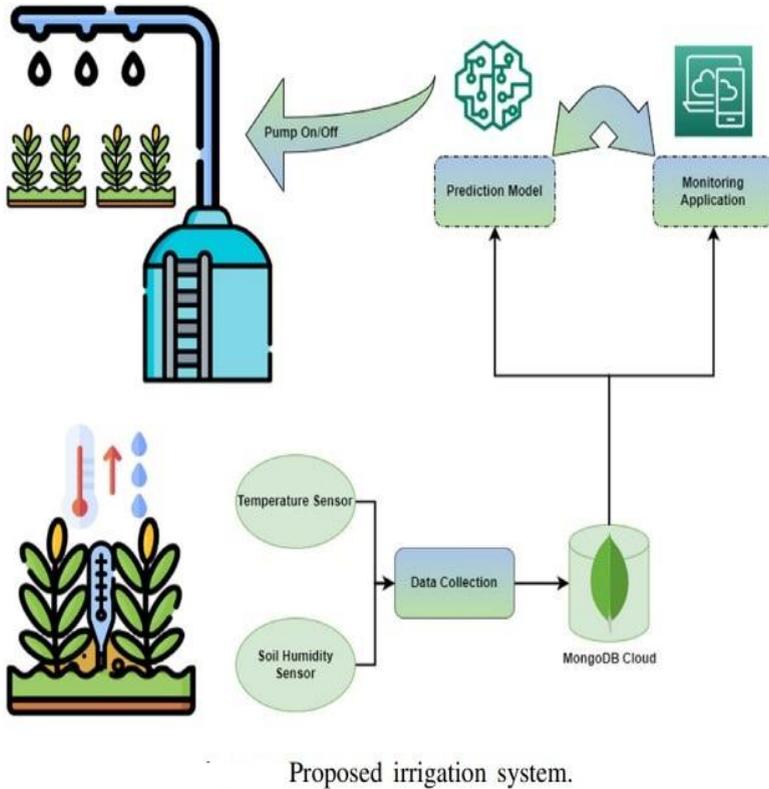
Reference	Supervised model	Features	Experimental		Simulation
			Edge	Cloud	
[17]	Linear regression	This paper allows the prediction of required irrigation water and this using a database collected through several detection sensors	✓	✓	✓
[18]	KNN, SVM, Logistic regression	This paper model presents a system for forecasting the amount of water required in real-time by plants for irrigation and using several sensors	✓	✓	×
[19]	SVM, KNN, Naïve Bayes	These models enable threshold-based classification using sensor data in a cloud database “ThingSpeak”. • Accuracy SVM:87%, Naïve bayes: 76%, KNN:71%	✓	×	✓
[20]	KNN, SVM	This model is used for the detection of infection on several plant samples without forgetting the real-time monitoring of temperature and soil humidity. • Accuracy: 96%	✓	×	✓
[21]	KNN	The algorithm used here is dedicated to the analysis and monitoring of agricultural images taken by drones	✓	×	✓
[22]	SVM	This model allows the adjustment of the amount of irrigation automatically in a domestic plant environment	×	✓	✓

**Fig. 5.** Previous work on supervised ML models

Based on this data set and learning they develop their own model, . To do this, they started with first step which consists of choosing the sensors necessary for the realization of the model starting with the soil moisture sensor, which is used to present the level of soil moisture, and then the temperature/humidity and rain sensors. Once the sensors are connected to the Arduino board, they start programming the board to operate the sensors in such a way as to have the different data grouped and transmitted in real-

time. After that, we ensured the storage of the data using Node-Red and MongoDB, we grouped months of data which allowed us to train these data to be able to predict the start or stop pumping.

The model of author looks like as shown in Fig. 6).



**Fig. 6.** Proposed Irrigation System

In this they also used the sensor with Arduino board this paper model simple and straight forward Comparatively other research paper in this model they also use the database MongoDB to store the data set and predict analyse the irrigation system based on the crop and based on the previous data.

Limitations But this Model also have some limitations According to this paper they not described completely the web application which have the monitoring application because the application which help in monitoring are very essential for the farmer how to operate this and this paper, they not describe it properly the model of the working is very correct way they describe all sensors database predication system but the web application have less explanation.

## 4 Security Considerations

With the increased reliance on IoT for data collection the security considerations is very important to maintain, The security is most important factor which help to secure a model and the data by the attackers in malicious activities because without security consideration our model is not efficient to work.

Generally, IOT based system face multiple challenges in the development. IOT based device have lack robust secure functionality which increase the targeting point of the hacker.

The transmission of unencrypted data and the loosely encrypted data increase the manipulation insensitive data which affects the model and irrigation system and the water management system

Data encryption is very efficient process to encrypt the data at the point of transmit using algorithms such as AES (Advanced Encryption Standard) and TLS (Transport Layer Security) Which help in unauthorized access.

Another important method is implementing multi step authentication and authorization which help to identify the correct user and the correct accessibility of the model.

To increase the efficiency and working of the IOT model in the field of Agriculture or agriculture 4.0 for the sustainable development first we need to focus on the security and data encryption methods Like we need to combine the iot based system with the blockchain technology which have the high data encryption method and the security.

The awareness is a very important factor to increase the security and the usability of the IOT based motor in the farmer because without awareness the model usability will not increases

## 5 Conclusion

Discuss the cost–benefit analysis of smart irrigation systems considering both initial investment and long-term savings. address potential security vulnerabilities and measures to protect data and system control.

Smart irrigation systems using machine learning and IoT have proven effective in optimizing water usage and increasing crop yields. However, these technologies are not without limitations, including scalability, data dependency, and implementation challenges. Future research should focus on creating more scalable, user-friendly systems that can work efficiently across various agricultural settings. By addressing these gaps, we can further improve the sustainability and productivity of agriculture.

This review highlights the increasing importance of smart irrigation systems driven by AI and IoT technologies. Smart irrigation offers clear advantages over conventional

irrigation systems in terms of efficiency and resource management. However, there remains a significant opportunity to explore the application of these technologies in urban agriculture. The integration of ML, ANNs, DL, and fuzzy logic continues to evolve, offering new possibilities for optimizing irrigation systems and improving agricultural productivity in both rural and urban settings.

Smart agriculture powered by Internet-of-Things and artificial intelligence technologies has significant promise for enhancing agricultural productivity. This work aims to bridge existing knowledge gaps by developing an innovative irrigation system that uses ensemble learning, IoT applications, and advanced algorithms for rainfall and yield prediction. Addressing these challenges will contribute to more efficient agricultural practices and improved food security.

In conclusion, smart irrigation systems represent a significant advancement in agricultural practices and contribute to food security and sustainable development goals (SDGs). However, to maximize benefits, organizations must invest in R&D, enhance communication systems, and prioritize security measures. By doing so, they can not only improve operational efficiency and ensure the sustainability of vital resources.

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