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AN OVERVIEW OF IOT BASED INTELLIGENT IRRIGATION SYSTEMS FOR GREENHOUSE: RECENT TRENDS AND CHALLENGES

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Food security is an issue that arises as a result of the rising population since population growth decreases agricultural land, leading to water scarcity. Agriculture requires large amounts of water, but water scarcity forces farmers to irrigate their crops with little or low-quality water, leading to the idea of developing smart irrigation. The challenge is how to manage the interactions between plants, growing media, microclimate, and water using manufactured systems. Good irrigation management will minimize the occurrence of poor irrigation design. This review is a way to present various methods and approaches for using sensors, controllers, the Internet of Things, and artificial intelligence in irrigation systems with a focus on improving water use efficiency. The study uses SCOPUS indexed publications and proceedings to study the evolution of irrigation information technology over the last eleven years. We hope this review can serve as a source of information to broaden the validity of the findings of irrigation monitoring and control technologies and help researchers identify future research directions on this subject.

Keywords: intelligent irrigation, water efficiency, smart greenhouse, internet of things, monitoring and control

1 INTRODUCTION

Due to rising food demand and a growing human population, agriculture is the primary food supplier and the most prominent labor user. It is also one of the essential areas in a country's economy, according to gross domestic product (GDP) [1], [2]. Water availability is an essential factor in optimizing the growth of crops so that water scarcity can threaten food security. This reason makes water conservation an essential factor in overcoming water shortages while increasing yields. [3, 4]. Moreover, the development of agricultural technology and more efficient agricultural management can produce productive crops and quality harvests through greenhouse technology. Developing greenhouses for agriculture can increase crop yields and improve water use efficiency [5].

Around 3.5% of the world's agricultural land uses greenhouse and hydroponic systems to conserve water use and other benefits such as crop protection and quality yields. A greenhouse is a building with a wooden or metal foundation covered with nets or transparent material. Since 1960 the greenhouse has evolved from a building that only protects plants into a system for studying plant growth in a controlled environment [6, 7]. Changes in agricultural land usage, lower irrigation water output in primary, secondary, and tertiary canals, and global microclimate changes contribute to the rising use of greenhouses in world agriculture [8].

Agricultural ecosystems (soil, nutrients, temperature, humidity, sunlight, wind, and air composition) can be adapted to the needs of the plants planted in greenhouses to extend productive plant life, change planting seasons, increase crop yields and improve harvest quality. [9, 10]. Moving crops from their natural environment to greenhouses protect plants from weather and microclimate uncertainties. On the downside, a greenhouse is a place that can store solar heat and requires resources to manage the microclimate according to plant needs, especially in countries with tropical climates. [4, 11]. Crop growth problems arise in agriculture that depends on rain and drought; runoff and erosion problems also arise during heavy rains. Water control is needed to meet crop water needs while conserving water [12]. The water control system functioned as a regulator for water flow according to the plant's needs in its growth phase [13, 14].

Conventional irrigation systems use a uniform amount of water to fields from one corner to another during their growth period regardless of the type of plant and its water needs. The result is water-wasting, where one side of the land has sufficient water, while the other can have excess or lack of water [15]. Therefore, a control system known as an intelligent irrigation system is needed to support plants' water needs while saving water. The way the system works, in general, is to adapt to the type of plant and then automatically calculate the water needs of the plant and schedule water supply based on the plant growth phase [16]. Intelligent irrigation systems are suitable for use in a greenhouse because a greenhouse has an enclosed structure to reduce or eliminate parameters affecting plant growth, such as seasons, rainfall, climate change, plant pests and diseases, and environmental changes [17, 18].

Intelligent irrigation systems are part of precision agriculture, also known as smart farming, which integrates information technology, communication technology, and control technology to automate various agricultural activities that humans initially did. With an intelligent irrigation system, the irrigation process can run optimally in managing water to meet the needs of plants [19]. Intelligent irrigation systems can manage water needs based on various parameters such as microclimate conditions, weather, sunlight, water quality such as acidity (pH), turbidity (TDS), and electrical conductivity (EC), along with plant growth phases through the Internet of Things (IoT) devices. An intelligent irrigation system can improve irrigation decisions to achieve water savings and increased yields [20–22].

The intelligent irrigation system is one of the best systems in managing and saving water while maximizing harvests; water is distributed evenly to each plant according to its needs and minimizes wasted water [23]. This system can also mix nutrients and water and help deliver them directly to the root zone, ensuring it is always in optimal moist conditions, minimizing surface runoff, preventing root rot, and eliminating percolation. The advantage is increased crop productivity, and better harvest quality also ensures optimal water efficiency. Nevertheless, good integration between IoT devices, monitoring, control, and data acquisition can be done automatically with minimum intervention to get an optimal and efficient, intelligent irrigation system [24, 25].

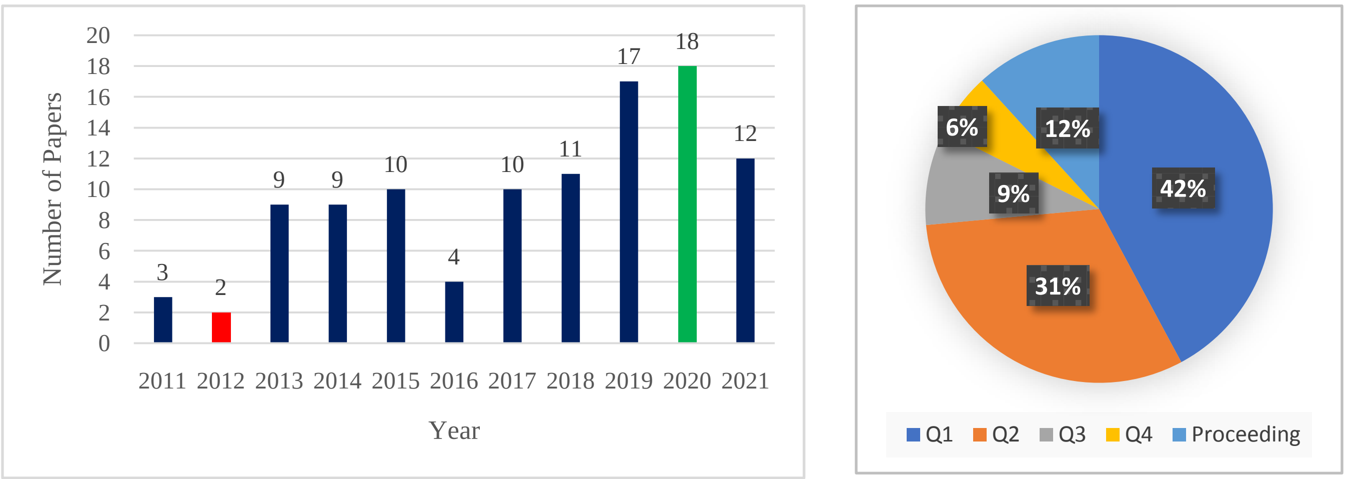
In the intelligent irrigation system, the controller can process input data, present information, and manage irrigation based on greenhouse conditions, especially crop conditions to prevent water deficit. Nevertheless, in addition to system automation, it is necessary to present current and past system conditions to users, both plant responses to the system and vice versa. This method ensures that water management runs smoothly, and users can study historical data as a reference for the next planting period and ensure optimal farming [26–29]. This process requires real-time monitoring, sophisticated control systems, and precise instruments. The difference between a monitoring system and a control system is that the control system regulates the hardware according to conditional constraints. The control system manages the hardware and software by defining the output and input parameters precisely. The input is microclimate parameters, plant properties, weather conditions, water quality, and other sensors collect helpful information [30–33].

Many articles published on IoT focus on agriculture, as discussed by [30, 34]. IoT is one of the best inventions of the 21st century in agriculture. In addition, review articles [21], [35] discuss IoT opportunities in agriculture or intelligent farming and how the connection between IoT, data mining, data science, and machine learning sustainability supports agriculture. [36] describes the automation model for monitoring and controlling the agricultural sector and predicting information based on past data. There are currently no review studies that explore the monitoring and control strategy of intelligent irrigation systems in greenhouses, necessitating the formation of intelligent irrigation system review articles that focus on integrating various monitoring and control materials. As a result, this study will cover intelligent irrigation system monitoring and control mechanisms and their relevance to greenhouses and irrigation.

This study aims to classify the results of previous research, identify the results, and bridge them with future trends to identify future research. Chapter 2 discusses research methodology, and Chapter 3 discusses various irrigation methods used by intelligent irrigation systems. In contrast, Chapter 4 discusses monitoring and controlling strategies for IoT and then continues to Chapter 5, discussing the integration of artificial intelligence. The last chapter discusses future directions and trends in intelligent irrigation.

2 REVIEW METHODOLOGY

The methodology applied in selecting published literature with the theme of intelligent farming focuses on the topic of intelligent irrigation systems and their control systems by using an extensive search on several online libraries of multidisciplinary journals as Google Scholar, ScienceDirect, Springer, MDPI, and IOP, as well as online engineering libraries as Agricola and IEEE Xplore. This technique produces many research articles relevant to intelligent farming and irrigation systems and their relationship to monitoring and control. That is why it is essential to check the reputation of the publisher's journal before using the article through the SCOPUS and ScimagoJR websites. This review's selection of relevant articles emphasizes the latest journal articles in the last eleven years (2011 - 2021); it can be seen in Figure 1a that in 2020 there was a surge in articles discussing monitoring, control, and artificial intelligence in agriculture. Other conditions are that all articles must be published in SCOPUS indexed journals and conference proceedings. As shown in Figure 1b, which shows the percentage of articles indexed by SCOPUS with articles with Quartile 1 dominating research in this field means that the research is internationally recognized and has the best quality content. All articles used are smart farming, intelligent irrigation system, and precision agriculture. Articles are carefully selected by reading and summarizing them to ensure continuity of ideas.



(a) (b)

Fig 1. IoT based intelligent irrigation systems papers distribution based on (a) publication years, and (b) Quartile positions

3 TYPES OF IRRIGATION

Plants need water at regular intervals to grow and develop; in agriculture, this watering technique is called irrigation. Irrigation has two methods, namely conventional and modern. Conventional agriculture usually uses rain and surface irrigation to irrigate its land [37, 38]. The problem is how to predict rain accurately, and surface irrigation does not continuously irrigate the entire land with a uniform discharge. Surface irrigation, classified as conventional irrigation, works by distributing water from springs or rivers to the ground surface following gravity; monitoring is done manually by looking at the water level without IoT and automation [37].

Developing countries generally use surface irrigation, for example, Indonesia. It uses it to irrigate paddy fields by constructing furrows that connect water sources with rice fields and irrigate them. However, this method requires a level ground surface to ensure adequate water distribution [39]. On the other hand, surface irrigation results in high levels of water loss due to evaporation, uncontrolled water discharge, and percolation, which can reduce soil nutrient levels resulting in sub-optimal crop yields [37]. There are two commonly used surface irrigations: (1) Furrow irrigation is interpreted as water flowing through small furrows made on the land slope. Water enters the soil from the bottom and sides of the furrow and moves laterally and downwards to moisten the soil and simultaneously carry dissolved salts, fertilizers, and herbicides [40]. Good tillage with uniform slopes can give better results from this method. Furrow irrigation is suitable for various soils, slopes, and crops especially row crops. Crops that will be damaged if water covers the stems or crowns should use furrow irrigation [40, 41]. Furrow irrigation is also suitable for tree crops. In the early stages of tree planting, using one furrow beside the tree row may be sufficient, but as the tree grows, creating two or more new furrows is necessary to provide sufficient water [42]. (2) Flooding Irrigation is an irrigation method commonly used to provide water in lowland rice cultivation and generally, water carried out continuously. Flooding is carried out continuously at the same height throughout plant growth, starting from planting until several days before harvest [43]. The use of flooding irrigation depends on sufficient water to flood the land surface with 10 cm of water. The disadvantage is inhibiting plant growth and water wastage [44]. Because flooding irrigation uses water excessively, flooding irrigation evolved into intermittent irrigation by flooding and drying the land alternately from planting season until one week before the flowering. The water level is maintained at 3 to 5 cm during flowering. Giving water this way can reduce water usage up to 30 percent without reducing crop yields [43–45]

Modern irrigation offers uniform discharge for each plant, including nutrients and saving water, mainly when planting is carried out in a greenhouse, making it easier to monitor water quantity and quality and regulate water supply schedules [46, 47]. The amount of water delivered is determined by the plant's demands, irrigation method, and type of growing medium. The choice of irrigation method influences the type of nutrients, the number of nutrients, the rate of infiltration, evaporation, water absorption, and drainage [12].

Modern irrigation uses less water and is more efficient than conventional irrigation, and this method saves more energy and water. It is an effective method for use in areas where water is scarce or has irregular rains. This method allows farmers to cultivate crops consistently, creating a reliable food supply [3, 11]. Modern irrigation relies on water from wells, lakes, and reservoirs stored in water tanks and then irrigates plants using gravity or water pumps [12]. The method of giving water is even more specific, such as spraying water through a sprinkler or dripping water through an emitter onto plants. [39] developed an automatic irrigation data communication system through the General Packet Radio Service (GPRS) and Zigbee module and built a microprocessor-based gateway to better control water discharge with water efficiency than conventional irrigation systems, with the difference between conventional and modern irrigation can be seen in Figure 2.

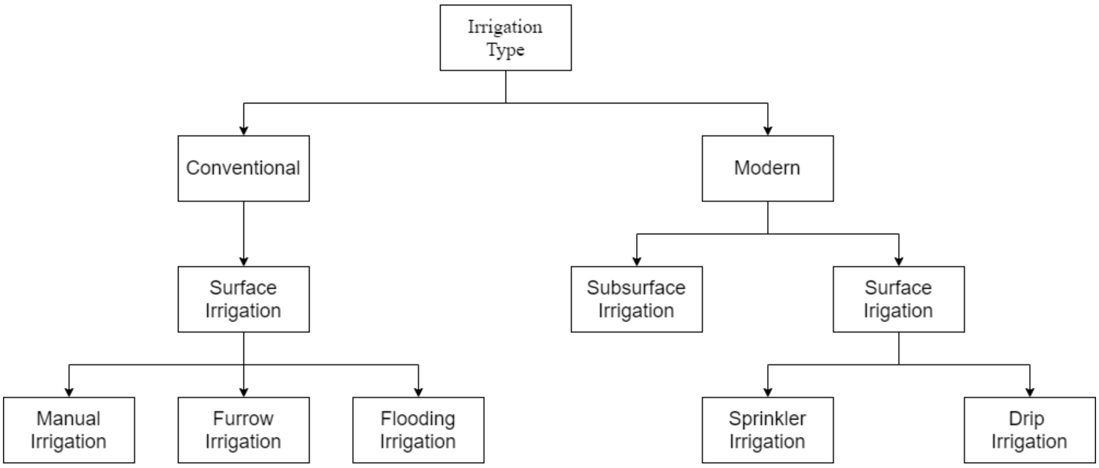


Fig 2. Types of irrigation

3.1 Sprinkler Irrigation

Farmers use sprinkler irrigation to mimic precipitation patterns. They used small sprinkler nozzles connected to an extensive piping system to ensure comprehensive irrigation coverage and used pumps to spray high-pressure water onto the air [48]. The advantage of sprinkler is that it minimizes runoff, is suitable for all types of soil, and has a water-saving rate of between 30 - 50%. Sprinkles can be mixed with fertilizer solutions and used in close cropping and high plant population [28]. However, this method has high operating costs for cleaning sprinkler nozzles and maintaining high-pressure pumps and pipes. In addition, sprinkler irrigation is unsuitable for use in windy areas because wind gusts and evapotranspiration cause high water loss rates. Moreover, regular maintenance of the pipes and their connections to avoid leaks or clogs can reduce the water spray pressure, reducing water distribution to the plants [37, 48].

3.2 Drip Irrigation

In drip irrigation, the water source moistens the soil or planting media through the holes in the pipes and flows through a hose connected to the emitter with low pressure. The focus of water droplets is a small part of the soil or growing medium that covers the root zone by adjusting it to get water droplets [49]. Drip irrigation is the most efficient irrigation because it can distribute water and nutrients simultaneously to the root zone, which results in better nutrient uptake. Due to the circulation of water in the roots through the capillary principle, the pores of the soil or planting medium remain dry so that air circulation is maintained and soil moisture is at field capacity. Produces a root zone capable of breathing more intensely during its growth cycle [25, 37, 50].

Drip irrigation uses dripping water delivered at a rate of between 2 - 20 liters per hour. The application of this method is to place an emitter on each plant. It is suitable for use on vegetables and fruit, but farmers usually only consider high-value plants because the investment value is relatively high [37, 49]. This method supports various types of soil by adjusting the speed of water application. Hefty porous sandy soils need a fast drip-rate; conversely, clay soil needs a slow drip rate to avoid water logging and runoff [25, 37].

4 MONITORING AND CONTROLLING STRATEGIES

A total of 30 papers were used to examine the irrigation system's monitoring and control method. These publications provide ways for regulating irrigation by employing sensors to measure changes in microclimate, water quality, and soil moisture values. The paper's distribution is represented in Figure 3 below.

An effective and efficient monitoring system is needed to collect different plant growth parameters. Monitoring in an intelligent irrigation system involves collecting data representing the latest microclimate data and water and soil conditions around the irrigation area through a microcontroller connected to the IoT [51], shown in Figure 4. The development of real-time monitoring devices was made possible due to the rapid development of microcontrollers and sensors, low-cost hardware (Arduino UNO, ESP8266, Raspberry Pi), and fast internet, which enhanced the performance of monitoring and control systems [17, 52]. There are two types of internet connections: wired and wireless; Wired connections make the internet connection stable, but with fixed hardware location. Wireless connection makes flexible hardware placement but has signal interference [53].

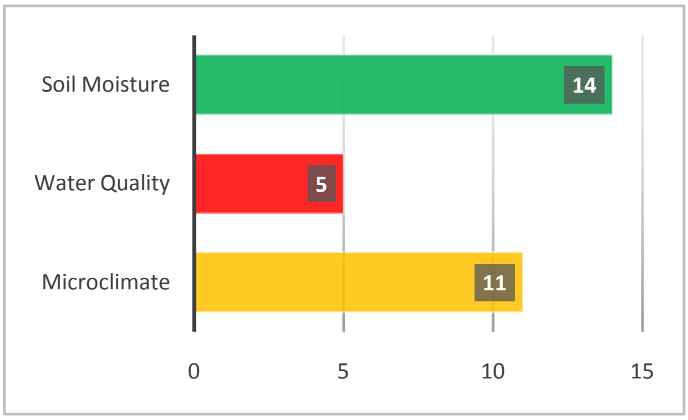


Fig 3. Distribution of papers on monitoring and controlling strategies

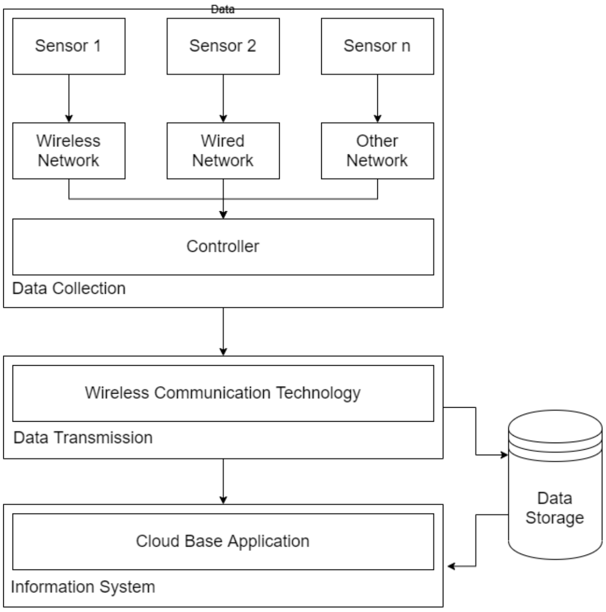


Fig 4. Block diagram of IoT based Smart Farming

All devices and sensors are connected directly to the server via a cabling system in a wired connection case. This system is only effective when a few parameters are measured and use a small greenhouse; it is crucial because the more connected devices, the more cables are used. So, the wired greenhouse system is not suitable for large or commercial greenhouses. The advantage is that data transactions are safe and have minimal interference [51, 53, 54]. WSN is the latest technology in intelligent farming that can be expanded and scaled up without modifying the greenhouse infrastructure. Its wireless form makes it easy to receive and transmit data between nodes using low-power frequencies. Unfortunately, interference and signal loss are common problems because of the high frequency in the air. However, the increase in greenhouse size, the number of parameters, sensors variety, node size, and devices distant is not a problem because an additional WSN only needs to be attached to an existing network. Another advantage is Wireless Sensor Networks (WSN) technology, wirelessly connected sensor nodes network to sense and send various data, and extensible [36, 54, 55].

The implementation of WSN in agriculture itself is extensive, with sensors, RFID, cameras, drones, and cloud services connected seamlessly for data acquisition and transmission. Cloud computing serves data collection and analysis to generate visualizations, decision support, and commands; system users (farmers or researchers) can then access data remotely via their devices to gain real-time insights [19, 56]. Thus, monitoring and controlling the intelligent irrigation system can be effective, efficient, convenient, and optimal yields. [55] proposed the approach with WSN and gateway node to collect soil moisture values in plants by taking soil and cultivated plants images. The challenges in building a system that can accommodate these two technologies are sensor coverage, communication between devices, computational process efficiency, and electricity usage. [57] also offers UAVs for aerial monitoring of vegetation and irrigation areas.

Appropriate control techniques in intelligent irrigation systems can increase crop water supply precisely to improve the efficiency of water use, energy savings, harvest optimization, proper use of nutrients, and effective use of labor.

Therefore, a control system can manipulate several irrigation parameters, like air circulation, air temperature, relative humidity, wind speed, and solar radiation [58–60]. A technology that can analyze the surface temperature of agricultural land without touching it using thermal imaging was proposed by [61] to determine which areas of land are in dire need of water because the non-uniformity of soil moisture can inhibit spinach growth. Studies by [56, 62–64] also state that it is possible to use thermal imaging for nurseries, forecasting crop yields, pest and disease disturbances, maintenance of agricultural machinery, and irrigation scheduling.

4.1 Microclimate based

Monitoring and controlling the microclimate in the greenhouse is a critical factor to account for water loss due to evaporation. Air temperature, relative humidity, solar radiation, and wind speed need precision measurements to meet crop water requirements [30, 65]. The Raspberry Pi, various Arduino models, connected to WSN, and cloud servers are popular hardware. WSN implementation is an efficient way to interconnect various sensors placed far apart in the greenhouse. The system performs accurate system monitoring, collects data, and presents charts, and control devices are activated, referring to predefined threshold values compared with real-time data [30, 36, 66].

[59] presented a technique for evaluating microclimate parameters in two tropical greenhouses before planting tomatoes using LoRa wireless and IoT sensors. The comfort ratio model (CftM) and scenario analysis show that environmental conditions can adapt to the growth phase of tomato plants. The microclimate before and during planting was analyzed using the Simulink app. Also, a study by [67] showed that a microclimate parameter measurement device in a greenhouse could yield comprehensive data for temperature, humidity, CO2 levels, lighting levels, soil moisture, acidity, irrigation water conductivity, and airflow velocity. In winter, the greenhouse behavior was studied by [68] using fuzzy logic control (FLC) due to uncertainty in the greenhouse environment. The fuzzy set was developed based on experts in greenhouse thermal behavior. Fuzzy control manages decisions based on weather forecasts and user interactions. [54] also took a similar approach to measure leaf temperature, air temperature, and soil moisture using three connected sensors to assess the level of microclimate in a greenhouse and use Zigbee to transmit sensor data.

Controlling the microclimate in the greenhouse by using fan ventilation and fan-pad ventilation can also be an option. This forced ventilation can prevent plants from overheating even if the greenhouse does not use an evaporative cooling system. Greenhouses can produce good harvests in the spring, and the data show a relationship between the greenhouse microclimate and water uptake that minimizes drainage [69]. [70] built a monitoring system using an open-source platform to collect microclimate variables (air temperature, humidity, soil temperature, and soil moisture). Communication between devices uses Bluetooth and obtain electricity supply through solar panels. [71] has proposed improvements to the greenhouse IoT-based system by adding color spectrum monitoring using a camera system to get photos of the plant canopies translated into color (RGB, HSL, and brightness), plant texture, thermal (plant temperature), and plant morphology. The system works with NFT to irrigate lettuce plants in the greenhouse, automatically recording data and identifying plant stress levels.

4.2 Water Quality-based

Water quality safety is a challenge in the 21st century because of the many pollutants, which are predominantly artificial such as environmental damage, packaging waste, or chemical waste. Overexploitation of natural resources, rapid industrial development, and agricultural expansion are the leading causes of the problem. [72]. Water quality is affected by direct and indirect sources of pollution such as sewage, factory waste, agricultural and urban runoff. The need for human involvement in water quality management is essential [73, 74]. Water quality management is a way to regularly collect water quality information in a location to find out its current condition. Water quality management aims to measure water quality variables such as microbial content physical and chemical properties, provide an early warning system and provide decision support for further treatment [75, 76]. WSN and IoT are inevitable to manage variables over a wide area for larger areas such as lakes or oceans.

[75] has proposed a system that assesses irrigation water quality with IoT by detecting potential hydrogen (pH), electrical conductivity (EC), turbidity, and salinity in real-time using different sensors to maintain plant health status. Also, [77] undertook a study to build a continuous water quality monitoring system using open-source hardware and low-cost sensors. Preliminary results show that the device can produce accurate results at a lower cost than existing technologies with proper calibration.

4.3 Soil Moisture-based

Farmers need to consider soil conditions because moist soil means the plant still has enough water for growth [11]. Monitoring soil moisture content becomes vital as the basis for irrigation scheduling. Raspberry Pi and Arduino UNO have commonly used devices in developing low-cost IoT-based soil moisture management interfaced using various sensors [30, 60, 75]. The sensor used is a capacitive type and transmits electricity without conduction; it can measure soil moisture changes by planting them into the soil and measuring its volumetric water content. The Time Domain Reflectometry (TDR) sensor is a more precise option for measuring soil moisture, consisting of two metal rods embedded at the depth at which the humidity is to be measured. Works by sending pulses to the soil and then calculating the response of the soil as soil moisture content. Due to its good quality in measuring soil moisture, this TDR sensor is quite expensive to use in large-scale greenhouses [78, 79].

[80] proposed a soil moisture control system for measuring water content in soil at different soil depths, soil types, and air temperatures using various sensors integrated with Arduino UNO. The ESP8266 wireless module is then linked to the Arduino to upload data to the cloud server. A similar study by [81] succeeded in developing an IoT-based field control system integrated with cloud-based data monitoring and analysis. The analysis results help predict water consumption for better crop yields. [82] approach to controlling soil moisture uses wireless technology utilizing GSM networks and push notifications to automate water supply for plants. A system proposed by [83] presents an Android application-based humidity monitoring method, where an Arduino interface sensor connected to Wi-Fi sends state data to a smartphone. Another monitoring approach is carried out by [60] using IoT and soil nutrient sensors to detect nutrient adequacy for plants. The decision support system then receives the data parameters and processes them as a farming decision.

[84] implemented a user-friendly system, representing the soil moisture level with colors. These colors have helped farmers visually identify and manage soil moisture content without understanding the values displayed. Likewise, [85] proposed a soil nutrient control system that can manage the concentration of nutrients in the soil by planting sensors in the soil to map nutrient variability. Also, [86] developed an innovative device that uses a camera-integrated drone for field mapping. Images are analyzed to generate soil moisture and nutrient values and use them for irrigation planning and scheduling.

5 ARTIFICIAL INTELLIGENCE IN IRRIGATION SYSTEM

Artificial intelligence in intelligent irrigation systems was the subject of 25 papers. These studies concentrate on developing decision support systems, fuzzy logic models, and artificial neural network models that can take decisions automatically in response to changes in field conditions. The distribution of articles based on the theme of artificial intelligence is shown in Figure 5 below.

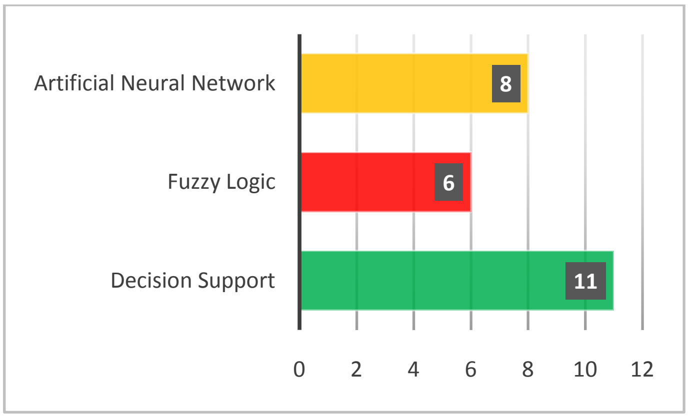


Fig 5. Distribution of papers on artificial intelligence in irrigation system

Artificial intelligence (AI) is a branch of science concerned with creating machines that can understand and act in the same way as humans. Machine learning is a burgeoning sub-domain of AI that explores patterns in large amounts of data [58, 87]. The popularity of machine learning is due to more and more data generated by various applications and IoT. The system can generate helpful information for making decisions or becoming input to other systems by studying data patterns. The need for agricultural products is directly proportional to the increase in the earth's population, so agroindustry and innovative agriculture technology get the spotlight in the industrial revolution 4.0 [16, 46].

AI has the potential to solve nonlinear, multiparameter, and time-varying problems in managing intelligent irrigation systems. By applying AI algorithms to specific problem areas, the system tries to imitate human logic, thought processes, and decision making through the application of Fuzzy Logic, Support Vector Machine (SVM), k-Nearest Neighbor (kNN), Decision Tree and Random Forest by using past data to feed AI and provides new knowledge to the system [58, 61]. [88] has researched by applying different regression and machine learning algorithms to several sensor datasets to develop weekly irrigation plan predictions.

A study implementing an intelligent irrigation system shows many advantages, such as minimizing soil stress to changing microclimate conditions, efficient water use, and reducing human interaction. This solar panel-powered system has a Sensor Layer, Central Layer, and Valve Layer running together. The function of the Central Layer is to control the process that produces input (sensor layer detects moisture content) and output (valve layer opens to provide water). The system also enables fertilizers and pesticides by calibrating other sensors according to the required input [89].

5.1 Decision Support System

Water management for irrigation requires extensive and comprehensive data on dispersed and spatial agriculture. In general, farmers have difficulty processing their data because they do not have the experience and expertise to make irrigation management decisions; this is where the decision support system (DSS) comes in [76, 90]. DSS has a framework that can represent complex systems with an efficient and robust approach that is easy to understand generates additional information and new perspectives to improve the quality of irrigation management. DSS is an information system that analyzes data and represents it to make decisions quickly. The primary purpose of DSS is to support and improve decision-making [28, 76]. Figure 6 shows a DSS logic diagram that consists of four connected components: Database, model base, knowledge base, and user interface.

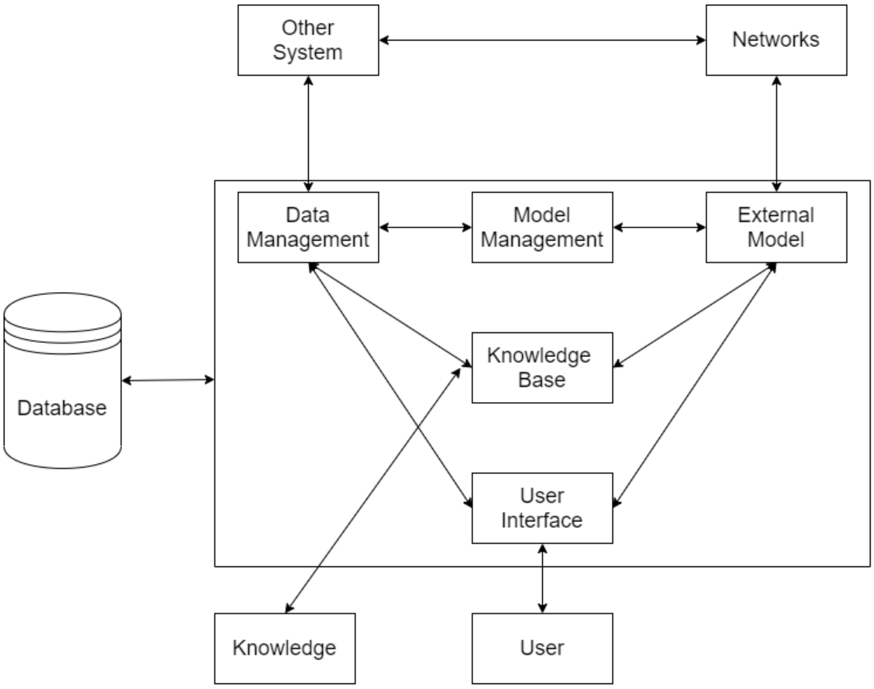


Fig 6. Block diagram of Decision Support System

The Database in irrigation DSS collects and manages air temperature, relative humidity, crop water requirements, irrigation records, and solar radiation. The knowledge base has three parts: fact base, rule base, and inference engine used to analyze data, solve uncertain problems and draw conclusions. The model base creates optimization models, integrates numerous decision models, analyzes them to create crop water simulations, and offers farmers irrigation scheduling. [71, 76].

Developing and utilizing a decision support system in irrigation management is essential for scheduling water delivery based on crop needs. The main problem is how moist the soil is and how much water the plants need based on the type of plant, planting technique, availability of water, amount of fertilizer applied, microclimate conditions, and stage of plant development [91]. With DSS, farmers can manage their farms daily using plant databases and water supply strategies to perform irrigation calculations and fertilization adjustments to obtain optimal yields. There are times when a system has a crop suggestion feature that advises farmers to plant a crop that yields the highest profit under certain constraints [92].

The problem is that the characteristics of crops, soils, and microclimatic conditions in agriculture are dynamic and not linear, varying with seasons. Therefore, setting the proper irrigation schedule will directly influence plant growth. The core of DSS includes monitoring different parameters using different sensors and configuring their rules. DSS manages sensor readings stored in the cloud to adjust irrigation scheduling to maintain irrigation system efficiency routinely [76, 90]. An intelligent irrigation DSS must have the ability to adapt to changes in transient and spatial plant dynamics, such as uncertainties in microclimate conditions, nutrient requirements, and environmental changes. Researchers have proposed many studies on DSS applied to irrigation systems, such as [93], who developed an automated irrigation system using a single lateral pipe covering a large area to manage water at varying speeds.

Sprinkler irrigation developed by [94] uses an automatic linear moving sprinkler system with WSN based DSS. The system can adapt to crop types, irrigation requirements, and planting locations to command individual sprinkler heads how and where water must be applied. Similarly, [76] built a DSS integrated fertigation simulator for designing drip or sprinkler irrigation for on-site olives and grapes farms. The system has a database, simulation model, and user interface that shows the ranking of design alternatives through multicriteria decision-making (MCDM). The scope of the calculation of this system includes land analysis, water requirements, and plant nutrition.

5.2 Fuzzy Logic Model

A fuzzy logic model is a data-driven technique with easy-to-understand logical rules. [50, 68, 95] proposed a fuzzy logic-based irrigation scheduling by enforcing control rules to microclimate data, evaporation data, and soil conditions. The process flow can be seen in Figure 7.

[96] succeeded in building and testing a rule-based Fuzzy Logic application to assess the water stress index of plants in a greenhouse; the application accepts three input variables, namely air temperature, solar radiation, and water pressure. Results show that Fuzzy Logic eliminates the need for air aerodynamic resistance data, making this system more straightforward.

[95] developed fuzzy logic using the LabVIEW application to create a graphical user interface (GUI) for a drip irrigation control system in a greenhouse. The input parameters used are air temperature and soil moisture and process them using fuzzy rules to produce information of irrigation duration. The test results show that fuzzy logic control can efficiently estimate irrigation schedules in an automated system, and greenhouse managers can monitor real-time data and devices that are easy to manage, even for ordinary users. [97] research also designed an irrigation control based on fuzzy logic applying the Penman-Monteith equation for rice cultivation with a parameter model in the difference between actual and target evapotranspiration following the plant growth phase. Each phase has its water requirement. The research aims to develop an intelligent system that helps irrigation management and produces a system that can work better than conventional irrigation systems. The results showed that the control system saves water, improves irrigation performance, improves crop quality, and saves labor.

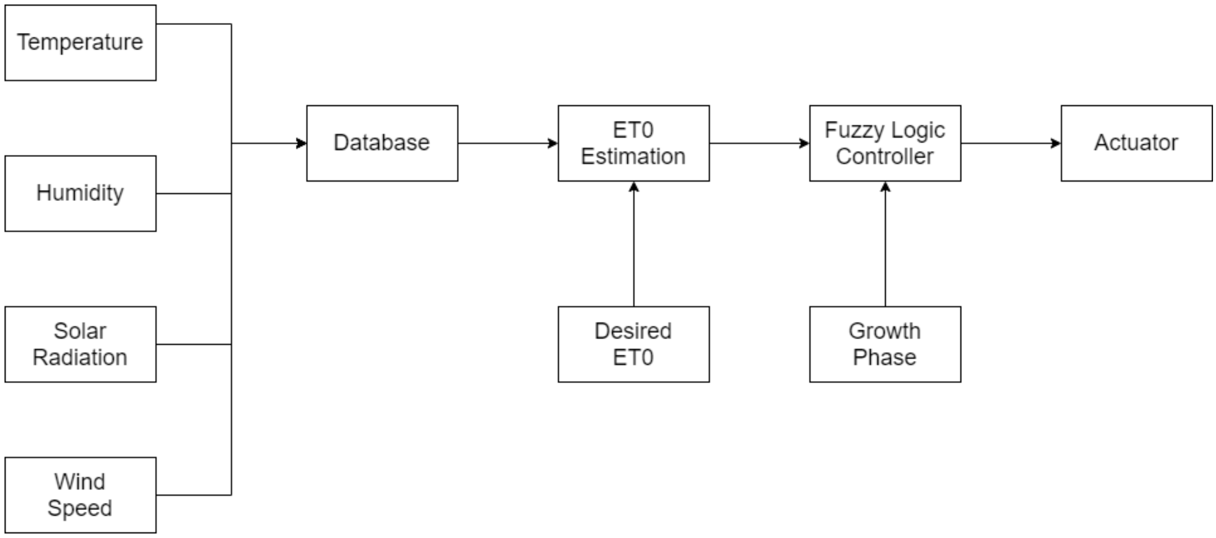


Fig 7. Fuzzy Logic-based Intelligent Irrigation System

Also, [50] developed a fuzzy logic system that evaluates the irrigation system based on the variable availability of irrigation water during the planting period on the level of farmers' income which results in the efficiency of the irrigation system performance. To assist in making decisions on irrigation distribution. [98] conducted similar research by developing an intelligent irrigation system to turn on and off the irrigation system using input parameters of water use, water and air temperature, and soil moisture. They implement WSN-based monitoring to send data on fuzzy logic, which then performs irrigation scheduling by applying fuzzy rules. The system can maintain soil moisture content at the specified limit to save the use of electrical energy, water, and runoff.

5.3 Artificial Neural Network Model

One application of AI in agriculture is Artificial Neural Networks (ANN) algorithms, which can predict using elements interconnected and work in parallel. The advantage of neural networks is that they can be trained, for example, to distinguish grass from rice or to compare tomatoes to peppers [71]. The ANN system can predict with high accuracy when fed reliable and precise data. A trained ANN is considered an expert in a category of data. This expert can then predict possible future conditions and prepare what-if scenarios [73, 87]. Other advantages of ANN are (1) Adaptive learning, the ability to learn and carry out tasks based on the data provided, (2) Self-organization, the system can independently compile and build information representations during the learning process, and (3) Real-time operations, computations are carried out in parallel, so it is faster to get calculation results [99].

The ANN model is a simple model consisting of three primary neurons distributed in the input layer, multiples of the hidden layer, and the output layer. ANN development requires necessary basic steps, namely datasets, ANN model training data, and ANN model test data for evaluation. Using quality data, the ANN model has a mechanism for self-study and solving complex problems. Input neurons receive parameters, then hidden neurons perform computations, and output neurons send signals to other network layers; and interconnect neurons using linear and nonlinear functions [26, 87, 99, 100].

The following Figure 8 shows the ANN process flow. In general, the use of ANN includes problem-solving in system optimization, process control, pattern classification, forecasting, and prediction. The main components of an ANN model consist of neuron nodes, a hidden layer containing weights between parameters and distribution rules to generate information for learning rules and independent learning skills through experience. There are two types of ANN models based on their input choices: feed-forward and feed-backward networks [99].

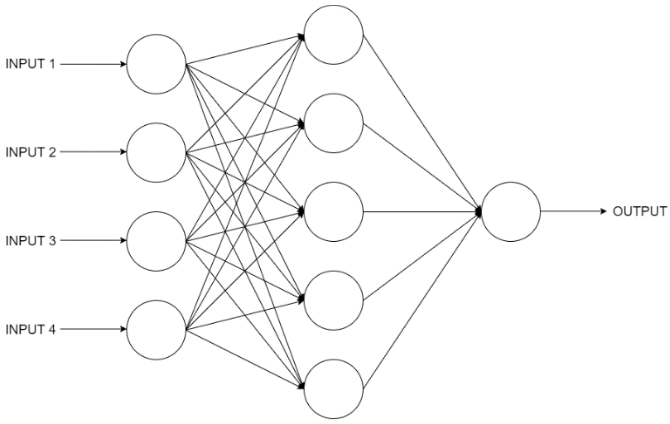


Fig 8. The flow of feed-forward artificial neurons

Evapotranspiration is essential information that needs to be known to optimize plant growth, especially in water management and sustainable irrigation systems. Knowledge of the parameters of air temperature, relative humidity, wind speed, hours of sunshine, and latitude can optimize the management of ET0 in a greenhouse [97]. ANN research on intelligent irrigation systems is applied to scheduling and irrigation discharge to achieve savings in irrigation water use. [87] conducted a study to estimate the value of soil moisture in rice farming land using minimal micro and macro climate data by applying two ANN models. The first model predicts the value of ET0 using the minimum, maximum and average air temperature variables. The second model does the same thing but uses air temperature, precipitation, and solar radiation. The test results show that both models produce reliable and accurate soil moisture estimates.

A study by [101] has developed an ANN model to calculate evapotranspiration (ET0). After testing, they concluded that the ANN model predicts evapotranspiration better than the conventional ET0 equation. Similarly, [90] developed an ANN to calculate ET0 and compared it with the Penman-FAO equation and Penman-Monteith model using four and six microclimate variables as inputs. The test indicates that the three models provide accurate results using six input parameters. In contrast, the test results with four parameters show that only the ANN model can accurately predict the ET0 value. This research shows that building an ANN model is possible even with limited microclimate data.

In addition, irrigation control system automation was also proposed by [102] using the ANN cluster and closed-loop control, which resulted in better performance than time-based irrigation control. However, they did not provide information regarding the irrigation method used and the percentage of water savings. [100] developed an intelligent irrigation system for evapotranspiration using the ANN model and a photovoltaic system to predict irrigation scheduling based on cropping moisture distribution data; this study reported better daily water and electrical energy savings also better crop yields. The application of ANN in irrigation water management has also discussed prediction of water salinity, water quality, rain runoff, and forecasting of surface irrigation infiltration,

[73] proposed two ANN models to predict Biochemical Oxygen Demand (BOD) and Dissolved Oxygen (DO) for irrigation water originating from rivers; the conclusion is that water quality management in other areas can also use this ANN model. Similarly, [103] uses the ANN model to design an intelligent system to manage water systems for agriculture and fisheries. [104] explained that the greenhouse environment has dynamic and complex characteristics, making it difficult to use conventional control methods as a solution. Radial Basis Function Neural Networks (RBF) algorithm and nonlinear adaptive controllers become solutions to control greenhouse microclimate. [74] discusses the use of ANN in drip irrigation systems to predict the distribution of subsurface irrigation water. The development of the ANN is to model the continuous wetting pattern after the water droplets from the emitter touch the ground surface.

6 FUTURE OPPORTUNITIES AND CHALLENGES

This review explored the various studies and progress to improve irrigation water use efficiency, nutrient optimization, and crop yields. The aim is to improve and increase food availability by implementing IoT-based monitoring and control on agricultural land, especially greenhouses. The review results show that researchers and farmers can maximize the use of the latest IoT technologies for environmental conditions monitoring, data-driven control, and artificial intelligence. Nowadays, there is an increase in research that develops techniques and models for developing irrigation control systems. The trend is due to the emergence of various sensors and controls on the market; this provides vast opportunities for the development of precision agriculture, especially for making intelligent predictions of agricultural processes such as crop yields, crop water requirements, and microclimate conditions. Researchers also need to explore other factors that influence irrigation scheduling planning, especially in large agricultural areas, because researchers generally conduct studies on a laboratory scale. Research from different perspectives will enrich intelligent irrigation systems and result in inaccurate predictions that can advise farmers regarding their farming activities and notify them when anomalies occur.

Furthermore, researchers need to test various control systems in the irrigation systems discussed, focus on adaptive control, and combine it with real-time monitoring. It is essential to build systems that can adapt to dynamic parameters of microclimate, soil, and plant. At the same time, ensure the intelligent irrigation system runs optimally. In addition, it is essential to develop intelligent irrigation systems that are increasingly complex and digital-based so that the technology is suitable, affordable, and stable for smallholders. The hope is to increase water use efficiency and solve water scarcity.

7 CONCLUSION

Limited water has become the biggest challenge for farmers, and efficiency must solve water scarcity in irrigation management. The main objective is to control the amount and frequency of irrigation so that the amount of water received by plants is sufficient to keep the root zone moist. Farmers who are generally ignorant about the complexity of optimal irrigation management need a system that can facilitate big data processing analysis tools and transmit quality information quickly and efficiently. The system must be able to provide recommendations according to the conditions of the agricultural environment to increase the experience and decision-making of farmers.

This problem challenges researchers to increase efforts to develop sophisticated monitoring and control strategies for intelligent farming that minimize irrigation water use. This review draws on previous relevant studies on agriculture water saving. The review results describe research trends in intelligent irrigation systems monitoring and control strategies and assess research opportunities to ensure water availability and savings. We hope this review provides insight and inspiration for researchers to continue research on irrigation monitoring and control to achieve food security and water savings.

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