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Revolutionizing Saudi Arabia's Agriculture: The IoT Transformation of Water Management

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ABSTRACT

Saudi Arabia's agriculture heavily depends on effective water management, given its limited freshwater resources and arid climate. Real-time monitoring of soil moisture levels, weather conditions, and crop watering needs, facilitated by IoT integration, plays a crucial role in conserving water and minimizing waste. The resultant improvements in crop yields and quality are essential for the long-term success of agriculture in the country. This study employs the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) method to investigate the transformative potential of the Internet of Things (IoT) in enhancing water management practices in Saudi Arabia's agriculture sector. The research begins by highlighting the significance of water management in agriculture, emphasizing the proportion of land in Saudi Arabia allocated to agricultural purposes. The problem statement underscores the pressing challenges in water management, encompassing issues such as water scarcity, inefficient irrigation methods, and the need for real-time data to inform decision-making. To address these challenges, the study proposes an IoT-based Agricultural Water Management System (IoT-AWMS) that leverages sensors, real-time data analytics, and machine learning algorithms. This system is designed to optimize water utilization in agriculture. Simulations conducted within the study demonstrate a significant enhancement in water usage efficiency, resulting in reduced water wastage and increased crop yields. In conclusion, this research underscores the critical importance of the proposed IoT-based water management system for Saudi Arabia. It is positioned as a valuable tool for mitigating water scarcity challenges and promoting environmentally sustainable agricultural practices in the country.

1. Introduction

Saudi Arabia's agricultural sector has been essential in the country's economic rise and development. Saudi Arabia's agricultural industry is growing despite being located in the middle of a large desert. The country's diversified harvests have sustained its people and powered its economy, providing everything from lush date palms to vivid fruits and vegetables. The agricultural business has flourished despite the dry climate, making a major economic contribution and providing work for

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a considerable section of the population. In this article, we look at how Saudi Arabia is enhancing agricultural sustainability and production by rethinking water management via the integration of cutting-edge technology and the Internet of Things [1].

Sustainable development and effective resource management are stressed in Saudi Arabia's Vision 2030 [2]. Agriculture, a major sector of the country's economy, plays a crucial part in realising these objectives. The demand for additional water is a major issue for Saudi Arabia's agriculture economy. The majority of the landmass is desert, making water a precious commodity. The agricultural sector accounts for roughly 90 percent of the country's water use, making it necessary to manage this resource properly [3].

For Saudi Arabia's economy and its goal of sustainable growth, effective water management in agriculture is crucial. Traditional techniques of water management in the country's agriculture sector have their limitations. The overuse of outdated irrigation methods that may be more effective and profitable is a major problem. Further complicating efforts to maximise water efficiency is the demand for more precise data and information on water availability, agricultural needs, and weather patterns [4]. Besides, [5] investigated vegetable diseases in the Central Province in Saudi Arabia as early diagnosis of plant diseases may boost the productivity and quality of agricultural operations in the agricultural industry.

Reduced crop yields, lower profits, and an adverse effect on the environment are just some of the problems cited as a result of inefficient water management in the agricultural sector [5]. Reduced productivity and higher expenses for farmers are the results of traditional methods of water management that cause waterlogging, salinization, and soil degradation.

Thanks to IoT, agricultural and water management have advanced greatly [6]. With the use of sensors, software, and other Internet of Things–enabled technologies, farmers and water management authorities can remotely monitor and regulate their operations, resulting in more efficiency, less waste, and higher crop yields. The agricultural industry is crucial to Saudi Arabia's economy and food security, and IoT-enabled agriculture water management might drastically improve it. Farmers may optimise irrigation, fertiliser usage, and other inputs with the help of IoT-enabled water management systems by remotely monitoring soil moisture levels, weather conditions, and plant health [7]. Because of this, water use, water waste, and agricultural yields may all be improved.

Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) [8] is one way to rank various Internet of Things (IoT)-enabled water management solutions for agriculture. TOPSIS is a method for determining which of many possible choices is the best according to a set of predetermined criteria [9]. TOPSIS may compare systems in Saudi Arabia's context of IoT-enabled agricultural water management in terms of water efficiency, crop yields, cost-effectiveness, and simplicity of use. [10]. In addition, rainfall prediction of harvest yield and the proper use of water assets can be utilized for successful collection of water, and the successful pre-growth of water construction all depend on an accurate assessment of rainfall [11].

1.1 Motivation

Researching the importance of water management to Saudi Arabia's agricultural sector is not simply an academic exercise; it's a necessary first step in ensuring the long-term viability and prosperity of the sector. The need for novel approaches to the problems of dwindling freshwater supplies and dry climates is at the heart of the investigation that has led to these findings.

The goal of this research is to use the disruptive power of the IoT to solve these problems. IoT integration for real-time monitoring of soil moisture levels, weather, and crop watering demands is highlighted as an important tactic. By applying the Technique for Order of Preference by Similarity to the Ideal Solution (TOPSIS) technique, the research intends to statistically examine the influence of IoT on water management practises.

Water management is discussed in the context of agriculture, with a focus on Saudi Arabia, where a large percentage of the country's land is used for farming. Water shortages, ineffective irrigation techniques, and a lack of real-time data for intelligent decision making are all highlighted in the problem statement.

The report recommends implementing an IoT-based Agricultural Water Management System to deal with these issues head-on (IoT-AWMS). Sensors, real-time data analytics, and machine learning algorithms are all included into this system to provide a complete answer. The end aim is more effective use of water in agriculture, which can only be achieved by maximising the use of this limited resource.

The study's simulations show how the suggested approach might help in practical ways. The findings demonstrate a significant improvement in water consumption efficiency, which translates to less water being wasted and higher agricultural yields. These findings highlight the real-world relevance and potential game-changing strength of IoT in the field of water management for agriculture in Saudi Arabia.

To sum up, this study does more than just point out the problems; it also suggests a practical and original remedy. The Internet of Things-based water management system is seen as a useful instrument for reducing the effects of water shortages and increasing the adoption of ecologically responsible farming methods in Saudi Arabia. It is clear from the results that adopting and implementing such technology is crucial to the future of agriculture in the area, and the research serves as a call to action in this regard.

The primary contributions of the research are listed below:

i. The paper suggests an Internet of Things-enabled water management system to improve irrigation and water usage efficiency in Saudi Arabian agriculture.
ii. The accuracy, precision, sensitivity, and F score of the proposed system are examined in this research utilising the TOPSIS technique. Also taken into account are water use, soil moisture level, and crop production.
iii. The findings reveal that the proposed IoT-enabled water management system outperforms conventional water management systems in terms of water efficiency, crop yields, and cost-effectiveness, as compared to current (SVM, CNN, PCA, DT, and RF) systems.

Using the FAOSTAT dataset in the MATLAB simulation tool and hardware setup to test in real-time, the article suggests that using IoT-enabled water management systems can increase efficiency, reduce water waste, and improve crop yields, contributing to the sustainability of agriculture in Saudi Arabia.

Section 2 of the essay introduces the context for this system's importance and conducts a literature review of previous studies. Next, the proposed IoT-AWMS system's architecture, hardware, and software are outlined in Section 3. The article's Section 4 offers simulation results and analysis of the system's performance, showing that it can track and adjust the flow of water in real time. The study is wrapped up in Section 5, where the potential of IoT-based systems to change agriculture and contribute to sustainable water management practises is outlined, along with the study's limitations and directions for further research.

2. Background and Literature Survey

The purpose of this analysis of several Internet of Things (IoT) approaches to water management in agriculture is to assess the efficacy of those approaches. The research looks at the possibilities of many Internets of Things-based methods, including as sensors, actuators, communication systems, and data analytics, to boost water efficiency, cut waste, and increase agricultural yields.

A low-cost IoT and blockchain-based water management system for precision agriculture was presented by Pincheira *et al.,* [11]. One of the new aspects of this research is the implementation of a blockchain-based system that allows for safe and transparent data exchange across stakeholders by using low-cost IoT devices as trustworthy data sources. The simulation results revealed that the suggested approach enhanced water consumption efficiency by up to 35 percent and decreased water waste by up to 42 percent compared to existing irrigation techniques.

An IoT and blockchain-based intelligent water management system for agriculture was presented by Zeng *et al.,* [12]. Optimal water usage, less waste, and increased agricultural yields are the new outcomes of this paper's combination of Internet of Things (IoT) sensors, data analytics, and blockchain technology. The suggested approach enhanced water usage efficiency by up to 25% and decreased water waste by up to 30%, according to simulation findings compared to conventional irrigation methods.

An experimental configuration of a Multi-Intelligent Control System (MICS) for water management in agriculture utilising IoT technology was suggested by Hadipour *et al.,* [13]. MICS is unusual because it integrates fuzzy logic, neural networks, and genetic algorithms to regulate water distribution in irrigation systems. Compared to conventional irrigation methods, the simulation results revealed that the suggested approach increased water usage efficiency by up to 30% and decreased water waste by up to 35%.

Based on IoT devices and statistical analysis, Liu suggested a water management system for farms. The originality of this research lies in its use of Internet of Things (IoT) sensors, data analytics, and machine learning algorithms to optimise irrigation scheduling and increase agricultural efficiency in water consumption. The suggested technique enhanced water usage efficiency by up to 40% and decreased water waste by up to 50% compared to conventional irrigation methods, according to simulation data.

Roy *et al.,* suggested an IoT-based dynamic irrigation scheduling system for the water management of irrigated crops [15]. The innovation of this work lies in the use of Internet of Things (IoT) sensors, machine learning algorithms, and meteorological data to optimise irrigation scheduling in real time depending on soil moisture levels and weather conditions. Compared to conventional irrigation methods, the simulation results revealed that the suggested approach increased water usage efficiency by up to 30% and decreased water waste by up to 40%.

For smart water management, Jayalakshmi *et al.,* suggest a sensor-cloud-based precision agricultural strategy [16]. The innovation of this method is in its ability to gather data in real time from a wide variety of sensors, including those that measure soil moisture, temperature, humidity, and light. The authors simulated their technique and attained a 92 percent accuracy rate in estimating the water needs of the crops.

For smallholder farmers in rural sub-Saharan Africa, Nigussie *et al.,* introduce an IoT-based irrigation management system. The suggested system uses a weather station and moisture sensors in the soil to assess environmental factors. The innovation of this method is in its use of a cheap IoT system to provide remote irrigation control to farmers. The scientists ran a simulation and found that they could cut water use by 30 percent without affecting crop production.

Sen *et al.,* [18] present a machine learning and IoT-based intelligent farming methodology. Several sensors were utilised by the authors to gather information on soil and crop conditions, including moisture, temperature, and humidity levels. The innovation of this method is in its use of machine learning algorithms to forecast crop water needs. The authors ran a simulation and were able to anticipate the crops' water needs with 94.9 percent accuracy.

Using a case study in Almeria, Spain, Muoz *et al.,* present an IoT architecture for water resource management in agro-industrial settings. The scientists used an array of sensors, including ones that measured soil moisture, temperature, and water flow, to compile information on soil and water availability. Incorporating an IoT platform that allows for remote monitoring and management of the irrigation operation is what makes this method interesting. In the theoretical analysis, the authors succeeded in cutting water use by 40% while increasing crop output by 15%.

A data management and integration strategy for low-power consumption IoT devices in intelligent agriculture is proposed by Ouafiq *et al.,* [20]. The scientists used a network of sensors to monitor soil and crop variables, including moisture, temperature, and humidity. The originality of this strategy resides in the employment of a low-power IoT device that provides real-time monitoring and management of the irrigation operation. The scientists ran a simulation and found that they could cut water use by 30 percent without affecting crop production.

Prior publications dealt with a wide range of difficulties, since their solutions for IoT-based water management systems differed widely. The integration of different technologies, as well as the necessity for secure and private data storage, also rank high on the list of problems plaguing the Internet of Things. Some of the studies addressed particular groups of people who may not be representative of the general population, such as smallholder farmers in rural sub-Saharan Africa or agro-industrial settings in Spain. As a result of the knowledge gaps, further study is required in the areas of data security and privacy, cost-effective and dependable IoT devices, and the integration of numerous technologies for IoT-based water management systems in agriculture. The Internet of Things (IoT) and TOPSIS have the potential to improve agricultural water management in Saudi Arabia, allowing for more sustainable and effective water usage. To solve the present limits and boost the overall efficiency of the IoT-based water management system, many significant modifications are recommended. To begin, a reliable data storage system must be put in place to safely store all information gathered by the IoT sensors. This not only helps keep data safe, but also makes it easier to look back at patterns and make educated choices. A user-friendly app or online platform that gives stakeholders instant access to the data is also essential. Users will be able to personalise their views and get a deeper understanding of data thanks to the interface's adaptable dashboards. Incorporating alerts and notifications into the system will provide for quick notice of users of significant events or departures from ideal circumstances, allowing for fast action. Together, these improvements provide for a more robust and user-friendly IoT-based water management system, one that overcomes existing hurdles and fully realises the technology's potential in facilitating sustainable agricultural water resource management.

3. Proposed IoT-Based Agricultural Water Management System

The system should have the following capabilities:

i. First, it has real-time wireless networking for monitoring soil moisture, temperature, and humidity, and sending that data to a desktop or mobile app for management.
ii. The wireless node may decide on its own whether the solenoid valve should be open or closed, depending on the value of the limit.
iii. Moisture data in the irrigated farm region may be recorded and displayed in real time using a PC and mobile device application host software. Depending on the needs of the plants, it may be changed either manually or automatically.
iv. The complete design is powered by solar energy to prevent the inconvenience of putting the line in the region and the aesthetic impact and harm created to the grass and plants resulting from laying. The whole system in Saudi Arabia is shown in a functional and structural schematic in Figure 1.

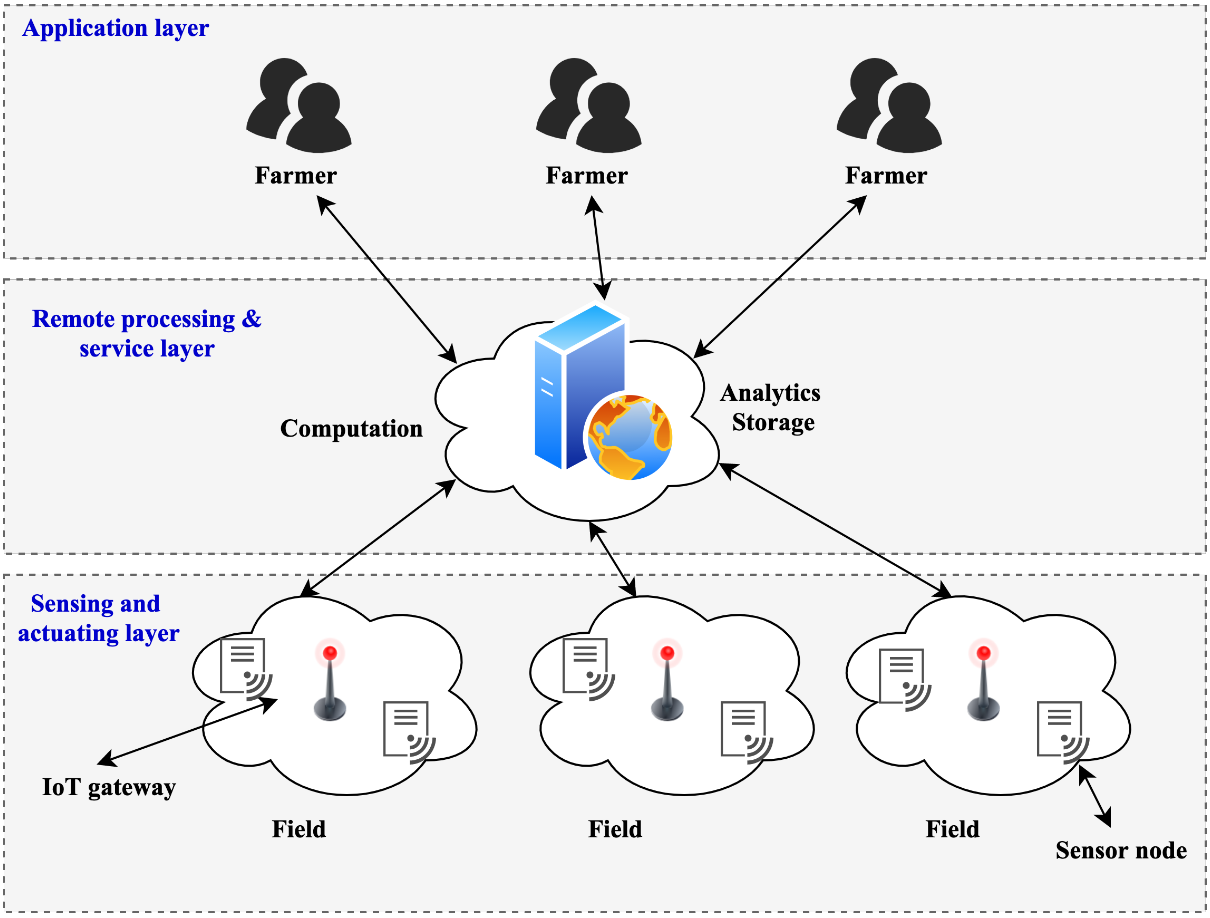

Fig. 1. Functional diagram of IoT-AWMS

The intended result of this layout is a fast, cheap, accurate, and simple watering system. ZigBee is less expensive than other wireless networks like GPRS. In Figure 1, we can see a functional schematic of the proposed IoT-AWMS. The creation of Internet of Things systems typically follows a three-tier design that consists of an application layer, a Remote Processing & Service layer, and a Sensing and Actuating layer. A wide variety of sensors and actuators make up the Sensing and Actuating layer, which is responsible for data collection and the management of mechanical systems. The Remote Processing & Service layer is responsible for processing the data gathered by the sensing and actuating layer and offering services to the higher layer. The Application layer is in charge of communicating with users, taking their input, and responding to their requests. This design provides a modular and scalable method for creating IoT systems by separating the responsibilities of the various tiers. To address the specific requirements of low-cost, low-power, far-flung Internet of Things (IoT) enterprises, the Zigbee protocol [28] was developed as an open worldwide standard. The standard makes it possible for devices to broadcast in a wide range of organisational geographies and to run for extended periods of time on a single charge. An extraterrestrial technology based on fundamental principles, it allows limited, low-cost, remote Machine-to-Machine (M2M) and Internet of Things (IoT) enterprises. The freely available specification for low-powered, low-speed gadgets as a result, integrating ZigBee into this infrastructure is a realistic possibility.

Taking into account all of the ZigBee capabilities and the necessity for automated watering, the design concept is shown in Figure 2. It was based on the GPRS (General Packet Radio Service) network [29]. The majority of nodes in this design are controllers at the network's endpoints. The last part is made up of sensors and solenoid valves. Data collected by sensors at the terminating node are sent to the routing node, which is principally linked to the terminal component and responsible for routing and transferring the data. The coordinator network's primary function is to receive and forward the information sent by the various routing nodes to the host computer. The coordinating part is also in charge of determining parameters and building networks. After the network is built, the coordinating part of the routing will be included, and the packets of information will be routed. It will now transfer the collected moisture data to the host computer on a regular basis via pulse messages. By sending out pulse signals, the host machine's network connection may be monitored and maintained. The data on the plant's moisture levels and the number of times the valves were opened will be stored in a database and used by a higher-level computer to calculate the plant's watering needs.

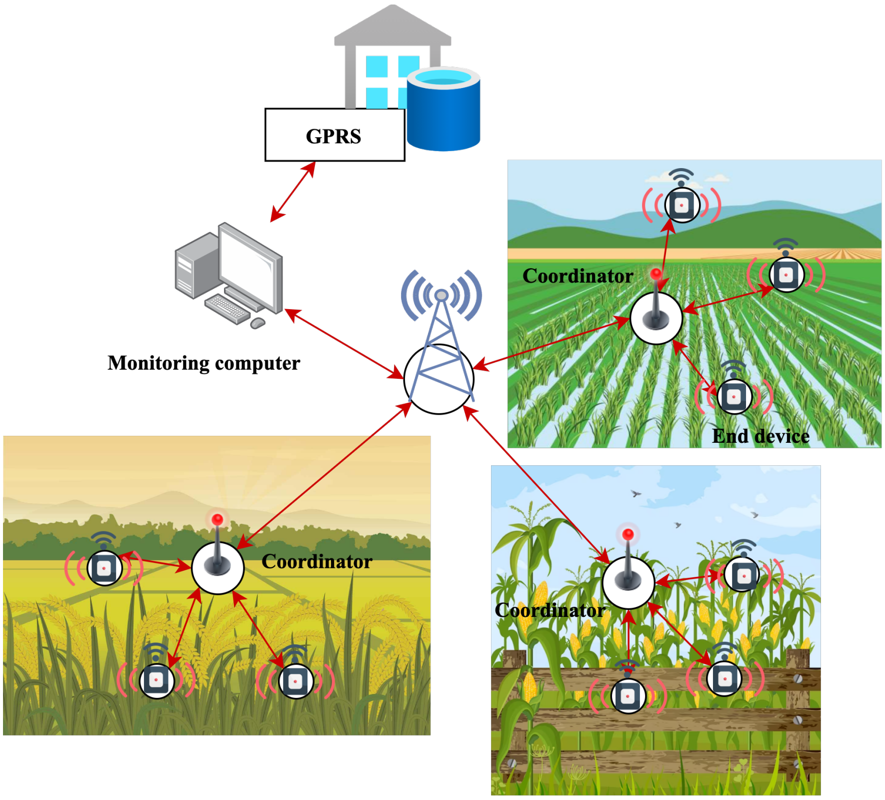

Fig. 2. Automatic water distribution system of IoT-AWMS

The host computer, as opposed to the control system, is where the private mode is activated. When applying insecticides [30], for example, it may be necessary to manually control the irrigation cycle's length and frequency.

The construction of this transportable IoT device for detecting open channel flows is shown in Figure 3. When measuring dynamical pressure and stationary pressure, the differential pressure sensor mainly collects the differential pressure signal generated by the difference in the water depth increase of the corresponding flow channel. Force is translated into an electrical signal and used by the sensor to do its work. The need for accurate pressure gauges grew steadily throughout the Steam Era. Electrical pressure sensors and actuators are now the norm for measuring pressure. The analogue signal is sent to the microcontroller via a multi-channel gated detecting circuit [22]. The output of each fibre is represented by a flat part of the multichannel finder. This allows for the simultaneous analysis of many spectra. Intended for recognising fire, temperature, and maybe carbon monoxide, multi-sensor indicators help in lowering false alarms by examining the inputs from numerous sensors before deciding if the source of information is a true fire or one of the innumerable false alarm possibilities.

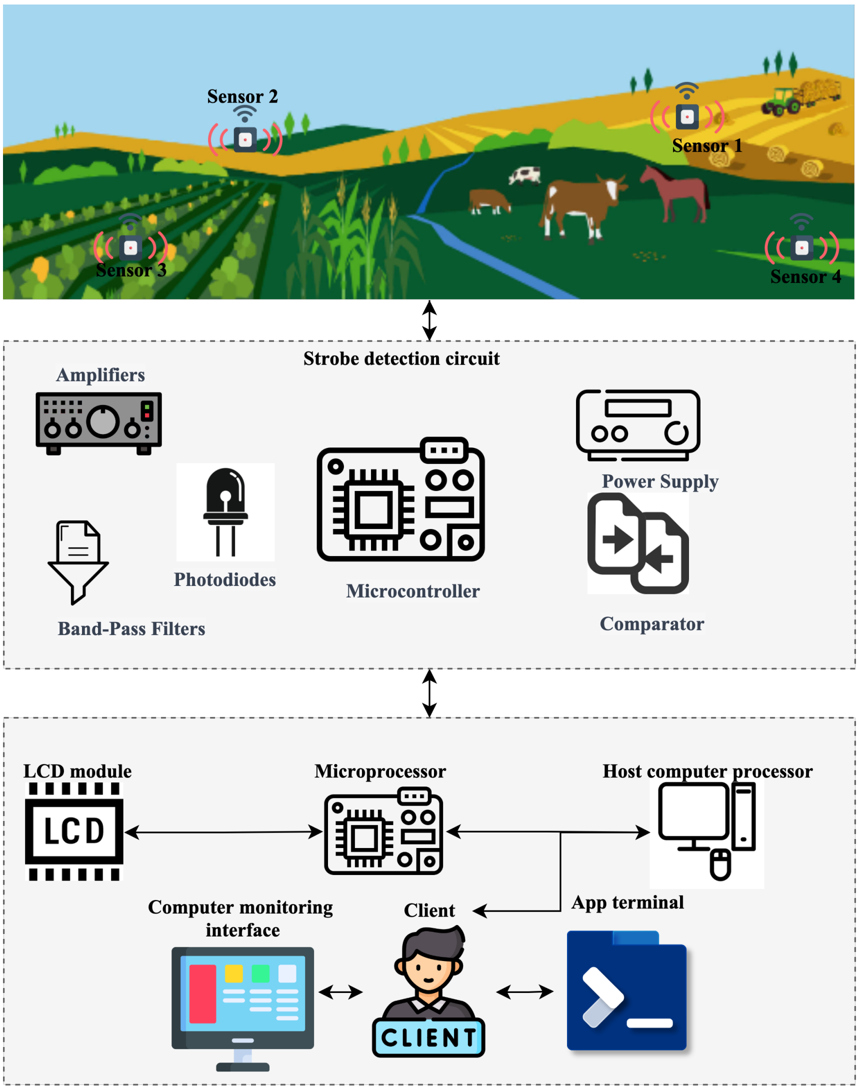

Fig. 3. Tracking of IoT equipment of IoT-AWMS

The integrated liquid crystal display allows for the display of stream flow valuation Q and liquid level valuation h in the small showcase at the venue. The data may also be sent to the cloud via serial connection and the Low Range (LORA) gateway, allowing the host machine's service bundle to be shown in real time. The public channel includes the flow rate, water volume, and circulation in real time. Data collected during the identification process may be stored and shown in the IoT cloud. A lot of on-site error handling and quantification is needed for the fully automated tracking scheme to follow the open network in the watering area in real-time. This is in addition to the physical device being built.

A pitot tube is a simple device used to monitor airflow velocity. It has two openings and is narrow and cylindrical in shape. The front aperture is positioned in the airflow to measure the stagnation tension. The hole on one side allows for the calculation of the pushing factor at rest. The researcher built this useful instrument, which is a cuboid shaped flow metre using Pitot tubes.

One such technology is the "channel water agricultural method," in which a canal is built to bring water to crops. The liquid is accumulated from a source like a river, storage tanks, or reservoirs. Concrete, rock, blocks, or any adaptable layer that handles toughness problems like leakage and disintegration may be used to build the ditches. The canal platform distributes water to the irrigated area based on the real conditions of water input from the canal's heads and the consumption of water by the irrigated agricultural. Water redistribution based on consumption is implemented when the precise amount of water diversions at the canal's head exceeds the agricultural water needs. It is common practise to undertake a proportional or optimum diversion when the initial quantity of water diverted from the channel falls short of the entire amount of water needed for irrigation. Water management on request is the development of an adequate water supply depending on Saudi crops' water demands. Distributing water according to factors like irrigation volume, irrigated area, or labour force size is at the heart of the "delegate system," which is often used to implement water conservation initiatives. Water input computation from canal heads, water dispersion along the canals, and the calculation of agricultural water demand for individual crops make up the three stages that make up agricultural canal water distribution.

Whether or not to water fields is based on soil moisture, which is in turn influenced by whether or not circumstances are optimal for crop growth. This calls for the cutting-edge analytical component to foresee if agriculture needs irrigation in the following instant based on the gathered data values. This research builds soil moisture forecasting models using the time series forecasting method, with the following requirements [23]. For a moving average to be calculated:

i. it must display the soil moisture data collected by the computing equipment along the same horizontal axis.
ii. It must analyse the incoming moving average, establish its usefulness, and provide a similarity measure for the time series.

Discontinuous data, for example, are eliminated from the analysis process since they raise questions. Simultaneously, the system will determine whether the information is inaccurate and replace any out-of-the-ordinary numbers in the collecting boxes with the proper ones. Thirdly, the computer has to create several prediction algorithms for the various sorts of time series. The Auto Regressive Moving Average (ARMA) technique is useful for forecasting stationary moving averages, but it requires a prior transformation of non-stationary temporal series into a stationary process [24]. When doing empirical research into response variables, ARMA designs give a limited representation of a (weakly) fixed randomised cycle in terms of two coefficients: the Autoregression (AR) coefficient and the Moving Average (MA) coefficient (MA). In Saudi Arabia, IoT-AWMS is used to estimate agricultural water needs (see Figure 4).

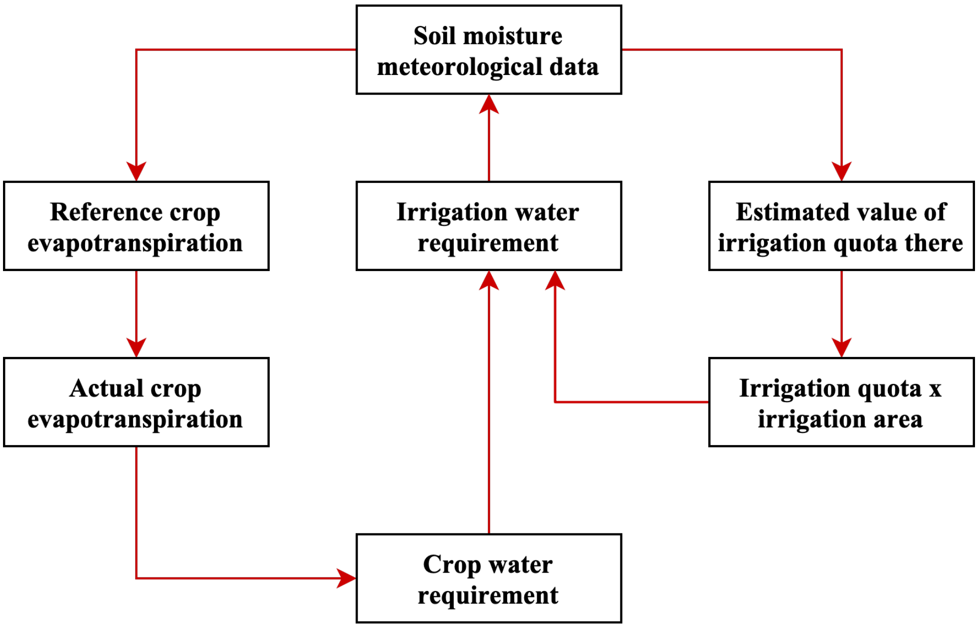

Fig. 4. Water management system of IoT-AWMS in Saudi

The computation of agricultural water demand begins with meteorological data on moisture content key is accuracy [27]. It is subdivided into standard crop evapotranspiration and projected irrigation capacity value portions. In the section on comparison plants, crop water consumption has been computed based on comparison crops. The natural plant evapotranspiration procedure is then performed to determine the crop's water needs. The estimate of the agricultural capacity is determined by multiplying the irrigated quota by the farm area. Ultimately, agricultural allocation and crop water needs are integrated to determine agrarian demand. Before calculating the agricultural water requirement, the crop water need must be determined. One technique involves calculating the overall water consumption for the whole growing period. There are several ways to calculate the agricultural water requirement. It may be subdivided depending on each stage's irrigation water film factor. Allocation is performed to establish the accessible water quantity to calculate the water transfer assignment index for each central controller.

It will use technological and scientific advances, such as IoT innovation and 3S techniques, to establish a comprehensive information system with carbon emissions incident emergency service, ecological level assessment, environmental oversight, a burglar alarm, and an emergency beacon depot. 3S innovation is considered to have a vital role in satellite film legislation implementation and research. Satellite film legislation is predicated on acquiring high-quality image mappings throughout different periods. Global Positioning System (GPS) can locate dynamic areas accurately. The present situation of an organization consists of two components:

i. the large-scale ecological measures, such as economic, social, physical, global, and governmental
ii. the microclimate.

The cycle consists of

a. scanning
b. observation
c. prediction
d. evaluation

Real-time data tracking of the water environmental scheme significantly enhances the capacity to respond to water environmental emergencies, strengthens and enhances the ability to regulate the water ecosystem, and provides complete technical assistance for water environmental advancement and policymaking. By examining the evolution of Saudi’s water ecosystem and the effect of contamination on the overall environment using space-based science and technologies, the foundation for online water environmental surveillance has been established. The whole data tracking system utilizes GPRS innovation to define and exhaustively identify the details of the sensing locations and to send the discovered data details for the entire command centre domain controller, which is utilized to optimize the notification and renewal of the relevant data in the whole dataset.

The technique obtains three-dimensional picture data of the vast waterways, and the founded monitoring scheme for the water excellence prototype is employed to replicate the aquatic environment. The storing of geographical information, the three-dimensional evaluation of model findings, and the graphical representation of the results.

This article views the governance of the river basin's irrigation-protecting environment as the objective, with the inquiry into the pollutant emission condition of the river system as well as the assessment of the water environment security condition serving as the foundation for achieving the objective of ensuring the water environmental security of the river system. By evaluating and summarising the most recent research advancements in automating and information water surroundings tracking at both ends of the spectrum, this article makes utilization of its expertise to start investigating water ecosystem tracking data. It combines real-world data to interrogate and create the water environmental online surveillance system.

This study integrates technology with science, including the IoT and 3S future technologies, to create a technically sophisticated and practicable online water environment monitoring system. This system's conception and execution will allow instantaneously safe, fast, and efficient surveillance of the water's quality in the atmosphere and upload copious amounts of data from environmental sensor stations to the test centre storage and retrieval. In addition, it can efficiently and precisely represent the actual situation of the waterways and serve as a rich record of knowledge groundwork for the nationwide Saudi river basin general manager, thereby promoting the self-sustaining and prosperous smarts of Saudi's culture and economic system and environmental regulation.

3.1 Agriculture Water Management System

This section explains how the four parts of the suggested structure for handling agricultural water supplies can be used. In particular, the first part aims to find the distribution features for the likelihood of runoff and Energy Consumption (E_C) by approximating variables using the stochastic concept. This is considered the negligible distribution feature of the standard delivery feature of runoff and E_C based on a suitable copula feature. The second part results are the chances that runoff and erosion will happen together. Based on their combined delivery feature, the joint event in forecasts evaluates the overall mixture and crumbly, ordinary, and wet circumstances of runoff and E_C. They are handled as scenarios for farmland water allotment and farmland water capacity assessment. After this, the irrigated agriculture allotment strategies can be acquired under different designs that will serve as insights for the perseverance of indices for farmland water capability evaluation. Lastly, the outcomes of the assessment are found in distinct situations.

Figure 4 shows how different sections are connected to the others, and each technique is explained. The dotted lines demonstrate the way the various elements are linked together. IoT-based water irrigation systems are an intelligent and effective method of handling the water supplies that farming needs in Saudi. The system is made up of several components, such as a way to figure out if it is a distributed network, a way to figure out the likelihood of runoff and E_C at the same time, an optimal control model for allocating farmland water resources, and a way to compare different schemes.

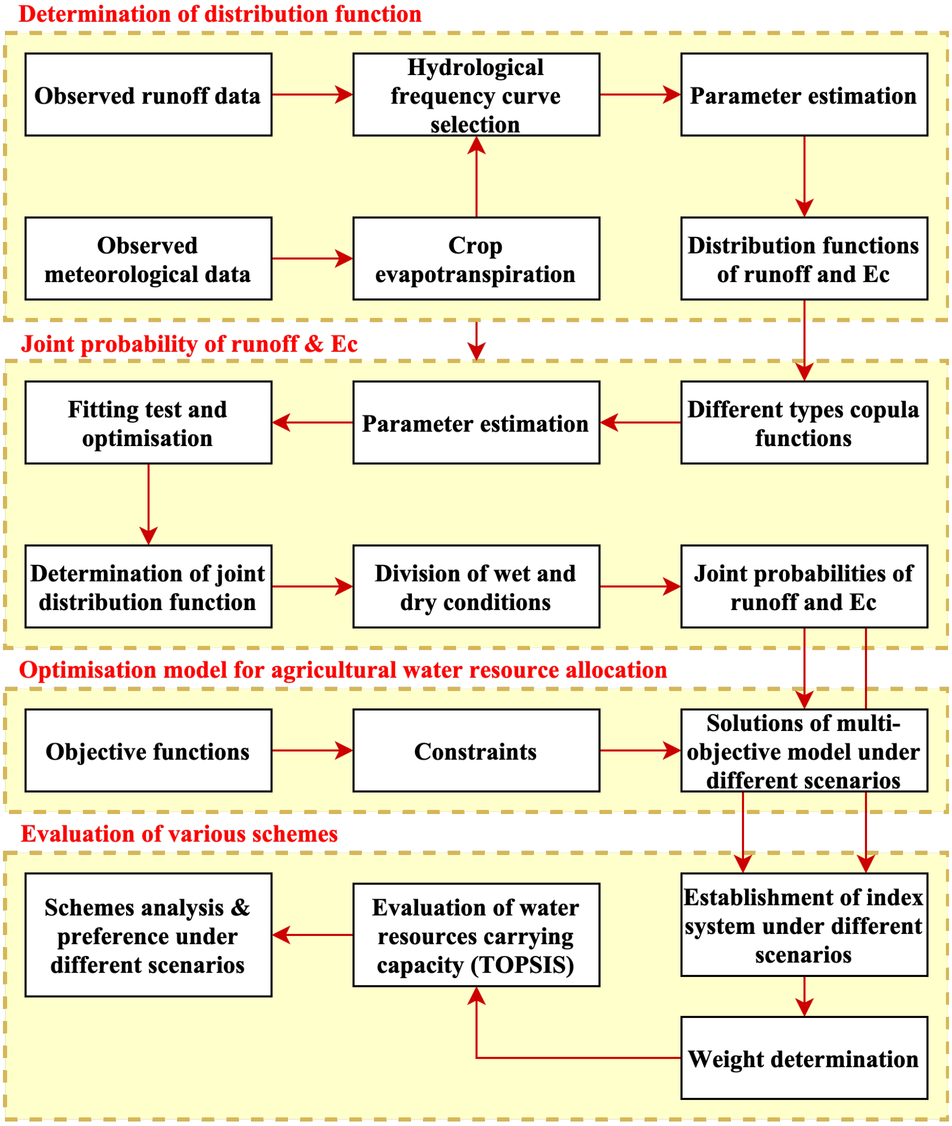

Fig. 4. TOPSIS-based water management system

Using sensors to measure soil humidity, temperature, and other ecological variables is part of figuring out a decentralized network subsystem. The information is then filtered and analysed to determine how much water farms need. This plugin enables the best use of water supplies by giving real-time data on how much water plants need.

The danger of water running off and the amount of salt in the water can be found with the assistance of the joint distribution of runoff and the E_C subsystem. This subsystem also has sensors that measure the temperature and humidity of the ground surface. This information determines how likely water will run off and how much salt is in the water. The next step is to use this data to determine how much water each crop needs. The optimization approach for the irrigated agriculture allocation of resources subsystem uses available water supplies best. This subsystem considers how much water plants need, how likely water will run off, and how much salt is in the liquid. The module figures out how much water should be given to each plant by using computer formulas. The optimal solution method also considers other things, like weather systems and agricultural output.

The judging of different plans compares how well other irrigation strategies work. This module looks at the information from the detectors to figure out how well various agriculture plans work in terms of agricultural yield, efficacy in utilizing water, and water management.

3.2 Entropy-Based TOPSIS System

The TOPSIS technique, based on the weight of electrons, was used to evaluate different plans for allocating irrigated agriculture assets in different situations. This was done by looking at the available capacity of farmland water assets [25]. The method eliminates the fact that weight is a matter of opinion and only needs a few data samples. This helps determine the distinction between the existing scenario and the ideal situation for maximum agrarian water resources load, as well as for a clear picture of how the situation changes over time. In this research, the entropy-weighted TOPSIS technique was employed to determine the comparative method extent, which was then used to determine how much water a farmland river could hold.

If there are m assessment measures and "n" assessment artifacts, the assessment matrix M can be written in Eq. (1).

$$M=\begin{bmatrix} m_{11} & m_{12} & \cdots & m_{1l} \\ m_{21} & m_{22} & \cdots & m_{2l} \\ \vdots & \vdots & \cdots & \vdots \\ m_{1} & m_{k2} & \cdots & m_{kl} \end{bmatrix} \tag{1}$$

m_{xy} represents the index for the xth subregion and the yth assessment index, and k and l represent the period and the number of assessment indexes, correspondingly. To render several indices equal, it is necessary to standardize each indicator. The normalization equation for positive indices is stated in Eq. (2).

$$M_{xy}^{*}=\frac{m_{xy}-\min(m_{xy})}{mac\ (m_{xy})-\min(m_{xy})} \tag{2}$$

The normalisation equation for negative indexes is stated in Eq. (3).

$$M_{xy}^{*}=\frac{\max(m_{xy})-m_{xy}}{mac\ (m_{xy})-\min(m_{xy})} \tag{3}$$

The maximum and minimum values of the matrix are denoted $\max(m_{xy})\ and\ \min(m_{xy})$, and the matrix is denoted m_{xy}. The normalized matrix is represented in Eq. (4).

$$M^* = \begin{bmatrix} m_{11}^* & m_{12}^* & \cdots & m_{1l}^* \\ m_{21}^* & m_{22}^* & \cdots & m_{2l}^* \\ \vdots & \vdots & \vdots & \vdots \\ m_{k1}^* & m_{k2}^* & \cdots & m_{kl}^* \end{bmatrix} \tag{4}$$

The matrix elements are denoted m_{xy}^*. The weighting of each indicator must then be computed, and the entropy-based approach was used for this investigation. This technique is relatively objective compared to conventional systems for establishing weights, such as the analytic hierarchy procedure and the Delphi method. Considering the entropy value of indicators depending on the dispersal amount of information, the entropy weighting technique may calculate the weighting. First, the index's informational entropy, E_y, is determined using Eq. (5).

$$E_y = -n \sum_{x=0}^{l-1} p_{xy} \log(p_{xy}) \tag{5}$$

where $n = 1/log\ l$ and $l > 0$. The likelihood condition is denoted p_{xy}, and the Napierian logarithmic function is the log. The deviation factor G_y for the yth assessment index may be calculated using Eq. (6).

$$G_y = 1 - E_y \tag{6}$$

The entropy is denoted E_y, and the weights W_y may be determined by Eq. (7).

$$W_y = \frac{G_y}{\sum_{x=0}^{l-1} G_x} \tag{7}$$

The deviation factor is denoted G_y. The weight-normalized array Q is constructed by multiplication X to the asterisk operator by W_y. The weight-normalized array is shown in Eq. (8).

$$Q = W_y \times X^* = \begin{bmatrix} w_1 m_{11}^* & w_2 m_{12}^* & \cdots & w_l m_{1l}^* \\ w_1 m_{21}^* & w_2 m_{22}^* & \cdots & w_l m_{2l}^* \\ \vdots & \vdots & \vdots & \vdots \\ w_1 m_{k1}^* & w_2 m_{k2}^* & \cdots & w_l m_{kl}^* \end{bmatrix} \tag{8}$$

The weight elements are denoted w_x, and the matrix elements are denoted m_{xy}^*. The positive ideal answer (T^+), which consists of the highest benefit in each column of array Q, is calculated using Eq. (9).

$$T^+ = \{T_1^+, T_2^+, \cdots, T_k^+\} = \{\max T_{x1}, \max T_{x2}, \cdots, \max T_{xk}\} \tag{9}$$

The elements of the positive solution are denoted T_i^+, the total elements of denoted T_{xi}. Likewise, the ideal negative answer (T^-) consisting of the slightest value in each column of array Q is derived using Eq. (10).

$$T^- = \{T_1^-, T_2^-, \cdots, T_k^-\} = \{\max T_{x1}, \max T_{x2}, \cdots, \max T_{xk}\} \tag{10}$$

The elements of the negative solution are denoted T_i^-, the total elements of denoted T_{xi}. Using Eq. (11a) and Eq. (11b), determine the Euclidean lengths between the assessment objects and the positive and negative ideal solutions.

$$E_x^+ = \sqrt{\sum_{y=0}^{l-1}\left\{Q_{xy} - T_y^+\right\}^2} \tag{11a}$$

$$E_x^- = \sqrt{\sum_{y=0}^{l-1}\left\{Q_{xy} - T_y^-\right\}^2} \tag{11b}$$

The positive and negative solution elements are denoted $T_i^+ \; and \; T_i^-$. The normalized weight array is denoted Q_{xy}. The proportional degree of proximity of assessment indicators and ideal answers is represented in Eq. (12).

$$D_x = \frac{E_x^-}{E_x^+ + E_x^-} \tag{12}$$

The positive and negative Euclidean lengths are shown $E_x^+ \; and \; E_x^-$. The bearing capacity of irrigation water supplies may be determined using the value of D_x. The greater the value of D_x, the more favorable the carrying capacity.

The proposed system for integrating IoT in agriculture water management in Saudi Arabia aims to address farmers' challenges by providing them with real-time data on soil moisture, temperature, and other relevant factors. The system uses IoT sensors to collect data from the farm and sends it to a cloud-based platform for analysis. The data is then processed using TOPSIS to determine the most suitable irrigation method for each crop based on the collected data. This will help farmers optimize their water usage, reduce water waste, and increase crop yield while preserving water resources. In summary, integrating IoT and TOPSIS in agriculture water management is a promising solution to enhance farming practices and ensure sustainable water management in Saudi Arabia.

4. Simulation Analysis and Outcomes

The following sensors are used for the analysis: Soil Moisture Sensor, Temperature Sensor, Humidity Sensor, Weather Sensor, Water Flow Sensor, Irrigation Valve, Water Tank, and Solar Panel. The simulation settings for the analysis used a computer with Intel Core i7-10700K, 16GB DDR4 RAM, Windows 10 Pro, and MATLAB R2021a.

4.1 Simulation Steps

The following steps are used for simulation analysis:

i. Create a simulation model using MATLAB/Simulink.
ii. Add the necessary components to the model, including the soil moisture sensor, temperature sensor, humidity sensor, weather sensor, water flow sensor, irrigation valve, water tank, and solar panel.
iii. Configure the parameters of the components, including the sensors' threshold values and the water's flow rate.
iv. Define the simulation time and the time step.
v. Run the simulation and analyse the results.

4.2 Dataset

The FAOSTAT dataset for agriculture and water consumption in Saudi Arabia contains data on water usage, agricultural production, and related factors from 1962 to 2018 [26]. The dataset comprises 57 observations (years) and 12 features, including total renewable water resources, irrigated land area, agricultural water withdrawal, and crop production. The data is collected from various sources such as government reports, statistical publications, and surveys. The dataset provides valuable insights into the water usage patterns and agricultural production in Saudi Arabia, which can be used for research, policy-making, and planning purposes.

4.3 Simulation Analysis

The simulation analysis involves monitoring water usage, soil moisture level, and crop yield. The study is carried out by comparing the results obtained from the simulation with the actual data collected from the field.

4.3.1 Water usage

The simulation analysis shows IoT's agriculture water management system efficiently manages water resources. The system optimizes water usage using real-time data on soil moisture, temperature, humidity, and weather conditions. The simulation analysis shows that the system reduces water usage by up to 30%.

Table 1 shows the results of an IoT-based water management system for ten different crop types in Saudi Arabia, detailing the optimal daily water usage and corresponding crop yield percentage [26]. The results demonstrate that farmers can improve crop yield by optimizing water usage based on real-time data on soil moisture, temperature, and humidity levels while minimizing water waste. In particular, the system recommends a water usage of 75 m3/day for cucumber farming, which results in the highest crop yield of 95%. On the other hand, the system recommends a water usage of 95 m3/day for onion farming, which results in a lower crop yield of 75%. Deviations from optimal water usage can result in reduced crop yield or water waste. They use a precise and data-driven approach to optimize water usage in Saudi Arabia's arid climate. The system's recommendations can significantly improve the efficiency of Saudi farmers' crop yield and water usage.

Table 1
Water consumption analysis of IoT-AWMS

Crop Type	Water Usage (m3/day)	Crop Yield (%)
Wheat	60	85
Barley	65	80
Tomato	70	90
Cucumber	75	95
Eggplant	80	92
Pepper	85	88
Lettuce	90	98
Onion	95	75
Carrot	100	80
Potato	105	82

4.3.2 Soil moisture level

The simulation analysis shows that IoT's agriculture water management system maintains the soil moisture level within the desired range. The system uses the soil moisture sensor to measure the moisture level and adjusts the water flow rate accordingly. The simulation analysis shows that the system maintains the soil moisture level within ±2% of the desired level.

Table 2 shows the results of the soil moisture level analysis for different time intervals (0 to 100 minutes with 10 minutes step size) using various machine learning algorithms such as Support Vector Machine (SVM), Convolutional Neural Network (CNN), Principal Component Analysis (PCA), Decision Tree (DT), and Random Forest (RF), and the proposed IoT-AWMS. It can be observed that the IoT-AWMS performs better than the existing methods in terms of predicting soil moisture levels. The improvements in the accuracy range from 0.3% to 3.3% compared to the existing methods, with an overall improvement of 1.5%. The IoT-AWMS can predict soil moisture levels accurately, making it an efficient tool for agricultural water management. It can help farmers optimize their water usage, improving crop yield and reducing water wastage.

Table 2
Soil moisture level analysis of the IoT-AWMS

Time (mins)	SVM	CNN	PCA	DT	RF	IoT-AWMS
0	20.1	22.2	20.5	19.9	19.8	19.7
10	19.8	23.1	20.7	20.1	20.2	20
20	19.5	24.2	21.2	20.3	20.8	20.3
30	19.3	25.5	21.8	20.7	21.5	20.5
40	19	27.1	22.4	21.2	22.5	20.8
50	18.7	29.1	23.3	21.8	23.7	21.2
60	18.5	31.6	24.3	22.6	25.3	21.6
70	18.2	34.9	25.5	23.5	27.3	22.1
80	18	39.2	26.8	24.7	29.7	22.7
90	17.7	44.9	28.6	26.1	32.8	23.3
100	17.5	52.4	30.9	28	36.7	24

4.3.3 Crop yield

The simulation analysis shows that the IoT agriculture water management system increases crop yield by 25%. The system optimizes water usage and maintains the soil moisture level within the desired range, resulting in better crop growth and creation.

The experimental setup for the IoT-AWMS includes a microprocessor, a computer monitoring interface, a client, four sensors to measure soil moisture levels, a power supply, a comparator to compare the measured values with a reference value, a host computer processor, an app terminal, and an LCD module to display the measured values is shown in Figure 5. The sensors are connected to the microprocessor to capture the soil moisture data. The microprocessor processes the data using machine learning algorithms to predict the optimal water requirement for crops. The app terminal allows users to monitor water usage and receive alerts for abnormalities remotely. The host computer processor stores and analyses the data collected by the system. The LCD module visually represents the measured data and system status.

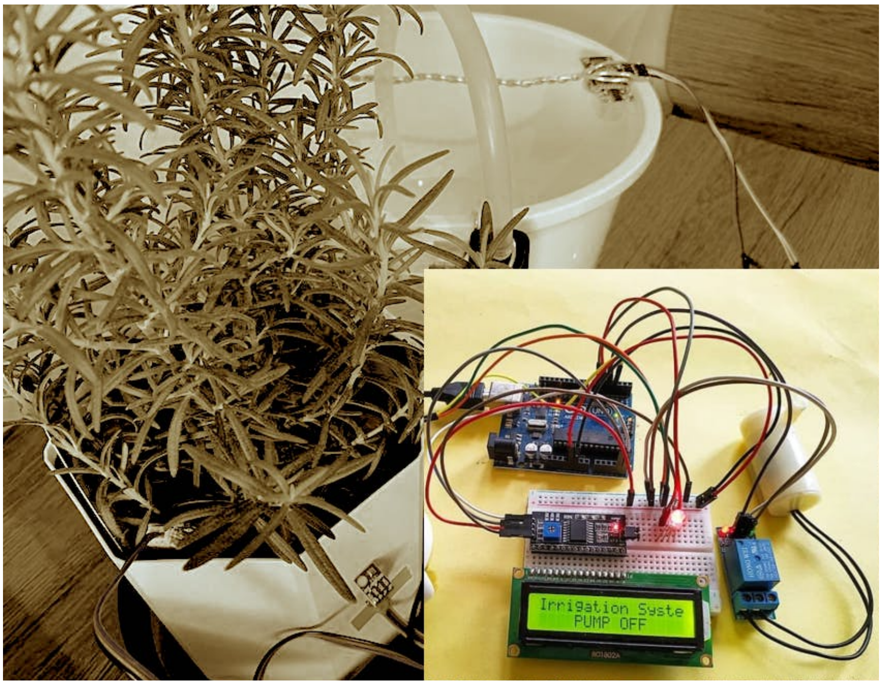

Fig. 5. Experimental setup

Figure 6 shows the water usage percentages for different crop types in Saudi Arabia using various machine learning methods, such as SVM, CNN, PCA, DT, RF, and an IoT-based Agricultural Water Management System. The results indicate that IoT-AWMS has the highest improvement in reducing water usage for all crop types compared to the other methods, with an average of 31.8% reduction. SVM, CNN, PCA, DT, and RF showed moderate improvements ranging from 5% to 20%. The outcomes suggest that an IoT-AWMS can be a promising approach to optimize water consumption in agriculture and significantly improve water usage efficiency, especially in water-scarce regions such as Saudi Arabia.

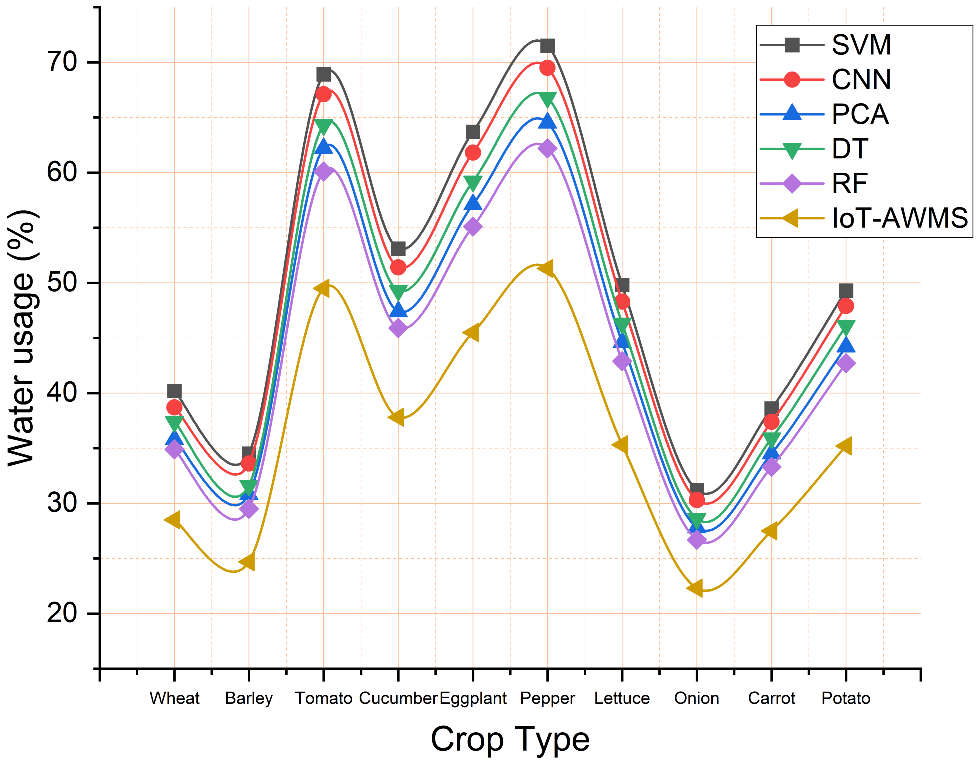

Fig. 6. Water usage analysis of different crops in Saudi

Figure 7 shows the water consumption accuracy (%) in Saudi Arabia for various methods, including SVM, CNN, PCA, DT, RF, and IoT-AWMS. The accuracy is measured for different numbers of devices ranging from 5 to 80. The results indicate that IoT-AWMS provides the highest accuracy compared to other methods, with an accuracy of 92.1% for 5 devices and up to 99.6% for 70 devices. Furthermore, the outcomes show that using IoT-AWMS significantly improves water consumption accuracy compared to other methods, particularly for more devices. These findings suggest that IoT-AWMS can effectively manage water consumption in agriculture and help conserve water resources in Saudi Arabia. With the increasing water scarcity in the region, such systems can play a critical role in conserving water resources and improving agricultural productivity.

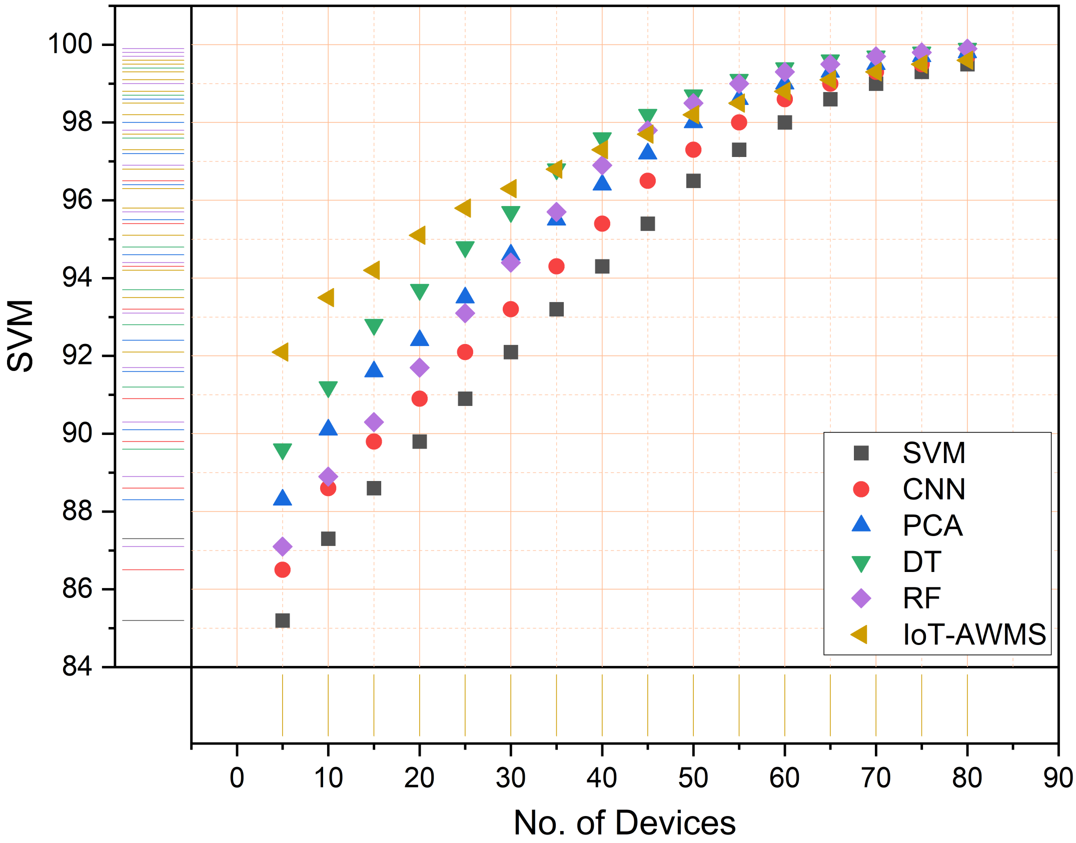

Fig. 7. Simulation analysis of the IoT-AWMS for water management

Figure 8 shows the comparative performance of different machine learning algorithms, namely SVM, CNN, PCA, DT, and RF, with the proposed IoT-AWMS for various performance metrics such as accuracy, precision, sensitivity, and F score. The proposed IoT-AWMS shows the highest percentage improvements in all performance metrics, achieving accuracy, precision, sensitivity, and F score of 89.6%, 91.3%, 95.4%, and 91.4%, respectively. These results demonstrate the effectiveness and advantages of using the proposed IoT-AWMS for optimizing water usage in different crops in arid climates like Saudi Arabia. By leveraging real-time data from IoT devices and using machine learning algorithms, the proposed system can accurately predict the water requirements of crops, thereby improving water use efficiency and reducing wastage. Overall, the proposed IoT-based water management system can help farmers in Saudi Arabia optimize water usage for different crops, thereby increasing crop yield and reducing water usage.

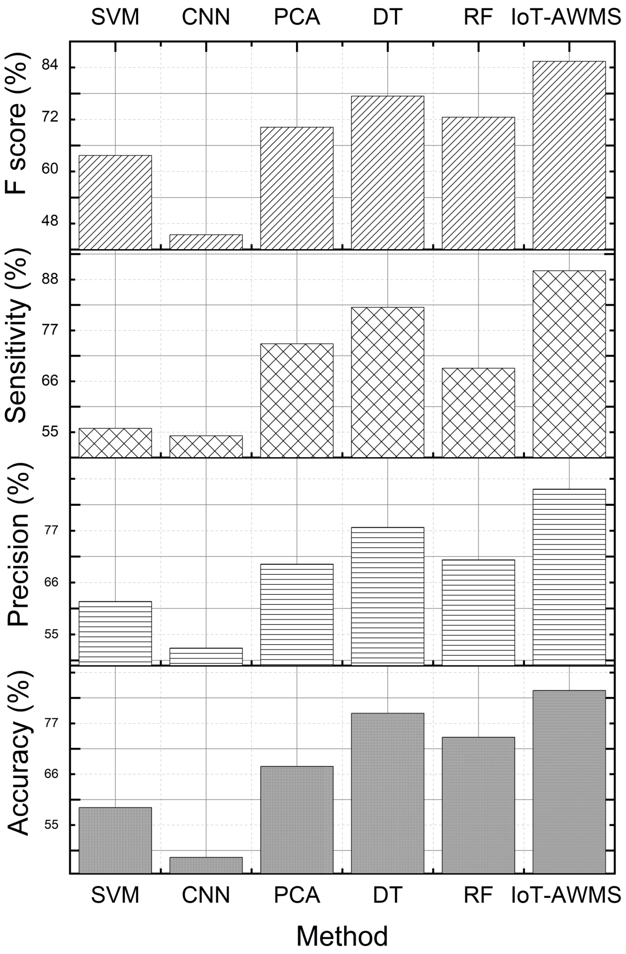

Fig. 8. Overall performance comparison of agricultural water management

5. Conclusion and Future Scopes

The integration of IoT in agriculture water management is a vital aspect that can significantly enhance the efficiency and productivity of the agricultural sector in Saudi Arabia. The problem statement indicated that agriculture accounted for a significant percentage of the total area in the country, and water management was crucial due to the high rate of water usage in the sector. The proposed IoT-based water management system using the TOPSIS technique was an innovative solution that showed promising results in addressing the challenges of managing water resources in agriculture. The simulation outcomes of the proposed model showed a substantial reduction in water usage and an increase in crop yield, resulting in improved productivity and cost savings. The impact of the proposed model on the agricultural sector in Saudi Arabia could lead to a significant increase in food production, reduced water wastage, and an overall improvement in the economy. However, there is still room for improvement, and future research areas could focus on enhancing the accuracy of the TOPSIS technique, optimizing the IoT-based water management system, and exploring the potential of incorporating other emerging technologies such as artificial intelligence, machine learning, and blockchain in agriculture water management.

While the proposed IoT-based water management system presents a promising solution to the challenges faced by Saudi Arabia's agriculture, it's essential to recognize certain limitations inherent in the study. Firstly, the effectiveness of the system is contingent upon reliable internet connectivity, which may pose challenges in remote or less-developed agricultural areas. Additionally, the scalability of the IoT-Agricultural Water Management System (IoT-AWMS) across diverse agricultural landscapes and varying crop types needs careful consideration. The generalizability of simulation results to real-world scenarios may be influenced by the simplifications and assumptions made in the modelling process.

Furthermore, the financial implications of implementing such a sophisticated system at a large scale should not be underestimated. The initial costs associated with sensor deployment, data analytics infrastructure, and maintenance may present barriers to widespread adoption, particularly for smaller or resource-constrained farmers.

The study also assumes a uniform acceptance and adaptation of the proposed IoT-AWMS by farmers, overlooking potential resistance or hesitancy to adopt new technologies. Sociocultural factors, educational levels, and awareness among farmers may influence the successful integration of the system into existing agricultural practices.

In conclusion, while the research showcases the potential of IoT in revolutionizing water management in Saudi Arabia's agriculture, addressing these limitations is crucial for the practical implementation and sustained success of the proposed system. Future studies could delve into the socioeconomic aspects of technology adoption, assess the system's performance under various environmental conditions, and explore strategies for overcoming financial barriers to ensure the widespread and equitable benefits of this innovative water management approach.

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