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SOLAR-BASED AUTOMATIC IRRIGATION SYSTEM

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Abstract

By combining different technologies to improve agricultural performance, nations strive to make agriculture more sustainable. The UN Sustainable Development Goals (SDGs), particularly Goals 6 and 6.4, may be attained through improving irrigation systems since it increases water usage efficiency. With the use of the IoT (Internet of Things) and sensor systems, this article intends to demonstrate how smart irrigation may help achieve the SDGs. The research focused on secondary data-gathering techniques and had a qualitative methodology. Automatic irrigation systems are crucial for water conservation, and these improvements may significantly lower water use. IoT and automation are related to agriculture and agricultural technology, which improves the effectiveness and efficiency of the whole process. Sensory systems improve agricultural understanding, lessen environmental impact, and preserve resources for farmers. Effective soil and weather monitoring goes hand in hand with effective water management through these advanced systems. A focus on enhancing sustainable operations and cutting costs has led researchers to identify irrigation systems as active contributors to the optimization of irrigation systems that may improve the utilization of current R&D. The benefits and limitations of using a sensor-based irrigation system are finally examined. Researchers and farmers will benefit from this review's improved understanding of irrigation techniques and the appropriate approaches that are adequate for carrying out irrigation-related tasks.

Keywords: Smart Irrigation; Irrigation Sustainable Development Goals; IoT; Agriculture Sensors; SDG 6; Water Use Efficiency.

Abbreviations: AI, artificial intelligence; CSR, corporate social responsibility; LoRa, long-range; GSM, global system for mobile communication; IoT, internet of things; R&D, research and development; MQTT, message queuing telemetry transport; WSN, wireless sensor networks; WS, water stress; SDG, sustainable development goals.

1. INTRODUCTION

The basis of the economy and a significant sector is agriculture. In many nations, agricultural automation is a significant and growing issue of concern. The requirement for food increases as the world's population expands, which is occurring at an accelerated rate. It is exceedingly challenging for the agricultural sector to create technology and methods capable of appropriately addressing the expanding requirements and expectations due to the development of both the food demand and consumer demand [1], [2], [3]. It is agriculture that contributes to the progress already made.

Therefore, it is imperative to ensure that the industry upgrades to enhance its overall performance and outcomes. To address evolving consumer expectations, food production technologies are anticipated to drive significant advancements and innovations [4]. Since most countries depend on the agricultural sector, it is crucial to utilize agricultural resources [5]. A

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new scientific field called "smart irrigation" is developing that uses data-intensive techniques to boost agricultural output while lowering its environmental effect. To better comprehend the operational environment and processes, modern agricultural operations produce data from many sensors [6], [7], [8], [9].

Decision-making becomes more precise and effective as a result. The department's intended goals are met, and the resource optimization process maximizes available resources. Water resources are preserved when these technologies are used in irrigation systems, which significantly advances the SDGs, particularly Goals 6 and 6.4. When smart irrigation systems are implemented, SDGs relating to water and the environment may be fulfilled for long-term benefits and a better world for everyone [10], [11], [12], [13].

Drinking water and sanitation are covered by SDG 6, and all water-related services, including irrigation, are covered by the different indicators and objectives of SDG 6. Water usage efficiency and water stress are the two key metrics used in Target 6.4, which addresses the issue of WS [14], [15], [16]. The quality of the available water data has a significant impact on how well this indicator is evaluated. Consequently, the development and management of irrigation systems must now meet new expectations for sustainable and healthier food systems.

However, poor exploitation of agricultural resources may result in the degradation of the ecosystem and negative effects [17], [18], [19], [20]. The shortage of onshore tanks and the lack of knowledge in the area are two major factors that might be recognized. Regular groundwater extraction lowers the water table, which supports the growth of rain-fed land. As a result, governments are now seeking efficient cadres who can manage the systems efficiently, and agriculture system reform is now important [21].

Modern applications of artificial intelligence (AI) systems and solutions are seen in sustainable agriculture and agricultural practices [22], [23], [24], [25].

In recent decades, researchers across disciplines have shown a special interest in the multidimensional area of sustainability [26], [27], [28], [29]. The term "sustainability" refers to a wide range of themes, such as climate [30], ecology [31], the "green economy" [32], "food security" [33], "sustainable agriculture" [34], "clean technology" [35], etc. As a result, the application of AI in agriculture has received significant interest.

The SMART irrigation system is a cutting-edge innovation that automates irrigation systems and saves water while improving performance.

This technology allows farmers to satisfy their demands using a newly accepted irrigation method that conserves water by adjusting irrigation depending on real soil and weather conditions [36]. Data collecting (sensors), irrigation management, wireless connection, data processing, and error detection are all shown in Figure 1 for the SMART irrigation system. IoT devices may make use of each of these parts.

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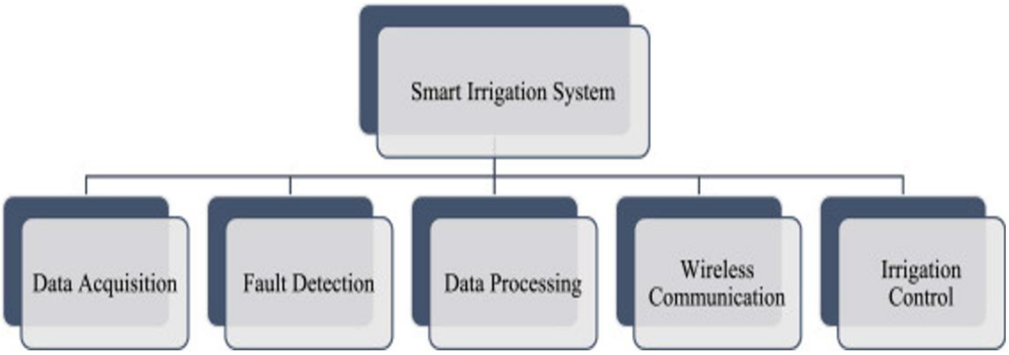

Fig 1: SMART Irrigation System

Farmers may better comprehend the precise status of their crops by using technologies like the IoT, smartphone tools, and sensors, which can also provide information on soil temperature, water requirements, weather, and other factors [37]. The IoT may be seen as an expansion of the present Internet, enabling communication between any electronic equipment and connections to the Internet, resulting in more simple-to-use and user-friendly products. As a result, IoT is related to the automation of all aspects of agriculture and agricultural activities, increasing the productivity and efficiency of the whole process [38]. To better understand their crops, lessen their influence on the environment, and save resources, farmers must employ sensors. So, by using SMART farming, farmers may boost production while utilizing limited resources, like seeds, water, as well as fertilizers [39,40].

To achieve Sustainable Development Goals, this document intends to illustrate how SMART irrigation employs the IoT and sensor systems. The review will aid researchers and farmers in their understanding of irrigation techniques, and suitable approaches will be adequate to do irrigation-related tasks.

2. SOIL AND WEATHER MONITORING

When designing effective irrigation management systems to improve food production and decrease water loss, effective and efficient monitoring systems have a significant influence on plant growth and development [41]. Using the IoT and WSNs, monitoring in the specific context of precision irrigation generates a gathering of data large enough to represent the state of plants, weather, and soil in the irrigated area in real time. The IoT has enabled the development of a low-cost technological method that enhances the control and monitoring system of the irrigation method to construct a real-time monitoring system. WSNs have significantly aided in the real-time observation of precision agriculture.

This method creates a WSN nodes that can detect, transmit, and compute data considering different parameters [42].

Soil moisture is considered a fundamental parameter necessary for plant growth. One may argue that accurate soil moisture content monitoring is crucial for ensuring the best irrigation plan. The focus of soil moisture detection is on inexpensive capacitive kinds, which are

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primarily dependent on the operation of dielectric devices [43]. Utilizing well-based approaches in SMART irrigation systems, the objective of soil monitoring is to estimate the amount of soil moisture present.

When buried in the root zone of grass, shrubs, or trees, moisture sensors may precisely monitor the soil's moisture content and send the data to the controller. Using this approach, key information can be conveyed to understand how relevant activities should be designed and executed for optimal results [44].

Two of the most important systems based on soil moisture sensors can be considered pause cycle irrigation systems and demand irrigation. The pause loop has a watering schedule, duration, start, and end times, just like a conventional timer controller. The distinction is that when the soil moisture is enough, the device automatically terminates the next planned watering [45].

On the other side, on-demand irrigation doesn't require any kind of schedule or irrigation length. In this approach, thresholds are established by the user, and the irrigation procedure begins when the soil moisture does not reach the required level [46].

The technique of evaluating the weather in a place and its expanding surroundings across large regions is known as weather monitoring. However, analyzing environmental parameters in the work area to identify hazards and develop strategies that can mitigate adversity. Once again, WSN implementation may be seen as a crucial method of linking various sensors to keep track of the physical parameters of the environment [47].

In addition to real-time monitoring, installed sensors' data are analyzed, which further activates control machinery through a feedback loop. Another IoT-based weather monitoring system has been designed to monitor and evaluate the agricultural environment, like humidity, air temperature, sun radiation, weather management, and wind speed. Among them is the use of meteorological sensors connected to wireless communication standards for real-time data transmission. By using this method, detailed weather information can be obtained, which ultimately helps in the development of methods that can support long-term irrigation processes [48].

3. WATER MANAGEMENT

It is possible to see water management as a crucial irrigation-related concept. The agriculture industry and other businesses must take the lack of clean water seriously and concentrate on finding solutions since it has become a worldwide issue. To apply the adequate quantity and quality of water at the right time, the control of soil moisture may be regarded as a kind of water management [49]. The agriculture industry needs effective water management because it lowers costs and boosts crop yields. Water resource management is crucial because it helps businesses in the agriculture industry to effectively control their resources and perform the necessary tasks. It is vital to understand if these projects can be completed successfully since different projects are done at varying scales [50].

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Today, more and more organizations are concerned with the conservation of natural resources, because the shortage of such resources concerns everyone. Water is one of the most significant and practical resources in this respect, and it has to be maintained and safeguarded in a variety of ways [51]. In reality, irrigation requires a significant quantity of water, and the organizations concerned and associated with these operations must be incredibly smart and deliberate in designing ways that may maximize the use of water.

Therefore, effective water management solutions are needed to deliver many benefits to the agricultural sector [52].

Agriculture-related operations may be significantly impacted by the external environment's extreme uncertainty. For instance, rising fuel costs may make it more expensive to pump irrigation water. Pumping irrigation water will cost more if fuel costs rise, which might reduce the project's overall efficiency. Organizations may create extra water reservoirs and adopt new tactics through the management of water resources, lowering related risks and adverse effects [53].

Understanding the basic relationships between soil, crops, and water is considered one of the crucial elements in effective irrigation management system. To carry out the desired agricultural activity (irrigation), it is necessary to have sufficient information about the process and the products. If such knowledge is acquired, only the required activities will be performed appropriately. The inability to research how irrigation operations should be handled and regulated in challenging circumstances results in a potential reduction in overall performance [54].

One of the main factors that make effective water management important is maintaining high levels of work productivity.

It is feasible to guarantee that crops get enough water resources in arid sites and during low rainfall times by using water management [52]. Since many projects are undertaken in regions with low water resources, attention must be given to water resources management for resources to be allocated and used promptly. Additionally, rainfall is quite scarce in many regions, thus enough water has to be conserved to guarantee that the lack of rainfall can be addressed [55].

The necessity for water resource management to fulfil future water demand without interfering with operations is enhanced by uncertainty and fragility. In the modern world, a significant quantity of water is lost through various uses like irrigation [56].

The demand for improved management grows when enormous amounts of unused water are wasted. Technologies and approaches must be developed to reduce waste and use resources efficiently. The necessity for water resource management will only grow due to the potential future issue of drinking water shortage. The agricultural sector uses different approaches and approaches related to water resources management, each with its advantages and limitations [57].

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Some of them can be identified as follows:

- Metering/metering/management
- Use of water-efficient landscaping and irrigation
- Reverse osmosis control
- Rainwater recycling
- Water tanks
- Used by the agricultural sector can be identified as the most efficient way to manage water resources.

While these approaches can enable effective management of water resources, they largely depend on implementation and effectiveness to achieve results.

4. SMART SYSTEMS AND IoT USED IN IRRIGATION

4.1 Communication Technology

The communication technology utilized in the deployment of IoT devices may be seen as an essential and crucial factor for proper operation. In addition, depending on the situation in which they are employed, communication technologies might be deemed to be used [58]. There are two basic types of IoT irrigation technology.

Considerable volumes of data may be sent over short distances by devices that serve as nodes and use minimal power. Other devices are thus power-hungry and capable of sending massive volumes of data over great distances. IoT devices, which may be categorized as devices communicating over long or short distances, can communicate using a variety of wireless protocols [59].

Wi-Fi has been described as one of the most popular and successful communication technologies because of its accessibility. Additionally, it has been discovered that the majority of the present low-cost IoT devices enable Wi-Fi, which is regarded as an efficient all-encompassing strategy despite its drawbacks (coverage and range) [60].

Further mentioned as a commonly utilized wireless technology that enables long-distance communications is the GSM (Global System for Mobile Communications). All that is required is a cellular plan from a service provider that is active and active in that location. LoRa (Long Range) and MQTT (Message Queue Telemetry Transport) are two other noteworthy recent inventions. LoRa has a very great range, making it a highly practical and valuable technology for remote regions without service. MQTT, on the other hand, has not been extensively employed in irrigation systems, although it has also grown to be a popular protocol because of its low overhead as well as power consumption [61].

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4.2 Cloud Technologies

The cloud and conventional databases may be regarded as two of the most significant and frequently utilized storage systems. The capacity to store and retrieve important information when required makes these storage systems crucial for several businesses working in diverse industries. The idea of "big data"—which denotes the enormous data sets that organizations employ for a variety of purposes—emerges through the utilization of these storage systems [62]. The usage of middleware is critical for providing the fundamental services needed for IoT.

By using middleware, it becomes possible to wire together initially undeveloped programs. Different interface features and protocols make it easier to categorize IoT middleware [63].

Consider utilizing the cloud in agriculture to gather and analyze data using sensor technology, particularly in irrigation-based systems. It was also implied in some studies that individuals might examine the data by connecting to the cloud, where the data is processed. The main purpose of using clouds in irrigation is to store monitoring data and then retrieve it as required [64].

Users have access to both paid and free solutions for storing, analyzing, and displaying data across a variety of platforms and devices due to cloud computing. In reality, this technology is used to save data relevant to the workplace, which may greatly enhance overall performance effectiveness. Research and development might be regarded as one of the most important applications of stored data since it is accessed often and for many different reasons. Several organizations in the agriculture industry are now able to store and view information that helps to produce more effective and efficient operations due to the ease of cloud technology [65].

Cloud technology is also utilized to provide notifications for the irrigation process by creating algorithms.

These notifications are meant to reduce the risks and dangers that may otherwise exist. Utilizing these alerts makes it easier to alter work procedures and take the appropriate safety steps to minimize any adverse effects [66]. While each programme has its consequences and applications, they are all connected to cloud technologies and may assist increase performance. These programmes are executed depending on service, availability, cost, and other considerations. In terms of dangers, damages, and problems involved, installing irrigation systems may be regarded as a challenging task. Having stated that, people engaged in irrigation operations may employ cloud technology to decrease risk and enhance work outcomes to meet goals [67].

4.3. Advantages of IoT Systems in Irrigation

IoT systems for irrigation provide several benefits, some of which are average water consumption reduction, cost-effectiveness, performance efficiency, reduced water and energy consumption, reduced harvest waste, etc. [68]. The advantages of IoT uses in irrigation systems are shown in Fig. 2.

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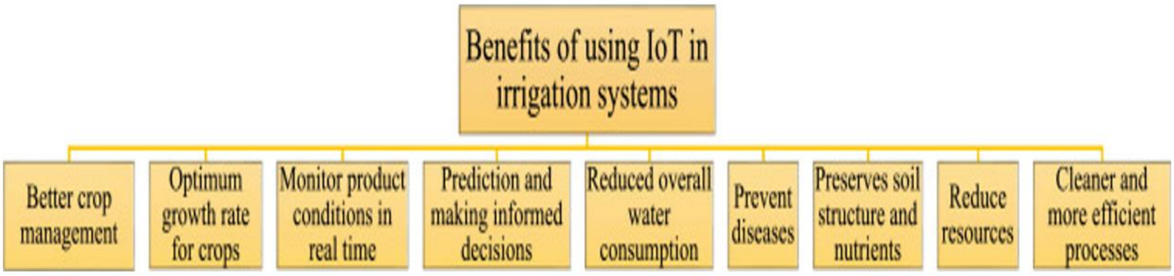

Fig 2: IoT Benefits in Irrigation Systems

Low water use is one of the key advantages of IoT systems in irrigation [69]. Through this technology, the majority of irrigation-related tasks are also automated, and the irrigation process uses only the appropriate quantity of water, reducing waste. Water is lost significantly in irrigation procedures that need human involvement in conventional irrigation, where the majority of operations and manipulations are carried out manually [2]. Smart irrigation requires little or no human involvement, and water resources are only used within the required range. Additionally, one of the other advantages is high-cost efficiency, since reduced water consumption and accuracy in the process may lower total prices and expenditures [70].

Because machines must run for shorter periods and schedule irregularities occur while lowering total energy usage, this strategy also dramatically lowers energy use [71].

Additionally, since resources are finite and businesses must control expenditures to some level, cost management and resource conservation are crucial. Cost considerations are made with smart irrigation, making it possible to do associated tasks quickly and inexpensively [72]. The improved irrigation technique and water resource management, which ensures that plants and crops get just the necessary quantity of water, reduce agricultural waste caused by inadequate or excessive water usage [73].

5. DEBATE

5.1. Optimization of irrigation systems using IoT and Big Data

It has been established that IoT systems usually generate large amounts of data due to real-time monitoring of various parameters, the systems of IoT irrigation also exploit Big Data. To understand the existence of large data, it has become essential to develop systems capable of evaluating and efficiently handling the data [74]. More attention must be paid to the sustainable handling of massive data, since large data management in general may be a challenging endeavor and overuse natural resources.

Some suggestions made in this respect involve adopting blockchain technology, removing irrelevant data and just keeping vital information, and powering gadgets with solar energy [75], implementing the technology of cluster for the overall volume of information, the efficient use of algorithms and the sustainable resources available. Despite the fact that big data may significantly influence the whole irrigation method, it is crucial to maintain efficient information management and control [76].

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According to further research, data analysis was necessary to optimize irrigation depending on crop and weather conditions, even if the information given by the sensors gave sufficient relevant information. Various irrigation-related institutions can reasonably get the necessary data, but they fall short of properly analyzing the material and drawing helpful conclusions from it. The inability to analyze is a major impediment to increasing productivity and lowering risk at work [77].

The obstacles to smart irrigation are shown in Figure 3.

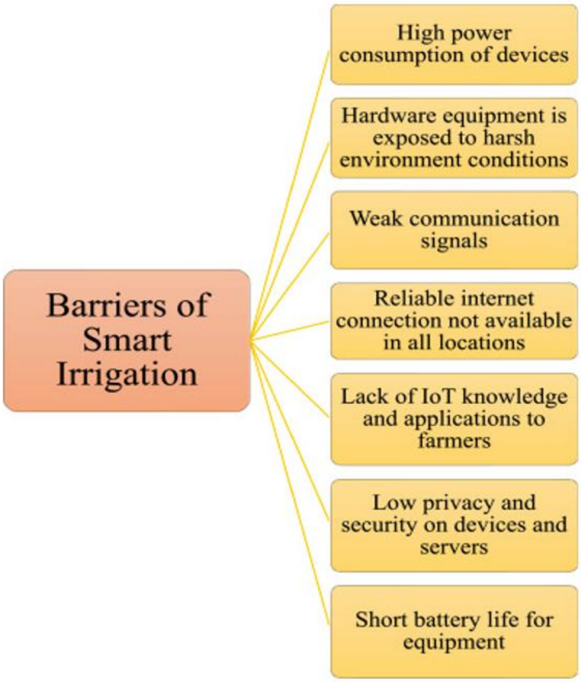

Fig 3: Barriers of Smart Irrigation Systems

Furthermore, AI is considered a technology that most organizations use for different purposes. The optimization of available resources as well as the collection of crop-related information including diseases or the correct growth of plants become more feasible through the use of AI. Fuzzy logic is a comparable method in this context for assessing data gathered from sensors to carry out irrigation-related tasks. This method is used to enhance drainage and irrigation planning [78]. One such method for making predictions in irrigation systems is machine learning. The quantity of water available for irrigation is determined using forecasting algorithms. Predicting potential difficulties and outlining risk management strategies to achieve maximum work efficiency, enhances the irrigation process. So, less water use, better profits, and better agricultural yields may all be considered advantages of machine learning. Achieving efficient performance while delivering economic benefits may become more achievable by using machine learning to reduce the risks associated with irrigation [79]. Crop diseases, pesticide control, weed management, inadequate storage management,

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inadequate irrigation, and inadequate water management are just a few of the issues in agriculture that may all be resolved by utilizing different artificial intelligence techniques.

Overall irrigation-related activities and procedures are improved by machine learning algorithms, which also aid in meeting performance goals. Machine learning also supports the prediction of irrigation patterns based primarily on crop and weather scenarios. Machine learning may be directly linked to predictions since it aids in developing strategies and actions that consider potential future behaviour. These projections enable it to finally take the necessary steps to sustain irrigation over the long run [80]. A concise overview of significant AI technologies and smart irrigation is provided by Banerjee et al. [81], who also classify recent advances in AI. Chlingaryan et al. also introduced a ML expert system with an adaptable architecture for data-driven decision-making [82]. Similar to how good management of sensing data for soil, weather, and plants has been shown to lead to the creation of sustainable precision irrigation systems [83], [84], [85], [86]. Elavarasan et al. [87] explored a variety of ML methods to determine the best way to manage irrigation choices. Precision irrigation systems may be utilized to adaptably regulate the environment's changing circumstances. The literature has examined several ML applications, including soil management [46], crop management [72], livestock management [88], and water resource management [89].

5.2. Irrigation Systems and Durability

One crucial element of irrigation systems is durability. For any system to be sustainable, the three pillars of sustainability must remain in balance. Economic, social, and environmental factors are the three cornerstones of sustainable development. The possible social, economic, and environmental effects of irrigation systems are shown in Figure 4.

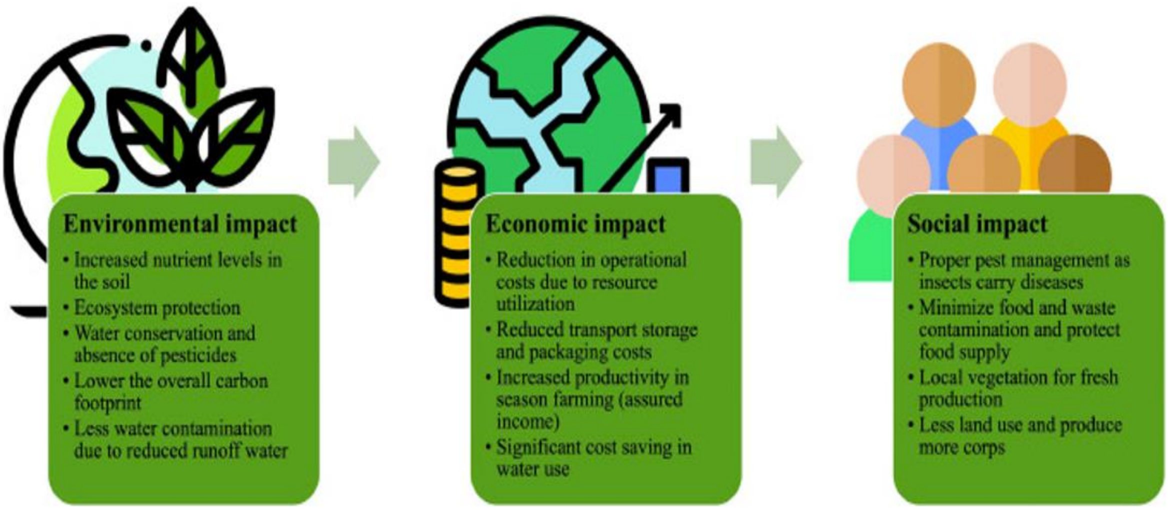

Fig 4: Potential social, economic, and environmental benefits of the irrigation system

Organizations engaged in certain industries and associated operations should take these factors into account since the components of sustainability may be evaluated in various situations and mediums. Making sure irrigation practices have no detrimental effects on the environment is one facet of sustainability [90]. It has been shown that irrigation operations have many adverse effects on the environment, including waterlogging, a rise in the prevalence of waterborne illnesses, soil salinization, issues with resettlement, etc. Despite being a significant component of the agricultural industry, irrigation-related activities must not be developed in a manner that has a detrimental effect on either wildlife or human health. A sustainable irrigation system may also include water management.

Since water is a necessary component of irrigation, it is crucial to manage and regulate the resource effectively to reduce water waste [91]. Thus, the development and management of irrigation are subject to new requirements as a result of the need for more sustainable and healthier food systems. It can improve agricultural production, promote equitable development, enhance water security, and bring about good change to fulfil many SDGs at all scales, from individual to national level irrigation systems. Pump power is required for the drip irrigation system to work. Different energy sources are employed in this operation to produce the pumping power, which also negatively affects the environment as a whole.

To guarantee that energy consumption and environmental effect are reduced while considering sustainable irrigation, it is crucial to use green working practices [92]. Organizations must increasingly focus on techniques to reduce pollution, disease, cost and other factors when conducting irrigation activities. If irrigation does not result in the loss of natural or human capital, a high level of irrigation sustainability may be reached. The primary connections between this sustainability factor and economic and environmental factors [93].

To maintain economic viability, it is important to make sure that irrigation costs do not exceed irrigation's marginal production.

If the process of irrigation is particularly expensive, it may not be seen as a sustainable operation, and the strategy for the related activity could need to be revised [94]. One such idea that might be regarded as crucial for sustainability and irrigation is water depletion. Water is a limited resource, and worries over it have grown significantly. It turns out that the agriculture industry is struggling greatly with a shortage of freshwater supplies, making sustainability even more crucial. In this respect, cutting down on water waste and putting effective irrigation techniques into practice will help save water that can then be utilized for desirable long-term activities [95].

Crop irrigation is necessary and is one of the primary factors contributing to the fast-growing water shortage in many locations [96]. Smart irrigation is crucial for water conservation as it guarantees that each crop gets the appropriate water quantity. The irrigation process can cause the plants to reach, causing the crop to dry out. An automated controller included in the drip irrigation system is the greatest solution to this issue. Therefore, combining current technology

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with irrigation may enhance the water used for irrigation in many regions. This research suggests using established IoT technology.

IoT applications may provide unbiased data on water resources, their usage, and management, which can help with SDG 6 implementation. For instance, Khelifa [48] created a smart irrigation system for southern Algeria by fusing IoT and ICT technology. Their study makes sure that irrigation schemes are cost-effective, utilize the least amount of water possible, and are labor-efficient.

5.3 Security and Collection

Technology advancements have produced many modes through which novel techniques for gathering data from field-installed sensors have been devised. Despite several developments and applications, using drones is still one of the most efficient ways to gather data from sensor nodes. Drone technology has further enabled the collection of new data that would otherwise not be available like aerial imagery of fields [97].

Robots that trigger sensors as well as actuators to perform various tasks, including water spraying, soil moisture monitoring, animal scaring, or weeding, have been highlighted as another kind of data collecting. Thus, the robotic technique can be used for area irrigation as it can go where it is needed. The robot has sensors that lessen the chance of collisions and can also measure soil moisture [98].

Robots are one of the most effective methods to carry out tasks linked to irrigation, and many firms are already using this technology. Improvements in robotics have come with their usefulness and impact.

Wireless robots include soil monitoring and environmental monitoring and are capable of performing tasks such as spraying water and moving around fields [99]. Overlay path planning methods for maps with static features and environmental data may be utilised to enhance the navigation of irrigation robots. The robot operating system may also be utilized to create three major layers of robot control systems. Reading sensor data is done by the first layer, communication is done by the second layer, and route planning and decision-making are done by the third layer. Additionally, solar panels may be used to power robots, ensuring their autonomy as well as robustness and efficiency [100,101].

As a result of many risks, implementing IoT systems for security might become quite challenging process. Cloning, weak software, private information leak, covert eavesdropping attacks, firmware assaults, denial of service attacks, routing attacks, and other security risks might materialize and have negative impacts. It is now crucial to create security solutions that might lessen overall difficulties in consideration of all these risks [102]. Information about an organization's operations and activities in a given sector is so crucial and significant that protecting it becomes of the utmost importance. While several methods have been created to lessen the related issues, blockchain technology is one of the more successful ones.

It is a technique used to secure IoT systems, allowing more secure communication and data storage [103]. It is well known that technologies like blockchain are mostly employed in

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agriculture to protect supply networks. Concerning the blockchain and IoT agricultural irrigation systems, it is utilized to monitor and trace the information exchange for the suggested smart irrigation system. Due to technological advancements, security problems have grown in the past, and it is crucial to improve security [56]. By increasing research and development, organizations focus on containing threats and ensuring that malicious activity can be significantly reduced. Additionally, over the years, the need for secure storage systems has grown, and as agriculture-related activities have become more automated and technology-infused, the likelihood and incidence of attacks have increased dramatically. Although some organizations have been successful in containing threats, continuous improvement through method development can still produce desired results [57]. The many sensor types that may be utilized in an irrigation process are illustrated in Figure 5.

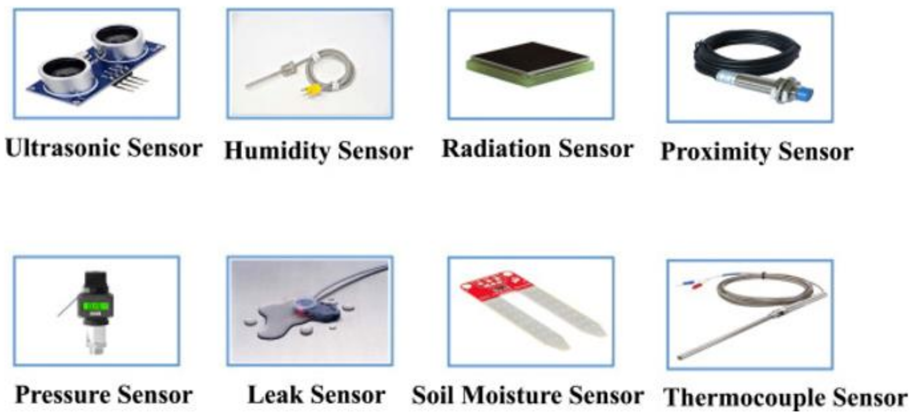

Fig 5: Smart irrigation system sensors (Source: Wikipedia)

5.4 General layout and architecture of IoT-based sensing irrigation system

It has been shown that irrigation management and its IoT solutions use a multi-agent architecture that is highly obvious and well-known. Such specific architectural kinds result in distinguishing the different elements that compose them. In most cases, architectural distinctions are developed based on the hierarchy of architectural elements. For example, here the position of a node in the hierarchy can lead to acting as a proxy for lower nodes in the hierarchy [58]. The most of the systems are also assumed to be composed of functional blocks that reflect the particular operations and functions that must be carried out. These architectures' key components include devices, management, security, communications, applications, and services. The IoT is a network of interconnected devices that may control, monitor, sense, as well as manipulate data at various locations. These particular devices are also taken into account as interfaces for connecting to other devices and transferring simple data. Additionally, the data will often be analyzed by several sensors, with the outcomes being applied to a variety of actuators [59].

Three basic levels have historically been used to describe IoT layout. The perception layer, application layer, and network layer are the different categories for these layers. Similar to these levels, the service layer is inserted between the network layer and the application layer.

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The particular layer is implemented to process and store data using fog and cloud computing [60]. In addition, various new architectural proposals have been developed and proposed by different researchers, one of the clearest proposals comes from Ferrández-Pastor, who established a four-layer architecture. The four levels are cloud, communication, edge, and object. In this approach, the edge layer is responsible for identifying key applications and carrying out fundamental control operations. Different layered techniques have been utilized and deployed in the context of irrigation IoT systems to provide various outcomes [61]. The middle layer often comprises gateways to facilitate data transfer, while the lower layer typically consists of sensor and actuator nodes. Cloud services, databases, or applications make up the architecture's third layer. Although these three layers are the most developed, they may still be distinct and have various characteristics [104]. The entire layout of the smart irrigation process is seen in Figure 6.

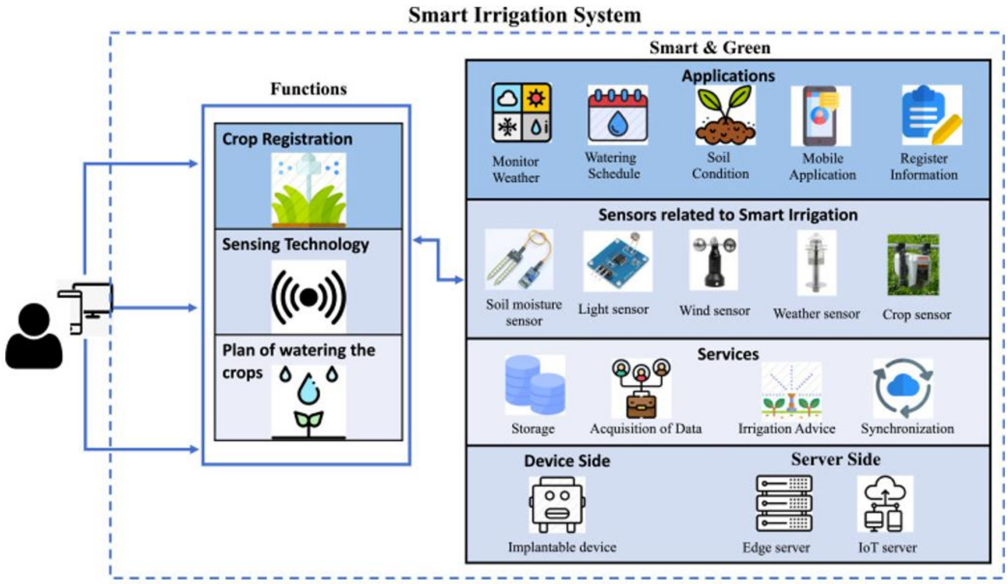

Fig 6. Smart irrigation system layout (Source: flaticon.com)

6. CURRENT PROSPECTS AND CHALLENGES

This section presents the prospects and challenges of ML applications. When creating digital software and ML programs for smart irrigation systems that handle a range of crops, particularly to support sustainable agriculture, there are many challenges to solve. To address food shortages, total food production should be raised. Also, additional industrial needs must be met by growing more cash crops like cotton and rubber, particularly if they are combined with sustainable materials to prevent soil degradation [105].

These issues have also contributed to many other issues, including the fall in the agricultural labor force, the reduction in agricultural land, the shortage of water supplies, and the consequences of weather change. As the world urbanizes, populations in rural areas are agin and shrinking rapidly. A broad variety of IoT applications in agriculture and food production are feasible due to irrigation system integration. The autonomous operation, cost, minimal maintenance, portability, strong design, efficiency, and dependability are just a few of the numerous IoT-related aspects of smart irrigation that need consideration. Agriculture has the potential to develop into a successful industry when integrated systems realize the possibilities of big data and AI.

These integrated systems, which may be utilized for tasks like planting and production forecasts, will integrate numerous agricultural tools, machinery, and management strategies. Agricultural robots, cloud computing, AI, and big data, are just a few of the cutting-edge devices that might usher in a new age of agricultural IoT. These instruments are considered important for ensuring sustainable agriculture. Farmers and other stakeholders have several potentials to use wearable software solutions in combination with machine learning forecasts. By enhancing irrigation demand forecasting, modifying timing and amount in accordance with plant water requirements, and adaptively correcting for water loss, water usage efficiency may be increased. By enhancing irrigation demand forecasting, modifying timing and amount in accordance with plant water requirements, and adaptively correcting for water loss, water usage efficiency may be increased. This will result in higher yields with less irrigation water needed. Better-trained models will be used as systems grow more sophisticated and intelligent to make better irrigation choices. By doing this, irrigation-related stress and load may be minimized for both users and farmers.

7. CASE STUDY

Various cases of successful inculcation and implementation of elements of a SMART irrigation system can be considered. All over the world, the agricultural industry and other organizations involved in irrigation activities want to implement smart irrigation methods to reduce costs and improve labour efficiency. One of the distinguishable situations comes from the industrial business WaterBit. The firm is a cutting-edge technology provider that has teamed up with AT&T, one of the biggest telecommunications companies in the world, to offer secure wireless connection for its autonomous irrigation systems, enabling the control and administration of local irrigation. It enables farmers to considerably save resources while simultaneously increasing total productivity [106].

The WaterBit Gateway wirelessly transmits soil moisture data collected in the field to the cloud securely and reliably. Users may access and manage this particular data using a mobile-friendly application, and it is often updated every few minutes [107].

Town of Ipswich-Another Australian Council case study demonstrates how irrigation may be controlled by an automated soil moisture monitoring system, which can result in considerable water and financial savings. A web-based automated system is more efficient than precipitation-based distribution methods. The specific approach adopted by the committee not only improves performance but also reduces the knowledge of the soil and the labor required to manage a specific irrigation system [108]. Additionally, water consumption and wastage are reduced through implementation, which conserves resources and improves

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overall quality. In another effort, Maeju University in Thailand has built a smart farm using solar energy to provide alternative power to smart mushroom farms. Use IoT technology to improve performance and automate irrigation control. The Internet of Things controls all the necessary environments for mushroom lighting, temperature, humidity and airflow.

Through network sectorization, Garcia et al. [109] lowers energy use and achieve energy savings of 20% to 29%. The plants within the scale will get irrigation water across the day. If more time is needed for irrigation, either keep the water in the ground or increase it. So, farmers' energy expenditures may be decreased or eliminated by employing solar energy to power irrigation equipment. When compared to traditional electricity or diesel engines utilized in irrigation, the exploitation of renewable energy will minimize greenhouse gas emissions. To provide irrigation water directly to the grid without the need for intermediary storage elements like reservoirs or batteries, smart irrigation management models are combined with solar PV energy [110]. An overview of the cases is shown in Table 1.

Table 1 : Comparative review of work presented by researchers

S. No	Year	Methodology	Remarks	Reference
1	2017	MATLAB, Neural Network Toolbox	Water usage optimization as part of the Smart Farm Automated Irrigation System to ensure optimal water resources.	[117]
2	2018	Arduino Uno and Raspberry pi	The developed system is sustainable, reliable and efficient. The smart irrigation system was developed utilizing PV panels and a combination of control devices.	[115]
3	2018	Generic IoT framework for improving agriculture irrigation	chilli farming irrigation system was used to validate the general framework. To transmit this information to farmers in their native language, a user-friendly smartphone application has been developed.	[114]
4	2019	Arduino microcontroller	The system reduces energy consumption, saves time and enhances irrigation efficiency. A low-cost automated irrigation system for green walls has been designed.	[112]
5	2019	Fuzzy Logic based	The valve control commands using a fuzzy logic-based weather condition modelling system that considers different weather conditions.	[41]
6	2019	Radial Basis Function Network, RBFN	The irrigation system forecasts the anticipated water level values, humidity, weather forecasts, irrigation data, and temperature. The solar-powered smart irrigation system is developed with an IoE environment.	[116]

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7	2020	AgriSens	Design of a dynamic irrigation scheduling system based on IoT (farmer-friendly user interface) Based on farmer requirements, an algorithm for autonomous dynamic-cum-manual irrigation is designed	[113]
8	2020	TelosB and the IRIS motes	Reference network architecture aimed primarily towards smart irrigation. The full-scale smart irrigation system was designed in a strawberry greenhouse environment in Greece	[111]

8. THE ROLE OF IRRIGATION IN OBTAINING THE SDGs

Irrigation responds to several SDGs aimed at poverty reduction and food security. Smart irrigation, on the other hand, is a sign of more general SDGs meant to support industrial innovation and production for food security and more responsible consumption. This is directly linked to progress towards the current Sustainable Development Goals. The effect of smart irrigation systems on sustainable growth is seen in Table 2. The primary purpose of water resources is to improve food production and irrigation system.

Table 2: The role of irrigation in attaining the SDGs.

SDGs	Smart Irrigation contribution to the SDGs
SDG 1: No Poverty	Supports rural communities in emerging nations.
SDG 2: Zero Hunger	Increases agricultural productivity and fights hunger.
SDG 3: Good Health and Well-being	Lowers the danger of pesticides and other ailments that are caused by the soil.
SDG 6: Clean Water and Sanitation	Utilities and agriculture irrigation are used to provide access to sanitation.
SDG 7: Affordable and Clean Energy	When combined with a solar system, aids in achieving a sustainable energy option for farms.
SDG 8: Decent Work and Economic Growth	Enhances other industries and quickens the development of rural economies.
SDG 9: Industry, Innovation and Infrastructure	Promotes sustainable industrialization and fosters innovation.
SDG 11: Sustainable Cities and Communities	Using smart irrigation systems to build sustainable cities.
SDG 12: Responsible Consumption and Production	Ensuring efficient resource management and reducing the quantity of waste produced.
SDG 13: Climate Action	Improving crop yields and, eventually, changing rainfall patterns.

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SDG 14: Life Below Water	Compared to conventional irrigation methods, a moderate quantity of water is utilized.
SDG 15: Life on Land	Boosts both the quality and quantity of agricultural output and establishes a stable food supply.

Additionally, two of the most vital commodities on the planet are food and water. As a result, agriculture is essential to human life since it requires water to produce food. Water resources, which are crucial for sustainable development, are under significant strain from agriculture due to climate change and the fast-growing population. As a result, it has been shown that smart irrigation systems dramatically boost agricultural profitability and crop productivity. This strategy supports the SDGs and aids the sector in achieving more effective, equitable, and sustainable irrigation management.

9. CONCLUSIONS AND RECOMMENDATIONS

Today's business environment depends heavily on technological innovation as firms across all sectors seek to succeed. Irrigation and its applications may be enhanced in this respect to provide the highest level of operational efficiency while reaching the required performance outcomes. Farmers have chosen to implement sensory systems to better understand their crops, decrease environmental effect, and save resources since IoT is connected with automating numerous agricultural processes and elements, making the whole operation more efficient and effective. These technologies were developed in the past, and not all businesses can properly integrate and use them in the best manner. On the other hand, a major problem including water shortage, water stress, or scarcity, and water crisis is water scarcity.

The idea of managing water resources has arisen, inspiring organizations to find strategies for resource conservation and productivity growth. SMART irrigation systems are now required in today's climate where businesses employ technology to meet their performance objectives. The effects of sensor systems and IoT are quite significant. The IoT lowers the total cost of technology and creates new possibilities for irrigation management systems. Precision irrigation and real-time monitoring in agriculture are further applications of WSN.

The system comprises WSN nodes that can detect, compute, and transmit data on a variety of parameters. Although each of these technologies has benefits and drawbacks, carrying out irrigation-related tasks just requires the use of the proper technique.

A more thorough explanation of the suggestions for putting a SMART irrigation in place for agriculture can be found below:

- One of the suggestions involved extensive research and development to identify inadequacies in current methods and methods and develop better technologies for improved outcomes. Gains from R&D are substantial and enable organizations to guarantee long-term effectiveness. As a result, organizations have the chance to pinpoint IoT and WSN technology enhancement opportunities.

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- When deploying smart irrigation systems, management and safety concerns should get more consideration. To make sure that the nodes complete the essential actions, an effective communication system is crucial. Systems are often connected to different sensors and maintaining point-to-point communication is essential. Better communication will provide better outcomes as well as fewer errors and adversity.
- Aspects of safety policies and systems, as well as organizations, play an important role in irrigation operations.
- This is required to preserve system security and safeguard vital data. It can result in increased costs for the organization, but a strong security system is always beneficial and desirable in the long run. Additionally, security lessens the dangers caused by cyber-attacks.
- Focuses on improving sustainable activities as well as reducing costs. To fully benefit from the three pillars (environmental, economic, and social), the irrigation system's environmental effect must be considered and in line with the SDGs.

Overexploitation of natural resources should be prevented, and this may be done with careful planning. To maintain sustainability, it must also be made sure that the costs associated with the company's operations do not exceed the outcomes seen. This ongoing development of automation and technological usage is very productive and useful, and it may further lower related expenses. Leaning toward green activities and functions can help companies achieve desired goals, and a greater focus on corporate social responsibility can lead organizations to achieve great results.

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