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An Overview of Smart Irrigation Systems Using IoT

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ABSTRACT

Countries are focusing on sustainable agriculture through technological integration, particularly in improving irrigation systems to enhance water-use efficiency and contribute to Sustainable Development Goals (SDGs), notably Goal 6. This paper examines the role of SMART irrigation utilizing Internet of Things (IoT) and sensory systems in achieving SDGs. The study employs a qualitative design and secondary data collection. Automated irrigation conserves water, crucial for sustainable agriculture, while IoT and automation optimize farming processes. Sensory systems aid farmers in crop understanding, reducing environmental impacts and resource conservation. These systems facilitate effective soil and weather monitoring and efficient water management. Continued research and development are key to enhancing irrigation systems for sustainability and cost reduction. The review addresses challenges and benefits of implementing sensory-based irrigation systems, offering insights for researchers and farmers to improve irrigation techniques.

Key words: sustainable agriculture, Internet of Things, irrigation systems, water management, irrigation techniques

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INTRODUCTION

Agriculture is crucial for economies worldwide, facing challenges due to population growth and evolving consumer demands. To meet increasing food needs, innovation in agricultural practices is essential. Smart technologies like automation and data-driven approaches, such as smart irrigation, are emerging to boost productivity while reducing environmental impact. This sector's advancements are pivotal, considering its significance in global food production and resource utilization. Implementing smart irrigation technologies enables precise decision-making, optimizing resource use and achieving sector objectives. This aligns with UN Sustainable Development Goals (SDGs), particularly Goal 6 and Target 6.4, focusing on water conservation. Smart irrigation contributes to water and environmental sustainability, supporting a universal access to clean water and addressing water scarcity. Accurate assessment of water stress relies on quality data, reshaping irrigation practices for healthier and sustainable food systems. The misuse of agricultural practices can lead to environmental pollution and negative outcomes due to factors like land scarcity and lack of expertise. Artificial intelligence (AI) is increasingly applied in agriculture for sustainability. Scholars have long explored sustainability across various disciplines such as climate, ecology, green economy, food safety, and clean technology. Recently, attention has shifted to AI's role in agriculture. The SMART irrigation system automates irrigation, conserving water by adjusting irrigation based on soil and weather conditions. It includes components like data acquisition, irrigation control, wireless communication, data processing, and fault detection. Technologies like IoT, smartphones, and sensors enable farmers to monitor soil conditions, water requirements, and weather. IoT extends internet connectivity to devices, facilitating automation in agriculture for increased productivity and efficiency. Sensors aid farmers in understanding crops, reducing environmental impact, and conserving resources. SMART agriculture allows farmers to produce yields using fewer resources. This paper highlights SMART irrigation's contribution to sustainable development goals (SDGs) through IoT and sensory systems. This review will assist researchers and farmers to better understand irrigation tech- niques and provide an adequate approach would be sufficient to carry out irrigation related activities.

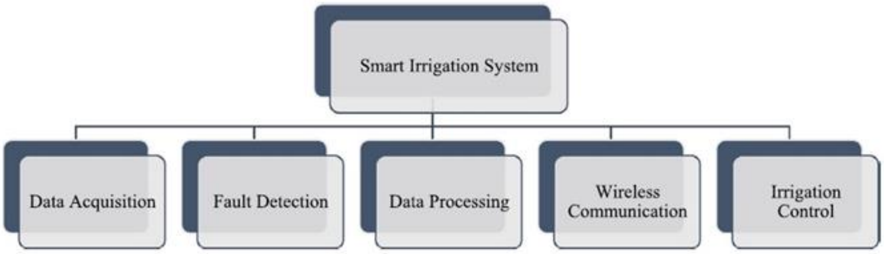


Figure 1: SMART Irrigation System

IOT AND SMART SYSTEMS USED IN IRRIGATION

A. Soil and weather monitoring

Efficient monitoring systems are crucial for plant development and optimizing irrigation. This involves real-time data collection using IoT and Wireless Sensor Networks (WSN). These technologies provide low-cost methods for monitoring soil moisture, a key parameter for plant growth. Soil moisture sensors, buried in the root zone, transmit readings to controllers for precise irrigation scheduling. Two main approaches are suspended cycle irrigation, which adjusts watering based on soil moisture, and water on-demand irrigation, triggered when soil moisture falls below a set threshold. Weather monitoring, essential for assessing environmental conditions, utilizes WSN and IoT for real-time data analysis and control. These systems track humidity, temperature, wind speed, solar radiation, and soil moisture, aiding in irrigation management and crop health.

B. Water Management

Water management is crucial for irrigation due to global water scarcity. It ensures optimal soil moisture and timing of water application, reducing costs and boosting crop production. Conservation of natural resources, especially water, is vital for agricultural organizations. Effective water management mitigates risks from uncertain factors like fuel price fluctuations, ensuring project efficiency. Understanding soil-crop-water relationships is essential for effective irrigation. Proper water management improves work efficiency, especially in dry regions or areas with low rainfall. Techniques like metering, water-smart landscaping, and rainwater recovery are effective for water management in agriculture, though their success depends on implementation and efficiency.

C. Communication technologies

In the realm of implementing IoT devices, the selection of communication technologies plays a pivotal role in achieving successful operations. These technologies are chosen based on the specific environment in which they will be deployed. For irrigation systems, the technologies used can generally be categorized into two types: those serving as nodes for transmitting small amounts of data over short distances with low energy consumption, and those capable of transmitting large volumes of data over long distances with higher energy consumption. Various wireless standards are available for IoT communication, typically classified by their suitability for short or longdistance communication. Among these, Wi-Fi stands out as one of the most utilized and effective options due to its widespread accessibility. Despite its liitations in terms of coverage and reach, Wi-Fi remains a popular choice, particularly because many low-cost IoT devices support it. Additionally, Global System for Mobile communication (GSM) is a widely adopted wireless technology known for its long-range communication capabilities, requiring only a mobile plan from the service provider operating in the area. More recently, Long Range (LoRa) and Message Queuing Telemetry Transport (MQTT) have emerged as notable technologies. LoRa offers extensive range, making it highly suitable for remote areas lacking traditional service coverage. Conversely, while MQTT boasts low overhead and power consumption, it has yet to see widespread adoption for irrigation systems.

D. Cloud technologies

Cloud and traditional databases are vital storage systems for organizations across industries, facilitating data storage and access. They enable the handling of big data, supporting various organizational needs. Middleware is crucial for IoT services, facilitating connectivity between programs. Cloud technology is increasingly utilized in sectors like agriculture, particularly in irrigation systems, where data collected by sensors is processed and stored in the cloud. This technology offers paid and free options for storing and accessing data, enhancing overall efficiency and supporting research and development efforts. Additionally, cloud technology is leveraged to generate alerts in irrigation processes, mitigating risks and improving work activities. Various cloud programs are available, each with its own significance and implementation factors, aiding in work performance based on cost, applicability, and services. Overall, cloud technologies play a significant role in optimizing irrigation processes, reducing risks, and enhancing outcomes

E. Benefits of IoT system in irrigation

IoT systems in irrigation offer a range of benefits, including reduced overall water consumption, enhanced cost-efficiency, improved performance, decreased energy usage, minimized crop wastage, and more. The advantages of employing IoT in irrigation systems are illustrated in Fig. 2. A significant benefit of IoT systems in irrigation is their capacity to lower water consumption. By automating much of the irrigation process, only the necessary amount of water is used, resulting in reduced wastage. In contrast, traditional manual irrigation methods often led to excessive water usage whenever human intervention was required. Smart irrigation minimizes or eliminates human involvement, ensuring water resources are utilized precisely as needed. Additionally, smart irrigation offers high cost-efficiency by optimizing water usage and enhancing precision, leading to cost savings and reduced overall expenses. Energy consumption is also notably reduced since machinery operates for shorter durations and follows planned intervals, resulting in lower overall energy usage. Given the constraints of limited resources and the necessity for cost control in businesses, smart irrigation plays a crucial role in managing expenses and conserving resources effectively. Furthermore, another advantage is the increased efficiency in irrigation and water management, which ensures that plants receive the appropriate amount of water, thereby reducing crop wastage caused by under or overwatering.

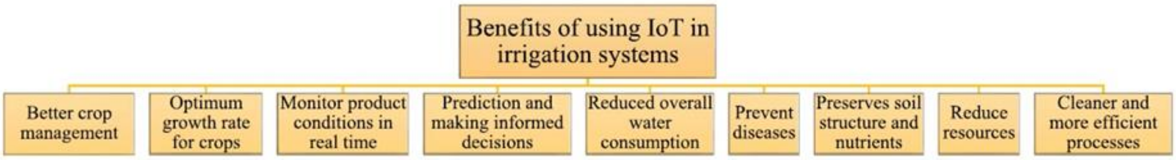


Figure 2: Benefits of inrrigation systems

DISCUSSION

A. Use of IoT and big data for optimisation of irrigation systems

It has been noted that IoT systems generate vast amounts of data due to real-time monitoring of diverse parameters, including IoT irrigation systems which also contribute to the accumulation of big data. Recognizing the significance of big data, it has become imperative to establish mechanisms for its effective assessment and management. Given the potential strain on natural resources caused by managing big data, there is a pressing need to prioritize sustainable approaches to its management. Suggestions in this regard include leveraging blockchain technology, discarding redundant data while retaining pertinent information, utilizing solar energy to power devices, implementing clustering techniques to reduce data volume, employing efficient algorithms, and utilizing sustainable resources. While big data holds significant potential for improving irrigation processes, it is crucial to ensure efficient management and control of this information. Furthermore, although sensor-collected data provides valuable insights, effective data analysis is essential for optimizing irrigation processes in alignment with weather conditions and crop requirements. Many organizations involved in irrigation activities gather ample data but often struggle with proper analysis, hindering efforts to enhance work efficiency and mitigate associated risks. Artificial intelligence (AI) is widely adopted by organizations for various purposes, facilitating resource optimization and gathering crop-related information such as diseases or plant growth abnormalities. Fuzzy logic is another technique used to improve irrigation scheduling and drainage management by analyzing sensor-collected data. Machine learning is a technique employed in irrigation systems to make predictions, aiming to evaluate available water for irrigation. This approach enhances the irrigation process by anticipating potential challenges and devising strategies to manage risks effectively, thereby ensuring optimal efficiency. The advantages associated with machine learning include reductions in water usage, increased profitability, and improved crop yields. By mitigating risks associated with irrigation, machine learning facilitates achieving effective performance and financial benefits. In agriculture, challenges such as crop diseases, storage management, pesticide control, weed management, irrigation, and water management can be addressed through various artificial intelligence methods. Machine learning enhances irrigation-related activities and processes through algorithms, aiding in achieving performance objectives. It supports predictions for irrigation patterns based on weather and crop scenarios, enabling proactive measures to be taken. Bannerjee et al. classified AI breakthroughs and summarized major AI techniques and smart irrigation. Additionally, Chlingaryan et al. demonstrated a machine learning expert system for flexible data-driven decision-making. Sustainable precision irrigation systems have been developed through effective management of sensed data about soil, plants, and weather. Elavarasan et al. explored the integration of different machine learning models for optimal irrigation decision management. Precision irrigation systems adaptively control changing environmental conditions. Various machine learning applications have been researched in literature, including crop management, livestock management, water management, and soil management.

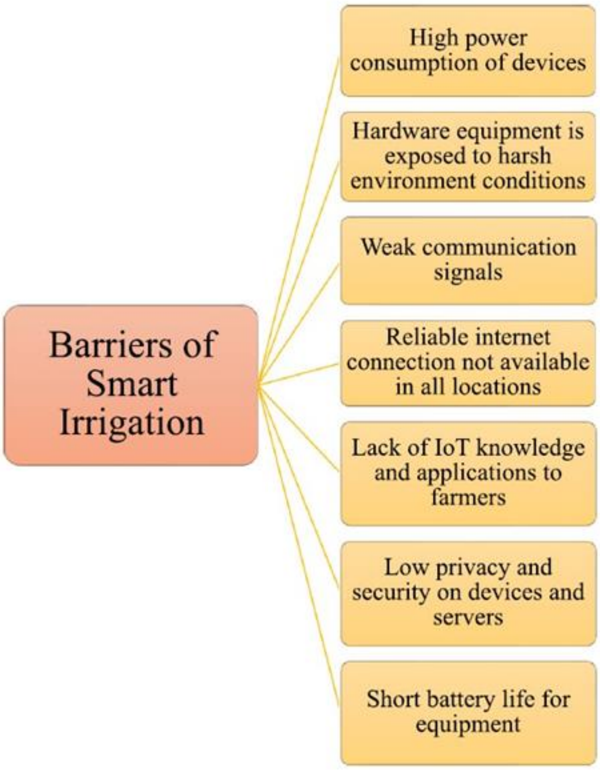
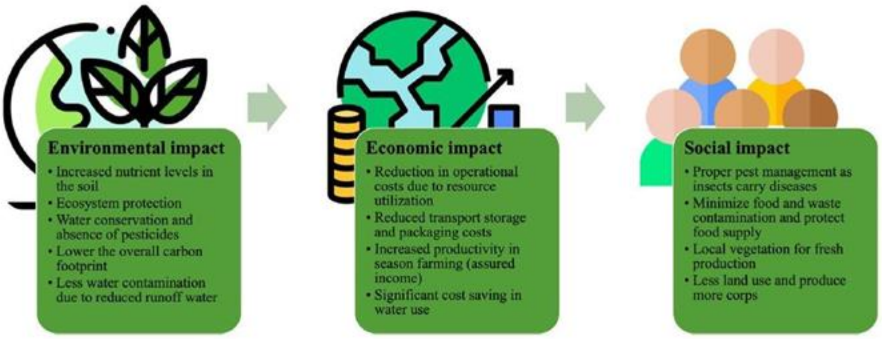


Figure 3: Barriers of smart irrigation systems

B. Irrigation systems and sustainability

Sustainability is a crucial consideration in the realm of irrigation systems, encompassing economic, social, and environmental dimensions. Maintaining balance among these pillars is essential for sustainable outcomes. Various factors impact sustainability, which must be evaluated by organizations within the sector. It's imperative to ensure that irrigation practices do not harm the environment, as evidenced by issues such as waterlogging, waterborne diseases, soil salinization, and resettlement challenges. Water management is integral to sustainable irrigation, aiming to minimize water wastage and environmental impact. Efforts towards sustainable irrigation systems are driven by the need for healthier food systems, emphasizing inclusive growth and alignment with Sustainable Development Goals (SDGs). However, the operation of irrigation systems, particularly those reliant on drip irrigation, necessitates energy consumption, posing environmental concerns. Thus, sustainable irrigation practices should prioritize green operational methods to minimize energy usage and environmental harm. This involves reducing pollution, diseases, and costs associated with irrigation activities. Economic sustainability requires ensuring that irrigation costs do not outweigh productivity gains. High irrigational sustainability is achieved when irrigation activities do not deplete human or natural capital, focusing on economic and environmental aspects. Water depletion is a critical issue, especially in agriculture, necessitating efficient water use and conservation methods. Smart irrigation technologies, such as IoT integration, offer solutions to optimize water usage, reduce costs, and support SDG 6 objectives.

For instance, Khelifa et al. developed a smart irrigation system for Algeria, leveraging ICT and IoT to optimize costs, minimize water usage, and streamline operations.



Environmental impact
- Increased nutrient levels in the soil
- Ecosystem protection
- Water conservation and absence of pesticides
- Lower the overall carbon footprint
- Less water contamination due to reduced runoff water

Economic impact
- Reduction in operational costs due to resource utilization
- Reduced transport storage and packaging costs
- Increased productivity in season farming (assured income)
- Significant cost saving in water use

Social impact
- Proper pest management as insects carry diseases
- Minimize food and waste contamination and protect food supply
- Local vegetation for fresh production
- Less land use and produce more corps

Figure 4: Potential economic,enviroment and social benefits of the irrigation system

C. Security and acquisition

Advancements in technology have led to the creation of new methods for collecting data from field-deployed sensors. Among these methods, drones have emerged as a successful means of gathering data from sensor nodes, enabling the acquisition of aerial images of fields that would otherwise be inaccessible. Another effective approach involves the utilization of robots equipped with actuators and sensors to perform tasks such as watering, monitoring soil moisture, deterring pests, or weeding. These robots offer potential for efficient irrigation by autonomously navigating to designated areas and assessing soil conditions while incorporating collision-prevention sensors. The adoption of robot technology for irrigation purposes is increasingly prevalent in contemporary organizations due to its efficiency and versatility. Ongoing improvements in robot technology focus on enhancing functionality and practicality. Wireless robots equipped for both soil and environmental monitoring can perform various tasks such as spraying water and traversing fields. Navigation enhancements for irrigation robots can be achieved through coverage path planning algorithms utilizing static element maps and environmental data. The development of robot control systems, divided into layers for sensor data acquisition, communication, and decision-making, can be facilitated by the Robot Operating System (ROS). Ensuring sustainability and autonomy, robots can be powered by solar panels. However, the implementation of Internet of Things (IoT) systems introduces security challenges, including cloning, software vulnerabilities, data breaches, firmware attacks, and various other threats. Given the critical nature of organizational data within the agricultural sector, it's imperative to establish security measures. Blockchain technology emerges as an effective solution for securing IoT systems, facilitating safer communication and data storage. In agriculture, blockchain is primarily utilized to secure supply chains. In IoT irrigation systems, it enables tracking and tracing of information exchange for smart watering systems. Despite advancements in technology, security concerns persist, necessitating ongoing research and development efforts to mitigate threats and safeguard automated agricultural activities. Continuous improvement through R&D remains essential to address evolving security challenges effectively. Figure 5 illustrates various sensor types applicable in smart irrigation systems.

Figure 5: Smart irrigation system sensors, pic- tures taken from Wikipedia.

D. General architecture and layout of the sensory irrigation systems based on IoT

It has been identified that multi-agent architectures are pretty evident and famous in irrigation management and its IoT solutions. These particular architecture types lead to establishing a distinction in the varied elements of which they are comprised. In most cases, the architectural distinction is developed in accordance with the layer of architectural elements. For instance, higher position nodes in the hierarchy may lead to acting as a broker for the ones that are placed lower in the hierarchy. Majority of the architectures are further considered to be divided into functional blocks which lead to represent the specific functions and actions that have to be carried out. Some of the major elements of such architectures are identified as management devices, communications, security services and application. The IoT systems consist of different devices that are located to conduct numerous different activities such as control, monitoring, detection, and action. Such particular devices are further considered to be having interfaces through which connection is developed with other devices in order to transmit the imperative data. Further, the gathered data through various sensors will generally be treated and the results attained from it will be applied to varied actuators. The architecture of IoT has traditionally been considered to be divided into three major layers. These layers are classified as perception, network, and application. With regards to these layers, another one has been added which has been placed between network and application layers known as the service layer. This particular layer is implemented in order to store and process the data through the use of fog and cloud computing. Moreover, different researchers have led to develop and present varied new architecture proposals and one of the most evident ones has been of Ferrández-Pastor who has established four layered architectures. These four layers are things, edge, communication, and cloud. The edge layer in this proposal has been identified to locate critical applications and conduct basic control processes. With regards to the IoT systems for irrigation, different layered approaches have been used and implemented attaining varied results from each. In common cases, the lower layer comprises actuators and sensor node whereas the middle layer consists of a gateway and supports transmission of data. Lastly, the third layer of the architecture is comprised of cloud services, applications, or databases. While these three are the most commonly established layers, they could be unique and varied having different characteristics as well. Fig. 6 shows the overall structures of smart irrigation system.

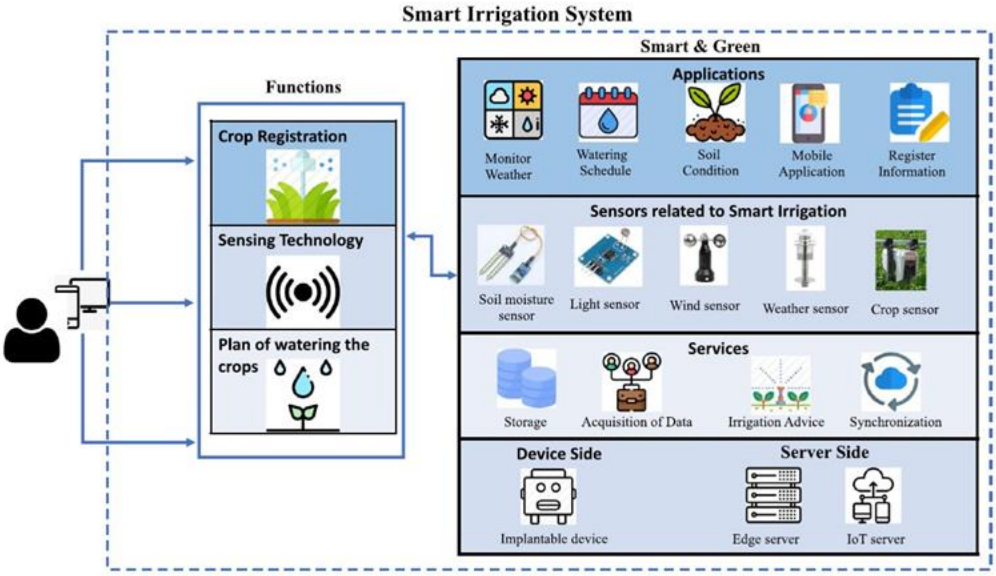


Figure 6: Smart irrigation system structures,icons taken from flaticon.com

E. Current challenges and future prospects

This section discusses the challenges and potential of applying machine learning in smart irrigation systems for sustainable agriculture. Key obstacles include increasing food production to address shortages, growing cash crops like cotton and rubber sustainably, and dealing with agricultural manpower decline, shrinking arable land, water scarcity, and climate change effects. As rural populations age and urbanize, integrating IoT techniques into irrigation offers various benefits, including cost-effectiveness, autonomy, portability, low maintenance, and reliability. When combined with AI and big data, integrated systems can revolutionize agriculture, facilitating activities from planting to yield forecasting. Advanced technologies like agricultural robots, cloud computing, AI, and big data play crucial roles in ensuring sustainability. Farmers and stakeholders stand to benefit from combining machine learning forecasting with portable software solutions, improving water use efficiency, timing, and volume matching, resulting in increased yield with less water. As systems become more advanced, better-trained models can enhance irrigation decision-making, reducing stress and burden for farmers and users

Table 1: Comparative review of work carried out by researchers

S.no	Year	Methodology	Remarks
1	2020	TelosB and the IRIS motes	Full scale smart irrigation system was developed in a strawberry greenhouse enviroment in Greece Reference network architecture aimed primerily towards smart irrigation
2	2019	Ardunio microcontroller	A low cost automated irrigation system for green walls has been designed. System reduces energy consumption,increases irrigation efficiency and saves time
3	2020	AgriSens	Design of a dynamic irrigation scheduling system based on IoT (Farmer friendly user interface) Based on farmer requirements an algorithm for automous dynamic cum manual irrigation is designed
4	2018	Generic IoT framework for improving agriculture irrigation	To transmit this information to farmers in their native language, a user friendly smartphone application has been developed Chilli farming irrigation system was used to validate the general Framework
5	2018	Ardunio Uno and Raspberry pi	The smart irrigation system is designed using photovoltaic panels and a combination of control devices The designed system is sustainable, efficient and reliable.
6	2019	Radial Basis Function Network, RBFN	Solar powered smart irrigation system is designed using IoE enviroment, The irrigation system predicts the expected water level values,weather forcasts,humidity,temperature,and irrigation data
7	2017	MATLAB, Netural Netwok Toolbox	Water usage optimization as part of the smart farm Automated Irrigation System to ensure optimum water resource
8	2019	Fuzzy Logic based	The value control commands using a fuzzy logic based water condition modelling system that considers various weather situations

F. Case studies

Various instances demonstrate successful integration and application of SMART irrigation systems. Organizations worldwide, particularly in the agricultural sector, have shown keen interest in adopting Smart irrigation methods to reduce costs and enhance operational efficiency. One notable case is WaterBit, an innovative technology company partnering with AT&T to offer secure wireless connectivity for its autonomous irrigation solution. This collaboration enables precise management and control of local irrigation, leading to increased yield and significant resource savings. The WaterBit gateway securely transmits in-field soil moisture data wirelessly to the cloud, allowing users to access and manage it through a user-friendly mobile application. Another example is the Ipswich City Council in Australia, which has effectively utilized an automated soilmoisture monitoring system to optimize irrigation practices, resulting in substantial water conservation and cost savings compared to traditional rainfall-based methods. This approach not only improves performance but also reduces the need for extensive soil expertise and labor to operate the irrigation system. Additionally, it minimizes water usage and waste, resulting in better overall resource management. In another instance, Maejo University in Thailand developed a smart farm powered by solar energy to support a mushroom cultivation facility. IoT technology was employed to enhance performance and automate irrigation control, optimizing environmental factors such as light, temperature, humidity, and airflow crucial for mushroom growth. This initiative led to significant energy savings through network sectoring, reducing consumption by 20% to 29%. Solar energy was utilized to directly power irrigation systems, eliminating the need for intermediary storage elements like water tanks or batteries. This approach not only reduces energy costs for farmers but also lowers greenhouse gas emissions compared to conventional energy sources such as electric or diesel-powered irrigation systems. The integration of a smart irrigation management model with solar photovoltaic technology offers a sustainable solution for efficient water management in agriculture.

G. The role of irrigation in ach achieving the sustainable development goals

Irrigation addresses various SDGs for the purpose of food security and reducing poverty. However, smart irrigation indicates a wider range of SDGs for the purpose of industry innovation and providing a more responsible consumption and production for food security. It has a direct influence on the current progress in SDGs. Table 2 provides the contri- bution of the smart irrigation system into the sustainable development. The water resources are based on irrigation expansion in order to en- hance food grain production. Moreover, water and food are two of the most essential commodities in the world, hence agriculture is vital to humanity since it uses wa- ter to provide food. Climate change and rapid population growth have put a lot of strain on agriculture, which effects the water resources that is critical for sustainable development. Thus, smart irrigation systems have been shown to significantly increase crop output and agricultural profitability. This approach supports the sector for a more productive, equitable and sustainable irrigation management and promotes the development of the SDGs.

Table 2: The role of irrigation in achieving the SDGs

SDGs	Smart Irrigation contribution to the SDGs
SDG 1: No Proverty	Supports communites in rural areas in developing countries
SDG 2: Zero Hunger	Fights hunger and enhances the productivity og farms
SDG 3: Good Health and Well being	Reduces the risk of pesticides and other diseases originated from the soil
SDG 4: Clean Water and Sanitation	Provides acces to sanitation by utilities and crop irrigation
SDG 5: Affordable and Clean Energy	Contributes to reaching a clean energy solution in farms when coupled with a solar system
SDG 6: Decent Work and Economic Growth	Accelwrates the growth of rural economics and contributes to other sectors
SDG 7: Industry,I nnovation and Infarastructure	Promotes sustainable cities through efficient use of smart irrigation systems
SDG 8: Sustainable Cities and Communites	Bulding sustainable cities through efficent use of smart irrigation
SDG 9: Responsible Consumptiob and Production	Ensuring a responsible management of resource and lowering the amount of waste generated.
SDG 10: Climate Action	Enhancing the agriculture yiels, and ultimatily altering the rainfall patterns
SDG 11: Life Below Water	Moderate amount of water used compared to traditional irrigation systems
SDG 12: Life on Land	Creates a reliable food supply and increases the quality and quanity of the farm production

CONCLUSION AND RECOMMENDATIONS

In today's business environment, technological innovations are crucial for growth and efficiency. Improving irrigation methods through IoT and sensory systems enhances operational effectiveness in agriculture. While these technologies have been developed, not all organizations have successfully implemented them. Water scarcity is a pressing issue, driving the need for water management solutions. SMART irrigation systems are essential for achieving performance goals. IoT and sensory systems reduce technology costs and enable real-time monitoring for precision farming and irrigation. The technique involves a network of wireless sensor nodes for sensing, computing, and communicating various data. Advantages and disadvantages exist, requiring a balanced approach for irrigation activities. Recommendations for SMART irrigation systems in agriculture include:

1. Emphasize substantial R&D to identify inefficiencies and improve IoT and WSN techniques.
2. Prioritize management and security to ensure effective communication and system protection against digital threats
3. Implement security strategies to safeguard data, despite potential increased costs, which can mitigate digital risks.
4. Focus on sustainable operations and cost reduction, aligning with Sustainable Development Goals for environmental, social, and economic benefits. This involves preserving natural resources through effective planning and ensuring operational costs remain feasible. Embracing green practices and corporate social responsibility (CSR) can aid in achieving these goals.

Authors and Affiliations

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