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Smart Watering System of the Plant Based on the IoT and Sensors, Energy-Efficient

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***Abstract* - Nations around the world are currently attaching great importance to enhancing the sustainability of agricultural practices by using recent and powerful technologies that ease and modernize agricultural practices. Enhancing irrigation has turned out to be a pressing necessity to increase the efficiency of water use and assist in the goals of the United Nations. This paper is an analysis of how smart irrigation, sensor-based surveillance, and interconnected water efficiency and conservation are boosted.**

The study contains a qualitative approach since it uses mainly secondary sources of information. This consequently leads to the saving of tremendous amounts of water in comparison to normal irrigation practices. Besides this, the contemporary agricultural business practices are being transformed by the use of IoT systems and automation that has strongly facilitated productivity and operation efficiency. The tools of monitoring help with the observation of the properties of the soil and the conditions of the atmosphere; it is easy to apply water in the most economical way and only when it is needed. Optimization of water use is thus primarily fueled by efficient irrigation systems and promotes ongoing studies to enhance an organization of greater sustainability with the minimum brunt over operational budgets. This paper also discusses the advantages of sensor-based irrigation systems and the limitations that come with the implementation of the system. Finally, the review will also serve the researchers, as well as farmers, since it is supposed to have a detailed model of how irrigation can be enhanced.

Introduction- Agriculture is a very vital industry and plays an essential role as a building block in a global economy. Nations all over the world have a new concern in automating their farms. As the population of the earth grows at a steady rate, the food demand also grows. This increased food demand coupled with consumer preference has had a big challenge on the agricultural sector to develop ways that will cater to the demands and expectations in full [1], [2], [3]. Agriculture is also among one of the most important spheres of society and allows it to develop. Consequently, it is necessary to make sure that progress is achieved in this area to enhance its overall performance and results. The continual advancements in technology in the production of foods are expected to trigger a significantly wide growth so as to address the evolving demand of the consumers [4]. The agricultural resources must be used efficiently, particularly when most nations rely on the sector greatly [5]. Smart irrigation is becoming a field of research that applies data-type approaches to grow farming and assist in producing more crops and is less damaging to the environment. The sensors will help farmers gain more knowledge about their land and make more intelligent decisions about their work, as they will be able to get valuable data [6], [7], [8], [9].

This information may be used to make more accurate decisions and optimize the use of resources, leading to attaining agricultural objectives. The adoption of these technologies in irrigation mechanisms improves water conservation and makes them a crucial element in SDGs, especially Goal 6 and Target 6.4. The usage of smart irrigation can contribute to such SDGs as water conservation and environmental sustainability, which are beneficial to the planet in general [10], [11], [12], [13]. Ratings on this indicator depend on the precision of the availability of the exact data on water. Due to this, the growing demand for sustainable food systems is laying out the new requirements for better management of irrigation and development.

The misuse of agricultural resources may cause environmental degradation and irreversible destruction of the ecology in the long term [17], [18], [19], [20]. The lack of sufficient reservoirs of land that would be used to store water and the lack of technical expertise on irrigation methods are two of the most critical factors that have added to this challenge. Additional depletion of the water resources has been brought about by the heavy usage of natural water bodies, leading to the development of non-irrigated and drought-prone lands. This state of affairs has raised the need to improve agricultural systems, thus motivating most nations to adopt smart strategies in the management of resource sustainability [21].

The use of artificial intelligence (AI) and digital technologies in agricultural activities and sustainable farming is gradually being implemented into the sphere of operations and sustainable farming [22], [23], [24], [25]. Sustainability has become one of

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the main concerns of study in various fields over the last few years [26], [27], [28], [29]. It is a wide topic offering many issues of great concern, such as climate change [30], ecology [31], clean technologies [15], food security [33], green economic systems [32], and sustainable agricultural practices [24]. In recent years, the demand to use AI-based solutions in the agricultural industry has increased.

The smart irrigation systems enhance the workflows, and they are a new innovation in automating water provision to crops. These systems control schedules of irrigation based on real-time soil and weather data and allow farmers to more precisely apply water and also save on wasteful usage [32]. An average smart irrigation system comprises data collection with the help of sensors, data processing, wireless communication, problem detection, and automated water distribution control. All these are incorporated in IoT-powered devices.

Examples of such technologies include sensors, mobile applications, and IoT platforms, enabling farmers to have accurate information about their farms, including the soil temperature, moisture needs, and environmental factors [27]. The Internet of Things may be regarded as the continuation of the traditional internet, when some linked devices become interactive using electronic systems and online networks, which simplify and streamline the work process. IoT agricultural automation, on the same note, has enhanced high productivity and operational performance of systems [28].

Sensors are important because they enable farmers to have accurate information on their crops, minimize the impact on the environment, and save on resources. Through the use of SMART agriculture procedures, there is an increase in crop production with less input in the form of water, fertilizers, and seeds [19], [20]. This research paper suggests the significance of SMART irrigation by implementing the IoT and sensor technologies and the priorities of the Sustainable Development Goals (SDGs). The results will be useful to researchers and farmers, as they will provide practical information to these groups on how to manage irrigation effectively.

Further innovations in the field of smart irrigation can be the presence of AI-based predictive analytics, which rely on real-time and historical data to enhance the irrigation planning process and reduce water losses. Platforms based on blockchain might enhance the level of data security through the clear and valid records of the irrigation operations, enabling the farmers to monitor more precisely the consumption of water and the efficiency of the system. Besides that, renewable ones like wind and solar energy might serve as the source of energy that will run continuous and environmentally friendly IoT-powered irrigation systems and will save the reliance upon standard power and decrease the operating costs. Such developments can make irrigation systems economical, sustainable, and green.

Abbreviations and Acronyms: The protocol allows the exchange of data in these systems with the help of the Message Queuing Telemetry Transport (MQTT) protocol. Sustainable Development Goals (SDGs) can be used in their application, especially in solving Water Stress (WS) with the help of such tools as Wireless Sensor Networks (WSN). Corporate Social Responsibility (CSR) makes certain that such technological improvements do not target the immoral and unsustainable goals.

IoT systems, mobile gadgets, and sensor-based technologies can give the farmers precise data regarding field parameters [27]. IoT is the internet expansion that has enabled related devices to interact with each other via digital systems that enable easy operation of the systems. It is also at the center of automation of farming activities, hence increasing efficiency and productivity [11]. The sensors provide vital information regarding crops in place of the environmentally conscious practices and resource preservation. Through SMART agricultural methods, farmers will be able to yield higher without necessarily consuming much water, fertilizers, and seeds [19], [20]. Aligning the language of SMART irrigation with the SDG objectives, this paper highlights the importance of the IoT and sensor technologies and attempts to help the researcher and the farmer implement an efficient irrigation strategy.

Effective monitoring networks are critical towards the management of irrigation and the growth of healthy plants. Proper monitoring of the environmental conditions will lead to high crop production at minimal losses of water. It is based on the real-time soil, plant, and weather monitoring using technologies, including IoT and Wireless Sensor Networks (WSN). The affordable irrigation monitoring solutions offered through IoT-based platforms have enhanced water management practices by being accessible to many people. WSN is an important part of gathering the field data and providing control systems in terms of automated irrigation. Water-on-demand, on the other hand, does not require programmed irrigation schedules. Rather, a moisture level can be set by the user, and only once soil moisture drops below the specified value is the irrigation done [16].

WEATHER SURVEILLANCE AND SENSOR NETWORKS:

Weather monitoring entails evaluation of climatic conditions in both the region of the target agricultural area and the adjacent regions, especially where large agricultural regions are involved. This is done to aid in the process of identifying risks in the environment and coming up with correct mitigation measures. One of the essential parts of this solution is the employment of the Wireless Sensor Networks (WSNs), in which numerous linked sensors constantly monitor environmental variables [23]. Such systems make it possible to get real-time data and process it, which creates a balance between the supply and demand of controlling mechanisms.

Another IoT-based weather monitoring system has also been implemented to assess the conditions of the crops. In this system the parameters that are monitored include soil moisture, temperature, speed of wind, humidity, and solar radiation. Sensors installed per weather demand and use of wireless communication technologies can transmit real-time information to provide comprehensive climatic information. These systems

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are useful in the development of sustainable irrigation systems to be used for agricultural production in the long term [31].

WATER MANAGEMENT ON IRRIGATION:

Water management is an element of the irrigation system. With the global issue of clean water rising to a high alarming rate, particularly in the agricultural sector, it is only necessary to have accurate and accountable water consumption. Maintaining the right moisture levels in the soil is one of the ways that would guarantee water is available at the most appropriate time and in the right amount. Water management saves on costs of operation and at the same time enhances crop yields. Agricultural organizations have to then prudently utilize the resources and carry out operations within the provisions of sustainability.

The number of irrigation projects is increasing, and proper implementation of the system is very crucial. The protection and conservation of the water, which is a valuable resource, are now of great priority owing to the rising scarcity of natural resources. Irrigation constitutes a significant share of the water utilization in the country, and accordingly, the stakeholders have to consider the maximization of water utilization. The technological means to provide more water management solutions is obligatory in order to gain long-term effects in the agricultural industry.

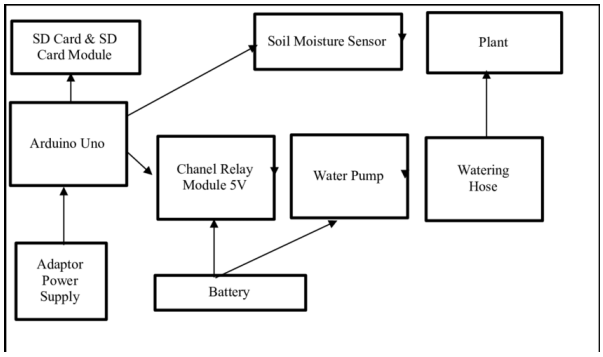

Fig. 1. *entire irrigation system.*

The external environmental factors also present uncertainty and possibly have an impact on agricultural performance. As an example, the cost of pumping irrigation water may also rise due to the escalation of fuel prices, something that affects the system efficiency in general.

The value of integrated water management:

Successful irrigation water management is based on the knowledge of interdependence between soil, crops, and water. Agricultural management is interdependent and needs detailed understanding of such interacting systems. Lack of proper information makes irrigation hard to manage, especially in poor environmental conditions, resulting in low performance.

Effective water management also makes sure that the crops in the dry areas and those in the rainfall shortages have enough water. This is important, more so in regions that are water strapped, whereby water delivery must be timely and efficient. In low-rain areas, there should be sufficient water storage to offset deficiency in precipitation.

The inconsistency and uncertainty that the water will be available in the future require the management process to be very efficient in order to bring about uninterrupted agricultural production. Much water is lost in the process of irrigation, which highlights the importance of better management concepts. Less wastage and enhanced use of the resource are thus fundamental objectives. With freshwater shortages ever increasing globally, issues around proper water management in agriculture will be of increasing value. There are various measures that are being taken currently so as to deal with these drawbacks and achieve better efficiency in water use.

- Water Treatment Methodologies.
- Monitoring, regulation and measurement.
- High-tech water-saving irrigation and landscaping.
- The control of the reverse osmosis system.
- The techniques of harvesting rainwater.
- Building of water storage reservoirs.

These methods are among the most viable and useful approaches to management of water in agriculture. But, their success will all depend on the way it is designed, how it is implemented and how efficiently it is working.

COMMUNICATION TECHNOLOGIES

Without communication technologies, the IoT devices that have been deployed in irrigation industry can not succeed. Environmental conditions in the place where the application is going to be implemented determine the type of technology to be applied. The IoT irrigation devices are distinguished based on the data transmission capabilities: the ones that need small data packets and partially long distance and low energy consumption and the ones that need high data volumes and long distance and high energy consumption. IoT systems embrace varying regulations of wireless communications that are defined according to the range of transmission.

The Wi-Fi is considered to be one of the most widespread technologies since it is cheaper yet available simultaneously. The Wi-Fi connection is sometimes a highly preferred option of connection as it is widespread and marketable products within limited coverage area are commonly priced low than the others. The other other significant technology that is currently being applied is GSM which is involved in long distance communication. Such new technologies as Internet of Things (IoRa) and Internet of Things (MQTT) have gained traction. LoRa can significantly cover long-range areas that have poor cell phone coverage, and MQTT offers the lowest overheads and minimum power consumption but are not implemented in the irrigation systems yet.

CLOUD TECHNOLOGIES

The cloud storage and conventional databases have found extensive use in the IoT application and enable organizations store and retrieve much data and facilitate the formation of big

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data. The middleware also plays a significant role in the IoT since it promotes the functionality of applications that were never designed to cooperate with each other. Cloud platform in irrigation of the module is of utmost importance to hold the observed data which may be inaccessible due to the need to retrieve information when the situation occurred. The platforms to save, analyze, and visualize the data can be seen at the feed of the cloud-based storage services that offer both free and paid versions, making a significant contribution to the enhanced efficiency of the operations.

The assistance of algorithms is also used to create alerts to prevent risks and hazards of irrigation on cloud technologies. This kind of notification provides a user with the possibility to react to the activity and puts pressure to reduce the potential errors. The cloud technologies have created many programs that can be used to sustain various costs, applications, and service demands. The utilization of the cloud systems has been quite rewarding in the reduction of the risks and optimization of the overall performance of the irrigation.

COMPARATIVE ANALYSIS

Criteria	**Historic agrarian uses of irrigation.**	**IoT irrigation is smart irrigation.**
Efficiency	Normally operated based on preset patterns or by human lack of knowledge, and this may lead to overwatering or underwatering. This may cause inefficient water utilization and reduced yield of crops.	Uses sensor data to control water in real-time to apply water where and when it is required to reduce wastage and improve the health of the plants.
Cost	Less costly to set up upfront, more costly in the long term because of water wastage, higher workforce costs, and higher maintenance costs.	Increased initial cost, and later savings, through both a reduction of water consumption and labor needs and a decrease in crop productiveness.
Feasibility	Easy to use and manage; however, less effective in regions characterized by water shortage or unreliable climatic conditions.	Needs use of technology and basic technical understanding yet offers scaled-up solutions to fit all types of climates and field sizes.
Environmental Impact	Does not contribute to harming the local ecosystems by contributing to soil erosion, runoff of nutrients, and needless depletion of water.	Ensures sustainability through water conservation, runoff reduction, and lowering of the environmental impact.
Automation & Monitoring	Hand mostly, and at times it requires a lot of supervision and adjustment in the field, which may also result in human error.	Exceptionally automated and remotely monitored and controlled to enable the farmers to make wise decisions and to fine-tune the irrigation process wherever they are.

IOT SYSTEMS ADVANTAGES IN IRRIGATION.

The benefits of IoT-based irrigation systems are quite numerous because they will result in fewer cases of water use and cost-effectiveness, as well as improve the operational performance. Conservation of water is also one of the major advantages since the smart systems automatize the irrigation process, and hence the required amount of water is consumed. The traditional irrigation techniques are mostly manual and are characterized by wastage of water. Smart irrigation systems save on wastage and enhance accuracy because they have limited human participation. Reduction in consumption of water also results in cost savings.

The third prominent advantage of the IoT irrigation systems is that they use less energy. Automated systems take shorter durations, which reduces total energy usage. Greater accuracy in irrigation and precision means that crops will be given the necessary amount of water, and this will decrease the chances of crop damage due to over- and under-watering.

DIFFICULTIES AND DRAWBACKS OF THIS IRRIGATION

Even though these irrigation systems are associated with numerous advantages, it is true that they still have several obstacles to their widespread use. These challenges include:

Huge starting costs:

The adoption of IoT systems is an expensive undertaking that will need a high initial outlay in sensors, communication systems, and infrastructure. These costs may be prohibitive to the small-scale farmers, and this prevents access.

Technical Complexity:

IoT systems are costly to operate and maintain, thus requiring technical expertise, which might not be easily accessible to everyone. This barrier could be resolved through training programs, as well as simplified interfaces.

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Connectivity Challenges:

IoT systems can be compromised in remote places where the network has a weak area. Such technologies as LoRa and satellite communication are the potential solutions that need to be developed and optimized in terms of costs.

Environmental Durability:

IoT devices should be able to survive in harsh conditions like extreme temperature, dust, and humidity.

Fig. 2 Plant watering system

FUTURE DEVELOPMENTS OF SMART IRRIGATION.

The development of IoT and other technologies at large is likely to determine the future of smart irrigation. Emerging trends include:

Artificial Intelligence (AI) embodies software applications that are integrated with the company and involves embedding AI capabilities into its processes.

Artificial Intelligence (AI):

AI algorithms have the ability to process sensor data to predict the time of irrigation and schedule water distribution more efficiently.

Security of data through blockchain:

Blockchain technology will allow the secure transfer of data between devices that will improve trust in the IoT systems. It is also capable of making clear monitoring of water consumption and adhering to environmental sustainability.

Energy-Efficient Systems:

IoT technology, which is powered by the sun, is also becoming common, especially in regions with low energy accessibility to conventional power sources. Such systems contribute to a decrease of energy dependency and cost.

Assistance and Subsidies:

International bodies and governments are starting to realize the possibilities of the use of SMART irrigation in tackling the problem of water scarcity. Adoption of these technologies can be facilitated using policy frameworks and subsidies.

TABLE I.

SMART Water Saving irrigation Systems and Full Sustainability.		
Aspect	***System Features***	***Sustainability contributions***
Water Management	Real time soil moisture sensors and weather sensors.	Reduces water wastage, regulates the adequate utilization of water and fosters SDG Target 6.4 water-use efficiency.
Energy Efficiency	Smart CVS-IoT operated on the solar power and more intelligent irrigation parameters.	Lowers energy consumption and the costs of running the farming activities, lowering the carbon footprint of the farming industry.
Resource Optimization	Precise water application, fertilizer application and application systems of the mechanical type.	Less consumption of resources, green agriculture, and the environmental pollution.
Environmental Monitoring	Applications of monitoring of climatic and soil conditions by Wireless Sensor Networks (WSNs).	Helps decrease the environmental risks and assists in adaptation to the changed climate conditions.

ACKNOWLEDGMENT

The study has highlighted the essence of employing real-time measurement of the moisture value of soil, weather, and health of crops to make effective decisions to maximize resource utilization and, in addition, enhance crop production and productivity. Furthermore, the impact of IoT-based solutions in the sphere of agriculture also leads to the sustainability of agricultural activities by decreasing the damages to the

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environment and decreasing waste, thereby creating a stable ecological situation in the long run.

Although the application of SMART irrigation systems can provide it with a significant number of advantages, issues like upfront cost and technical factors, as well as the necessity of the large-scale use of success in developing areas, have to be considered. Nonetheless, the further development of technologies, combined with the attempts of the global community to facilitate sustainable agriculture, can promote the widespread implementation of SMART irrigation systems, which in the end will help keep the resources under better control and lead to food security globally.

CONCLUSION

Smart irrigation has a vast potential to revolutionize the agricultural industry with the maximization of water utilization and agro-crop productivity, as well as environmental sustainability. It is possible to use modern technologies like IoT, sensors, and automated control systems to make qualified decisions that will not only enhance efficiency but also eliminate the waste of water. Due to the current increase in population around the world, the production of food is going to increase, and it is important to embrace the idea of sustainable irrigation that will not deplete the essential natural resources. The use of smart irrigation systems is a viable answer to this dilemma, which makes agricultural activities productive and responsible to the environment. With such innovations uniting, the agricultural sector can proceed to a future where the use of water is more reasonable and efficient, the levels of crop production also increase, and the well-being of the ecosystem in the long term is not endangered.

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