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An overview of smart irrigation systems using IoT

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A R T I C L E I N F O

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A B S T R A C T

Countries are working into making agriculture more sustainable by integrating different technologies to enhance its operation. Implementing improvements in irrigation systems is crucial for the water-use efficiency and works as a contributor to Sustainable Development Goals (SDGs) under the United Nations specifically Goal 6 and Target 6.4. This paper aims to highlight the contribution of SMART irrigation using Internet of Things (IoT) and sensory systems in relation to the SDGs. The study is based on a qualitative design along with focusing on secondary data collection method. Automated irrigation systems are essential for conservation of water, this improvement could have a vital role in minimizing water usage. Agriculture and farming techniques is also linked with IoT and automation, to make the whole processes much more effective and efficient. Sensory systems helped farmers better understand their crops and reduced the environmental impacts and conserve resources. Through these advanced systems effective soil and weather monitoring takes place along with efficient water management. Irrigation systems have been determined as positive contributor toward optimized irrigation systems that could enhance the use of continuous research and development which focus on enhancing the sustainable operations and cost reduction. Lastly, the challenges and benefits for the implementation of sensory based irrigation systems are discussed. This review will assist researchers and farmers to better understand irrigation techniques and provide an adequate approach would be sufficient to carry out irrigation related activities.

1. Introduction

Agriculture is an important industry as well as the foundation of the economy. Agriculture automation is a major concern and emerging topic for all countries. The world's population is rapidly increasing, and as the population grows, the demand for food increases. The developing need for food, as well as changing consumer demands, have made it extremely difficult for the agriculture industry to develop techniques and practices that will allow them to fully satisfy the increasing needs and requirements [1–3]. One of the most essential sectors in society is agriculture, where it fosters the improvements made. Thus, it is vital to ensure that upgrades are made in this industry to improve its general outcomes and results. Food production technology should foster major improvement and innovation to fulfil the customers' advancing needs [4]. It is critical to make use of the agricultural resources since most of the countries rely on the agricultural sector [5]. Smart irrigation is emerging as new scientific disciplines that use data-intensive methods to increase agricultural productivity while reducing its environmental impact. Modern agricultural operations generate data from a variety of sensors, leading to a better understanding of both the operation environment and the operation activities [6–9]. This enables more accurate and efficient decision-making. In addition, this allows optimizing resources and achieving the intended objectives from this sector. The water is conserved when implementing these technologies in irrigation systems such

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

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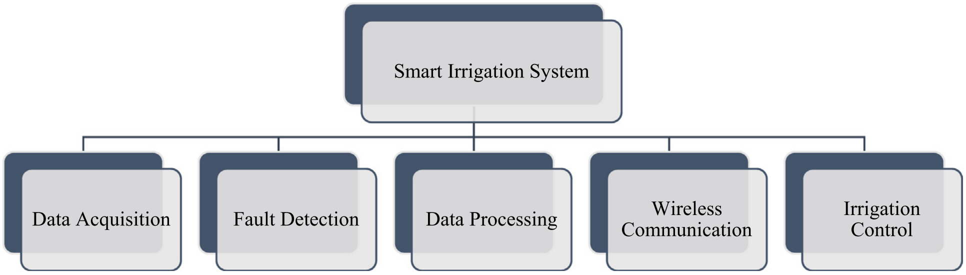

Fig. 1. SMART irrigation system.

that it plays as an important contributor to Sustainable Development Goals (SDGs) under the United Nations specifically Goal 6 and Target 6.4. The SDGs related to water and the environment could be achieved when implementing smart irrigation systems to attain sustainable benefit and better planet for all [10–13]. SDG 6 is about clean water and sanitation for all, the different targets and indicators of SDG 6 are linked to all water functions and services, considering irrigation. The target 6.4 deals with water scarcity and refers to two main indicators which are water use efficiency and water stress (WS) [14–16]. The quality of the assessment of this indicator depends primarily on the quality of available water data. Therefore, the call for healthier and more sustainable food systems is placing new demands on how irrigation is developed and managed.

However, the misuse of agricultural elements can result in environmental pollution and negative outcomes [17–20]. One of the primary reasons could be identified for scarcity of land reservoirs and lack of field expertise. The constant extraction of water from earth has resulted in lowering the water levels, which contributed to developing un-irrigated land zones. Therefore, improving agriculture systems has become a necessity and countries are now looking to implement effective frameworks where systems could be adequately run [21].

The sector of agriculture and sustainable agricultural practices are seeing modern uses for artificial intelligence (AI) systems and solutions [22–25]. For the past few decades, scholars have been particularly interested in the multidimensional field of sustainability in different disciplines [26–29]. Sustainability covers a broad range of topics, including climate [30], ecology [31], green economy [32], food safety [33], sustainable agriculture [34], clean technology [35], etc., due to its multidisciplinary nature. Thus, a more recent attention has focused on the provision of AI in agriculture.

The SMART irrigation system enhances the performance and is an emerging technique that automates irrigation systems and conserves water usage. This technique adjusts irrigation based on actual soil and weather conditions, therefore it allows farmers to meet their demand with a new adopted technique which conserves the water for irrigation process [36]. Fig. 1 shows the SMART irrigation system includes data acquisition (sensor), irrigation control, wireless communication, data processing and fault detection. Each of these components can be used in IoT devices.

Internet of Things (IoT), smartphone tools, and sensors are technologies that further enable farmers to know the exact status of their field, including soil temperature, amount of water required, weather conditions, and much more [37]. IoT can be thought of as an extension of the current internet to all devices that can communicate with electronic equipment and are linked to the internet, making devices user friendly and easy to handle. Correspondingly, IoT is linked to automation of all areas of agriculture and farming processes in order to make the entire process more productive and efficient [38]. The use of sensors is also important for farmers to better understand their crops, reduce the environmental impacts and conserve resources. Therefore by the usage of SMART agriculture, farmers are given the opportunity to produce yields while using fewer resources, such as fertilizers, water, and seeds [39,40]. This paper aims to highlight the contribution of SMART irrigation using Internet of Things (IoT) and sensory systems with SDGs. This review will assist researchers and farmers to better understand irrigation techniques and provide an adequate approach would be sufficient to carry out irrigation related activities.

2. Soil and weather monitoring

Efficient and effective monitoring systems have an impact on the development and growth of plants and are highly vital in designing an effective irrigation control system in order to enhance the production of food with minimum water loss [41]. Monitoring in the particular context of precision irrigation inculcates collecting data, which adequately leads to reflect the real-time status of the plant, soil, and weather of irrigation areas through the use of the Internet of Things (IoT) and Wireless Sensor Networks (WSN). In order to establish a real-time system of monitoring, IoT has led to establish a low-cost technology method that leads to improve the control and monitoring system for the irrigation process. Also, WSN also significantly contributes in real-time monitoring for precision farming. In this technique, a network of wireless sensor nodes is developed in order to sense, compute, and transmit information of different parameters [42].

Soil moisture is regarded as an essential parameter that is required for the growth of the plant. The effective monitoring of soil moisture content could be regarded as critical to ensure an optimal irrigation schedule. The soil moisture sensing focuses on a low-cost capacitance-based type which is basically based on the working principle of a dielectric device [43]. The aim of soil monitoring is to measure soil moisture content through the use of well-based technologies in the SMART irrigation system. The soil moisture sensors are buried in the root zone of trees, shrubs, or turfs which lead to precisely measure the level of moisture in the soil and transmit the reading forward to the controller. With the use of this method, the critical information is carried forward to understand how the related activities have to be designed and carried out for optimum results [44].

The two major soil moisture sensor-based systems could be considered as suspended cycle irrigation system and water on-demand irrigation. A suspended cycle is more like a traditional timer controller which has schedules of watering, duration, start, and end time. The difference in this is that the system would automatically stop the next scheduled irrigation when the soil has enough moisture [45]. On the other hand, water on demand irrigation does not require any sort of programming or irrigation duration. The threshold is set by the user in this technique which starts the process of irrigation when the moisture in the soil fails to meet the required levels [46].

Furthermore, weather monitoring is the process of assessing the weather of the area and its surrounding for a large cropping area. In other words, the environmental conditions of the area of work are analysed in order to identify the risks and develop strategies through which the adversities could be mitigated. The implementation of WSN could again be regarded as an imperative way in which different sensors are interconnected with each other in order to monitor physical environmental conditions [47]. The real-time monitoring takes place along with the analysis of data from the installed sensors through a feedback loop which further leads to activate the control devices. Another IoT-based weather monitoring system has been established which leads to monitor and assess the environment of the crop such as humidity, air temperature, wind speed, solar radiation, and moisture control in the soil. The use of weather-based sensors is taken in it which is interfaced with the wireless standard of communication for transfer of real-time data. Through the use of this method, it becomes feasible to attain detailed information regarding the weather which eventually leads to assist in developing methods that could support the process of irrigation in the long run [48].

3. Water management

Water management could be considered a highly imperative concept with regards to irrigation. The scarcity of clean water has turned out to be a concern globally and so the agricultural sectors along with other industries must give keen attention and focus on this issue. Water management could be considered as the management of soil moisture in order to make sure that optimum level and quantity of water is applied at the right time [49]. Effective water management is extremely crucial for the agricultural sector as it could decrease cost and augment crop production. Water management is also critical as it allows the organizations in the agricultural sector to manage the resources and carry out the required activities in accordance. The fact that various projects are being carried out at different scales, it is essential to understand if these projects will be carried out effectively or not [50].

An increasing number of organizations today have been focusing on conserving natural resources as the scarcity of these have led to develop a huge concern for all. In this regard, water is one of the most critical and useful resource that needs to be saved and protected by all means [51]. The fact that ample water consumption is involved in irrigation processes, the organizations involved and associated to these activities must be highly keen and considerate about developing ways through which usage of water could be optimized. Thus, effective solutions of water management are required to provide numerous benefits to agriculture industry [52].

The external environment is highly uncertain, and it may lead to affect the agricultural activities in a significant manner. Fuel prices for instance could result in increasing the expense of pumping irrigation water. If there is an increase in the fuel price, the costs of pumping irrigation water will also increase, and this could have an impact on the overall efficiency of the project. Through water management, organizations may be able to develop more reservoirs and adapt to different strategies through which the related risks and negativities could be lowered [53]. One of the most vital steps in good irrigation water management is regarded as knowledge of basic soil, crop relationship and water. To be able to carry out the required activities of agriculture (irrigation) effectively, it is necessary that ample information about the processes and products are attained. The required activities would be carried out in an adequate manner only if such knowledge is gained. With lesser knowledge and information, it would be not possible to explore how the irrigation activities have to be managed and controlled in adverse conditions and this may eventually lower the overall performance [54].

Water management is critical for various reasons and one of the other reasons could be identified as ensuring optimum work efficiency level. Through the use of water management, it may become possible to make sure agricultural crops attain proper application of water in dry areas and in periods of scarce rainfall [52]. The fact that various projects are being run in areas that do not have enough water, it is necessary to focus on water management so that timely distribution and application of water could be carried out. Also, in many geographical areas, rainfall is considerably low and so ample water has to be stored in order to make sure that the scarcity of rainfall could be overcome [55].

The uncertainty and vulnerability augment the need of water management so that the requirements of water in the future could be met and there is no break in the operations. Considerably, large amount of water in the contemporary environment is being wasted through different applications such as irrigation [56]. The wastage of huge amounts of water which is not being taken in any use augments the need of better management. Techniques and methods need to be developed through which the wastage could be lowered, and efficient utilization of the resource could be ensued. Also, the fact that scarcity of clean water could be a major concern in the future, the need of water management increases even further. Different ways and methods related to water management are being used in the agricultural sector and each of these methods has had their own benefits and limitations [57]. Some of these could be identified as:

- Measure/metre/manage
- Using water-smart landscaping and irrigation
- Control reverse osmosis
- Recover rainwater
- Build reservoirs

These could be identified as some of the most effective ways of water management that are being used by agricultural sectors. While these methods may result in effective water management, it highly depends on the implementation and efficiency regarding how well the outcomes could be deduced.

4. IoT and smart systems used in irrigation

4.1. Communication technologies

With regards to the implementation of IoT devices, the used communication technologies could be considered as a vital and imperative point to attain successful operations. The communication technologies could further be regarded as being used in accordance with the environment where they will be applied [58]. The main technologies that are used in IoT for irrigation could be classified into two categories. One could be regarded as the devices that function as nodes and lead to forward or transmit small data amount at short distances along with having low consumption of energy. Consequently, the other devices are the ones that have the ability to transmit huge amounts of data over long distances, having high-energy consumption. There are various wireless standards that could be used in the communication of IoT devices and they could generally be classified between devices that communicate at long or short distances [59].

One of the most used and effective communication technologies has been identified to be Wi-Fi due to the possible accessibility for it. It has further been identified that the current low-cost devices for IoT mostly lead to support Wi-Fi, and while it has its limitations (area coverage and reach), it is regarded an effective overall method [60]. Global System for Mobile communication (GSM) further has been identified to be a widely spread wireless technology which provides long-range communication and all it requires is a mobile plan of the service provider which operates and functions in that particular area. Two other noticeable technologies that have been established more recently are Long Range (LoRa) and Message Queuing Telemetry Transport (MQTT). LoRa provides very long ranges, and this has led to make this technology highly feasible and useful for secluded areas that do not have any service. On the other hand, although MQTT has also resulted in being a widely spread protocol as it have low overhead and low power consumption, it is not being highly used for an irrigation system as yet [61].

4.2. Cloud technologies

Two of the most imperative and mostly used storage systems could be regarded as cloud and traditional database. These storage systems are critical for various organisations working in different industries and sectors as they provide the opportunity to save and access useful information when needed. Through such storage systems, the concept of big data has taken place which defines huge amount of datasets being used for firms for various purposes [62]. With regards to the required services which are in demand in IoT, it is vital to use middleware. With the

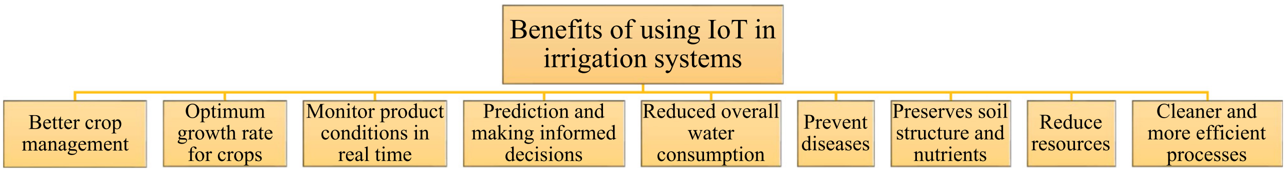

Fig. 2. Benefits of IoT in irrigation systems.

use of middleware, it becomes feasible to connect programs that have not been developed initially to be connected to each other. The classification of IoT middleware is further based on different features and interface protocol assistance [63].

Considering the usage of cloud in the agricultural sector and specifically in irrigation-based systems, data is gathered and processed by the use of sensors. In several studies, it has further been deduced that the data is processed in the cloud itself, and the users of it are able to view the information by connecting to the cloud. The usage of cloud in irrigation is mainly taken in terms of storing the monitored data and then retrieving it when needed [64]. Cloud technology provides both paid and free options to the users for storing, assessing, and displaying the data on varied devices and platforms. The fact that this technology is being used to store the information related to work significantly contributes to augmenting the overall performance efficiency. The stored data is accessed on various occasions and for various purposes out of which research and development could also be considered as one of the most critical uses. The facility of cloud technology has enabled many organisations in the agricultural sector to store and view information that assists in improving work efficiency and effectiveness [65].

Considering the process of irrigation, cloud technology has also been used to generate alerts through developing algorithms. These alerts have been used to mitigate various risks and hazards that could have taken place otherwise. With the use of these alerts, it becomes more feasible to amend the work activities and take the necessary precautions through which any adversities could be mitigated [66]. Many programs have been developed related to cloud technologies that have been providing assistance in the work performance and while all of these programs have their own significance and use, they are implemented in accordance with their cost, applicability, services, and other factors. The irrigation system could be considered as a complex activity that has to be carried out in terms of its related risks, damages, and intricacies. Having said this, cloud technologies are used by individuals involved in the irrigational activities to not only reduce risks but also improve the outcomes of work in order to attain the set objectives [67].

4.3. Benefits of IoT system in irrigation

There are various benefits associated with IoT systems in irrigation and some of them could be considered as overall water consumption reduction, high cost-efficiency, high performance efficiency, lesser energy consumption, lesser wastage of crops, and more [68]. Fig. 2 shows the benefits of using IoT in irrigation systems.

One of the main benefits of IoT systems in irrigation is associated with the lower water consumption [69]. Also, most of the work related to irrigation is automated through such an approach, only the required amount of water is utilized for the irrigation process and lesser wastage takes place. In traditional ways of irrigation where most of the handling and operations were carried out manually, an ample amount of water was wasted in the irrigation process where human intervention was required [2]. With Smart irrigation, there is no or less human involvement and the resource of water is only used to the extent to which it is required only. Further, high cost-efficiency is one of the other benefits linked to it as lesser water utilization and precision in the process allows saving costs and overall expenses [70]. Energy consumption is also reduced significantly through the approach as machines have to run for a lower amount of time and planned intervals take place during the process that lowers the utilization of overall energy [71].

Moreover, resources are limited and businesses have to limit their costs to a certain extent, it is imperative to control the costs and save resources. With Smart irrigation, the factor of cost is taken into consideration and it becomes feasible to carry out related activities in an effective manner with lesser expenses incurred [72]. Lastly, one of the other advantages is that with higher efficiency in the irrigation process and water management, the plants and crops are only provided the needed amount of water, and this reduces the wastage of crops due to lesser or over the provision of water [73].

5. Discussion

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

It has been identified that IoT systems in general produce a huge amount of data because of monitoring varied parameters in real-time and IoT irrigation systems develops big data as well. Understanding the presence of big data, it has become essential and imperative to develop mechanisms that adequately assess and manage the data [74]. That fact that managing big data could be a difficult activity on the whole and may over-utilise nature resources, it has been suggested that there is a dire need of focusing more on sustainable management of big data. Some of the suggestions that have been understood in this regard have been identified to be using blockchain technology, discarding unnecessary data and only selecting the useful information, powering the devices through the use of solar energy [75], implement clustering techniques to lower the overall information volume, employing efficient algorithms and utilising sustainable resources. While big data could be of immense usage in the overall irrigation process, it is highly vital to ensure effective management and control of the information [76].

It has further been explored that while the collected data from the sensors provide ample information that could be used, the data analysis is critical to optimise the irrigation process in accordance with the weather and crop conditions. Various organisations involved and related to the activity of irrigation are rightly able to gather the required information, but they fail to properly assess the data and deduce the useful outcomes out of it. This inability of analysis acts as a huge barrier in improving work efficiency and lowering the related risks to the activities [77]. Fig. 3 shows the barriers of smart irrigation.

Moreover, artificial intelligence (AI) is regarded as the technology which is being used by most the organisations for varied purposes. Through the use of AI, optimisation of available resources becomes more feasible along with gathering information related to the crops such as diseases or corrected growth of plants. A related technique in this to assess the collected data from the sensors to carry out the irrigation related activities is fuzzy logic. This technique is employed to enhance irrigation scheduling and managing the drainage [78].

One of the other techniques that is used in irrigation systems to carry out predictions is machine learning. The techniques of prediction are used to assess the amount of available water for irrigation. This allows improving the irrigation process through foreseeing the probable adversities that could take place and how the risks must be managed in order to ensure optimum work efficiency. Some of the benefits that could be linked with machine learning could therefore be regarded as water usage reduction, increased profits, and enhanced crop yields. With lowering

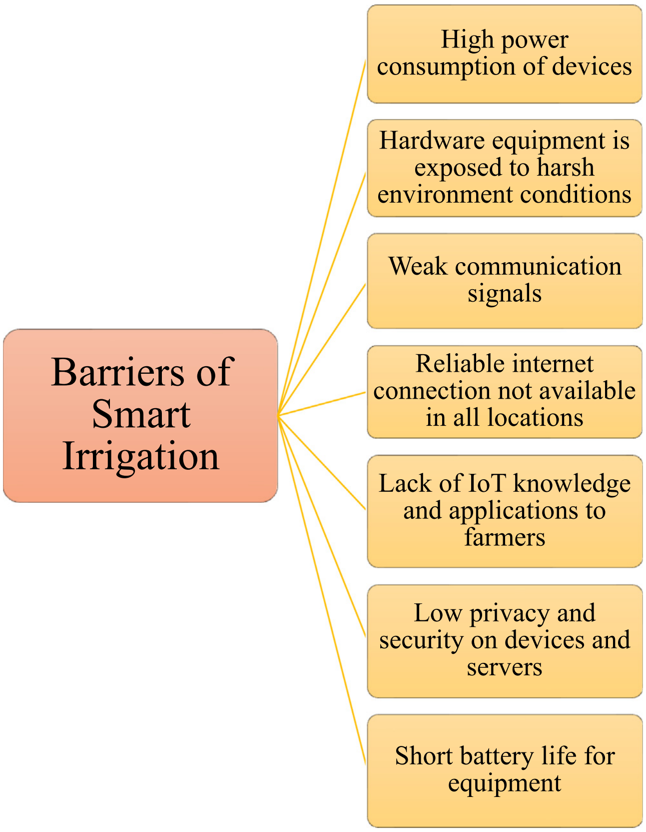

Fig. 3. Barriers of smart irrigation systems.

the risks related to irrigation through the use of machine learning, it may become more feasible to attain effective performance along with providing financial benefits [79]. There are various issues to agriculture field like crop diseases, lack of storage management, pesticide control, weed management, lack of irrigation, and water management and all these issues can be resolved by using various artificial intelligence methods. Machine learning improves the overall activities and processes related to irrigation through algorithms and allow achieving the performance objectives. The machine learning further supports predictions for irrigation patterns which are mainly based on weather and crop scenarios. Predictions could be directly associated with the usage of machine learning as it assists in taking measures and adopting strategies considering the probable activities that may take in the future. These predictions therefore eventually allow taking necessary measures which could support the irrigation process in the long run [80]. Bannerjee et al. [81] classified AI breakthroughs and provided a quick summary of major AI techniques and smart irrigation. Also, Chlingaryan et al. [82] demonstrated a machine learning expert system that provides a flexible architecture for data driven decision making. Similarly, the development of a sustainable precision irrigation system was demonstrated through the effective management of sensed data about soil, plants, and weather [83–86]. Correspondingly, Elavarasan et al. [87] investigated the integration of different machine learning models to find the optimal irrigation decision management. The precision irrigation systems could be used to control the changing environmental circumstances in an adaptive manner. Various machine learning applications have been studied in literature, namely crop management [72], livestock management [88], water management [89] and soil management [46].

5.2. Irrigation systems and sustainability

Sustainability could be considered as an essential aspect that is related to irrigation systems. To maintain the sustainability within any system, balance between the three pillars of sustainability should be ensured. The three pillars of sustainability are economic, social, and environment. Fig. 4 shows the potential economic, environmental, and social impact of irrigation systems.

The elements of sustainability could be assessed in different contexts and mediums and so these considerations need to be made by the organisations involved in the particular sector and related work. One of the aspects of sustainability is related to ensuring that the irrigation activities do not lead to negatively impact the environment [90]. It has been identified that several sorts of negative environmental impacts are created through the activity of irrigation such as waterlogging, augmented incidents of water-borne diseases, salinisation of soils, issues of resettlement and many more. Even though irrigation is a vital part of the agricultural sector, it is critical that the activities designed for irrigation are developed in a way that they do not negatively affect the health of humans or wildlife. Also, water management could be considered as a part of sustainable irrigation systems. Due to water involvement in the process of irrigation, it has to be made sure that the resource is managed and controlled effectively through which water wastage could be minimised [91]. Therefore, the call for healthier and more sustainable food systems is placing new demands on how irrigation is developed and managed. From individual irrigation systems to national levels, all have the potential to improve agricultural productivity, enhance water security and contribute to inclusive growth and drive positive change towards different SDGs.

Drip irrigation systems need pumping power to operate. In order to provide pumping power, different energy sources are utilised for the process, and this also leads to negatively affect the environment on the whole. Considering sustainable irrigation, it needs to be made sure that the energy usage and impact on environment is minimised through inculcating green methods of operations [92]. Carrying out irrigation activities, the organisations need to increasingly focus on techniques that lower the aspects such as pollution, diseases, costs, and other factors. High irrigational sustainability can be attained when irrigation does not consist of the depletion of human or natural capital. Sustainability in this regard could be associated to mainly economic and environmental aspects [93].

With regards to economic sustainability, it has to be ensured that the irrigation cost does not exceed the value of marginal productivity of irrigation. If the costs of the irrigation process are considerably high, it may not be regarded as sustainable operations and may require amending the approaches to related activities [94]. Furthermore, water depletion is one of the other concepts that could be regarded highly imperative in irrigation and sustainability. Water is a scarce resource and the concerns related to it have been augmenting a lot. The lack of availability of fresh water has turned out to be a huge issue for the agricultural sector and for this sustainability becomes even more important. In this regard, reducing wastage of water and implementing effective methods for irrigation may lead to save water that could eventually be used for the required activities in the long-run [95].

Agricultural cropping systems irrigation is necessary and considered as one of the main reasons that cause rapid increase in water scarcity in many regions [96]. In order to conserve water, smart irrigation is crucial and plays key role in providing the required water amount to each crop. The process of irrigation may reach the plant late, causing the crops to get dried. An optimal solution for this problem is an automatic controller built based on drip irrigation system. Thus, the integration between the recent technology and irrigation can improve the use of irrigation water in many regions, the developed technology Internet of things (IoT) is proposed in this study. The IoT application can give objective information related to water resources, their use, and management, assisting in the achievement of SDG 6. As an example, Khelifa et al. [48] developed a smart irrigation system for south of Algeria combining ICT and IoT technologies. Their research ensured that the irrigation is designed to optimize the cost, minimize the water usage in irrigation, and reduce the cost of the working force.

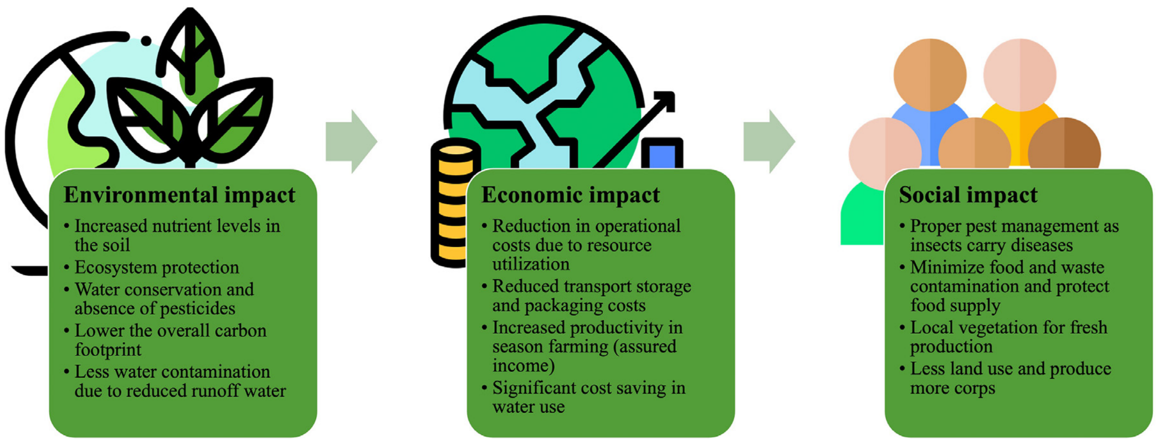

Fig. 4. Potential economic, environmental and social benefits of the irrigation system.

5.3. Security and acquisition

The improvements and advances made in technology have led to develop ways through which new method for collecting data from the sensors deployed in the field have been established. While various advancements have been made and applied, one of the successful means of data collection from sensor nodes is through drones. The technology of drones has further allowed gathering new data that could not otherwise be attained in other ways like aerial images of fields [97]. One of the other ways of data gathering has been identified to be robots that lead to inculcate actuators and sensors to carry out different activities such as spraying water, soil moisture, scaring away animals or weeding. This technology of robots could therefore be used for the irrigation of areas because of their ability to travel to the required locations. The robots are also able to assess the soil moisture and include sensors that mitigate the probability of collision [98].

Robots have been identified to be one of the most efficient ways of carrying out activities related to irrigation and many organisations in the contemporary environment have been taking use of this technology. Improvements in robot technology are also being made along with their utility and implications. The wireless robot comprises both soil monitoring and environmental monitoring to be able to carry out tasks such as water spraying, moving through the field, and much more [99]. To enhance the navigation of robots for irrigation, the coverage path planning algorithm could be used which consists of a map of static elements and environmental data. Robot operating system could be further used to develop the control system of the robot that is divided into three main layers. The first layer leads to reading the data from sensors, the second layer carried out communication and the third layer focuses on performing path planning and decision making. Furthermore, in order to ensure sustainability and efficiency, the robots can be powered through the use of solar panels and ensure autonomy [100,101].

The implementation of IoT systems, ensuring security could become a difficult task as varied types of threats may lead to taking place. Some of the security threats that may take place and have adverse impacts are cloning, vulnerable software, leakage of private information, firmware attacks, routing attack, denial of service attacks, eavesdropping attacks, and many more. With regards to all of such threats, it has become essential to develop security measures that may mitigate the overall adversities [102]. The fact that data regarding the operations and functionality of organisations in the particular sector is highly imperative and critical, protecting it becomes extremely vital. While different techniques have been developed to lower the linked issues, one of the most effective methods is related to the blockchain technique. This is a technique that is applied to secure the systems of IoT, allowing safer communication and data storage [103].

Considering the industry of agriculture, it has been understood that technologies such as blockchain are used to secure mainly the supply chain. With regards to blockchain-related to IoT irrigation systems for agriculture, it is used for tracking and tracing information exchange of proposed smart watering system. As much as the security concerns have been rising over the past due to improvements in technology, the need to ensure better security is also equally critical [56]. Through the use of increased research and development, organisations have been focused on controlling the threats and making sure that malicious activities could be lowered in a significant manner. Further, the need for a secure storage system has augmented over the years, and as activities related to agriculture are becoming more automated inculcating technology, the probability and incidence of attack are also increasing majorly. Even though various organisations have successfully been able to control the threats, a continuous improvement approach through R&D may further provide the desired results [57]. Fig. 5 shows different types of sensors that can be used in smart irrigation system.

5.4. 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, hither position nodes in the hierarchy may lead to acting as a broker for the ones that are placed lower in the hierarchy [58]. 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 [59].

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 [60]. Moreover, different researchers have led to develop and present varied new architecture proposals and one of the most evident one has been of Ferrández-Pastor who has established four layered architectures. These four layers are things, edge, communication, and

Fig. 5. Smart irrigation system sensors, pictures taken from Wikipedia.

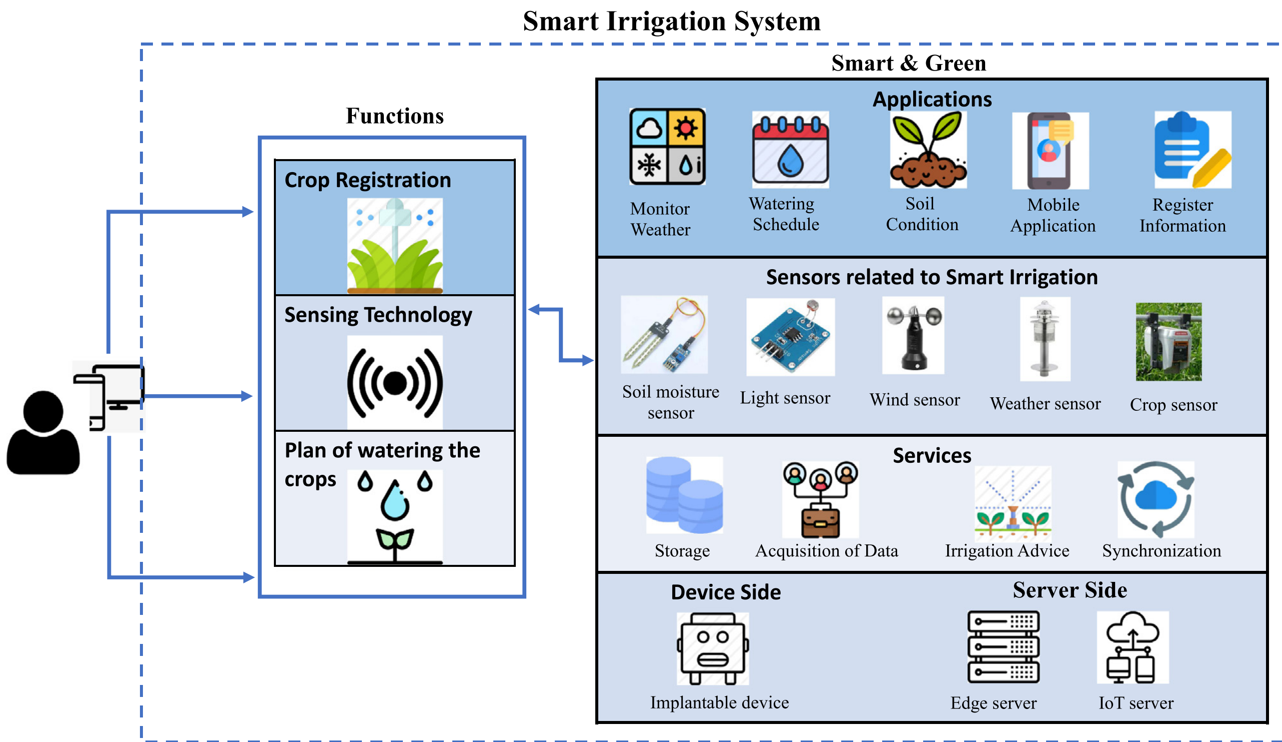

Fig. 6. Smart irrigation system structures, icons taken from flaticon.com.

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 [61]. 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 [104]. Fig. 6 shows the overall structures of smart irrigation system.

6. Current challenges and future prospects

The challenges and prospects of applying machine learning are covered in this section. There are several obstacles to overcome in the development of machine learning and digital software programs for smart irrigation systems for managing various crops specially to help attain sustainable agriculture. The overall food production must be increased to address the fold shortages. In addition, more cash crops like cotton and rubber need to be grown to meet industrial demands, particularly if mixed with a sustainable materials to refrain from polluting the soil [105]. Moreover, these problems present a number of difficulties, including the decline in agricultural manpower, the shrinking area of arable land, the scarcity of water supplies, the effects of climate change, etc. The population of rural areas is ageing quickly and declining as the world moves toward urbanization.

IoT techniques integrated in irrigation systems have a wide range of possible uses in farming and food production. There are numerous factors associated with IoT in smart irrigation that needs further attention which includes, cost, autonomous operation, portability, low maintenance, effectiveness, robust architecture, and reliability. When integrated systems recognize the capabilities of artificial intelligence and big data, it is anticipated that agriculture will evolve into a dynamic industry. These integrated systems will combine a variety of agricultural tools, equipment, and management techniques that can be used for var-

Table 1
Comparative review of work carried out by researchers.

Si. No	Year	Methodology	Remarks	Reference
1	2020	TelosB and the IRIS motes	Full-scale smart irrigation system was developed in a strawberry greenhouse environment in Greece Reference network architecture aimed primarily towards smart irrigation	[111]
2	2019	Arduino microcontroller	A low-cost automated irrigation system for green walls has been designed. System reduces energy consumption, increases irrigation efficiency and saves time	[112]
3	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]
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.	[114]
5	2018	Arduino Uno and Raspberry pi	The smart irrigation system was designed using photovoltaic panels and a combination of control devices. The designed system is sustainable, efficient and reliable.	[115]
6	2019	Radial Basis Function Network, RBFN	Solar powered smart irrigation system is designed using IoE environment. The irrigation system predicts the expected water level values, weather forecasts, humidity, temperature, and irrigation data.	[116]
7	2017	MATLAB, Neural Network Toolbox	Water usage optimization as part of the Smart Farm Automated Irrigation System to ensure optimum water resource.	[117]
8	2019	Fuzzy Logic based	The valve control commands using a fuzzy logic-based weather condition modelling system that considers various weather situations.	[41]

ious activities ranging from planting to yield forecasting. A new era of IoT in the farming industry may be introduced by advanced machines like agricultural robots, cloud computing, artificial intelligence, and big data. These tools are deemed with high importance to ensure sustainable agriculture.

There are several prospects for farmers and stakeholders who combine machine learning forecasting with portable software solutions. Water use efficiency can be enhanced by improving the predictions on irrigation needs, matching timing and volume to plant water needs, and adaptively compensating for water loss.

Water use efficiency can be enhanced by improving the predictions on irrigation needs, matching timing and volume to plant water needs, and adaptively compensating for water loss. This will result in increased yield while using less irrigation water. As the system becomes more advanced and intelligent, a better trained model will be deployed for better irrigation decision making. Thus, much of the stress and burden associated with irrigation can be reduced for farmers and users.

7. Case studies

Different cases could be taken into consideration that has been able to successfully inculcate and implement elements of SMART irrigation systems. Organisations all around the world related to agricultural sector and others that have been involved in irrigation activities have become keen regarding implementation of Smart irrigation methods in order to lower the costs and augment work efficiency. One of the cases that could be identified is of WaterBit, which is a company in the industrial sector. The organisation is an innovative technology firm that has collaborated with AT&T (one the largest telecommunications company in the world) in order to provide secured wireless connectivity to its autonomous irrigation solution, allowing management and control of local irrigation. This has allowed the farmers to not only augment their overall yield but also save resources in a considerable way [106]. WaterBit gateway sends in-field data gathering of soil moisture through wireless technology to the cloud in a secure and reliable manner. This particular data is updated after every few minutes regularly through which users are given the opportunity to access and control via a mobile-friendly application [107].

The other case if of Ipswich city- Australian council which has depicted that using an automated soil-moisture monitoring system as a driver of irrigation leads to significantly conserve water along with saving costs. The automated web-based system has resulted in being highly efficient in comparison to a rainfall-based allocation method. The particular method applied by the council not only enhances the performance but also allows having lesser soil-knowledge and lesser need of labour to run the particular irrigation system [108]. Further, the usage and wastage of water has also been reduced through the implementation that has allowed saving the resource with better quality results overall.

In another work, smart farm using solar energy was built in Maejo University in Thailand, to provide alternative electrical supply for a smart mushroom farm. IoT technology was adopted to enhance the performance and control the irrigation automatically. IoT controls the environment of mushroom light, temperature, humidity, and air flow that is all needed. Garcia et al. [109] reduced energy consumption by network sectoring, achieving energy savings of between 20% and 29%. During the daylight hours the irrigation water will be supplied to the plants within the balance. Either the water stored in the soil or by extending the duration of irrigation events when necessary. Therefore, the usage of solar energy to power irrigation systems could reduce or remove the energy costs for farmers. The usage of renewable energies will lower the greenhouse gas emissions compared to conventional electric energy or diesel engines used in irrigation systems. Smart irrigation management model integrated with solar photovoltaic to directly supply the irrigation water to the network, without intermediate storage elements such as water tanks or batteries [110]. Table 1 presents a summary of the provided cases.

8. 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 contribution of the smart irrigation system into the sustainable development. The water resources are based on irrigation expansion in order to enhance 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 water to provide food. Climate change and rapid population growth have put a lot of strain on agriculture, which effects the water resources that

Table 2
The role of irrigation in achieving the SDGs.

SDGs	Smart Irrigation contribution to the SDGs
SDG 1: No Poverty	Supports communities in rural areas in developing countries.
SDG 2: Zero Hunger	Fights hunger and enhances the productivity of farms.
SDG 3: Good Health and Well-being	Reduces the risk of pesticides and other diseases originated from the soil.
SDG 6: Clean Water and Sanitation	Provides access to sanitation by utilities and crop irrigation.
SDG 7: Affordable and Clean Energy	Contributes to reaching a clean energy solution in farms when coupled with a solar system.
SDG 8: Decent Work and Economic Growth	Accelerates the growth of rural economies and contributes to other sectors.
SDG 9: Industry, Innovation and Infrastructure	Promotes sustainable industrialization and foster innovation.
SDG 11: Sustainable Cities and Communities	Building sustainable cities through efficient use of smart irrigation systems.
SDG 12: Responsible Consumption and Production	Ensuring a responsible management of resources and lowering the amount of waste generated.
SDG 13: Climate Action	Enhancing the agricultural yields, and ultimately altering the rainfall patterns.
SDG 14: Life Below Water	Moderate amount of water used compared to traditional irrigation systems.
SDG 15: Life on Land	Creates a reliable food supply and increases the quality and quantity of the farm production.

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.

9. Conclusion and recommendations

Technological innovations have become essential for businesses in today's environment, and organizations in every industry are making improvements to thrive and expand in size. In this regard, irrigation and its implementations can be improved to provide maximum operating efficiency while achieving the necessary performance results. While IoT has been associated with the automation of all aspects of agriculture and farming methods to make the entire process much more effective and efficient, sensory systems have been identified as being deployed by farmers to better understand their crops, reduce environmental impact, and conserve resources. These technologies have been established over the past, not all organisations have been able to successfully implement them and make use of it in the most adequate way. In the other hand, water scarcity is a critical issue that involves water stress, water shortage or deficits and water crisis. The concept of water management has occurred, and organizations have been attracted toward discovering solutions to save the resource while also improving their work efficiency. SMART irrigation system has become a need in today's environment when organizations are utilizing technology to achieve their performance goals. The consequences of both IoT and sensor systems have been extremely imperative. IoT reduces the total cost of technology which allows the opportunity to manage the monitor system for irrigation processes. Wireless sensor network (WSN) also contributes to real time monitoring for precision farming and irrigation activates.

This technique consists of a network of wireless sensor nodes designed to sense, compute, and communicate information on various characteristics. However, these techniques have their own set of advantages and disadvantages, an adequate approach would be sufficient to carry out irrigation related activities. Moreover, recommendation for implementing a SMART irrigation system for agriculture are described further below:

- One of the recommendations is linked with the substantial R&D to identify the current inefficiencies in processes and approaches and establish a better technique for better results. The R&D benefits are significant and may allow the organization to ensure long term effectiveness. Therefore, the organization may be given the opportunity to identify areas of improvement in IoT and WSN techniques.
- More focus should be directed towards management and security issues, in deploying Smart irrigation systems. An effective communication system is highly crucial in making sure that the nodes perform the required activities. The system is usually interconnected with different sensors, and it is critical to maintain the communication between the points. Improvements in communication will allow better results and fewer errors and adversities.
- Elements of security strategies and systems play a vital role in operations of irrigation along with the organization. It is necessary to maintain the security of the system and protect the assessable data. This may lead to increase the cost of the organization, however, in the long run strong security systems are always beneficial and advisable. Security may also lead to mitigate the risks associated with digital threats.
- Focus on enhancing the sustainable operations and cost reduction. The environmental impacts of the irrigation system should be considered and well aligned with Sustainable Development Goals to achieve ultimate benefit of the three pillars (environment, social, economic). Natural resources must be preserved from overuse, which can be accomplished through effective planning. Furthermore, it must be assured that the cost of operational activities is not greater than the perceived outcomes to ensure sustainability. This continuous improvement in automation and use of technology is highly effective and efficient, and associated costs could be further reduced. Inclination toward green activities and functions may assist the firm to achieve the intended goals, and a greater emphasis on CSR may allow the organizations to accomplish great achievements.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] K.G. Liakos, P. Busato, D. Moshou, S. Pearson, D. Bochtis, Machine learning in agriculture: a review, Sensors 18 (8) (2018) 2674.

[2] K. Jha, A. Doshi, P. Patel, M. Shah, A comprehensive review on automation in agriculture using artificial intelligence, Artif. Intell. Agric. 2 (2019) 1–12.

[3] N. Khan, R.L. Ray, G.R. Sargani, M. Ihtisham, M. Khayyam, S. Ismail, Current progress and future prospects of agriculture technology: gateway to sustainable agriculture, Sustainability 13 (9) (2021) 4883.

[4] A. Nasiakou, M. Vavalis, D. Zimeris, Smart energy for smart irrigation, Comput. Electron. Agric. 129 (2016) 74–83 2016/11/01/, doi:10.1016/j.compag.2016.09.008.

[5] T. Ojha, S. Misra, N.S. Raghuwanshi, Wireless sensor networks for agriculture: the state-of-the-art in practice and future challenges, Comput. Electron. Agric. 118 (2015) 66–84 2015/10/01/, doi:10.1016/j.compag.2015.08.011.

[6] H. Van Es and J. Woodard, "Innovation in agriculture and food systems in the digital age," The global innovation index, pp. 97–104, 2017.

[7] N. Tantalaki, S. Souravlas, M. Roumeliotis, Data-driven decision making in precision agriculture: the rise of big data in agricultural systems, J. Agric. Food Inf. 20 (4) (2019) 344–380.

[8] O. Elijah, T.A. Rahman, I. Orikumhi, C.Y. Leow, M.N. Hindia, An overview of Internet of Things (IoT) and data analytics in agriculture: benefits and challenges, IEEE Internet Things J. 5 (5) (2018) 3758–3773.

[9] A. Weersink, E. Fraser, D. Pannell, E. Duncan, S. Rotz, Opportunities and challenges for big data in agricultural and environmental analysis, Annu. Rev. Resour. Econ. 10 (1) (2018) 19–37.

[10] A.J. Lynch, et al., Speaking the same language: can the sustainable development goals translate the needs of inland fisheries into irrigation decisions? Mar. Freshw. Res. 70 (9) (2019) 1211–1228.
[11] J. Alcamo, Water quality and its interlinkages with the sustainable development goals, Curr. Opin. Environ. Sustain. 36 (2019) 126–140.
[12] A. Bashir, C. Kyung-Sook, A review of the evaluation of irrigation practice in Nigeria: past, present and future prospects, Afr. J. Agric. Res. 13 (40) (2018) 2087–2097.
[13] N. Shehata, et al., Role of refuse-derived fuel in circular economy and sustainable development goals, Process Saf. Environ. Prot. 163 (2022) 558–573 2022/07/01/, doi:10.1016/j.psep.2022.05.052.
[14] S. Keesstra, et al., The role of soils in regulation and provision of blue and green water, Philos. Trans. R. Soc. B 376 (1834) (2021) 20200175.
[15] R. Fehri, S. Khlifi, M. Vanclooster, Disaggregating SDG-6 water stress indicator at different spatial and temporal scales in Tunisia, Sci. Total Environ. 694 (2019) 133766.
[16] J. Amezaga, et al., SDG 6: clean water and sanitation–forest-related targets and their impacts on forests and people, in: Sustainable Development Goals: their Impacts on Forests and People, Cambridge University Press, Cambridge, 2019, pp. 178–205.
[17] R.K. Kodali, M.S. Kuthada, Y.K.Y. Borra, LoRa based smart irrigation system, in: 2018 4th International Conference on Computing Communication and Automation (ICCCA), 2018, pp. 1–5, doi:10.1109/CCAA.2018.8777583. 14-15 Dec. 2018.
[18] H. Elbasiouny, et al., Agricultural waste management for climate change mitigation: some implications to Egypt, in: Waste Management in MENA Regions, Springer, 2020, pp. 149–169.
[19] Y. Shao, Y. Wang, Y. Yuan, Y. Xie, A systematic review on antibiotics misuse in livestock and aquaculture and regulation implications in China, Sci. Total Environ. 798 (2021) 149205.
[20] M. Kumar, et al., Microplastics as pollutants in agricultural soils, Environ. Pollut. 265 (2020) 114980.
[21] A. Fahmi, Advanced internet of things irrigation mechanism, Int. J. Eng. Res. V9 (2020) 07/16, doi:10.17577/IJERTV9IS070263.
[22] R. Ben Ayed, M. Hanana, Artificial intelligence to improve the food and agriculture sector, J. Food Qual. 2021 (2021). https://www.hindawi.com/journals/jfq/2021/5584754/.
[23] A. Sharma, M. Georgi, M. Tregubenko, A. Tselykh, A. Tselykh, Enabling smart agriculture by implementing artificial intelligence and embedded sensing, Comput. Ind. Eng. 165 (2022) 107936.
[24] T.A. Shaikh, T. Rasool, F.R. Lone, Towards leveraging the role of machine learning and artificial intelligence in precision agriculture and smart farming, Comput. Electron.Agric. 198 (2022) 107119.
[25] S. Mohr, R. Kühl, Acceptance of artificial intelligence in German agriculture: an application of the technology acceptance model and the theory of planned behavior, Precis. Agric. 22 (6) (2021) 1816–1844.
[26] M.E.H. Assad, M.N. AlMallahi, M.A. Abdelsalam, M. AlShabi, W.N. AlMallahi, Desalination technologies: overview, in: 2022 Advances in Science and Engineering Technology International Conferences (ASET), 2022, pp. 1–4, doi:10.1109/ASET53988.2022.9734991. 21-24 Feb. 2022.
[27] E.T. Sayed, et al., Progress in plant-based bioelectrochemical systems and their connection with sustainable development goals, Carbon Resour. Convers. 4 (2021) 169–183 2021/01/01/, doi:10.1016/j.crcon.2021.04.004.
[28] M. Al Radi, et al., Recent progress, economic potential, and environmental benefits of mineral recovery geothermal brine treatment systems, Arab. J. Geosci. 15 (9) (2022) 832 2022/04/22, doi:10.1007/s12517-022-10115-4.
[29] A. Nasseri, Effects of tillage practices on wheat production using groundwater-based irrigation: multidimensional analysis of energy use, greenhouse gases emissions and economic parameters, Environ. Dev. Sustain. (2022) 1–28, doi:10.1007/s10668-022-02352-0.
[30] S.M. Schneider, A. Sanguinetti, Positive reinforcement is just the beginning: associative learning principles for energy efficiency and climate sustainability, Energy Res. Soc. Sci. 74 (2021) 101958.
[31] K. Baylis, T. Heckelei, T.W. Hertel, Agricultural trade and environmental sustainability, Annu. Rev. Resour. Econ. 13 (2021) 379–401.
[32] D. D'amato, J. Korhonen, Integrating the green economy, circular economy and bioeconomy in a strategic sustainability framework, Ecol. Econ. 188 (2021) 107143.
[33] A.K. Chakka, M. Sriraksha, C. Ravishankar, Sustainability of emerging green non-thermal technologies in the food industry with food safety perspective: a review, LWT 151 (2021) 112140.
[34] I.C. Melchior, J. Newig, Governing transitions towards sustainable agriculture—taking stock of an emerging field of research, Sustainability 13 (2) (2021) 528 [Online]. Available https://www.mdpi.com/2071-1050/13/2/528 .
[35] T. Pukšec, N. Duić, Sustainability of energy, water and environmental systems: a view of recent advances, Clean Technol. Environ. Policy 24 (2) (2022) 457–465 2022/03/01, doi:10.1007/s10098-022-02281-6.
[36] Z. Abedin et al., *An interoperable IP based WSN for smart irrigation systems*. 2017.
[37] M. Ayaz, M. Ammad-Uddin, Z. Sharif, A. Mansour, E.H.M. Aggoune, Internet-of-Things (IoT)-based smart agriculture: toward making the fields talk, IEEE Access 7 (2019) 129551–129583, doi:10.1109/ACCESS.2019.2932609.
[38] N.K. Nawandar, V.R. Satpute, IoT based low cost and intelligent module for smart irrigation system, Comput. Electron. Agric. 162 (2019) 979–990.
[39] V. Suma, Internet-of-Things (IoT) based smart agriculture in india - an overview, J. ISMAC 3 (2021) 1–15 02/26, doi:10.36548/jismac.2021.1.001.
[40] S.F.P.D. Musa, K.H. Basir, Smart farming: towards a sustainable agri-food system, Brit. Food J. 123 (9) (2021) 3085–3099, doi:10.1108/BFJ-03-2021-0325.
[41] B. Keswani, et al., Adapting weather conditions based IoT enabled smart irrigation technique in precision agriculture mechanisms, Neural Comput. Appl. 31 (1) (2019) 277–292.
[42] L.G. Paucar, A.R. Diaz, F. Viani, F. Robol, A. Polo, A. Massa, Decision support for smart irrigation by means of wireless distributed sensors, in: 2015 IEEE 15th Mediterranean Microwave Symposium (MMS), IEEE, 2015, pp. 1–4.
[43] J.D. González-Teruel, R. Torres-Sánchez, P.J. Blaya-Ros, A.B. Toledo-Moreo, M. Jiménez-Buendía, F. Soto-Valles, Design and calibration of a low-cost SDI-12 soil moisture sensor, Sensors 19 (3) (2019) 491.
[44] D.K. Roy, M.H. Ansari, Smart irrigation control system, Int. J. Environ. Res. Dev. 4 (4) (2014) 371–374.
[45] S. Koduru, V.P.R. Padala, P. Padala, Smart irrigation system using cloud and internet of things, in: Proceedings of 2nd International Conference on Communication, Computing and Networking, Springer, 2019, pp. 195–203.
[46] A. Goap, D. Sharma, A.K. Shukla, C.R. Krishna, An IoT based smart irrigation management system using Machine learning and open source technologies, Comput. Electron. Agric. 155 (2018) 41–49.
[47] M.N. Rajkumar, S. Abinaya, V.V. Kumar, Intelligent irrigation system—an IOT based approach, in: 2017 International Conference on Innovations in Green Energy and Healthcare Technologies (IGEHT, IEEE, 2017, pp. 1–5.
[48] B. Khelifa, D. Amel, B. Amel, C. Mohamed, B. Tarek, Smart irrigation using internet of things, in: 2015 Fourth International Conference on Future Generation Communication Technology (FGCT), IEEE, 2015, pp. 1–6.
[49] J. Knox, M. Kay, E. Weatherhead, Water regulation, crop production, and agricultural water management—Understanding farmer perspectives on irrigation efficiency, Agric. Water Manage. 108 (2012) 3–8.
[50] C. Kamienski, et al., Smart water management platform: IoT-based precision irrigation for agriculture, Sensors 19 (2) (2019) 276.
[51] J.M. Tarjuelo, J.A. Rodriguez-Diaz, R. Abadía, E. Camacho, C. Rocamora, M.A. Moreno, Efficient water and energy use in irrigation modernization: lessons from Spanish case studies, Agric. Water Manage. 162 (2015) 67–77.
[52] C. Kamienski, et al., Swamp: an iot-based smart water management platform for precision irrigation in agriculture, in: 2018 Global Internet of Things Summit (GIoTS), IEEE, 2018, pp. 1–6.
[53] H.A. Mansour, S.K. Abd-Elmabod, B. Engel, Adaptation of modeling to the irrigation system and water management for corn growth and yield, Plant Arch. 19 (Supplement 1) (2019) 644–651.
[54] A. Glória, C. Dionisio, G. Simões, J. Cardoso, P. Sebastião, Water management for sustainable irrigation systems using internet-of-things, Sensors 20 (5) (2020) 1402.
[55] I. Pluchinotta, A. Pagano, R. Giordano, A. Tsoukiàs, A system dynamics model for supporting decision-makers in irrigation water management, J. Environ. Manage. 223 (2018) 815–824.
[56] L. Levidow, D. Zaccaria, R. Maia, E. Vivas, M. Todorovic, A. Scardigno, Improving water-efficient irrigation: prospects and difficulties of innovative practices, Agric. Water Manage. 146 (2014) 84–94.
[57] K. Chartzoulakis, M. Bertaki, Sustainable water management in agriculture under climate change, Agric. Agric. Sci. Proce. 4 (2015) 88–98.
[58] S. Ghosh, S. Sayyed, K. Wani, M. Mhatre, H.A. Hingoliwala, Smart irrigation: a smart drip irrigation system using cloud, android and data mining, in: 2016 IEEE International Conference on Advances in Electronics, Communication and Computer Technology (ICAECCT), IEEE, 2016, pp. 236–239.
[59] A.T. Abagissa, A. Behura, S.K. Pani, IoT based smart agricultural device controlling system, in: 2018 Second International Conference on Inventive Communication and Computational Technologies (ICICCT), IEEE, 2018, pp. 26–30.
[60] M. Soto-Garcia, P. Del-Amor-Saavedra, B. Martin-Gorriz, V. Martínez-Alvarez, The role of information and communication technologies in the modernisation of water user associations' management, Comput. Electron. Agric. 98 (2013) 121–130.
[61] M.S. Munir, I.S. Bajwa, S.M. Cheema, An intelligent and secure smart watering system using fuzzy logic and blockchain, Comput. Electr. Eng. 77 (2019) 109–119.
[62] M. Monica, B. Yeshika, G. Abhishek, H. Sanjay, S. Dasiga, IoT based control and automation of smart irrigation system: an automated irrigation system using sensors, GSM, Bluetooth and cloud technology, in: 2017 International Conference on Recent Innovations in Signal Processing and Embedded Systems (RISE), IEEE, 2017, pp. 601–607.
[63] M. Roopaei, P. Rad, K.-K.R. Choo, Cloud of things in smart agriculture: intelligent irrigation monitoring by thermal imaging, IEEE Cloud Comput. 4 (1) (2017) 10–15.
[64] S. Salvi, et al., Cloud based data analysis and monitoring of smart multi-level irrigation system using IoT, in: 2017 International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud)(I-SMAC), IEEE, 2017, pp. 752–757.
[65] S. Tyagi, M.S. Obaidat, S. Tanwar, N. Kumar, M. Lal, Sensor cloud based measurement to management system for precise irrigation, in: GLOBECOM 2017-2017 IEEE Global Communications Conference, IEEE, 2017, pp. 1–6.
[66] N. Sales, O. Remédios, A. Arsenio, Wireless sensor and actuator system for smart irrigation on the cloud, in: 2015 IEEE 2nd World Forum on Internet of Things (WF-IoT), IEEE, 2015, pp. 693–698.
[67] L.M. Fernández-Ahumada, J. Ramírez-Faz, M. Torres-Romero, R. López-Luque, Proposal for the design of monitoring and operating irrigation networks based on IoT, cloud computing and free hardware technologies, Sensors 19 (10) (2019) 2318.
[68] L. García, L. Parra, J.M. Jimenez, J. Lloret, P. Lorenz, IoT-based smart irrigation systems: an overview on the recent trends on sensors and IoT systems for irrigation in precision agriculture, Sensors 20 (4) (2020) 1042.
[69] K. Pernapati, IoT based low cost smart irrigation system, in: 2018 Second International Conference on Inventive Communication and Computational Technologies (ICICCT), IEEE, 2018, pp. 1312–1315.

[70] B.B. Sinha, R. Dhanalakshmi, Recent advancements and challenges of Internet of Things in smart agriculture: a survey, Future Gen. Comput. Syst. 126 (2022) 169–184.
[71] S. Ishak, N. Abd Malik, N.A. Latiff, N.E. Ghazali, M. Baharudin, Smart home garden irrigation system using Raspberry Pi, in: 2017 IEEE 13th Malaysia International Conference on Communications (MICC), IEEE, 2017, pp. 101–106.
[72] N.K. Nawandar, V.R. Satpute, IoT based low cost and intelligent module for smart irrigation system, Comput. Electron. Agric. 162 (2019) 979–990.
[73] S. Biswas, L.K. Sharma, R. Ranjan, S. Saha, A. Chakraborty, J.S. Banerjee, Smart farming and water saving-based intelligent irrigation system implementation using the internet of things, in: Recent Trends in Computational Intelligence Enabled Research, Elsevier, 2021, pp. 339–354.
[74] B. Keswani, A.G. Mohapatra, P. Keswani, A. Khanna, D. Gupta, J. Rodrigues, Improving weather dependent zone specific irrigation control scheme in IoT and big data enabled self driven precision agriculture mechanism, Enterp. Inf. Syst. 14 (9–10) (2020) 1494–1515.
[75] E.H. Bani-Hani, M.E.H. Assad, M.N. AlMallahi, M. AlShabi, Experimental study on solar hot water heating system, in: 2022 Advances in Science and Engineering Technology International Conferences (ASET), 2022, pp. 1–4, doi:10.1109/ASET53988.2022.9735075. 21-24 Feb. 2022.
[76] P. Zhang, Q. Zhang, F. Liu, J. Li, N. Cao, C. Song, The construction of the integration of water and fertilizer smart water saving irrigation system based on big data, in: 2017 IEEE International Conference on Computational Science and Engineering (CSE) and IEEE International Conference on Embedded and Ubiquitous Computing (EUC), 2, IEEE, 2017, pp. 392–397.
[77] R.C. Andrew, R. Malekian, D.C. Bogatinoska, IoT solutions for precision agriculture, in: 2018 41st International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), IEEE, 2018, pp. 0345–0349.
[78] A. Sandybayev, Artificial intelligence: are we all going to be unemployed? in: 2018 Fifth HCT Information Technology Trends (ITT), IEEE, 2018, pp. 23–27.
[79] S. Rajeswari, K. Suthendran, K. Rajakumar, A smart agricultural model by integrating IoT, mobile and cloud-based big data analytics, in: 2017 International Conference on Intelligent Computing and Control (I2C2), 2017, pp. 1–5, doi:10.1109/I2C2.2017.8321902. 23-24 June 2017.
[80] F.-H. Tseng, H.-H. Cho, H.-T. Wu, Applying big data for intelligent agriculture-based crop selection analysis, IEEE Access 7 (2019) 116965–116974.
[81] G. Bannerjee, U. Sarkar, S. Das, I. Ghosh, Artificial intelligence in agriculture: a literature survey, Int. J. Sci. Res. Comput. Sci. Appl. Manage. Stud. 7 (3) (2018) 1–6.
[82] A. Chlingaryan, S. Sukkarieh, B. Whelan, Machine learning approaches for crop yield prediction and nitrogen status estimation in precision agriculture: a review, Comput. Electron. Agric. 151 (2018) 61–69.
[83] Z. Liang, X. Liu, J. Xiong, J. Xiao, Water allocation and integrative management of precision irrigation: a systematic review, Water 12 (11) (2020) 3135.
[84] E.A. Abioye, et al., A review on monitoring and advanced control strategies for precision irrigation, Comput. Electron. Agric. 173 (2020) 105441.
[85] E.A. Abioye, et al., Precision irrigation management using machine learning and digital farming solutions, AgriEngineering 4 (1) (2022) 70–103.
[86] S. Khriji, D. El Houssaini, I. Kammoun, O. Kanoun, Precision irrigation: an IoT-enabled wireless sensor network for smart irrigation systems, in: Women in Precision Agriculture, Springer, 2021, pp. 107–129.
[87] D. Elavarasan, D.R. Vincent, V. Sharma, A.Y. Zomaya, K. Srinivasan, Forecasting yield by integrating agrarian factors and machine learning models: a survey, Comput. Electron. Agric. 155 (2018) 257–282.
[88] E.S. Mohamed, A. Belal, S.K. Abd-Elmabod, M.A. El-Shirbeny, A. Gad, M.B. Zahran, Smart farming for improving agricultural management, Egypt. J. Remote Sens. Space Sci. (2021) 971–981.
[89] R. Ullah, et al., EEWMP: an IoT-based energy-efficient water management platform for smart irrigation, Sci. Program. 2021 (2021). https://www.hindawi.com/journals/sp/2021/5536884/.
[90] S.K.Y. Donzia, H.k. Kim, Architecture design of a smart farm system based on big data appliance machine learning, in: 2020 20th International Conference on Computational Science and Its Applications (ICCSA), 2020, pp. 45–52, doi:10.1109/ICCSA50381.2020.00019. 1-4 July 2020.
[91] H. Khachatryan, D.H. Suh, W. Xu, P. Useche, M.D. Dukes, Towards sustainable water management: preferences and willingness to pay for smart landscape irrigation technologies, Land Use Policy 85 (2019) 33–41 2019/06/01/, doi:10.1016/j.landusepol.2019.03.014.
[92] J. Miranda, P. Ponce, A. Molina, Sensing, smart and sustainable technologies for Agri-Food 4.0, Comput. Ind. 108 (2019) 21–36 02/25, doi:10.1016/j.compind.2019.02.002.
[93] E. Alreshidi, Smart sustainable agriculture (SSA) solution underpinned by internet of Things (IoT) and artificial intelligence (AI), Int. J. Adv. Comput. Sci. Appl. (2019) 93–102.
[94] A. Gloria, C. Dionisio, G. Simoes, P. Sebastião, and N. Souto, *WSN application for sustainable water management in irrigation systems*. 2019, pp. 833–836.
[95] J.A. López-Riquelme, N. Pavón-Pulido, H. Navarro-Hellín, F. Soto-Valles, R. Torres-Sánchez, A software architecture based on FIWARE cloud for precision agriculture, Agric. Water Manage. 183 (2017) 123–135 2017/03/31/, doi:10.1016/j.agwat.2016.10.020.
[96] U. Nations, *SDG 6 synthesis report 2018 on water and sanitation*. United Nations, 2018.
[97] C. Kamienski, et al., SWAMP: smart water management platform overview and security challenges, in: 2018 48th Annual IEEE/IFIP International Conference on Dependable Systems and Networks Workshops (DSN-W), 2018, pp. 49–50, doi:10.1109/DSN-W.2018.00024. 25-28 June 2018.
[98] S.K. Mousavi, A. Ghaffari, S. Besharat, H. Afshari, Improving the security of internet of things using cryptographic algorithms: a case of smart irrigation systems, J. Ambient Intell. Humaniz. Comput. 12 (2) (2021) 2033–2051 2021/02/01, doi:10.1007/s12652-020-02303-5.
[99] K.L. Krishna, O. Silver, W.F. Malende, K. Anuradha, Internet of Things application for implementation of smart agriculture system, in: 2017 International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC), 2017, pp. 54–59, doi:10.1109/I-SMAC.2017.8058236. 10-11 Feb. 2017.
[100] Q. Wu, Y. Liang, Y. Li, Y. Liang, Research on intelligent acquisition of smart agricultural big data, in: 2017 25th International Conference on Geoinformatics, 2017, pp. 1–7, doi:10.1109/GEOINFORMATICS.2017.8090913. 2-4 Aug. 2017.
[101] M.N. AlMallahi, M. El Haj Assad, S. AlShihabi, R. Alayi, Multi-criteria decision-making approach for the selection of cleaning method of solar PV panels in United Arab Emirates based on sustainability perspective, Int. J. Low-Carbon Technol. 17 (2022) 380–393, doi:10.1093/ijlct/ctac010.
[102] R.N. Rao, B. Sridhar, IoT based smart crop-field monitoring and automation irrigation system, in: 2018 2nd International Conference on Inventive Systems and Control (ICISC), 2018, pp. 478–483, doi:10.1109/ICISC.2018.8399118. 19-20 Jan. 2018.
[103] B. Chandrasekar, K. Vasanth, S.M. S, S. Selvaraj, Smart solar energy based irrigation system with GSM, in: Third International Conference on Intelligent Information Technologies, ICIIT 2018, Chennai, India, 2019, pp. 75–85. December 11–14, 2018, Proceedings.
[104] P. Tanomkiat, K. Sripapha, H. Sintuya, N. Tantranont, and W. Setthapun, "The development of smart farm with environmental analysis," 2019, pp. 210–214.
[105] E. Hussein Bani-Hani, M. El Haj Assad, M. Al Mallahi, Z. Almuqahwi, M. Meraj, M. Azhar, Overview of the effect of aggregates from recycled materials on thermal and physical properties of concrete, Clean. Mater. 4 (2022) 100087 2022/06/01/, doi:10.1016/j.clema.2022.100087.
[106] C. Xu, Y. Song, M. Han, H. Zhang, Portable and wearable self-powered systems based on emerging energy harvesting technology, Microsyst. Nanoeng. 7 (1) (2021) 25 2021/03/17, doi:10.1038/s41378-021-00248-z.
[107] J.T. Stegeman, A. Shen, Agricultural SWARM Robotic System, Worcester Polytechnic Institute, 2018/12/12 2018 [Online]. Available https://digital.wpi.edu/show/1c18dh59v .
[108] "Ipswich. Case study: smart irrigation," 2020. [Online]. Available: http://www.mait.com.au/wp-content/uploads/CaseStudy-Smart-irrigation-Ispwich.pdf.
[109] A.M. García, I.F. García, E.C. Poyato, P.M. Barrios, J.R. Díaz, Coupling irrigation scheduling with solar energy production in a smart irrigation management system, J. Clean. Prod. 175 (2018) 670–682.
[110] K. Obaideen, et al., On the contribution of solar energy to sustainable developments goals: case study on Mohammed bin Rashid Al Maktoum Solar Park, Int. J. Thermofluids 12 (2021) 100123 2021/11/01/, doi:10.1016/j.ijft.2021.100123.
[111] C.M. Angelopoulos, G. Filios, S. Nikoletseas, T.P. Raptis, Keeping data at the edge of smart irrigation networks: a case study in strawberry greenhouses, Comput. Netw. 167 (2020) 107039.
[112] Y.A. Rivas-Sánchez, M.F. Moreno-Pérez, J. Roldán-Cañas, Environment control with low-cost microcontrollers and microprocessors: application for green walls, Sustainability 11 (3) (2019) 782.
[113] S.K. Roy, S. Misra, N.S. Raghuwanshi, S.K. Das, AgriSens: IoT-based dynamic irrigation scheduling system for water management of irrigated crops, IEEE Internet Things J. 8 (6) (2020) 5023–5030.
[114] R. Prabha, E. Sinitambirivoutin, F. Passelaigue, M.V. Ramesh, Design and development of an IoT based smart irrigation and fertilization system for chilli farming, in: 2018 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET), IEEE, 2018, pp. 1–7.
[115] S. Ali, H. Saif, H. Rashed, H. AlSharqi, A. Natsheh, Photovoltaic energy conversion smart irrigation system-Dubai case study (goodbye overwatering & waste energy, hello water & energy saving), in: 2018 IEEE 7th World Conference on Photovoltaic Energy Conversion (WCPEC)(A Joint Conference of 45th IEEE PVSC, 28th PVSEC & 34th EU PVSEC), IEEE, 2018, pp. 2395–2398.
[116] F. Adenugba, S. Misra, R. Maskeliūnas, R. Damaševičius, E. Kazanavičius, Smart irrigation system for environmental sustainability in Africa: an Internet of Everything (IoE) approach, Math. Biosci. Eng. 16 (5) (2019) 5490–5503.
[117] J.R. dela Cruz, R.G. Baldovino, A.A. Bandala, E.P. Dadios, Water usage optimization of Smart Farm Automated Irrigation System using artificial neural network, in: *2017 5th International Conference on Information and Communication Technology (ICo*IC7), IEEE, 2017, pp. 1–5.