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SURVEY

Smart Irrigation Systems: Overview

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ABSTRACT Countries are collaborating to make agriculture more efficient by combining new technologies to improve its procedures. Improving irrigation efficiency in agriculture is thus critical for the survival of sustainable agricultural production. Smart irrigation methods can enhance irrigation efficiency, especially with the introduction of wireless communication systems, monitoring devices, and enhanced control techniques for efficient irrigation scheduling. The study compared a wide range of study subjects to investigate scientific approaches for smart irrigation. As a result, this project included a wide range of topics related to irrigation methods, decision-making, and the technology used. Information was gathered from a variety of scientific papers. So, our research relied on several published documents, the majority of which were published during the last four years, and authors from all over the world. In the meantime, various irrigation initiatives were given special attention. Following that, the evaluation focuses on the key components of smart irrigation, such as real-time irrigation scheduling, IoT, the importance of an internet connection, smart sensing, and energy harvesting.

INDEX TERMS Smart irrigation, soil monitoring, smart agriculture, IoT, energy harvesting.

I. INTRODUCTION

Irrigation is considered an artificial utilization of the water on the soil using different methods such as pumps, tubes, and sprays. Usually, the need for irrigation appears in places where the rainfall is irregular, in dry times, or in places where dehydration is regular [1]. Too many irrigation systems are available, with different types according to the environment of the soil. Irrigation water comes from a variety of sources, including underground water from wells or springs, surface water from lakes or rivers, and water from treated wastewater or desalinated seawater. Therefore, farmers have to save and protect their agricultural water sources by minimizing the potential for diseases. Users of irrigation water must be careful not to drain groundwater faster than it is being regenerated, as is the case with any groundwater extraction. There are two methodologies for modern irrigation systems: traditional irrigation methodologies and intelligent irrigation methodologies. Traditional irrigation methods include surface irrigation, drip irrigation, and sprinkler irrigation. In the future, several severe and complicated problems will be met by irrigated agriculture. An example of a significant problem is the low efficiency of the water resources for irrigation. According to a relevant safe approximation, more than 40% of the redirected irrigation water is spent earlier at the farm level, either through deep percolation or surface runoff [2]. However, often these losses represent missed opportunities for water, as they prevent water from arriving at the downstream diversions. One of the most visible coming problems is the extension of different water requirements, such as industrial and urban needs. These are used to give water resources a higher value, so as a result, researchers

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favor giving more attention to practices with a high waste rate. In the upcoming years, irrigation science will obviously face problems to maximize usage efficiency [2]. There are three major categories of irrigation systems:

- Pressurized distribution: The pressurized systems' main components are a trickle, sprinkler, and array of the same systems, where water is carried and spread along the land surface within networks of pressurized pipes. Besides, many individual system configurations are presented by novel features, such as center-pivot sprinkler systems.
- Gravity-Flow Distribution: Systems based on gravity flow carry and distribute the water at the field level through the overland, free-surface flow regime. These surface irrigation methods are classified according to their operational specifications and configuration.
- Drainage Flow Distribution: An irrigation system using drainage control-sub-irrigation is not commonly used. Comparatively huge quantities of irrigation water percolate within the root zone and form drainage, or underground water flow [3].

In places where water is rare, water management is vital. Agriculture is also impacted, as a significant amount of water is used. Water adaptation techniques are being studied due to the probable repercussions of global warming to make sure that there is water accessible for food production and consumption. As a consequence, the number of studies focused on lowering irrigation water demand has steadily increased over time. However, sensors on the market for farming irrigation systems are expensive, making this device unsustainable for small-scale farmers. On the other hand, companies are producing low-cost sensing devices that may be linked to nodes to construct cost-effective agriculture monitoring and irrigation management systems.

The main objectives of irrigation systems are minimizing labor and resource requirements and maximizing efficiencies [3]. The management practices with the most effects depend on the irrigation systems type and design. Several well-known problems determine how far the irrigation system succeeds, such as determining when to irrigate the soil, what is the suitable quantity of water, and the ability to improve efficiency. When selecting an irrigation system, many considerations must be taken into account. such as crop type, location of the farm and farmer, and time of the year. Generally, all these factors must cover system compatibility with the best services of the farm, the topography and properties of the soil, crop specifications, economic feasibility, and some social constraints [4].

Because of the widespread application of IoT technology in agriculture, influenced by the growth of digital technology and embedded sensors, sensors made with technological innovations are constantly evolving and designed to be intelligent, integrated, and smaller. Soil, weather, water, and crop sensors are examples of agricultural sensors with highly varied functionalities. These sensors that sense a variety of things offer invaluable assistance in collecting agricultural production data.

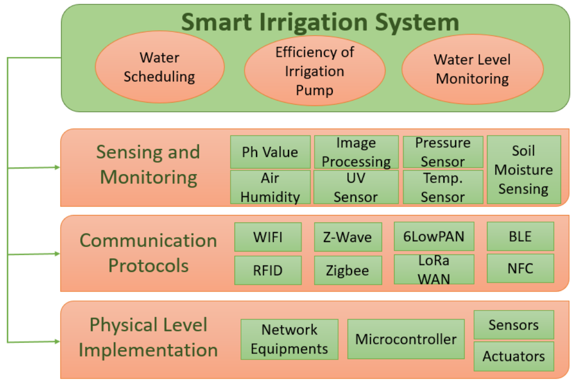

FIGURE 1. Smart irrigation systems building layers.

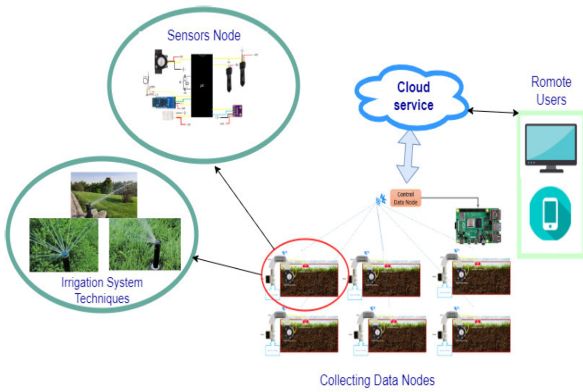

FIGURE 2. Architecture of smart irrigation system.

Several studies have focused on the use of smart technology in agriculture, such as IoT, Wireless Sensor Networks (WSNs), and smart sensors [5], [6], [7], [8]. Other survey studies on improving water productivity in agriculture [9], [10], [11], [12], [13].

This study adds to current knowledge by merging intelligent crop water monitoring systems with irrigation control methods to enhance water productivity. The previous studies fail to demonstrate how monitoring and control systems improve the accuracy of agricultural water productivity. Figure 1 depicts the various building layers of smart irrigation systems.

Figure 2 depicts an example of a smart irrigation system that is dependable, reliable, scalable, and cost-effective IoT-based innovative agriculture. solution. Also, present a real-time water management monitoring method that reduces power consumption. The transmitting module is a vital component that impacts energy dissipation in sensor nodes

II. IRRIGATION DEVELOPMENT

This section shows how irrigation has changed over time, from 1970 through 2022, in four separate peri-

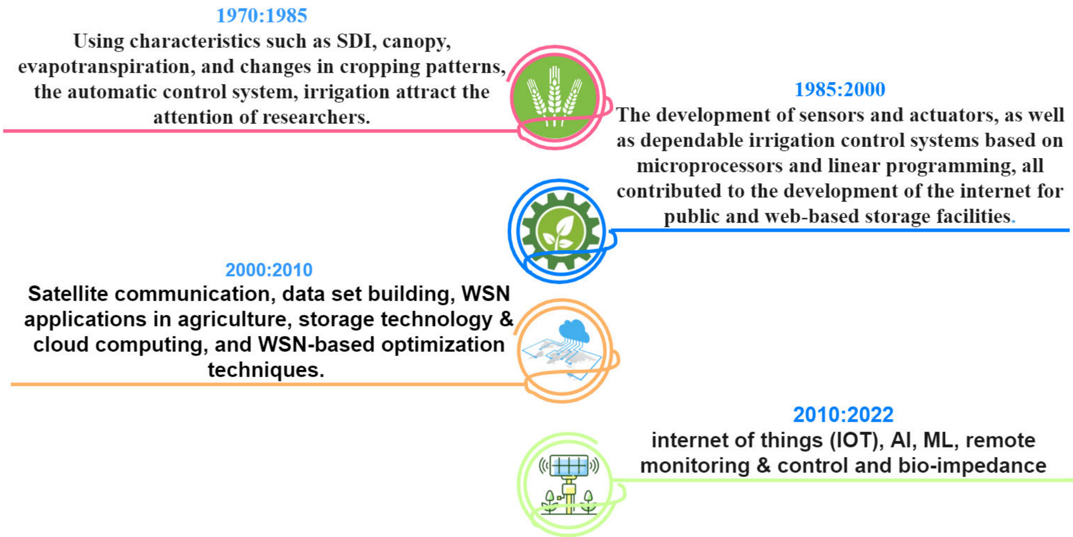

FIGURE 3. Irrigation development from 1970 to present.

ods. Researchers were interested in irrigation optimization from 1970 to 1985 because of the introduction of intelligent monitoring systems and water limitations for irrigation. Water usage efficiency and information were introduced in the late 1970s when water demand began to rise with population growth and natural resource depletion. The scenario necessitated the improvement of the irrigation technique. The stress day index (SDI), factors of normalized crop susceptibility (NCS), evapotranspiration (ET) crop canopy, and climate variables were all recognized as important in achieving irrigation optimization [14], [15], [16], [17], [18], [19], [20], [21], [22], [23]. After 1989, when the Internet became available to the general public, it sparked the development of control systems based on the internet and web-based data storage [24], [25], [26], [27], [28], [29]. Since 2000, WSNs have begun to gain traction as a simple and effective solution for monitoring the environment. Actuators and sensors for many WSN applications, including agricultural ones, have been developed. WSNs value existing irrigation systems by giving the grower instant input on the crop's water requirements. Also, construct WSNs that can monitor and regulate irrigation water applications using different methods and an efficient routing protocol [30], [31], [32], [33]. Precision agriculture researchers have been paying close attention to smart applications and approaches for irrigation, soil fertilization, insect management, and disease forecasting [34], [35], [36], [37], [38] by employing cutting-edge advanced technologies including Machine Learning (ML), Artificial Intelligence (AI), Unmanned Aerial Vehicles (UAV), and the Internet of Things (IoT) [39], [40], [41], [42]. Fig. 3 shows this progression.

III. REAL-TIME IRRIGATION SCHEDULING SYSTEMS

Irrigation schedules that are updated in real-time aim to reduce crop water stress, increase harvest yields, and improve crop quality by regulating soil moisture. Evaporation (E) and transpiration (T), sometimes known as evapotranspiration (ET), require water for crops. However, too much water is detrimental to a variety of plants. The quantity of water needed by plants is determined by their growth stage, climate, and crop kind. So, irrigation solutions that improve water efficiency are scheduled [43]. In arid, sandy soils, determine the effects of various irrigation scheduling methods on corn yield and water productivity and provide irrigation scheduling suggestions that optimize marginal profit per unit of applied water. Statistics that measure the degree of fit were calculated by comparing dry matter, crop phenology, soil moisture, ET, and grain yield simulations and observations. Three irrigation scheduling options were tested in this study: (i) irrigation scheduling based on soil water, (ii) watering schedules based on ET thresholds, and (iii) irrigation scheduling based on growth stage ET. The long-term model results showed that it is more effective to schedule watering at regular intervals for greater yield than varied intervals based on ET, and the widely accepted threshold of 50% available soil water content (AWC) in the production of crops was found to be a practical irrigation scheduling choice for the production of corn on arid sandy soils. In the system of soil-land-atmosphere, AI algorithms are used to understand the soil moisture's dynamic behavior, which is then implemented in a low-cost controller to create efficient irrigation timelines. In order to conserve water and maintain yield, a neural network (NN) model ensemble was evaluated and proven to boost the accuracy and moisture resistance of soil forecasting and scheduling performance. The effectiveness of the ensemble-based NN irrigation organizing approach was comparable to that used in the RZWQM2-WS technique, which outperformed the ET-based technique and improved water balance by up to 20%. The ensemble-based NN and ensemble NN model irrigation

TABLE 1. Smart scheduling irrigation systems.

Type of crop	Scale of Field	irrigation scheduling technique	contribution	Ref.
wheat	open Field experiment for 16 years	Net groundwater depletion Irrigation water performance (IWP), water performance (WP), Total yearly water consumption (ETa)	Improving water use efficiency while reducing groundwater pumpage for irrigation	[48]
plants	open Field	Raspberry Pi and xbee devices to collect data and used to define irrigation time using membership functions	permits the Volumetric Water Content in the soil is close to the field capacity value, soil moisture is towards the optimal value.	[45]
root zone of plant	open Field	NN model accurately predicted Moisture in the soil variations occurred with low error rate during the principal harvest period the error was greater at lower soil moisture, lowering scheduling performance.	With minimal errors, the NN model estimates soil moisture changes during the main crop cycle.	[47]
olive	orchard	The Smart Photovoltaic Irrigation Manager (SPIM)	By solar panels, the photovoltaic water system deliver to meet Irrigation of crops needs, avoiding the emission of 1.2 tn CO_2 eq	[49]
bean	Field data and the CROPWAT model were used to test the model.	Using climatological, agricultural, and soil data as input, a daily water balancing approach is used.	Irrigation scheduling model user-friendly and adaptable.	[50]

scheduling approaches could be used instead of traditional methods for achieving effective irrigation scheduling and forecasting soil moisture.

A. ARTIFICIAL INTELLIGENCE IRRIGATION SCHEDULING SYSTEM

Artificial intelligence algorithms might be used to comprehend the dynamics of soil moisture in the soil and crop atmosphere framework, which could then be implemented in a low-cost control system to develop efficient irrigation time slots [44], [45], [46]. This research looked at [43], a NN model to gain knowledge from the Root Zone Water Quality Model (RZWQM2), an agricultural systems model based on processes to forecast soil moisture in the plant roots during the growing season. When the soil moisture content falls below a certain threshold defined by the supplier of allowed control depletion, which is calculated by multiplying by the crop's water depth, irrigation is initiated using the NN-based irrigation methodology. The irrigation rate was chosen to return the soil water in the root zone to the field's capability.The NN approach was compared to the RZWQM2-based reported water stress (WS) technique. The study found that while the developed NN model accurately estimated soil moisture variations with minimal errors throughout the primary crop cycle, a lower soil moisture error was more significant, lowering scheduling performance. Forecasts of evapotranspiration (ETo) can help with irrigation scheduling and water resource management. For forecast ETo, three cutting-edge deep learning algorithms were tested: long short-term memory (LSTM), convolutional LSTM (ConvLSTM), and one-dimensional CNN (1D-CNN) [47]. Table 1 represents different smart scheduling irrigation systems based on the type of crop and scale that they were made for, as well as the benefits of each one.

IV. IRRIGATION SYSTEM TECHNIQUES

Water can be collected from various sources and used in a variety of irrigation methods. However, the ultimate goal is to distribute water evenly across the entire field, ensuring that each plant receives an adequate amount of water [3]. Modern irrigation systems are designed to supply water directly to the crops or the root zone. Modern methods efficiently reduce wasted water, uniformly distribute the provided amount of water and energy conserved, and efficiently manage the irrigation phase. The diagram in Fig. 4 shows modern and traditional irrigation techniques.

A. SURFACE IRRIGATION SYSTEM

The surface irrigation system is expected to supply the root zone reservoir uniformly and efficiently to avoid plant stress and ensure resource conservation such as water, nutrient, energy, and labor. Other uses for the irrigation system include cooling the climate around some sensitive fruits and vegetables or warming the climate to save the plants from damage by frost in freezing areas. In addition, an irrigation system has to leach salts into the root region. Besides, it might be used to soften the soil in preparation for better farming or to fertilize the field and distribute insecticides [3].

Because of its simplicity and minimal energy use, one of the most common types of irrigation is surface irrigation, an extensively used method of irrigation. Although deep percolation and unequal irrigation water distribution are

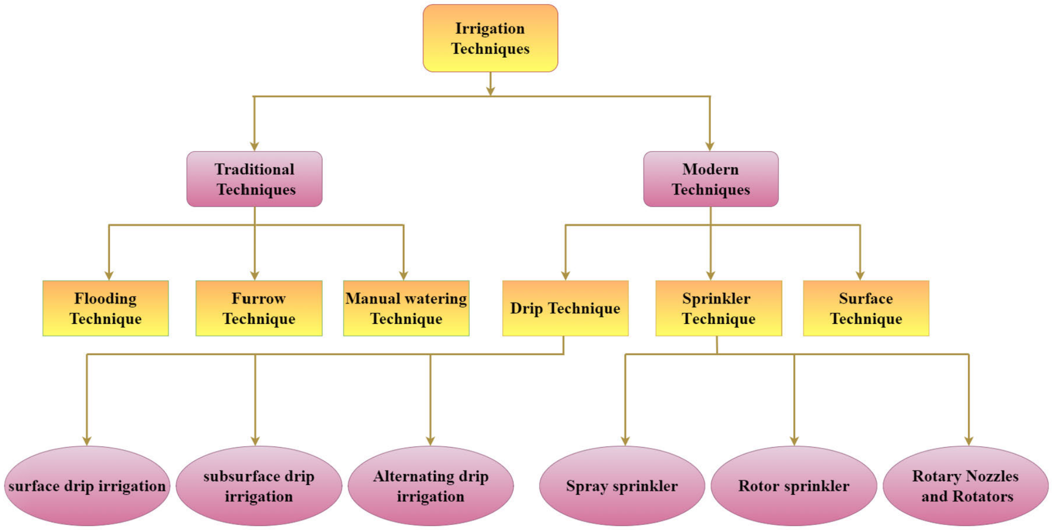

FIGURE 4. Different techniques of irrigation.

most commonly associated with poor irrigation application efficiency, some studies try to solve this problem to make surface irrigation more efficient [51], [52], [53], [54], [55].

Assessing irrigated farming land resource element output on a long-term basis Physical soil features, such as soil level, drains, and texture, in addition to the land ramp, land utilize, and nearness to water sources [51], [52]. In [51] there are two goals: (1) to evaluate acceptable surface irrigation land and (2) to evaluate suitable areas for irrigation purposes on a small, medium, and wide scale. An Analytic Hierarchy Process incorporating a Geographic Information System (GIS) based multi-criterion (MCE) making decisions was used to determine the soil's suitability for irrigation systems. Highly appropriate (S1), mildly appropriate (S2), mildly appropriate (S3), and presently not appropriate (N) were the four categories used to classify irrigation land suitability. In [53] Using Remote Sensing (RS) and GIS techniques analyze land surface water availability and suitability for surface irrigation in the Gilgel Gibe watershed. The availability of surface water was assessed by creating a flow duration curve (FDC), and assessing the Gilgel Gibe River's 90% available flow. The appropriateness of the land surface was estimated using an MCE technique that took into account the communication among important land suitability characteristics such as Slope, type of soil, river closeness, and land utilization. Using a couple of comparison matrix, determine the importance of one element over another in order to favor one over the other for physical land viability.

Simulation optimization models help determine the best system performance. The primary goal of this study was to develop and validate the Evaluation, Design, and Optimization of the Irrigational Model (EDOSIM), which is a simulation model of surface irrigation. The quantity estimate accuracy was applied to the simulation, which included designing or evaluating basin, furrow, and border irrigation. Twenty meta-heuristic techniques were used to optimize the results. The quantity of water that has entered the soil was determined in this irrigation-based model without obtaining advanced or recession data [56]. When the EDOSIM technique's simulated results were compared to those of the SIRMOD software's Hydrodynamic technique, it was found that the proposed method for estimating the volume of infiltration and the EDOSIM model performed well, with CRM = 0.005, NRMSE = 4.2 %, RMSE = 0.068, and R2 = 0.988. In addition, the Shuffled Complex Evolution (SCE) method has been discovered to be the most effective approach to improving field performance; the objective function was lowered in all fields [56].

This study [54] increased surface irrigation efficiency up to 86.6 %. An IoT-based system was established and tested in a layout of a level basin with a fixed end in sandy loam soil using a wireless link between the soil moisture sensors and an auto checkpoint that can be remotely managed using data from real-time soil moisture conditions. Aiming to improve irrigation efficiency, an effort was made to place the sensor in the most appropriate place in the basin layout. To control the water flow, an aluminum automatic check gate with a steel framework was installed in the water supply system. Three soil moisture sensors based on capacitance were put at 37.5, 15, and 7.5 cm depths at 25%, 50%, and 75% of the field's length, respectively. There are three distinct operational schedules based on the location of the soil moisture sensors that were investigated under 40 %, 30 %, and % soil moisture deficiency situations. The study found that sensors should be put at 37.5 cm depth and 25 % distance from the injector in increased moisture in the soil deficit conditions. When there is a lack of moisture, sensors shall be placed at 7.5 cm depth and 75 % length from the entrance [54]

B. DRIP IRRIGATION

Drip irrigation is a critical method for dealing with the world's scarcity of water. Trickle irrigation is another name for drip irrigation. Drip irrigation is a type of irrigation in which water is given drop by drop to the root region of plants. Because evaporation and runoff are reduced, this technique can be the most water-efficient type of irrigation. In modern agriculture, drip irrigation is frequently used in conjunction with organic or inorganic (plastic) mulches, which provide additional benefits such as reduced evaporation, increased soil warmth, weed control, etc. The issue of drip irrigation emitter blockage, on the other hand, has a significant effect on irrigation uniformity and efficiency, even causing the system to be disabled and crop productivity to be reduced [55].

This research [57] presents an automated drip irrigation system. The technology is tested on a paddy field for three months. In comparison to conventional flood and drip irrigation systems, it saves roughly 41.5 % and 13% of water, respectively, according to the experimental setting.

This study [58] shows the consequences of surface drip irrigation (DI), subsurface drip irrigation (SDI), and alternating drip irrigation (ADI) on tomato yield and soil microbes in the roots' reactions. The homogeneity of moisture distribution in the soil in the root region (0–60 cm depth) was diminished according to the sequence $SDI > DI > ADI$. The SDI method produces tomato root lengths that are 4.83 and 3.94 times longer than those produced by the ADI and DI methods, respectively. Root length was 1.23 times longer in the ADI treatment than in the DI treatment, resulting in different root-soil microbial interactions. The SDI treatment had the most positive root-soil-microbe interactions, followed by ADI and DI. Variations in root-soil-microbe reactions controlled tobacco yield. Compared to the DI and ADI methods, the SDI method boosted tomato field outcomes by 9.77 % and 7.77 %. The ADI method produced 24.09% more tomatoes than the DI method. As a result, various drip watering systems can govern tomato productivity by influencing root-soil-microbe reactions. The findings can be used to improve the drip irrigation method to control root-soil microbe reactions and boost tomato yield. Compared to previous irrigation methods, the modern drip irrigation system saves a large quantity of water. Moreover, some crops, such as paddy, require a varying quantity of water as they grow.

This research [59] is to assess and evaluate production efficiency (WP), economic water productivity (EWP), and land productivity levels (LEP) in cotton using various amounts of irrigation water and drip systems (SDI and subsurface drip irrigation (SSDI)). The results of an experiment conducted during the growing seasons of cotton for two years—2016 and 2017, were evaluated. By using an irrigation water quantity based on plant water requirements, SSDI reduced water use and increased water productivity. As a result, this method was more relevant to farming methods. Finally, WPIng, EWP, WP, and LEP all need to be taken into account to enhance water productivity and save water for farmers and irrigation techniques [59].

This study [60] used pear to look at two years of irrigation studies, taking two aspects of drip irrigation systems into account: pipe design and soil moisture loss rate. Five drip irrigation modes and control techniques were used to investigate the impact of drip irrigation techniques on the water productivity of the field and enhance the effective utilisation of water resources. As a result, it was found that the SSDI with two points under a soil moisture lower level of 60 % FC was the optimal irrigation method in a pear field after considering all factors.

C. SPRINKLER IRRIGATION

The concept of sprinkler irrigation is to spray water into the air and fall as a rainfall pattern. The spray output water is controlled by the pressure of the water and passes via a network of pipes, which comes out through tiny nozzles. Nozzle sizes should be selected carefully depending on the sprinkler formatting and operating pressure. The quantity of water required for crop irrigation and refill the root region can be used almost uniformly at a reasonable rate, the leakage rate of the soil [61]. The concept of sprinkler irrigation is to spray water into the air and let it fall as a rainfall pattern. The sprayed-out water is controlled by the water pressure and travels through a network of pipes before exiting through tiny nozzles. Choose the size of the nozzle carefully based on how the sprinkler is set up and how much pressure is being used. The amount of water needed to water crops and their roots can be used almost evenly and at a reasonable rate, which is called the soil leakage rate. Many crops can be planted under the sprinkler irrigation method, such as vegetables like onion, potato, carrot, garlic, lettuce, and others; spices like cardamom and pepper; flowers like jasmine and carnations; oilseeds like sunflower, groundnut, and safflower; and fibers like cotton and Sisal [62]. Sprinkler irrigation is appropriate for different types of soil except for heavy clay. Also, it provides mobility to the system as well as saves water. Irrigating plants with a high plant population per unit area, such as oilseeds and vegetables [3]. There are many types of sprinkler irrigation based on portability, like fully portable, semi-portable, semi-permanent, and fully permanent sprinkler systems.

Reduced sprinkler working pressure can significantly reduce the energy required for sprinkler irrigation. However, the sprinkler's hydraulic performance changes are unavoidable as working pressure is reduced and nozzle shape changes. Therefore, experiments were carried out to examine the impact of operating pressures, injector shape, and injector diameter on the rate of flow, the throw radius, irrigation water rate, droplet dimensions, droplet speed of the rotating sprinkler, and kinetic energy of water droplets that influence the surface soil to assess the spray properties of various non-circular sprinklers. The watering similarity coefficients for circular and non-circular injectors were calculated by varying rectangular sprinklers' spacing and operating pressures. Under the same operating pressure and nozzle size, the circulation flow rates of circular and non-circular injectors were equal, while the circular nozzle's throw radius was greater than that of the non-circular nozzle. In addition, the circular nozzle generates larger droplets than the non-circular nozzle [63].

On the other hand, the sprinkler heads, which are split into three types, are based on how they are used to distribute the water over the entire land and how much they distribute.

In Table 2 a brief comparison between different irrigation methods is provided; the comparison is according to several parameters that directly affect the choice of the irrigation method, such as soil type, suitable slopes, suitable crops, suitable irrigation water, and the layout of each system.

V. SMART IRRIGATION SYSTEM MONITORING

It is necessary to keep track of specific factors influencing plant development and growth to improve water use efficiency. Contextual monitoring of intelligent irrigation necessitates the accumulation of actual data on soil status, plant health, and climatic variables in the cropped region via cutting-edge communication technologies [64].

The IoT, AI, cloud computing, and edge computing play essential roles in increasing agricultural land productivity and irrigation efficiency. Technologies such as crop and soil monitoring using IoT, data analysis using artificial intelligence to make appropriate decisions, irrigation systems that work automatically, and weather measurement and prediction are in high demand to enhance the quality of crops and recognize diseases in insects and plants, leading to increased crop efficiency with a significant reduction in farmers' reliance on human labor. The plant field can be monitored using sensors and IoT devices. Edge computing gathers Sensor data is gathered in the field and sent to the cloud, where it is processed and analyzed to determine the best course of action based on the analysis. As a result, crop production will increase while less water, fertilizer, and pesticides are used in the field crop [65]. WSN are an exciting and important technology that has made remarkable progress in recent years and can be used in various fields; agriculture is one of the fields where WSN are broadly used and successfully deployed [66], [67], [68]. The utilization of WSN technology to manage and control irrigation methods is a perfect scenario for ensuring rational and effective water use, which contributes to the gravity of the global water crisis [5]. Figure 5 shows the possible monitoring types in intelligent irrigation systems.

Soil quality (SQ) evaluation is required to track changes in soil performance as a result of management practices. Soil quality measurement also warns of the potential effects that various primary land use activities may have on long-term soil quality. In addition, it can assist in determining whether soil quality is deteriorating over time and what factors may be able to contribute to soil degradation. This data is then used

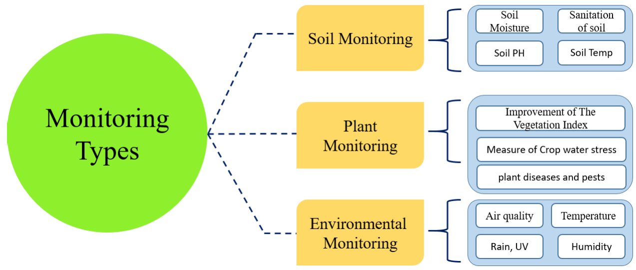

FIGURE 5. Monitoring techniques in smart irrigation.

to help us manage our soil resources more sustainably in the future.

Soil Moisture Monitoring: In comparison to the quantity of freshwater resources worldwide, the temporary storage of water in soil is known as "soil moisture" inside a shallow level of the earth's top surface in comparison to the quantity of freshwater resources worldwide. It is essential across all spatial scales, including agricultural, hydrological, and weather forecasting processes. It is critical for detecting water stress and managing irrigation. Soil moisture data can also be used to forecast natural disasters like dryness and flooding, as well as environmental changes like sandstorms and erosion. Accurate estimation of soil moisture through in situ measurement, on the other hand, is prohibitively expensive because it necessitates a replication sampling process to evaluate the periodic change in soil moisture. Because soil moisture is extremely dynamic, both temporally and spatially, it must be monitored continuously. There are several methods to ascertain the moisture status of the soil; the techniques can be summarized in Fig. 6. All of these methods have advantages and disadvantages and should be used with caution depending on the project's requirements and demand [69]. The accuracy level depends on weighing accuracy, though these errors are negligible compared to soil variability in the field. This technique is pretty accurate, but there are practical issues, such as the fact that measurements are not instantaneous and results must be obtained at least 48 hours after sampling, which precludes its use for real-time irrigation scheduling. Because estimations of soil water content are not instantaneous, this method is primarily used as a guide [70].

Farmers frequently use the feel method. This method indicates how well the soil is irrigated based on the feel and appearance of the soil. A person with experience may be able to judge things more accurately and provide guidance for scheduling irrigation events. This method, however, lacks precision when it comes to deciding how much to irrigate and when to irrigate. As a result, while this method is inaccurate, it is useful when no other options are available. The direct method entails collecting soil from the field, weighing it, and oven drying it at 105 °C to calculate the moisture of the soil. The total soil water content is determined by the difference in mass between wet and dry soil samples. This method is also known as the Thermo Gravimetric or Gravimetric

TABLE 2. Comparison between different irrigation systems.

<table>
<tr><th rowspan="2"></th><th rowspan="2">Drip Irrigation</th><th colspan="3">Surface Irrigation</th><th colspan="3">Sprinklers Irrigation</th></tr>
<tr><th>Basin Irrigation</th><th>Border Irrigation</th><th>Furrow Irrigation</th><th>Spray type sprinklers</th><th>Rotor type sprinklers</th><th>Rotate Nozzles</th></tr>
<tr><td>Soil Type</td><td>Most of the soil types.</td><td>It mainly depends on the crops.</td><td>Preferred clay soils with medium infiltration rates or deep homogenous loams.</td><td>Most of soil types</td><td colspan="3">Sandy soils with increased flow rates, though adaptable to most soil types.</td></tr>
<tr><td rowspan="2">Suitable slopes</td><td rowspan="2">Can be adapted to any farmable slope.</td><td rowspan="2">Flatter land surfaces are easier to construct basins.</td><td rowspan="2">Suitable slopes have to be uniform slopes 0.05% : 2% to avoid soil erosion.</td><td rowspan="2">Uniform-flat or the tiny slopes with a max slope of 0.5%</td><td colspan="3">Any farmable slope, whether flat or rippling.</td></tr>
<tr><td>small ground and landscape.</td><td>wide areas</td><td>wide areas and limited water resources areas.</td></tr>
<tr><td>Crops</td><td>Row crops (vegetables, soft fruit), tree and vine crops are all suitable.</td><td>Suits many field crops as paddy rice</td><td>More suitable with close-growing crops like alfalfa or pasture.</td><td>Many types of crops, especially the row crops and the growth of the tree crops.</td><td colspan="3">Field, and tree crops. And water can be sprayed over or under the crop canopy.</td></tr>
<tr><td>Sutable Water</td><td>The irrigation water should be free of any sediments.</td><td>Two methods: Direct method, Cascade method.</td><td colspan="2">Normal water like the traditional irrigation systems</td><td colspan="3">The irrigation water should be clean and free of s ediments to avoid any problems in the sprinkler nozzle.</td></tr>
<tr><td>System Layout</td><td>Pump unit, Control head Main and sub-main lines emitters, drippers, or laterals</td><td colspan="3">The dimensions and the shape of basins, borders, or furrows depend on the stream size, soil type, slopes, irrigation depth, and other parameters such as the farm size</td><td colspan="3">Pump unit Mainline or sub-mainlines Laterals</td></tr>
</table>

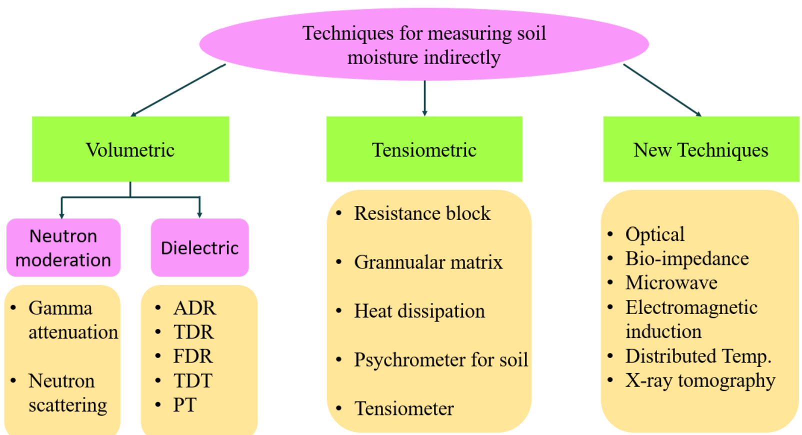

FIGURE 6. Techniques for measuring soil moisture indirectly.

method. The bulk density of the soil can be used to convert a weight-based estimate of soil water content to a volumetric assessment [70].

Volumetric techniques determine indirectly, soil moisture content by measuring some variable in the soil profile. As a result, these techniques are more useful for real-time irrigation management decisions. These techniques employ a variety of principles, based on which they are broadly classified (i) Dielectric sensors and (ii) Neutron moderation.

(i) **Dielectric sensors** operate by determining the soil's dielectric constant. It measures a nonconducting material's ability to transmit electromagnetic waves or pulses. Because the dielectric constant of dry soil is lower than that of water, even small changes in soil quantity have a significant influence on the electromagnetic properties of soil water. An alternating electric field is generated in the surrounding medium by dielectric sensors. By measuring the currents and voltages influenced by this field in the measuring rods, the cumulative complex electrical impedance of the medium

TABLE 3. Volumetric soil moisture sensors.

Types of sensors	pros.	cons.
TDR	Independent of soil texture temperature or salt content.	i) Small sensing volume. ii) Requires soil calibration. iii) High cost.
FDR	i) Can determine water content at any depth. ii) Can provide the exact soil water content.	i) Small sensing sphere. ii) Require perfect conduct with soil to get accurate results.
Resistive sensor	i) Can provide the exact soil water content ii) High precision when the soil's ionic concentration doesn't change	Calibration is required as soil, and ionic concentrations change.
ADR	i) Because of standard circuitry, it is inexpensive. ii) With proper calibration,it is accurate.	i) Small sensing volume, ii) Soil specific calibration, iii) Measurement affect of air gaps and stones
TDT	i) Accurate with large scale ii) Because of standard circuitry, it is inexpensive.	Soil disturbance during installation necessitates permanent installation.
PT	i) Inexpensive ii) Accurate with large scale iii) Accurate with soil specific calibration	Need to permanently installed Soil specific calibration
Neutron moderation	i) Water can be measured at any phase ii) Accurate with large volume at any depth	i) High cost ii) Hazard radiation iii) Insensitivity to small variation
Gamma attenuation	Can measure mean water content with depth as well as moisture content changes over time	i) High cost and difficult to use, ii) Measurement in highly stratified soil produces large errors iii) Changes in soil bulk density have an impact.

is calculated.The form and volume of the electric field are determined primarily by the form and size of the electrodes used for the sensors. Dielectric sensors are classified into several types based on the output signal, which include Time Domain Reflectometry (TDR), Capacitance or Frequency Domain Reflectometry (FDR), Time Domain Transmission (TDT), Amplitude Domain Reflectometry (ADR), and Phase Transmission sensors (PT), different in aspects of the use, maintenance, measurement requirements, accuracy, and cost [71].

(ii) **Neutron moderation** There are two types of neutron moderation methods to monitor the soil water content. The neutron scattering method is determined by the interplay of high-energy (fast) neutrons in the soil with the nuclei of hydrogen atoms. The other technique determines the attenuation of gamma rays as they travel through soil. Both methods use portable devices to collect measurement invariance at fixed monitoring sites and require accurate calibration, which is preferable for the soil where the devices are to be used [71]. When properly calibrated, neutron probes are highly accurate. They are not affected by salts, have a large measuring radius, and can measure at various depths. They are, however, extremely costly radiation hazards (requiring certified personnel), which can be hard to calibrate and install. Table 3 shows the advantages and disadvantages of dielectric and Neutron moderation sensors.

Tensiometric sensors are those that measure the potential of soil matrices. Tensiometers, electric resistance sensors, thermal conductivity sensors, and psychrometers are some of the most commonly used. The most common resistance types are electric and tensiometers. A tensiometer is a water-filled tube designed to mimic the movement of a plant root. A porous cup with negative pressure (vacuum) measured at the other end is buried in the soil. As the soil dries, water is drawn out of the tensiometer, causing the pressure reading to fall, indicating that the soil moisture decreases. When the cup is irrigated, soil water returns and the pressure decreases. Tensiometers are sensitive to conditions in a large soil volume and are simple to install and maintain.

New techniques several researchers have captured, represented, and discussed some new techniques, which are discussed below. The majority of these techniques are highly advanced and used at various scales.

(i) **Temperature distribution** this method employs fiber optics to evaluate changes in soil thermal conductivity in terms of soil moisture and ambient temperature. In this paper, In [72] they use the Active Distributed Temperature Sensing (A-DTS) method that advances ground heat transfer efficiency and detects soil moisture through a thermal behavior caused by an active electrical charge. In that order, the correlation in both thermal conductivity and soil water content was formed using this method for silt, clay, natural soil, and sand.

This paper [73] proposes a new approach for determining evaporation rates of underground water that combines the actively heated fiber-optic (A-HFO) technique with the vadose zone technique, with the evaporation front remaining at the soil surface. The A-HFO approach produced soil moisture characteristics assessments with a locative resolution of 6.5 mm and an accuracy of 0.026 m3 m-3. The calculation produced a somewhat different soil moisture profile than the measured one, with the greatest changes occurring near the soil surface.

(ii) **Microwave** Moisture monitoring has remained a challenge for agricultural outcomes with high water content. In [74], a brand-new microwave detecting system based on a multi-frequency sweeping technique was built with off-the-shelf components and used to collect moisture data from sweet corn.To collect enough data, a signal with a frequency sweep (including 41 frequencies ranging from 2.60 to 3.00 GHz) was used as the earliest detected signal.

VI. CONTROL

Soil moisture sensor device: handheld with an integrated controller for controlling a soil moisture sensor. To generate an electrical signal of precise frequency, an oscillator is used, and to get the moisture content of the soil, a sensing unit is used. The controller could be an 8051, AVR, PIC, or another microcontroller. It controls the sensor circuit in accordance with the software system dumped into the controller. The soil moisture sensor could be a capacitance sensor, a granular matrix sensor, or something similar. Depending on the type of controller, the oscillator may be a crystal oscillator, a Hartley oscillator, or another type of oscillator to provide clock signals. The sensing unit could be a gravimetric probe, a neutron probe, or other similar sensing units, and the sensing unit's material may be a conducting material such as copper, metal, aluminum, or another such material. The sensing unit is inserted into the soil to determine the moisture content, which is displayed with a precise value. The invention comprises a portable soil moisture sensor and a single display unit. This allows the user to monitor the soil's moisture level in multiple locations from a single conveniently placed display unit.

VII. CONCLUSION

This is a review of intelligent irrigation control and monitoring strategies to improve irrigation efficiency in smart agriculture. The study has been built around monitoring techniques for irrigation scheduling and control. Furthermore, a discussion on future research opportunities based on study gaps has also been organized. In this context, it is noted that a mixture of soil-based, weather-based, and plant-based monitoring techniques, combined with a discrete forecasting control method, should be studied in open fields. In contrast to environmentally controlled agriculture research, open-area agricultural and irrigation systems face uncertainties that must be investigated. Thus, future studies will focus on the development of process dynamics approaches for irrigation systems, as well as the impacts of intelligent controlling and monitoring techniques on irrigation productivity in open-field agricultural systems.

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