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Sensor based technology in water management

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Abstract

To enhance the productivity of water in irrigation practices, the knowledge of efficient water consumption and crop water demand has become the utmost priority; as the country is facing a major concern in form of ever-growing water demand. Traditional practices are futile considering the aim, which is to achieve sustainable agriculture, as traditional practices lead to uneven irrigation wherein one part of the field is heavily irrigated and the other barely moist. Changes in environmental conditions and a severe shortage of water have made it necessary for us to develop an efficient irrigation system. Using advanced, modern technologies such as sensors, we can manage the ever-increasing demand of food, fiber and feed; while also conserving the limited available water resources. Sensor-based technology has attracted global attention, as it guarantees the water and food security across the globe when installed in irrigation systems. To enhance the yield of crop and to assure the efficient and rational use of water, a smart irrigation system needs installation in agricultural fields, and we have developed certain such systems and measures; Sensors being the most widely used ones. These sensors include Soil Moisture Sensors (SMS), Evapotranspiration (ET) controllers and Rain Sensors. One may still ask the question, why the smart irrigation? Well, it will ensure sustainable agriculture, environment conservation, water saving and better yield and also a reduction in fertilizer dependency and thus result in efficient and profitable agriculture.

Keywords: Sensors, Soil moisture sensors, Smart irrigation, Evapotranspiration controllers, Water saving, Rain sensors

1. Introduction

India supports 17% of world's population but only constitutes 2.4% of the land and 4% of the water resources, thus the efficient utilization of available resources is crucial (Jain and Kishore, 2020). Rapid population growth has resulted in a greater demand for the food availability thus pressuring the water resources. Approximately 70% of the global fresh water is consumed by the irrigation thus agriculture is the sector which withdraws the maximum amount of global fresh water (Touil *et al.*, 2022) ^[45]. There is a competition in the consumption of already scarce water resources between the agriculture and other fields like urban consumption, industries etc. making it even more essential to improve the efficiency of water use in irrigated fields and hence contributing to the sustainability of agricultural systems (Simionesei *et al.*, 2020) ^[42]. The imbalance between water demand and supply in agriculture has resulted in the search for new methods to optimize the irrigation water use via adopting modern technologies and management tools (Pereira *et al.*, 2020) ^[36]. An irrigation system that can predict, adapt and deliver the appropriate amount of water to the crops at various stages in response to the changing dynamics of soil, weather and the plant needs to be designed (Abioye *et al.*, 2020) ^[1]. In developing countries fresh water utilized for agriculture (about 40%) is either lost through evaporation, spills or immersion by soil layers, beyond the range of plant roots, thus contributing to one of the primary concerns in agriculture i.e. inefficient water use (Shah and Das, 2012) ^[40]. An important parameter to increase the yield of a crop is irrigation scheduling, which also contributes to efficient water consumption in agriculture and also helping the grower to know how to irrigate, how much to irrigate and when to irrigate (Durga *et al.*, 2020) ^[19]. The conventional methods for irrigation scheduling include soil moisture measurement and

Estimation of soil water equilibrium that are slow and tedious. The traditional techniques used in irrigation in India are mostly manually operated and include ditch irrigation, terraced irrigation, drip irrigation, and sprinkler system which are now being replaced with semi-automated and automated techniques (Kansara *et al.*, 2015) ^[26]. Sensors, the devices or gadgets, are used in crop cultivation to attain elevated water use efficiency (WUE) and to estimate moisture content of soil at various growth stages of the crop to wisely meet its water requirement (Chaitra *et al.*, 2021) ^[9]. The sensors either measure the moisture content of soil or determine soil water tension. Soil Moisture Sensors (SMS), Rain sensors (RS) and Evapotranspiration controllers (ET) are some of the commercially available technologies that support irrigation and reduces the outdoor water use (McCready *et al.*, 2011) ^[31]. The data from the sensor is used by the irrigation controller to approve or disapprove timed watering events and with adjustable threshold setting controls the various scheduled events in case of increased soil water content (Dukes, 2005) ^[16]. Evapotranspiration technology applies irrigation based on estimated water loss by

understanding of evaporation and

Transpiration processes which in turn are measured using various weather parameters and knowledge of gas exchange characteristics of plants species (Migliaccio *et al.*, 2010) ^[33]. Standalone controllers, signal-based controllers and historical-based controllers were the ET controllers used in the recent decade (Kisekka *et al.*, 2019) ^[29]. The advanced technologies has made it feasible to create systems that don't involve farmers directly in irrigating their fields and collect real time data from their fields using sensors, thus providing reliable potential for monitoring soil water status (Munoth *et al.*, 2016) ^[34]. The sensor characteristics, cost, applicability, merits and demerits, should be taken into consideration before choosing the proper type of sensor (Garg *et al.*, 2016) ^[22]. The primary aim of this very paper is to review the necessity of automatic irrigation system using sensor-based technology which would promote optimal water use, save time and money of farmers.

2. Irrigation methods

The different methods of irrigation are given below in Fig.1

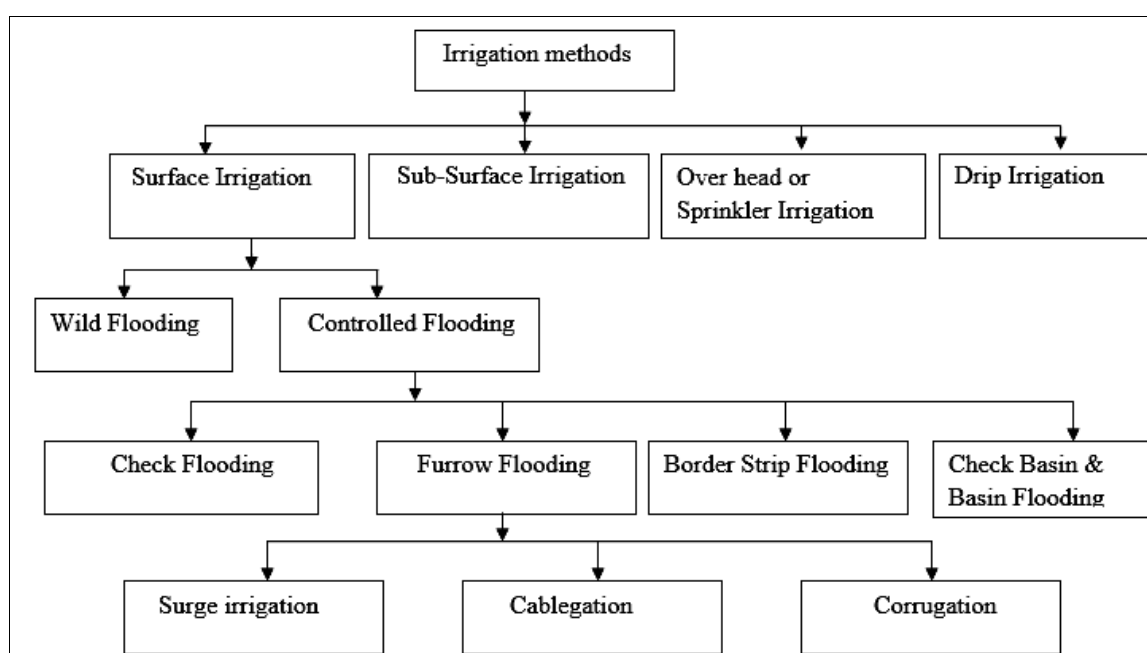


Fig 1: Methods of irrigation

“Surface irrigation water is scattered throughout the land with the help of gravitational pull. The different types of surface irrigation method includes, flood irrigation, furrow irrigation, border strip irrigation and basin irrigation. About 85% of the 299 million hectares of irrigated agricultural land worldwide are subjected to surface irrigation, according to the International Commission on Irrigation and Drainage (FAO-2013) ^[20]. Areas with a flat surface or parallel slope and a somewhat fine-textured soil type are ideal for this system.

"Sub-surface irrigation is a minor irrigation method, where the water table is raised to or held near the plant root zone using ditches, underground tile lines or subsurface drains to supply the water".

“Sprinkler irrigation delivers water to the soil by spraying water

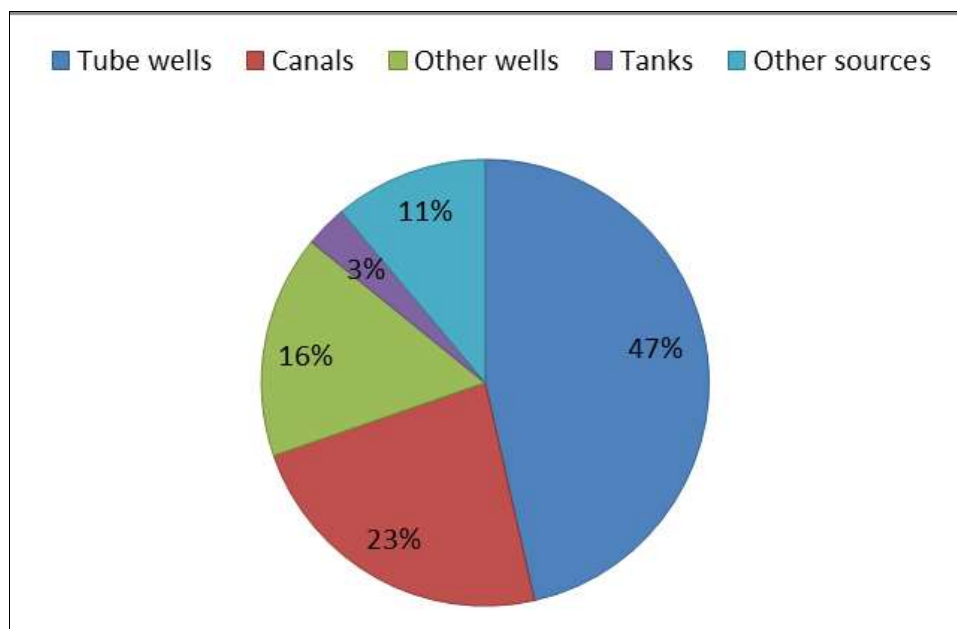
droplets from stationary or mobile apparatus. Sprinkler irrigation tends to be more efficient than surface irrigation due to more controlled water application."

“Drip irrigation employs frequent, small, slow and direct application of water into the root zone of plants. It applies water drop-by-drop through a network of valves, pipes, tubing, and emitters.”

The choice of an irrigation method rely on the crop type, soil, water, and climatic conditions, as well as the user's expertise and choices, capital and operational costs, and the infrastructure availability.

3. Sources of irrigation in india

The different sources of irrigation in India are shown in Fig.2



Source: Meena and Sihag (2021)

Fig 2: Sources of irrigation in India

4. Sensor based technology for precision irrigation

To prevent water wastage while irrigating the field, there are typically

three smart irrigation technologies available in market i.e. Soil moisture sensors, Evapotranspiration controllers and Rain sensors.

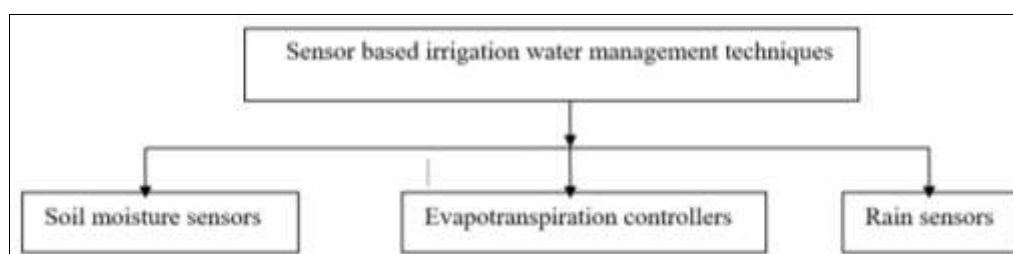


Fig.3: Sensors used in irrigation management

4.1 Soil moisture sensor based irrigation management

Soil volumetric water content and electrical conductivity in the real-time can be estimated with the help of Soil Moisture Sensors, by monitoring moisture of the soil, the proper irrigation water management can be achieved, and it is thus important to study and understand the dynamic changes and spatial distribution of soil moisture as well as the crop's requirement of the soil water content (Yu *et al.*, 2021) ^[46, 47].

Soil Moisture Content (SMC) is measured to estimate the water equilibrium in the soil and the demand for crop irrigation.

Rajaram and Sundareswaran (2020) ^[39] carried out a study in brinjal plants, soil moisture sensors were employed for precise application of water to brinjal plants. Temperature and humidity readings from the sensors were used to determine the amount of water required. The outcome showed that 53% of the water was prevented from being wasted.

Hamouda *et al.* (2021) ^[23] conducted an experiment in pear orchard with SMS installed and found that about 50% of the water was saved, without hampering the crop quality and productivity.

Panigrahi *et al.* (2019) ^[35] carried out an experiment in banana to assess the effectiveness of automated drip irrigation. He observed that the soil moisture sensor-based drip irrigation utilized 20% less water.

Rajalakshmi and Mahalakshmi (2016) ^[38] conducted an experiment where an automated crop field irrigation system employing temperature, humidity, and soil moisture

sensors found to be 92% more effective than conventional techniques. In their experiment, the total water need for a crop field of 600m² area for traditional irrigation practice was 341m³, whereas only 29m³ for controlled irrigation over a period of two months. Chaitra *et al.* (2021) ^[9] conducted an experiment at GKVK Bangalore and observed that drip irrigation based on sensor at 25% DASM in Maize resulted significantly higher growth parameters, stover yield (12,273kg/ha⁻¹) and kernel yield (10,676kg/ha⁻¹).

Singh *et al.* (2021) ^[43] carried out an experiment at university of Nebraska where he compared the soil moisture sensor treatment with traditional treatment in maize and soybean and found that the sensor-based treatment witnessed higher IWUE, 17.35 kg/ha/mm and 3.93 kg/ha/mm respectively for maize and soybean against conventional 8.29 kg/ha/mm and 3.09kg/ha/mm for the same.

Liao *et al.* (2021) ^[30] conducted a study in a tomato greenhouse in Beijing, China using wireless soil moisture sensors and drip irrigation, and found that the irrigation water use efficiency in SMS based treatment was 41.23kg/m³ which was higher when compared against 31.58Kg/m³ efficiency in traditional irrigation system.

Sui (2018) ^[44] reported that each form of soil moisture monitoring devices has its advantages and shortcomings in terms of reliability, cost, and accuracy.

Yu *et al.* (2021) ^[46, 47] evaluated the soil moisture sensors, their advantages and disadvantage;

Table 1: Soil moisture sensors

Sensor	Principle	Advantage	Disadvantage
Tensiometer	- Vacuum gauge measures the pressure built inside the plastic tube. - Water pulled out of the tube by the soil causes a change in the pressure. - Higher gauge implies less soil moisture and vice-versa.	- Easily operable. - Fast measurement. - Easy to read the data	-Needs routine maintenance. - Cannot be used during winters.
Granular matrix sensor	- Two electrodes inside the porous material measures the resistance. - Decrease in soil moisture results in increased resistance and vice-versa.	- Better version of gypsum block. - Easy to operate. - Low cost (\$25-\$50) - Long duration.	-Larger particle size of sandy soils makes it less effective.
Time domain reflectometry(TDR)	- Soil Moisture content is determined indirectly by measuring the soil dielectric constant. - Dielectric permittivity of soil changes the velocity.	- Easy to operate - Fast measurement - High accuracy.	- Expensive - Needs constant calibration.
Frequency domain reflectometry(FDR)	- Electromagnetic pulse is used to determine the dielectric constant of the soil medium.	-Fast measurement. -Automation without disturbance. - Less calibration.	- Vulnerable to soil texture, bulk density.

Source: Yu *et al.* (2021) ^[46, 47]

4.2 ET controller-based irrigation management

Evapotranspiration estimates and soil moisture sensors have both been used for scheduling the irrigation, while the former is also considered new latent water saving device (Davis and Dukes, 2009) ^[12].

When scheduling irrigation, ET controllers take into account a number of variables include weather information (solar radiation, precipitation rate, air temperature, relative humidity and wind velocity), site-specific characteristics that include soil type and slope, crop attributes that include K_c and root depth, and irrigation system features that include irrigation efficiency and system type (Dukes *et al.* 2018) ^[18]

Water lost through evaporation from soil surface and from the plants through transpiration is reflected by the ET controllers. (Khachatryan *et al.* 2019) ^[27]

Weathermatic (Weathermatic Inc. Dallas, TX), Toro (Toro Company Inc. Riverside, CA) and ET Water (ET Water Systems LLC, Corte Madera, CA) are three primary ET controllers used for precision irrigation (Davis & Dukes, 2012) ^[13].

A study conducted in gardens and parks in Valdebebas, Madrid, Spain by Canales-Ide *et al.* (2019) ^[7] found that the water savings was up to 35% in the gardens that were well managed by ET controllers.

Al-Ghobari *et al.* (2016) ^[3] evaluated three treatments wherein two were equipped with Smartline and Hunter ET sensors while third being the control treatment, the average irrigation depths were 508.8, 556.2 and 675.1 mm respectively. It was found that control treatment received 25% and 18% more water respectively than Smartline and Hunter ET sensor equipped treatment.

Kisekka *et al.* (2010) ^[28] found in a study, he conducted on Carambola orchard in Florida that around 70% less irrigation water was consumed using evapotranspiration based irrigation system be it historical weather data or real time when compared against the time-based treatment.

In an experiment conducted by Devitt *et al.* (2008) ^[14] in landscapes of Las Vegas, it was observed that about 20% water utilization was decreased in signal-based ET controllers when compared to control sites. Al-Ghobari and Mohammad (2011) ^[2] found that Evapotranspiration controller treatments saved up to 25% water compared to control treatments.

Cruz *et al.* (2020) ^[10] in a study conducted on mustard green crop using ET-based irrigation systems, recorded variables such

as humidity, solar radiation, temperature, and wind velocity from Microclimatic Weather station and Public Weather Forecast and reported that both had demonstrated water savings of about 71% when compared to traditional irrigation, without impacting the growth of crop.

4.3 Rain sensor based irrigation management

Rainsensing, the most straight forward irrigation technique, proved effective for water conservation at a comparatively lower cost. When a specific amount of rainfall occurs, Rain sensors halt the cycle of automatic irrigation system controller (Dukes and Haman, 2002) ^[17].

For monitoring irrigation in paddy, Barkunan *et al.* (2019) ^[5] conducted an experiment based on smart irrigation system for a period of three months and concluded that this system saved about 41.5% of water when compared to drip irrigation method and 13% water compared to the conventional flood irrigation methods. In another experiment, Barkunan *et al.* (2020) ^[6] tested the automatic irrigation system equipped with rainfall detection and observed that that in germination stage up to 50% water was saved and in ripening periods greater than 30% for tomato when compared to traditional irrigation system.

RS is an effective tool in minimizing percolation and drainage losses, reducing weed infestation and disease infestation and eliminating various unnecessary irrigation events.

Dobbs *et al.* (2014) ^[15] found that Rain sensing-based irrigation systems were capable of conserving about 49% more water than traditional irrigation systems at irrigation depths of 32 mm and frequency of twice weekly, in a study he conducted on Bahia grass.

“The different smart irrigation strategies outlined above proved cost-effective and efficient for scheduling irrigation, however soil salts may pose a threat to the sensors and thus their durability. Although the technology is advanced beyond the imagination, yet it’s flawed and absolute accuracy is yet to be achieved”.

5. Conclusion

Sensor-based irrigation technologies represent a significant advancement in the pursuit of sustainable and efficient water management in agriculture. By enabling real-time monitoring and precise control of irrigation, these systems improve water use efficiency, enhance crop productivity, and reduce

unnecessary resource utilization. Technologies such as soil moisture sensors, evapotranspiration-based controllers, and rain sensors have demonstrated their effectiveness in minimizing water losses and optimizing irrigation scheduling across diverse cropping systems.

However, challenges related to high initial costs, maintenance requirements, and variability in sensor performance under different soil and climatic conditions still need to be addressed for wider adoption. Future research should focus on improving the affordability, accuracy, and adaptability of these technologies, along with their integration with advanced tools such as IoT and artificial intelligence for smart decision-making. Overall, sensor-based irrigation systems have strong potential to support climate-resilient agriculture and ensure sustainable use of water resources in the face of increasing environmental and agricultural pressures.

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