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Traditional to Smart Irrigation Methods in India: Review

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ABSTRACT

Irrigation is the controlled application of water for agricultural purposes through manmade systems to supply water requirements that are not satisfied by the rainfall. Crop irrigation is vital throughout the world in order to provide the world's ever-growing populations with enough food. Many different irrigation methods from traditional to smart ones are used over worldwide, including: surface, sub-surface, sprinkler, drip, and advanced or smart to satisfy the plants thrust. In this paper efforts have been made to present the basics of different irrigation systems adapted by the Indian farmers to grow their crops.

Keywords

Irrigation methods
Wireless sensor networks
Sprinkler
Drip
Surface
India

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Introduction

Irrigation is a fundamental need for the survival farmers as it provides water (life blood of crops) to the growing plants. Irrigation systems involve different ways of obtaining water from different sources and deliver it to various mediums and are necessary in all forms of agriculture due to the unpredictability of the weather. It can be argued that embracing the sustainable and cost-efficient traditional irrigation methods are important for local communities in India. Therefore, different traditional methods are designed and implemented locally/regionally in India over the past 10-15 centuries to meet the needs of the local people in an eco-friendly way (Sengupta, 1985). The three common traditional methods that exist in India are diversion channels (use of boulders and tree branches), small scale water bodies like irrigation tanks to store rainwater, and wells to collect groundwater. These methods are typically designed for small-scale/local (meant for a village) and large-scale/regional (basins) applications. The small-scale traditional irrigation methods (Ahar-Pynes, Bamboo drip, Cheruvu, Ramtek, Kuva etc.) are not only planned and constructed by the local people but are also managed by them locally, whereas the large-scale traditional irrigation methods are the surface or flood irrigation methods (basin, border, and furrows).

In the era of only traditional irrigation methods, there was no water scarcity as it was amply available with water table 3-5 m below the surface due to simple life-style for India's population of 350 million. As the population increases, the needs on the water increases for various purposes such as irrigation, domestic, hydro power, industrial, mining, recreation, etc. Though India has the largest irrigated area in the world, the coverage of irrigation is only about 40% of the gross cropped area (Narayanamoorthy, 2005). One of the main reasons for the low coverage of irrigation is the predominant use of traditional irrigation methods, which undergo low water use efficiency (WUE) of about 35-40% because of huge conveyance and distribution losses (Rosegrant et al., 2002).

Therefore, to increase the WUE and gross cropped area, new technologies have been implemented to improve the traditional styles of irrigation India. One of the significant technological revolutions is by using poly vinyl chloride (PVC) pipes for creating a network on the farm for carrying water from the source to different places, which results in 2-3 crops per year by using the same water quantity in traditional irrigation methods. This modern or microirrigation (MI) has given a ray of hope to reduce total dependence on most undistributed, uneven, and uncertained rain to irrigate the farms economically. Under MI (drip and sprinkler), unlike traditional irrigation methods, water is supplied at a required number of intervals and quantity using pipe network, emitters, and nozzles. Therefore, the conveyance and distribution losses are reduced completely, which results in higher WUE. Unlike traditional irrigation methods, drip supplies water directly to the root zone of the crop, instead of land, and therefore, the water losses occurring through evaporation and distribution are completely absent (Dhawan, 2002).

In India, drip has been in practice since the early seventies, whereas sprinkler has been used over the mid fifties (GOI, 2004). The scientists at the Tamil Nadu Agricultural University (TNAU), Coimbatore, who are considered to be the pioneers in drip irrigation research in India, have conducted large-scale demonstration in the farmers' field for various crops, which received encouraging response from the farmers (INCID, 1994). However, an appreciable improvement in the adoption of MI has taken place only from the eighties, mainly because of various promotional programs introduced by the Central and State governments. Apart from the government efforts, some research institutes and private drip manufactures have also been playing an important role in promoting MI in India. For instance, the 'Jain Irrigation Systems Ltd., Jalgaon' has been playing a pioneering role since its inception in 1989 for promoting MI.

The post-independence percent (%) area under irrigation, i.e. during 1950, 1960, 1970, 1980, 1990, 2000, and 2010 are 18.1, 19.1, 24.1, 29.7, 35.1, 43.4, and 47.5, respectively (Dept. of Agriculture and Cooperation, Agricultural Census Division, 2010). It is observed that the irrigated area gained kinetics of growth from 1970's, with the initiation of MI. However, a closer look reveals that it took 40 years (1950 to 1990) to double the acreage of land under irrigation. The speed picked up for irrigation since then is impressive. Though remarkable growth has been achieved over the last 15 years in adopting MI, its share to the gross irrigated area of the country is only negligible percent as of today. Further, out of the 69 Mha net irrigated area in the country, only 0.5 Mha under drip and 0.7 Mha under sprinkler has been achieved (GOI, 2004). Maharashtra has 46% of the highest area under drip in the country. Karnataka, Tamil Nadu, and Andhra Pradesh follow with percent-

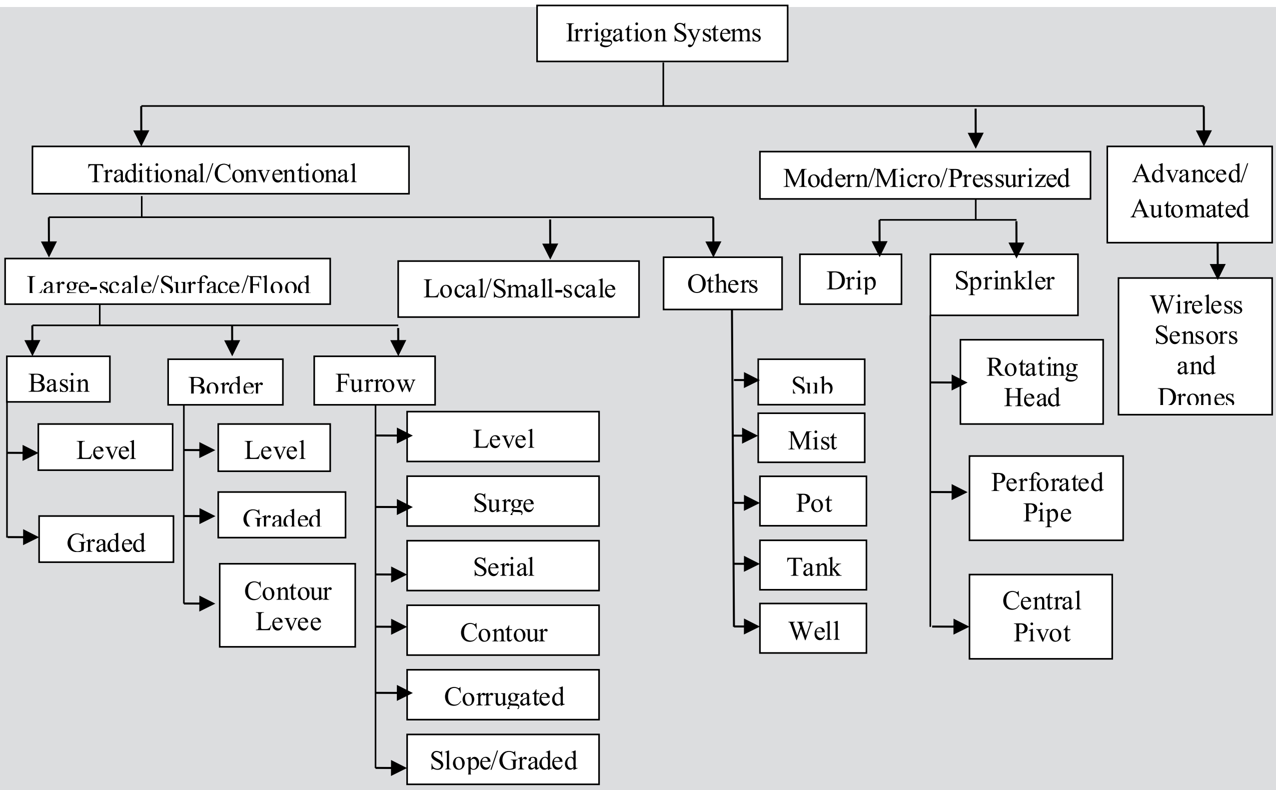

Fig. 1 Different types of irrigation methods in India

Table 1 Traditional irrigation methods in India according to terrain

Eco-zone	Structures
Trans Himalayan	Water from melting snow and ice is the only source of water
Western Himalayas	Canals to collect water from hill streams, springs, and melted snow
Eastern Himalayas	Bamboo pipes are used to divert the streams water for irrigation
Northeastern Hill Ranges	Rainfall & groundwater are main sources of water in natural springs
Brahmaputra Valley	Floodwaters accumulate in natural depressions are used
Indo-Gangetic Plains	Rivers and their floodwaters are the main source of water
Thar Desert	Rainwater was captured and stored in ponds and underground tanks
Central Highlands	Irrigation by wells and tanks is very common in this region
Deccan Plateau	Wells, embankments across rivers & streams, reservoirs and tanks
Western Ghats	Horizontal well in hard laterite rock formations
Western Coastal Plains	Shallow wells in low depressions to yield sweet potable freshwater
Eastern Coastal Plains	Ponds in areas of waterlogging, floods or saltwater ingress
Islands	Wooden bunds to collect water in the pits through split bamboos

age areas of 21%, 14%, and 12%, respectively (Report of the Task Force on Irrigation, 2009).

Among the various reasons for the slow progress of adoption of this MI, its capital-intensive nature seems to be one of the main deterrent factors. MI requires a fixed investment that varies from Rs. 20,000 to Rs. 55,000 per hectare depending upon the nature of crops (wide or narrow spaced) and the material to be used for the system. Government of India has taken an initiative to give a subsidy of 30-90% to the farmers in order to popularize this method. The subsidy is channelized through the 'National Committee on Plasticulture Application in Horticulture', which sponsors precision farming development centers all over the country for conducting research, demonstration, and training for disseminating the benefits of MI among the farming community.

There are many irrigation methods, achieving water savings in agricultural crops, from traditional and modern to more technologically advanced/automated/smart ones. Present day agriculture requires automated and advanced irrigation methods to optimize the water usage in farming (Ojha et al., 2015). The alarming reduction of ground water level is another motivation for the requirement of an automated method. In this context, MI techniques are cost-effective and water-usage efficient. However, MI efficiency can be further improved with the wireless sensor networks (WSNs) and drones as a coordinating technology.

Irrigation methods

Various types of irrigation methods differ in how the water obtained from the source is distributed within the field with a goal to supply the entire field uniformly with water, so that each plant has the amount of water it needs, neither too much nor too little. The different types of irrigation methods used in India are depicted in Fig. 1.

Local traditional irrigation methods

The design and structure of each local tradition irrigation method are decided by the terrain and rainfall pattern of the region. Hence, irrigation in each ecozone of India had unique techniques of traditional method. Table 1 highlights some of the representative local structures being practiced in different regions across the country. On the hill and mountainous regions, simple engineering structures are used to divert the water into channels as there are plenty of streams, whereas in semi-arid and arid regions, diversion channels are used to lead the water to a storage structure as there streams are seasonal. Several unique systems are built to control the flood waters and saline water in flood plains and coastal areas, respectively. In areas of good groundwater aquifers, dug wells with innovative methods are used to lift the water and in the scarce rainfall areas, people are devised to use methods that 'catch each and every drop of rainwater where it fell'. These traditional irrigation methods have made life possible, even in the Thar Desert.

Surface/Flood irrigation

In this method, water moves over and across the land by simple gravity flow in order to wet it and to infiltrate into the soil. This is the most common method used over worldwide, where water control is manual and therefore, it induces large variations in volumes of water applied per unit area. Under such situation, moisture distribution is uneven and deep percolation is unavoidable. Surface irrigation can be subdivided into the furrow, border/strip, and basin irrigation.

Basin irrigation

It is the most common method and in this method, the field is divided into small units which are surrounded by small levees or dikes to prevent runoff. This method is not suitable for all crops and soils, but it is generally favored by moderate to slow intake soils, deep-rooted, and closely spaced crops that are unaffected by standing water like rice for long periods. Trees can also be grown in basins are called as check basins. Level and graded basins are a variant of basin irrigation, where the field is divided into a number of terraced rectangular bays which are graded level or have no significant slope.

Border irrigation

Border or bay irrigation can be viewed as an extension of basin irrigation to sloping, long rectangular or contoured field shapes, with free draining conditions at the lower end. Irrigation water can be fed to the border in several ways: opening up the channel bank, using small outlets or gates or by means of siphons or spiles. A sheet of water flows down the slope of the border, guided by the bunds on either side.

Furrow irrigation

Furrow irrigation avoids flooding the entire field surface by channeling the flow along the primary direction of the field using 'furrows', 'creases', or 'corruga-

Table 2 Classification of sprinkler irrigation system

Sprinkler type	Description
Based on arrangement for spraying irrigation water	
Rotating head	Most common device to rotate the sprinkler heads is with a small hammer activated by the thrust of water striking against a vane connected to it. It is best suited for larger areas with small amounts of water over a longer period of time.
Perforated pipe	Consists of drilled holes or nozzles along their length through which water is sprayed under pressure. This system is usually designed for relatively low pressure (1 kg/cm^2) and he application rate ranges from 1.25-5 cm/hr.
Center pivot	This is a form of overhead irrigation. Steel or aluminum pipes are joined together, supported by trusses, mounted on wheeled towers. The sprinklers are situated on the length of the tower and they move in a circular motion.
Based on portability	
Portable	Consists of portable main lines, laterals, and pumping plant.
Semi portable	It is similar to a portable system except that the location of water source and pumping plant is fixed.
Semi permanent	It has portable lateral lines, permanent main lines, and sub mains and a stationery water source and pumping plant.
Solid set	It has enough laterals to eliminate their movement. The laterals are positions in the field early in the crop season and remain for the season.
Permanent	It consists of permanently laid mains, sub mains, and laterals and a stationery water source and pumping plant.

Table 3 Irrigation efficiencies (%) under different methods of irrigation (Sivanappan, 1998)

Irrigation efficiencies	Methods of irrigation		
	Surface	Sprinkler	Drip
Conveyance	40-50 (Canal) 60-70 (Well)	100	100
Application	60-70	70-80	90
Water use	35-40	80-95	
Surface water moisture evaporation	30-40	30-40	20-25

tions'. Water infiltrates through the wetted perimeter and spreads vertically and horizontally to refill the soil reservoir. The crop is usually grown on the ridges between the furrows. This method is suitable for all row crops. In different situations, different furrow methods are used such as slope, leveled, contour, serial, and corrugated. Surge Irrigation is a variant of furrow irrigation where the water supply is pulsed on and off in planned time periods.

Sub-irrigation

Sub-irrigation or seepage irrigation is used in field crops with high water table areas. It is a method of artificially raising the water table to allow the soil to be moistened from below the plants' root zone. Often these methods are located on permanent grasslands in lowlands or river valleys and combined with drainage infrastructure.

Mist irrigation

This type of irrigation is a prerequisite for tissue culture derived crops during a primary hardening stage, where the plantlets were indeed tender and require a higher humidity level to overcome 'heating'. Misting is helping in delay maturation, arrest over-sweetening, overcome heat stress under scorching period, and retains the freshness.

Pot irrigation

This method is more suitable for areas having scanty rainfall and saline areas, where surface irrigation is not suited. An earthen pitcher is used in this method. Holes are made in the pitcher and water is filled in it so that seepage of water through the holes keeps the nearby soil moist. This method can be considered as an alternative of drip irrigation method.

Tank irrigation

Tanks are small reservoirs with earthen walls, used for storing water diverted from a stream or runoff during the unpredictable monsoon rains having a wide diversity of distribution. Tank irrigation in India is concentrated in coastal Tamil Nadu and Andhra Pradesh, south central Karnataka, Telangana and eastern Vidarbha, north eastern Uttar Pradesh, and Aravalli mountains (Rajasthan). There exist about 1,60,000 temporary tanks in the three southern states of Tamil Nadu, Karnataka, and Andhra Pradesh and many more in other states. Under the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), the government has taken an initiation to make them as permanent tanks (Gover et al., 2013).

Well irrigation

Well irrigation is popular in those areas, where there is a plenty of groundwater resources. Traditional well irrigation methods use the 'Rahat' (known as Persian wheel) for lifting water. Many of these methods, however, are becoming extinct in north-eastern states due to the modern methods implemented by the government (CE IIT Kharagpur, 2011).

Modern or microirrigation

A frequent application of required and measured quantity water directly on or below the soil surface near the root zone of plants is achieved through this type of irrigation. Water is applied as continuous drops, tiny streams, or fine spray through emitters placed along a low-pressure delivery system. Such system provides water precisely to plant root zones and maintains ideal moisture conditions for plant growth. It is the latest and most efficient method of water utilization for crop growth and has high water use efficiency up to 70-75%.

The basic types of microirrigation system are as follows:

Surface system: It is the system in which emitters and laterals are laid on the ground surface along the rows of crops. The emitting devices are located in the root zone area of trees.

Subsurface system: It is a system in which water is applied slowly below the land surface through emitters. Such systems are generally preferred in semi permanent/permanent installations.

Bubbler system: In this system the water is applied to the soil surface in a small stream or fountain. These are suitable in situations where large amounts of water need to be applied in a short period of time and suitable for irrigating trees with wide root zones and high water requirements.

Micro and mini sprinklers: These are small plastic sprinklers with rotating spinners. The spinners rotate with water pressure and sprinkle the water.

Pulse: Pulse system uses high discharge rate emitters and consequently has short water application time. The primary advantage of this system is a possible reduction in the clogging problem.

Biwall: It is extruded dual chamber microirrigation

Table 4 Comparative performance of traditional irrigation with microirrigation

Performance indicator	Traditional irrigation methods	Microirrigation
Water saving	Waste a lot of water. Losses occur due to percolation, runoff, and evaporation	40-70% of water can be saved. Runoff and deep percolation losses are nil or negligible
Labour saving	Labour engaged per irrigation is higher	Labour required only for the operation and periodic maintenance of the system
Weed infestation	Weed infestation is very high	Less wetting of soil and weed infestation is very less or almost nil
Saline water use	Concentration of salts increases and adversely affects the plant growth.	Frequent irrigation keeps the salt concentration within the root zone below harmful level
Diseases and pest problems	High	Relatively less because of less atmospheric humidity
Suitability in different soils	Deep percolation is more in light soil and with limited soil depths. Runoff loss is more in heavy soils	Suitable for all soil types as flow rate can be controlled
Water control	Inadequate	Very precise and easy
Fertilizer use efficiency	Low because of heavy losses due to leaching and runoff	Very high due to reduced loss of nutrients through leaching and runoff
Soil erosion	High because of large stream sizes	Less due to partial wetting of soil surface and slow application rates
Crop yield increase	Non-uniformity in available moisture, reducing the crop yield	15-150%

Table 5 Advantages and disadvantages of various irrigation systems

Irrigation Method		Advantages	Disadvantages
Flood or Surface	Basin	Less investment; Beneficial for more trees; Water covers the basin rapidly to ensure good uniformity; Once the water is opened, it reaches other trees automatically.	Not useful for all crops; Wastage of water; Diseases spread in trees; Levees interfere with movement of farm equipment; Reduce the area available for cultivation.
	Border	Possible to irrigate more area at a lesser expenditure; Less labour; Easy and it causes lesser erosion.	Not suitable for all crops and soil compositions; Not possible to get balanced supply of water.
	Furrow	Large areas can be irrigated at a time; Saves labour; Comparatively cheaper method; Plants gets suitable quantity of water.	Wastage of water due to imbalance water flow; Not suitable in all types of crops; Due to filling of excess water, there is risk of underground salts coming up to the surface layer.
Micro or Modern	Drip	Water, chemical fertilizers, and pesticides saving by 30-70%, 30-60%, and 40-50%; Plant growth and yield enhanced by 20-40%; Minimum diseases and pest infestation; Uniform and better quality of produce; Less weed growth; Possibility of using saline water; No soil erosion; Saves land as no bunds are required.	Plants are able to get nutritive elements in a very limited area; Not suitable for every crop; Care has to be taken for holes of drippers; Animals may cause damage to branch and dripper pipelines; For sloppy land, pressure on valves increases by 50-10%, which results in stoppage of working of valves on the upper side.
	Sprinkler	Improvement of waste land; Ideal system when application rates are high and farms are large; Suitable to all types of soils except heavy clay; Higher elevated areas than source can be irrigated; Saves land as no bunds are required; Used for undulating area.	Expensive; Requires technical knowledge; Water should be clean; Requires higher water pressure to improve the reach of water over larger surface area and therefore not appropriate for smaller fields; Not suitable for slopping farms, degraded land, heavy soils and windy conditions.
Advanced	Wireless Sensors and Drones	Potential applications towards the goal of automation in agriculture, precision agriculture, automated irrigation scheduling, farmland monitoring, greenhouse gases monitoring.	Low battery power, Limited computation capability and small memory of the sensor nodes; Very high cost.

tubing manufactured from linear low density polyethylene. This system is suitable for all closely spaced row crops like sugarcane, cotton, vegetables, onion, tea etc.

Microirrigation components

The components of microirrigation system can be grouped into two major groups viz. head control unit and distribution network. The head control unit includes pump/overhead tank, fertilizer applicator, filters (gravel or media, screen, centrifugal, and disk), pressure relief valves, regulators, and check or non-return valves. The distribution network constitutes main line, sub-mains, laterals, and drippers (online pressure compensating or online non-pressure compensating, in-line, adjustable discharge type, vortex type, and micro tubing of 1-4 mm diameter), and other accessories (takeout/starter, rubber grommet, end plug, joints, tees, manifolds etc). In addition to above components, the microirrigation system consists of fertigation and chemigation equipment such as by-pass pressure tank, venturi system, and direct injection system to apply soluble fertilizers and other agrochemicals (herbicides and pesticides) with irrigation water.

Drip irrigation

In this irrigation system, a precise amount of water equal to the daily consumptive use or the depleted soil water is applied at frequent intervals in the form of water droplets through perforations in plastic pipes or through nozzles attached to tubes spread over the soil to irrigate a limited area around the plant. The basic equipment for drip irrigation consists of a water pump, main PVC, pipeline, branch PVC, plastic pipes, drippers, fertilizer tank, valves, water measure, pressure controller, filter etc. Drip irrigation is ideally suited for horticulture crops such as pomegranate, grapes, mango, banana, guava, coconut, amla, and cash crops such as sugarcane.

Sprinkler irrigation

In the sprinkler method of irrigation, water is sprayed into the air and allowed to fall on the ground surface somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping. With careful selection of nozzle sizes, operating pressure, and sprinkler spacing the amount of irrigation water required to refill the crop root zone can be applied nearly uniform at the rate to suit the infiltration rate of soil. The components of a typical sprinkler system are a pump unit, tubings (main/sub-mains and laterals), couplers, sprinkler head, and other accessories such as valves, bends, plugs, and risers. Sprinklers are classified as rotating head, perforated pipe, and center pivot based on the arrangement of spraying irrigation water and portable, semi portable, semi permanent, solid set, and permanent based on the portability (Table 2).

The comparative irrigation efficiencies under different methods of irrigation are given in Table 3. The MI has surely a number of advantages over the traditional irrigation methods like border, basin, and furrows, which is depicted in Table 4 and Table 5.

Advanced or automated irrigation

At present, labor and water-saving technology is a key issue in irrigation. The main aim of using the advanced or automated irrigation system is to make a precision irrigation by optimizing water use for agricultural crops. In this system, different transmitters (sensor, Bluetooth, radio-frequency identification (RFID), wireless local area network (WLAN), 3rd Generation Partnership Project (3GPP), WiMAX (Worldwide Interoperability for Microwave Access), ZigBee) sense the in-field soil moisture, temperature, and various climate data and send them to the base station (BS). In a BS, a computer is connected to the Internet and the irrigation control unit gets the decision or control signal processed by the software resides in the BS. The irrigation control units send the position of the irrigation system (e.g., sprinkler or drip) using the 'global positioning system' receiver to the BS for the real time monitoring. The BS sends again control signals to the irrigation control station to operate the sprinkler/drip based on the water requirement of the fields. In this context, a number of studies have been carried out by using automated sensor-based irrigation systems (Shock et al., 1999; Damas et al., 2001; Evans and Bergman, 2003; Miranda et al., 2005; Wall and King, 2004; Kim et al., 2008; Xiong et al., 2009; de Lima et al., 2010; Jaria and Madramootoo, 2011; Sudha et al., 2011; Dhivya et al., 2012; Pravina et al., 2015), thereby permitting the farmer to better and more precisely schedule drip and sprinkler irrigation applications.

In addition to the above wireless sensor networks, there is much boom to capitalize the use of nanotechnology and biotechnology in MI. The soil moisture sensors designed using these technologies are called as 'Nano based bio-sensors', which can recognize, measure, and monitor the presence of contaminants in filtration units and help in emitter clogging reduction.

In spite of the fact that advanced/smart irrigation systems are environmentally feasible, but very less studies seems to have attempted to use the drone technology, which is going to experience an explosive growth in near future. Drones are low-cost, can fly at low heights and capture images in all resolutions needed to assess photosynthesis rates and crop damage. They are even better than satellites and remote sensing when it comes to avoiding cloud cover and have higher frequency images. According to some projections, about 80-90% of the growth in the drone market in the next decade will come from agriculture. At present, the application of the drone or Unmanned Aerial Vehicles (UAVs) technology is popular only in the military for remote surveillance. However, in the last decade, researchers have begun using them to monitor their fields as well as aiding precision agriculture programs (Chao et al., 2008). However the challenge lies with these innovations is in transferring the research into practice. There are currently some limits in drone usage in several applications. Improved cost-effectiveness, availability, and informed management will help in adopting these promising technologies in today's farm fields for agricultural and irrigation use.

Concluding Remarks

Agriculture being the major user of water, which consumes more than 80% of water resources of the country, besides reliance on rain-fed irrigation, gradually surface or flood irrigation is being replaced by sub-surface (drip/sprinkler/mist) microirrigation, which has inherent capacity to double the acreage under irrigation, without loss to agri-output. By experience, the farmers have also got educated that flood irrigation largely employed in sugarcane, rice and banana cultivation has rendered soil saline and less productive over the years. The demand for water has been consistently increasing from various sectors like municipal use, industry etc. and such use can often be at the cost of agriculture. To increase the production of crops for feeding the world population with dwindling water resources is a challenge. The conventional method of irrigation has not been as efficient in use of water, thus resulting in excessive wastage besides creation of problems in many regions by thorough water logging and salinity. Therefore, judicious use of water is vital to achieve higher productivity in a sustainable manner. Modern system of irrigation like microirrigation and smart irrigation using wireless sensor networks enhance the water use efficiency and productivity without injurious effects on soil health. Everything said and done, the ultimate success of farming depends on farmer's wise choice of choosing appropriate irrigation method.

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