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15. Water Management Innovation for Sustainable Farming

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Abstract:

Worldwide, water is regarded as the most important resource for the development of sustainable agriculture. In the upcoming years, there will be a rise in irrigated areas as freshwater resources are diverted from agriculture to fulfill the growing demands of industry and home consumption. Moreover, the effectiveness of irrigation is quite low, as the crops utilize less than 65% of the water that is applied. For agriculture in arid regions, conserving irrigation water is essential. Therefore, a great deal of work has been done over the years to adopt policies aiming at increasing water efficiency under conditions of scarcity and climate change, with the premise that better management may achieve more with less water. Improved irrigation water efficiency and/or water allocation are typically referred to as better management. While the latter is contingent on the type of irrigation technology, environmental factors, and water application schedule, the former is intimately linked to appropriate pricing.

Keywords:

Water, Sustainable farming, Resources, Environment, Population.

15.1 Introduction:

One of the most important resources for humanity is fresh water. In India, with the current shifts occurring in many different areas, its significance is considerably greater. India's diversified environment, growing population, and intricate socioeconomic structure make water management a crucial and challenging task. Sustainable water management is now essential to guaranteeing both water security and environmental sustainability, as the needs of agriculture and fast urbanization are placing an increasing strain on available water supplies.

The natural system's quantity and quality are currently under stress due to the fast expansion of irrigation agriculture, industrial development, population growth, and climate change. Man has started to realize that he can no longer use water resources or any other natural resource in a "use and discard" manner due to the growing challenges. This has made it clear that a consistent policy of sensible water resource management is required. Over the past century, the amount of land under irrigation worldwide has expanded more than six times, from about 40 million hectares in 1900 to over 260 million hectares (Postel, 1999; FAO, 1999).

Currently, the 18% of cropland that receives irrigation provides 40% of the food consumed worldwide. According to Jensen (1993), the area under irrigation grows by nearly 1% annually, and by 2025, the demand for irrigation water is expected to rise by 13.6% (Rosegrant and Cai, 2002).

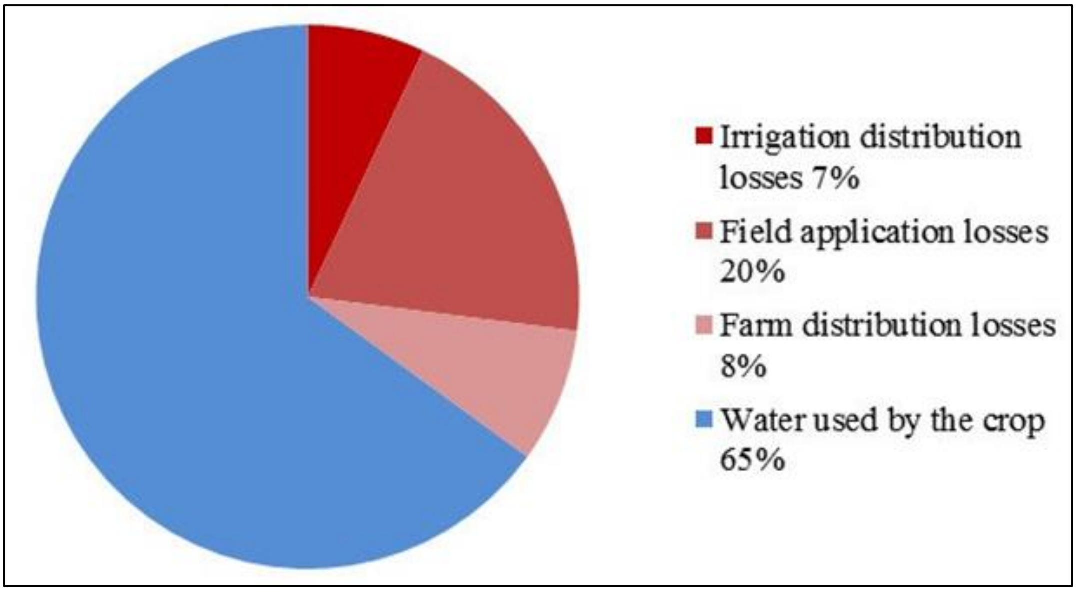

Figure. 15.1 Water Losses in Agriculture

A growing number of well-known businesses have already started water stewardship programmes to lessen the "water footprint" of their goods and services. Diffuse freshwater mitigation measures in the agriculture sector include the use of organic or biofertilizer during farming operations, as well as drip or deficit irrigation (Aivazidou et al., 2020 and Rodias et al.,2021). Water-efficient machinery and wastewater treatment enable the manufacturing sector to decrease freshwater consumption and pollution (Aivazidou et al., 2015). Notably, in areas at high risk of water scarcity, the use of treated industrial or urban wastewater in agricultural operations has been gaining traction (Wang, 2021 and Minhas et al., 2022), in keeping with the circular economy concept that promotes waste reduction through resource recycling. Simultaneously, monitoring water use and leaks in residential and/or industrial infrastructures could improve freshwater sustainability at the urban level (Gautam, 2020).

A. Water Scarcity:

Life cannot exist without water, which is a necessary resource. However, the amount of fresh water in the world is drastically decreasing annually as a result of industrialization, agriculture, and population growth. A sizable, populated area has experienced severe water stress, and some of the places have turned into deserts. Owing to its significance and need for prompt action, the United Nations (UN) has categorised the water crisis and its remedies under Sustainable Development Goal (SDG) 6: guaranteeing universal access to potable water and sanitary facilities.

Over two billion people live in countries with inadequate water supplies; half of the world's population may live in areas facing water scarcity as early as 2025; more than 700 million people may be displaced by intense water scarcity by 2030; and by 2040, nearly one in four children worldwide will be living in areas of extremely high-water stress, according to UNICEF and the world water development report of the UN.

15.2 Water Saving Techniques:

15.2.1 Optimum Groundwater Withdrawn:

The main factor contributing to groundwater depletion is ongoing groundwater pumping. The following are a few detrimental effects of groundwater depletion:

- Wells drying up
- A decrease in water in lakes and streams
- Deterioration of water quality
- Increased pumping costs
- Subsidence of the land

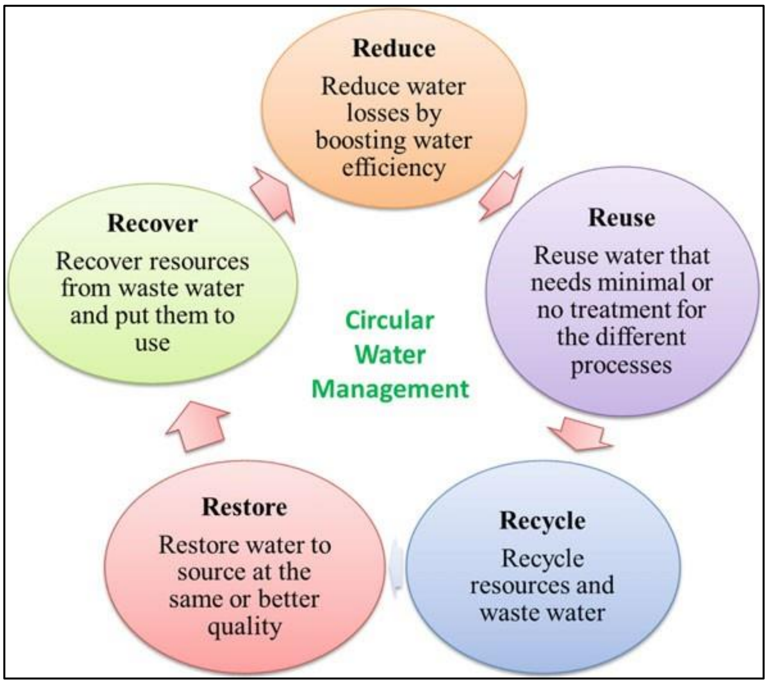

Figure 15.2: Circular water management for sustainable use. (*Source* World Business Council for Sustainable Development, 2017)

Though challenging to manage, groundwater abstraction has shown to be an essential source of readily available agricultural water. Consequently, in significant cereal-producing regions of high-, middle-, and low-income countries, locally intense groundwater withdrawals exceed natural replenishment rates. Depleting aquifer levels and ongoing nonrenewable groundwater abstraction represent a growing hazard to the local and global food supply because many important regions for food production depend on groundwater (Dubois 2011).

Approximately 40% of irrigated area today uses groundwater either as a primary source or in conjunction with surface irrigation, indicating the fast-increasing use of groundwater for irrigation. Multilevel stakeholder engagement across land and water systems may significantly increase water productivity and lessen stress by increasing allocation efficiency among sectors and implementing technology and a governance framework that support efficient water use. Two examples are groundwater management and community-based irrigation.

15.2.2 Rainwater-Harvesting:

A simple method for gathering and preserving rainwater for later use is called rainwater harvesting. Artificially constructed systems are used to collect and store rainwater from natural or man-made catchment areas, such as rooftops, apartment buildings, rocky surfaces, hill slopes or purposefully restored impermeable or semi-pervious land surfaces.

Rainwater collected from surfaces that experience precipitation can be stored, filtered, and utilised in a number of ways, or it can be used right away to refuel. Impurities limit rainwater collecting, which also has a reduced cost of storage and requires little upkeep save the odd cleaning. This strategy can help lessen the negative effects of increasing water shortages because of declining groundwater levels and shifting climate conditions.

Rainwater conservation may help restore aquifers and rivers, lessen urban flooding, and—most importantly—provide access to water in places where water is limited.

Rainwater harvesting has the following benefits:

a. Provides water for additional irrigation.
b. Lowers groundwater withdrawals.
c. Saves energy and money for pumping groundwater.
d. Has an ecological advantage
e. Lessens soil erosion and flooding.

A. Methods of Collecting Rainfall

a. Surface Runoff Harvesting:

With this method, surface runoff rainwater is gathered and stored for later use. Surface water can be collected by redirecting the flow of small creeks and streams into underground or surface reservoirs. It can provide water for domestic use, livestock, and farming. Surface runoff collecting is the ideal solution in urban areas. Rooftop rainfall and storm runoff in urban areas can be collected using a variety of techniques, including recharging trenches, recharge pits, tubewells, and recharge wells.

b. Groundwater Recharge:

Water moves from surface to groundwater through a hydrologic process called groundwater recharge. The most frequent method of water entry into an aquifer is recharge. The aquifer serves as a distribution mechanism in addition. After then, the extra precipitation might be utilised to replenish the groundwater aquifer by artificial recharge methods. Gully plugs, contour bunds, percolation tanks, check dams, recharge shafts and dugwell recharge are a few techniques that can be used to collect rainfall in rural areas.

15.2.3 Watershed Management:

Considerable progress has been made in the last several years in comprehending the relationship between basin hydrology and on-farm irrigation. Consequently, more individuals are coming to understand that farm irrigation losses aren't always losses in the basin. This is because runoff and deep percolation losses from one farm enter the general drainage network of the basin and can be recovered as part of the water supply of another farm downstream.

Therefore, if water conservation is the goal, approaches for improving irrigation water usage efficiency must first take the nature of the potential water savings into account. Irrigation losses are therefore at least partially recoverable within a basin. Reducing irrecoverable water losses leads to a net reduction in the amount of water consumed in the basin. The methods employed to lower recoverable losses won't decrease the requirement for basin water and might have an impact on the water supplies of downstream consumers. The results of an investigation of irrigation water use in the Western United States (Interagency Task Force Report 1979) provide as an example of the importance of these differences. The goal of the project was to determine whether a range of irrigation efficiency and water conservation techniques, both on and off farms, may assist lower the amount of water required for irrigation.

15.2.4 Reduce Water Losses from Field:

Water balance equation can be written as:

$$(\Delta S + \Delta V) = (P + I + U) - (R + D + E + T)$$

Whereas ΔS = Water held within the root system

ΔV = amount of water that the vegetation has stored

P = precipitation

I = irrigation

U = Upward water capillary flow into root zone

R = runoff

D = drainage out from the root zone

E = evaporation from the soil surface

T = plant transpiration

The volume of water per unit area is used to estimate all of the water quantities in the field water balance.

A. Lowering the Soil's Rate of Evaporation:

When soils are wet, evaporation rates are often high and are correlated with sun energy incident on the surface. Due to restrictions on soil water movement to the surface, evaporation rates drastically decrease as soon as the soil surface dries out, usually within one or two days. The primary factor influencing evaporation loss is the amount of radiant energy that strikes the soil surface. Therefore, in situations where crop cover is poor, such as in the early stages of crop development when soil is often wetted by irrigation or rain, evaporation rates may be considerable. When the crop canopy entirely covers the ground, there may be little to no evaporation—perhaps 10% of evapotranspiration (ET) or less. When averaged across a season, evaporation can account for a sizable portion of ET, particularly in crops that are rainfed, where there is little growth and the soil is exposed for a large portion of the growing season. Conversely, high rates of growth under irrigation reduce field crop seasonal evaporation values to a mostly inevitable percentage of 20–35% of ET. Unlike other irrigation methods that saturate the entire ground surface, drip irrigation lowers soil evaporation. Drip irrigation reduces evaporation, which helps young orchards preserve vital water; but large field crops cannot be watered with this method. A study comparing drip and furrow irrigation in processing tomatoes showed that, even if drip irrigation were cost-effective, evaporation savings in row crops would be negligible or nonexistent (Pruitt et al. 1984). In an olive grove, the potential evaporation savings from converting from surface to subsurface drip irrigation are less than 7% of the seasonal irrigation depth, according to Bonachela et al. (1999). Such savings may be substantial in water-scarce places, but they are typically inadequate to justify switching irrigation techniques.

B. Lowering Losses in Irrigation Systems:

Numerous irrigation technologies and procedures that can increase irrigation efficiency while lowering losses from runoff and deep percolation have been produced by science and technology. Design guidelines for minimal loss surface irrigation systems have been made possible by recent developments in surface irrigation optimization. There is a variety of sprinkler and drip systems with great potential efficiency and uniformity available if soil heterogeneity and geography render surface systems impracticable. Because of this, there are numerous technical options available to address the majority of irrigation-related issues on a field-by-field basis. Optimising the design and operation of current surface irrigation systems may need modifications to land consolidation, water delivery techniques and flows, and distribution network design and operation. Such improvements require the cooperation of many users as well as monetary inputs. In order to incorporate pressurized systems into community irrigation networks, additional physical infrastructure changes are necessary (reservoirs). Consequently, financial resources and incentives must be made accessible at the very least in order to carry out the necessary changes that would increase the system's potential efficiency and uniformity. Prior to applying strategies to reduce irrigation system losses, one must comprehend the potential net water savings. Significant limitations in science and technology have made it challenging to quantify water sources and sinks at the district and basin levels. New technology advances based on modelling, remote sensing, and GIS have made it possible to quantify irrigation return flows and the effects of different on-farm conservation methods on net water savings and environmental implications at the basin level.

15.3 Sustainable Water Management in Agriculture:

In agriculture, sustainable water management strives to balance water availability and demands in terms of quantity and quality, space and time, fair cost, and acceptable environmental impact. Adoption is impacted by issues with technology, rural communities' social dynamics, financial limitations, institutional and legal frameworks, and agricultural practices. Irrigation scheduling, or when and how much water to apply, has received the greatest attention under water demand management, with irrigation methods, or how to apply the water in the field, receiving less attention. Numerous factors, such as the crop's growth stage and susceptibility to water stress, the climate, and the amount of water in the soil, influence when irrigation is necessary, or the "frequency" of irrigation. But since the irrigation technique affects this frequency, there is a relationship between irrigation scheduling and irrigation technique.

A. Localized Irrigation:

It is often acknowledged that one of the best ways to irrigate crops is through localised irrigation (Keller and Blienser, 1990). Water is applied to individual plants using miniature sprayers or drip or trickle irrigation systems, which use plastic pipes that are typically placed on the ground. With drip irrigation, water is gradually delivered via tiny emitter apertures from plastic pipes at a discharge rate of no more than 12 litres per hour. Irrigation water is sprayed at a discharge rate of 12 to 200 l/h over the area of the soil surface that is occupied by the plant using a micro-sprayer (micro-sprinkler). The primary objectives of localised irrigation are to apply water directly into the root system when there is a high availability of water, prevent water loss during or after water application, and lower the cost of water application (less labour).

B. Irrigation scheduling:

The practice of choosing when and how much water to use to irrigate crops is known as irrigation scheduling. It is the only way to maximise agricultural output while conserving water, and it is essential to enhancing irrigation systems' sustainability and performance. The appropriateness of the irrigation technique dictates the precision of the amount of water to apply, while a thorough understanding of the crops' water needs and the properties of the soil is necessary to decide when to irrigate. The majority of the time, a farmer's skill level dictates how successful irrigation scheduling is at the field level. The optimum soil water conditions for plant growth are created, waterlogging is avoided, less water is used (saving water and energy), deeper percolation and the transport of fertilizers and agrochemicals out of the root zone are controlled, higher yields and better quality are obtained, and rising salinity of the water table is avoided with proper irrigation scheduling. Irrigation scheduling is more crucial in areas with limited water resources than it is in areas with plenty of it, as any overuse of water could result in shortages for other users or purposes.

The methods and equipment used for irrigation scheduling are very diverse in terms of their usefulness and efficacy. In order to determine the timing and depth parameters for irrigation scheduling, several methods based on plant stress indicators, soil water balance calculations, and soil water measurements can be combined with very basic rules or complex models (Huygen et al., 1995). Many of them still have use in research or require more work before being put into practical usage. The majority of them call for technical assistance from extension agents, extension initiatives, and/or the farmers' technological know-how.

However, the majority of countries lack these programmes due to a number of factors, including high costs, a shortage of experienced extension agents, a lack of farmer understanding regarding irrigation water conservation, and a low priority placed on farm systems by institutional mechanisms designed for irrigation management. As a result, there are typically significant restrictions on their use in farming practices. The following provides a concise overview of irrigation scheduling methods along with an analysis of their efficacy and suitability.

C. Soil Water Estimates And Measurements:

Plant water status is regulated by soil water, which has a direct impact on plant growth. Measuring the soil water content and the degree to which that water is retained in the soil (soil water potential) are the two methods available for determining the availability of soil water for plant growth. Due to the variability of soil water in both space and depth, the accuracy of the data depends on the sampling techniques used and the locations chosen for point observations (Peymorte and Chol, 1992). Soil look and feel, soil water content measurement (TDR), soil water potential measurement (tensiometers, soil spectrometers, and pressure transducers), and remotely sensed soil moisture are among the soil water estimates and measures used for irrigation scheduling.

D. Crop Stress Parameters:

It is feasible to receive a signal from the plant itself specifying the irrigation time but not the irrigation depths, in place of measuring or estimating the soil water parameters. This message may originate from the canopy as a whole or from specific plant tissues, where an accurate sample is necessary. Crop stress parameters are therefore helpful in situations where irrigation depths are preset and maintained throughout the irrigation season.

According to Deumier et al. (1996), Idso et al. (1981), Jackson et al. (1981), Itier et al. (1993), variations in stem or fruit diameter, sap flow measurement, canopy temperature, and leaf water content and leaf water potential are examples of agricultural water stress parameters.

E. Climatic Parameters:

For irrigation projects, whether local or regional, climatic criteria are commonly employed. Utilised are meteorological data and empirical equations that, after local calibration, yield precise estimates of reference evapotranspiration (ETo) for a specific region. Next, crop coefficients that are appropriate are used to estimate crop evapotranspiration (ETc). Data can be analysed in real time or, more frequently, by utilising past information. These methods include remote sensing ET, evaporation measurements for ETo computation, and crop evapotranspiration assessment utilising meteorological data (air temperature, RH, wind speed, sunshine hours) (Allen et al., 1998).

D. Soil – Water Balance:

AWC is the available water content. The goal of the soil water balance technique is to estimate the water content of the rooted soil using the following water conservation equation: Δ (AWC $\times$ Root depth) = Balance of entering + outgoing water fluxes. Sophisticated models use crop, climate, and soil water holding qualities data to generate typical irrigation calendars. This method can be used for small-scale farming as well as extensive regional irrigation projects. It does, however, require knowledge and backing from reliable extension services or connections to information systems. Its great efficacy is contingent upon advancements in farm technology and/or support services. Commercial software for scheduling irrigation based on the soil-water balance technique includes SIMIS (FAO, 1999b), MARKVAND, SALTMED (Ragab, 2002), IMS (Hess, 1996), and MARKVAND.

E. Effective Irrigation Scheduling:

It is acknowledged that better irrigation management performance, particularly at the farm level, should result from adequate irrigation scheduling. The depth or volume of irrigation as well as its time should be under the farmer's control. But the approaches and methodologies' actual use has fallen well short of expectations. Reliance on a group structure suggests limitations imposed by social, cultural, and legal norms.

The primary obstacles include inflexibility brought on by strict schedules or system limitations, unfeasible water pricing (price covering less than 30% of total cost), high labor and/or technology costs associated with irrigation scheduling, a lack of farmer education and training, institutional issues, behavioral adaptation, a lack of interactive communication between farmers, research, and extension, and, lastly, a lack of demonstration and technology transfer.

The ability of the collective system to physically deliver water in accordance with this schedule and the management's ability to operate the system effectively will determine the effectiveness of any irrigation scheduling method and the corresponding delivery schedule. A primary barrier to the efficient execution of crop-based and water-efficient irrigation scheduling is the majority of conveyance and delivery systems' incapacity to reliably and flexibly supply water to the farm gates. Water is accessible on demand in contemporary pressurized irrigation networks, yet discharges may be restricted for practical or financial reasons. Farmers have the liberty to choose and implement irrigation schedules that they deem better suitable for their crops and farming methods. Managers may, however, impose limitations on the amount of water distributed and/or impose fines for excessive water use in the event of a drought or low water supply.

F. Fertigation:

Fertigation, or the administration of fertilizers through irrigation, has become a standard procedure in contemporary irrigated agriculture. Fertigation is a good use for localized irrigation systems, which have the potential to be very effective for water application. Thus, the irrigation system provides soluble fertilisers to the wetted volume of soil at concentrations needed by crops. Inadequate irrigation design or operation may result in non-uniform chemical distribution; overfertilization may occur when irrigation is not based on actual crop requirements; and over usage of soluble fertilisers may be drawbacks.

G. Deficit irrigation practices:

Crop irrigation requirements in the past did not take the availability of water supply into account. The scheduling of irrigation was then determined by providing all of the crop's water needs. However, as urban and industrial water needs rise in arid and semi-arid countries, agricultural water allotment continuously declines. As a result, there is typically not enough water available to produce at maximum yields. For a more efficient and sensible use of water, irrigation systems that are not focused on the total crop water requirements should be implemented. Subsurface irrigation, partial root drying, and deficit watering are a few examples of these management techniques.

H. Regulated Deficit Irrigation:

An optimising technique called regulated deficit irrigation (RDI) permits crops to withstand a certain amount of water shortage and yield decline. The crop is subjected to varying degrees of water stress during controlled deficit irrigation, either for a specific duration or the whole growing season. The primary goal of RDI is to increase crop water use efficiency (WUE) by getting rid of irrigations that don't significantly affect yield. In order to deal with water scarcity, RDI is a sustainable solution because it allows for leaching requirements to deal with salinity, saves water, controls percolation and runoff return flows, and reduces fertiliser and agrochemical losses. Additionally, the optimisation approach makes RDI economically viable. Adopting deficit irrigation requires having the necessary information about agricultural ET, how crops respond to water shortages, particularly when to identify key growth stages, and how yield reduction techniques affect the bottom line.

I. Partial Root Drying:

A novel method of irrigation known as partial root drying (PRD) was initially used on grapevines, wherein half of the root system is irrigated and the other is exposed to dry or drying conditions. The root system's wet and dry sides switch every seven to fourteen days. In PRD, the balance between vegetative and reproductive growth is achieved by the biochemical reactions of plants to water stress. The vine's initial defence mechanism when water stress develops is to restrict its stomata to retain moisture. Abscisic acid (ABA) is one of the main substances that causes this reaction. After irrigation is stopped, the amount of water in the soil decreases, and the transpiration stream carries the ABA from the drying roots to the leaves (Loveys et al., 1999). In response, stomata narrow their opening, which limits the amount of water lost. Partial stomatal closure leads to an improvement in WUE. However, decreased photosynthesis is an inevitable result. This transitory reaction was overcome with PRD, which involved regularly alternating the wet and dry sectors of the root zone (Dry and Loveys, 1998).

L. Subsurface Drip Irrigation

Water is applied using subsurface drip irrigation (SDI), a low-pressure, low-volume irrigation technique that uses underground tubes. Through the soil matrix suction, the applied water exits the tubes. Water seeps out of the tube and travels in all directions through the earth.

Potential benefits of SDI include:

a. conserving water;
b. improving fertiliser efficiency;
c. applying water uniformly and highly efficiently;
d. eliminating surface infiltration issues and evaporation losses;
e. having flexibility in scheduling frequent, light irrigations;
f. reducing disease and weed problems; and
g. requiring less pressure to operate.

Nearly all crops, notably high-value fruits and vegetables, turf, and landscapes, can benefit from subsurface irrigation. The market offers a wide range of tubes, including porous tubes that leak water out of them all the way to PE tubes with emitters built right in. Installing the tube beneath the soil's surface involves either excavating ditches or using a specialized tool hauled by a tractor. The planting depth varies depending on the type of crop and the properties of the soil; it ranges from 15-20 cm for vegetables to 30-50 cm for tree crops.

15.4 Challenges and Opportunities:

- Climate change is one of the biggest issues facing the food and waterfront industries. The phrase "global climate change" describes how the earth's temperature is rising as a result of more greenhouse gases (GHGs) and carbon dioxide (CO2). Climate change is a factor that has intensified uncertainty about water availability, making it challenging to plan and schedule measures effectively (OECD, 2014).
- Natural resources are now at risk. India's agricultural sector is growing in an unusually vulnerable way. Annual changes in rainfall during the past century have contributed significantly to the annual variation in GDP growth in India. Serious concerns include the potential for irrigation as well as the sea level rise and the depletion of drinkable water. According to estimates, agricultural productivity is expected to decrease by 10–40% by 2080–2100 due to temperature increases (Hans, 2011; Hans 2012). The modern

green revolution is challenged by the Green House Effect.

- A new issue is emerging in numerous of the nation's coastal regions. Farmers have increased the horsepower of their motors as a result of sand mining, which has caused the water table to drop. This has had an impact on the cost and profitability of irrigation and crops (Selvakumar et.al, 2008).
- In order to effectively manage irrigation in India, Participatory Irrigation Management (PIM) and Water Users Associations (WUAs) have been proposed as the key initiatives. PIM involves an associate's farmers in the design, management, and upkeep of irrigation systems. Similarly, states are enthusiastic about the Irrigation Management Transfers (IMT) Programmers (Mahapatra, 2006). Farmers' increasing participation in water management has produced positive outcomes in terms of economics, efficiency, and equity.

15.5 Conclusion:

After outlining how water is used and managed, it is necessary to analyses the water resources, identify problems that arise from water use, and provide appropriate remedies. The following issues arise when water resources are being used. The management issues with water resources themselves are more evident because the supplies themselves are contaminated and their spatial distribution is unbalanced. The relevant governments must develop rules and regulations for the appropriate management of water resources, tighten technical regulation, limit certain irrational water usage circumstances, and promote the sensible use of water resources in order to address these issues. There is a great deal of promise for attaining resource conservation, environmental sustainability, and food security when modern farming and water resources engineering work together. For the agricultural and engineering communities to fully benefit from this integrated strategy and overcome current obstacles, more research, funding, and cooperation are required. By working together, we can pave the way for a time when water resource engineering and contemporary farming methods live harmoniously to maintain a robust and prosperous agricultural industry. Modern farming has revolutionized agricultural techniques by including water resources engineering, which ensures optimal water usage, environmental sustainability, and increased productivity.

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