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Enhancing Water Productivity under Climate Change Scenarios: Indian Perspective

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The scarcity of water has grown into a significant obstacle to ecosystem preservation, food production for the expanding population, and social security and health maintenance. Our ecology is also threatened by water logging and salinity in numerous canal commands, seawater intrusion along the coast, wetland drying up, low stream flows, etc. Water supplies have suffered as a result of climate change. The issue of water shortage and agricultural production are made worse by the regular occurrence of catastrophic events like drought and floods. The problems facing a large nation like India include the temporal and geographical variability of floods and droughts as well as the stark spatial differences in the growing irrigated area. The irrigated agro-ecosystem faces several obstacles. The new challenges confronting the country include geographic variations in groundwater development, low usage and filtration of wastewater for irrigation, poor irrigation efficiency, particularly for canal irrigation, and spatial disparities in the country's growing irrigated area. One of the best ways to establish a favorable water regime for improved crop development and production in a rainfed argo-ecosystem is to save rainwater in various land forms and use it effectively. The most difficult places to manage are those that are prone to flooding and waterlogging. However, a number of technologies are available to help with the difficulties. In broadest sense, water productivity reflects the objectives of producing more food, income, livelihoods and ecological benefits at less social and environmental cost per unit of water.

Keywords: Water productivity; water efficiency; rainfed and water-logged.

1. INTRODUCTION

“About 2.45% of the world's surface area, 4% of its water resources, and almost 17% of its people are found in India. At least 70% of all water withdrawals worldwide are used for agriculture, making it the largest user of water”. Managing and conserving water effectively is a difficulty for the country. India receives 1170 mm of rain annually on average. The uneven distribution of agricultural yield throughout time and geography is one of the primary problems. Of the 4,000 billion cubic meters (BCM) of water resources, 1123 BCM are thought to be usable (690 BCM surface water and 433 BCM groundwater sources). The average annual flow in all of India's river basins is 1,869 km3, according to calculations. There are now 324 BCM fewer useable water resources available than the 1447 BCM water demand predicted by 2050. In addition to agriculture, other sectors such as industry, energy, municipalities, etc., are also experiencing daily increases in demand. Therefore, it is necessary to identify and analyze the challenges in the agricultural water management sector and develop strategies to produce more with less water by efficiently using surface and groundwater in irrigated areas, safely use a portion of grey water for agricultural production purposes in a sustainable manner, and increase the productivity of agro-ecosystems that are challenged, such as rainfed and water-logged areas.

2. GROUNDWATER RESOURCES

Groundwater is an important part of India's economy. The country's groundwater table has dropped, springs and aquifers have dried up in a number of areas as a result of excessive groundwater consumption brought on by unchecked extraction (Sethi et al., 2022). The draft (245 BCM) and the annual replenishable groundwater reserve (433 BCM) account for around 62% of the net water available. 91% of this was due to irrigation. However, the effects on groundwater have not been uniform throughout the country. The situation is worrisome in places where groundwater extraction exceeds replenishment. At the moment, states like Haryana, Punjab, and Rajasthan consume more water annually than they replenish. According to many findings there will be a 50% increase in the need for water in agriculture by 2050 compared to 2013.

“Food and water security are the two greatest concerns confronting the globe now, and they are expected to get worse in the future mostly as a result of climate change” (Foley, 2011). “Global warming is predicted to result from climate change (CC), which is mostly caused by an increase in greenhouse gases (GHGs), during the course of the next century”. “Consequently, variations in mean climatic conditions may have a substantial impact on agricultural yield. However, under extreme climate change scenarios, the benefits of increasing CO_2 may change the future yield on the other hand. Ultimately, productivity could be altered through the enhancement of photosynthesis due to the fertilization effect of increasing CO2, especially of C3 plants" (P. Döll, 2002). "Crop water productivity (WP), or More crops per drop of water, may be a key strategy to solve both challenges. From the standpoint of water use, CO2 fertilization may increase crop WP by causing a lower rate of transpiration at the leaf, which may drastically change the amount of water needed for crop production". On the other hand, variations in rainfall patterns may also affect the crop fields' water balance. According to projections made by Döll (2002) and certain locations may see a decrease in irrigated water to compensate for soil-water scarcities and increasing seasonal rainfall, while other regions may experience the opposite.

"The majority of people in India are employed in agriculture, and the country has made significant progress in developing its water resources over the past 60 years. Modern agronomic practices combined with the expansion of irrigation systems have increased food grain production from a meager 51 million tonne in 1951 to over 315.7 million tonnes in 2021-22. Doubling land productivity in the next 40 years could help India meet most of its increasing food demand, which is expected to reach about 400-450 million tons by 2050" (Amarasinghe et al., 2017). However, "in contrast to forty years ago, water is also running out. Water is essential for agriculture as well as other uses by people and ecosystems. A water crisis and a higher danger of extinction for 20–30% of India's plant and animal species are among the negative effects of climate change. The latter occurs if world average temperatures rise over 1.5–2.5 degrees Celsius. Deforestation will have a more detrimental effect on water control due to climate change. When river flows fall to 15-20% below average, irrigation shortages develop, even though the Indus system is now strong enough to handle shortfalls of 10–13%" (Khan, 2009). Thus, variations in climate will have an impact on several aspects such as soil moisture, groundwater recharge, frequency of flood or drought episodes, and groundwater level.

In situations when water is more limited than land and other resources used in production, increasing crop water productivity is an important response strategy. A growing, wealthier, and more urbanized population places increasing demands on food, and improvements to agricultural water productivity—that is, the productivity of water used for crops, livestock, and aquaculture—help to meet those demands. At the same time, pressure to reallocate water from agriculture to cities and to make more water available for environmental uses adds to the urgency of making progress in agricultural water management.

3. WATER PRODUCTIVITY

The quantity of water required to produce a certain amount (or value) of produce is known as water productivity. Crop output divided by the sum of irrigation flow and rainfall is known as the water productivity per unit of gross inflow, or WPG. Water production may be measured, which makes it possible to record changes and promote quicker growth (Amarasinghe et al.,

Table 1. Projected water demand in India for different sectors

Table 6.1.1 Projected Water Demand in India (By Different Use)

Sector	Water Demand in BCM(Billion Cubic Meter)									
	Standing Sub-Committee of MOWR			NCIWRD						
	2010	2025	2050	2010		2025		2050	
				Low	High	Low	High	Low	High
Irrigation	688	910	1072	543	557	561	611	628	807
Drinking Water	56	73	102	42	43	55	62	90	111
Industry	12	23	63	37	37	67	67	81	81
Energy	5	15	130	18	19	31	33	63	70
Other	52	72	80	54	54	70	70	111	111
Total	**813**	**1093**	**1447**	**694**	**710**	**784**	**843**	**973**	**1180**

Source: *Basin Planning Directorate, CWC, XI Plan Document (MOSPI: Projected Water Demand in India)*
Note: *NCIWRD: National Commission on Integrated Water Resources Development; BCM: Billion Cubic Meters; MOWR: Ministry of Water Resources*

2017). In fact, as long as they are used at the level of individual farmers or irrigation projects and are well defined, irrigation efficiency and water usage efficiency remain valuable metrics.

"Higher scales allow for the quantification of water productivity, but clear definitions are also necessary for its useful application. While there are pressures to reallocate water from agriculture to cities and to make more water available for environmental uses, the primary motivation for improving agricultural water productivity (water productivity in crop, livestock, and aquaculture production) is to meet rising food demands from a growing, wealthier, and increasingly urbanized population" (Molden et al., 2019).

4. ASSESSMENT OF WATER PRODUCTIVITY (WP)

In contrast to other major foodgrain producing nations in the globe, India's WP remains persistently low at this time (Molden et al, 1998; Rosegrant et al., 2002; Cai and Rosegrant, 2003). Foodgrains in India had a WP of just 0.48 kg/m3 of consumptive water usage (CWU) in 2000. The main cause of this was the modest rise in yields. India's food grain output grew by just 1.0 tons/ha between 1960 and 2000, to 1.7 tons/ha (FAO, 2005). In contrast, China's output (and soil-climate conditions) grew from 0.9 tons/ha in 1960 to around 4.0 tons/ha by the year 2000Additionally, China produces far more grain with less water from a much smaller crop area than India, which produces less grain in a much greater cropped area (205 million mt in 124 million ha). India may, in fact, raise the WP levels significantly just by boosting crop productivity. In many areas, improved water management can lead to a further rise in WP. Regional estimations reveal a notable geographical difference in WP between Indian states and districts.

The amount of water used to generate cattle and livestock-related goods and services, such as energy, is known as livestock water productivity, or LWP. When calculating the LWP benefits from livestock, the mix of livestock species owned by a household's milk output, carcass weight, draught usage, and manure values are calculated per unit of water utilized. Based on local market values, the amount of virtual water in the crop residue was calculated in relation to its grain worth. The amount of water used by livestock to produce various livestock products and to deplete or divert water is indirectly addressed in the context of water productivity, but most authors (Kijne et al., 2003) do not account for it in the water productivity equations, or if they do, they do not account for additional benefits provided by livestock (Singh and Kishore, 2004). If the amount of crop residues in livestock feed grows to fulfill the yearly need, there's a good chance that animal water productivity will also rise.

"Due to the low overall efficiency of both surface and groundwater irrigation systems, the volume of irrigation water applied in the field is frequently greater than the actual water requirement of the crop, making this scientific estimation of water productivity based solely on PWP inappropriate for irrigation intensive crops like wheat, sugarcane, and paddy. We have therefore proposed the idea of irrigation water productivity, which calculates crop yield relative to the farmer's applied unit volume of irrigation water. Three important water-guzzler crops—rice, wheat, and sugarcane—have had their IWP and associated economic water productivity assessed. Together, these three crops use more than 80% of the nation's freshwater supply that is available for irrigation. The advantages and disadvantages of using water for agriculture in terrestrial and aquatic environments are now included in the discussion of water productivity" (Molden & Oweis, 2007). In its broadest meaning, it represents the goals of reducing social and environmental costs per unit of water utilized while creating more food, income, livelihoods, and ecological benefits. The ratio of agricultural output to water consumption (from all available sources such as rainfall, irrigation, etc.) is known as physical water productivity. The evapo-transpiration rate in the area is used to calculate the total consumptive water use (TCWU) concept in PWP.

a. Physical water productivity is measured in kilograms of produce per cubic meter of water used (via evapo-transpiration) during crop growth, or kg/m3. It is the ratio of agricultural production to the quantity of water consumed from all available sources, including irrigation, rainfall, etc.
b. The ratio of crop yield to irrigation water applied by the farmer or irrigation system through surface canals, tanks, ponds, wells, and tube wells during the crop's growth is known as irrigation water productivity. Therefore, applying water (kg/m3) requires a farmer to incur specific expenses, making irrigation an economic activity.

c. The value of agricultural yield divided by the quantity of water used or irrigation water used by the farmer (expressed as Rs /m3) is known as economic water productivity.

5. CHALLENGES IN WATER PRODUCTIVITY

5.1 Rainfed Agro-ecosystem Challenges

Rainfed agro-ecosystems are problematic from the perspective of water management. Low agricultural output in both drought-prone and flood-prone/waterlogged areas is a defining feature of the area. Approximately 72 million hectares of net planted area are now used for rainfed agriculture. It is noteworthy that around one-third of rainfed areas receive rainfall exceeding 1100 mm, while another third receive rainfall between 750 and 1100 mm.

5.1.1 Spatial and temporal heterogeneity of flood and drought

Floods and droughts accounted for 51% of all natural catastrophes and 76% of damages in India between 2000 and 2020 (EM-DAT, 2020). Floods and droughts are commonplace in India. The southwest monsoon rains, which take place from June to October, are responsible for almost 70% of the annual precipitation in states located in numerous large river basins (GOI, 2019). “The plains flood significantly as a result of the monsoon runoff from large river basins including the Ganges, Indus, and Brahmaputra. About 43 percent of Indians reside in regions that frequently flood. The northeast monsoon season (November to March) is characterized by dry weather, and many regions experience droughts during a year with below-normal monsoon. Annual droughts also affect a similar percentage of the population” (Amarnath et al., 2017).

5.1.2 High spatial variation of crop production and productivity

The nation's average food grain productivity is roughly 1.9 t/ha. The average productivity in eastern Indian states was 2.4 t/ha in West Bengal, 1.5 t/ha in Assam, 1.7 t/ha in Bihar, 1.0 t/ha in Chhattisgarh, 2.0 t/ha in eastern Uttar Pradesh, 1.7 t/ha in Jharkhand, 1.3 t/ha in Odisha, 4.2 t/ha in Punjab, 3.3 t/ha in Haryana, and 2.7 t/ha in Andhra Pradesh, according to the Directorate of Economics and Statistics (2020). This wide gap between productivity and food grain output can be significantly decreased with efficient irrigation water management.

5.1.3 Saline and waterlogged area

There are over 11.6 million hectares of flooded land in India. Excessive irrigation, runoff congestion, inadequate in-situ water management, an imbalance in the amount of water entering and exiting irrigated fields, and blockage of natural drainage networks are some of the causes of waterlogging. In dry and semi-arid areas, it leads to the buildup of soluble salts in the root zone, which simultaneously results in the twin problems of soil salinity and waterlogging. The eastern region of India contains the most flooded land in the nation. Because of its saucer-shaped terrain and frequent severe rains, this region has a large area under water stagnation at various depths. In moist regions, crop productivity significantly declines, and in some cases, total crop failure occurs.

5.2 Irrigated Agro-ecosystem Challenges

5.2.1 Spatial disparity in expanding irrigated area

Across the country, 49.2% of the agricultural area is irrigated. In Haryana and Punjab, it reaches 91.4% and 98.6%, respectively. But in eastern India, it is only 47.7%. Compared to the national average, the amount of irrigation potential that is developed and used in eastern India is quite little. Therefore, additional irrigation infrastructure must be built in order to irrigate a larger area in the eastern region.

5.2.2 Poor irrigation efficiency

India uses water less efficiently than other developed countries. In developed nations, the total efficiency of irrigation projects ranges from 50 to 60%, but in India, it is just 38%. As a result, India needs more water per unit of production than other nations that cultivate comparable crops. To improve the overall efficiency of the project, a number of technical choices are accessible.

5.2.3 Regional disparity in groundwater development

The average groundwater development rate in India is 63.3%. At 40.7% and 2.4%, respectively, the eastern and northeastern regions exhibit comparatively low levels of development. It is just 11%, 46%, 44%, 28%, 42%, and 69% in Assam, Bihar, Chhattisgarh, Jharkhand, Odisha, West Bengal, and eastern Uttar Pradesh, respectively. The average phases in the southern, northern, and western parts of India are 64.6%, 94.3%, and 84.7%, respectively. As a result, it is imperative to lessen this regional disparity and support governments that have enough water to increase groundwater development.

5.2.4 Declining of groundwater table

Since independence, the use of groundwater for irrigation has grown significantly, whereas the use of surface water has decreased. According to the census, India's groundwater level dropped by 61% between 2007 and 2017, and 89% of the water that was removed was utilized for cultivation. Of the nation's 6881 assessment units (blocks/mandals), 313 units (5%) are classified as "Critical" and 1186 units (17%) as "Over Exploited." 4310 assessment units (63%) have been classified as "Safe," whereas 972 semi-critical units (14%) have been identified. Additionally, because a large portion of the ground water in phreatic aquifers is brackish or salty, 100 assessment units (1%), have been classified as "Saline." (CGWB, 2019).

5.2.5 Spatial heterogeneity in spreading micro irrigation

In India, micro irrigation with a financial component is being promoted by both the central and state governments. 12.9 million hectares of agricultural land are covered by micro-irrigation, of which 6.11 million hectares are under drip irrigation and 6.79 million hectares are under spray irrigation, This suggests that micro-irrigation accounts for only 19% of the country's irrigated area. Gujarat, Maharashtra, Andhra Pradesh, Telangana, and Karnataka share about 85% of all drip-irrigated land. In terms of sprinkler systems, Rajasthan and Haryana are at the top of the list. Madhya Pradesh, Punjab, and Haryana are far from reaching their full potential. However, groundwater development is present in more than all of these states.

5.2.6 Poor groundwater quality

Poor groundwater quality is one of the causes of water scarcity in certain parts of India. In some areas, groundwater is unsuitable for irrigation due to geological causes and/or salinity. For example, there have been reports of increased iron in Odisha, the north eastern states, and other parts of the country, elevated fluoride in 13 states, and excessive arsenic in West Bengal. In West Bengal, overdraft—that is, greater groundwater removal for summer paddy irrigation during lean periods—has resulted in reports of arsenic poisoning.

5.3 Issues Related to Wastewater Management

5.3.1 High microbial load

There are many different types of bacteria found in wastewater. There are high concentrations of expelled pathogens, such as fecal coliforms, viruses, bacteria, and helminth eggs. These ejected pathogens may cause illness or disease if they are present in sufficient numbers in a human host. While the risk from bacteria is low, intestinal nematodes pose the highest threat of infection.

5.3.2 Rich source of organic and chemical pollutants

Due to the careless discharge of wastewater from households, agricultural, and industrial sectors, which contains biological as well as harmful organic and inorganic contaminants, around 70% of surface water resources and significant amounts of groundwater reserves have become polluted. About 75 percent of point source pollution comes from industrial pollutants, and 25 percent comes from municipal sewage. Together, Class-I and Class-II cities produce an estimated 38,254 million liters of sewage per day (MLD) (CPCB, 2015), and by 2050, that amount will have increased three and a half times to 132,253 MLD. Urban and periurban wastewaters are a desirable alternative water supply for aquaculture and agriculture due to their high water content and fertilizer content. It is possible to repurpose treated wastewater from off-site treatment facilities for irrigation.

6. STRATEGY FOR IMPROVED WATER PRODUCTIVITY

Although efficient agricultural production is necessary for people's lives and the nation's food security, water is frequently the limiting issue. There is competition from other water users as well as the environment because water resources are limited. In order to increase food and water security as well as farm profits, it is crucial to increase the efficiency of water usage in agriculture. By 2030, significantly increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater. In its widest definition, water productivity refers to the production of more food, cash, livelihoods, and ecological advantages per unit of water input at a lower social and environmental cost. Water use, on the other hand, refers to the delivery of water to a use or the depletion of water by a use. The fundamental idea behind raising WP may be achieved in one of two ways: either by increasing the numerator (or yield) by closing the current yield gap between actual and maximal yield, or by adding more irrigation or choosing the right crops in mostly rainfed regions.

-Reducing the denominator (i.e., the CWU per unit land) while maintaining yield and returns per unit of water used.

It is commonly acknowledged that the world is currently experiencing an unprecedented water crisis, and that one of the main factors contributing to this situation is the agricultural sector's water management issues. Two fundamental factors are important to consider: first, the agricultural sector is by far the largest user of freshwater (Molden & Oweis, 2007); and second, water use in agriculture tends to have lower net returns as compared to other competing uses (Sharma et al., 2015). Estimates suggest that the world's food systems will require 40-50% more freshwater than they do now over the next three decades. During this time, municipal and industrial demand for water will increase by 50–70%, while the demand for energy sector will increase by 85%. India has some of the world's most brittle and unpredictable water supplies, and the nation suffers from severe water stress. With a nearly 78% share, the irrigation sector controls the majority of India's water consumption, both now and in the future. Improving water productivity in agriculture is one of the primary responses to these new difficulties since even little gains might have a significant impact on regional and national water distribution and budgetary strategies. The three most important resources in agricultural production are labor, land, and water. But unlike labor and land productivity, the idea of water productivity, or WP, has been around for a while but has only lately gained traction, particularly in developing nations. Over the past ten years, analyses of cropping systems, agricultural production systems, and WP of crops have included the well-known slogan "More Crop per Drop" (Molden et al., 2010) or "Per Drop More Crop," as renamed by the Indian Prime Minister (Kijne et al., 2003; Amarasinghe et al., 2007; Amarasinghe & Smakhtin, 2014).

There are several viable options available along the range from entirely rainfed to fully irrigated farming systems for increasing water production. These include minimum or zero tillage, mulching, bed planting, laser levelling, and small-scale water harvesting and storage, delivery and application techniques, auxiliary storage in the canal command areas, precision irrigation technologies (such as drips, micro-sprinklers, and sprinklers), deficit irrigation, soil fertility management, and supplemental irrigation. The following are a few of the more modern and cutting-edge methods and regulations for raising water productivity:

6.1 Water Productivity Strategies in Rainfed Agro-ecosystems

6.1.1 Rainwater conservation in different land forms and its efficient utilization

The main water management method to increase the productivity of rain-fed agriculture has been thought to be rainwater conservation/harvesting, which involves employing suitable techniques at reasonable locations and making effective use of the collected rainwater. Field bunding, contour bunding, terraces, micro-catchment rainwater harvesting, tillage methods, check dams, and farm ponds are a few of the potential strategies. Tanks and wells are built in sequence along a watershed's drainage line as part of the tank cum well system. It is advised to use the technology in plateau regions with a slope of 2 to 5%. In flat to rolling areas (slopes less than 6%), field bunding or contour bunding is used to catch runoff that is running down the slope (Mishra et al., 1998). In rainfed medium lands where irrigation water is unavailable after monsoon, which restricts rabi crop cultivation, dugout ponds are typically advised (Mishra et al., 2014). An inflatable structure erected across a stream for flood control, water conservation, and stream flow regulation is called a rubber check dam.

6.1.2 Management of waterlogged areas

Waterlogging and soil salinity issues in irrigation command areas were always a result of the development of irrigation projects in arid and semi-arid regions. Therefore, irrigation and drainage systems have to be designed, constructed, and operated as a single, integrated system in order to make the best and most sustainable use of irrigated land. Some areas of eastern India continue to be waterlogged (> 1 m surface water ponding) as a result of the excessive monsoon rainfall and the saucer-shaped terrain. Surface drainage or subsurface drainage must be used to remove the surplus water in these locations where there is room to do so. The safe evacuation of surplus water from the ground surface by channel building or land shaping is known as surface drainage. Utilizing the transpiration capacity of plants to mitigate waterlogging is not only an environmentally benign approach that works with current physical methods, but it also provides an extra supply of biomass, such as fuel wood, lumber, feed, etc., which can be used to generate additional revenue. Potential biodrainage plants include eucalyptus and casuarina. Waterlogging-resistant cultivars respond better and reduce production loss in submerged environments.

6.1.3 Management of flood prone areas

The majority of flood-prone areas are found in eastern India, where lakes that might yield 2.0 to 2.5 t/ha/yr of fish in a semi-intensive culture system with the correct technical inputs are still largely underutilized. These lakes can be stocked with fingerlings of Indian Major Carp (IMC) that have been grown in hatcheries or collected naturally. Many oxbow lakes, which are deserted river loops that have been cut off from the main rivers, can also be found in Bihar, West Bengal, and Assam. Selective IMC stocking and cage and pen culture techniques can yield 1.5 t/ha/yr of fish in these lakes (Bhatt et al., 2012).

6.1.4 Adequate and timely irrigation

Low yields in rain-fed locations are mostly determined by water stress during critical stages of crop growth, as is widely understood. A modest amount of additional irrigation applied correctly and on time during times of water stress might close the yield gap on its own; further irrigation combined with improved non-water input application could raise the average yield parallel to the growing path of the maximum yield. According to recent studies (Sharma et al., 2018), the major cause of crop (and investment) failures and low yields is the frequent occurrence of mid-season and terminal droughts lasting one to three weeks consecutively throughout the main cropping season. For a every crops crucial irrigation during critical irrigation could have increased yields from 29 to 114%.

6.1.5 Resource conservation technologies (RCTs)

Numerous well-known techniques exist for increasing agricultural water productivity, such as deficit and supplementary irrigation, water-saving devices, improved soil fertility, conservation of soil, and resource conservation technologies (RCTs) including bed planting and zero tillage. Laser land leveling, furrow bed planting, and zero tillage (or reduced/minimum tillage) are examples of RCTs. Numerous studies, particularly in the field, have demonstrated how well RCTs work to reduce the amount of water applied. Utilizing RCTs, such as laser leveling, zero tillage, and bed and furrow planting, decreased water usage by 23% to 45% while boosting yield. Water savings in rice-wheat systems can rise by up to 30% with the implementation of zero tillage (Hobbs and Gupta, 2003).

6.1.6 Auxiliary storage reservoirs in canal commands

One of the main obstacles to attaining increased agricultural and water production in canal irrigation systems is frequently identified as the unreliable water supply. Additionally, it limits crop diversification choices, forces farmers to meet water and other agro-input requirements at key stages of crop growth, and results in yields that are only slightly above ideal. In rotating water distribution systems like Warabandi in north and north-west India and Pakistan, inflexible or incorrectly executed water delivery schedules are frequently linked to unreliable water supplies. These water storage structures simplify the use of sprinklers for water application and provide farmers more control over on-farm water management. This immediately led to an increase in irrigable area and water conservation. If small landholdings cultivate high-value crops (fruits and vegetables), diversify their agricultural practices to include fisheries in these tanks, or employ a shared resource to lower the construction cost, these storage structures and application systems may prove to be a feasible choice.

6.1.7 Integrated farming system approach for LWP improvement

An increase in the percentage of agricultural residues used to satisfy the total needs for livestock feed is anticipated to result in higher livestock water productivity. Systems of integrated crop-livestock production have several opportunities to raise the current extremely low productivity per animal head. Appropriate multifunctional forage crops may be integrated into current agricultural systems to reduce topsoil erosion, boost crop land fertility, and boost the availability of nutrient-rich animal feed. LWP will rise even more if community-based projects are supported for better communal grazing land usage. These projects will concentrate on doable strategies for improving the productivity of community pastures by restoring damaged grazing area and addressing the overstocking issue. In the end, this would ultimately bring higher livestock productivity in a sustainable way.

6.1.8 Social awareness programme

To help people and organizations modify their behavior and stop wasting water, a comprehensive strategy is needed. Through tools like public campaigns to instill a common vision of a wealthy and environmentally sustainable future, water-efficient public behavior may be fostered. The formal education system is another effective means of reaching a broad audience. Through the use of hands-on projects, practical learning, training, and better teaching materials, this system may encourage the efficient use of water.

6.1.9 Modelling approaches for improving CWP

Accurate crop yield and crop water productivity (CWP, defined as the ratio of crop yield to real evapo transpiration) data at a broad scale and high resolution are essential for a better understanding of the global water-food link. However, given the significant spatial and temporal variability across various geographical areas, standard approaches are insufficient for predicting agricultural yield and CWP on a worldwide scale19. There is a growing need to assist water and food policy and decision making at the international and national levels due to the increasing scarcity of water and the interconnectedness of the global economy.

It would be extremely helpful to have a systematic tool that can analyze water-food connections at high geographical resolutions. The variety of applications for a crop growth model may be expanded by integrating GIS with it. Liu et al. (2018) developed and evaluated a GIS-based model called EPIC (Environmental Policy Integrated climatic) that takes into account many aspects such soil qualities, climatic conditions, land use, water and fertilizer management, etc. to simulate agricultural production and CWP. GEPIC was used to model maize yield and CWP at a grid resolution of 30 arc-minutes on the land surface on a global scale.

6.2 Strategy for Water Productivity in Irrigated Agro-ecosystems

6.2.1 Groundwater Utilization and Management

Since independence, the irrigated area has grown significantly, and tube wells are primarily responsible for this. India's net irrigation grew by 20% between 2001–02 and 2014–15, with a concerning trend of huge groundwater extraction. In 2001-02, tube wells provided water to 41% of India's net irrigated land; by 2014-15, that number had risen to 46%. Remarkably, well irrigation decreased from 21% to 17% within the same time period, and irrigation based on canal systems decreased from 27% to 24%. It should come as no surprise that although the irrigated land under surface water projects is decreasing throughout India, the area under groundwater systems is growing. Because of this, there is a great deal of variety in regional development. The western region requires recharge, whereas the eastern region requires groundwater development. More government investment is required in the area of groundwater utilization. The detrimental impacts of groundwater extraction, such as excessive drawdown, land subsidence, and deterioration of groundwater quality, will also be lessened by a planned government intervention. Open-dug and tube wells used for groundwater extraction should be planned such that the total amount of groundwater extracted does not surpass the amount of groundwater recharged. Since groundwater irrigation is more expensive due to the energy needed for pumping, it is better suited for low-duty, high-value crops. Giving farmers financial support and incentives to switch to solar pumps can boost groundwater use and reduce the amount of land left fallow during the rabi season. India has suffered greatly as a result of the geological pollution of groundwater with iron, fluoride, and arsenic. One should refrain from drawing groundwater from an aquifer that has been poisoned by arsenic. Harvesting rainwater is crucial. Because it will lessen the impact of arsenic pollution, using surface water and groundwater together is a wise choice. Adsorption or precipitation and coagulation techniques can be used to treat groundwater for the removal of arsenic. Mapping affected areas is necessary to prevent fluoride pollution in groundwater and fluorosis. Because they are less likely to clog, pressurized irrigation systems are better suited for groundwater commands.

6.2.2 Efficient utilization of canal water

Individuals, panchayats, and the state government must work together to control canal water. An excellent idea for overseeing the upkeep and functioning of irrigation minors and sub-minors is the panchayat. To enable the members to get inputs at the appropriate time and cost, they must be significantly enhanced. Additionally, WUAs could work on creating market infrastructure, which is essential for value addition and agricultural diversity. The canal supply schedule should closely correspond with the command's agricultural water requirement in order to ensure effective water usage. One solution that may be applied to waterlogged areas of canal channels is the raised and sunken bed system. Alternate raised and sunken beds are created by digging out soil from one strip of land and placing it on an adjacent strip. Vegetables may be grown in the raised bed, while paddy can be grown in the sunken bed. To increase output and make efficient use of the irrigation water that is available, the outlet command must adhere to optimal water management principles. Some of the management techniques that must be properly implemented include the use of field channels, pressured irrigation techniques, optimum planting geometry, alternating soaking and drying in paddy crops, the system of rice intensification, raised and sunken bed technology, land leveling, etc.

6.2.3 Pressurized irrigation system

Pressurized irrigation systems will be useful in places that are watered by groundwater as well as canals. In the nation, drip and sprinkler irrigation systems have grown in popularity as pressured watering methods. Because there is less possibility of system blockage, they are more suited for groundwater commands. The drip irrigation system's application efficiency ranges from 90 to 95 percent. The benefits of drip irrigation include reduced weed growth, reduced labor and energy requirements, enhanced fertilizer efficiency (saving approximately 25% of fertilizer), a 50% reduction in irrigation water, and a 25% increase in crop production as a result of frequent watering. The sprinkler irrigation system's application efficiency is around 75%.

6.2.4 Drip fertigation for better water and nutrient use efficiency

Drip fertigation is the most effective as it has high WUE with low loss of nutrient through runoff and leaching and minimize groundwater contamination. Urea is the most common and popular fertilizer used for drip fertigation.

6.2.5 Partial root zone drying

The partial root zone drying approach is another way to boost drip efficiency. A portion of the plant's root zone is watered while the other portion is not, a technique known as partial root zone drying (PRD). Each side of the root zone receives watering alternately, enabling the moist side to dry and the dry side to get wet. Vegetables and other horticultural crops may be grown using the PRD approach. When the partial root zone drying technique was tested on a drip-irrigated mango crop, the 60% PRD treatment showed the highest water usage efficiency, an 85% improvement over the full irrigation treatment.

6.2.6 Sensor based irrigation

Automation in irrigation system would further save water and enhance yield over manual irrigation. Panigrahi et al. (2021) studied automated drip irrigation and fertigation in banana crop based on soil moisture sensor and found that automated drip irrigation and fertigation system has given higher banana yield (70 t ha-1) than manual drip irrigation system (60 t ha-1) and surface irrigation system (44 t ha-1). Sensor based system has also increased water productivity of banana crop.

7. CONCLUSIONS

In recent times India has made remarkable achievements in water sector, which is evident from the large growth in irrigated agriculture, increase in agricultural production, and advancements in drinking water supplies in rural and urban areas. In doing so, development of water resources has crossed the thresholds of physical sustainability in many areas, manifested by groundwater depletion, groundwater quality deterioration, dwindling supplies and increasing pollution of 11 surface water. Recent advancements in water technology and water management in both the rainfed and irrigated ago ecosystems are capable enough to address and manage the challenges in water sector in India.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models

(ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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