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A review on approaches to improve water use efficiency in command areas

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Abstract
Command areas are those systematically irrigated by strategically demarcated and managed reservoirs to ensure efficient and equitable distribution of water for crop cultivation. Many of these reservoirs supply irrigation water to the command areas through an open-channel gravity flow water distribution network, which leads to significant water loss. Only 40 to 60 percent of the water is effectively utilized by the crops. The rest is lost in the system or on the farm, either through evaporation, seepage, runoff or percolation into the groundwater. The population of mankind is increasing at a distressing rate and humans are tapping into natural resources to meet their needs. Available resources, including water and food are falling short to cope with mankind's increasing demand for industrial, agricultural and domestic purposes. To overcome this problem, it is essential to conserve water in many ways and utilize it so that food production is sufficient to meet mankind's needs at a reasonably low cost. Irrigation is one of the tools to increase food production from agricultural land and conserve water. Increasing water use efficiency through improved agronomic practices and modern technologies will help attain higher crop yields and increase the net returns of farmers, making agriculture profitable (Anon., 2017). Here, we will discuss different approaches to improve water use efficiency in command areas.

Keywords: Command areas, water use efficiency, open channel, conservation of water

Introduction
Water is a precious natural resource gifted to mankind on the planet earth without which life is impossible. As the industrialization and urbanization are expected to accelerate at faster pace, the available water resources need to be very effectively utilized to maximize the production per unit of water. Improper management of water has contributed extensively to the current water scarcity in many parts of the world and is also a serious challenge to future food security and environmental sustainability. Water scarcity is increasing worldwide resulting in stringent regulation of its use for agriculture. Efficient utilization of available water resources is crucial for a country like, India, which shares 17 percent of the global population with only 2.4 percent of land and 4 percent of the water resources. Further, per capita availability in terms of average utilizable water resources, which was 5247 m^3 in 1951 (presently 1453 m^3) is expected to dwindle down to 1170 m^3 by 2050 (CWC, 2015). Agricultural sector alone consumes 80 percent of the ground water (Harsha, 2017) [28]. The declining trend of groundwater level in all parts of the country also indicates that the assured supply of good quality water will become a concern for country's development (Manivannan *et al*., 2017) [38]. The overall efficiency of the flood irrigation system range between 25-40 percent (Amarasinghe, 2007) [3]. Overall, average irrigation efficiency is observed as 38 percent, which is much below desired efficiency. Average conveyance efficiency is 70 percent. Thus, there is scope to reduce losses occurring due to poor irrigation infrastructure like unlined canal and channels. Similarly on farm application efficiency is also only 50 percent. It was estimated (Arshad *et al*., 2009) [5]. That lining of watercourses reduced water loss by 22.5 percent. The probable causes of water leakage are cracks, eroded mortar and structural failure of lined walls. Also due to absence of non-availability of control structures and regulation gates, there is inadequate and irregular canal water supply in many command areas. Further, many times canals have breaches, which cause displacement of thousands of people, destruction of properties, land and damage to costly crops worth millions

of Rupees. In addition to that, breach failures also can cause water shortages when the failure occurs during the peak demand period. There are various causes of embankment failures, which include overtopping, internal erosion, structural defects and piping. Only 40 to 60 percent of the water is effectively utilized by the crop, the rest of the water is lost in the system or in the farm either through evaporation, seepage, runoff or by percolation into the groundwater. The paper is organized as follows. Firstly, the paper presents Irrigation potential development and reasons for poor water use efficiency in command areas followed by different ways to measure the irrigation efficiency in command areas. Lastly, we discuss various options to overcome these challenges and efficient water management in command areas followed by conclusions.

Irrigation potential development

Irrigation potential development refers to the concerted efforts aimed at enhancing the capacity to irrigate agricultural land through various infrastructure projects and management strategies. This process involves the construction, rehabilitation and maintenance of irrigation systems such as canals, reservoirs, pumps and pipelines to effectively deliver water to farmlands. The goal is to expand the area of cultivable land that can be supplied with water, thereby increasing agricultural productivity, ensuring food security and mitigating the impacts of water scarcity (FAO, 2019).

Irrigation Potential Created: This term refers to the estimated capacity or capability of an area of land to be irrigated, typically through the development of irrigation infrastructure such as canals, dams, reservoirs, pumps and pipelines. It represents the total area of land that could potentially benefit from irrigation if adequate water resources and infrastructure were available. This measurement serves as a benchmark for assessing the scope and impact of irrigation development projects and initiatives. It is often calculated based on factors such as water availability, topography, soil characteristics and the capacity of irrigation systems (FAO., 2016) [24].

Irrigation Potential Utilization: This concept refers to the actual utilization or utilization rate of the irrigation potential created in a given area. It represents the portion of the total irrigation potential that is actively being used for agricultural purposes, measured in terms of the area of land under irrigation compared to the total irrigation potential available. This metric reflects the efficiency and effectiveness of irrigation systems, water management practices and agricultural activities in utilizing available water resources to support crop cultivation. Monitoring irrigation potential utilization is essential for evaluating the performance and impact of irrigation projects, optimizing resource allocation and ensuring sustainable water use in agriculture (Bhattacharya *et al*., 2016) [8].

Huge and increasing gap between created and utilized irrigation potential

There has been a large gap in utilization of created potential. Total utilization of irrigation potential was to the extent of 96.5 million hectares as against the total created potential of 112.53 million hectares showing a gap of 16.03 million hectares (CWC, 2017). The main reasons behind this non-utilization of created potential are delay involved in the development of on-farm works like construction of field channels, land levelling or shaping and adoption of the warabandi system and finally the time taken by farmers in switching over the new cropping patterns, *i.e*., from dry farming to irrigated farming. To reduce the gap between irrigation potential created and that utilized by construction of On-farm Developmental works like, construction of field channel, field drain etc. by judicious and equitable distribution of the available irrigation water and with active involvement of farmers through participatory irrigation management (PIM).

- Bridge the gap between irrigation potential created & utilized by following practices as follows:
- Ensure timely and equitable distribution of irrigation water in the command
- Enhance the irrigated area by means of efficient water management
- Boost agriculture production and productivity in the command
- Involve the beneficiary farmers at grass roots level for management of water resources through Participatory Irrigation Management (PIM) & organization of Pani Panchayats.
- Initiate participation of the farmers in water management, irrigation scheduling, distribution and maintenance of system at micro level.
- Improve irrigation as well as water use efficiency.
- Make best use of natural precipitation and ground water in conjunctive with the canal water.
- Develop a sense of economy in water use amongst the users.
- Facilitate the users to have a choice in selecting crops, cropping sequence, timing of water supply depending upon the soil and availability of water, climate and other infrastructure facilities available in the command such as road, markets, cold storage etc., so as to maximize the income and profit.
- Delineate responsibilities of water distribution and maintenance of system between the users both relating to allocation and actual supply of water.
- Facilitate resolution of conflicts among farmers.

Why water use efficiency is low in command areas?

Water use efficiency can be low in command areas because of several reasons such as.

1. **Poor Infrastructure and Design issues:** In many command areas, the infrastructure for water distribution may be old or poorly maintained. Leaks in canals, inefficient water gates and inadequate lining of canals can lead to significant water losses before it even reaches the fields (Singh., 2009) [52].
2. **Farmers' Practices:** In some cases, farmers may not adopt water-efficient farming practices. This could include using flood irrigation instead of more precise methods like drip or sprinkler irrigation, which can lead to water wastage (Rana and Singh., 2003) [47].
3. **Poor Maintenance:** Inadequate maintenance of irrigation infrastructure can result in leaks and inefficiencies. Regular maintenance is crucial for ensuring that the system operates optimally (Shrestha and shah, 2003) [51].
4. **Crop Selection and Management:** Certain crops may be grown in command areas that are not well-suited to the local climate or water availability. Growing water-intensive crops in areas with limited water resources can lead to low water use efficiency (Mahajan and Singh., 2010) [37].
5. **Lack of Technology Adoption:** Many farmers in command areas may not have access to or may not adopt modern

irrigation technologies such as drip irrigation, sprinkler systems or precision agriculture techniques. These technologies can significantly improve water use efficiency by applying water directly to the root zone of plants and minimizing losses (Shah., 2007) [50].

6. **Inefficient Irrigation Practices:** Farmers in command areas may not adopt efficient irrigation techniques. Traditional flood irrigation methods, where water is simply released into fields, can lead to significant water wastage through evaporation, runoff and deep percolation beyond the root zone of crops (Kijne *et al*., 2003) [33].
7. **Issues Related to Irrigation Water:** It includes wastage of water, excessive use of water, unregulated cropping pattern, Loss due to poor conveyance, Canal construction and reuse of irrigation water (Biswas., 2008) [9].
8. **Issues Related to Crop Productivity:** It includes mono-cropping, late release of water- reduced productivity, practice of plot-to-plot irrigation, Crop selection & crop diversification and Lack of alternate cropping plans for drought years (Bhatia and Rana., 2007) [7].

The efficiency of irrigation systems is also often evaluated and expressed as water use efficiency or field water use efficiency

Water use efficiency (WUE) is a concept introduced 100 years ago by Briggs and Shantz (1913) showing a relationship between plant productivity and water use. Water use efficiency (WUE) is defined as the amount of carbon assimilated as biomass or grain produced per unit of water used by the crop. It is expressed in kg ha-cm^{-1}or kg ha-mm^{-1}.

$$\text{WUE (kg ha-cm}^{-1}\text{)} = \frac{\text{Economic crop yield (kg)}}{\text{Water requirement (ha-cm)}}$$

Irrigation efficiency can be measured in different ways based on

1. Conveyance of water from a source
2. Application of water
3. Storage of water in profile
4. Distribution of water

Based on Conveyance of water from a source

Conveyance Efficiency (E_c): It is the ratio between water delivered to the farm (W_f) and total quantity delivered at the reservoir (W_r)

$$E_c = \frac{\text{Water delivered to the farm } (W_f)}{\text{Total quantity delivered at the reservoir } (W_r)}$$

Source: FAO Irrigation Management Training Manual 2019[26].

- The conveyance efficiency mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals (Srivastava et.al 2017). While in transit through canals losses like, evaporation, deep percolation, seepage, bund breaks, overtopping of the bunds, runoff in the drain, rat holes in the canal bunds etc. Out of these losses seepage (98.37%) is most important and evaporation loss (0.3%) is negligible.

Soil type	Sand	Loam	Clay	Conveyance Efficiency
Canal length				
Long (> 2000 m)	60%	70%	80%	95%
Medium (200-2000 m)	70%	75%	85%	95%
Short (< 200 m)	80%	85%	90%	95%

Ways to improve Conveyance efficiency in command areas

Conveyance efficiency can be increased in following ways

Lining of irrigation canals using impervious materials: This involves lining the canals with materials such as brick, stone masonry, tile or cement concrete. The purpose is to reduce seepage losses, which occur when water leaks through the soil, especially in unlined canals. This source mentions the advantages of this technique, including seepage reduction. (Sivanappan, 1998) [57].

Maintain uniform slope: A uniform slope along the canal helps maintain consistent water flow, preventing stagnation or excessive flow velocity. This ensures that water reaches the fields evenly and efficiently.

Land levelling and shaping: This involves shaping the land to ensure proper water distribution and prevent waterlogging or runoff. Levelling the land allows for more efficient irrigation as water can evenly spread across the fields.

Use drop structures when slope is steep or uneven: Drop structures are used to manage sudden changes in elevation along the canal. They help control the flow of water and prevent erosion, especially in areas with steep or uneven slopes. This ensures that water is conveyed smoothly without causing damage to the canal or surrounding land.

Use erosion control structures like drop and chute spillways: Erosion control structures such as drop and chute spillways help prevent soil erosion caused by water flow. By controlling the speed and direction of water, these structures protect the canal banks and maintain conveyance efficiency (FAO, 2006) [24].

Use of control structures like check gates: Check gates are installed along the canal to regulate the flow of water. They help control water levels, especially during periods of high flow or when water needs to be diverted to different areas. This ensures efficient water distribution and prevents wastage.

Repair and maintenance of laterals and field irrigation channels: Regular maintenance of laterals and field irrigation channels is essential to prevent leaks and ensure efficient water delivery to the fields. This includes repairing any damages and clearing obstructions that may hinder water flow.

Weed growth should be checked in unlined canals and waterways: Weed growth in unlined canals can obstruct water flow and reduce conveyance efficiency. Regular maintenance, such as clearing weeds and vegetation, helps ensure smooth water flow and efficient irrigation.

Strengthen the embankments ensuring no slips and bank failures and effectiveness of lining: Strong embankments are essential to prevent bank failures and ensure the stability of the canal. This includes reinforcing embankments to prevent erosion and maintaining the effectiveness of the lining to reduce seepage losses (Deng *et al.*, 2004) [18].

Participatory irrigation management: Involving local communities in the management of irrigation systems can help ensure efficient water distribution and maintenance. This participatory approach encourages collaboration and shared responsibility, leading to better management practices and increased conveyance efficiency (Amarasinghe *et al.*, 2007) [3].

Rectify design defects in canal systems and structures: Identifying and addressing design defects in canal systems and structures is crucial for optimal conveyance efficiency. This may involve redesigning certain components or implementing improvements to enhance water flow and reduce losses.

Based on application of water to crop root zone

Application efficiency: It is the ratio between the quantity of water stored in the root zone and water delivered to the farm.

$$E_a = \frac{\text{Water stored in the root zone } (W_s) \times 100}{\text{Water delivered to the farm } (W_f)}$$

- Operational losses due to inefficient water handling during conveyance and losses on farm due to uneven distribution, poor handling, evaporation and deep percolation further reduces the efficiency of irrigation water.

Ways to improve application efficiency in command areas

Application efficiency can be increased in following ways

Adopt water-saving irrigation techniques like drip and sprinkler: Drip and sprinkler irrigation are modern methods that apply water directly to the root zone of plants, minimizing evaporation and runoff. Drip irrigation delivers water slowly and precisely to the root zone through a network of tubes and emitters, while sprinkler irrigation distributes water through overhead sprinklers. Both techniques help conserve water and enhance application efficiency.

Proper selection of irrigation methods according to crops, soil types, topography, climate, and stream sizes: Different crops, soil types, and environmental conditions require specific irrigation methods for optimal water use efficiency (Choudhari, 1997) [17]. Factors such as crop water requirements, soil infiltration rates, terrain, and water availability should be considered when selecting irrigation methods.

Proper land levelling and grading is a prerequisite for efficient water application: Levelling and grading the land ensure uniform water distribution, preventing waterlogging and runoff. This enhances water infiltration and root zone moisture distribution, leading to improved application efficiency.

Appropriate selection of crops: Choosing crops suited to the local climate, soil conditions, and water availability can significantly impact water use efficiency. Some crops are more drought-tolerant or water-efficient than others and selecting suitable varieties can help maximize yield per unit of water applied (Bandyopadhyay *et al.*, 2010) [6].

SCADA automation system: Supervisory Control and Data Acquisition (SCADA) systems automate irrigation management by monitoring and controlling water flow based on real-time data. These systems optimize irrigation scheduling, water distribution and system performance, thereby improving application efficiency.

Improve water holding capacity of soil: Soil amendments and management practices can enhance the water-holding capacity of soil, reducing irrigation requirements and improving water use efficiency. Techniques such as organic matter addition, mulching and conservation tillage can improve soil structure and moisture retention (Arshad *et al.*, 2009) [5].

By implementing these strategies, command areas can enhance application efficiency, optimize water use and improve agricultural productivity while conserving water resources.

Based on Storage of water in profile

- Storage efficiency is the water stored in root zone after irrigation to water stored in root zone before irrigation
- Storage efficiency: 98-99 percent (if adequate water is provided) 50-60 percent (if irrigation supplied does not satisfy WHC)

Based on Distribution of water

- **Distribution Efficiency (E_d): It** is the ratio between average numerical deviation in depth of water stored from average depth stored during irrigation (y) and the average depth stored along the water movement(d).

$$E_d = (1 - y/d) \times 100$$

- Distribution efficiency indicates how efficiently a given quantity of water is distributed on a given land
- Uniformity of water distribution on the surface as well as in the root zone is most important.
- Uneven surface distribution, due to uneven land leveling, leaves some unirrigated spots unless excess water is applied.
- It is a measure of water distribution within the field.

Use of distribution control structures such as turnouts, diversion boxes, checks, spiles and siphon tubes: Distribution control structures help regulate and distribute water effectively within the irrigation network. Turnouts, diversion boxes, checks, spiles and siphon tubes are examples of such structures. They enable precise control over water flow, allowing for efficient allocation to different fields or areas within the command area (CGWB, 2017) [12].

Match flow rate with infiltration rate: Matching the flow rate of water with the infiltration rate of the soil ensures that water is applied at a rate that the soil can absorb without causing runoff or deep percolation (Ali and Ehsanullah, 2007) [1]. This approach optimizes water use and minimizes losses due to inefficient application.

Selection of proper irrigation methods: Choosing the appropriate irrigation method based on factors such as crop water requirements, soil characteristics, topography and water availability is crucial for enhancing distribution efficiency (Prihar *et al.*, 2000) [45].

Adoption of uniform slope: Maintaining a uniform slope along the irrigation channels ensures consistent water flow and distribution. This prevents water stagnation or uneven distribution, leading to improved distribution efficiency.

Proper gradient of land: The gradient or slope of the land influences the flow of water within the command area. Proper land gradient design ensures that water flows smoothly and uniformly, enhancing distribution efficiency (CWC, 2015) [13].

Enforcement of warabandi system: The warabandi system, common in some irrigation networks, involves the rotational allocation of water to different farmers or fields at specific time intervals. Enforcement of this system ensures equitable distribution and optimal utilization of available water resources within the command area.

Table 1: Comparison of irrigation efficiency of Canal Distribution Network (CDN) & Pipe Distribution Network (PIN)

Method of conveyance/irrigation		Micro Irrigation		Surface Irrigation
		Sprinkler	Drip	
Canal based conveyance (CDN)	Conveyance Efficiency (%)	70	70	70
	Field canal efficiency (%)	90	90	90
	Field application efficiency (%)	75	90	60
	Overall efficiency (%)	47.25	56.7	37.8
Pipe based conveyance (PIN)	Conveyance efficiency (%)	95	95	95
	Field Pipe Efficiency (%)	95	95	95
	Field Application efficiency (%)	75	90	60
	Overall efficiency (%)	67.68	81.23	54.15
Increase of overall efficiency% (pipe against canal)		20.43	24.53	16.35

Overall irrigation efficiency under sprinkler, drip and surface irrigation was higher in pipe-based conveyance system of irrigation (67.68, 81.23 and 54.15%, respectively) than open canal-based conveyance system (47.25, 56.7 and 37.8%, respectively) in Gunjavani dam command area of Kanandi river (Pune). The overall efficiency of irrigation projects is around 41–48 percent, it means that the average 50 percent of water get lost. It implies that benefit of capital cost incurred on the traditional open channel system for irrigation purpose is less than 50 percent. Also at many places, extra water is supplied to agriculture field due to bad practice of irrigation, it creates the problem of water logging and thereby reducing the fertility of land. To save the precious water storage and to utilize the maximum efficiency of irrigation project we need to overcome with Pipe distribution network (Kadam *et al*., 2020) [31].

Table 2: Comparison between conventional system and pipe distribution network

Particular	Traditional open channel gravity flow irrigation system	Pipe Distribution Network (PDN) system of irrigation	% increase
Discharge at head regulator	1040 LPS	1040 LPS	--
Overall efficiency	41%	Efficiency on farm – 85% Efficiency of lateral- 95% Efficiency of sub main – 98% Efficiency of main – 98%	36%
Culturable command area	643 ha	1207 ha	88%
Discharge at chak head	30 LPS	82 LPS	173%

Satpute *et al*. (2012) [49] compare with traditional open channel gravity irrigation system, in PDN Water application efficiency on Farm is 85 percent, Efficiency of lateral is 95 percent, Efficiency of sub-main is 98 percent and Efficiency of Main is 98 percent which shows that there is potential increase in efficiency of overall system. Likewise culturable command area which is 643 ha was covered under irrigation using open channel irrigation system increased by 2 times, i.e., 1207 ha of area now being irrigated using PDN system. (DoE & S, 2018) [21].

Reasons for Deprivation in tail end users for water

- Policy and Enforcement
- Availability of Water
- Unauthorised Irrigation
- Violation of Cropping Pattern
- Poor Maintenance
- Shortage of Funds and Regular Staff
- Lack of Night
- Slow Progress of WUAs in the Region Irrigation
- Supply to Non-agricultural Sector

Policy and Enforcement: Inadequate policies or lack of enforcement of existing regulations can lead to unequal water distribution, with priority given to upstream or influential users, leaving tail-end users deprived. This can result from governance issues or regulatory inefficiencies. Relevant studies can be found in journals focusing on water policy and governance. (CWC, 2017) [15].

Availability of Water: Limited water availability due to factors like drought, over-extraction, or inefficient water management practices can leave tail-end users with insufficient water for their needs. Research on water scarcity and its impacts on agriculture can provide insights into this issue (Palanisami and Ramesh, 2009) [44].

Unauthorised Irrigation: Unauthorized tapping of water by individuals or entities upstream of tail-end users can significantly reduce water availability downstream, depriving them of their rightful share (El Bakia *et al.*, 2018) [23]. and unauthorized water use can shed light on this issue.

Violation of Cropping Pattern: Deviations from recommended cropping patterns, such as cultivating water-intensive crops in areas with limited water availability, can exacerbate water scarcity for tail-end users. Agricultural research focusing on cropping patterns and water use efficiency can provide relevant information (Harsh, 2017) [27].

Poor Maintenance: Inadequate maintenance of irrigation infrastructure, such as canals and distribution networks, can lead to water losses through leaks and seepage, further reducing water availability for tail-end users. Engineering and irrigation management literature may offer insights into the importance of infrastructure maintenance (NMM, 2014) [42].

Shortage of Funds and Regular Staff: Insufficient financial resources and manpower for irrigation management can result in ineffective operation and maintenance of irrigation systems, impacting water delivery to tail-end users. Reports from irrigation departments or studies on irrigation financing can provide relevant data (Chandrakanth *et al.*, 2013) [16].

Lack of Night: The absence of equitable water distribution scheduling, including night-time irrigation, can disadvantage tail-end users who may receive water during less favorable times, affecting crop growth and productivity. Research on irrigation scheduling and water allocation practices may address this issue.

Slow Progress of WUAs in the Region: Weaknesses in the establishment or functioning of Water User Associations (WUAs) can hinder participatory water management efforts, leading to inequitable water distribution and deprivation among tail-end users. Literature on WUAs and participatory irrigation management can provide insights into this challenge (Jain *et al*., 2019) [30].

Supply to Non-agricultural Sector: Allocation of water to non-agricultural sectors, such as urban or industrial uses, at the expense of agricultural needs can exacerbate water scarcity for tail-end users reliant on irrigation. Studies on water allocation priorities and competing water demands may address this issue (Jain *et al*., 2016) [30].

Each of these factors contributes to the deprivation experienced by tail-end water users in irrigation systems. Understanding and addressing these challenges require a holistic approach involving policy reforms, infrastructure improvements, community participation and sustainable water management practices (Kulkarni and shah, 2013) [34].

Strategies adapted to overcome tail-end deprivation

Water Management: Implementing efficient water management practices involves optimizing water distribution, reducing losses, and improving water-use efficiency (Singh, 2004). This can include measures such as canal lining, modernizing irrigation infrastructure and promoting water-saving technologies (Suresh *et al*., 2014) [60].

Rotation Schedule: Establishing a rotation schedule for water allocation ensures equitable distribution among users, including those at the tail-end of irrigation networks (Singh, 2012) [56]. This approach allows each user group to receive water at regular intervals, reducing deprivation.

Lift Irrigation: Lift irrigation systems pump water from a lower source to higher elevation fields, providing access to water in areas where gravity-fed systems may not reach. (Saleth, 2009) [47]. This strategy is particularly useful in regions with uneven terrain or limited water availability.

Informal Organizations: Informal community-based organizations or networks play a vital role in advocating for the rights of marginalized users and organizing local water management initiatives. They facilitate collective action and address tail-end deprivation through community-driven approaches (Narayanamoorthy, 2005) [42].

Water Users Association (WUA): Formalized user groups like WUAs enable participatory management of irrigation systems. By empowering local stakeholders, WUAs facilitate inclusive decision-making, equitable water allocation and infrastructure maintenance (Kumar and Palaniswamy, 2010) [35].

CADA (Command Area Development Authority): CADA is an institutional framework focused on comprehensive development and management of irrigation commands. Through coordinated planning and implementation, CADA initiatives address issues of water distribution equity and alleviate tail-end deprivation (Ali and Talukder, 2008) [2].

Farmers, NGOs: Active involvement of farmers and non-governmental organizations (NGOs) is crucial in advocating for policy reforms, implementing water-saving technologies, and promoting community-based solutions. Collaborative efforts between farmers, NGOs, and government agencies lead to more inclusive and sustainable water management practices. (Manivannan *et al.*, 2017) [38].

Each of these strategies addresses tail-end deprivation by improving water allocation, enhancing community participation, and implementing efficient water management practices.

Recommendations related to major and medium irrigation commands

Implementation of on and off system: The on and off irrigation system involves alternating periods of water supply and rest for the soil (Morison *et al.*, 2008) [41]. This practice helps prevent waterlogging, improve water use efficiency and promote better crop growth.

Participatory irrigation management: Participatory irrigation management involves involving local stakeholders, including farmers and water users, in decision-making processes related to irrigation management. This approach enhances transparency, accountability and sustainability in water resource management.

Crop diversification: Crop diversification involves cultivating a variety of crops instead of relying solely on one or two crops (Samra *et al.*, 2004) [49]. This practice helps reduce risks associated with climate variability, pests and market fluctuations while promoting sustainable land use

Cultivation of paddy under limited water: Cultivating paddy under limited water conditions involves adopting water-saving techniques such as alternate wetting and drying (AWD) or system of rice intensification (SRI). These practices reduce water use while maintaining or even increasing rice yields (Dhawan, 2017) [19].

Capacity building – Training to farmers: Capacity building through training programs enhances farmers' knowledge and skills in sustainable agricultural practices, water management techniques, and modern farming technologies (Singh *et al.*, 2005) [54]. These programs empower farmers to make informed decisions and adopt best practices.

Strengthening research and development: Investing in research and development (R&D) initiatives focused on irrigation technologies, water management strategies, and crop improvement is essential for addressing the challenges faced by major and medium irrigation commands (Dhawan, 2002) [19].

Land development on outlet command basis: Land development on an outlet command basis involves improving land drainage, levelling and soil conservation measures at the outlet of irrigation commands. This enhances water distribution efficiency and ensures uniform water availability across the command area (Singh *et al.*, 2008) [53].

Implementing these recommendations can contribute to enhancing the effectiveness and sustainability of major and medium irrigation commands, leading to improved agricultural productivity and livelihoods for farmers (Swarup *et al.*, 2008) [61].

Recommendations related to minor irrigation commands

Management of tank irrigation commands through WUS: Tank irrigation commands can be effectively managed through Water Users' Associations (WUAs) or Water Users' Societies (WUS). These community-based organizations enable participatory management of water resources, ensuring equitable distribution and efficient utilization of water from tanks or reservoirs. WUAs/WUSs facilitate collective decision-making, maintenance of irrigation infrastructure, and resolution of water-related conflicts among users.

Crop diversification and cropping plan: Encouraging crop diversification and implementing a cropping plan suitable for the local agro-climatic conditions can enhance the resilience of minor irrigation commands (Yadav, 2000) [62]. Diversifying crops reduces the risk of crop failure and improves soil health by rotating crops with different nutrient requirements and growth characteristics. A well-designed cropping plan ensures optimal utilization of water resources and maximizes agricultural productivity.

Revision of water rates: Regular revision of water rates based on factors such as the cost of water supply, maintenance expenses, and prevailing agricultural practices is essential for sustainable management of minor irrigation commands (Lei *et al.*, 2003) [36]. Fair and transparent water pricing encourages efficient water use, discourages wasteful practices, and ensures the financial viability of irrigation systems (Srivastava *et al.*, 2017) [59].

Banning cultivation of paddy and sugarcane: In regions facing water scarcity or where water resources are limited, banning the cultivation of water-intensive crops like paddy and sugarcane can alleviate pressure on irrigation systems and conserve water. Instead, promoting the cultivation of less water-intensive crops that are better suited to local conditions can help optimize water use efficiency and sustain agricultural production (Sivanappan., 1998) [57].

Conveyance of water through pipelines: Conveying water through pipelines instead of traditional open channels can minimize water losses due to seepage and evaporation, particularly in minor irrigation commands. Pipeline systems provide more precise control over water delivery, reduce energy consumption for pumping, and minimize land requirements. They also offer flexibility in water distribution and can be easily managed and maintained (Mohanty *et al.*, 2008) [40].

Adoption of micro irrigation methods: Implementing micro irrigation methods such as drip irrigation and sprinkler irrigation in minor irrigation commands can significantly improve water use efficiency and crop yield (Kar *et al.*, 2004) [32]. These precision irrigation techniques deliver water directly to the root zone of plants, reducing losses from evaporation and runoff. Micro irrigation also allows for precise control of water application, thereby optimizing water use and minimizing wastage (Srivastava *et al.*, 2015) [58].

By implementing these recommendations, minor irrigation commands can achieve improved water management, increased agricultural productivity, and greater resilience to water-related challenges.

Conclusion: Improving water use efficiency in command areas is critical for sustainable agriculture, economic development and environmental conservation. By implementing strategies such as infrastructure upgrades, policy reforms, community participation, research and innovation, significant progress can be made in optimizing water use and minimizing wastage in irrigation systems.

Future Prospects: For improving water use efficiency in command areas lie in harnessing technological innovations, strengthening institutional frameworks, and promoting holistic approaches to water management. By addressing the challenges of water scarcity, climate change, and socio-economic disparities, we can build resilient and sustainable irrigation systems that meet the needs of present and future generations.

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