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Review

Irrigating India: Water Resources and Modern Irrigation Development for Different Crops

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Abstract

Irrigation is vital for sustaining agricultural productivity and food security in India, given its diverse agro-climatic conditions and uneven rainfall. Indian agriculture relies mainly on groundwater and surface water sources, with increasing emphasis on micro-irrigation technologies such as drip and sprinkler systems to improve water-use efficiency. Government initiatives, particularly PMKSY, have significantly supported irrigation expansion and modernization. However, challenges like groundwater depletion, regional disparities and climate variability persist. Promoting efficient, climate-resilient irrigation practices is essential for sustainable agricultural development in India.

Keywords: Irrigation, Water resources, Groundwater, Drip irrigation, Sprinkler irrigation, PMKSY, Sustainable agriculture, Water-use efficiency and India.

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Introduction

India, endowed with immense agro-climatic diversity ranging from arid and semi-arid zones to humid tropical and temperate regions, is one of the world's leading agricultural producers. Agriculture plays a central role in the Indian economy, providing livelihood support to a large segment of the population and contributing significantly to national food security. The performance, stability, and sustainability of this sector are intrinsically linked to the availability and efficient management of water resources, as Indian agriculture remains highly dependent on monsoon rainfall, which is often erratic and unevenly distributed across regions and seasons.

Irrigation has therefore emerged as a critical component of agricultural development in India, helping to stabilize crop production by reducing dependence on rainfall variability. Adequate and timely irrigation enhances crop yields, increases cropping intensity, enables multiple cropping, and supports the cultivation of water-sensitive and high-value crops. In the face of climate change, marked by increased frequency of droughts, extreme weather events, and shifting rainfall patterns, the role of irrigation in ensuring food security has become even more crucial. However, increasing water demand from agriculture, coupled with rapid urbanization and industrial growth, has placed immense pressure on both surface and groundwater resources.

Over-extraction of groundwater, declining water tables, and inefficient irrigation practices have raised serious concerns regarding the long-term sustainability of agricultural water use. Inefficient methods often lead to water losses, soil salinity, waterlogging, and reduced productivity. Consequently, the adoption of sustainable irrigation solutions has become imperative. These include the

promotion of micro-irrigation systems such as drip and sprinkler irrigation, improvement in water-use efficiency, conjunctive use of surface and groundwater, rainwater harvesting, and climate-smart irrigation management practices. Such measures aim to optimize water use, conserve limited water resources, and enhance the resilience of Indian agriculture under changing climatic and socio-economic conditions (Central Ground Water Board, 2023; Ministry of Jal Shakti, 2024).

Water Resources of India

India's irrigation relies primarily on four main water sources: surface water (rivers, canals, and tanks), groundwater (wells and tube wells), rainfall, and minor water harvesting structures. According to the 2023 Dynamic Ground Water Resources report by the Central Ground Water Board, groundwater contributes nearly 62% of irrigation water use, with extraction totaling approximately 241 billion cubic meters annually. Large canal systems, particularly in the Indo-Gangetic plains, supply a significant proportion of surface water irrigation (Central Ground Water Board, 2023; Ministry of Jal Shakti, 2024). Rainfall serves as the principal source in rain- fed regions, notably central and southern India, though its uneven distribution often poses water management challenges (RajPriya, 2024).

Evolution of Irrigation in India

Post-independence, India invested heavily in irrigation infrastructure such as the Bhakra-Nangal Dam and the Indira Gandhi Canal, efforts that significantly expanded agricultural productivity and catalyzed the Green Revolution in states like Punjab, Haryana, and Western Uttar Pradesh (Ministry of Agriculture, 2023; RajPriya, 2024). Nonetheless, regional disparities remain stark, with eastern and tribal regions characterized by inadequate irrigation facilities and dependency on rainfall. Contemporary government policies emphasize modernizing irrigation through micro-irrigation, rainwater harvesting, and rejuvenation of canal networks to bridge these gaps (Ministry of Jal Shakti, 2024; Daugherty Water for Food, 2024).

Major Irrigation Methods

Surface Irrigation: The most traditional form involves flooding fields or directing water through canals and tanks. Although widely used for crops such as rice and sugarcane, it suffers from inefficiencies including water loss via evaporation and runoff (Soman, 2022).

Groundwater Irrigation: Accessed through wells and tube wells, groundwater irrigation accounts for a large share of India's irrigated area but raises sustainability concerns due to over-extraction in critical regions like Punjab and Tamil Nadu (Central Ground Water Board, 2023).

Drip and Sprinkler Irrigation: These micro-irrigation systems provide precise water application directly to the plant root zone, significantly enhancing water use efficiency by up to 50%, especially for horticultural crops and pulses (Soman, 2022; Daugherty Water for Food, 2024).

Micro-Irrigation and Fertigation: These systems further optimize water and nutrient delivery simultaneously, boosting productivity and resource use efficiency (RajPriya, 2024).

Rainwater Harvesting: Supplementary irrigation through rainwater harvesting methods such as farm ponds and rooftop tanks is being increasingly promoted in drought-prone areas noted for water scarcity (Ministry of Jal Shakti, 2024).

Table .1 Comparative Tables of Irrigation Methods in India

Method	Description	Advantages	Limitations	Typical Crops
Surface Irrigation	Use of canals, tanks, and floodwaters to irrigate fields.	Simple, low-cost, suitable for water-intensive crops.	Low efficiency due to evaporation and runoff.	Rice, Sugarcane, Wheat
Groundwater Irrigation	Use of wells and tube wells to extract groundwater.	Reliable water source, localized supply.	Over-extraction risks, high energy costs.	Wheat, Rice, Vegetables
Drip Irrigation	Slow, precise delivery of water directly to the plant root zone.	High water use efficiency reduces weed growth.	Initial cost, clogging issues.	Fruits, Vegetables, Pulses
Sprinkler Irrigation	Water sprayed over crops like rainfall using nozzles.	Uniform distribution, suitable for uneven terrain.	High energy requirement, affected by wind.	Wheat, Sugarcane, Vegetables

Irrigation Needs of Different Crops

Rice is highly water-intensive, traditionally grown under continuous flooding; however, recent pilot studies in Tamil Nadu using drip irrigation techniques have demonstrated substantial water savings and yield increases (Soman, 2022).

Wheat receives moderate irrigation, primarily in northern India, where sprinkler irrigation has been shown to reduce water requirements and prevent waterlogging (RajPriya, 2024).

Sugarcane irrigation demands are met through continuous supply; micro-irrigation has been successful in improving water productivity and reducing pest incidences in Maharashtra and Uttar Pradesh (Ministry of Agriculture, 2023).

Pulses and Oilseeds are largely rain-fed but benefit significantly from well-timed supplemental irrigation during flowering and grain filling stages (Daugherty Water for Food, 2024).

Vegetables and Orchards increasingly adopt drip and sprinkler irrigation to effectively manage water and improve crop quality (Soman, 2022).

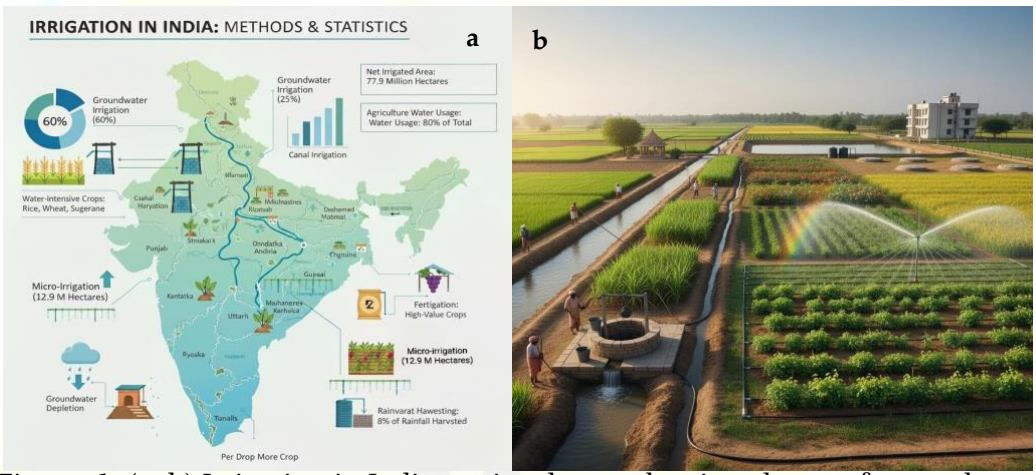

Figure: 1. (a, b) Irrigation in India: national map showing shares of groundwater and canal irrigation, net irrigated area, micro irrigation coverage, and regions with rainwater harvesting and high-water demand crops (rice, wheat, sugarcane), Field level examples of canal fed surface irrigation, tube well based groundwater use, and micro irrigation (sprinkler and drip) for vegetables and horticulture as promoted under PMKSY.

Irrigation Systems across Indian States and Typical Crops (CGWB, 2023; Ministry of Jal Shakti, 2024)

Andhra Pradesh: Canal irrigation, Groundwater, Micro-irrigation (Drip, Sprinkler), Smart Irrigation, (Rice, Cotton, Pulses).

Arunachal Pradesh: Surface water (river lift), Rainfed, (Rice, Maize, Millet).

Assam: Surface water (river lift), Rainfed, (Rice, Maize, Oilseeds).

Bihar: Canal and Groundwater irrigation, growing micro-irrigation adoption, (Rice, Wheat, Maize).
Chhattisgarh: Groundwater, Surface water (tanks, canals), Micro-irrigation initiatives, (Rice, Pulses).
Goa: Surface water, Rainfed, (Rice, Cashew, Coconut).
Gujarat: Groundwater, Drip irrigation, Sprinkler irrigation, Smart Irrigation, (Cotton, Groundnut, Vegetables).
Haryana: Groundwater irrigation (tube wells), Micro-irrigation, Smart Irrigation, (Wheat, Rice, Sugarcane)
Himachal Pradesh: Canal irrigation, Groundwater, Micro-irrigation, (Wheat, Maize, Fruits).
Jharkhand: Surface irrigation, Rainfed, Emerging micro-irrigation, (Rice, Pulses).
Karnataka: Canal irrigation, Groundwater, Drip and Sprinkler irrigation, Smart Irrigation, (Sugarcane, Horticulture).
Kerala: Surface irrigation (tanks), Rainfed, Limited micro-irrigation, (Rice, Coconut, and Rubber).
Madhya Pradesh: Groundwater, Canal irrigation, Micro-irrigation growth, Smart irrigation pilots, (Wheat, Soybean, Pulses).
Maharashtra: Surface irrigation, Drip and Sprinkler irrigation, Widespread Smart irrigation, (Sugarcane, Cotton, Horticulture).
Manipur: Surface water, Rainfed, (Rice, Maize).
Meghalaya, Mizoram, Nagaland: Rainfed, Surface water, (Rice, Maize).
Odisha: Canal irrigation, Rainwater harvesting, growing micro-irrigation adoption, (Rice, Pulses).
Punjab: Groundwater irrigation (bore wells), Micro-irrigation expansion, (Wheat, Rice, Sugarcane).
Rajasthan: Groundwater irrigation, Rainwater harvesting, Drip irrigation promotion, (Wheat, Bajra, Mustard).
Sikkim: Rainfed, Surface water, (Rice, Maize).
Tamil Nadu: Groundwater, Drip and Sprinkler irrigation, Smart irrigation adoption, (Rice, Banana, Sugarcane).
Telangana: Canal irrigation, Groundwater, Micro-irrigation, Smart Irrigation, (Rice, Cotton, Pulses).
Tripura: Surface water, Rainfed, (Rice, Maize).
Uttar Pradesh: Canal and Groundwater irrigation, Micro-irrigation progressing, (Wheat, Rice, Sugarcane).
Uttarakhand: Canal irrigation, Groundwater, Emerging drip and sprinkler systems, (Wheat, Rice, Maize).
West Bengal: Surface irrigation (canals, tanks), Groundwater, Micro-irrigation adoption, (Rice, Jute, Vegetables).

Government Initiatives for Irrigation Development

The flagship government initiative, Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), launched in 2015, aims for 'Har Khet Ko Pani'—water to every field enhancing irrigation potential by over 14 lakh hectares and facilitating installation of solar-driven pumps for over 22 lakh farmers by 2024 (Ministry of Jal Shakti, 2024). Complementary programs like the Accelerated Irrigation Benefit Programme (AIBP) focus on completing major irrigation projects. Subsidies and capacity building mechanisms foster adoption of efficient irrigation technologies while extension services promote farmer training (Ministry of Agriculture, 2023).

Challenges and Opportunities

India faces multiple irrigation challenges, including groundwater depletion mainly due to over drafting (Central Ground Water Board, 2023), stark regional inequalities in irrigation infrastructure (RajPriya, 2024), increased rainfall

variability due to climate change (Daugherty Water for Food, 2024), and limited awareness or capital investment for efficient technologies among smallholders (Soman, 2022). Opportunities lie in leveraging smart irrigation technologies, integrating traditional water conservation with modern innovations, and strengthening policy and farmer empowerment to build a resilient irrigation sector (Ministry of Jal Shakti, 2024).

Future Outlook

Future irrigation development rests on scaling micro-irrigation coverage, promoting solar-powered pumps, revitalizing traditional water harvesting methods, and applying precision agriculture techniques. Continued governmental support combined with farmer engagement will be crucial to enhancing water use efficiency, ensuring food security, and adapting to climate variability (RajPriya, 2024; Ministry of Jal Shakti, 2024).

Conclusion

India's irrigation development has greatly improved agricultural productivity and rural livelihoods. Continued emphasis on water-efficient, climate-resilient irrigation methods, supported by government policies and technology adoption, will be vital for sustainability. Addressing regional disparities and enhancing smart water management techniques remain key to meeting future challenges.

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