zef
Center for Development Research University of Bonn

ICRIER

PARI

Working Paper 243

Ashok Gulati, Ankana Rana and Ritika Juneja

Enhancing Agricultural Sustainability through Micro-Irrigation

ISSN 1864-6638 Bonn, March 2025

ZEF Working Paper Series, ISSN 1864-6638
Center for Development Research, University of Bonn

ZEF Working Papers are intended to stimulate discussion among researchers, practitioners and policy makers on current and emerging development issues. The papers are not peer-reviewed. They reflect work in progress and should be regarded as preprints.

Authors' addresses

Ashok Gulati, Indian Council for Research on International Economic Relations (ICRIER)
Email: agulati115@gmail.com, agulati@icrier.res.in

Ankana Rana, Indian Council for Research on International Economic Relations (ICRIER)
Email: ankanarana2001@gmail.com

Ritika Juneja, Indian Council for Research on International Economic Relations (ICRIER)
Email: ritikajuneja93@gmail.com

Enhancing Agricultural Sustainability through Micro-Irrigation

Ashok Gulati, Ankana Rana and Ritika Juneja

Abstract

This paper delves into the significant impact of micro-irrigation systems on agricultural sustainability in India. By analysing the evolution of micro-irrigation, government schemes promoting its adoption, case studies on benefit-cost analysis, challenges faced, and success stories, this paper aims to provide a comprehensive understanding of how micro-irrigation can revolutionize the agricultural landscape in India. The study compares the impact of drip irrigation adoption on various factors such as electricity consumption, costs, benefits, water use efficiency, and overall productivity. Through a detailed examination of the benefits of micro-irrigation systems on different crops and regions in India, this paper highlights the crucial role of this technology in achieving sustainable agriculture.

Keywords: irrigation, micro-irrigation, India, irrigation technology, cost-benefit analysis

JEL codes: Q12, Q15, Q25, Q55

Acknowledgments

This study was developed in the context of the Program of Accompanying Research for Agricultural Innovation (PARI), supported by the Federal German Ministry for Economic Cooperation and Development (BMZ).

Table of contents

List of Figures and Tables

1 Introduction

Globally, achieving water security has been identified as a critical development goal essential for environmental sustainability and human well-being. The agriculture sector, which accounts for approximately 69% of global water withdrawals according to United Nations estimates (2021), is central to discussions on water scarcity. Over the past three decades, there has been a growing recognition of the urgent need to develop strategies for managing scarce water resources within agriculture. India is currently facing a significant water scarcity crisis, which is exacerbated by the reliance on flood irrigation methods. The country has only about 4% of the world's freshwater resources, yet it supports over 1.4 billion people. This imbalance leads to widespread water shortages affecting both urban and rural populations, with agriculture consuming approximately 87% of available groundwater resources.

Empirical evidence shows that micro-irrigation can significantly reduce the energy footprint of agricultural practices while boosting crop yields and farmer incomes. Micro irrigation is a method which delivers water directly to plant roots in small, controlled amounts, ensuring water is applied precisely where it's needed. As a result, runoff and evaporation are minimized, making it particularly effective in conserving water in areas with limited resources. Micro-irrigation includes techniques such as drip irrigation and sprinkler irrigation. Drip irrigation irrigates root zone through emitters fitted on a lateral tube. Whereas, in sprinkler irrigation, water is discharged under pressure in the air through a set of nozzles attached to a network of pipes. As of March 2024, approximately 16.7 million hectare (mha)[1] or 21.6% of the net irrigated area[2] in India is under micro-irrigation , with significant variations among states. Numerous studies have highlighted substantial improvements in water use efficiency across various crops thanks to micro-irrigation. For example, in rice cultivation, drip irrigation can reduce water usage by up to 66.3%, cutting the traditional water requirement from 8,333 liters per kilogram of unmilled rice to just 1,724 liters (P. Soman, 2022).

India, with its diverse agro-climatic conditions and substantial reliance on agriculture for livelihoods, stands to benefit significantly from the widespread adoption of micro-irrigation systems. Recognizing this potential, the Indian government has implemented various schemes and policies to promote micro-irrigation. These initiatives aim to mitigate the adverse effects of water scarcity, enhance agricultural productivity, and ensure the long-term sustainability of the agriculture sector.

[1] As of 31st March 2022, the area under micro-irrigation, as reported in Agricultural Statistics at a Glance 2022 (Pg 194, Table 4.7), is 14.5 mha, with 6.67 mha under drip irrigation and 7.81 mha under sprinkler irrigation. For the years 2022-23 and 2023-24 (up to March), the data is sourced from the Micro Irrigation Progress Monitoring Portal, showing an area of 1.1 mha in 2022-23 and 1.14 mha in 2023-24, respectively.

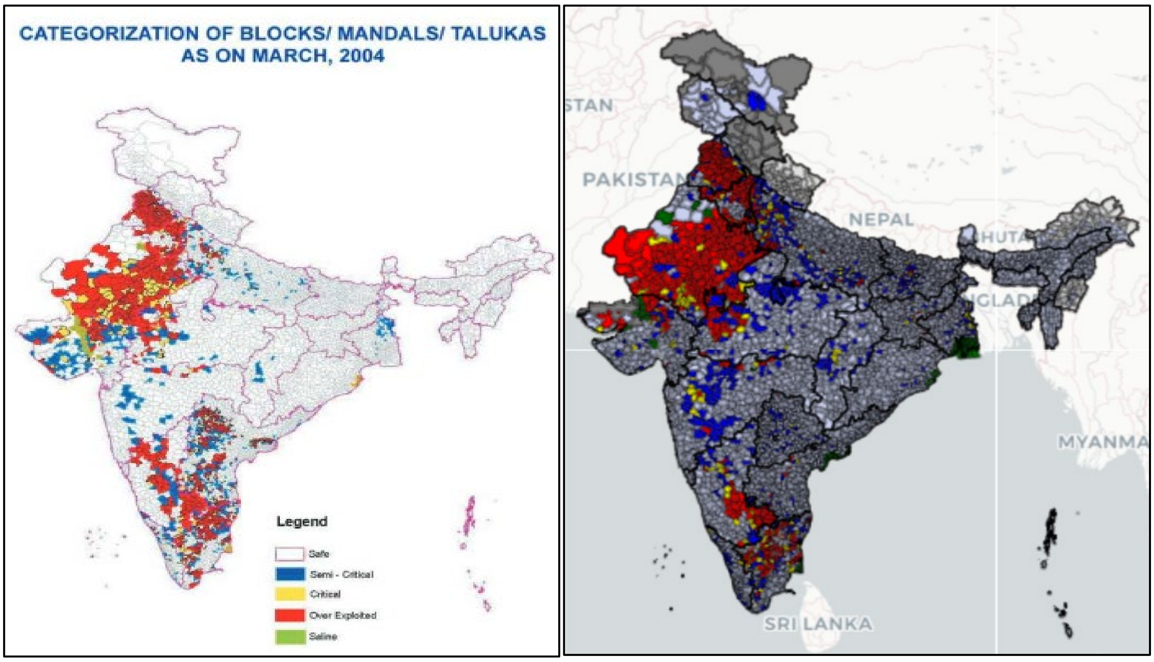
[2] Obtained by dividing area under micro-irrigation (16.7 mha) by net irrigated area (77.4 mha).

2 Irrigation Problem: Current Situation

Despite abundant water on Earth, only 2.5% is fresh water. According to the United Nations Food and Agriculture Organization (FAO), the Earth's total water reserve is approximately 1.4 billion km³, with fresh water making up 35 million km³. Of this, 68.7% is locked in ice and snow, and 30.1% exists as groundwater (GoI, 2021).

Groundwater recharge and extraction: In India, the annual groundwater recharge was 433 billion cubic meters (bcm) in 2004, fluctuated slightly, and peaked at 449 bcm in 2023. The main source of groundwater recharge is recharge through rainfall which contributes nearly 67% of the total annual groundwater recharge (GoI, 2021). The annual extractable groundwater resource, the sustainable portion of this recharge, was 399 bcm in 2004, decreasing slightly over the years but rising to 407 bcm by 2023. Annual groundwater extraction, which includes irrigation, domestic, and industrial usage, increased from 231 bcm in 2004 to 253 bcm in 2013, then varied slightly before settling at 241 bcm in 2023. As of 2023, the overall stage of groundwater extraction in India stands at 59.26%. However, some states and Union Territories (UTs) exhibit critical levels of extraction: Haryana (135.74%), Punjab (163.76%), and Rajasthan (148.77%), consuming more groundwater annually than is sustainably available. Delhi, Tamil Nadu, Uttar Pradesh, Karnataka, and the UTs of Chandigarh, Lakshadweep, and Puducherry fall between 60-100%. These findings underscore the urgent need for effective groundwater management and conservation, particularly in regions with high extraction rates (Central Ground Water Board, 2023).

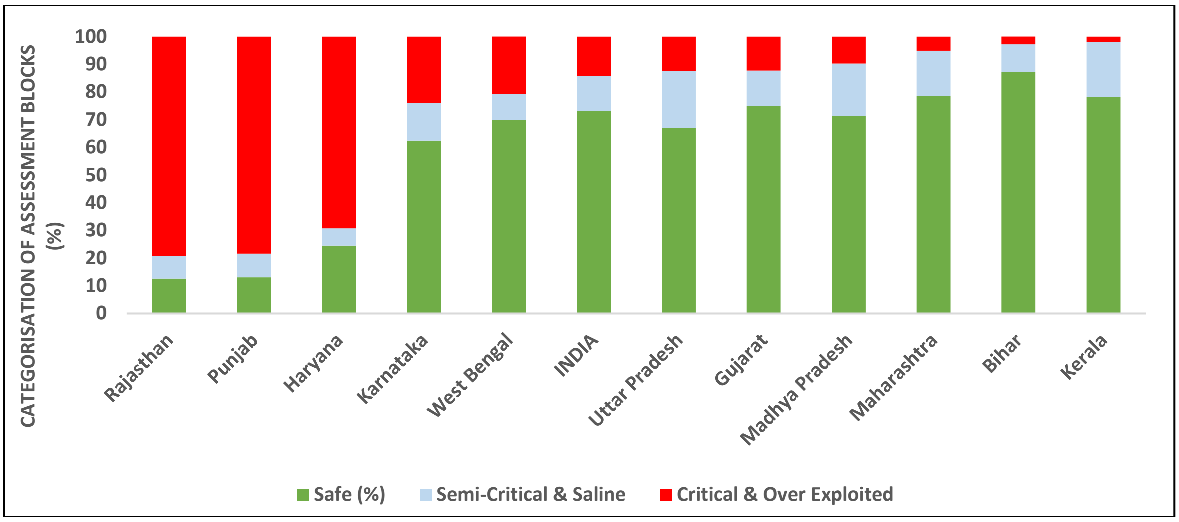
Figure 1: Changing Status of groundwater assessment blocks 2004 to 2022



Source: Central Ground Water Board (2023)

In the 75 years since Independence, annual per capita water availability has declined by 75% – from 6,042 cubic meters in 1947 to 1,486 cubic meters in 2021 (GoI, 2021). The per capita availability of water in India will be 1219 cum in the year 2050 against 1434 cum during 2025. Per capita availability of less than 1700 cum is termed as a water-stressed condition while if per capita availability falls below 1000 cum it is termed as a water scarcity condition (GoI, 2021). Groundwater, which supplies 40% of India's water needs, is being depleted at an unsustainable rate, as reported by Niti Aayog. As the largest groundwater user in the world, India is experiencing a widespread decline in water levels across the country. India accounts for 12% of global groundwater extraction, pumping some 230 billion cubic meters each year. At this rate, by 2030, nearly 60% of the aquifers will be in a critical state (Groundwater Yearbook in India, 2017-18).

Figure 2: Groundwater Development 2023



Source: Central Ground Water Board (2023)

Flood irrigation leads to Soil Salinization: Poor irrigation practices, such as excessive use of water or inadequate drainage, can result in the accumulation of salts in the soil. Soil salinization reduces soil fertility and can render land unsuitable for agriculture over time. The estimates based on 2012–14 data suggest that due to soil salinization India loses annually 16.84 million metric tonnes (MMT) of farm production (cereals, oilseeds, pulses, and cash crops) valued at Rs. 230.20 billion (Mandal et al., 2018). It has strong implications for the national economy. The state of Uttar Pradesh topped the list with 7.69 MMT production loss, followed by Gujarat state with 4.83 MMT production loss Gujarat experienced the highest monetary loss, amounting to Rs. 100.63 billion, followed by Uttar Pradesh with losses of Rs. 81.29 billion. Currently, about 6.74 mha of land in India are salt-affected, with an estimated 10% of arable land becoming salinized annually. If this trend continues, up to 50% of the country's arable land could be affected by 2050 (Sharma, 2020). Additionally, improper irrigation can lead to waterlogging, which restricts oxygen to plant roots, causing root rot and reduced crop yields.

Monsoon-dependent agricultural land: India's irrigation infrastructure includes major and minor canals, groundwater well systems, tanks, and rainwater harvesting projects. Groundwater systems irrigate about 39 mha, while canals serve around 22 mha of the 160 mha of cultivated land. Despite these systems, two-thirds of India's farmland still depends on monsoon rains. Improvements in irrigation over the past 50 years have enhanced food security, reduced monsoon reliance, increased agricultural productivity, and created rural jobs (Dr.S.Arunpriya, 2024).

The agricultural sector is the predominant consumer of groundwater resources. About 87% of total annual groundwater extraction i.e. 209.74 BCM is for irrigation use. The remaining is for Domestic (27.57 BCM) & Industrial (4.01 BCM) use (Central Ground Water Board, 2023; State wise groundwater resources of India, 2023). India's population, nearing 1.44 billion, raises concerns about boosting agricultural production to meet growing food demands. 48% of the geographical area of India received less than 1000 mm of rain and the rest 1000-2500 mm. and it lasts only for 3-4 months duration. Only 54.9% is irrigated area over Gross Cropped Area (GCA) according to Land Use Statistics 2021-22. With unpredictable rainfall India's agricultural sector is affected. The uniform distribution of water will improve crop yield.

3 Solution: Micro-irrigation

Micro-irrigation is a highly efficient water delivery system that directly applies a small amount of water to the root zone of plants. It helps in conserving water and energy, promoting sustainability in agriculture.

Cost-Benefit Analysis: The implementation of micro irrigation systems has consistently shown favourable benefit-cost ratios (BCRs) across various crops and regions, indicating significant economic benefits. For rice, P. Soman (2022) reported BCRs ranging from 1.4 to 2.1 across states like Andhra Pradesh, Maharashtra, and Punjab. Vegetable cultivation, particularly brinjal in Tamil Nadu, showed high BCRs of 4.7 with subsidy and 4.3 without subsidy, highlighting the profitability of drip irrigation (Narayanamoorthya et al., 2020). Sugarcane in Tamil Nadu demonstrated a BCR of 2.1 with subsidy and 2.02 without subsidy, with farmers recovering the initial investment within the first year (Narayanamoorthy, 2004). In Northern Maharashtra, sugarcane and banana had a BCR of 2.08 with subsidy (Subrata Gorain, 2018). Mango cultivation in Gujarat showed an impressive BCR of 4.68, while cotton and groundnut had BCRs of 2.21 and 4.16, respectively (Ram Vaibhav et al., 2018). Bajra and wheat in Gujarat had more moderate BCRs of 1.12 and 1.68, respectively, still reflecting economic benefits (Ram Vaibhav et al., 2018). Tomato cultivation in Tamil Nadu showed BCRs of 2.51 with subsidy and 2.15 without subsidy, demonstrating economic viability (K. Arulmani, 2022).

The benefit-cost ratio (BCR) analysis from the "National Mission on Micro Irrigation (NMMI)" 2014 study evaluates the economic returns from using MI systems for various crops across different states. In this study, BC ratio has been based on the estimates of incremental return/ income from the MI system that is taken into account the increase in individual farmer's income and MI system cost and crop wise average increase in income and average MI cost for each state worked out from the same. The field survey 2012-13 to get first-hand information was conducted for a total sample of 7400, comprising beneficiary and non-beneficiary farmers in these 13 states. For Brinjal, the highest BCR is observed in Maharashtra (2.98), indicating excellent financial returns for farmers. Similarly, cauliflower cultivation in Tamil Nadu shows a high BCR of 2.85, while guava in Bihar report a BCR of 2.97, demonstrating strong economic benefits in these regions. Haryana leads in Cauliflower production with a BCR of 2.88, and UP shows a notable BCR of 2.86 for guava and potato, highlighting the efficiency of MI systems in these areas. Okra achieves its highest BCR in Odisha (2.87). Tomato cultivation in Odisha and Sikkim yields the highest BCR of 2.94, emphasizing the cost-effectiveness of MI systems. The analysis also highlights significant returns for Banana in Maharashtra (BCR 2.91) and Coconut in Odisha (BCR 2.72). Mango in UP has a BCR of 2.95, showcasing the lucrative nature of these crops with MI systems.

A study by D. Suresh Kumar on the Social Benefit-Cost Analysis of Drip Irrigation in Coimbatore, Tamil Nadu, found that drip irrigation leads to significant water savings. In over-exploited regions, it saves Rs 1,49,393.60 per hectare, while in semi-critical regions, the savings amount to Rs 76,943.60 per hectare. Here value of water is priced by multiplying marginal physical product (MPP) by price of the crop[3]. Additionally, drip irrigation reduces power consumption, with electricity usage of 1,554.6 kWh/year per hectare in over-exploited areas (62.2% less than traditional methods) and 974.9 kWh/year per hectare in semi-critical regions (77.68% less).

The benefit-cost ratio (BCR) is a crucial measure for determining the economic viability of micro irrigation systems in agriculture. The literature consistently shows that micro irrigation, despite its initial costs, offers significant economic benefits by enhancing crop yields and reducing water and energy usage. High BCRs indicate that farmers can quickly recoup their investment and achieve substantial profits. This technology proves particularly beneficial for high-value crops, providing impressive returns even without subsidies. Overall, micro irrigation not only boosts productivity but also ensures sustainable resource management, making it a highly profitable investment for farmers.

[3] It is important to note that here the MMP could be a result of other factors of production besides water like fertilizers etc.

Types of Micro Irrigation

1. Drip Irrigation System

Drip irrigation is highly efficient, reducing water wastage and ensuring that water reaches the root zone of plants directly. Different types of drip irrigation system are:

Figure 3: Type of drip irrigation systems

(i) Surface Drip Irrigation

- **Characteristics**: Water is applied directly to the soil surface using emitters placed along the drip lines.
- **Advantages**: Easy to install and maintain; suitable for various crops, including vegetables, fruits, and row crops.
- **Applications**: Used in regions with water scarcity and for crops that require precise water application.

(ii) Sub-surface Drip Irrigation

- **Characteristics**: Emitters are buried below the soil surface, delivering water directly to the root zone.
- **Advantages**: Reduces evaporation and surface runoff; minimizes weed growth and soil erosion.
- **Applications**: Ideal for perennial crops, orchards, and vineyards.

(iii) Family Drip

- **Characteristics**: A scaled-down version of drip irrigation systems, designed for small-scale farming or home gardens.
- **Advantages**: Cost-effective and easy to manage; suitable for family gardens and smallholder farms.
- **Applications**: Used for growing vegetables, herbs, and small fruit orchards.

(iv) Online Drip

- **Characteristics**: Emitters are attached externally to the lateral pipes, allowing flexibility in emitter placement.
- **Advantages**: Easy to customize and replace emitters; suitable for crops with varying water requirements.
- **Applications**: Used for orchards, vineyards, and landscape irrigation.

(v) In-line Drip

- **Characteristics**: Emitters are integrated into the drip lines at regular intervals, ensuring uniform water distribution.
- **Advantages**: Low maintenance and reduced clogging; suitable for crops planted in rows.
- **Applications**: Used for row crops, vegetables, and field crops.

2. Sprinkler Irrigation System

Sprinkler irrigation mimics natural rainfall, making it suitable for a wide range of crops and terrains.

Figure 4: Types of sprinkler irrigation systems

(i) Centre Pivot

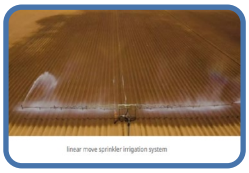
- **Characteristics**: A rotating arm with sprinklers attached, pivoting around a central point to irrigate circular fields.
- **Advantages**: Covers large areas efficiently; automated operation reduces labor.
- **Applications**: Commonly used for large-scale farming of crops like corn, wheat, and alfalfa.

(ii) Towable Pivot

- **Characteristics**: Similar to center pivot but can be moved between fields to maximize equipment usage.
- **Advantages**: Flexible and cost-effective for farmers with multiple fields; reduces equipment investment
- **Applications**: Suitable for medium to large farms growing diverse crops.

(iii) Rain Gun

- **Characteristics**: High-pressure sprinklers that can cover large areas with a single jet.
- **Advantages**: Ideal for large fields; can be used for irrigation, dust control, and frost protection.
- **Applications**: Used for crops like sugarcane, maize, and pasture lands.



(iv) Linear Move Sprinkler

- **Characteristics**: Moves laterally across the field, providing uniform water distribution over rectangular areas.
- **Advantages**: Even coverage; suitable for fields that are not suitable for center pivots.
- **Applications**: Used for large, rectangular fields growing crops like wheat, barley, and soybeans.

(v) Solid Set and Permanent sprinkler irrigation Systems

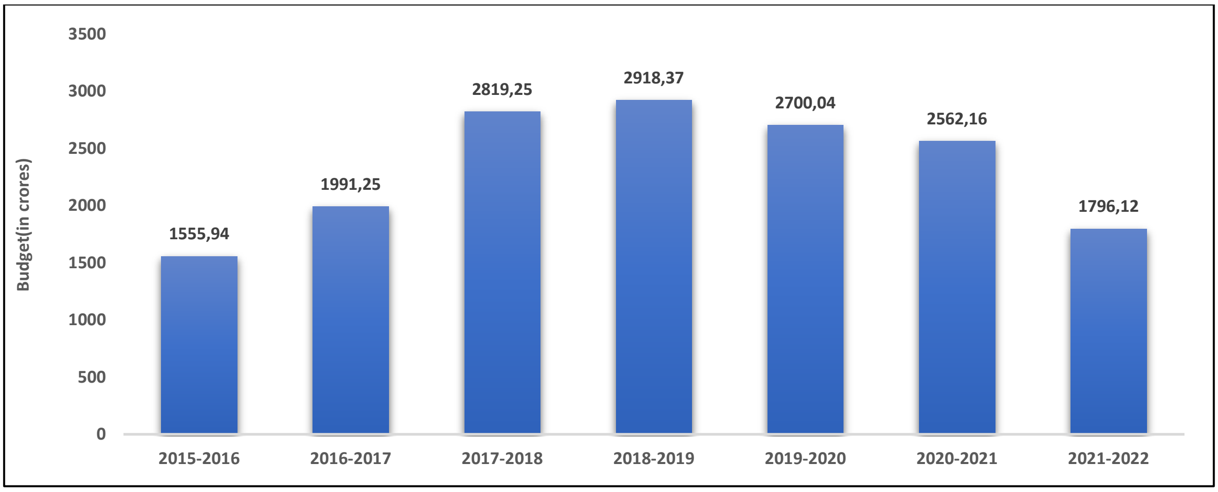
- Solid Set and Permanent sprinkler irrigation SystemsIn this type of sprinkler irrigation system, a sprinkler irrigates from a fixed position. For a solid set sprinkler irrigation system, the pipe laterals are moved into the field at the beginning of each irrigation season, and remain there until the season is over

4 Government Schemes and Subsidies for Promoting Micro Irrigation in India

The journey of micro-irrigation in India began in 1981 with the establishment of the National Committee on Use of Plastics in Agriculture (NCPA) under the Department of Chemicals and Petrochemicals. This committee aimed to promote the use of plastics in agriculture, including micro-irrigation systems. By 1985, the National Bank for Agriculture and Rural Development (NABARD) started financing these systems, initially allocating Rs. 385 crores, which increased to Rs. 499.76 crore by 1989-90. In 1992, the Centrally Sponsored Scheme on Use of Plastic in Agriculture was introduced to popularize plasticulture applications like drip irrigation and greenhouses, providing substantial financial assistance to farmers. The following year, the NCPA was transferred to the Ministry of Agriculture, becoming the National Committee on Plasticulture Applications in Horticulture (NCPAH), focusing on horticultural applications.

The Rural Infrastructure Development Fund (RIDF), launched by NABARD in 1995, provided loans for rural infrastructure projects, including irrigation. The National Horticulture Mission (NHM) was established in 2005 to boost horticultural growth through micro-irrigation. In 2006, the Centrally Sponsored Scheme on Micro-Irrigation aimed to implement drip and sprinkler irrigation systems with subsidies, improving water use efficiency and crop yields. The Rashtriya Krishi Vikas Yojana (RKVY), launched in 2007, aimed to accelerate agricultural growth, including the promotion of micro-irrigation. The same year, the National Food Security Mission (NFSM) was introduced to increase the production of rice, wheat, and pulses, providing funding opportunities for micro-irrigation projects. In 2010, the National Mission on Micro-Irrigation (NMMI) was reintroduced to further promote drip and sprinkler irrigation with increased subsidies for small and marginal farmers. By 2014, the National Mission on Micro Irrigation (NMMI) was integrated into the National Mission on Sustainable Agriculture (NMSA) under the "On-Farm Water Management" (OFWM) initiative. The Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), launched on July 1, 2015, adopted the "Per Drop More Crop" principle, with micro-irrigation as a pivotal component.

Figure 5: Expenditure Budget For PMKSY – PDMC (India)



Source: indiabudget.gov.in previous union budget

Under the micro irrigation scheme, the assistance provided to beneficiaries is structured such that small and marginal farmers receive 55% assistance, while other farmers receive 45%. This support is funded jointly by the Central and State Governments in a 60:40 ratio for all states, except for the North Eastern and Himalayan states, which may have different funding arrangements. In the case of these states, the ratio of sharing is 90:10. For the Union Territories, the funding pattern is 100% granted by the Central Government. And the subsidy limits of 5 ha. per farmer and the subsidy cycle is 7 years.

From 2022-23 PDMC comes under the RKVY umbrella budget of Rs. 5247.43 Cr. However, PMKSY website gives 4043.4 Cr. for PDMC (2022-23) and while adding individual state budget (Fund Release) the sum amount is to 1807 Cr. (2022-23) and 1165 Cr. for (2023-2024). An amount of Rs. 18714.69 crore has been released as Central Assistance to the States under PDMC Scheme from 2015-16 to December 2023 (Ministry of Agriculture & Farmers Welfare:Per Drop More Crop, 2023).

Table 1: State-wise Budget under PMKSY-PDMC (RS CRORES)

States	**2019-20**	**2020-21**	**2021-22**	**2022-23**	**2023-24**
Bihar	0	0	21.6	9.5	11
Haryana	0	98	57.6	78	33
Madhya Pradesh	0	125	0	50	55
Punjab	0	0	0	3.75	6
Uttar Pradesh	38.8	200	150	149.2	121
West Bengal	0	57.4	0	0	23
Tamil Nadu	80	400	116	160	202.5
Gujarat	134.8	273	72.8	113	227.7
Rajashthan	0	200	100	186	51.2
Maharashtra	0	300	200	334	92.5
Karnataka	0	400	500	188	122

Source: pmksy.gov.in

Note: Before 2019-20 fund release for Supplementary Water Management Activities (SWMA)

State-wise budget allocations under the Pradhan Mantri Krishi Sinchayee Yojana-Per Drop More Crop (PMKSY-PDMC) scheme from 2019-20 to 2023-24 reveals significant variations influenced by multiple factors. States like Tamil Nadu, Gujarat, and Karnataka receive consistently higher allocations, likely due to their superior infrastructure, administrative capabilities, and readiness to implement micro-irrigation projects. These states have demonstrated effective utilization of funds. But Karnataka fund allocation is continuously decreasing. central grants, which are a major component of state budgets, are expected to decline from 19.9% of Karnataka's total revenue receipts in 2020-21 to 11.73% in 2022-23 (Hindu, 2023).

5 Present Micro-irrigation Scenario: Coverage

The gross cropped area was 219.15 mha in 2021-22, and the net area sown was 141 mha, accounting for 64.4% of the gross cropped area. The gross irrigated area was 120.47 mha, which is 55% of the gross cropped area. For the year 2023-24, the total micro-irrigation area covered is 16.7 mha as of March 2024, which is 21.5% of the net irrigated area. This micro-irrigation coverage includes 9.05 mha (54%) by sprinkler irrigation and 7.69 Mha (46%) by drip irrigation.

Table 2: Land use statistics (2021-22)

Land use statistics (2021-22)	**Area (mha)**
Geographical area	328.75
Total cropped area	219.16
Net area sown	141.01
Net irrigated area	77.92
Gross irrigated area	120.38
Net area irrigated from canals	19.22
Net area irrigated from wells	47.11

Source: Land use statistics (2021-22)

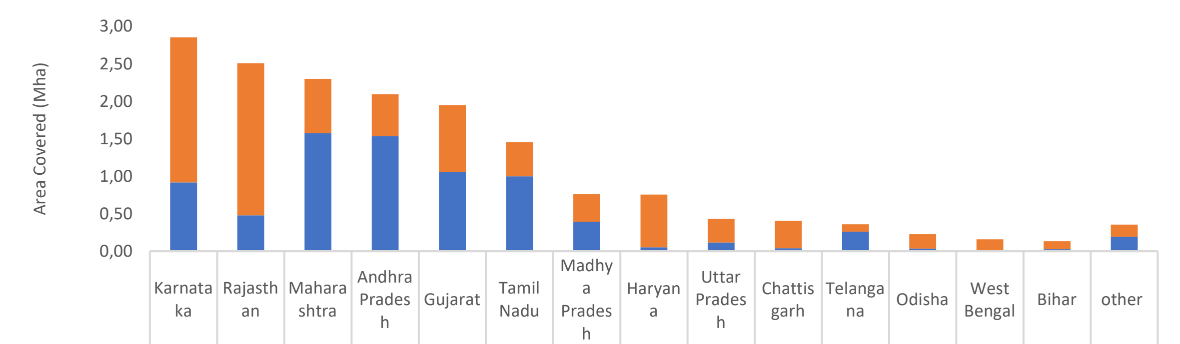
State-wise irrigated areas and the percentage of micro-irrigation (MI) potential covered in 2021-22 highlights significant disparities across different states in India. Karnataka, with an irrigated area of 4.92 mha, has covered 58.0% of its MI potential, showing substantial adoption. **Maharashtra and Andhra Pradesh** have notably high MI coverage of 74% and 71% respectively, despite having smaller irrigated areas of 3.10 mha and 2.95 mha. Conversely, states like Uttar Pradesh and Bihar, with larger irrigated areas of 13.94 mha and 3.08 mha respectively, but exhibit low MI adoption rates of 3.1% and 4.3%. Gujarat, with 5.80 mha of irrigated area, covers 33.6% of its MI potential, while Tamil Nadu, with 2.93 mha, achieves 49.7% coverage. Rajasthan, with the second-largest irrigated area of 8.92 mha, has a moderate MI coverage of 29.0%. Despite having significant irrigated areas (12.90 mha and 3.13 mha), states like Madhya Pradesh and West Bengal show low MI adoption rates of 5.9% and 5.0% respectively. The disparities suggest that while some states have made significant strides in adopting micro-irrigation, others lag due to various factors, including infrastructure, awareness, and state-specific agricultural policies.

Figure 6 shows the adoption of micro-irrigation systems (sprinkler and drip irrigation) across various Indian states (as of March, 2024). **Karnataka** leads with total coverage of 2.86 million hectares (mha) constituting 17% of the total area under MI, predominantly using sprinkler systems (1.94 mha), followed by Rajasthan at 2.58 mha (15%), and Maharashtra at 2.30 mha (14%). Rajasthan has the highest sprinkler irrigation coverage at 2.03 Mha, reflecting its water-scarce conditions, while Andhra Pradesh and Gujarat both cover significant portions, each accounting for 12% of the total MI area, with 2.09 mha and 1.95 mha respectively. Tamil Nadu covers 1.46 mha (9%), while Madhya Pradesh and Haryana each cover around 5% with 0.76 mha and 0.75 mha respectively. Other notable contributions include Uttar Pradesh at 0.43 mha (3%), Telangana at 0.36 mha (2%), and West Bengal at 0.16 mha (1%). Chhattisgarh, Odisha, and Bihar cover smaller portions, each contributing around 1% or less.

Area covered under drip irrigation: In the distribution of areas covered under drip irrigation across various states in India, **Maharashtra** leads with the largest area, covering 1.57 mha, accounting for 20% of the total area under drip irrigation. Andhra Pradesh follows closely with 1.53 mha, also representing 20%. Gujarat and Tamil Nadu have significant coverage, with 1.06 mha (14%) and 1 mha (13%), respectively. Karnataka, with 0.92 mha, accounts for 12%, while Rajasthan covers 0.48 mha (6%). Madhya Pradesh, Telangana, and Uttar Pradesh have smaller areas, ranging from 0.39 mha (5%)

to 0.12 mha (2%). Other states like Haryana, Chhattisgarh, Odisha, Bihar, and West Bengal have minimal coverage, each contributing less than 1%.

Figure 6: State-wise Area Covered under Micro Irrigation (as on March, 2024)

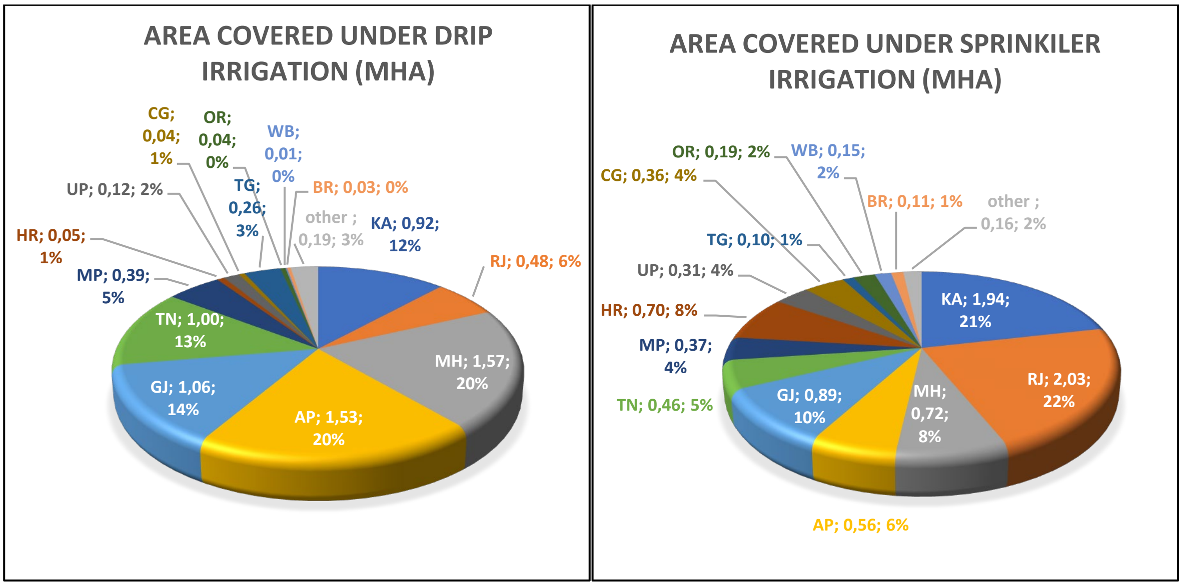


	Karnataka	Rajasthan	Maharashtra	Andhra Pradesh	Gujarat	Tamil Nadu	Madhya Pradesh	Haryana	Uttar Pradesh	Chattisgarh	Telangana	Odisha	West Bengal	Bihar	other
SPRINKLER	1,94	2,03	0,72	0,56	0,89	0,46	0,37	0,70	0,31	0,36	0,10	0,19	0,15	0,11	0,16
DRIP	0,92	0,48	1,57	1,53	1,06	1,00	0,39	0,05	0,12	0,04	0,26	0,04	0,01	0,03	0,19

Source: Agricultural statistics 2022 for up to 2022, PMKSY website for up to 2024

Area covered under sprinkler irrigation: In the distribution of areas covered under sprinkler irrigation across various states in India, **Rajasthan** leads with the largest area, covering 2.03 mha, accounting for 22% of the total area under sprinkler irrigation. Karnataka follows closely with 1.94 mha, making up 21%. Gujarat and Haryana also have significant coverage, with 0.89 mha (10%) and 0.70 mha (8%), respectively. Maharashtra, with 0.72 MHA, and Madhya Pradesh, with 0.37 mha, both contribute 8% and 4% to the total area. Other states like Tamil Nadu, Andhra Pradesh, and Chhattisgarh have smaller areas, ranging from 0.46 mha (5%) to 0.36 mha (4%). Additionally, Telangana, Uttar Pradesh, West Bengal, Odisha, and Bihar have minimal coverage, each contributing between 0.1% to 2%.

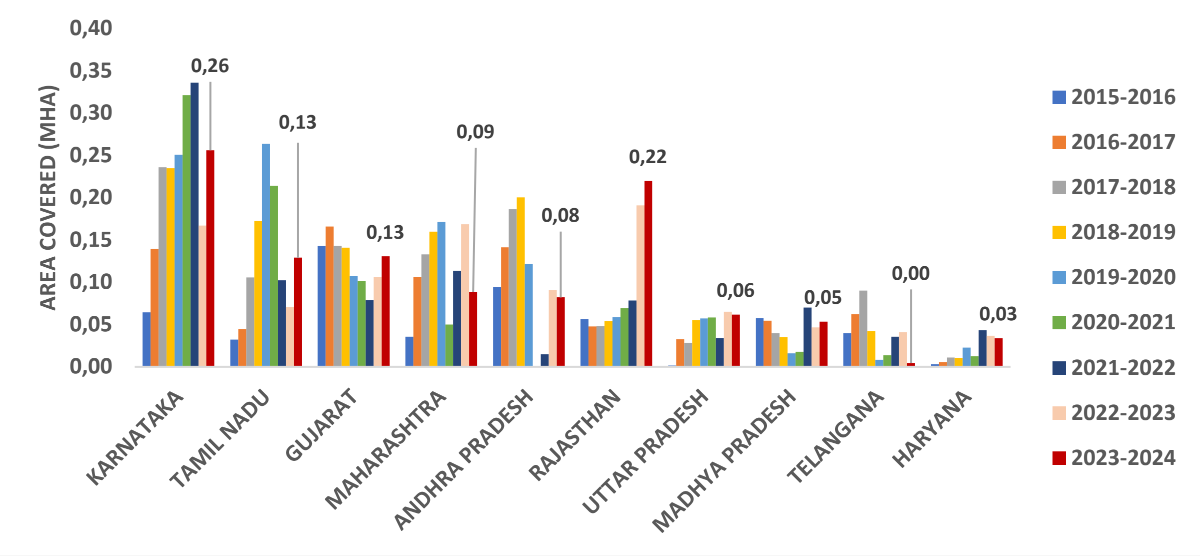
Figure 7: Area Covered under Drip Irrigation & Sprinkler Irrigation



Source: Agricultural statistics 2022 for up to 2022, PMKSY website for up to 2024

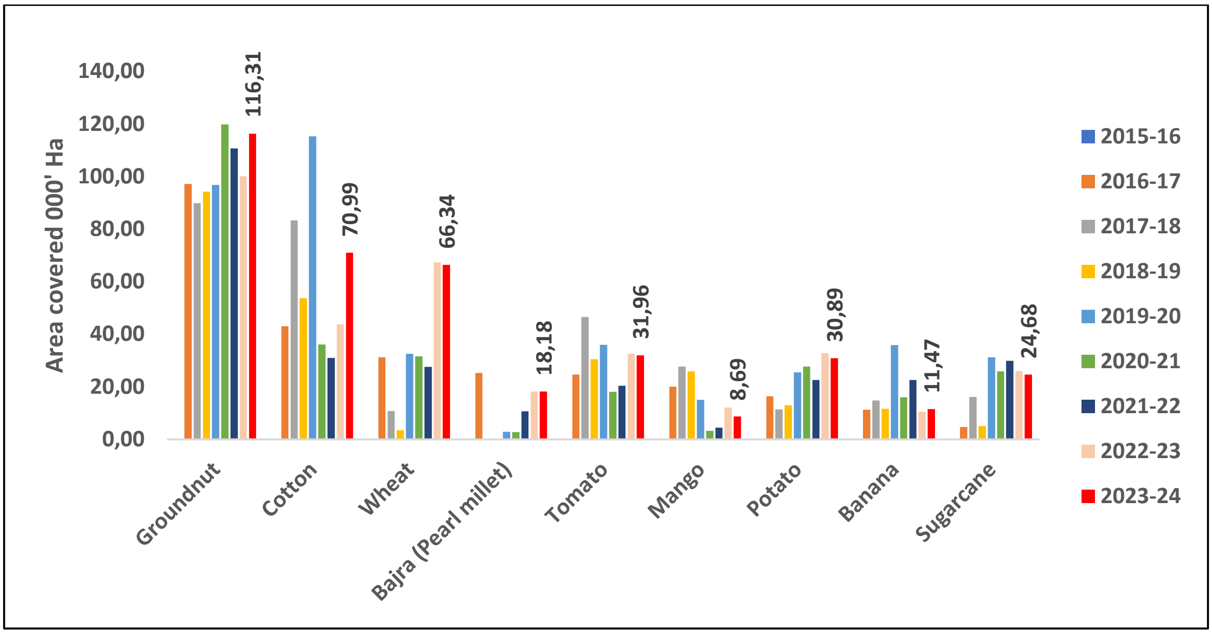
Figure 8 depicts the annual increase in the area covered by micro-irrigation across ten states over nine years, from 2015-16 to 2023-24. Karnataka and Tamil Nadu show the most significant growth, particularly in 2020-21 and 2021-22 for Karnataka, and in 2019-20 for Tamil Nadu. In 2023-24 Karnataka achieved highest increment of area covered followed by Rajasthan.

Figure 8: Increment of area of Micro irrigation top 10 states 2015-16 to 2023-24



Source: PMKSY

Figure 9: Crop-wise increment under MI 2015-16 to 2023-24



Source: PMKSY

The trend analysis of the incremental area covered under micro-irrigation (MI) from 2015 to 2024 shows a growing adoption across various crops in Figure 9. Groundnut and cotton have seen significant increases in MI use, especially groundnut, which peaked at about 119.83 thousand hectares in 2020-21. Cotton also reached a high of around 115.32 thousand hectares in 2019-20. Wheat's use of MI systems increased notably in recent years, particularly in 2022-23 and 2023-24. Other crops like tomato, mango, and banana have shown gradual growth in MI adoption. Sugarcane, known for its high-water needs, also sees a steady increase in MI use, reflecting a shift towards more efficient water management. Overall, these trends indicate that more farmers are recognizing the benefits of micro-irrigation in saving water and improving crop yields.

6 Comparison between Benefit-Cost analysis of MI vis-à-vis Conventional Irrigation

Soman's study investigates the impact of drip irrigation and fertigation technology on rice production across multiple Indian states, including Andhra Pradesh, Maharashtra, Rajasthan, Uttar Pradesh, Tamil Nadu, Punjab, and Chhattisgarh. The study reports a notable improvement in the benefit-cost (BC) ratio, ranging from 1.4 to 2.1 depending on the region and variety of rice. Key benefits observed in Coimbatore, Tamil Nadu (Rice variety, ADT 45) 2009-10 include a 22.5% increase in yield, a 66.3% reduction in water usage, and a 52% savings in energy consumption. This substantial reduction in water use not only enhances water productivity but also helps mitigate methane emissions associated with conventional rice cultivation. Methane is produced in rice fields primarily due to standing water and the anaerobic decomposition of organic matter. By implementing drip irrigation, which minimizes standing water, the conditions for methane formation are significantly reduced, thereby mitigating this major environmental issue. This study also examines the rotation crop after the main rice crop under drip irrigation improved yield like rice (3.6 t/acre) with rice (2.6 t/acre) but with maize (5.2t/acre), brinjal (40 t/acre) (P.Soman, 2022).

Narayanamoorthya (2018) conducted a detailed assessment of the economic impact of drip irrigation on vegetable production, focusing on brinjal cultivation in Tamil Nadu's Sivagangai district. For this study, we have selected a total of 50 brinjal farmers; 25 adopters of DMI and 25 non-adopters of DMI. The study reveals substantial benefits of adopting drip irrigation, including a 52% increase in yield, a 40% reduction in water usage, and improved fertilizer and energy use efficiencies of 31% and 41%, respectively. In this study it was found that in DMI the irrigation cost is Rs 2400/acre whereas in FMI Rs 6416/acre. For fertilizer cost in DMI Rs 10361/acre and in FMI Rs 15074. Economically, the benefit-cost ratio (BCR) is 4.7 with government subsidies and 4.3 without, indicating high returns on investment. The net present value (NPV) is favorable, and the payback period for the investment is relatively short, often within the first year. These findings highlight the economic viability and efficiency of drip irrigation, especially when supported by subsidies, demonstrating significant improvements in productivity and resource use for brinjal farmers.

Vasant P. Gandhi (2021) assesses the effectiveness of the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) – Per Drop More Crop (PDMC) program in enhancing micro irrigation through a survey involving 621 farmers across 5 states namely Uttar Pradesh, Madhya Pradesh, Maharashtra, Telangana, and Sikkim. The findings indicate that 90% of farmers reported increased yields due to micro-irrigation, while 92% noted improved water use efficiency, and 74% experienced reduced labor requirements. Despite these significant benefits, including enhanced crop yields, increased profits, and decreased water usage, the study highlights challenges such as high initial costs and maintenance issues, which hinder broader adoption program to maximize its benefits and facilitate wider adoption of micro irrigation in India.

Debajit Roy (2020) analyzed the impact of micro-irrigation under the Pradhan Mantri Krishi Sinchayee Yojana: Per Drop More Crop (PMKSY-PDMC) program in Sikkim, India. This survey-based study involved 120 farmers, with 96 adopting micro-irrigation and 24 not. The study reports that 100% of the installation costs were covered by subsidies, although farmers were responsible for maintenance expenses. The adoption of micro-irrigation led to a notable shift in cropping patterns toward high-value vegetables such as cauliflower, broccoli, and cabbage. This transition resulted in significant yield improvements—46.23% for broccoli, 36.26% for cauliflower, and 36.75% for cabbage. Additionally, labor costs were reduced 7.99% for broccoli, 6.14% for cauliflower, and 2.25% for cabbage. Micro-irrigation has also reduced water use and improved farm profitability, despite increased input costs like farmyard manure. Government subsidies have been pivotal in encouraging adoption, though challenges such as water scarcity and equipment maintenance remain. Sikkim's adherence to organic cultivation eliminates costs for fertilizers and pesticides, further enhancing the economic benefits of micro-irrigation.

Vaibhav R. (2018) conducted a comprehensive analysis of the impact of micro-irrigation systems (MIS) on a range of crops in the Junagadh District of Gujarat, covering an area of 210 hectares. Their study highlighted the economic viability of MIS, showing an average benefit-cost (BC) ratio of 3.113 among studied crops like sugarcane cotton wheat ground nut mango and bajra. The study reported significant improvements in crop yields, with mango seeing an increase of 81.9% and sugarcane benefiting from a 41.5% yield improvement. Groundnut and bajra also experienced notable yield increase of 40.8% and 25%, respectively. Water use efficiency was markedly improved, with water savings 37% for groundnut and cotton , 46% for sugarcane, 38% for bajra, 29 % for wheat, 64% for mango . Furthermore, the study observed reductions in fertilizer costs, with cotton experiencing a 51% and 40 % for bajra decrease . Despite the higher initial costs of installing MIS, the long-term benefits—including enhanced yields, reduced water use, and lower input costs—justify the investment. The findings advocate for the broader adoption of drip irrigation, underscoring its role in boosting agricultural productivity, sustainability, and farmers' livelihoods, particularly in semi-arid regions.

An economic analysis of tomato cultivation using drip irrigation systems in the Shoolagiri block of Krishnagiri district, Tamil Nadu was conducted. The study evaluates the cost-effectiveness of adopting drip irrigation technology for tomato farming. It revealed that the benefit-cost (BC) ratio is 2.51 with subsidies and 2.15 without subsidies, indicating favorable economic returns. The total cost of cultivation per hectare was Rs. 414,606.28, while the installation of the drip irrigation system cost Rs. 243,143. Despite these costs, the net profit per kilogram of tomato produced was Rs. 16.91, demonstrating significant economic benefits for farmers. The study emphasizes the economic viability of drip irrigation, showing that it can be a profitable investment for tomato cultivation. However, it also highlights the critical need for technical training and support for farmers. Proper maintenance and effective utilization of the drip irrigation systems are essential for sustaining the benefits. Providing technical training and support can help farmers overcome constraints and ensure the longevity and efficiency of the drip irrigation systems, thus maximizing their economic and productivity gains (Arulmani, 2022).

In 2017, the Gujarat Green Revolution Company Ltd. (GGRC) conducted a comprehensive study on the impact of micro irrigation (MI) across various crops, including banana, castor, cotton, potato, sugarcane, vegetables, orchard crops, and groundnut etc. This initiative involved 7,217 farmers and covered a substantial area of 158,992 hectares. The study revealed significant benefits of MI adoption. Crop productivity saw an increase of 20-38%, reflecting notable improvements in yield. Water use efficiency improved dramatically, with savings ranging from 20-55%, highlighting the system's effectiveness in reducing water consumption. Additionally, the use of pesticides decreased by 26%, indicating enhanced fertilizer use efficiency. The study also reported a 41% improvement in energy use efficiency. These outcomes underscore the advantages of micro irrigation in boosting agricultural productivity, conserving water, and improving overall farm efficiency.

Gorain, S. (2018) examined the social costs and benefits of drip irrigation systems in Northern Maharashtra. The study revealed substantial benefits cost ratio 2.08 , including a 51.8% increase in sugarcane yields and a 16.7% increase in banana yields. Energy savings were significant, with reductions of 30.68% for sugarcane and 26.38% for bananas. Water savings were even more pronounced, at 82% for sugarcane and 86% for banana. The economic value of water was calculated at ₹19.90 per cubic meter for sugarcane and ₹19.13 per cubic meter for bananas. However, this study did not calculate BCR with and without subsidy and also for sugarcane and bananas separately. Despite the high initial costs and subsidies required, the study highlights the positive externalities of drip irrigation, such as water and energy conservation and increased yields, while also noting the social costs, including investment in infrastructure and subsidies.

Narayanamoorthy (2004) also conducted an impact assessment of drip irrigation in sugarcane cultivation in Okkur village, Sivagangai district, Tamil Nadu. The study revealed a significant yield improvement of 54% when drip irrigation was adopted. Water savings were substantial, with a 58% reduction in water use and an efficiency increase of 73%. Energy savings were also notable, with a 58% reduction in energy use and a 73% improvement in electricity efficiency. The economic analysis showed that drip irrigation was viable even without government subsidies, with a benefit-cost ratio ranging from 1.97 to 2.02. With a 30% subsidy, the ratio improved to 2.06-2.10. The study concluded that farmers could recover the entire capital cost of the drip irrigation system from the increased income generated in the first year, underscoring the economic benefits of adopting drip irrigation for sugarcane cultivation (Narayanamoorthy, 2004).

Capital cost & Maintenance cost:

Total cost to drip (without subsidy) Rs 243143 / Ha which include PVC pipes (Rs 21175 /ha), Laterals (1467), emitting pipes (Rs 198373)/ha), Valves (Rs 5204/ha), Screen filters (Rs 3400), Venturi and main fold (Rs 2250/ha), bypass assembly (Rs700/Ha) Fitting (3609/ha) and maintenance cost (Rs 6965/ha). (K. Arulmani ,2022). But there is another study which calculated capital cost of drip set (without subsidy)-Rs 36928/acre. (Narayanamoorthya et al. (2018). Dr. soman cost of drip equipment varies state to state range is Rs 30000- 60000/ acre and seasonal cost varies from Rs 2000- 4500/acre. In Vasant Gandhi's paper it was found that drip irrigation sets, on average, cost Rs. 1,81,820/ha after government subsidies, while sprinkler sets are cheaper at Rs. 47,166/ha where farmers only paid Rs. 65889/ha and Rs 14511/ha respectively. Additional components such as filters, pipes, valves, and pumps (Rs. 40083/ha) contribute to the overall capital cost, which averages Rs. 1,76,967/ha where Rs 89792 /ha is paid and Rs 81843/ha is received by farmer. Farmers also incur yearly maintenance expenses of around Rs. 2,877/ha on items like filters, pipes, and valves. But there is no government support for these maintenance costs reported by farmers (Vasant P. Gandhi, 2021).

Table 3: Capital cost & Maintenance cost

Source	Capital Cost (Rs/acre)	Maintenance Cost (Rs/acre/year)	Total Cost (Rs/acre)	Remarks
(AGRI FARMING, n.d.), Times of Agriculture (Drip)	45,000 - 60,000	4,500 - 6,000	-	Capital cost varies by region; maintenance is approximately 10% of installation cost.
Jain Irrigation Ltd (Sprinkler)	61,300	6,130	1,226,000 (over 10 years)	Total cost includes installation and 10 years of maintenance.
(Asia Farming, n.d.) Micro Sprinkler			60000-80000	
(Asia Farming, n.d.) Drip Irrigation			80000-100000	
K. Arulmani, 2022	-	6,965	Rs 2,43,143/ ha	Detailed breakdown of component costs provided.
Narayanamoorthya et al., 2018	36,928	-	-	Lower capital cost estimate without subsidy.
P. Soman (varies by state)2022	30,000 - 60,000	2,000 - 4,500	-	Costs vary significantly across different states.
(National Mission on Micro Irrigation NMMI, 2014) **Drip System** **Sprinkler System**	Rs. 59,531/ha (Uttarakhand) to Rs. 72,086 /ha(Gujarat). Rs. 20,471/ha (Uttar Pradesh) to Rs. 28,171			The study involved a sample of 7400 farmers across various states.

	/ha (Rajasthan).			
(Kumar, 2007)			Rs 50246-76824 /ha/year-with subsidy Rs54694-80766 /ha/year-without subsidy	Here the range is for over-exploited and semi-critical regions in Tamil Nadu
(Narayanamoorthy, 2004) (Drip)	28000			

India Micro Irrigation Systems Top Companies

1. Jain Irrigation Systems Limited
2. Netafim
3. Kothari Agritech Private Limited
4. Finolex Plasson Industries Private Limited
5. Mahindra EPC Industries LTD.
6. Avanijal Agri Automation Pvt. Ltd
7. Agsmartic Technologies Pvt. Ltd
8. Finolex Plasson Industries Pvt. Ltd
9. Blurain
10. Ecoflo India

The India Micro Irrigation Systems Market size is estimated at USD 0.64 billion in 2024, and is expected to reach USD 1.08 billion by 2029, growing at a CAGR of 11.10% during the forecast period (2024-2029). The study period is 2019-2029 and the Base year for estimation 2023.

India, being heavily dependent on agriculture, often relies on rain-fed farming. This makes micro irrigation an attractive option for efficient water use. Rajasthan, in particular, has embraced micro-irrigation due to its limited water resources. In 2021, drip irrigation was the leading segment in the market, mainly due to government subsidies at both the central and state levels. Drip irrigation is most commonly used for fruit crops, followed by plantation crops. Key players in this market include Jain Irrigation Systems Limited, Netafim, Avanijal Agri Automation Pvt. Ltd, Agsmartic Technologies Pvt. Ltd, and Flybird Farm Innovations Pvt. Ltd. These companies are focusing on product innovation to stay ahead in the market (Mordor Intelligency, 2023).

7 Challenges

Despite the advantages, there are challenges associated with the adoption of micro irrigation systems:

- High Initial Costs: The significant upfront investment required for micro-irrigation systems remains a major barrier. The cost of purchasing and installing these systems can be prohibitive for small and marginal farmers, particularly those with limited financial resources. To overcome this challenge, increasing subsidies and financial assistance is crucial to make micro-irrigation technology more accessible and affordable.(Vasant P.G et al., 2021).
- Technical Training: Effective utilization and maintenance of micro irrigation systems require proper technical training. Farmers must be educated on system installation, operation, and maintenance to maximize the benefits and ensure the longevity of the systems (K. Arulmani, 2022).
- Maintenance and Repair: Regular maintenance and repair are essential for the optimal functioning of micro-irrigation systems. Issues such as emitter clogging, pipe leaks, and system damage can reduce water delivery and disrupt uniformity. The lack of technical expertise and limited access to repair services further complicates this issue, leading to reduced system effectiveness and increased maintenance challenges.

Economic problem

- Limited Budget: Despite the potential benefits, only 21% of the potential area in India is covered by micro-irrigation systems. This limited coverage is partly due to disparities in budget allocation among states. High initial and maintenance costs, coupled with limited subsidy provisions, contribute to the slow adoption of micro-irrigation technology. Addressing these financial constraints and ensuring equitable distribution of resources can help expand the reach of micro-irrigation systems.

8 Conclusion and Recommendations

Micro-irrigation systems offer a transformative solution for enhancing agricultural productivity and sustainability in India. The analysis demonstrates that micro-irrigation not only improves water-use efficiency but also significantly boosts crop yields, reduces input costs, and increases farmer profitability across various regions and crops. The adoption of micro-irrigation has shown favorable benefit-cost ratios (BCRs) for crops such as rice, vegetables, sugarcane, and fruits. For example, in Tamil Nadu, the BCR for sugarcane with subsidies was 2.1, indicating that farmers can recover their initial investment quickly and achieve substantial profits (Narayanamoorthy, 2004; P. Soman, 2022).

Recommendations:

1. **Increased Financial Support:** High initial installation and maintenance costs of micro-irrigation systems can deter many farmers, especially smallholders, from adopting and continuing with these technologies. To encourage wider adoption of micro-irrigation systems, it is crucial to enhance subsidies and financial incentives such as low-interest rate loans. These measures can help offset the high initial investment and maintenance costs associated with micro-irrigation, making it more accessible to small and medium-sized farmers.

2. **Capacity Building and Training Programs:** Establishing comprehensive training programs for farmers on the installation, operation, and maintenance of micro-irrigation systems is essential. Such programs will empower farmers with the knowledge required to maximize the benefits of these technologies and ensure their proper upkeep (K. Arulmani, 2022). Additionally, training programs should also be designed for local technicians to ensure skilled personnel are available for regular maintenance and repairs.

3. **Promotion of Drip Irrigation for High-Value Crops:** There should be a concerted effort to encourage farmers to use micro-irrigation systems for high-value crops such as fruits and vegetables, which have demonstrated high BCRs. Farmers should be provided with specialized support to transition to these systems, including financial incentives tailored to high-value crop cultivation.

4. **Scaling Up Implementation in Water-Scarce Regions or area with high extraction rate:** The social benefit-cost analysis by D. Suresh Kumar (2016) indicated that the social benefits outweigh the social costs in water scarce regions. This suggests that drip irrigation is a viable and more advantageous option in areas facing significant water scarcity. The study found that Social Benefit-Cost Ratios (SBCR) in over-exploited regions are 5.19 and 4.97, respectively, without and with subsidies, at a discount rate of 2%. In semi-critical regions, the SBCRs are 4.56 and 4.33. These results clearly demonstrate that the broader adoption of drip irrigation generates substantial social benefits. Thus, special emphasis should be placed on expanding micro-irrigation in water-scarce and drought-prone regions of India. These areas can particularly benefit from the efficiency of micro-irrigation systems, which allow farmers to use water more effectively. State and national policies should be tailored to provide additional support in these regions to drive adoption.

By addressing these areas, India can expand the use of micro-irrigation systems, ensuring more sustainable agricultural practices, better water management, and improved agricultural productivity across the country.

CASE STUDY 1

Social Benefit-Cost Analysis of Drip Irrigation in Coimbatore, Tamil Nadu By D. Suresh Kumar

This case study critically examines D. Suresh Kumar's analysis of the social benefits and costs associated with drip irrigation systems in Tamil Nadu, focusing on the Coimbatore district. The study evaluates the externalities generated by drip irrigation and assesses its overall social viability, particularly in regions with varying levels of groundwater stress.

Coimbatore district, heavily reliant on groundwater for irrigation, is divided into over-exploited and semi-critical regions based on groundwater development levels. The average well failure rate is notably high, with 47% for open wells and 9% for bore wells. The research surveyed 200 farmers—100 adopting drip irrigation and 100 not—from selected villages in both over-exploited and semi-critical regions. The over-exploited regions include Thondamuthur and Annur, which face severe water stress levels of 169% and 173%, respectively. The semi-critical regions are Anamalai and Madathukulam, with water stress levels of 51% and 56%. Each region's sampling framework included 25 farmers using drip irrigation and 25 using traditional methods, both for adopters and non-adopters. The crops studied were bananas, coconuts, grapes, maize, and turmeric, with the study conducted from 2007 to 2008.

The study identified two distinct categories of costs: private and external. Private costs encompass the capital investment required for drip irrigation systems and ongoing maintenance expenses. External costs includes the reduction in labor absorption per hectare from replacing traditionally irrigated crops with drip irrigation and the increased consumption expenditure incurred by local villagers due to higher cereal prices resulting from decreased local production. On the benefit side, private benefits consist of labor savings and increased output value. External benefits include enhanced water availability for irrigation, reduced power consumption, lower well deepening costs, and decreased well failure rates.

Findings

Private Costs and Benefits: Private costs involve the capital investment and maintenance of drip irrigation systems. For over-exploited regions, the total investment per hectare for drip irrigation is Rs 12,759.30, compared to Rs 26,595.92 for traditional methods. In semi-critical regions, the investment is Rs 9,325.91 for drip and Rs 5,788.71 for control villages. The private benefits of drip irrigation include significant yield improvements and labor savings. In over-exploited regions, yields increase by 4.41% for bananas, 15.1% for coconuts, 16.9% for grapes, and 22.8% for turmeric compared to traditional methods. In semi-critical regions, the yield improvements are 2.38% for bananas, 19.77% for coconuts, and 5.16% for turmeric. Labor costs for banana cultivation drop by 69% under drip irrigation, from Rs 31,487.1 to Rs 9,761.1 per hectare, with similar reductions for coconuts and a 15.6% reduction for grapes.

External benefit: External costs of drip irrigation include the reduction in labor absorption and increased local consumption expenditure due to higher cereal prices. However, these are mitigated by the substantial external benefits. Drip irrigation saves water significantly, with a value of Rs 1,49,393.60 per hectare in over-exploited regions and Rs 76,943.60 in semi-critical regions. The value of water saved due to adoption of drip irrigation in Rs/ha is calculated by multiplying reduction in the applied water in m3 with the area under crop in hectares divided by area under the crop and whole multiplied by the economic value of water used in agriculture in the region in Rs./m3 of water. Here, economic value of water is determined by multiplying the marginal physical product of water (MPP) with the price of crop produced (Py) (Gibbons, 1987)[4]. It also reduces power consumption, with a per hectare electricity use of 1,554.6 kWh/year in over-exploited regions (62.2% less than traditional methods) and 974.9 kWh/year in semi-critical regions (77.68% less). Additional positive externalities include lower costs for well failure and well deepening. In over-exploited regions, the cost due to well failure is Rs

[4] However, MMP could be a result of other factors of production besides water like fertilizers etc. which is not taken into account in this calculation.

1,563.9 per hectare in drip villages compared to Rs 1,957.8 in control villages, and well deepening costs are Rs 1,266.9 versus Rs 7,525.4. In semi-critical regions, well failure costs are Rs 411.6 versus Rs 1,168.9, and well deepening costs are Rs 626.4 versus Rs 1,554.6 in drip versus control villages, respectively.

Social cost-benefit: The Social Benefit-Cost Ratio (SBCR) evaluates the overall social viability of drip irrigation by comparing discounted social benefits to social costs. For the over-exploited region without subsidy, the SBCR is 5.19 at a 2% discount rate and 4.94 at a 5% rate. With subsidy, it is 4.97 and 4.71, respectively. In the semi-critical region, the SBCR is 4.56 and 4.34 without subsidy, and 4.33 and 4.01 with subsidy. These ratios indicate that drip irrigation offers substantial social benefits relative to its costs, highlighting its effectiveness and efficiency in water use and economic sustainability.

Remarks:

The study's strengths lie in its detailed methodology of both private and external costs and benefits. It effectively demonstrates the substantial yield improvements and labor savings associated with drip irrigation and significant water and power savings, which are critical in water-scarce regions. Moreover, the study's calculation of the Social Benefit-Cost Ratio (SBCR) underscores drip irrigation's economic viability, even without subsidies.

However, there are some limitations and potential drawbacks.

- **Outdated Data:** The reliance on data from 2007-2008 may not accurately reflect current conditions, technological advancements, or changes in market dynamics, limiting the relevance of the findings.
- **Maintenance Costs:** The study does not account for the maintenance costs associated with drip irrigation systems, which can be significant and affect the overall cost-benefit analysis.
- **Economic Value of Water:** The study does not provide a calculation for the economic value of water saved. While it mentions the number of irrigations, it does not quantify the monetary value of the water, which is crucial for a comprehensive economic analysis. Additionally, it remains unclear whether the increase in MMP (Marginal Physical Product) is solely attributed to water savings, as other factors could be influencing the results. In contrast, a chapter by M. Dinesh Kumar (2016) on 'Water Saving and Yield Enhancing Micro Irrigation Technologies in India: Theory and Practice' provides the price range at which water is traded in irrigation markets (Rs. 1.5/m3 to Rs. 2.5/m3 in north Gujarat and Rs. 6/m3 in Kolar). This market price can be considered as the minimum economic value of water from the supply side, i.e., the cost of providing water. How much it contributes to raising productivity of any crop in value terms could be the upper bound of economic value of water, which, in a way, is the demand side economic value of water.
- **Labour Cost Analysis:** While labor cost savings are highlighted for banana cultivation, similar analyses for other crops like coconuts, grapes, maize, and turmeric are missing. This omission reduces the comprehensiveness and applicability of the findings across different crop types.
- **External Costs:** The study mentions external costs such as the reduction in labor absorption and increased local consumption expenditure due to higher cereal prices but does not provide detailed quantification or analysis of these costs.
- **Regional Specificity:** The findings are based on specific regions within Coimbatore district, which may limit the generalizability of the results to other regions with different climatic, soil, and economic conditions.

CASE STUDY 2

The case study aims to evaluate the effectiveness of the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) - Per Drop More Crop (PDMC) in improving water use efficiency in Indian agriculture. The objectives include examining input savings, productivity enhancement, while identifying issues in the benefit transfer workflow. Conducted over 2020-21, the study covers a variety of crops such as vegetables, cotton, pulses, tomatoes, sugarcane, wheat, groundnut, banana, and chili across states like Uttar Pradesh, Madhya Pradesh, Maharashtra, Telangana, and Sikkim. The sample consists of 621 farmers, divided among adopters of drip and sprinkler irrigation systems and non-adopters. Notably, 50% of adopters have at least a 10th-standard education, and 98% utilized subsidy support.

Key findings reveal significant initial and maintenance costs for micro irrigation (MI) systems, with substantial subsidies mitigating these expenses as reported by farmers. The impact analysis shows a 72.28% increase in production and a 136.99% rise in revenue, indicating that MI greatly enhances agricultural productivity and financial returns. Despite higher costs for seeds and fertilizers, cost efficiency improves due to reduced water charges (47.53%) and pumping hours (36.19%). The net profit income increased by 279.64%, demonstrating a high return on investment.

The biggest advantage seen by the farmer farmers is less water needed indicated (strongly agree) by 93% of the farmers. This is followed by higher yields as indicated by 91% of the farmers, higher profits by 88% of the farmers, and better quality of output by 87% of the farmers. However, It is interesting to see that the major problems of micro-irrigation are not related to the technology. The most common problem indicated is damage by animals indicated (strongly agree) by 57% of farmers, followed by lack of fencing indicated by 52% and the Water table goes down fast. The other disadvantages include the water table going down fast indicated by 45%, high cost of tube wells/ wells by 43%, and poor after-sales service by 42 % of the respondents. Non-adoption reasons include unavailability of MI equipment (52% strongly agreed), high investment costs (49%), and insufficient subsidies (41%).

Remarks:

The study's large sample size of 621 farmers across multiple states (Uttar Pradesh, Madhya Pradesh, Maharashtra, Telangana, and Sikkim) provides a broad and diverse dataset. This extensive coverage enhances the reliability and generalizability of the findings, offering a comprehensive view of MI systems' impacts across different agro-climatic conditions and crop types. By detailing both initial capital investments and ongoing maintenance costs, along with the impact of subsidies, the study provides a clear and informative financial overview.

The study on the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) - Per Drop More Crop (PDMC) reveals several limitations that should be considered. First, while the study provides valuable insights into the effectiveness of micro irrigation (MI) systems, it primarily relies on self-reported data from farmers, which may introduce biases or inaccuracies. Farmers might bias about benefits or issues due to various factors, including perceived expectations from the program or social desirability bias. Regional variations in agricultural practices, infrastructure, and water availability could impact the effectiveness and challenges of MI systems differently across India.

References

A Narayanamoorthya, M. B. (2018). *An assessment of the economic impact of drip irrigation in vegetable production in India.* Agricultural Economics Research Review.

Abbas, G. (2019, june 25). *"65% of India's Reservoirs Running Dry, Maharashtra Worst Affected, Shows Water Panel's Report"*. Retrieved from News 18 india: https://www.news18.com/news/india/water-crisis-two-third-of-indias-reservoirs-have-below-normal-storage-maximum-are-dry-in-maha-2202279.html

AGRI FARMING. (n.d.). Retrieved from https://www.agrifarming.in/drip-irrigation-cost-per-acre-in-india-a-full-guide#

Arulmani, K. S. (2022). Economic analysis of tomato cultivation with drip irrigation system. *International Journal of Health Sciences*.

Asia Farming. (n.d.). Retrieved from https://www.asiafarming.com/sprinkler-irrigation-system-cost-analysis-per-acre-hectare-and-square-foot-in-india

Central Ground Water Board. (2023). *DYNAMIC GROUND WATER RESOURCES OF INDIA, 2023.*

Debajit Roy, D. M. (2020). *Improving Water Use Efficiency in India's Agriculture: The Impact, Benefits and Challenges of Micro-Irrigation under the Pradhan Mantri Krishi Sichai Yojana: Per Drop More Crop (PMKSY-PDMC) in Sikkim.*

Dr. S.Arunpriya, D. (2024). *Impact and Satisfaction on PDMC Scheme in PMKSY.* IJCRT.

GOI. (2021). *Water and Related Statistics 2021.* Department of Water Resources, RD & GR. Ministry of Jal Shakti. Government of India.

Groundwater Year Book in India. (2017-18).

Hindu, T. (2023, 2 17). *Declining funds from the Centre is cause for concern for Karnataka* . Retrieved from https://www.thehindu.com/news/national/karnataka/declining-funds-from-the-centre-is-cause-for-concern-for-karnataka/article66521615.ece

Kumar, S. (2016). Social benefit-cost analysis of drip irrigation.

Land use statistics (2021-22). Government of India.

Kumar, Dinesh M., (2016). Water Saving and Yield Enhancing Micro Irrigation Technologies in India: Theory and Practice. Micro Irrigation Systems in India: Emergence, Status, and Impacts
Ministry of Agriculture & Farmers Welfare:Per Drop More Crop. (2023, Dec 12). Retrieved from https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1985487

Mordor Intelligency. (2023). Retrieved from https://www.mordorintelligence.com/industry-reports/india-micro-irrigation-systems-market

Narayanamoorthy. (2004). *Impact assessment of drip irrigation in India: the case of sugarcane.*

National Mission on Micro Irrigation NMMI. (2014). *Impact Evaluation Study of "National Mission on Micro Irrigation (NMMI).*

P.Soman. (2022). *Drip irrigation and fertigation technology for rice production leading to higher water productivity.*

Ram Vaibhav, D. M. (2018). *Impact Analysis of Micro Irrigation System (MIS) on Yield, Water, Fertilizer Saving and Farmer's Economy.*

Sharma, P. K. (2020). Soil Salinity and Food Security in India.

Subrata Gorain, D. S. (2018). Social Costs and Benefits Analysis of Drip Irrigation System in. 1061-1065,.

Vasant P. Gandhi, N. J. (2021). *The Performance and Impact of Micro Irrigation in Improving Water Use Efficiency in India's Agriculture: Study of the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY) - Per Drop More Crop (PDMC).*

Annex

Table 4: Ground water Resources Assessment 2004 to 2023

Ground Water Resources Assessment	Annual Ground Water Recharge (bcm)	Annual Extractable Ground Water Resource (bcm)	Annual Ground Water Extraction for Irrigation, Domestic & Industrial uses (bcm)	Stage of Ground Water Extraction (%)
2004	433	399	231	58%
2009	431	396	243	61%
2011	433	398	245	62%
2013	447	411	253	62%
2017	432	393	249	63%
2020	436	398	245	62%
2022	438	398	239	60%
2023	449	407	241	59%

Source: (Central Ground Water Board, 2023)

Table 5: State wise Micro irrigation implementing agency

State	MI Implementing Agency
Andhra Pradesh	Andhra Pradesh Micro Irrigation Project (APMIP)
Bihar	State Horticultural Mission
Chhattisgarh	Department of Agriculture
Goa	Department of Agriculture
Gujarat	Gujarat Green Revolution Corporation
Haryana	Department of Agriculture
Himachal Pradesh	Department of Agriculture, Himachal Agro.
Jharkhand	Department of Agriculture
Karnataka	Department of Agriculture and Department of Horticulture
Kerala	Department of Horticulture
Madhya Pradesh	Department of Horticulture
Maharashtra	Department of Agriculture
Orissa	Orissa Horticultural Development Society (OHDS)
Punjab	Department of Soil and Water Conservation
Rajasthan	Department of Horticulture
Tamil Nadu	Tamil Nadu Horticultural Development Agency
Uttar Pradesh	Special Agricultural Department Scheme for Bundelkhand
Uttarakhand	Department of Horticulture
West Bengal	Department of Food Processing Industries and Horticulture

Table 6: Major components of PMKSY

Component	Budget (Rs. Crores) 2022-2023	Ministry
Har khet ko pani	436.00	Department of water resources, river development and ganga rejuvenation MINISTRY OF JAL SHAKTI
Accelerated irrigation benefit program and national/special projects	668.61	Department of water resources, river development and ganga rejuvenation MINISTRY OF JAL SHAKTI
Integrated watershed development program Watershed development component-Pradhan Mantri Krishi Sinchaee yojana	738.94 (net) 3.95 (net)	MINISTRY OF RURAL DEVELOPMENT department of land resources
More crop per drop(pdmc) scheme.	4043.38	Department of agriculture and farmers welfare MINISTRY OF AGRICULTURE AND FARMERS WELFARE (PMKSY)

Benefit Cost Ratio of MI System for Important Crops from *Impact Evaluation Study of "National Mission on Micro Irrigation (NMMI)" 2014*

The BC ratio has been based on the estimates of incremental return/ income from MI system that is taken into account the increase in individual farmer's income and MI system cost and crop wise average increase in income and average MI cost for each state were worked out from the same. The field survey 2012-13 to get first-hand information was conducted for a total sample of 7400, comprising beneficiary and non-beneficiary farmers in these selected states by adopting stratified–purposive-sampling design.

Table 7: Benefit cost ratio of MI system

Vegetable / Fruits	AP	Bihar	Chhattisgarh	Gujarat	Haryana	Karnataka	Maharashtra	Odisha	Rajasthan	Sikkim	Tamil Nadu	UP	Uttarakhand
Brinjal	2.15	2.18	1.44	1.45	1.85	2.15	2.98	2.38	2.3	2.57	1.66	2.57	
Cabbage		-	2.74	2.17	-	-	2.5	2.18	-	1.67	2.75	2.22	
Capsicum		2.62	2.62	-	2.74	-	-	1.61	-	-	-	2.29	
Cauliflower		1.17	-	-	2.88	2.68	-	2.56	2.29	2.29	2.85	2.74	
Chilli	1.56	1.72	2.1	2.65	2.58	2.33	2.73	2.28	1.79	2.59	1.81	2.82	
Okra	1.7	2.19	2.38	1.89	1.74	2.81	2.71	2.87	-	2.25	2.32	2.79	
Onion		-	2.36	1.76	2.1	-	2.7	2.93	2.39	-	2.51	1.93	
Potato	1.82	2.48	2.6	2.26	2.7	2.33	-	2.61	2.82	-	1.58	2.86	
Pumpkin		1.35	1.46	0.13		-	-	-	1.82	-	1.59	-	
Tomato		2.52	2.65	2.42	2	2.3	2.08	2.94	2.14	2.94	2.38	2.32	2.78
Banana	2.66	-	2.66	1.87	-	2.77	2.91	1.82	-	2.72	2.9	2.76	-
Coconut	2.26	-	-	-	-	2.63	2.44	2.72	-	-	2.51	-	-
Cucumber	-	-	-	-	2.06	1.31	-	-	-	-	-	-	-
Grapes	-	-	-	-	-	2.58	2.93	-	-	-	-	-	-
Guava	2.42	2.97	-	2.69	2.12	2.04	2.94	2.56	2.29	2.94	-	2.86	2.76
Lemon	2.67	-	-	2.8	-	2.88	1.48	2.98	2.31	-	2.09	2.36	-
Litchi	-	1.11	-	-	-	-	-	2.52	-	2.67	-	2.72	2.27
Mango	2.84	2.26	-	2.92	-	2.57	2.65	2.45	2.73	-	2.75	2.95	2.87
Orange	2.4	-	-	-	-	-	2.15	-	2.87	2.8	-	-	-
Papaya	1.33	1.25	2.42	-	-	2.79	2.34	2.68	-	-	2.3	2.74	-
Pomegranate	2.34	-	-	2.42	-	2.09	2.66	2.31	2.97	-	-	-	-
Water Melon	-	-	2.57	2.11	2.21	2.88	2.67	2.98	-	-	-	-	-

Source: (National Mission on Micro Irrigation NMMI, 2014)

zef
Center for
Development Research
University of Bonn

Working Paper Series

Authors: Ashok Gulati, Ankana Rana and Ritika Juneja
Contact: agulati@icrier.res.in, ankanarana2001@gmail.com, ritikajuneja93@gmail.com
Photos: ICRIER

Published by:
Zentrum für Entwicklungsforschung (ZEF)
Center for Development Research
Genscherallee 3
D – 53113 Bonn
Germany

Phone: +49-228-73-1861
Fax: +49-228-73-1869
E-Mail: presse.zef@uni-bonn.de

www.zef.de