POLICY PAPER 146

Water Security: Is Quantum or Management the Issue?

NATIONAL ACADEMY OF AGRICULTURAL SCIENCES, NEW DELHI
May 2026

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CITATION : NAAS 2026. Water Security: Is Quantum or Management the Issue? Policy Paper No. 146, National Academy of Agricultural Sciences, New Delhi: 16 pp.

Published by Executive Director on behalf of
NATIONAL ACADEMY OF AGRICULTURAL SCIENCES
NASC, Dev Prakash Shastry Marg, New Delhi - 110 012, India
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Preface

Water is an indispensable natural resource essential for the survival of all living organisms, from the smallest microbes to human beings. Despite covering nearly 71% of the earth's surface, only about 3% is fresh water, and less than 1% is readily accessible to meet our varied demands. As global populations grow and the adverse impact of climate change intensifies, this limited, finite resource faces unprecedented stress from over-extraction, pollution, and unpredictable weather patterns. Despite receiving more rainfall annually than the global average, extreme temporal and spatial variability in distribution in India adds to the complexity of managing this finite resource,

India, the most populous nation in the world, has to feed 18% of the global population as well as 11% of livestock, with only 4% of the water resources at its disposal. Agriculture sector, currently, consumes more than 80% of fresh water resources. It is a fact that with ~82 Mha, India surpasses China in having the largest net irrigated area, but it is a harsh fact that the productivity for most agricultural commodities does not make it to the first ten countries in the world. With other sectors like industry and domestic, competing strongly, efficient water use is no longer a choice but a necessity for survival to ensure food security, maintain ecological balance, and protect the health of future generations.

This publication provides the latest update of the water resources available in the country, the efficiency levels associated with various water management options and highlights the endeavours of the Government in developing and promoting water efficient technologies. Some of them are linked to carbon/green credits scheme. The takeaway message is that it is possible to feed India's billions utilizing the existing water resources available with the plethora of techniques, technologies and management options available.

On behalf of the Academy, I would like to thank the Convener (Dr. Anil Kumar Singh), Co-convener (Dr. K. Palanisami), Reviewers (Dr. Man Singh & Dr. A Sarangi) and Editors (Dr. R.K. Jain & Dr. R.K. Pal) as well as the esteemed Fellowships, which took part in the session, for their valuable inputs.

May 2026 **(M.L. Jat)**
New Delhi *President, NAAS*

Water Security: Is Quantum or Management the Issue?

1. INTRODUCTION

India, the most populous nation, has the formidable challenge of feeding 18% of the world's population, with only 4% of the water resources at its disposal to meet the continuously increasing demand of the agriculture, industrial, domestic and other sectors with adverse impact of climate change to reckon with. Glacier melt may increase river flow temporarily, but subsequently water flow will also decline, thus reducing water availability. Sea water intrusion is further negatively impacting the fresh water supplies in coastal regions. India receives an average annual rainfall to the tune of 117 cm, which is more than the world average of 110 cm per year, but significant temporal and spatial fluctuations of rainfall in India results in increased uncertainty and complexity (Singh, 2019). Water is one of the key inputs in agriculture, whether it is irrigated or rainfed, and is therefore, imperative to take stock of this finite resource and the technologies available for its judicious use, so that it can be managed efficiently. NITI Aayog (2019) had developed a Composite Water Management Index (CWMI). Through this index, it was possible to estimate the efficiency with which they are managing their water resources. CWMI has evaluated the performance of the states, identified the weak points and suggested remedial measures.

In India, irrigation sector consumes more than 75% of total water resources developed and the current overall water use efficiency in irrigation projects is 35-40% only. Water availability is becoming scarcer each passing day, while the demand by all sectors is on the rise. The efficiency of groundwater use is higher ranging from 45-50%, but its indiscriminate use is resulting in the increase in semi-critical, critical and over-exploited blocks in the country. Large volumes of waste waters are being generated and leading to contamination of the food chain and natural eco-systems. Climate change and associated global warming is further contributing towards enhanced uncertainty of rainfall, its pattern and distribution, affecting rainfed agriculture in particular. The water supply-demand gap is increasing over years.

Current water allocation in agriculture based on past norms/assumptions normally gives rise to over use of water by about 15%. Among other things, efficient water allocation in irrigated agriculture will lead to significant saving of water that could be effectively shared for other uses. One possibility will be reworking the actual crop water requirement under the current climate and soils as the crop water use and irrigation data are based on decades old norms/assumptions. There is a lot of scope to improve the crop water requirement estimation methodology, which in turn will help to estimate the future irrigation water requirement at farm, project, regional and national levels.

The brainstorming session took stock of the water resources of the country, technologies available for improving its efficient use and came out with an implementable action plan with appropriate policy matters for consideration by the planners and administration for both inter- and intra-sectoral water allocation. It is expected that this document would be a useful input for the Government of India (GoI), as the National Water Policy is currently under discussion.

2. STATUS OF WATER RESOURCES

Since water is a critical and non-renewable resource, its estimation is crucial for its judicious management and utilization. However, the estimates made over time by different agencies/organizations are presented in Table 1. Based on the earlier rainfall data, the water availability was estimated to be 1869 billion cubic meters (BCM), of which 1123 BCM was the quantum of usable water. This usable water quantity was further split into 690 BCM of surface and 433 BCM of groundwater resource (CWC, 2015). The revised estimates by CWC (2024) have indicated that the water resources are now 2115.95 BCM compared to 1869 BCM as referred earlier. Interestingly, the quantum of rainfall considered earlier was 4000 BCM, which has now been reduced to 3880 BCM.

Table 1: Water resources estimated by different organizations

Year	Authority/Method of estimation	Quantity (BCM)
1901-03	First Irrigation Commission/using coefficients of runoff	1443.2
1949	Khosla's empirical formula	1673
1960	CW & PC/Statistical analysis of flow data wherever available and rainfall-runoff relationships wherever data were meagre	1881
1988	Central Water Commission/General water balance approach	1880
1993	Central Water Commission	1869
1999	National Commission for Integrated Water Resources Development (NCIWRD)	1953
2019	Central Water Commission	1999.2
2024	Assessment of water resource of India Central Water Commission	2115.9

Source: Adopted and modified from CWC (2024)

This change in quantum has an implication on the per capita water availability, which has also increased slightly (Table 2). But as per the Falkenmark Water Stress Indicator (Falkenmark *et al.*, 1989), India became water stressed in 2006 (per capita water availability became <1700 m^3). If the basin-wise per capita water availability is examined, majority of the basins are already water stressed, and some of them come under water scarcity category on the basis of per capita availability <1000 m^3 (Singh, 2019). This factor will play a significant role in defining the basins with surplus and deficit water availability for executing the Inter-Linking of Rivers programme. The per capita availability of water will decrease from more than 5000 m^3/year in 1950-51 to 1300 in 2051. However, the computation of per capita availability does not account for the increase in consumption of water by the various sectors including agriculture, industry and domestic under the changed climate scenario and urbanization. For example, the Indian population which was around 35% of urban in 2021 is likely to be more than 55% in 2050. The water

Table 2: Historical and projected per capita water availability in India

Year	Population (million)	Per capita water availability (m^3 yr^{-1})	Revised Per capita water availability (m^3 yr^{-1})	Remarks
1951	361	5178	5178	Non-stressed
1955	395	4732	4732	Non-stressed
1991	846	2210	2210	Non-stressed
2001	1027	1820	1820	Non-stressed
2011	1211	1544	1651	Water stressed[@]
2015	1326*	1441[$]	1508[$]	Water stressed[@]
2021	1345[a]	1421[$]	1573[$]#	Water stressed[@]
2031	1463[a]	1306[$]	1446[$]#	Water stressed[@]
2041	1560[a]	1225[$]	1356[$]#	Water stressed[@]
2051	1628[a]	1174[$]	1300[$]#	Water stressed[@]

*Projected from 2011 census; [a]Population figures from 2021 to 2051 are taken from projected population by Planning Commission available at http://planningcommision.nic.in//; [$]The per capita availability from 2015 onwards has been calculated from 2017 WRA estimates; [@]According to the Falkenmark Water Stress Indicator (Falkenmark *et al*., 1989)

Source: NCIWRD (National Commission on Integrated Water Resources Development) (1999); # CWC (2024)

requirements of an urban population is greater than the rural population. The increased demand of processed food, textiles and other items will also enhance the water needs of the industrial sector. Climate change is going to further compound the water demand of crops, livestock and other sectors. The projected demand of various sectors is presented in Table 3. The recent estimates are higher than the figures projected by NCIWRD (1999) primarily due to increase in urban population's food requirements, dietary changes and

Table 3: Projected sectoral water demand in India in billion cubic metres (BCM)

Sector	Standing Sub-Committee of M/o Jal Shakti			Water Demand (NCIWRD, 1999)[#]					
	2010	2025	2050	2010		2025		2050	
				Low[@]	High[@]	Low[@]	High[@]	Low[@]	High[@]
Irrigation	688	910	1072	543	557	561	611	628	807
Drinking Water	56	73	102	42	43	55	62	90	111
Industry	12	23	63	37	37	67	67	81	81
Energy	5	15	130	18	19	31	33	63	70
Other	52	72	80	54	54	70	70	111	111
Total	813	1093	1447	694	710	784	843	973	1180

Source: Basin Planning Directorate, CWC, XI Plan document.
Report of the Standing Sub-Committee on "Assessment of Availability & Requirement of Water for Diverse Uses in the Country-2000"
[#]NCIWRD (1999); [@]Low/High Demand

related factors Since agriculture is and will remain the largest consumer of this precious resource, it is essential to increase the agricultural water use efficiency.

3. DEVELOPMENT OF WATER RESOURCES

Water being such a vital input for enhancing the production and productivity of crops, development of irrigation water resources became the one of the top priorities of Govt. of India, spending a huge amount in developing and maintaining irrigation-related infrastructure. The irrigation potential created and utilized up to XI Plan (2007-2012) is shown in Figure 1. The net irrigated area stands at 82.42 Mha (2023-24) which is the highest in the world. The per capita water storage in India is only around 225 m^3 which is less than one fifth of China, having a comparable population. It is an established fact that the assured availability of water for irrigation encourages the farmers to invest in other critical inputs like seeds of improved varieties, and fertilizers. Moreover, irrigation has certainly played a vital role in ensuring food security to the vast population. Figure 1 has also brought out a disturbing fact that the ever-widening gap between the Irrigation Potential Created (IPC) and the Irrigation Potential Utilized (IPU) is >25 Mha at the end of XI Plan period. There are several factors responsible for continuous widening of this gap. They are low water discharges, insufficient water distribution mechanism and associated inequalities, water losses during distribution, incorrect data related to irrigated area, diversion of productive irrigated lands within an irrigation command for non-agricultural purposes, dilapidated infrastructure and no provision of volumetric water supply besides low irrigation charges, supply dominated systems to mention a few (Panda *et al.*, 2024; Kumar *et al.*, 2025).

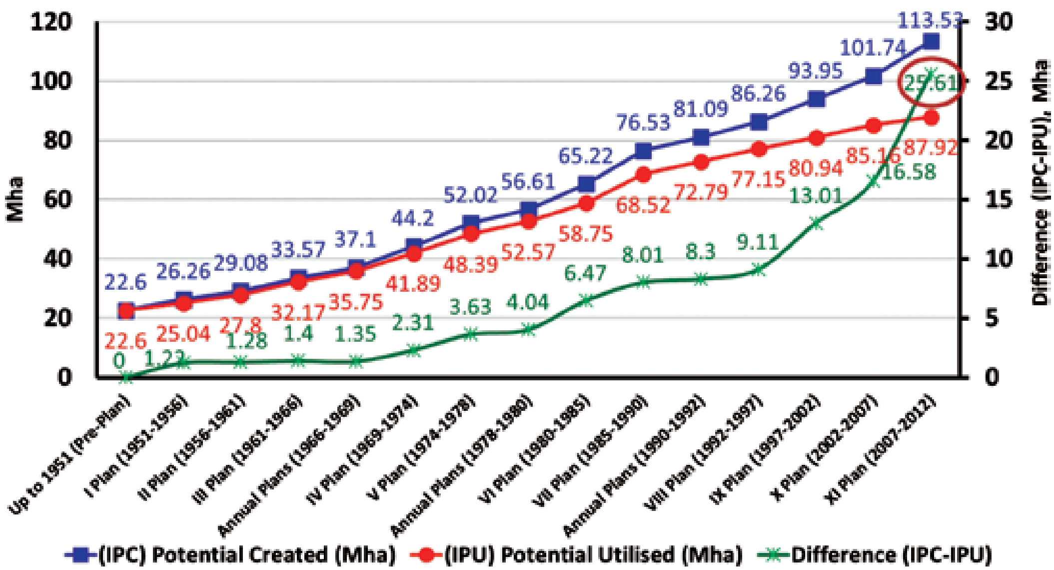

Fig. 1: Plan-wise position of irrigation potential created and utilized (Source: CWC, 2021)

3.1 Surface Water Resources

The major and medium irrigation projects of the country are generally associated with low water use efficiencies. CWC (2016) conducted a study on 35 major and medium projects, and reported that the overall water use efficiency was 36% only. The overall conveyance efficiency and on-farm application efficiency were 69% and 55%, respectively. These data indicated that a very significant quantum of water is exiting the system and adversely impacting the environment. It also implies a wastage of financial resources invested into developing the irrigation infrastructure. NCIWRD (1999) clearly indicated that the efficiency of surface water utilization should be increased to at least 60% and groundwater to 75% by 2050 for the country to meet its water requirement. However, if this report is examined critically, it can be observed that there are several major and medium projects having the overall water use efficiency hovering around the desired level of 60% (CWC, 2016; Singh, 2019).

When the irrigation water resources development work was initiated, the emphasis was on canal construction and associated infrastructure. But later on, there was a distinct shift towards irrigation based on groundwater. A perusal of Table 4 brings this out very explicitly. For example, in 1950-51, the canal irrigated area was 8.30 Mha occupying nearly 40% of the net irrigated area. Well-irrigated area was 6.00 Mha representing almost 29% of total irrigated area in 1950-51. In 2023-24, the canal irrigated area increased to 17.42 Mha an increase of 2.1 fold compared to 1950-51 but now comprises only 21% of net irrigated area. On the other hand, the well-irrigated area has increased to 51.87 Mha in 2023-24 from 6.00 Mha in 1950-51. This increase is 8.65 times during the same period and now comprises of almost 63% of net irrigated area, which is currently

Table 4: Source-wise net irrigated area in India (Mha)

Year	Canal	% of total	Tank	% of total	Wells	% of total	Other Sources	% of total	Total (All Sources)
1950-51	8.30	39.71	3.60	17.22	6.00	28.71	3.00	14.35	20.90
1960-61	10.40	42.11	4.60	18.62	7.30	29.55	2.40	9.72	24.70
1970-71	12.80	41.16	4.10	13.18	11.90	38.26	2.30	7.40	31.10
1980-81	15.30	39.53	3.20	8.27	17.70	45.74	2.60	6.72	38.70
1990-91	17.50	36.46	2.90	6.04	24.70	51.46	2.90	6.04	48.00
2000-01	16.01	29.00	2.47	4.47	33.82	61.26	2.91	5.27	55.21
2005-06	16.72	27.48	2.08	3.42	36.07	59.29	5.97	9.81	60.84
2010-11	15.65	24.58	1.98	3.11	39.17	61.53	6.87	10.79	63.67
2015-16	15.18	22.55	1.74	2.58	43.12	64.07	7.27	10.80	67.30
2020-21	18.60	23.93	2.19	2.82	47.32	60.89	9.61	12.37	77.72
2023-24(P)	17.42	21.14	3.13	3.81	51.87	62.94	9.94	12.07	82.42

Source: Land Use Statistics at a Glance 2023-24; Economics Statistics & Evaluation Division, DoA&FW, MoA&FW; P: Provisional.

82.42 Mha. The other sources mostly consist of structures like dug-out wells. This brings out clearly the farmers preference for well-irrigated systems and highlights the importance of increasing the efficiencies of groundwater irrigated areas. Since the major and medium projects have been created through huge investments by the Government, it is equally essential to close the gap between the IPC and IPU, which can be accomplished at a much lower cost than developing new irrigation projects.

3.2 Groundwater Resources

As evident from the information presented above, groundwater resources development has contributed more since 1980s towards the food basket. The productivity of tube-well irrigated crops is significantly higher than canal irrigated crops. This preferred means of irrigation resulted in the associated industry developing rapidly without the need of any government intervention. Supply of electricity or use of diesel pumps also contributed in popularizing this. However, this led to over extraction of groundwater, and India is extracting groundwater at a rate greater than that of USA and China put together (Figure 2). This has led to an increase in the number of over-exploited, critical and semi-critical blocks in the country (Figure 3). However, due to the government's focus on large scale recharging of aquifers, there is a marginal increase in the number of blocks categorized as 'safe' and decrease in 'critical' and 'over-exploited' blocks (CGWB, 2025). Although, the overall groundwater development is around 62%, the groundwater development in Eastern India including North East is only 34.5% and a huge potential exists in that region**.** Considering this situation, Govt. of India decided to implement a programme aptly titled "Bringing Green Revolution to Eastern India" (BGREI) (Singh, 2019).

Tank-based irrigation systems are more prevalent in Southern India. It is, therefore, important to focus on regionalized distribution and tank-based irrigation systems in India

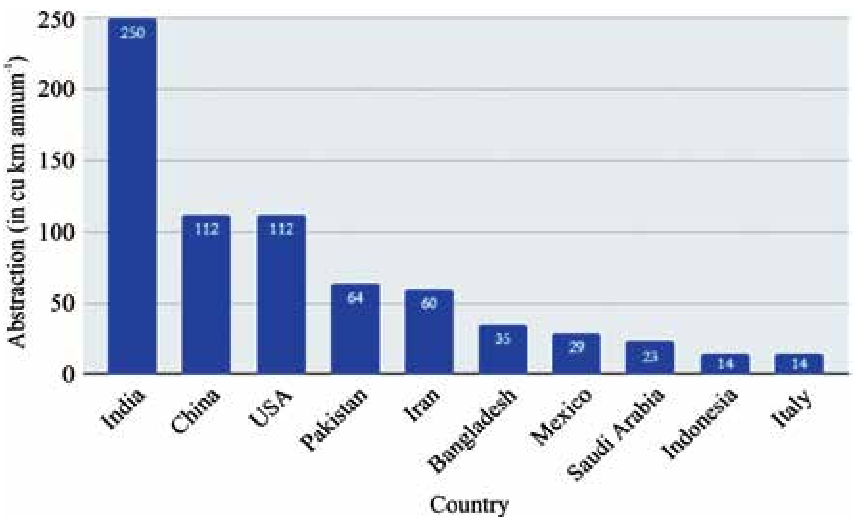

Fig. 2: Consumption of groundwater by different countries (Source: Margat and van der Gun, 2013)

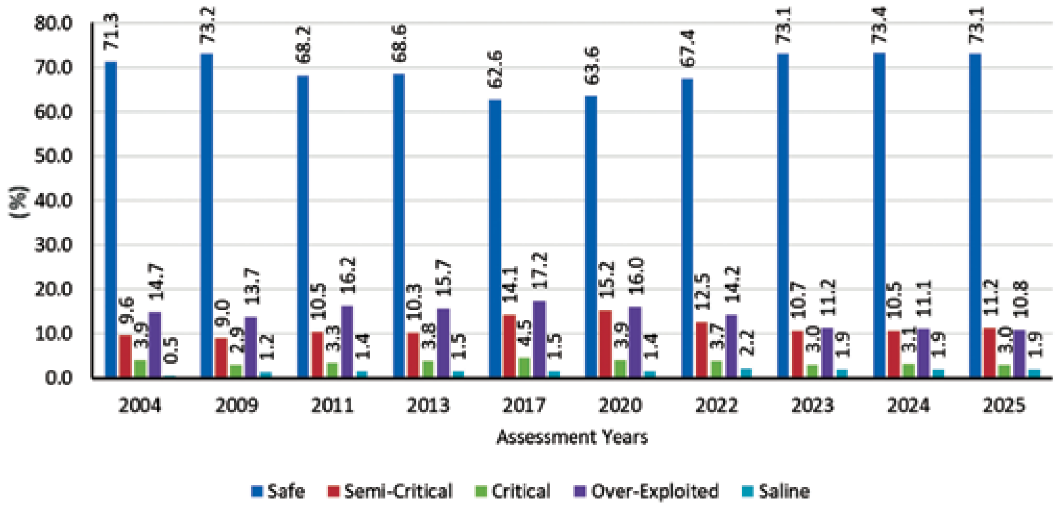

Fig. 3: Percentage of total assessment units under different categories from 2004-2025 (Source: CGWB, 2025)

with emphasis on the need for higher water productivity and effective management of tanks. A hydrological assessment approach was suggested, including the use of advanced remote sensing and GIS techniques for mapping tank networks, small water bodies and catchment areas besides evolving potential solutions.

4. RAINFED AGRICULTURE

Although India has the largest irrigated area in the world, it has a significant cultivated area under rainfed agriculture which caters largely to pulses, oilseeds, minor millets, cotton and even rice (~40%). The productivity of these areas is considerably lower (~1 t ha^{-1}) in comparison to irrigated areas. Out of the net cultivated area of ~140 Mha, almost 45% of the area is rainfed and it is estimated that around 40% of the net cultivated is likely to remain rainfed even when all the irrigation water resources are developed. The average annual rainfall in India is 117 cm which is higher than the global average of 110 cm but there is a wide spatial and temporal variation in its distribution and intensity. The proportion of the minimum, average and maximum rainfall is of the order of 1:10:100 with the maximum being more than 11000 mm in Mawsynram (Meghalaya) and minimum 100 mm in the Thar Desert. The number of rainy days can vary from 4 days to over 300 days a year and the intensity can vary anywhere from <1 cm hr^{-1} up to 15 cm hr^{-1}. It has also been estimated that almost 80% of the rain occurs in only 100 hr in a year. Soil and nutrients loss due to runoff is of the order of 5.34 billion tonnes and 6 million tonnes, respectively, resulting in production losses in excess of Rs. 115 billion. Climate change and the associated global warming are also going to adversely impact the rainfall pattern and increase the uncertainty associated with Indian Monsoons.

A comprehensive assessment of district level water harvesting potential had revealed that the potential to realize the rainfed agriculture lies in the harvest of small part of available surplus runoff and reutilize it for supplemental irrigation at critical crop growth stages (Sharma *et al.*, 2010). They identified about 28.5 Mha of potential rainfed area covering large number of districts in Central and Eastern India that can generate sufficient runoff (114 BCM) for harvesting and reutilization. It is possible to raise the rainfed crop production by a total of 28-36 Mt from an area of 20-25 Mha during normal monsoon years, which accounts for about 12% increase over the present production level. With adoption of improved technologies (the possibility of which increases once 'critical water requirements' are assured), the benefits could be still higher. Extensive area coverage rather than intensive irrigation, needs to be followed in regions with higher than 750 mm year^{-1} rainfall, since there is larger possibility of alleviating the in-season drought spells and ensuring a second crop with limited water application. This component may be made an integral part of the ongoing and new development schemes in the identified rural districts.

Joshi and his associates (2008) had evaluated 636 watersheds in the country and their study clearly brought out that watershed programmes have impacted the rainfed areas with a mean benefit-cost ratio of 1:2.03. The results have indicated that even in such fragile ecosystems, these programmes generated huge benefits. About 18% of watersheds generated benefit-cost ratios above 3. However, 68% of watersheds had a below average B:C ratio of 1:2.03, which indicated that there exists a large scope for proper watershed management (Joshi *et al*., 2008). Only 0.6% of the watersheds studied failed to commensurate with cost of the project. The mean internal rates of return (IRR) of 27.43% was significantly higher and comparable with any of the successful government programmes. The IRR in 41% of watersheds were in the range of 20 to 30%, whereas about 27% watersheds yielded IRR of 30 to 50%. The watersheds with IRR below 10% were only 1.9%.

Another important objective of the watershed programmes is to generate employment opportunities to address the equity concerns of landless labourers, marginal and small farmers. The results of meta-analysis carried out also clearly established that watershed programmes generated substantial employment opportunities. The estimated additional employment generation was about 154 person-days ha^{-1} year^{-1}. This also implies that the investment in watershed development programmes can be considered as poverty alleviation programme.

Focus on rain water harvesting is important because global warming is likely to result in a decrease in the number of rainy days and a consequent increase in intensity considering the prediction of Global Circulation Models (GCMs). It is predicted that rainfall will either increase or remain constant over the Indian sub-continent. Historical data analysis has also indicated that the low intensity rainfall events have decreased while the medium and high intensity rainfall events have increased over the past fifty years. This is likely to intensify as a consequence of climate change. As stated earlier, despite the development of all water resources for irrigation, almost 40% area would still remain rainfed. There is a possibility of easily enhancing the productivity of these areas by a minimum of 50% through rain water harvesting and supplemental irrigation. The reality is that:

- Only 29% of the annual rainfall is harnessed.

- Although 80% rain falls in 100 days during the monsoon season, the rainy days are confined to about 45 days only, resulting in water shortages during the rainy season.
- It is estimated that most of the total rainfall occurs in 100 hours out of 8760 hours in a year. This results in both floods/ droughts during the same season.
- More than 1/3rd of country's water resources are locked in the north-east region.
- About 215 Mha.m of rainfall can be stored in the underground aquifers.

5. MICRO-IRRIGATION

Pressurized irrigation systems have proved very efficient technologies in improving water use efficiencies compared to the conventional surface flooding. The potential area that could be brought under micro-irrigation was initially estimated to be 69.5 Mha. Later, Kishore and his associates (2022) have analysed the potential and suggested that the area can be further extended to 72-78 Mha. Since micro-irrigation systems have established beyond doubt that their adoption can result in huge water savings and increase nutrient use efficiency through fertigation, GoI has been actively promoting their adoption through the "per drop more crop" initiative, a vital component of PMKSY. The area under micro-irrigation was only 1500 ha in 1985, which increased to more than 70,000 ha in 1992 (Chakravarty and Singh, 1994) and was 221,000 ha in 1998 (Polak and Sivappan, 1998). The growth of micro-irrigation gained momentum in the last two decades. In India, the area covered under micro-irrigation was 16.73 Mha up to March 2024 (Figure 4) whereas the coverage was reported to be 8.34 Mha during the last decade (2014-15 to 2023-24) (DoA&FW, 2024). Out of the total area under micro-irrigation, the drip irrigation is implemented in 7.69 Mha against its potential of 27.0 Mha, whereas the area covered under sprinkler irrigation is 9.04 Mha against its potential of 42.5 Mha, with total micro-irrigation potential of 69.5 Mha in the country (MoA&FW, 2024). Contrastingly, another estimate indicated that the potential of micro-irrigation is 72.2 Mha, out of which the drip system potential is 21.2 Mha and

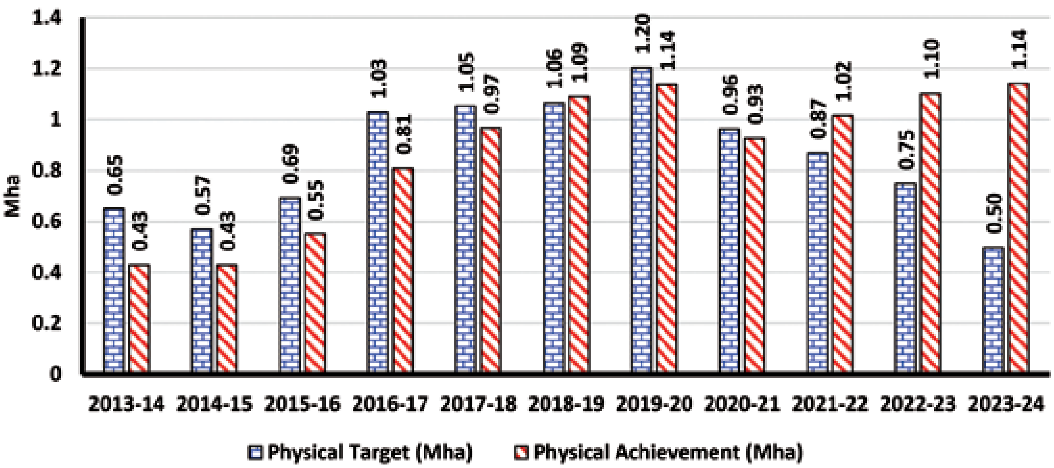

Fig. 4: Area covered under micro-irrigation between 2013-14 to 2023-24 (Source: https://pmksy.gov.in)

sprinkler is 51.0 Mha (Chand *et al*., 2020). It has also been estimated that with coverage of full potential of micro-irrigation, it would be possible to save about 114 billion cubic meters of irrigation water. Currently, it represents approximately 12% of the net cultivated area only. It has been suggested that there is a need to have state-specific scheme to scale-up adoption of micro-irrigation and have highlighted that a state like Punjab which is staring at water scarcity because of excessive groundwater extraction, has very low penetration compared to state like Gujarat and Andhra Pradesh. Suresh and his associates (2019) had also critically examined the micro-irrigation development in the country, highlighted the regional disparities and leading issues. They also proposed modifying the micro-irrigation development programme. In a recent development, GoI set up a target of bringing 10 Mha under micro-irrigation in a period of 5 years @ 2 Mha each year. It is a very challenging target considering progress made in the recent past. However, the major constraints in the wider adoption are high cost of the system, poor quality materials, poor operation and maintenance by the farmers etc. (Palanisami *et al*., 2012).

Rice consumes more water, but its production cannot be compromised as it is a staple food of the majority of the Indian population and also covered under the National Food Security Act. It is also associated with GHG emission. In an attempt to enhance its water productivity, the possibility of cultivating it through drip irrigation has been explored for the last several years over several locations in India and abroad (JSIL, 2018). Soman and his associates (2021) have conducted several trials on farmers' fields through Water Productivity Project (WAPRO) in the state of Haryana. The results obtained clearly indicated that rice can be grown with drip irrigation with the multiple benefits *viz*. enhanced crop yield (6.7%); higher water sue efficiency; savings in irrigation water (51% less in drip); less energy used for pumping (52% less in drip); reduced labour requirement for irrigation (81% less in drip) and planting (57% less in drip); and a reduction in methane emission (60% less in drip). Rice grown under aerobic conditions with drip irrigation has an additional benefit of almost negligible arsenic accumulation.

Pressurized irrigation systems can be easily adopted by tube-well farmers who already have a source of energy (pumps). Solar-based pumping systems are also becoming popular where electricity supply is an issue. In regions where rain water harvesting is done to provide life-saving irrigation(s), community based or single farmer owner based pumping systems will increase the overall water productivity. Adoption of these technologies should be incentivised.

6. EFFICIENT WATER MANAGEMENT TECHNOLOGIES

There is no dearth of field evaluated and well tested technologies developed by Indian Council of Agricultural Research (ICAR) and State Agricultural Universities (SAUs) for every conceivable agro-eco system in the country (Singh, 2019; NITI Aayog, 2021, 2023) for both irrigated and rainfed conditions (Table 5).

The impact of these technologies can be further magnified by breeding varieties using modern tools having higher water use efficiency in particular, and tolerating abiotic stresses.

There is an urgent need to switch over to precision water management, only then it will be possible to feed the 1.68 billion Indians in 2050 (Brahmanand and Singh, 2022;

Table 5: A brief summary of water management technologies

Technologies	% savings in water use
Crop water demand-based rostering in canal command using modern tools	40-60
Laser land leveling	15-20
Scientifically designed check basins/border strips:	10-30
Zero tillage	20-30
Adoption of pressurized irrigation systems:	40-70
Land configuration changes-ridge/furrow or raised/sunken beds:	20-25
Construction of groundwater recharge structures	15-25

Singh, 2022). It is imperative to bring the modern tools like sensors, artificial intelligence (AI), machine learning (ML), Internet of Things (IoT) into developing Decision Support Systems (DSS) coupled with water efficient application techniques to enhance water productivity. A good number of start-ups have already ventured into this field and can easily become Precision Farming Service Providers (PFSP).

Since GoI (http://www.myscheme.gov.in) is promoting use of drones in agriculture in a big way, their utilization has to move beyond the spraying of pesticides and nano-urea considering the Indian agro-eco systems. Drones can be used to monitor and assess the small farm holdings as well as the large areas with equal efficiency. They can be used very effectively through trained service providers for the following:

- Identify the water and nutrient stress status of crops.
- Monitor and assess the watershed development activities as frequently as desired.
- Since irrigation commands are spread over large areas, it is difficult to monitor the effectiveness of water distribution in the command by conventional means. Drones can easily identify areas which are over/under irrigated in real time.
- The spatial data processing time collected through drones is very fast and real time decision making can be easily accomplished with sensors-based systems.

7. DEMAND – SUPPLY MANAGEMENT

One of the biggest bottlenecks in improving the water use efficiency in irrigation projects is the mismatch between the demand and supply which is predominantly supply-based. It is estimated that 1122 BCM water needs to be supplied by the system, but only 744 BCM is accessible. The demand was expected to be 1093 BCM in 2025 and may increase to 1447 BCM in 2050. It implies that the supply-demand gap of 31% in 2025 will increase to 48% in 2050. However, due to the impact of climate change the supply-demand gap might have increased to 35% in 2025 and it might be 56% in 2050.

The measures detailed below could result in reducing this gap by 40% through supply side interventions (Table 6) and 60% through demand side interventions (Table 7).

Table 6: Water sector improvement interventions related to the supply side

S. No.	Interventions	% gap bridged
	Supply-Interventions types	40
1.	**Developing new irrigation projects** • Major, medium & minor projects (tanks and ponds)	30
2.	**Modernizing/rehabilitation existing projects** • Major & medium • Minor tanks –urban & rural tanks • Rejuvenation of open wells & water harvesting structures • Drainage improvements	40
3.	**Recharge aquifers through** • Taming floods • Rainwater harvesting structures • Managed aquifer recharge	20
4.	**Others** • Adoption of best cases & methods • Waste water recycle & reuse • Underground piped irrigation network • Improving policy framework • R&D activities	10

Source: Palanisami and Nagothu (2024)

Table 7: Water sector improvement interventions related to the demand side

S. No.	Interventions	% gap bridged
	Demand-Intervention types	60
1.	Climate smart agriculture Soil, crop, water-improving productivity	30
2.	Micro irrigation in canal commands, hill agriculture Updated crop water requirements data	20
3.	Crop diversification	10
4.	Good governance (institutions, laws, taxes, subsidies, incentives, pricing of water)	30
5.	Others • Digital agriculture: precision agriculture using geospatial and ICT tools, RS, GIS Development of DSS and mobile apps, agri-portals etc., • Improved marketing, insurance products • Strengthening rainfed agriculture • Awareness, capacity building and training of farmers and field staff • Empowering entrepreneurship in agriculture including new generation farmers; public private partnership business models • New R & D activities	10

Source: Palanisami and Nagothu (2024).

8. WASTEWATER UTILIZATION FOR IRRIGATION

Considering the fact that the inevitable increase in urbanization and industrialization would lead to the release of large volumes of wastewaters of varying quality, their safe disposal is also of paramount importance. Concomitantly, the demand of water for agricultural use will keep-on increasing. Therefore, using treated wastewaters for irrigating field crops is a viable option particularly for peri-urban areas (NAAS, 2022). The following action points are suggested:

- Low-cost user & environment friendly techniques for treating wastewaters including bioremediation measures for removing heavy metals and pathogens need to be developed and adopted on large scale.
- Strategies for use and management of domestic, municipal and individual household wastewater based on public-private partnership models should be evolved.
- The Ministry of *Jal Shakti* should consider wastewater as a resource and develop protocols for converting it into nutrient-rich safe irrigation water to supplement the scarce fresh water resources as increasing industrialization and urbanization will generate more wastewater with time.
- Since the industrial sector uses good-quality fresh water for its various uses and releases poor-quality wastewater, it should be made mandatory for the industry to adopt "zero grey water footprint", which must be regulated strictly.

9. WATER AUDITING IN AGRICULTURE

Water auditing has now become essential for optimizing water use in agriculture, ensuring sustainability, and supporting both economic and environmental goals. The focus should be on the following:

- **Efficient Water Management**: Water auditing helps farmers understand their water usage patterns, identify inefficiencies, and implement more effective irrigation practices. This leads to better water resource management and conservation.
- **Cost Savings**: By identifying and rectifying leaks, over-irrigation, and other inefficiencies, water auditing can significantly reduce water costs, making agricultural operations more economically sustainable.
- **Environmental Benefits**: Efficient water use reduces the strain on local water sources, helps maintain ecosystem health, and minimizes the negative impacts of agriculture on the environment, such as soil erosion and waterlogging. Quantification of ecosystem services due to good irrigation water management practices and the carbon credits or the voluntary carbon market (VCM) due to water saving technologies adopted by stakeholders.
- **Compliance and Sustainability**: Water auditing can help farmers comply with local water regulations and policies. It also aligns with sustainable farming practices, which are increasingly important for market access and consumer preference.

- **Yield Optimization**: Proper water management through auditing ensures that crops receive the right amount of water at the right time, which can enhance crop yields and quality.
- **Risk Mitigation**: Understanding water use and having data-driven insights from audits can help farmers better prepare for and respond to droughts and other water-related challenges.

10. RECOMMENDATIONS

It is obvious that the quantum of water resources in the country is not an issue, but their judicious management is essential using proven technologies. Based on the deliberations, following major recommendations emerged:

- Emphasis should be laid on bridging the gap between Irrigation Potential Created (IPC) and Irrigation Potential Utilized (IPU). Adoption of underground pipeline irrigation (UGPL) network, modernization of canal commands and adoption of micro-irrigation systems besides crop diversification are some options. Increased project efficiency (e.g., 60%) and water auditing should be adopted in all major and medium projects.
- Groundwater governance is extremely important. Community-based groundwater management holds the key for enhancing sustainable utilization of this precious resource. Watershed programs and artificial groundwater recharge programs should be given top priority. Micro-irrigation in the groundwater over-exploited regions should be the focus in investment programs. Small scale tank irrigation should be revived through suitable tank modernization programs.
- Farmers, in general, do not realize or are aware of the economic worth of water. One effective option is incentivizing adoption of water efficient technologies through an institutional mechanism for Payment for Ecosystem Services (PES) and/or voluntary carbon market (VCM)/green credits. Adoption of these technologies will reduce the water foot prints of the production systems. Virtual water concept can also be re-examined in the future planning programs.
- Treated waste-water should be considered for productive use both in agriculture and industry as this will help to minimize the future water demand to some extent.
- Switching-over to precision water management is vital. It can start with the fixing of price of water supply in the canal commands and use of IoT enabled digital water measuring devices or the canal automation gadgets to ensure volumetric supply as per crop water demand.
- Private-public partnership can play a very catalytic role in enhancing water productivity both at the farm and the systems level. This will help to generate affordable and appropriate business models in irrigated agriculture.
- It is important to prioritise capacity building of the farmers, water user associations (WUA) and the village youth under skilling India initiative for repair and maintenance of the hardware and software components of automated canal and micro-irrigation systems and in the adoption of climate smart technologies.

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