

Aligning Irrigation Demand to Sustainable Water Management Policies in India

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Historically, India's irrigation policies prioritized expanding canal infrastructure and subsidising groundwater extraction to provide farmers with reliable and affordable irrigation. Nationwide, massive public and private investments significantly expanded the net irrigated area from 21 million hectares (Mha) to 82 Mha between 1950–51 and 2023–24, and improved overall irrigation coverage from 17.6% to 59.3% in the country. While expanding irrigation infrastructure was instrumental in achieving food security, emerging challenges such as physical limits to new large-scale infrastructure, widespread low water use efficiencies, and rising inter-sectoral competition for water, have driven a shift towards demand-side management rather than merely augmenting supply. *Pradhan Mantri Krishi Sinchayee Yojana* (PMKSY), the flagship scheme of the Government of India, integrates water supply infrastructure with demand-side agricultural water management to ensure protective irrigation for all farms in India. Aligning quantified irrigation requirements to agricultural water management can enhance the effectiveness of both demand and supply-side strategies to attain water security.

The latest official estimates on actual irrigation water demand at the national level date back to the reference year 1997-98, as detailed in the report of the National Commission for Integrated Water Resources Development Plan (NCIWRD)¹. The NCIWRD projected water requirement up to the year 2050, keeping in view the past trend in land use, cropping pattern, and irrigation conditions with the goal of food self-sufficiency at the national level. As these conditions have evolved significantly since 1997-98, re-assessment of the irrigation water demand is vital for effective water management planning. Further, devising targeted strategies requires demand assessment at disaggregate and regional level – a critical gap in the existing literature. We have estimated irrigation water demand of the existing cropping pattern at district level

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¹ <https://cwc.gov.in/sites/default/files/nciwr-d-hashim-report-vol-i.pdf>

for the 2023-24 reference year. This policy brief presents the nationally-aggregated estimates of irrigation water demand, highlights spatial and temporal variation and discusses water management strategies that can be strengthened when aligned with irrigation demand.

Crop and irrigation water requirement

Crop water requirement (CWR) refers to the total amount of water a crop needs to compensate for evapotranspiration losses, ensuring optimal growth. This need is met through rainfall, irrigation, or both. The portion of rainfall that contributes to crop evapotranspiration is termed as effective rainfall (R_{eff}). The irrigation water requirement (IWR) is the additional water that must be artificially applied to the crop to ensure optimal growth when rainfall alone is insufficient to meet CWR. IWR is expressed in net and gross terms. Net irrigation water requirement (NIWR) is the actual volume of water needed in the root zone to satisfy a crop's evapotranspiration needs, whereas gross irrigation water requirement (GIWR) is the total volume or depth of water that must actually be diverted or pumped from the water source accounting for conveyance and application losses based on the system's irrigation efficiency. CWR, R_{eff} , NIWR and GIWR of the existing cropping pattern have been calculated at district level for the reference year 2023-24 using the FAO framework² separately for groundwater and surface irrigation systems and aggregated at national level. The efficiencies of groundwater and surface irrigation systems have been assumed at 65% and 40%, respectively, for all crops except paddy, for which efficiencies of 50% and 30% have been taken³.

The extent of irrigation water demand is primarily determined by the crop type, acreage, agro-climatic conditions, and system's efficiency. In 2023-24, India's net sown area (NSA) was 138.9 Mha, with a net irrigated area (NIA) of 82.4 Mha. The gross sown area (GSA) stood at 217.9 Mha, of which 130.5 Mha had access to irrigation (gross irrigated area or GIA). Further, irrigation development in

² <https://www.fao.org/aquastat/en/data-analysis/irrig-water-use/irrig-water-requirement>

³ <https://www.nabard.org/auth/writereaddata/tender/0803190338NSP%20on%20Water%20Resources%20.pdf>

the country is characterised by the rising dependency on groundwater, accounting for 62.9% of NIA. There exists wide inter-regional variation in the coverage and sources of irrigation. Access to irrigation along with resource endowment, varied agro-climatic conditions, and various socio-economic, policy, market and institutional related factors shape cropping pattern in a given region. At the national level, cereals predominated the cropping pattern with a 50.4% share in GSA. Within the cereals, rice and wheat constituted 22.9% and 16.1% share in GSA in 2023-24, respectively. Pulses, oilseeds, sugarcane, fibers, fruits, and vegetables constituted 12.0%, 14.9%, 3.1%, 6.1%, 2.3%, and 3.4% share in GSA, respectively.

Estimates at aggregated level

At the national level, the CWR and GIWR for all crops cultivated across the GSA have been estimated at 1276.2 billion cubic meters (BCM) and 896.5 BCM, respectively (Table 1). In other words, 896.5 BCM represents the total irrigation water needed to realize optimum growth for the crops grown on the entire cultivated area. This also sets the upper limit for irrigation water demand required to meet the PMKSY's objective of providing protected irrigation to all agricultural farms. At the present level of irrigation coverage and efficiencies (without considering adoption of water-efficient technologies), irrigation water demand is estimated at 630.5 BCM which shall be met by the existing irrigation infrastructure. The gross irrigation water demand reduces to 614.5 BCM if we account for relatively higher application efficiency (~20% higher) from the adoption of micro-irrigation in 16.7 Mha area (as on March 31, 2024). The estimated value of 614 BCM is close to the upper range (561-611 BCM) of NCIWRD's projections for the year 2025.

Table 1. Aggregate-level estimates for crop and irrigation water requirement in India in 2023-24

Billion Cubic Meter

Particular	For gross cropped area	For gross irrigated area
Crop water requirement	1276.2	751.7
Net irrigation water requirement	605.7	426.6
Gross irrigation water requirement		
Without adoption of micro irrigation	896.5	630.5
With adoption of micro irrigation	880.5	614.5

Note: Estimations are made at district-level for existing cropping pattern (separately for surface and groundwater irrigated areas) and aggregated at national level

Source: Authors' estimates.

Estimates at disaggregate level

GIWR depends significantly on the composition of the cropping pattern due to wide inter-crop variation in CWR. Disaggregate-level analysis revealed that cereals account for a predominant share (58.8%) of GIWR in India. Within

cereals, rice has emerged as the most water-intensive crop, accounting for 37.2% of the GIWR while occupying 26.5% of GIA (Table 2). Similarly, sugarcane and fruits require disproportionately higher share of total GIWR than their acreage in GIA. On the other hand, crops such as pulses, oilseeds, maize and millets have relatively less water requirements and diversification toward these crops can significantly reduce the overall water footprints in agriculture. Additionally, the strategy of diversification towards these crops is also recommended to improve nutritional security, achieve self-sufficiency, and reduce fossil fuel dependency through bioethanol production.

Spatial variation

It is prudent to devise water management strategies at a regional level given the wide spatial variation in water demand caused by differing cropping patterns and agro-climatic conditions. Figure 1 illustrates the normalized annual estimates of CWR and GIWR per unit of NSA (m^3/ha) across districts. The analysis reveals that the majority (65.4%) of the country's regions require an annual water allocation up to $7360 \text{ m}^3/\text{ha}$ to meet the irrigation requirement of the existing cropping pattern. Interestingly, large areas of the Indo-Gangetic Plains and certain southern districts require higher irrigation water to sustain agriculture. These evidences provide empirical basis for managing the water resources efficiently, prioritizing demand-side interventions, delineating water-abundant versus water-scarce zones, and optimizing crop selections where necessary.

Irrigation demand-based strategies of agricultural water management

Volumetric quantification of irrigation water demand forms a core element of agricultural water management planning. Aligning quantified irrigation requirement with demand-based strategies significantly contributes to water security by enabling optimization of the application of water to exact crop requirements, and thus improving water use efficiency. Furthermore, it also provides an empirical basis for making informed decisions regarding supply-side interventions. Some of the agricultural water management strategies which can be strengthened by aligning with volumetric irrigation demand include the following.

- Integrating water budgeting into planning:** Quantifying irrigation water requirements is a major component of water budgeting which aligns water supply and demand (from all uses) in a defined geographical unit. It enables local authorities and communities to assess the available surface and groundwater resources, water demand and water gap, and identify context-specific demand and supply-side interventions. For instance, in a geographical area with negative water balance-

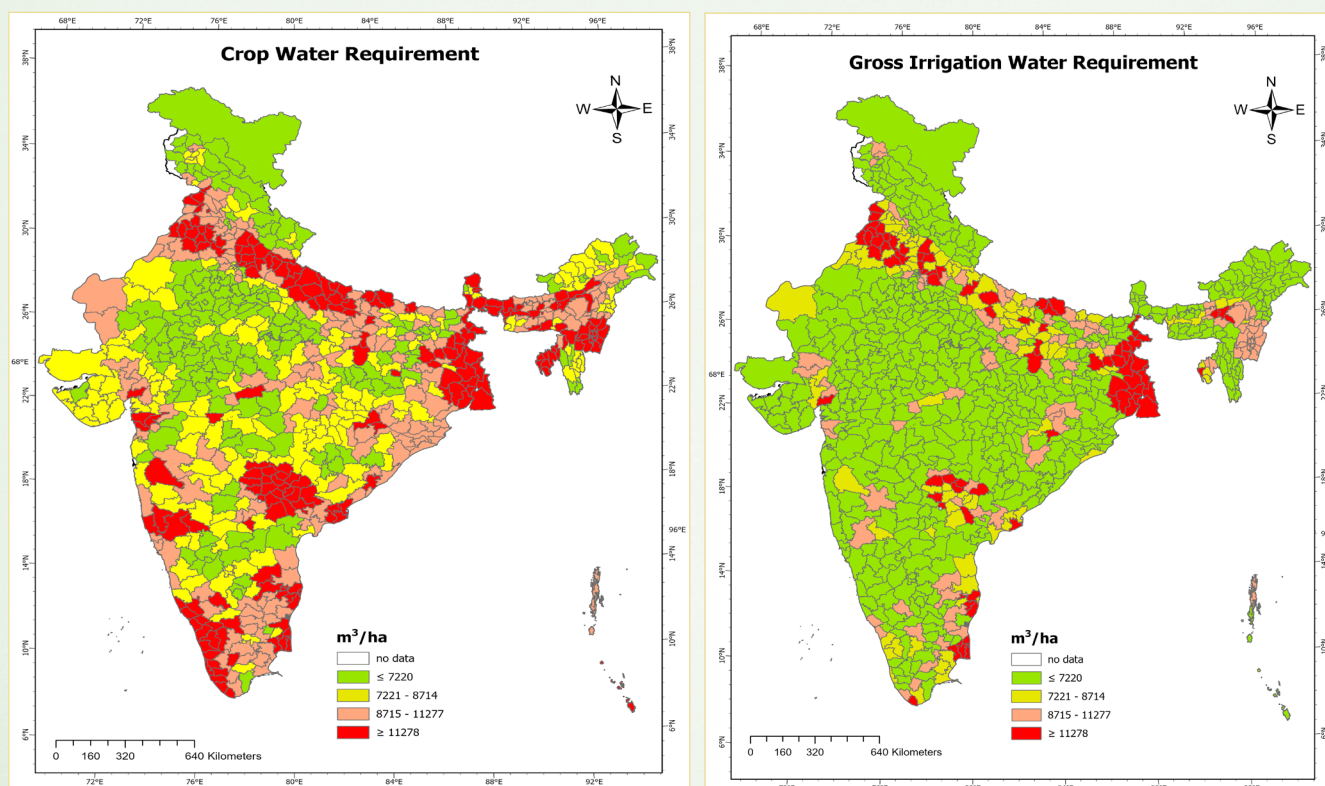
Table 2. Disaggregate-level estimates of CWR and IWR in India in 2023-24

Crops	CWR (mm)	NIWR (mm)	GSA (Mha)	GIA (Mha)	GIWR at GSA (BCM)	GIWR at GIA [#] (BCM)	Crop irrigated area (%)	Crop water volume (%)
Cereals			109.9	76.1	479.0	370.5	58.3	58.8
Rice	871.1	552.4	49.8	34.6	320.0	234.7	26.5	37.2
Wheat	305.7	247.4	35.0	33.4	126.4	121.7	25.6	19.3
Maize	384.2	177.8	11.2	4.7	11.3	7.7	3.6	1.2
Other cereals & Millets	319.8	151.3	13.9	3.3	21.2	6.5	2.5	1.1
Pulses			26.1	9.1	81.2	34.3	7.0	5.4
Gram	272.2	224.2	8.9	4.7	35.7	19.5	3.6	3.1
Arhar	562.4	134.2	3.9	0.5	7.2	1.2	0.4	0.2
Other Pulses	369.0	194.2	13.4	3.9	38.2	13.6	3.0	2.1
Oilseeds			32.5	14.2	59.6	33.0	10.9	5.2
Rapeseed & Mustard	234.5	190.4	9.0	7.6	25.1	21.6	5.8	3.4
Soyabean*	310.5	77.9	13.0	1.4	0.014	0.005	1.1	0.001
Groundnut	421.6	222.1	4.7	2.5	4.0	3.0	1.9	0.5
Other Oilseeds	357.5	205.1	5.8	2.8	30.5	8.4	2.1	1.3
Sugarcane	1517.8	814.2	6.7	6.5	86.2	83.5	4.9	13.2
Total Fibres			13.2	6.4	34.2	25.0	4.9	4.0
Cotton	679.5	269.8	12.5	6.4	33.2	25.0	4.9	4.0
Other Fibres	468.5	213.3	0.7	0.0	1.0	0.0	0.0	0.0
Fruits & Vegetables			12.6	8.9	70.4	53.6	6.8	8.5
Fruits	1016.7	650.1	5.1	3.6	41.6	30.4	2.7	4.8
Vegetables	524.8	247.8	7.5	5.3	28.8	23.3	4.1	3.7
Other Crops	485.5	216.5	16.9	9.4	85.9	30.6	7.2	4.9
Total			217.9	130.5	896.5	630.5	100.0	100.0

Note: *Very low value of irrigation water requirement for soybean is due to the fact that a large portion of total water requirement is met from effective rainfall; [#]The estimate does not account for efficiency improvements resulting from the adoption of micro irrigation in irrigated areas; Estimations are made at district-level for existing cropping pattern (separately for surface and groundwater irrigated areas) and aggregated at national level. CWR- Crop Water Requirement; NIWR- Net Irrigation Water Requirement; GIWR- Gross Irrigation Water Requirement; GSA- Gross Sown Area; GIA- Gross Irrigated Area.

Source: Authors' estimates.

Figure 1. Inter-district variation in CWR and GIWR at GSA (m³/ha of net sown area) in 2023-24



where demand is more than availability- farmers can be incentivised to reduce water demand either by switching towards less water-intensive crops or by adopting efficient irrigation practices. Cultivating water saving alternatives crops successfully requires optimizing revenue terms of trade in their favour through estimating and attaining threshold yield and targeted prices. From supply side, infrastructure for augmenting groundwater recharge and surface water storage can be planned.

- **Delineating water surplus versus deficit regions:** Comparing irrigation water requirement with the water availability can delineate potential water surplus and deficit regions, and therefore help in making informed water management decisions. For instance, water authorities can implement volumetric allocations per farm, plan irrigation scheduling at most critical stages, and promote precision technology, groundwater recharge and better pumping policy in water deficit regions. On the other hand, water surplus regions can emphasize creating storage infrastructure for minimizing seasonal water imbalances, preventing issues related to waterlogging through drainage cum recharge system, preferring high-yielding water-intensive crops, preparing micro-plans for wetlands, and exploring possibilities of inter-regional water transfers. Efforts shall be extended to delineate regions at smaller scale (at the district level or below) as water scarcity may exist within areas that look surplus overall.
- **Modernising irrigation infrastructure:** Presently, farmers rely on the *warabandi* system of canal water distribution wherein water is allocated to the farms based on a time-based rotational system, proportional to the farm-size and crops. Aligning volumetric irrigation water demand to the infrastructure planning is a prerequisite to the transition from traditional ‘supply-driven models’ (such as the *warabandi* system) to ‘demand-based designing’ (delivering exact water volumes dictated by real-time plant need). The demand-based system, utilizing a modernized, automated infrastructure network, significantly improves the efficiency and equity in water distribution over the traditional system. For such system to work, the physical water delivery infrastructure must be structurally aligned with actual demand metrics. Pilot studies are needed to evaluate technical feasibility and socio-economic impacts of small-scale modernized irrigation infrastructure and assess the scaling up potential.
- **Devising sustainable energy pricing for irrigation:** Volumetric assessment of irrigation water requirement helps in devising optimum energy pricing to regulate extraction of groundwater within the sustainability limits. It is found that a tiered pricing model, in which electricity tariff increases when its consumption crosses the established thresholds, optimizes the trade-off between farmers’ economic welfare and sustainable use of groundwater⁴. The appropriate threshold for energy subsidy can be anchored at the corresponding electrical energy needed to pump the estimated volume of GIWR for the existing cropping pattern in a geographical unit. Savings from rationalizing energy subsidy can be used further to incentivise farmers who use energy efficiently.
- **Adopting sustainable cropping pattern and precision irrigation technologies:** Volumetric irrigation water demand is a critical parameter for mapping regional crop suitability against the water availability and optimizing existing cropping patterns for long term sustainability. Quantifying irrigation demand is also a foundation step for transitioning from conventional irrigation to precision irrigation technologies such as micro-irrigation, to improve water use efficiency. Improvement in efficiency, in turn, lowers the GIWR and thus drives the system towards sustainability. Although adoption of precision irrigation technologies is accelerating, comprehensive studies are required to understand farmers’ behaviour response to the promotion of these technologies.
- **Strengthening community-based organizations:** Distribution of irrigation water to individual farmers and maintenance of lower levels of the canal system are entrusted to water users associations (WUAs) whose functional autonomy and financial status needs to be further strengthened suiting their diversified socio-economic conditions. The traditional *warabandi* system of water allocation adversely affects the performance of WUAs by creating extreme operational rigidity, amplifying head-to-tail inequities, and undermining the associations’ financial viability. Allocating water quotas to individual farmers based on estimated irrigation water requirements can transform WUAs from supply-driven system to demand-based management, and lead to equitable water sharing, improve fee collection and boost overall system performance.

⁴ Srivastava, S.K., Kishore, P., BIRTHAL, P.S., Singh, J. and Sethi, R.R. (2025). Tiered electricity pricing for sustainable groundwater use for irrigation. Policy Brief-63. ICAR-National Institute of Agricultural Economics and Policy Research.

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