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The water paradox in India: Managing abundance amid growing scarcity

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THE WATER PARADOX IN INDIA: MANAGING ABUNDANCE AMID GROWING SCARCITY

NCAER Working Paper

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Abstract

India is facing a looming water crisis driven by rapid urbanisation, population growth, groundwater depletion, and climate variability. Despite receiving over 3,800 billion cubic metres of annual precipitation, the country utilises less than one-third effectively due to uneven rainfall distribution, inadequate storage infrastructure, and poor water governance. Per capita water availability has declined sharply, while demand is projected to double by 2030. Agriculture remains the dominant water consumer, though industrial and domestic demands are rising rapidly. Groundwater over-extraction—particularly in states like Punjab, Rajasthan, and Delhi—has led to critical depletion, with 22% of groundwater blocks categorised as overexploited. Climate change further exacerbates water stress through erratic monsoons, glacial retreats, and increasing droughts and floods. This paper assesses systemic challenges across the water sector in India, from source sustainability to end-use efficiency. It also highlights policy evolution, institutional bottlenecks, and emerging governance initiatives. The study emphasises the urgent need for integrated water resource management, investment in wastewater recycling, demand-side interventions, and climate-resilient infrastructure to ensure water security. A multi-pronged strategy is essential for safeguarding livelihoods, supporting economic development, and achieving long-term sustainability.

JEL codes: O21, Q25, Q53, R11

Keywords: Water scarcity, Groundwater depletion, Climate change, Urbanisation, Water governance and management, India

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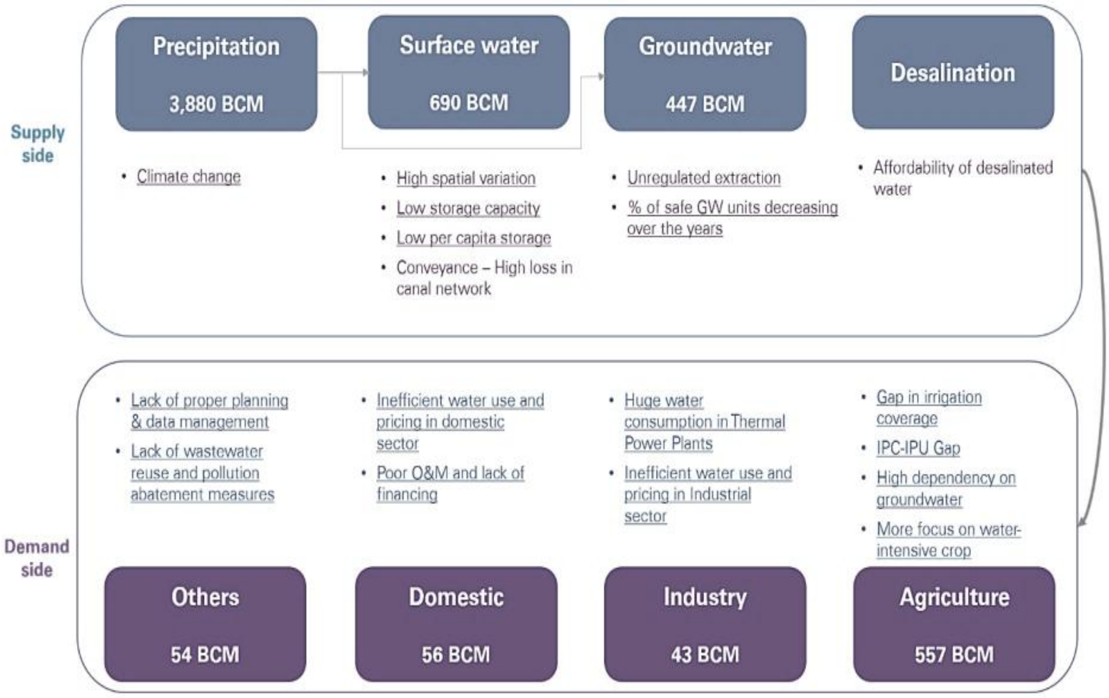
1 Introduction

India is grappling with an intensifying water crisis, particularly in its urban centres, as the country's urban population is projected to surge from 377 million in 2011 to nearly 600 million by 2031 (Amarasinghe et al., 2004). Despite having substantial surface water resources, persistent water scarcity remains a critical challenge. India supports 18% of the global population but spans only 2.4% of the world's land area and depends on just 4% of the planet's freshwater resources. Water is vital for sustaining livelihoods and underpins key sectors such as agriculture, industry, and livestock production (Franks et al., 2002). However, the country's existing water infrastructure is inadequate to meet the rapidly growing demands, posing serious risks to urban development and human well-being.

This raise pressing questions: How can India ensure a sustainable and equitable water supply for its expanding cities? What policy measures, infrastructure investments, and water management strategies are required to avert worsening shortages and their cascading effects on sanitation, housing, healthcare, and transportation?

Although India receives an average annual rainfall of 118 cm, the nation remains under acute water stress due to hydrological imbalances, excessive consumption, and rising pollution levels. A sectoral assessment of the water economy, using an end-to-end value chain approach (Figure 1), highlights critical gaps across both the supply and demand dimensions. Rampant groundwater extraction by farmers, industries, and urban households has significantly depleted water reserves. Per capita water availability has declined sharply by 75%, from 6,042 m^3 in 1947 to just 1,486 m^3 in 2021 (Vishwa Mohan, 2023). Looking ahead, projections indicate that by 2030, water demand may be over twice the available supply, leading to severe shortages and far-reaching economic and social consequences (TERI, 2022; NITI Aayog, 2019).

Figure 1. Water resources sector—value chain with key issues



Source: NITI Aayog (2021)

As urban centres continue to expand, particularly across the western, southern, and northwestern regions of India, this growth in demand increasingly encroaches upon agricultural lands and ecologically sensitive zones, placing additional strain on already stressed water resources. Unplanned, rapid urbanisation has accelerated concretisation, reducing the natural permeability of land, impeding groundwater recharge (M. R. Kumar, 2019) and amplifying surface runoff, thereby increasing the risk of urban flooding.

At the heart of this challenge lies the stark contradiction between India's abundant rainfall and its acute local water scarcity. Despite receiving nearly 3,880 billion cubic metres (BCM) of annual precipitation, only a fraction is effectively utilised due to regional imbalances, inadequate storage, and inefficient management. With just 4% of global freshwater resources for nearly 20% of the world's population, water security has emerged as a critical development challenge (Biswas et al., 2025). The crisis spans multiple dimensions. Groundwater, which supports over 80% of rural drinking water and nearly two-thirds of irrigation, is severely over-exploited in several states, including Punjab, Rajasthan, Haryana, and Delhi. Widespread contamination from fluoride, arsenic, and industrial pollutants further compounds the problem. At the core lies a skewed supply-demand equation. Agriculture consumes nearly 78% of total withdrawals, yet inefficient irrigation and policy distortions accelerate wastage.

Meanwhile, urbanisation, industrial growth, and rising energy demands are rapidly reshaping water-use patterns. Projections suggest that by 2030, demand may exceed supply by almost twofold (Financial Express, 2019), posing serious risks to food security, health, and economic stability. Climate change intensifies these vulnerabilities through erratic monsoons, glacial retreat, rising sea levels, and more frequent floods and droughts, particularly in already stressed regions. These compounding shocks threaten to deepen water insecurity and disrupt livelihoods across the country.

This study makes a significant contribution by providing a comprehensive and integrated analysis of India's ongoing water crisis. Employing an end-to-end value chain approach, the analysis traces the entire water system—from source sustainability and storage to distribution and end-use efficiency—exposing critical gaps and systemic inefficiencies that have long undermined effective water management in the country. This approach offers a unified framework for understanding the complex and interlinked nature of India's water challenges. A second key contribution lies in the use of rich, disaggregated data at the state, district, and river basin levels. By compiling detailed information on groundwater extraction rates, recharge capacities, and per capita water availability, the study reveals stark regional disparities. Its third major contribution is a sectoral analysis of water demand. The study systematically tracks how water consumption patterns across agriculture, industry, domestic use, and energy production are evolving, and projects these trends into the future.

Additionally, the study offers valuable insights into the evolution of India's water governance landscape, examining how historical policy developments, institutional structures, and decentralised governance mechanisms have sought, often with limited success, to address the deepening crisis. This assessment underscores the urgent need for integrated water resource management strategies that balance ecological sustainability with socioeconomic development.

Furthermore, the study attempts to connect macro-level trends with micro-level vulnerabilities. By weaving together diverse strands—from encroached urban water bodies and declining rural aquifers to the retreat of Himalayan glaciers—the study presents a cohesive narrative of how climate variability and human pressures converge to intensify water risks at multiple scales. Importantly, the study moves beyond diagnosis to offer forward-looking solutions. It synthesises a broad set of policy and technological recommendations, ranging from wastewater re-use and rainwater harvesting to AI-based hydrological modelling and demand-side management strategies.

The remainder of the paper is structured as follows: Section 2 evaluates India's surface and groundwater storage capacities, rainfall patterns, and basin-wise supply dynamics. Section 3 analyses sectoral demand trajectories, with a primary focus on agriculture, followed by the domestic and industrial sectors. Section 4 explores the impacts of climate variability, extreme weather events, and region-specific vulnerabilities on water resources. Section 5 reviews India's water governance architecture, covering constitutional roles, policy evolution, and institutional mechanisms at the national and state levels. Section 6 concludes with key findings, policy implications, and directions for future research.

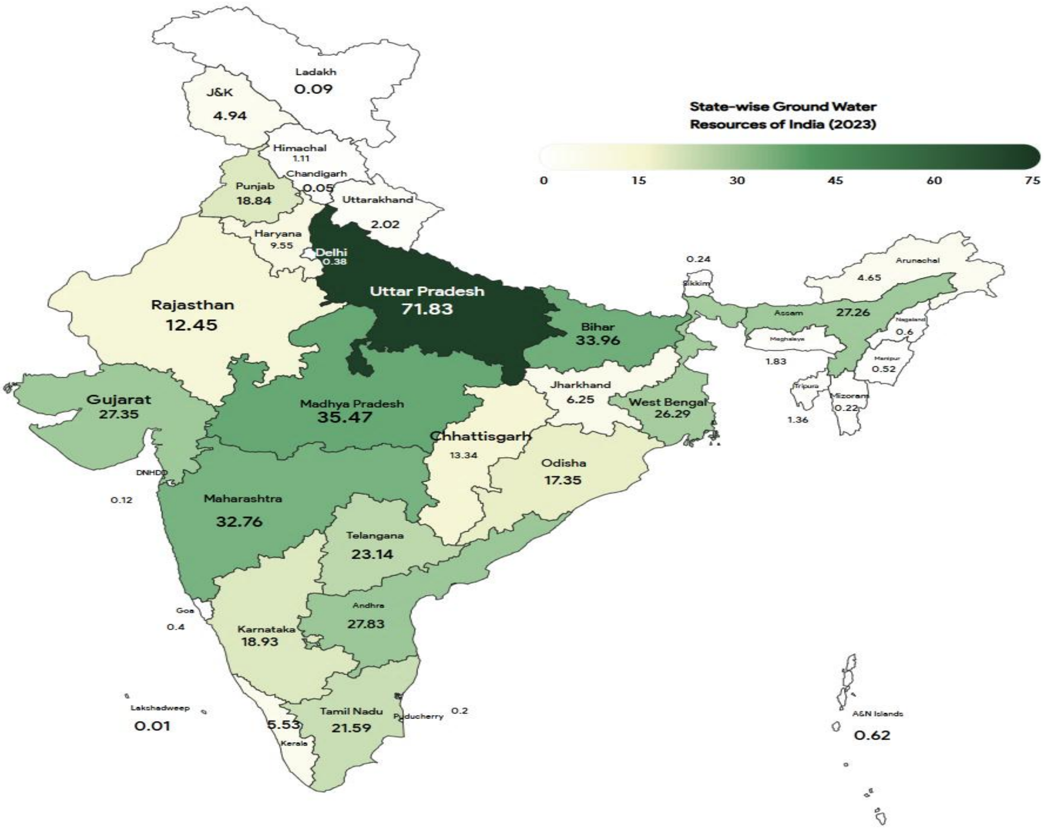
2 Water supply overview

This section provides a detailed assessment of India's water supply landscape, highlighting growing stress due to rising demand, uneven rainfall, over-extraction, and inadequate infrastructure. The discussion covers the distribution of surface and groundwater resources, with a focus on regional disparities. It also explains the challenges of monsoon dependence and inadequate storage infrastructure, which restrict water availability during non-monsoon months. It highlights the over-exploitation of groundwater, driven by irrigation needs and policy distortions like subsidised power, pushing many districts into critical and over-exploited categories. Additionally, the section sheds light on serious water quality issues, including contamination by fluoride, arsenic, iron, and nitrates, posing significant health risks. Infrastructure gaps, particularly the decline of traditional water bodies and poor maintenance of minor irrigation systems, further compound the crisis. Overall, this section sets the context for understanding India's water challenges and the urgent need for policy reforms, sustainable groundwater management, pollution control, and infrastructure upgrades.

2.1 Overview of water resources distribution

India receives an estimated 3,880 BCM of precipitation annually, benefitting from an extensive network of rivers and snow-fed mountain sources. However, the distribution of rainfall is highly uneven across regions, and significant water loss occurs due to high evaporation rates. As a result, the total usable water availability is limited to approximately 1,123 BCM, with 690 BCM derived from surface water sources and 436 BCM from groundwater reserves (PIB, 2017). As of 2023, the country's total annual groundwater recharge is estimated at 449.08 BCM, but only 398.08 BCM is considered extractable. The distribution of groundwater recharge varies significantly across states (as shown in Figure 2), with northern states like Punjab, Haryana, and Rajasthan facing particularly severe challenges. In Punjab and Haryana, groundwater extraction rates far exceed recharge rates, leading to alarming depletion levels. By 2022, India's groundwater extraction reached 239.16 BCM as per the Central Ground Water Board (CGWB, 2022), reinforcing its status as the world's largest consumer of groundwater. This heavy reliance on groundwater raises concerns about long-term sustainability, especially given the increasing demand for irrigation, industrial use, and domestic consumption.

Figure 2. State-wise groundwater recharge, 2023 (in BMC)



Source: IndiaStat (2025)

Although monsoon rains provide significant water input, inadequate storage facilities limit retention capacity. Around 80% of river water flows during the four-month southwest monsoon season (Qazi et al., 2020). Groundwater serves as a lifeline, supplying 62% of irrigation needs, 85% of rural water demands, and 50% of urban water requirements.

A key challenge is the disparity between water availability and population distribution. Densely populated regions often suffer from water shortages, whereas some areas experience excess water or flooding. Differences in rainfall distribution, topographical features, and hydrological factors further contribute to regional imbalances. Major river basins, including the Ganges, Yamuna, Brahmaputra, and Godavari, endure seasonal changes, resulting in periods of water scarcity and flooding.

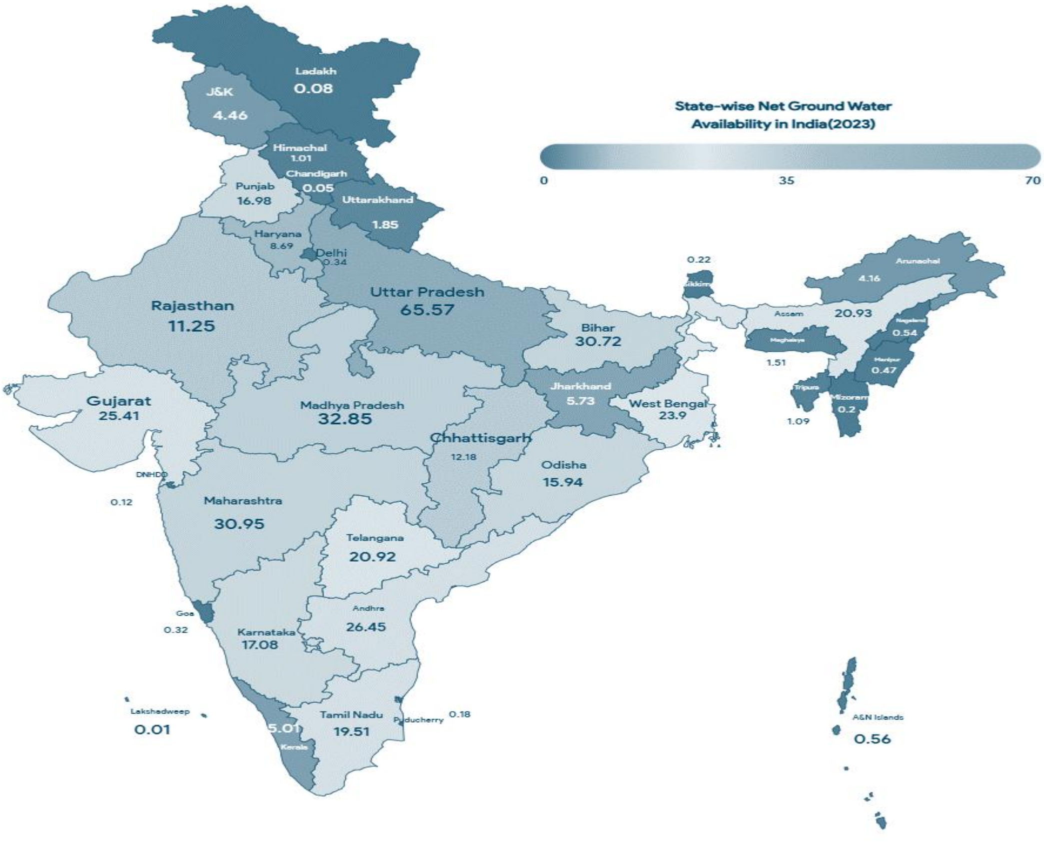
Regional disparities in groundwater availability further exacerbate this challenge. As seen in Figure 3, states like Uttar Pradesh (65.57 BCM), Madhya Pradesh (32.85 BCM), and Maharashtra (30.95 BCM) have relatively high per capita groundwater availability, yet localised over-extraction in densely populated districts leads to seasonal shortages. In contrast, states such as Delhi (0.34 BCM), Chandigarh (0.05 BCM), and Ladakh (0.08 BCM) face extreme groundwater scarcity due to limited recharge potential and high population density.

Rajasthan, despite its vast land area, has only 11.25 BCM available (CGWB, 2024), making water management a crucial concern. Meanwhile, northeastern states like Arunachal Pradesh (4.16 BCM) and Meghalaya (1.51 BCM) receive abundant rainfall, but steep topography and lack of storage infrastructure limit groundwater utilisation. Coastal states like Tamil Nadu (19.51 BCM) and Andhra Pradesh (26.45 BCM) depend heavily on monsoonal recharge, making them vulnerable to variability in rainfall patterns.

India is home to 19 major river basins, each exhibiting significant disparities in per capita water availability. For instance, the Sabarmati basin experiences extreme water scarcity (A. Sharma et al., 2025), with just 260 m^3 per capita, whereas the Narmada basin enjoys a far more abundant supply of 2,227 m^3 per capita. Similarly, water withdrawals vary considerably, ranging from as low as 235 m^3 in the east-flowing river basins to a much higher 1,255 m^3 in the Indus basin (see Figure 4).

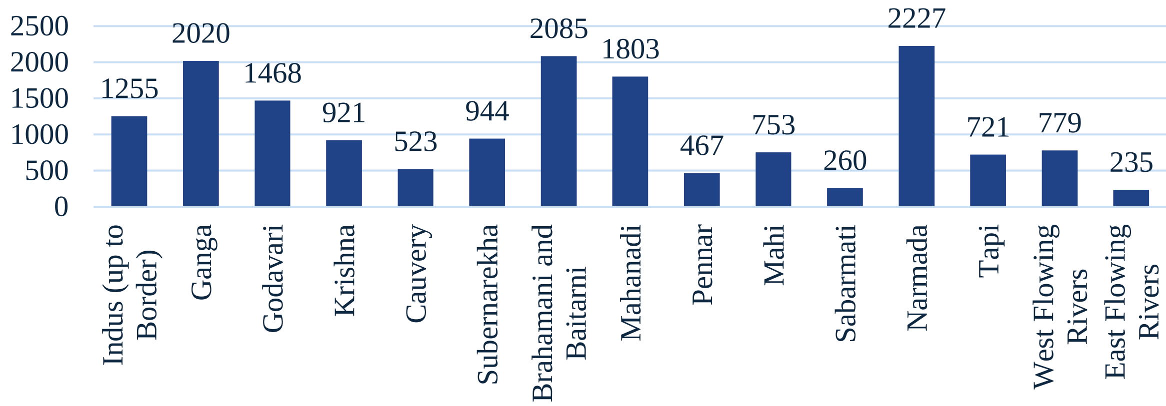
The United Nations defines water stress as occurring when annual per capita water availability drops below 1,700 m^3, while water scarcity is marked by levels below 1,000 m^3 (PIB, 2024) and absolute scarcity is reached when availability falls under 500 m^3. Over the decades, India has witnessed a steady decline in per capita water availability (see Figure 5) — from approximately 6,042 m^3 in 1947 to 1,816 m^3 in 2001 and further down to 1,545 m^3 by 2011. Future projections suggest a continued downward trend, with expected availability shrinking to 1,340 m^3 by 2025 and potentially reaching 1,140 m^3 by 2050, highlighting growing concerns over water security in the country.

Figure 3. State-wise net groundwater availability, 2023 (in BCM)



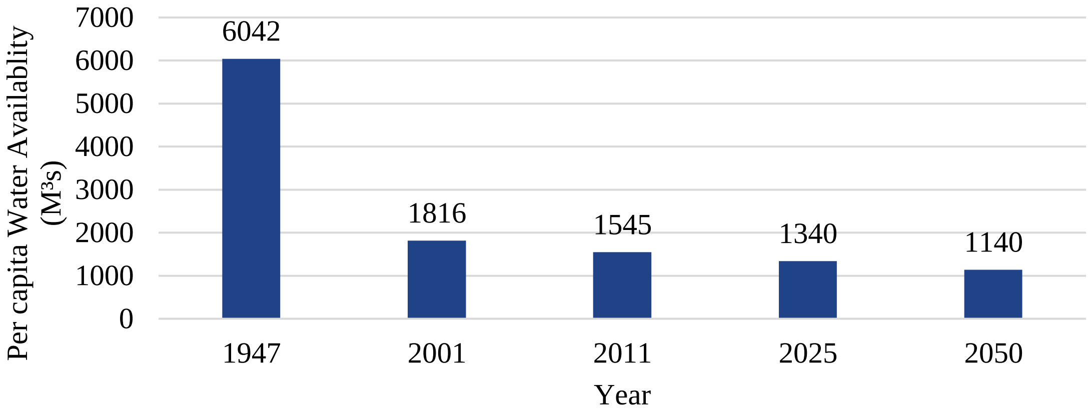
Source: IndiaStat (2025)

Figure 4. River basin-wise annual per capita water availability, 2010 (in m³)



Source: IndiaStat (2025)

Figure 5. Annual per capita water availability pattern, 1947-2050



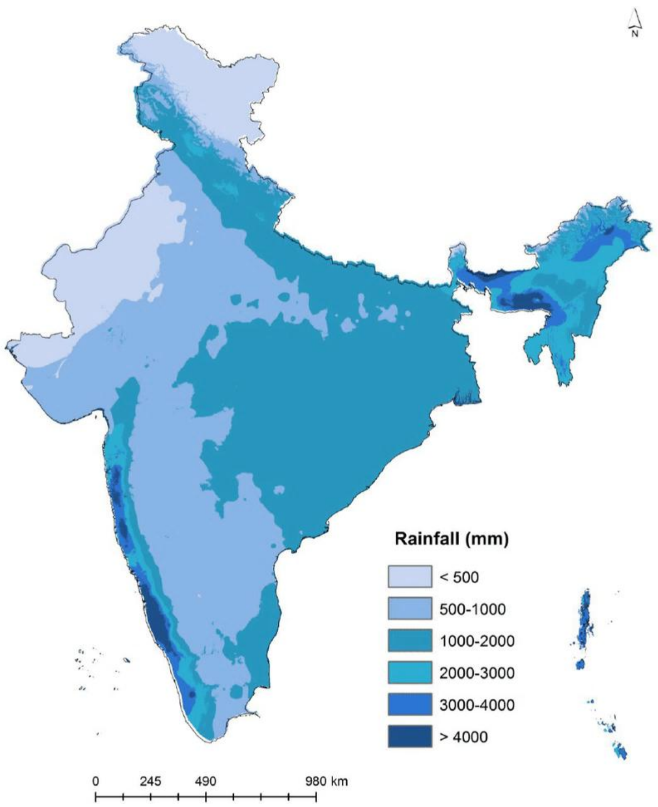
Source: Vincent et al. (2017)

Urbanisation, rising consumption, and climate change are compounding water shortages. India receives most of its annual precipitation (80–95%) during the monsoon season, leading to significant regional disparities. Rainfall varies from 300–500 mm annually in the arid western regions to about 3,000 mm in the humid eastern areas. However, due to infrastructure and technological constraints, less than a third of this precipitation is effectively utilised. The total usable surface and groundwater resources are estimated at 690 BCM and 431 BCM, respectively (TERI, 2022). Over the last two decades, per capita water availability has dropped by 20% and is expected to decline another 20% by 2050, exacerbating water scarcity (PIB, 2024). Climate change further intensifies these concerns, with rainfall reductions observed in at least 14 states since the 1950s.

2.2 Annual rainfall and surface water resources

India receives approximately 3,880 BCM of annual precipitation, but only 1,999 BCM is retained for use. The country's total usable water resources are 1,126 BCM, comprising 690 BCM from surface water and 436 BCM from replenishable groundwater (Jindal & Das, 2024). About 75% of the annual rainfall occurs during the monsoon season from June to September (MoEFCC, 2019). However, rainfall patterns are highly uneven (see Figure 6). The Western Ghats and northeastern regions receive over 2,500 mm of rain annually, while arid zones such as the Thar desert and parts of Kashmir receive less than 400 mm. This disparity leads to flooding in some regions and drought in others. From 2000 to 2020, rainfall variability ranged from +6% to -14% of the long-term average, with 30% of meteorological subdivisions experiencing deficits over 20% (EnviStats, 2025).

Figure 6. Annual mean rainfall map



Source: Reddy et al. (2015)

India has 20 major river basins, with the Brahmaputra basin providing the highest water availability at 527.28 BCM, followed by the Ganges basin at 509.52 BCM (CWC, 2019). Despite its abundant resources, per capita surface water availability dropped from 1,816 m^3 in 2001 to 1,545 m^3 in 2011 (CWC, 2015). Limited storage capacity is a significant issue, restricting water access during dry periods.

The country's gross water storage capacity is 325.455 BCM, which is less than 45% of its total surface water potential (NITI Aayog, 2021). Major river basins, including the Ganga, Brahmaputra, Indus, Godavari, and Mahanadi, suffer from inadequate storage facilities. Even with proposed irrigation projects, storage capacity is projected to reach only 304.4 BCM, which remains below the required levels (EnviStats, 2025). As of July 2024, the total live capacity of reservoirs across India was 178.78 BCM, with significant regional variations in storage levels (see Table 1). The decline of traditional storage methods exacerbates water scarcity. The First Water Bodies Census (CWB, 2023) reported that 38,496 water bodies had been encroached upon. Additionally, the area under tank irrigation dropped from 46.30 lakh hectares in 1960–61 to 22.05 lakh hectares in 2021–22, signalling a deterioration of traditional water management practices.

Table 1. Basin-wise status of reservoir storage

Basin	Live Capacity at Full Reservoir Level (FRL)	This Year's Storage (2024)		Last Year's Storage (2023)		Normal Storage		%age Departure W.R.T. Normal Storage
		In BCM	In %age	In BCM	In %age	In BCM	In %age	
Ganga	33.25	10.54	31.7	13.39	40.27	11.77	35.38	-10.42
Subarnarekha	0.22	0.07	33.94	0.06	29.36	0.09	39.45	-13.95
Brahmaputra	0.87	0.57	65.33	0.32	36.27	0.45	51.6	26.61
Barak & Others	0.31	0.19	60.58	0.12	37.18	0.16	52.24	15.95
Indus	14.82	4.51	30.44	9.5	64.11	5.08	34.26	-11.15
Brahmani & Baitarni	4.3	0.6	14.05	0.62	14.38	0.76	17.56	-20
East-flowing Rivers Between Mahanadi & Pennar	0.51	0	0	0.07	12.99	0.07	14.17	-100
East-flowing Rivers Between Pennar & Kanyakumari	2.17	0.16	7.19	0.63	29.02	0.39	17.73	-59.48
Pennar	1.99	0.07	-51	0.52	26.23	0.58	29.14	-88.3
West-flowing Rivers of Kutch & Saurashtra, Including Luni	1.38	0.24	17.33	0.9	64.97	0.31	22.19	-21.9
Narmada	22.34	4.35	19.46	7.51	33.61	5.25	23.5	-17.18
Tapi	7.39	2.03	27.41	2.14	28.97	1.87	25.26	8.51
Mahi	4.31	1.19	27.72	1.32	30.59	1.52	35.26	-21.4
Sabarmati	1.04	0.25	24.28	0.59	56.53	0.23	21.69	11.95
Godavari	17.92	3.76	20.96	5.56	31.01	4.77	26.61	-21.24
Krishna	32.94	7.74	23.5	5.1	15.47	7.52	22.83	2.91
Mahanadi	9.85	2.23	22.59	4.07	41.3	3.08	31.24	-27.68
Cauvery	6.19	2.19	35.31	2.42	39.03	2.46	39.71	-11.06
West-flowing Rivers from Tapi to Tadri	7.21	2.5	34.67	2.02	28.09	2.49	34.58	0.24
West-flowing Rivers from Tadri to Kanyakumari	9.76	3.13	32.09	2.02	20.74	2.9	29.73	7.93
In %age	-	-	-	-	-	-	-	-10.47
Total	178.78	46.31	-	58.86	-	51.72	-	-

Source: IndiaStat (2025)

2.3 Groundwater depletion and over-exploitation

Groundwater is a vital water source for India, supporting 63% of its irrigation and 85% of its drinking water needs (CWC, 2019). However, over-extraction has caused groundwater use to increase from 58% in 2004 to 63% in 2017, resulting in severe depletion. In the northwestern and western states, water tables have fallen below 40 meters, indicating critical stress levels (CGWB, 2022). As of 2023, Rajasthan and Punjab reported the highest number of over-exploited districts, 29 and 18, respectively, reflecting acute regional disparities (see Table 2).

Table 2. Selected state-wise number of districts in the over-exploited and critical categories

States/UTs	Over-Exploited	Critical
Chhattisgarh	0	1
Dadra and Nagar Haveli and Daman and Diu	3	0
Delhi	5	4
Gujarat	2	2
Haryana	16	1
Karnataka	5	3
Madhya Pradesh	5	1
Maharashtra	0	1
Punjab	18	2
Rajasthan	29	0
Tamil Nadu	9	2
Telangana	0	1
Uttar Pradesh	6	6
India	98	24

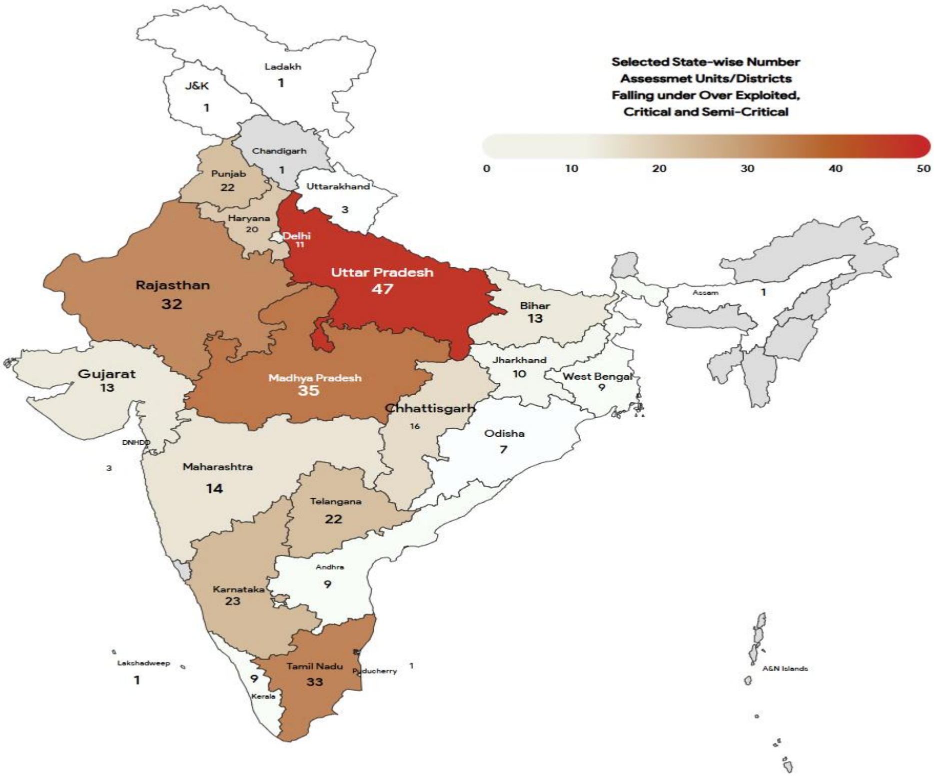
Source: IndiaStat (2025)

NITI Aayog's SDG 6.4 target aims to limit annual groundwater withdrawal to 70% of net availability by 2030. However, 202 districts already exceed this limit, with extraction rates ranging from 71% to 385% (CAG, 2021). Additionally, 63% of the observation wells recorded declining groundwater levels in 2020–21 (CGWB, 2021). Factors contributing to groundwater depletion include subsidised electricity for irrigation, the cultivation of water-intensive crops like rice and wheat incentivised by government procurement policies, and unrestricted groundwater access by private landowners. In the coastal areas, over-extraction has caused seawater intrusion, contaminating freshwater reserves.

Groundwater plays a crucial role in India's water supply, largely due to its widespread accessibility. Despite the convenience of surface water sources, groundwater remains the most heavily exploited resource. Around 89% of available groundwater is used for agricultural irrigation, while the remaining 11% supports domestic and industrial needs (India Observatory, 2020). Over 80% of the population, particularly in rural areas, relies on groundwater for their daily water supply.

The extensive use of groundwater has led to significant over-extraction, pushing many regions into critical or overexploited categories. According to the CGWB, 22% of groundwater blocks across India fall into these classifications. The situation is particularly severe in states like Punjab (22 districts), Haryana (20 districts), Rajasthan (32 districts), and Delhi (11 districts), where annual groundwater extraction surpasses natural recharge levels, exceeding 100%. Tamil Nadu (33 districts), Uttar Pradesh (47 districts), and Madhya Pradesh (35 districts) also report a high number of overexploited, critical, and semi-critical (OCS) groundwater units, highlighting widespread concerns (see Figure 7). In contrast, states like Assam (1 district), Jammu & Kashmir (1 district), and Odisha (7 districts) have relatively fewer districts under groundwater stress.

Figure 7. Selected state-wise number of assessment units/districts labelled over-exploited, critical, and semi-critical (2023)



Source: IndiaStat (2025)

Over the years, accessibility to and overreliance on groundwater have worsened resource depletion in many regions. The CGWB data underscores the pressing need for sustainable groundwater management to prevent further depletion and ensure long-term water security.

2.4 Water quality concerns and pollution

The quality of India's water resources is deteriorating significantly due to pollution from industrial and municipal sources. According to the CWC (2019), 275 rivers are severely polluted, primarily due to untreated sewage and industrial waste. Groundwater contamination has also become a pressing concern, with harmful substances such as fluoride, arsenic, iron, and nitrates posing serious health risks.

Fluoride contamination is widespread, with levels exceeding 1.5 mg/L in several regions, leading to cases of skeletal fluorosis. As of August 2023, Punjab and Rajasthan reported the highest number of fluoride-affected habitations, with 176 and 112, respectively, while West Bengal recorded 39 (see Table 3). Arsenic pollution is prevalent in the Ganga-Brahmaputra plains, where concentrations surpass the safe limit of 0.01 mg/L, as established by the Bureau of Indian Standards (BIS, 2012). Punjab also reported 319 arsenic-affected habitations, followed by West Bengal with 76. High levels of iron, exceeding 1.0 mg/L, have been detected in more than 1.1 lakh habitations, particularly in the states of Assam, Bihar, West Bengal, and Jharkhand; nitrate contamination, primarily caused by the excessive use of chemical fertilisers, further contributes to the degradation of groundwater quality.

2.5 Water supply infrastructure

India's water storage capacity is considerably below global standards. By 2015, large-scale irrigation projects stored only 253.4 BCM of water. Additionally, the Fifth Minor Irrigation Census (2017) found that 72,853 of 5.92 lakh minor water bodies were non-functional due to poor maintenance.

Table 3. Selected state-wise habitations with water quality affected by contaminants and covered by community water purification plants under Jal Jeevan Mission (7 August 2023)

State/UTs	Number of Quality-Affected Habitations								
	Fluoride		Arsenic		Heavy Metals		Iron	Salinity	Nitrate
	Total	Covered by CWPPs	Total	Covered by CWPPs	Total	Covered by CWPPs			
Arunachal Pradesh	-	-	-	-	-	-	33	-	-
Assam	-	-	-	-	-	-	6,225	-	-
Bihar	-	-	-	-	-	-	66	-	-
Jharkhand	2	2	-	-	-	-	-	-	-
Kerala	4	4	-	-	-	-	58	17	8
Lakshadweep	-	-	-	-	-	-	-	10	-
Odisha	24	24	-	-	-	-	1,067	11	6
Punjab	176	176	319	319	84	57	3	-	16
Rajasthan	112	112	-	-	-	-	4	8,824	432
Tripura	-	-	-	-	-	-	316	-	-
Uttar Pradesh	3	3	41	41	-	-	89	7	-
Uttarakhand	-	-	-	-	-	-	2	-	1
West Bengal	39	39	76	76	-	-	3	-	-

Source: IndiaStat (2025)

In India, freshwater availability also faces challenges due to limited reservoir storage (refer to Table 4). As of February 2022, the CWC reported that India's 140 monitored reservoirs have a combined live storage capacity of 175.96 BCM, with current live storage at 78.88 BCM (45% of full reservoir level). States like Gujarat and Karnataka, which house significant desalination plants, report live storage capacities of 7.24 BCM (40%) and 9.24 BCM (38%), respectively. Maharashtra, with 29 reservoirs, reports live storage of 9.46 BCM (51%), while Tamil Nadu's seven reservoirs collectively store 1.6 BCM (36%).

Table 4. Selected state-wise storage position of reservoirs under CWC monitoring (24 February 2022)

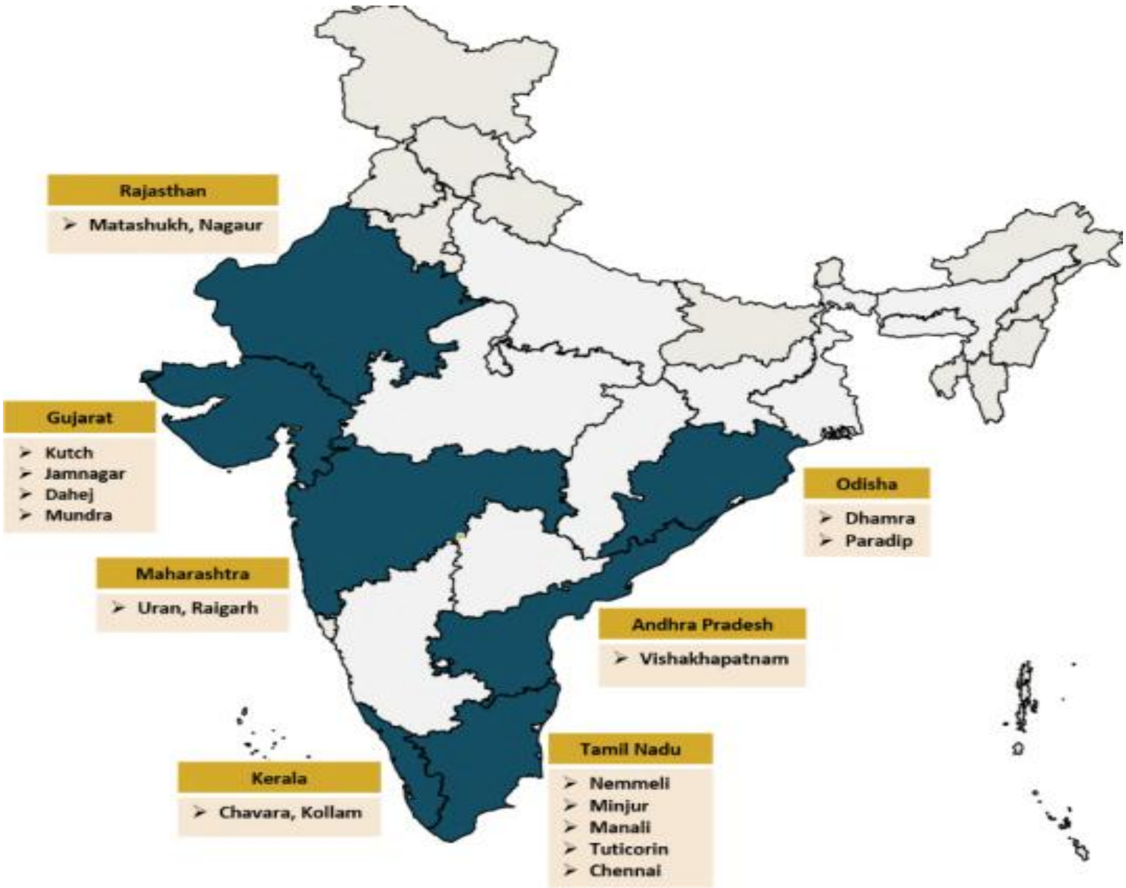
States/UTs	No. of Reservoirs Monitored	Live Capacity at FRL (BCM)	Last 10 Years Average	
			Live Storage (BCM)	Storage as % of Live Capacity at FRL %
Andhra Pradesh	3	4.29	1.66	36
Andhra Pradesh & Telangana	2	11.12	2.8	25
Bihar	1	0.14	0.04	29
Chhattisgarh	4	4.41	2.92	66
Gujarat	17	17.96	7.24	40
Himachal Pradesh	3	12.48	4.96	40
Jharkhand	6	2.01	1.19	59
Karnataka	16	24.63	9.24	38
Kerala	6	3.83	1.99	52
Madhya Pradesh	10	30.34	15.5	51
Maharashtra	29	18.45	9.46	51
Nagaland	1	0.54	0.24	44
Odisha	10	15.7	9.38	60
Punjab	1	2.34	0.82	35
Rajasthan	5	4.55	2.11	46
Tamil Nadu	7	4.44	1.6	36
Telangana	5	4.39	1.9	43
Tripura	1	0.31	0.11	35
Uttar Pradesh	8	7.66	2.92	32
Uttarakhand	3	4.99	2.21	44
West Bengal	2	1.39	0.59	42
India	140	175.96	78.88	45

Source: IndiaStat (2025)

As freshwater resources diminish, desalination offers a promising solution, especially for coastal areas. Desalination converts seawater into potable water by removing salts and impurities. Globally, desalination plants produce 86,572 million litres per day (MLD), with 44% of capacity in the Middle East and North Africa (Aqua Tech, 2023). Currently, around 1% of the global population depends on desalinated water, a figure projected to reach 14% by 2025 (Esmaeilion, 2020). India operates 182 desalination plants, primarily for industrial purposes. Key plants are located in Gujarat (Kutch, Jamnagar, and Metapur) and Tamil Nadu (Minjur and Nemmeli, each with a 100 MLD capacity) (see Figure 8). Additional projects in Nemmeli and Porur (Chennai) aim to add 400 MLD of capacity.

However, desalination remains costly, with production costs of ₹70–80 per kilolitre, compared to current water tariffs of ₹20–25 per kilolitre. Government subsidies, such as through the AMRUT programme, could reduce operational costs to ₹35–40 per kilolitre, making desalinated water more affordable.

Figure 8. Desalinated water generation states



Source: NITI Aayog (2021)

India grapples with mounting challenges in water management, including declining availability, groundwater depletion, pollution, and inadequate storage infrastructure. Although the country possesses significant water resources, poor management practices have intensified water stress. In order to address these pressing issues, comprehensive reforms are essential. Expanding storage infrastructure through the construction of new reservoirs and the restoration of traditional water bodies can enhance water conservation (Awasti, 2021).

Additionally, regulating groundwater use with stringent policies is vital to prevent over-extraction and preserve this critical resource. Improving wastewater treatment systems can significantly reduce pollution in rivers and aquifers, safeguarding water quality. In coastal regions, promoting cost-effective desalination projects can provide an alternative source of fresh water (Aggarwal, 2023). These reforms must be implemented immediately and sustained over time to prevent acute water scarcity, ensuring future food security, public health, and ecological balance. Sustainable water management is not only crucial for environmental protection but also for strengthening India's socioeconomic resilience.

3 Water resource demand

In India, while efforts to enhance water supply have been prominent, managing water demand is equally vital for conserving depleting water resources. Rising consumption patterns emphasise the need to improve water-use efficiency and promote wastewater recycling. India's water demand is distributed across four main sectors: agriculture, domestic use, industry, and the environment (including evaporation losses). Among these, agriculture remains the largest consumer of water resources. Forecasts project that India's total water demand will grow from 634 BCM in 2000 to 1,093 BCM by 2025, eventually reaching 1,447 BCM by 2050 (NITI Aayog, 2019). Additionally, the NITI Aayog's 2018 report warns that by 2030, water demand could surpass supply by twofold, potentially hindering economic progress and public well-being. According to FAO (2025), annual per capita water withdrawals cover agricultural, industrial, and municipal needs, encompassing both surface and groundwater resources.

The National Commission for Integrated Water Resources Development estimated that by 2050 water demand will range between 973 BCM (low-demand scenario) and 1,180 BCM (high-demand scenario). Agriculture is expected to account for 68% of total demand, followed by domestic use (9%), and industrial use (7%). These projections assume improvements in irrigation efficiency from the current 35–40% to 60%, although achieving this target remains uncertain.

This section on water resource demand explores how rising consumption across the agriculture, industry, and domestic sectors is intensifying pressure on India's limited water resources.

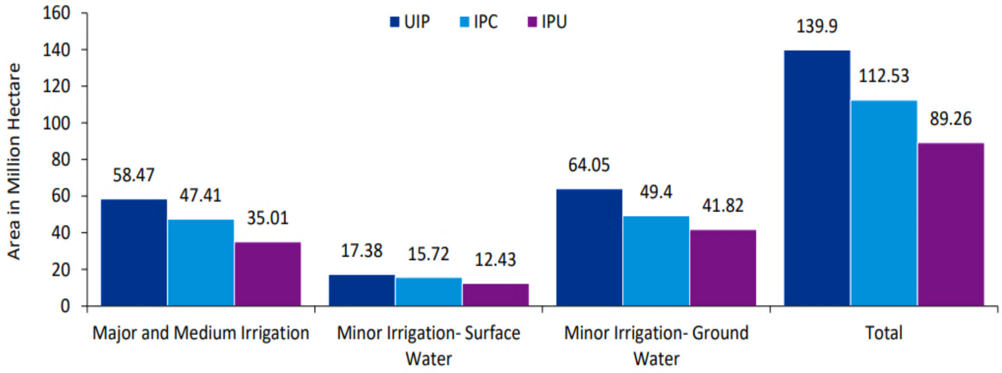
3.1 Agriculture: The largest water consumer

Agriculture is pivotal to India's economy, contributing 16% to GDP and employing 46% of the population as of 2024 (Frontline, 2025). India's irrigation network includes wells, reservoirs, canals, tanks, and multipurpose river projects, with techniques ranging from traditional flood and surface irrigation to modern drip-and-sprinkler systems. Currently, agriculture consumes approximately 78% of India's total water demand, though this share is projected to reduce to 68% by 2050. Historically, large dams served as primary irrigation sources, but since the 1970s, groundwater extraction from wells and tube wells has become predominant, now supplying over 63% of agricultural water (Mihir Shah Committee, 2016).

Despite extensive investments, India underutilises its irrigation capacity, with a 21% gap between created and utilised irrigation potential, translating to roughly 23 million hectares of unused capacity (Mihir Shah Committee, 2016). Surface water projects contribute 56% to IPC, while groundwater-based minor projects account for 44%. The overall irrigation development status as of March 2012 is summarised in Figure 9 below.

Groundwater irrigation is notably more efficient than surface irrigation due to lower conveyance losses. Conventional irrigation practices cause substantial water losses; however, transitioning to efficient methods like drip-and-sprinkler systems could conserve up to 146 BCM annually (CWC, 2019). By 2050, India's total irrigation water requirement is projected to rise to 805 BCM from 611 BCM in 2025, with Uttar Pradesh alone demanding over 124.5 BCM (see Table 5). States like Bihar and Madhya Pradesh will also witness sharp increases, from 47.4 to 79.1 BCM and 43.1 to 77.8 BCM, respectively. Even northeastern states like Assam show a more than twofold rise, from 19.8 to 43 BCM, underlining the growing pressure on water resources.

Figure 9. Area under various types of irrigation, 2012



Source: NITI Aayog (2021)

Table 5. State-wise estimated water requirement for irrigation (2025 and 2050, in BCM)

State/UT	2025	2050
Andhra Pradesh	56.8	77.6
Arunachal Pradesh	0.7	1.4
Assam	19.8	43
Bihar	47.4	79.1
Goa	0.4	0.4
Gujarat	32.6	37.7
Haryana	28.2	25.4
Himachal Pradesh	1.7	1.5
Jammu & Kashmir	4.4	7.2
Karnataka	28	36.2
Kerala	8.9	19.7
Madhya Pradesh	43.1	77.8
Maharashtra	51.3	65.8
Manipur	1	4
Meghalaya	0.7	1.2
Mizoram	0.2	0.5
Nagaland	0.9	0.8
Odisha	22.5	33.6
Punjab	44.9	41
Rajasthan	41.3	39.1
Sikkim	0.4	0.5
Tamil Nadu	39.9	43
Tripura	1.4	1.9
Uttar Pradesh	106.9	124.5
West Bengal	26.4	41
UTs	0.8	1.2
India	611	805

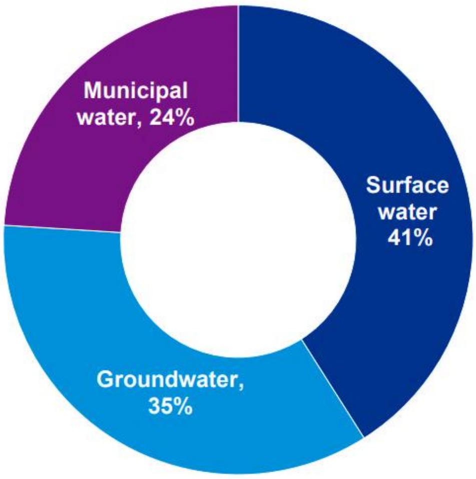
Source: IndiaStat (2025)

3.2 Industrial sector: A growing water consumer

The industrial sector's water demand is steadily increasing, driven mainly by the energy sector. Industry's share of total water demand is projected to rise from 8% in 2010 to 13% by 2050, reflecting rapid industrialisation and rising living standards. Among the most water-intensive industries is power generation, particularly thermal power plants, which produce 64% of India's electricity. Between 2011 and 2016, water consumption in this sector surged by 43% (Luo, 2018), rising from 1.5 BCM to 2.1 BCM. However, future demand patterns may shift due to the growing adoption of renewable energy sources and the introduction of stricter regulatory norms.

The iron and steel industry is another significant consumer of water. According to the National Steel Policy of 2017, this sector is projected to require approximately 1.5 BCM annually by 2030–31, reflecting its crucial role in supporting industrial growth. The textile industry, known for its heavy water consumption, also stands out for its particularly high usage. Producing one ton of cotton fabric in India requires between 200-250 m^3 of water, a figure that exceeds the global standard of 100 m^3 per ton (Mikucioniene et al., 2024), as reported by the Centre for Science and Environment. Industries source water primarily from surface water (41%), groundwater (35%), and municipal supplies (24%), with groundwater being a preferred source due to its accessibility and cost-effectiveness. The analysis of water supplied to the industrial sector in India by source of water is presented in Figure 10 below.

Figure 10. Sources of water supply to the industrial sector



Source: NITI Aayog (2021)

3.3 Domestic sector: The fastest-growing water consumer

The domestic sector is witnessing the highest growth rate in water demand, projected to rise by 158% between 2010 and 2050. Domestic water usage covers drinking, cooking, sanitation, bathing, and livestock needs. Urban and rural areas exhibit distinct patterns in water use. In urban regions, the average water consumption reaches 195 litres per capita per day (IPCS), which is significantly higher than the global average of 135 IPCS (Khandelwal & Monga, 2024). In contrast, rural areas report a much lower average consumption, with individuals using only 50 IPCS. This stark difference highlights the disparity in water access and usage between urban and rural communities.

By 2050, total domestic water demand in India is expected to reach 111 (BCM), with Uttar Pradesh alone accounting for 18.3 BCM. Maharashtra (10.4 BCM), Bihar (11.4 BCM), and West Bengal (9 BCM) also reflect high demand, underscoring the growing urbanisation and population pressure in these states. Even relatively water-rich states like Kerala and Tamil Nadu are projected to require 3.8 and 7.3 BCM, respectively (see Table 6).

Table 6. State-wise projected water requirement for domestic use, 2050

State/UT	Water Requirement (in BCM)
Andhra Pradesh	8.7
Arunachal Pradesh	0.1
Assam	3
Bihar	11.4
Goa	0.1
Gujarat	5.4
Haryana	2.1
Himachal Pradesh	0.7
Jammu & Kashmir	1
Karnataka	5.9
Kerala	3.8
Madhya Pradesh	8.7
Maharashtra	10.4
Manipur	0.3
Meghalaya	0.3
Mizoram	0.1
Nagaland	1
Odisha	4.2
Punjab	2.7
Rajasthan	5.8
Sikkim	0
Tamil Nadu	7.3
Tripura	0.4
Uttar Pradesh	18.3
West Bengal	9
UTs	1.6
India	111

Source: IndiaStat (2025)

As of 2014, no major Indian city offered a 24/7 water supply, and only 35% of urban households had piped water connections. In the rural areas, 77% of households lacked piped water despite claims of 79% coverage. The JJM (2024) aims to bridge this gap by ensuring functional household tap connections to all rural households by 2024, providing a minimum supply of 55 IPCS. Currently, groundwater fulfils 85% of rural and 50% of urban domestic water needs.

First, the push for green hydrogen, produced through electrolysis using renewable energy, demands substantial volumes of high-purity water as an input. Producing one kilogram of green hydrogen via electrolysis typically requires 9-10 litres of deionised water (IRENA, 2020). As India accelerates its National Green Hydrogen Mission, aiming for an annual production target of 5 million tonnes of green hydrogen by 2030, the associated water requirement could reach 45–50 billion litres annually, posing additional stress on already water-scarce regions unless sustainably sourced.

Second, the rapid expansion of solar photovoltaic (PV) installations has introduced new water-intensive activities, particularly the cleaning of solar panels to maintain energy efficiency. Studies show that dust accumulation can reduce solar panel efficiency by up to 30% in arid and semi-arid regions, necessitating frequent cleaning (Yakubu et al., 2025). Manual or water-based cleaning remains the dominant practice in India, with estimates suggesting that up to 3–5 litres of water per panel per cleaning cycle may be required, depending on local conditions and technology used (IRENA, 2020). With India targeting 500 GW of non-fossil energy capacity by 2030, including significant solar capacity, the cumulative water demand for panel-cleaning could become a non-trivial component of industrial water use.

These emerging sectors highlight the importance of integrating water efficiency strategies within India's broader clean energy transition. Addressing these demands through wastewater reuse, rainwater harvesting, and the development of dry or robotic cleaning technologies will be critical for ensuring that the pursuit of decarbonisation does not inadvertently exacerbate water scarcity.

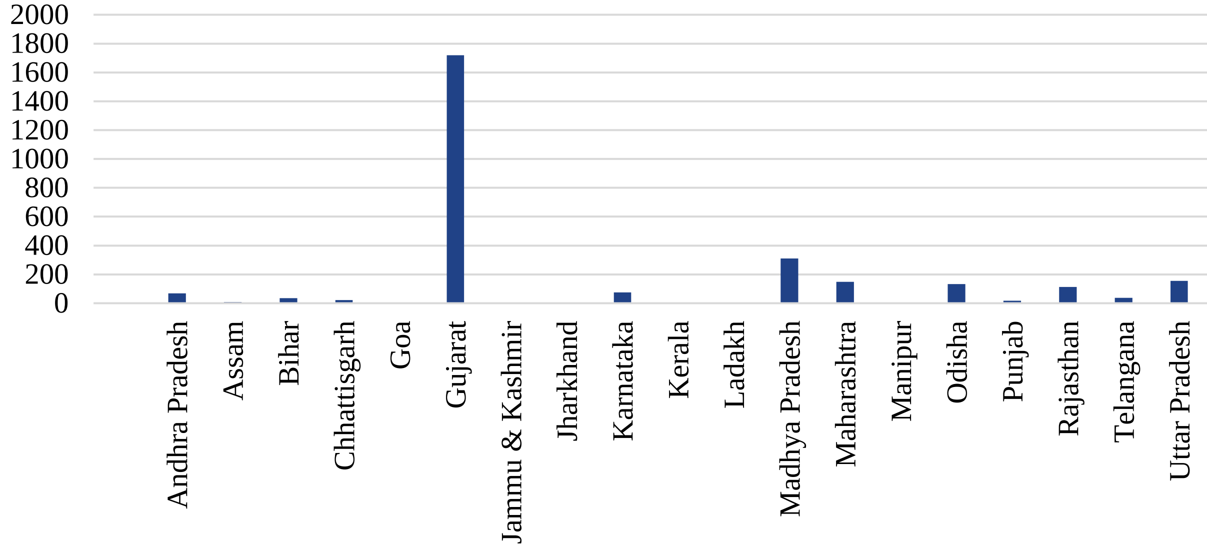
3.4 Wastewater management and reuse

Approximately 80% of domestic water becomes wastewater, but only 38% of municipal wastewater (22,963 MLD) is treated, contributing to severe environmental issues. As of 2021, the country generated about 72,368 MLD of municipal sewage, equivalent to approximately 26 BCM annually (Singhal & Ahmad, 2025). Alarmingly, only 31% of this sewage received proper treatment. The situation is somewhat better in the industrial sector, where around 60% of wastewater from major industries undergoes treatment. Despite these efforts, untreated wastewater from both municipal and industrial sources continues to pose a serious threat to the environment.

In order to address water management holistically, significant central assistance was provided under the Command Area Development and Water Management (CADWM) Programme between 2016–17 and 2021–22. Gujarat stands out with the highest allocation (Chitravanshi, 2019) at ₹1,719.15 crore, followed by Madhya Pradesh (₹310.52 crore), Uttar Pradesh (₹156 crore), and Maharashtra (₹149.2 crore). States like Odisha (₹131.96 crore) and Rajasthan (₹112.65 crore) have also received considerable support (see Figure 11). These investments are crucial for enhancing irrigation efficiency and reducing dependence on freshwater by enabling treated wastewater reuse in agriculture.

Recycled wastewater can significantly reduce freshwater demand and contribute to sustainable water management. Globally, around 32% of recycled wastewater is reused for agricultural irrigation (Tzanakakis et al., 2023). To promote reuse, the Ministry of Power's Tariff Policy (2016) mandates that all thermal power plants utilise treated wastewater if a sewage treatment plant (STP) is available within a 50-kilometre radius. Additionally, various states have introduced policies supporting wastewater treatment and reuse, particularly for agriculture and industry.

Figure 11. Selected state-wise cumulative central assistance released under CADWM Programme (2016-17 to 2021-22), Rs. crore



Source: IndiaStat (2025)

India faces a looming water crisis, with demand projected to double by 2030. While agriculture will remain the dominant consumer, industrial and domestic sectors will experience significant demand growth (Amarasinghe et al., 2009). Addressing this challenge requires a multi-dimensional strategy, including enhancing irrigation efficiency, reducing industrial water consumption, and expanding wastewater reuse. Advanced technologies such as remote sensing, AI-powered hydrological modelling, and efficient water management practices are essential for promoting sustainable water use and ensuring regional water security.

Remote-sensing technologies, such as satellite-based monitoring systems, enable real-time observation of water bodies, soil moisture, and vegetation health. These insights are valuable for identifying water-stressed areas and guiding resource allocation. For instance, NASA's GRACE satellites have been used to track groundwater depletion in northwestern India, providing data that informs sustainable groundwater policies. AI-powered hydrological modelling further enhances water forecasting and planning by integrating vast datasets, such as rainfall patterns, land use, and climate trends, to predict water availability and flood risks. For example, AI models have been used in the Mekong River basin to simulate river flows and optimise reservoir operations, improving resilience to seasonal variability. Additionally, efficient water management practices, including drip irrigation and smart metering, reduce water wastage and improve productivity, especially in agriculture, where water consumption is highest. In Israel, precision irrigation systems supported by IoT sensors and data analytics have significantly reduced freshwater usage while boosting crop yields.

Together, these technologies not only optimise current water use but also build adaptive capacities to face future water challenges, making them indispensable tools in achieving long-term water sustainability and regional security.

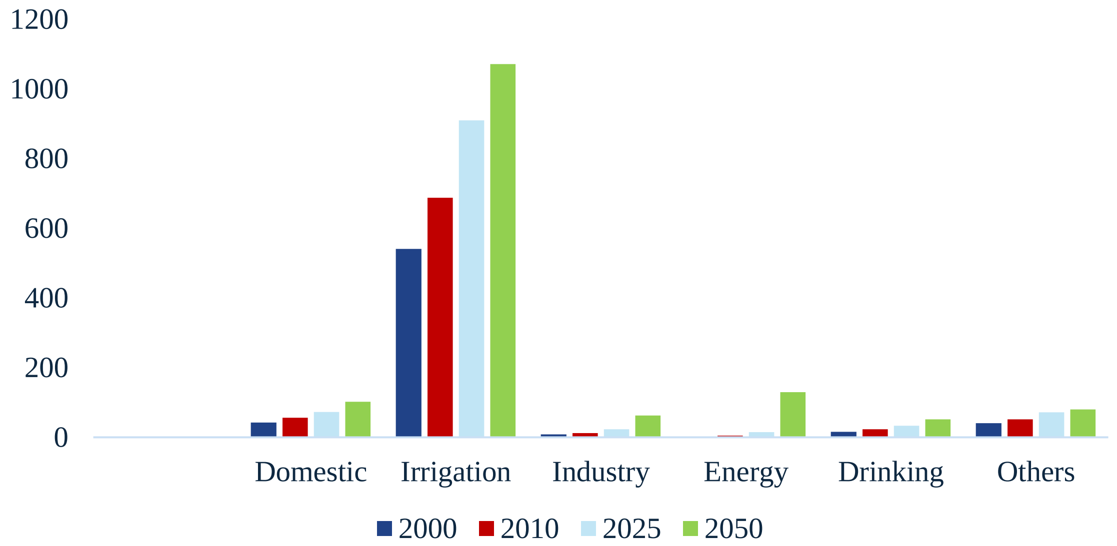
3.5 Projected water demand-supply gaps

India is grappling with an intensifying water crisis, with projections suggesting that by 2030, the country's water demand could be nearly double the available supply. Such a stark imbalance may lead to critical shortages, severely affecting livelihoods, industrial production, and overall economic stability. In urban households, essential daily activities like cooking and washing utensils currently account for approximately 6–8% of total water consumption. However, with the rapid pace of urbanisation and evolving lifestyle patterns, water usage for food-related purposes is anticipated to surge 1.5 times by 2031 (NITI Aayog, 2019).

The transition from rural to urban living has significantly reshaped water consumption trends, posing challenges for resource availability and sustainable management. Water usage in India is broadly categorised into five primary sectors: (i) irrigation, (ii) domestic consumption, (iii) industrial use, (iv) energy production, (v) drinking, and (vi) environmental and other miscellaneous needs. In 2010, irrigation accounted for 78% of total water withdrawals (PIB, 2013). However, as urbanisation and industrial activities continue to expand, the proportion of water used by agriculture is projected to decline to 68.4% by 2051 (see Figure 12). This reduction is largely driven by the increasing demand from domestic, industrial, and energy sectors, which are expected to claim a larger share of the country's water resources.

India's aspiration to emerge as the world's third-largest economy by 2030 is expected to intensify industrial and commercial development, consequently fuelling a sharp rise in energy consumption. By 2050, overall water demand in the country will increase by 67% from the 2010 level (Bassi et al., 2020). Domestic water requirements, spanning residential, public, and commercial needs, are anticipated to grow by 158%, largely due to a swelling urban population and shifting consumption patterns. These escalating demands underscore the urgent need for robust water management strategies to ensure long-term sustainability and resource security.

Figure 12. Estimated annual water requirement by use (2000, 2010, 2025 and 2050) (BCM)



Source: IndiaStat (2025)

These shifting water demands highlight the urgent need for effective resource management. Balancing agricultural requirements with growing urban, industrial, and energy needs will be critical. Moreover, preserving river ecosystems and ensuring their natural flow will be essential to mitigate climate change impacts and promote long-term ecological sustainability.

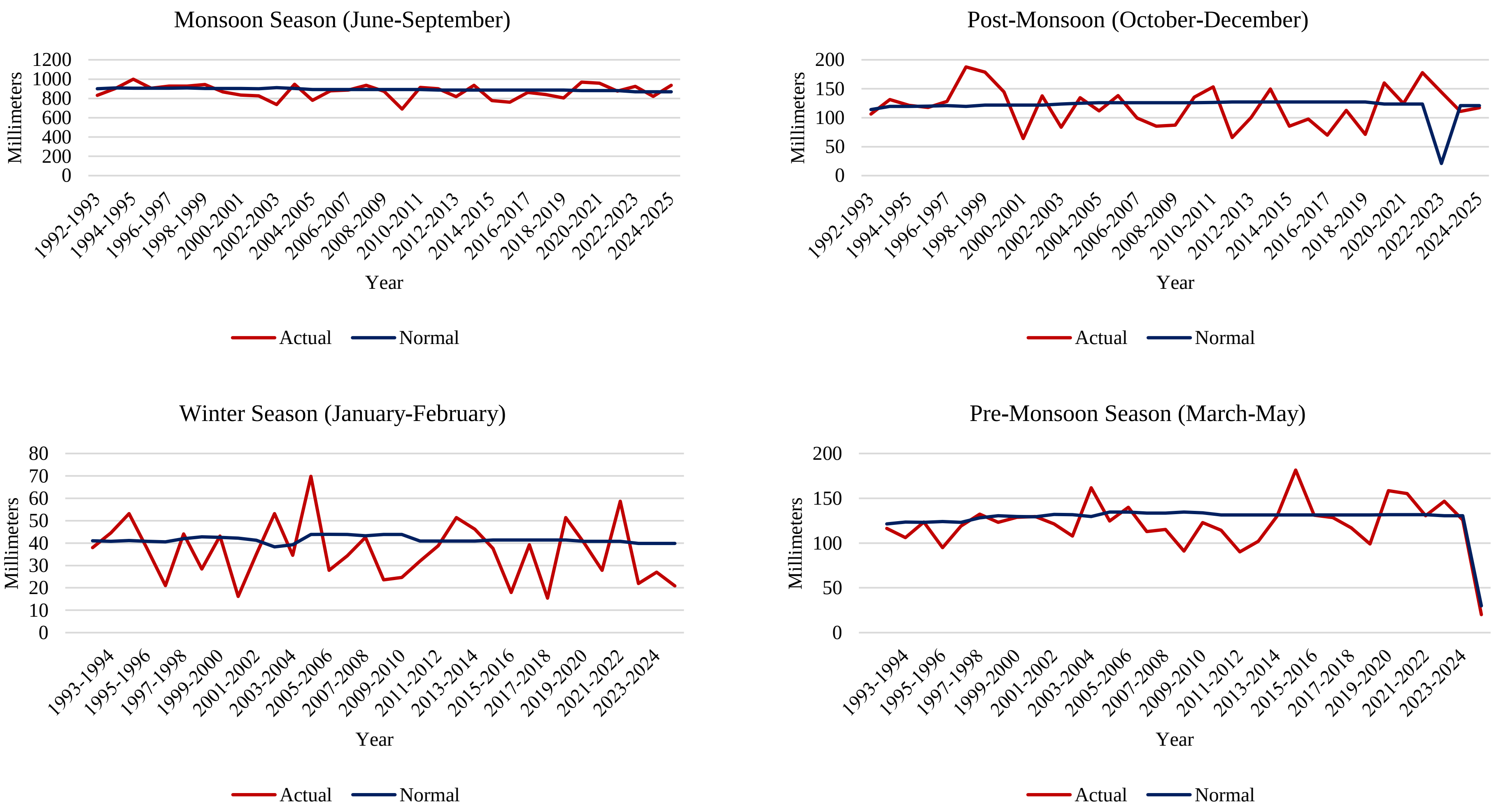
4 Climate change and the water crisis

India's vast and diverse agro-climatic zones, spanning the Himalayan ranges in the north to its expansive coastline going from West Bengal to Gujarat, make it particularly vulnerable to climate change. The country's varied climatic conditions include arid deserts and some of the wettest regions globally, leading to region-specific climate challenges. These include glacial melting in the Himalayas, rising sea levels along coastal areas, and unpredictable precipitation patterns that trigger both droughts and floods in different parts of the country. The increasing concentration of greenhouse gases is closely associated with shifts in rainfall patterns, exacerbating extreme weather events such as severe floods and prolonged droughts (Sachan et al., 2023; Sharif, 2023). These disruptions pose significant challenges to managing water resources. Research by Mall et al. (2022) highlights that major river basins in India have become more prone to flooding and drought, with these risks expected to intensify in the coming years.

Over the past decades, India has observed a rise in warm days and a decline in cold days. According to the IPCC (2014), the frequency of monsoon depressions has decreased, resulting in altered seasonal rainfall trends. The country receives an average annual precipitation of approximately 117 cm, with nearly 75% of it occurring during the southwest monsoon (June–September). However, rainfall distribution varies significantly: while the northeastern states and the Western Ghats receive 200–400 cm annually, the northwestern regions get as little as 50 cm (Mehrotra & Mehrotra, 1995). Figure 13 reveals the annual trend in rainfall variability across India from 1992 to 2025. Climate projections indicate a continued rise in temperatures, leading to an increase in extreme precipitation events, particularly in west and central India. Temperatures were projected to rise by 2020 by 1.0–1.4°C, with further increases of 2.23–2.87°C expected by 2050 (K. R. Kumar et al., 2006). These climatic changes are anticipated to intensify both drought and flood occurrences, further straining India's water resources.

This section delves into how climate change is intensifying India's water crisis, exposing the vulnerabilities of its diverse agro-climatic zones, from the Himalayan glaciers to the coastal belts and arid regions. It highlights the growing frequency of extreme weather events like heatwaves, droughts, floods, and cyclones, showing how these climate shocks disrupt water availability and threaten livelihoods, agriculture, and ecosystems. The discussion begins by examining the rise in extreme weather patterns—longer heatwaves, erratic monsoon rains, and intensifying droughts—while floods continue to devastate parts of eastern and central India. This growing variability has pushed rural farmers and urban populations alike into cycles of water insecurity, crop failures, and economic vulnerability. A key concern explored here is the rise of compound climate events, where multiple hazards occur at once, amplifying risks. The section then analyses the direct impacts on water systems, including changing river flows, reduced glacier meltwater, groundwater depletion, and rising sea levels along the coast. It underscores how these changes are not uniform: while some regions face drought, others battle excessive rainfall and floods, exposing the stark regional disparities in water stress.

Figure 13. Season-wise actual and normal rainfall (1992-93 to 2024-25 up to March 2025) (in millimetres)



Source: IndiaStat (2025)

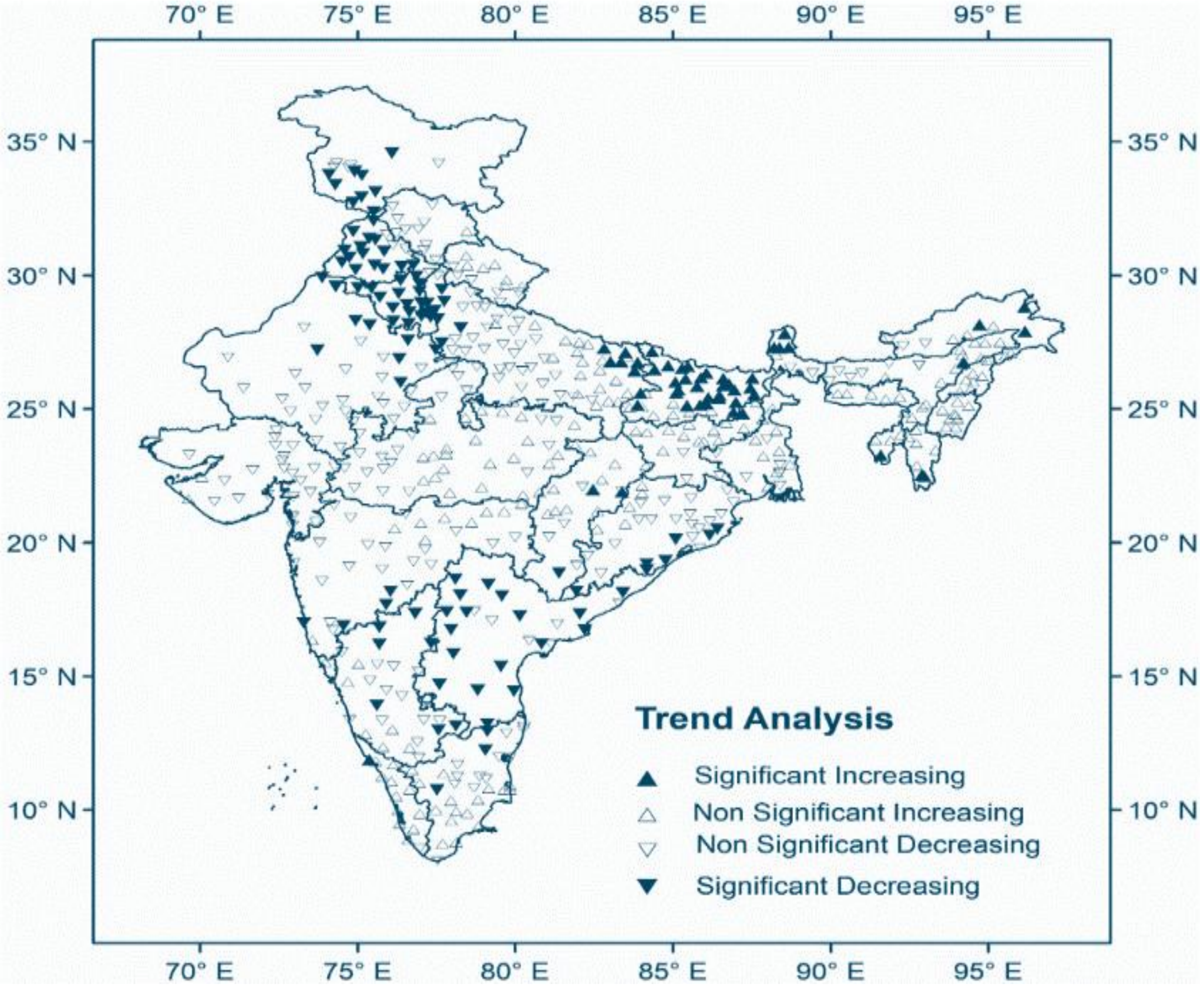
Data on groundwater over-extraction, especially in Punjab, Rajasthan, and Delhi, reveal the alarming imbalance between use and recharge (Vinayak, 2025). Attention is also given to the vulnerability of India's wetlands and river basins, which act as natural buffers but are increasingly threatened by climate-induced disruptions. The retreat of Himalayan glaciers and rise of the sea-level along the eastern coastline are identified as key risks, impacting millions dependent on these ecosystems for agriculture and water supply. The section concludes by emphasising the urgent need for adaptive strategies. It calls for region-specific water governance, climate-resilient infrastructure, improved irrigation efficiency, groundwater regulation, and wetland conservation. These measures are positioned as critical for mitigating risks and securing India's water future in the face of escalating climate challenges.

4.1 Increasing extreme weather events and their impacts

The country is experiencing a growing number of extreme weather events, each posing significant risks to lives, livelihoods, and ecosystems. Rising temperatures have led to more frequent and intense heatwaves, particularly in northern and central India, with severe health impacts such as heat strokes and fatalities, especially among vulnerable groups like outdoor workers and older people, as per the Indian Institute of Tropical Meteorology (2021). In addition to extreme heat, shifting monsoon patterns are disrupting critical agricultural cycles. Rainfall has become increasingly erratic, with some regions experiencing heavy downpours while others face prolonged dry spells. This variability is adversely affecting crop yields and threatening the livelihoods of millions of farmers dependent on monsoon irrigation.

Drought conditions in India are intensifying due to irregular rainfall patterns and rising temperatures, leading to water scarcity, crop failures, and livestock losses. These impacts deepen socioeconomic vulnerabilities in rural areas where agriculture remains the primary livelihood (IISC, 2019). A comprehensive analysis of drought trends across 566 meteorological stations using the Standardised Precipitation Index (SPI) over a 102-year period (1901–2002) further substantiates this concern. The study assessed key drought indicators such as Annual Drought Severity (ADS) and Annual Drought Duration (ADD), revealing significant regional disparities. As shown in Figure 14, increasing trends in ADS were observed in the northeastern, central eastern, and southern regions—particularly in Bihar—signifying a worsening drought intensity. Conversely, agriculturally crucial states like Uttar Pradesh and Punjab displayed decreasing trends in ADS. Western and northwestern states, traditionally prone to severe droughts, also showed declining ADS. Notably, while croplands—constituting over 50% of India's land cover—exhibited consistent reductions in drought variables, forested regions such as the northeastern hills and Western Ghats experienced rising trends. Meanwhile, the southern and eastern regions of India face a dual threat, with some areas also experiencing devastating floods driven by intense monsoonal rainfall and cyclonic activity. These floods not only destroy infrastructure, homes, and farmlands but also pose severe health hazards by contaminating water sources (Mukherjee et al., 2018), underscoring the uneven yet compounding effects of climate extremes across the country.

Figure 14. Trend analysis of ADS across 566 stations, 1901–2002



Source: Goyal and Surampalli (2018)

Coastal areas are facing more frequent and intense cyclones and storm surges, driven by rising sea surface temperatures and increasing sea levels. These extreme weather events bring strong winds, heavy rainfall, and coastal erosion, displacing communities and causing substantial economic losses (IMD, 2022). In the Himalayas, climate change is accelerating glacier retreat, threatening the water supply of major river systems. Rapid melting increases the likelihood of glacial lake outburst floods and avalanches, putting downstream communities and infrastructure at risk. Collectively, these extreme weather phenomena—including heatwaves, erratic monsoons, droughts, floods, cyclones, and glacial retreat—underscore the escalating threats climate change poses to India's environment and people.

Addressing these challenges requires urgent adaptation measures and sustainable water and disaster management strategies. India has also witnessed instances of compound extreme events, where multiple climate hazards occur simultaneously, amplifying their impact. These overlapping climate shocks have severe consequences for human lives, infrastructure, and ecosystems (Hazarika & Boro, 2023).

Several studies have analysed historical and projected climate change impacts on precipitation and temperature trends. Research from Krishnan et al. (2020) reports that monsoon rainfall from June to September declined by around 6% between 1951 and 2015, with significant reductions in precipitation over the Indo-Gangetic plains and the Western Ghats. Meanwhile, extreme daily rainfall events (above 150 mm) have surged by nearly 75% in central India. Drought frequency and intensity have also increased since the 1950s, with dry spells rising by 27% between 1981 and 2011 (A. Kulkarni et al., 2020). Climate models predict that drought occurrences will become more frequent, severe, and widespread by the end of the century. Additionally, flash droughts, triggered by high solar radiation and strong winds, are emerging as a new challenge.

4.2 Climate impact on water resources

India's extensive river systems primarily rely on monsoonal rainfall and glacial melt. The country receives an estimated 4,000 BCM of precipitation annually, including snowfall. In the central plains, an increase in surface runoff indicates changes in rainfall intensity and drainage patterns (Amrutha et al., 2023). Projections for the oceans around Asia, including the Indian coastline, estimate a rise of 0.3-0.5 metres under the low-emission scenario (SSP1-2.6) and 0.7-0.8 metres under the high-emission scenario (SSP5-8.5) by 2081–2100, relative to 1995–2014 (IPCC, 2021). Moreover, the encroaching sea could submerge about 5,763 km^2 of coastal land, potentially displacing 7.1 million people and triggering socioeconomic upheaval.

Given its diverse geography, India remains highly susceptible to climate change, with different regions facing unique water-related challenges. Rising temperatures, changing precipitation patterns, frequent extreme weather events, and glacial retreat are intensifying water stress across the country. The increasing frequency of floods, droughts, and heatwaves underscores the urgent need for effective water resource management, climate-resilient policies, and adaptive strategies to safeguard India's water security.

4.3 Regional impacts on water availability

The Himalayan region, often called the 'Third Pole,' plays a vital role in sustaining India's perennial river systems. Research conducted by the Indian Space Research Organisation (ISRO) indicates that glaciers in this region have retreated by approximately 13% between 1976 and 2006 (A. V. Kulkarni & Karyakarte, 2014). Variations in warming rates and precipitation patterns directly influence glacial melting, thereby impacting the hydrological cycle of these rivers. Glacial and snowmelt significantly contribute to river flows, particularly during summer. However, continued glacial retreat is expected to reduce meltwater availability, altering river discharge patterns over time (Lutz et al., 2014). Such changes could have severe consequences, particularly for downstream agricultural regions like the Indo-Gangetic plains, which rely heavily on these water sources. Additionally, disputes between upstream and downstream riparian states may escalate due to shifting water availability. Studies suggest that seasonal discharge patterns may shift in the future (Grover et al., 2021), increasing the likelihood of glacial lake outburst floods, which pose risks to lives and infrastructure.

India is home to an extensive network of wetland ecosystems, often referred to as the 'kidneys of the Earth' due to their role in maintaining ecological balance and providing essential ecosystem services. The country has designated 49 Ramsar sites—wetlands of international importance—spanning over 1.09 million hectares. Notable wetlands include the Sundarbans in West Bengal, Chilka Lake in Odisha, Wular Lake in Jammu and Kashmir, and Keoladeo National Park in Rajasthan. Spread across diverse agro-climatic zones, these wetlands are experiencing varied impacts of climate change. Shifts in rainfall and temperature patterns have led to biodiversity loss and diminished ecosystem services. Protecting and conserving these wetlands is critical for both climate adaptation and mitigation efforts

(Niranjana, 2025). Wetlands function as major carbon reservoirs, storing twice as much carbon as forests. Their climate-related benefits include carbon sequestration, greenhouse gas regulation, flood and drought mitigation, water purification, biodiversity conservation, and ecosystem restoration.

4.4 Groundwater and hydrological effects

Groundwater serves as the primary water source for over 80% of rural households and 50% of urban populations in India while also fulfilling nearly half of the country's irrigation needs. Over-extraction has led to declining water tables, increased salinity intrusion in coastal areas, and contamination from human activities. Studies highlight the significant influence of changing precipitation patterns on groundwater recharge. Cross-correlation analysis by Chen et al. (2004) found a strong correlation between annual rainfall and groundwater levels. However, excessive extraction remains a critical concern. Additionally, rising temperatures accelerate evapotranspiration, further reducing groundwater replenishment. A one-metre decline in groundwater levels could raise India's carbon emissions by 4.8% due to the increased energy required for water extraction (Panwar & Chakrapani, 2013).

The 2023 state-wise categorisation of groundwater recharge-worthy areas, as shown in Table 7, offers a concerning snapshot of the national groundwater scenario. Out of the total 2.46 million km^2 of assessed recharge-worthy areas in India, only 66.15% are classified as 'Safe.' In contrast, nearly 17% fall under the over-exploited category, indicating a widespread imbalance between groundwater extraction and recharge (PIB, 2023). States like Punjab and Rajasthan are among the most severely affected, with 72.78% and 70.26% of their recharge-worthy areas, respectively, falling into the over-exploited category. In Delhi, the figure is alarmingly high at 41.49%, reflecting the intense pressure on its limited groundwater reserves. Conversely, several northeastern states such as Meghalaya, Sikkim, and Nagaland have 100% of their recharge-worthy areas categorised as safe, underlining regional disparities in groundwater stress. These findings stress the urgent need for localised groundwater management strategies (Kapoor & Anand, 2024), improved irrigation practices, and stricter regulation of extraction to ensure the long-term sustainability of this critical resource.

According to research by Woo et al. (2019) under the Representative Concentration Pathway (RCP) 4.5 scenario, seasonal summer precipitation in northwest, south peninsular, and west peninsular India could rise by 4–19% in the near-to-distant future, while northeast India may experience a 5% decline in rainfall. Under the RCP 8.5 scenario, precipitation is projected to increase more significantly in the south and west peninsular regions but decrease in northwest India. However, projections indicate substantial uncertainty in both spatial and temporal precipitation patterns. Regarding temperature, a study by Salunke et al. (2023) predicts a nationwide rise, with the northwestern region experiencing relatively higher warming. Moreover, temperature increases are expected to be more pronounced during winter compared to summer.

Table 7. State-wise categorisation of recharge-worthy area of assessed units under ground water, 2023 (in km^2)

State/UT	Total Recharge Worthy Area of Assessed Units	Safe		Semi-Critical		Critical		Over-Exploited		Saline	
		Recharge Worthy Area	In %age	Recharge Worthy Area	In %age	Recharge Worthy Area	In %age	Recharge Worthy Area	In %age	Recharge Worthy Area	In %age
Andaman & Nicobar Islands	2,120.07	2,120.07	100	-	-	-	-	-	-	-	-
Andhra Pradesh	139,599.85	126,905.28	90.91	3,936.09	2.82	775.78	0.56	1,886.36	1.35	6,096.33	4.37
Arunachal Pradesh	5,721.38	5,721.38	100	-	-	-	-	-	-	-	-
Assam	68,817.93	68,617.51	99.71	200.42	0.29	-	-	-	-	-	-
Bihar	9,0348.7	81,259.91	89.94	7,417.08	8.21	803.91	0.89	867.8	0.96	-	-
Chandigarh	114	-	-	114	100	-	-	-	-	-	-
Chhattisgarh	106,078.71	88,972.3	83.87	13,987.35	13.19	3,119.06	2.94	-	-	-	-
Dadra and Nagar Haveli	416	-	-	-	-	-	-	416	100	-	-
Daman and Diu	110.9	-	-	-	-	-	-	110.9	100	-	-
Delhi	1,487.61	330.23	22.2	233.73	15.71	306.4	20.6	617.25	41.49	-	-
Goa	2,209.59	2,209.59	100	-	-	-	-	-	-	-	-
Gujarat	16,2778.14	118,697.61	72.92	11,487.16	7.06	5,258.1	3.23	18,448.47	11.33	8,886.8	5.46
Haryana	43,205.82	12,097.86	28	2,558.1	5.92	2,590.43	6	25,959.44	60.08	-	-
Himachal Pradesh	3,468	3,468	100	-	-	-	-	-	-	-	-
Jammu & Kashmir	8,664.25	7,789.25	89.9	875	10.1	-	-	-	-	-	-
Jharkhand	60,646.73	56,945.2	93.9	2,169.13	3.58	1,068.48	1.76	463.92	0.76	-	-
Karnataka	17,0463.35	103,043.09	60.45	22,695.74	13.31	10,443.17	6.13	34,281.35	20.11	-	-
Kerala	27,047.53	22,059.01	81.56	4,211.15	15.57	777.38	2.87	-	-	-	-
Ladakh	963	632	65.63	331	34.37	-	-	-	-	-	-
Lakshadweep	26.21	19.87	75.81	6.34	24	-	-	-	-	-	-
Madhya Pradesh	269,333.27	190,725.58	70.81	51,803.76	19.23	4,249.07	1.58	22,554.86	8.37	-	-
Maharashtra	259,914.03	186,285.52	71.67	56,959.43	21.91	8,857.49	3.41	7,034.69	2.71	776.89	0.3
Manipur	2,559	2,559	100	-	-	-	-	-	-	-	-

State/UT	Total Recharge Worthy Area of Assessed Units	Safe	Semi-Critical	Critical	Over-Exploited	Saline	State/UT	Total Recharge Worthy Area of Assessed Units	Safe	Semi-Critical	Critical
Mizoram	3,149.41	3,149.41	100	-	-	-	-	-	-	-	-
Nagaland	3,855.07	3,855.07	100	-	-	-	-	-	-	-	-
Odisha	121,593.15	116,071.86	95.46	3,339.96	2.75	-	-	-	-	2,181.33	1.79
Puducherry	483	170	35.2	252.35	52.25	-	-	40.65	8.42	20	4.14
Punjab	50,175.27	8,159.54	16.26	4,307.45	8.58	1,192.98	2.38	36,515.3	72.78	-	-
Rajasthan	317,010.74	4,6451	14.65	19,080.79	6.02	19,808.7	6.25	222,734.36	70.26	8,935.89	2.82
Sikkim	1,496	1,496	100	-	-	-	-	-	-	-	-
Tamil Nadu	108,690.63	44,392.74	40.84	19,482.71	17.92	11,773.78	10.83	31,129.84	28.64	1,911.56	1.76
Telangana	105,777.24	96,504.46	91.23	8,510.64	8.05	605.7	0.57	156.44	0.15	-	-
Tripura	6,197.84	6,197.84	100	-	-	-	-	-	-	-	-
Uttar Pradesh	229,555.18	151,205.64	65.87	51,620.24	22.49	11,777.16	5.13	14,952.13	6.51	-	-
Uttarakhand	4,993.04	4,042.1	80.95	950.94	19.05	-	-	-	-	-	-
West Bengal	79,765.77	61,634.14	77.27	5,886.51	7.38	2,737.02	3.43	-	-	9,508.1	11.9
India	2,467,007.76	1,631,959.41	66.15	292,417.07	11.85	86,144.61	3.49	418,169.76	16.95	38,316.9	1.55

Source: IndiaStat (2025)

These shifts in temperature and precipitation patterns will likely affect the hydrological cycle. Rising temperatures may intensify this cycle, leading to increased evaporation rates and higher precipitation levels. However, precipitation trends are expected to exhibit regional and seasonal variability, disrupting overall water availability in India. The retreat of Himalayan glaciers and declining winter rainfall further jeopardise water security (Prakash, 2025). These glaciers, crucial for sustaining the Ganges, Brahmaputra, and Indus rivers, are shrinking rapidly, reducing summer river flows and exacerbating downstream water shortages. Long-term reductions in meltwater pose significant challenges for agriculture and hydroelectric power generation.

Conversely, some regions face the opposite issue—heightened flood risks. Western and central India have seen an increase in extreme rainfall events (Ray et al., 2019), with floods exacerbated by deforestation and inadequate urban drainage systems. These occurrences cause severe damage to property, livelihoods, and infrastructure, particularly in densely populated urban areas. Simultaneously, droughts are intensifying across peninsular India. States such as Maharashtra, Gujarat, and Tamil Nadu are experiencing prolonged dry spells, exacerbated by groundwater depletion due to over-extraction and low recharge rates. This depletion threatens agricultural productivity and drinking water supplies in already water-stressed regions.

4.5 Need for adaptive strategies

Now, looking ahead, future climate projections suggest further disruptions. According to Yadav (2022), the southwest monsoon is expected to become more intense over west-central India, heightening flood risks. However, most of India is likely to experience a reduction in the number of rainy days, except for the Himalayan foothills and the northeast, where rainfall may increase by 5–10 days. Rising temperatures will also accelerate evaporation rates across the country (Mishra et al., 2020), reducing surface water availability. Additionally, increasing CO_2 levels, projected to reach 605–755 ppm by 2070, could enhance soil moisture during the monsoon season by 15–20% (Geethalakshmi et al., 2024). However, this increase may be counteracted by higher evaporation rates and diminished groundwater recharge, further straining water resources.

In summary, climate change is reshaping India's water landscape, exacerbating water scarcity, flood risks, and drought occurrences. These challenges threaten food security, ecosystems, and livelihoods. Addressing these issues necessitates comprehensive adaptation strategies, including sustainable water management, improved irrigation techniques, and ecosystem restoration initiatives. By adopting these measures, India can enhance resilience and safeguard its water resources amid a changing climate.

5 Water governance, management and policy evolution

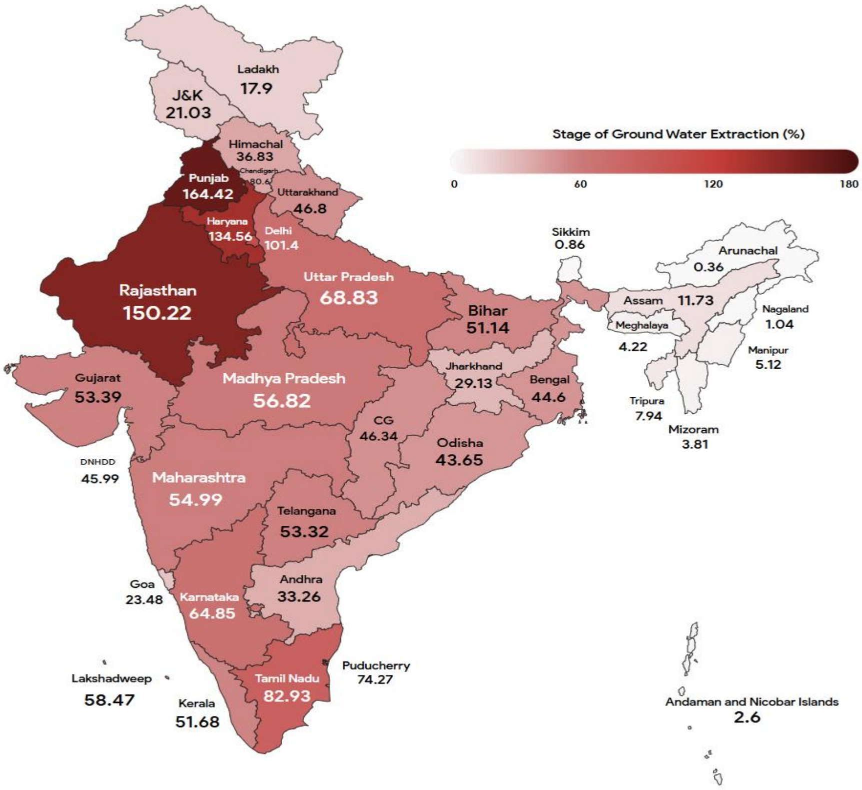
In India, water governance is primarily a state responsibility as per the Constitution, covering aspects such as water supply, irrigation, canals, drainage, embankments, water storage, and hydroelectric power. However, the central government plays a key role in the management of inter-state rivers and in resolving water-related disputes between states. A significant institutional framework supporting decentralised governance is the State Panchayati Raj Act, which facilitates the transfer of minor irrigation, water management, and watershed development duties to Panchayats, subject to state-specific regulations. Likewise, Urban Local Bodies are authorised to manage water supply, public health, sanitation, and waste management, as outlined in the Twelfth Schedule (Ahamed et al., 2014).

This section offers an in-depth overview of how India's water resources are governed, managed, and shaped by evolving policy frameworks. It explains the shared responsibility between state governments, which primarily handle water supply and irrigation, and the central government, which manages inter-state river disputes and national programmes. The section highlights how decentralised systems, including the panchayati raj institutions and urban local bodies, play a key role in local water management (Mehta & Bhaduri, 2021), though their effectiveness often depends on state-specific regulations and capacity. This section also traces the evolution of India's water policies—from traditional, community-led practices to formalised national policies like the National Water Policy (1987, 2002, 2012) and large-scale initiatives such as the Jal Jeevan Mission and Atal Bhujal Yojana. These policies reflect a gradual shift toward integrated, climate-adaptive, and participatory water resource management. A major focus here is on the critical challenge of groundwater depletion, where India ranks as the largest global user. Data on state-wise groundwater over-extraction underscore the urgency of the crisis, especially in states like Punjab, Rajasthan, and Delhi (PIB, 2023). The section explains how rapid urbanisation, unsustainable extraction, poor recharge infrastructure, and limited adoption of rainwater harvesting have worsened the problem, with severe consequences for both rural and urban water security. Further, it showcases a range of policy responses, conservation strategies, and innovative practices being implemented across India. These include community-led watershed management, women-led governance models, greywater reuse, and rainwater harvesting projects. Case studies highlight successful examples where local initiatives have improved water stewardship, demonstrating the potential for such models to be scaled up. Finally, the section addresses how India's water management is increasingly aligning with climate adaptation goals. It discusses national missions like the National Water Mission and climate-resilient programmes that integrate water conservation with sustainable agriculture, pollution control, and ecosystem restoration. Together, these discussions provide a clear understanding of the governance challenges and the evolving strategies needed to ensure long-term water security and resilience in India.

5.1 Challenges in water management and sustainability

India ranks as the world's largest consumer of groundwater, with many of its cities heavily dependent on this vital resource to meet their daily water demands. However, rapid urban expansion, soaring population growth, and inefficient water governance have significantly strained groundwater reserves, leading to alarming depletion levels (Nidhi & Charan, 2025). The gravity of the situation is reflected in the stage of groundwater extraction across states, with several regions surpassing critical thresholds (see Figure 15). Punjab (164.42%), Haryana (134.56%), and Rajasthan (150.22%) exhibit some of the most extreme levels of over-extraction, withdrawing far more groundwater than is naturally replenished. Delhi, India's capital, has reached an alarming 101.4%, signalling an imminent crisis where demand continues to outstrip supply.

Figure 15. State-wise stages of ground water exploitation (2020)



Source: IndiaStat (2025)

Many major urban centres, including Hyderabad, Delhi, Jalandhar, Jaisalmer, Amritsar, Gurugram, Jaipur, Jodhpur, Nagpur, Chennai, and Bengaluru, are already grappling with severe shortages. The situation in Tamil Nadu (82.93%) and Chandigarh (80.6%) is also critical, with groundwater depletion accelerating due to unsustainable extraction. Even coastal areas such as Puducherry (74.27%) and Daman and Diu (113.38%) are witnessing groundwater stress, increasing the risk of saltwater intrusion (Mann, 2023), which makes freshwater resources non-potable.

The primary driver of this crisis is the over-extraction of groundwater, which far exceeds the rate of both natural replenishment and artificial recharge efforts (Zektser & Everett, 2004). States like Bihar (51.14%), Gujarat (53.39%), and Maharashtra (54.99%) still maintain relatively moderate extraction levels but are at risk of crossing sustainable thresholds if current trends persist. In contrast, states with lower extraction rates, such as Arunachal Pradesh (0.36%), Nagaland (1.04%), and Sikkim (0.86%), benefit from better groundwater sustainability, though they, too, face challenges related to accessibility and seasonal variability.

The consequences of this unsustainable exploitation are severe and far-reaching. Excessive withdrawal has led to a drastic fall in groundwater tables, causing aquifer depletion, saltwater intrusion in coastal areas, and, in extreme cases, land subsidence, where the ground physically sinks due to the emptying of underground water reserves. Farmers in over-exploited regions struggle as well, and borewells dry up, forcing deeper drilling, which in turn raises extraction costs and further depletes reserves (Steinhübel et al., 2020). Cities like Bengaluru and Chennai, which once relied heavily on lakes and reservoirs, have turned to groundwater as an alternative, only to find that it, too, is vanishing at an alarming rate.

As India's population continues to expand and economic activities intensify, the demand for groundwater is projected to rise even further, exacerbating the existing crisis. Addressing this challenge requires a comprehensive and multi-faceted approach. Effective strategies must include large-scale water conservation initiatives, improved efficiency in water use, widespread adoption of wastewater recycling (Jacque et al., 2024), and the implementation of integrated water resource management practices. Strengthening regulatory frameworks and encouraging community participation will also be crucial in ensuring long-term water security across domestic, industrial, and agricultural sectors.

Indian cities are struggling with groundwater recharge due to over-extraction, rapid urbanisation, poor governance, and policy shortcomings. One of the primary causes is the excessive withdrawal of groundwater for agricultural, industrial, and domestic purposes, often exceeding the natural recharge rate and causing a continuous decline in water tables. Urban expansion has also significantly altered land use, with concrete and asphalt replacing natural recharge areas, reducing rainwater infiltration into the ground. The loss of open spaces and forested regions has further restricted groundwater replenishment (Ilstedt et al., 2016). Given India's unpredictable rainfall patterns, much of the rainwater fails to percolate effectively.

Another major issue is the insufficient adoption of rainwater harvesting. Many cities have not updated building codes to require the installation of rainwater harvesting systems, which could help capture monsoon rains for future use. The encroachment of vital water bodies worsens the crisis, with the Ministry of Jal Shakti (2023) reporting that nearly 1,800 urban water bodies have been encroached upon, including 24.19% of Delhi's 893 water bodies. This significantly hampers groundwater recharge. Additionally, pollution poses a severe threat, as nearly 70% of the surface water in India is deemed unsafe for human consumption. Of the 40 million litres of wastewater generated daily, only a small fraction undergoes proper treatment, leading to groundwater contamination.

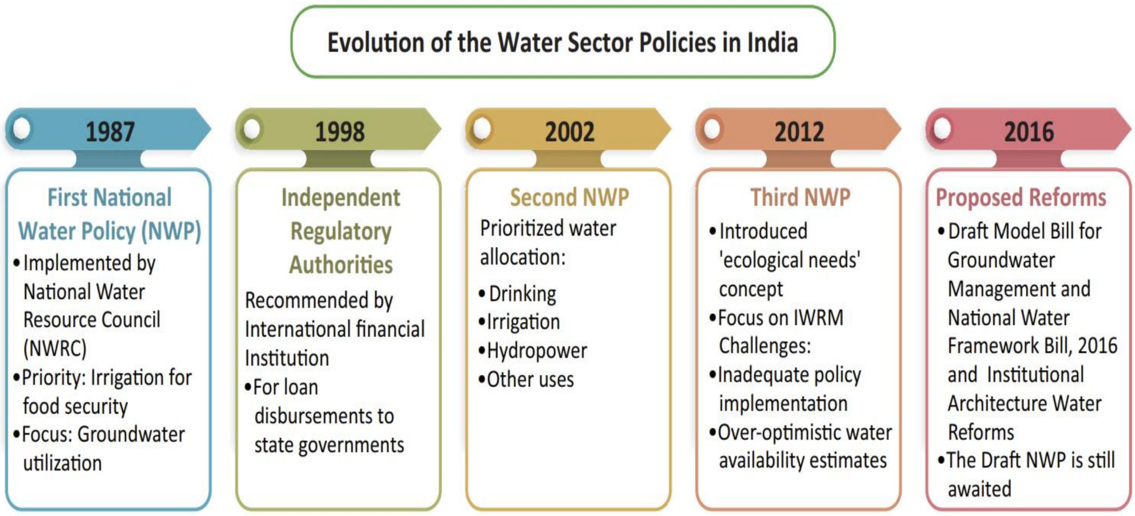
Furthermore, inefficient water management results in substantial wastage, with Kumar Sarangi (2020) estimating that 40-50% of potable water is lost due to theft and leaks in pipelines. A lack of skilled workforce, weak policy enforcement, and inadequate infrastructure further exacerbate the issue. Addressing these challenges requires comprehensive water management strategies, including rainwater harvesting, conservation of water bodies, efficient distribution systems, and strict regulations. Public awareness and community engagement are essential in fostering a collective commitment to sustainable groundwater management.

5.2 Evolution of water policies and conservation strategies

Traditionally, water resource management in India was based on community-led and indigenous practices, including structured maintenance systems. However, these systems saw a decline during British rule. After independence, participatory governance efforts resurfaced through watershed development initiatives. The National Water Policy (2012) emphasises an integrated approach to water resource planning, ensuring alignment between local, regional, and national priorities while promoting environmental sustainability. It recognises water as a shared resource managed by the state under the public trust doctrine, ensuring fair and sustainable allocation. Moreover, the Policy advocates for a shift in the state's role from direct service provider to regulatory entity (National Water Policy, 2012).

India's water policies have undergone several revisions (see Figure 16). The inaugural National Water Policy in 1987 prioritised water allocation for drinking purposes, followed by irrigation, hydroelectricity, navigation, and industrial use. It also recommended pricing mechanisms to reflect water scarcity while covering annual operation and maintenance costs and some irrigation infrastructure expenses (Ghosh & Bhowmick, 2023). The 2002 revision introduced ecological and environmental considerations, adjusting allocation priorities to include drinking water, irrigation, hydroelectricity, ecological needs, industrial use, and navigation. The 2012 policy revision further emphasised drinking water and ecological sustainability as top priorities.

Figure 16. Evolution of water sector policies



Source: Lakhwan et al. (2024)

State-led programmes such as MGNREGS, supported by the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), have played a crucial role in rural water asset development (PIB, 2019). Since the late 1980s, watershed development has followed a micro-watershed approach, encouraging community participation. Key interventions include constructing rainwater harvesting structures such as gully plugs, check dams, and percolation tanks, as well as stream desilting and farm pond development. Given that groundwater serves as the main source of drinking water and irrigation, and that more than half the agricultural land is rain-fed, rainwater conservation is vital for agricultural sustainability.

A World Bank-funded evaluation of watershed projects across three Indian states highlighted the benefits of decentralised planning, capacity-building, and integrating conservation with livelihoods. However, it also noted that increased water availability was predominantly directed towards irrigation, sometimes at the cost of drinking water and sanitation (Jim et al., 2014). A national initiative to rejuvenate three million springs across ten Himalayan states has been under consideration since 2019. NITI Aayog, in partnership with the International Water Management Institute, developed a resource book on spring-shed management, incorporating a gender-equity-socially inclusive framework to ensure a fair distribution of benefits (Ravandale, 2022).

5.3 Potential of the river-linking scheme

In an attempt to address water challenges, the Indian government has proposed interlinking major rivers to transfer water from surplus basins to deficit regions. This is expected to provide additional irrigation in about 30 million hectares, and a net power generation capacity of about 20,000 to 25,000 megawatts (Pant et al., 2008). The Ken-Betwa River linking project, the first under the National Perspective Plan (NPP), represents a significant milestone in this strategy. It aims to channel excess water from the Ken River in Madhya Pradesh to the Betwa River in Uttar Pradesh through an elaborate network of dams, canals, and tunnels. With an estimated cost of ₹45,000 crore (approximately $5 billion), this project is designed to irrigate 1.06 million hectares of land (The Economic Times, 2024), provide drinking water to 6.2 million people, and generate over 100 MW of hydropower alongside 27 MW of solar energy. Prime Minister Narendra Modi laid the foundation stone for the project on December 25, 2024, calling it a historic step toward solving the enduring water woes of the drought-prone Bundelkhand region, spread across Madhya Pradesh and Uttar Pradesh.

Proponents of the project argue that river interlinking offers a long-term solution to India's chronic water shortages, especially in regions like Bundelkhand, where irregular rainfall and arid climate have fostered poverty and underdevelopment. The Ken-Betwa project is projected to benefit 10 districts in Madhya Pradesh, including Chhatarpur, Tikamgarh, Niwari, and Panna, and four districts in Uttar Pradesh, which are Banda, Mahoba, Lalitpur, and Jhansi. In addition to providing irrigation and drinking water, the project is expected to stimulate the rural economy (H. Sharma, 2021), generate employment, and support renewable energy initiatives through hydropower and floating solar power plants.

Despite the promised benefits, the project has sparked significant opposition from environmentalists, civil society groups, and affected communities. A major point of contention is the likely submergence of nearly 98 square kilometres of the Panna Tiger Reserve, a biodiversity-rich area that successfully reintroduced tigers after local extinction in 2009. Conservationists warn that the project could undo years of wildlife preservation efforts, disrupt the ecosystem, and threaten habitats for not just tigers but also vultures and other species. The Congress party and several independent experts have raised alarms about the ecological risks, with claims that over 23 lakh trees will be felled and more than 21 villages, predominantly inhabited by indigenous Gond and Kol tribes, will be displaced. Around 7,000 families stand to lose their homes and livelihoods due to submergence caused by dam construction and canal development. Although the government has offered compensation and resettlement packages—including land-for-land or monetary pay-outs—villagers have protested against what they perceive as insufficient support and unclear relocation plans (Vishnukant Tiwari, 2025). Many argue that the compensation being offered does not reflect the real value of their properties or the cultural ties they have with their ancestral lands.

Beyond the Ken-Betwa project, India’s broader interlinking plan envisions 30 river interconnections across the country. Studies warn that fully implementing these could reduce the average annual discharge of affected river basins by up to 73%, severely impacting wetlands, estuaries, and marine ecosystems. Such changes could disrupt the salinity balance in the Bay of Bengal, influencing monsoon intensity and regional climate dynamics.

Going forward, the success of river interlinking projects like Ken-Betwa will depend on transparent data-sharing, robust climate adaptation and environmental safeguards, genuine community participation, and a balanced assessment of costs versus benefits. Otherwise, the scheme risks repeating the historical mistakes of top-down water management while failing the very people it seeks to serve.

5.4 Climate adaptation and water resource management

Established in June 2008 under the National Action Plan on Climate Change, the National Water Mission focuses on conserving water, minimising waste, and promoting fair distribution through integrated resource management. The National Water Mission, alongside the National Mission on Sustainable Agriculture, emphasises the interconnections between sectors and highlights strategic climate adaptation measures. The National Mission on Sustainable Agriculture supports customised agronomic practices, soil health management, efficient water use, and integrated farming systems, including agroforestry, fish farming, and crop-sericulture models (MoHUA, 1976).

Recognising the significance of water management in sustainable development, the central government consolidated various water-related agencies under the Ministry of Jal Shakti in 2019. The JJM aimed to provide functional household tap connections, delivering 55 litres per capita per day to all rural households by 2024. Sustainability measures such as greywater management, water conservation, and rainwater harvesting are integral to the mission. It also prioritises community participation, particularly encouraging women's involvement in decision-making for long-term rural water security (Har Ghar Jal, 2021). Similarly, the JJM (Urban) was introduced to enhance water supply and liquid waste management services across 4,378 Urban Local Bodies, benefitting approximately 2.86 crore households over five years (Majumdar, 2021). Other key initiatives include the Jal Shakti Abhiyan, targeting 1,592 water-stressed blocks in 256 districts, and the 'Catch the Rain' campaign (Business Standard, 2024), which promotes pre-monsoon rainwater harvesting efforts.

As a shared resource, groundwater is challenging to regulate. The CWC and CGWB formulate guidelines and monitoring frameworks for state governments. The Model Groundwater Bill, aimed at legislative reform, has been adopted by 19 states and Union Territories. Additionally, the Central Ground Water Authority, established under the Environment Protection Act of 1986, oversees groundwater extraction and encourages artificial recharge initiatives. The 2020 Master Plan for Artificial Recharge to Groundwater outlines the construction of 1.42 crore recharge structures to capture 185 BCM of monsoon rainfall (PIB, 2021)

The Atal Bhujal Yojana introduced in December 2019 promotes groundwater sustainability through community involvement in 8,353 gram panchayats across seven states (Kaur, 2025), which are Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan, and Uttar Pradesh. As highlighted in Table 8, Karnataka received the highest tentative fund allocation of ₹1,201.52 crore, with key districts such as Tumkur, Bangalore Rural, and Belgaum identified for implementation. Rajasthan followed with ₹1,189.65 crore earmarked for regions like Kota, Jaipur, and Jaisalmer. Maharashtra was allocated ₹925.77 crore, covering districts including Pune, Nagpur, and Nashik. Uttar Pradesh, with ₹729.24 crore, focuses on areas such as Jhansi, Muzaffarnagar, and Meerut. These allocations reflect the scale and geographical spread of the programme's groundwater management interventions.

Table 8. Selected state-wise tentative fund allocation and districts identified for implementation under Atal Bhujal Yojana (2020-21 to 2024-25)

State	Districts	Tentative Allocation (Rs. crore)
Gujarat	Ahmedabad, Banaskantha, Gandhinagar, Kachchh, Mehsana, Patan	756.76
Haryana	Bhiwani, Fatehabad, Gurugram, Kaithal Kurukshetra, Karnal, Panipat, Sirsa, Faridabad, Mahendragarh, Rewari, Palwal, Yamuna Nagar	723.19
Karnataka	Kolar, Chikaballapur, Tumkur, Bangalore Rural Ramnagara, Chikkamagalur, Chitradurga, Davangere, Bellary, Bagalkot, Gadag, Belgaum Chamrajnagar, Hassan	1.201.52
Madhya Pradesh	Chhatarpur, Sagar, Tikamgarh, Damoh, Panna	314.54
Maharashtra	Pune, Satara, Sangli, Solapur, Jalna, Osmanabad, Latur, Buldhana, Amravati, Ahmednagar, Nashik, Jalgaon, Nagpur	925.77
Rajasthan	Rajasmand, Chittorgarh, Jhalawar, Baran, Kota, Sawai Madhopur, Bhilawara, Ajmer, Dholpur, Dausa, Alwar, Jaipur, Sikar, Jhunjhunu, Jaisalmer, Karauli, Hanumangarh	1.189.65
Uttar Pradesh	Mahoba, Jhansi, Banda, Hamirpur, Chitrakoot, Lalitpur, Muzaffarnagar, Shamli, Baghpat, Meerut	729.24

Source: IndiaStat (2025)

5.5 Water conservation, pollution control, and awareness initiatives

Water management intersects with multiple sectors, requiring a coordinated approach. The Ministry of Rural Development, in collaboration with the Ministry of Water Resources and the Ministry of Agriculture, developed the 'Mission Water Conservation' framework. This initiative ensures synergy among programmes like MGNREGS, Pradhan Mantri Krishi Sinchayee Yojana: Per Drop More Crop, and the Integrated Watershed Management Programme. The central government primarily funds water conservation efforts through MGNREGS and PMKSY-Watershed Development. A joint advisory issued in April 2020 urged states to enhance water source augmentation, rainwater harvesting, and greywater management. Additionally, the Model Building Bye-Laws (2016), introduced by the Ministry of Housing & Urban Affairs, mandated rainwater harvesting, with 32 states and Union Territories adopting these provisions.

The Ganga Action Plan, launched in 1985, marked India's first major river pollution control initiative. The National River Conservation Plan, introduced in 1995, expanded these efforts to other significant rivers, focusing on pollution reduction and water quality improvement through sewage treatment plants and waste management (Sinha & Sedai, 2025). In 2014, the Namami Gange programme was launched to rejuvenate the Ganga River, integrating infrastructure development, afforestation, biodiversity conservation, and community engagement. In continuation of this, the programme has seen a consistent rise in both fund allocation and disbursement under the National Mission for Clean Ganga. As per recent data, the funds released by the central government rose from ₹1,553.4 crore in 2019–20 to ₹2,400 crore in 2023–24, while disbursements increased from ₹2,673.09 crore to ₹2,396.1 crore over the same period (see Table 9). This upward trajectory signals not only enhanced financial commitment but also improved fund utilisation, with disbursement levels closely matching or even exceeding releases in some years. Such sustained investments can significantly enhance the infrastructure for sewage treatment, industrial effluent regulation, and riverfront development, accelerating the rejuvenation of the Ganga and serving as a model for other river conservation efforts nationwide (Awasti, 2021).

Table 9. Funds released and disbursement by National Mission for Clean Ganga under Namami Gange Programme (2019-20 to 2023-24) (Rs. crore)

Year	Funds Released by the Central Government to the National Mission for Clean Ganga (NMCG)	Disbursement/ Release by National Mission for Clean Ganga (NMCG)
2019-2020	1,553.4	2,673.09
2020-2021	1,300	1,339.97
2021-2022	1,900	1,892.7
2022-2023	2,220	2,258.98
2023-2024	2,400	2,396.1

Source: IndiaStat (2025)

To enhance water conservation, the government has launched awareness campaigns, promoted efficient water use, and documented successful models for scaling up. NITI Aayog's Compendium of Best Practices in Water Management highlights exemplary initiatives for replication (NITI Aayog, 2021).

5.6 Innovative approaches to water management

Various stakeholders, including state governments, non-governmental organisations, corporate social responsibility initiatives, and individuals, have introduced creative strategies to strengthen water security at the village level in India. These initiatives focus on groundwater conservation, water stewardship, rainwater harvesting, community-led interventions, and climate-resilient agricultural practices. They also hold the potential for integration into national water policies.

The Bhujal Jankar initiative, launched by Arid Communities & Technologies (ACT) (2004) in Kachchh, Gujarat, trains local youth in groundwater management and the agriculture-water nexus. These trained individuals support gram panchayats in conducting hydrological monitoring, baseline surveys, participatory action research, and water governance. They can receive financial support through government schemes or local funds. Additionally, Bhujal

Jankars can get certified as 'barefoot technicians' under the MGNREGS, enabling them to oversee water projects within their villages (ACT, 2004).

The Water Stewardship Initiative, introduced by the Watershed Organisation Trust in 2016, aims to enhance climate-resilient water governance in semi-arid regions. Implemented in 41 villages across Maharashtra's Jalna and Ahmednagar districts with support from CAF India, the programme focuses on demand-side water management, participatory aquifer governance, and micro-irrigation systems. A Village Water Management Team develops and executes Stewardship Plans that emphasise water conservation, budgeting, and efficiency. Villages demonstrating excellence in governance, supply-demand equilibrium, and equitable resource distribution receive recognition and awards (Harsh, 2025).

The National Plan for Conservation of Aquatic Ecosystems—an integration of the earlier National Lake Conservation Plan and National Wetlands Conservation Programme—has been instrumental in rejuvenating degraded lakes and wetlands across India. Operational from 2001 until November 2019, the plan supported restoration activities through a combination of central and state funds, aiming to improve water quality, biodiversity, and community participation in ecosystem governance.

Table 10 reflects significant inter-state variation in both approved costs and fund disbursements. Of the total sanctioned amount of ₹1,176 crore across states, only ₹766.23 crore—roughly 65%—had been released by the end of 2019. States like Jammu & Kashmir, Rajasthan, and Uttar Pradesh were the largest beneficiaries, with projects such as Dal Lake and the Pichola-Fatehsagar system receiving substantial allocations. However, states like Tripura, despite having multiple lakes, saw relatively low financial commitment and disbursement. The data also points to disparities in fund-release efficiency—Nagaland, for instance, received over 78% of its approved amount, while Kerala managed just 17%. Such trends underscore both the potential and challenges of decentralised aquatic ecosystem management and highlight the need for improved implementation and monitoring frameworks.

Table 10. Selected state/lake-wise approved cost and funds released under National Lake Conservation Plan/National Plan for Conservation of Aquatic Ecosystem (NLCP/NPCA) (2001 to 30 November 2019) (Rs. crore)

States	Lake and Location	Approved Cost (central & state share)	Stipulated Time of Completion (months)	Funds Released* (central share)
Bihar	Moti Jheel, Motihari	21.99	18	9.89
	Sub-total	21.99	-	9.89
Jammu & Kashmir	Dal Lake, Srinagar	298.76	60	285.85
	Sub-total	298.76	-	285.85
Karnataka	Vengaiahnkere Lake, Bangalore	2.12	24	1.44
	Nagvara Lake, Bangalore	6.00	24	3.04
	Jarganahalli Lake, Bangalore	3.36	24	2.35
	Kotekere Lake, Belgaum	5.64	21	3.95
	Bhishma Lake, Gadag	2.50	18	1.58
	Lal Bagh, Bangalore	1.66	12	1.16
	Sharanbhasveshwara Lake, Gulbarga	4.89	15	3.35
	Akkamahadevi Lake, Haveri	2.64	12	1.62
	Kundawada Lake, Davangere	3.41	12	2.35
	Kote Tavarekere Lake, Chikmagalur	3.64	36	2.13
	Tripuranthkeshwar Lake, Bidar	4.67	15	3.02
	Bellandur Lake in Bangalore	5.54	18	2.63
	Channapatna Lake, Hasan	4.97	12	2.97
	Gowramma Lake, Magadi town in Bangalore Rural	4.77	12	2.60
	Hombalamma Lakes, Magadi town in Bangalore			
	Amanikere Lake, Tumkur	13.37	12	7.34
	Sub-total	69.18	-	41.49
Kerala	Veli Akkulum Lake, Thiruvananthapuram	24.56	24	4.30
	Sub-total	24.56	-	4.30
Madhya Pradesh	Rani Talab, Rewa	3.31	24	2.18
	Sagar Lake, Sagar	21.33	36	4.00
	Shivpuri Lakes, Shivpuri	51.99	36	27.71
	Sindhsagar Lake, Ashoknagar	10.78	36	2.50
	Sub-total	87.41	-	36.39
Maharashtra	Powai Lake, Mumbai	6.62	18	4.70
	9 Lakes in Thane	2.53	36.00	1.77
	(i) Rewale Lake			
	(ii) Jail Lake			
	(iii) Makhamali Lake			
	(iv) Kharegon Lake			
	(v) Kusa Lake			
	(vi) Upvan Lake			
	(vii) Kasaradawli Lake			
	(viii) Naar/oval Lake			
	(ix) Khidkali Lake			
	Mahalaxmi Lake, Vadagaon	1.85	15	1.29
	Rankala Lake, Kolhapur	8.65	27	5.36

	Varhala Devi Lake, Bhiwandi	4.60	24	2.80
	Siddheshwar Lake, Solapur	4.32	36	2.75
	Koradi Lake, Nagpur	43.69	24	10.00
	Dharanveer Shambhaji	12.21	12	3.66
	Sub-total	84.47	-	32.33
Nagaland	Twin Lakes, Mokokchung	25.83	24	20.34
	Sub-total	25.83	-	20.34
Odisha	Bindu Sagar Lake, Bhubaneshwar	3.50	12	2.21
	Sub-total	3.50	-	2.21
Rajasthan	Mansagar Lake, Jaipur	24.72	18	17.30
	Anasagar Lake, Ajmer	18.27	24	5.67
	Pushkar Sarovar, Ajmer	48.37	30	26.73
	Fatehsagar Lake, Udaipur	41.86	30	27.33
	Pichola Lake System, Udaipur	84.75	36	53.91
	Nakki Lake, Mount Abu	7.33	16	2.78
	Sub-total	225.30	-	133.72
Tamil Nadu	Ooty Lake	1.75	18	1.73
	Kodaikanal Lake, Dindigul	10.42	24	2.00
	Sub-total	12.17	-	3.73
Telangana	Banjara Lake, Hyderabad	4.30	12	2.70
	Sub-total	4.30	-	2.70
Tripura	3 Lakes of Agartala	2.02	12	0.50
	(i) Dimasagar Lake	0.63		-
	(ii) Laxminarayanibari Lake	0.70		-
	(iii) Durgabadi Lake	0.69	-	-
	Sub-total	4.04	-	0.50
Uttarakhand	4 Lakes in Nainital	16.85	36.00	11.17
	(i) Bhimtal Lake			
	(ii) Naukuchiatal Lake			
	(iii) Sattal Lake			
	(iv) Khurpatal Lake			
	Nainital Lake, Nainital	47.97	36	30.93
	Sub-total	64.82	-	42.10
Uttar Pradesh	Mansi Ganga Lake, Govardhan	22.71	24	14.72
	Ramgarh Tal, Gorakhpur	124.32	36	86.03
	Laxmi Tal, Jhansi	54.13	42	28.52
	Sub-total	201.16	-	129.27
West Bengal	Rabindra Sarovar	6.96	18	4.00
	Mirik Lake, Darjeeling	4.01	18	1.00
	Adi Ganga, South 24 Parganas	24.94	36	11.30
	Sahib Bundh, Purulia	12.60	30	5.10
	Sub-total	48.51	-	21.40
Appraisal Fee	-	-	-	0.01
India		1,176.00	-	766.23

Source: IndiaStat (2025)

The Srujal Project, undertaken by the Centre for Environment Education in partnership with Baxter Pharmaceuticals, established a rainwater harvesting system with a 1.96 lakh-litre capacity in Navanagri, a scheduled caste settlement in Ahmedabad. Prior to this, residents, particularly women, had to travel long distances to access water. By integrating rooftop catchment systems, it has facilitated a women-led governance structure for managing local water resources sustainably (Ravandale, 2022).

The Pune Municipal Corporation restored a neglected percolation pond that had been affected by urban expansion. During road construction, officials recognised its potential for groundwater recharge and initiated restoration efforts, including de-silting, protecting natural springs, and installing sand and stone filtration to capture urban rainwater runoff. The rejuvenated system significantly enhanced groundwater levels in the area.

Rainbow Drive, a private residential community in Bengaluru, faced severe groundwater depletion due to borewell dependence. To address this, residents implemented rainwater harvesting, wastewater recycling, and groundwater recharge techniques. These collective efforts transformed the community into a water-sustainable model, recharging more water than they extracted and demonstrating a successful approach to decentralised water management (Suvarna, 2020).

Women in Nagaland and Uttarakhand have revived over 1,099 springs through collaborative efforts with organisations such as the North East Initiative Development Agency, People's Science Institute, CHIRAG, and the BAIF Development Foundation. Women-led Pey Jal Samitis, working alongside Van Panchayats, conduct hydrogeological assessments, implement soil and water conservation measures, and establish community-led monitoring systems. Their work has contributed to social equity in water distribution (Ravandale, 2022).

In Zaheerabad, Telangana, the Deccan Development Society (DDS) has empowered Dalit women to revive traditional millet-based farming practices. Millets, known for their climate resilience, drought tolerance, and superior nutritional value compared to rice and wheat, enhance food, water, and nutrition security. The Pannendu Pantalu cropping system integrates millets with pulses and oilseeds, promoting biodiversity and sustainability. DDS's Sanghams (women's collectives) advocate millet cultivation as a viable alternative to rice monoculture, addressing food security challenges arising from the Public Distribution System (UNDP, 2021). These case studies illustrate diverse and effective water management strategies that combine scientific expertise, community engagement, and gender-inclusive governance. Initiatives such as Bhujal Jankar training, Water Stewards, rooftop rainwater harvesting, urban groundwater recharge, and millet-based sustainable agriculture highlight how localised interventions contribute to broader goals of climate resilience, groundwater sustainability, and improved rural livelihoods. With appropriate policy backing, these models have the potential to be scaled up nationwide to ensure long-term water security.

6 Conclusions

India stands today at the crossroads of a deepening water crisis—one that is as much about mismanagement and inefficiency as it is about scarcity. This study set out to explore the country's growing water stress through an integrated, value chain perspective, moving beyond simplistic supply-side explanations to reveal the systemic nature of the problem. The analysis traced the journey of water from source to end-use, unearthing critical bottlenecks across availability, distribution, quality, and governance.

The opening section of this paper painted a sobering picture of India's current water resources. Despite receiving close to 3,880 billion cubic metres of precipitation annually, effective utilisable water stands at merely 1,123 BCM, constrained by spatial and seasonal imbalances, high evaporation losses, and inadequate infrastructure. Groundwater, often regarded as the invisible backbone of the Indian water system, emerged as the most exploited resource—22 per cent of assessed blocks now fall into over-exploited or critical categories. States such as Punjab, Rajasthan, Haryana, and Delhi reflect the sharpest vulnerabilities, where extraction consistently outpaces natural recharge. These findings highlight an urgent need to rethink groundwater regulation and local recharge mechanisms.

The subsequent discussion on water supply revealed how underdeveloped storage facilities, poor maintenance of traditional water bodies, and water quality concerns further compound the crisis. Pollution, particularly contamination by fluoride, arsenic, and nitrates, poses a serious health risk in several states. While India boasts extensive river networks and significant rainfall, these advantages are undermined by fragmented management and underutilisation of rainwater and treated wastewater. The message here is clear: enhancing supply alone cannot solve the water challenge without equal focus on quality, efficiency, and equitable distribution.

Turning to water demand, the study underscored the continued dominance of agriculture, which currently consumes nearly four-fifths of total water withdrawals. Yet, what is particularly striking is the rapid growth of industrial and domestic water needs, driven by urbanisation, industrialisation, and rising living standards. Projections suggest that, by 2030 water demand could be twice the available supply. This impending gap calls for a decisive shift towards demand-side management—one that prioritises water use efficiency, promotes wastewater recycling, and encourages sustainable cropping patterns.

Climate change, examined in detail in the fourth section, is emerging as the great amplifier of India's water risks. Erratic monsoon patterns, melting Himalayan glaciers, increased frequency of floods, droughts, and heatwaves—all these phenomena are already reshaping the hydrological landscape. Vulnerable zones, particularly coastal areas and semi-arid regions, are likely to face the twin burden of too much water at times and too little at others. The analysis makes a strong case for embedding adaptive strategies into water management through climate-resilient infrastructure, early warning systems, and localised planning.

The exploration of water governance and policy evolution laid bare the complexities of India's institutional architecture. Water remains constitutionally a state subject, yet inter-state disputes, overlapping responsibilities, and lack of enforcement mechanisms weaken effective governance. National initiatives, such as the Jal Jeevan Mission and Atal Bhujal Yojana, mark significant steps forward, but their success will hinge on greater coordination between central and state authorities, improved accountability, and meaningful community participation.

The findings from this study lead to several policy insights. First, there is a pressing need to strengthen groundwater governance. Extraction caps for high-use regions, supported by metering and monitoring systems, could help arrest further depletion. Managed aquifer recharge, incentivised through subsidies and community schemes, should form a key pillar of groundwater sustainability. Second, storage infrastructure requires both expansion and rehabilitation. Beyond constructing new reservoirs, policy should prioritise the revival of traditional tanks, ponds, and decentralised storage systems, which offer more climate-resilient solutions.

Equally important is demand-side reform. Promoting micro-irrigation, enforcing treated wastewater reuse in industries, and encouraging crop diversification away from water-intensive crops such as paddy and sugarcane are essential to ease sectoral pressures. These efforts should be complemented by education and behavioural nudges, aimed at fostering a culture of conservation among farmers, industries, and households alike. Pollution control remains a critical blind spot in India's water policy. Enforcing zero-liquid discharge norms for major polluting industries, upgrading sewage treatment plants, and expanding community water purification facilities are urgent steps to safeguard water quality. Finally, a stronger push for integrated water governance is vital. River basin authorities, with powers to coordinate across states and sectors, could provide the institutional glue needed for effective planning and dispute resolution. Embedding climate risk assessments within local governance structures would further enhance resilience.

It is important to recognise the limitations of this research. Much of the analysis relies on secondary data, which, while comprehensive at the national level, may not capture the granularity of local water-use patterns, informal groundwater markets, or enforcement gaps. Climate projections, though based on the best available models, carry inherent uncertainties, especially at sub-national scales. Additionally, the paper’s focus on supply-demand dynamics and policy frameworks leaves scope for deeper exploration of social and political dimensions, such as caste-based inequalities in water access or gendered burdens of water collection.

Future studies would benefit from bridging these gaps through field-based research, household surveys, and participatory assessments. There is rich potential to examine behavioural drivers of water consumption, especially among farmers, urban households, and industries. Insights from behavioural economics could inform more effective demand management strategies. The energy-water nexus also deserves closer attention. With thermal power generation being one of the largest industrial water users, understanding the synergies and trade-offs between energy and water policy is increasingly crucial. Another promising area for future research lies in the adoption of emerging technologies—AI-powered hydrological models, IoT-enabled metering, and blockchain-based water rights trading—offering new avenues for real-time monitoring and adaptive governance. Lastly, there is a need for more focussed analysis of inter-state water politics and transboundary cooperation, particularly in light of shifting river flows and increasing interstate tensions.

In conclusion, India’s water paradox—the coexistence of abundant annual rainfall with severe local scarcity—demands more than technical fixes. It calls for an integrated, multi-pronged strategy that addresses ecological sustainability, economic efficiency, social equity, and institutional coherence. Without decisive action, the gap between supply and demand will only widen, with profound implications for food security, economic growth, and social stability. This study offers a foundation for such action, but the challenge ahead lies in turning these insights into meaningful, on-the-ground change.

References

ACT. (2004). *Arid Communities and Technologies: Memorandum of Understanding*. https://mrmgvp.in/csrmgvp/upload/placement/ARID-MOU.pdf

Aggarwal, S. (2023, August 16). Revolutionising water sustainability: Israel's desalination success and how India can benefit. *Down To Earth*. https://www.downtoearth.org.in/water/revolutionising-water-sustainability-israel-s-desalination-success-and-how-india-can-benefit-91187

Ahamed, S. M., Kumar, Y. V., Rahman, J. F., & Bharat, V. (2014). Mechanical Properties of Sub Zero Chilled Cast Iron useful for Wear Functional Requirements of Engineering Components. *Procedia Materials Science*, *5*, 540–549. https://doi.org/10.1016/j.mspro.2014.07.298

Amarasinghe, U. A., McCornick, P. G., & Shah, T. (Eds.). (2009). India's water demand scenarios to 2025 and 2050: A fresh look. In *India's water demand scenarios to 2025 and 2050: A fresh look*. https://doi.org/10.22004/ag.econ.127730

Amarasinghe, U. A., Sharma, B. R., Aloysius, N., Scott, C. A., Smakhtin, V. U., & Fraiture, C. de. (2004). *Spatial variation in water supply and demand across river basins of India*. International Water Management Institute. https://hdl.handle.net/10568/39870

Amrutha, K., Patnaik, R., Sandeep, A. S., & Pattanaik, J. K. (2023). Climate Change Impact on Major River Basins in the Indian Himalayan Region: Risk Assessment and Sustainable Management. In S. Sharma, J. C. Kuniyal, P. Chand, & P. Singh (Eds.), *Climate Change Adaptation, Risk Management and Sustainable Practices in the Himalaya* (pp. 45–63). Springer International Publishing. https://doi.org/10.1007/978-3-031-24659-3_3

Aqua Tech. (2023). *Our essential guide to desalination and the global water crisis*. https://www.aquatechtrade.com/news/desalination/desalination-essential-guide

Bassi, N., Schmidt, G., & De Stefano, L. (2020). Water accounting for water management at the river basin scale in India: Approaches and gaps. *Water Policy*, *22*(5), 768–788. https://doi.org/10.2166/wp.2020.080

BIS. (2012). *Indian Standard Drinking Water—Specification*. https://cpcb.nic.in/wqm/BIS_Drinking_Water_Specification.pdf

Biswas, A., Sarkar, S., Das, S., Dutta, S., Choudhury, M. R., Giri, A., Bera, B., Bag, K., Mukherjee, B., Banerjee, K., Gupta, D., & Paul, D. (2025). Water scarcity: A global hindrance to sustainable development and agricultural production – A critical review of the impacts and adaptation strategies. *Cambridge Prisms: Water*, *3*, e4. https://doi.org/10.1017/wat.2024.16

Business Standard. (2024, March 9). Govt starts 'Catch the Rain-2024' campaign to promote water sustainability. *Business Standard*. https://www.business-standard.com/india-news/govt-starts-catch-the-rain-2024-campaign-to-promote-water-sustainability-124030900628_1.html

CAG. (2021). *Audit Reports of the Comptroller and Auditor General of India on Ground Water Management and Regulation* (No. 9). Ministry of Jal Shakti Department of Water Resources. https://cag.gov.in/webroot/uploads/download_audit_report/2021/Report%20No.%209%20of%202021_GWMR_English-061c19df1d9dff7.23091105.pdf

CGWB. (2021). *Annual Report 2020-21, Central Ground Water Board*. Ministry of Water Resources, RD &GR Government of India. https://cgwb.gov.in/old_website/Annual-Reports/AGR%202020-21%20Final%2027%20Jan%202021%20RS%20Final%20Ranjan.pdf

CGWB. (2022). *Dynamic Ground Water Resources of India*. Ministry of Water Resources, Rd &gr Government of India. https://cgwb.gov.in/sites/default/files/inline-files/2022-11-11-gwra_2022_1_compressed.pdf

CGWB. (2024). *Dynamic Ground Water Resources, 2023 Rajasthan*. Ministry of Water Resources, Government of India. https://www.cgwb.gov.in/cgwbpnm/public/uploads/documents/1705647587593353300file.pdf

Chen, Z., Grasby, S. E., & Osadetz, K. G. (2004). Relation between climate variability and groundwater levels in the upper carbonate aquifer, southern Manitoba, Canada. *Journal of Hydrology*, *290*(1), 43–62. https://doi.org/10.1016/j.jhydrol.2003.11.029

Chitravanshi, R. (2019, August 24). Gujarat retains top position in water management, says NITI Aayog. *Business Standard*. https://www.business-standard.com/article/economy-policy/gujarat-retains-top-position-in-water-management-says-niti-aayog-119082400032_1.html

CWB. (2023). *India's first water bodies census*. Ministry of Jal Shakti. https://cdnbbsr.s3waas.gov.in/s3a70dc40477bc2adceef4d2c90f47eb82/uploads/2023/05/20240110191671260.pdf

CWC. (2015). *Annual Report, 2015-16, Central Ground Water Board*. Ministry of Water Resources, RD &GR Government of India. https://cgwb.gov.in/old_website/Annual-Reports/Annual%20Report%202015-16.pdf

CWC. (2019). *Annual Report—2019-20, Central Ground Water Board*. Ministry of Water Resources, RD &GR Government of India. https://cgwb.gov.in/old_website/Annual-Reports/Modified_ANNUAL%20REPORT%20of%20CGWB%202019-20%20by%20SND_21052021.pdf

EnviStats. (2025). *EnviStats—India 2018 | Ministry of Statistics and Program Implementation | Government Of India* [Dataset]. https://mospi.gov.in/publication/envistats-india-2018

Esmaeilion, F. (2020). Hybrid renewable energy systems for desalination. *Applied Water Science*, *10*(3), 84. https://doi.org/10.1007/s13201-020-1168-5

FAO. (2025). *Aquastat* [Dataset]. https://data.apps.fao.org/aquastat/?lang=en

Financial Express. (2019, August 31). Water scarcity: India's demand may exceed supply two times by 2030. *Financialexpress*. https://www.financialexpress.com/opinion/water-scarcity-indias-demand-may-exceed-supply-two-times-by-2030/1691788/

Franks, T., Kay, M., & Smith, L. E. D. (Eds.). (2002). *Water: Economics, Management and Demand*. CRC Press. https://doi.org/10.1201/9781482294972

Frontline. (2025, January 31). India's Economic Survey 2024-25: Key Insights on Agriculture, Employment, Technology, Education, and Healthcare for Sustainable Growth. *Frontline*. https://frontline.thehindu.com/news/economic-survey-india-budget-nirmala-sitharaman-agriculture-education-healthcare-artificial-intelligence/article69165256.ece

Geethalakshmi, V., Gowtham, R., Manikandan, N., Bhuvaneswari, K., Lakshmanan, A., Sekhar, N. U., & McDermid, S. (2024). Climate Change and Its Impact on Agriculture in India. In N. Chattopadhyay, R. Stefanski, S. D. Attri, & L. S. Rathore (Eds.), *Agrometeorological Applications for Climate Resilient Agriculture* (pp. 261–282). Springer International Publishing. https://doi.org/10.1007/978-3-031-51083-0_13

Ghosh, N., & Bhowmick, S. (2023). *Water Valuation and Pricing in India: Imperatives for Sustainable Water Governance*. Obsever Research Foundation. https://www.orfonline.org/research/water-valuation-and-pricing-in-india-imperatives-for-sustainable-water-governance

Goyal, M. K., & Surampalli, R. Y. (2018). Impact of Climate Change on Water Resources in India. *Journal of Environmental Engineering*, *144*(7), 04018054. https://doi.org/10.1061/(ASCE)EE.1943-7870.0001394

Grover, S., Tayal, S., Sharma, R., & Beldring, S. (2021). Effect of changes in climate variables on hydrological regime of Chenab basin, western Himalaya. *Journal of Water and Climate Change*, *13*(1), 357–371. https://doi.org/10.2166/wcc.2021.003

Har Ghar Jal. (2021). *Union Minister of Jal Shakti & Chief Minister of Karnataka Jointly Review Implementation of Jal Jeevan Mission in The State*. https://www-pib-gov-in.translate.goog/www.pib.gov.in/Pressreleaseshare.aspx?PRID=1735074

Harsh, H. (2025, March 22). How water conservation efforts have helped turn fortune of a Jharkhand village. *The Indian Express*. https://indianexpress.com/article/india/how-water-conservation-efforts-have-helped-turn-fortune-of-a-jharkhand-village-9899326/

Hazarika, J., & Boro, M. (2023). Impact of Climate Change on Precipitation Extremes in Northeast India Under CMIP5 Models. In P. V. Timbadiya, V. P. Singh, & P. J. Sharma (Eds.), *Climate Change Impact on Water Resources* (pp. 97–112). Springer Nature. https://doi.org/10.1007/978-981-19-8524-9_9

IISC. (2019). *Annual Report, 2019-20*. Indian Institute of Science, Bangalore. https://iisc.ac.in/wp-content/uploads/2021/07/IISc_AR_ENG2020_30th_October.pdf

IITM. (2021). *Annual Reports, 2021-22*. Indian Institute of Tropical Meteorology. https://www.tropmet.res.in/~lip/annual-reports/AR-English_2021-22.pdf

Ilstedt, U., Bargués Tobella, A., Bazié, H. R., Bayala, J., Verbeeten, E., Nyberg, G., Sanou, J., Benegas, L., Murdiyarso, D., Laudon, H., Sheil, D., & Malmer, A. (2016). Intermediate tree cover can maximize groundwater recharge in the seasonally dry tropics. *Scientific Reports*, *6*(1), 21930. https://doi.org/10.1038/srep21930

IMD. (2022). *Annual Report- 2022*. India Meteorological Department. https://metnet.imd.gov.in/docs/imdnews/ANNUAL_REPORT2022English.pdf

India Observatory. (2020). Groundwater Monitoring Tool. *India Observatory*. https://www.indiaobservatory.org.in/tool/gmt

Indiastat. (2025). *Water Resources in India, Water Projects Statistics in India* [Dataset]. https://www.indiastat.com/data/agriculture/water-resources

IPCC. (2014). *Climate Change 2014- Impacts, Adaptation, and Vulnerability Part B: Regional Aspects*. Intergovernmental Panel On Climate Change. https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-PartB_FINAL.pdf

IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_FullReport.pdf

IRENA. (2020). *Renewable Capacity Statistics 2020*. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Mar/IRENA_RE_Capacity_Statistics_2020.pdf

Jacque, H., Mozafari, B., Dereli, R. K., & Cotterill, S. (2024). Implications of water conservation measures on urban water cycle: A review. *Sustainable Production and Consumption*, *50*, 571–586. https://doi.org/10.1016/j.spc.2024.08.026

Jim, S., Lobo, C., Milne, G., & Williams, M. (2014). *Watershed development in India: An approach evolving through experience*. https://documents1.worldbank.org/curated/en/185611468259137769/pdf/880560NWP0Wate0Box385209B00PUIBLIC0.pdf

Jindal, M. K., & Das, B. (2024). Chapter 13a - Socioenvironmental aspects toward safeguarding river systems in India: A science-engineering approach. In M. Kumar, AL. Ramanathan, S. Shrestha, K. Kuroda, & S. Mukherjee (Eds.), *River Basin Ecohydrology in the Indian Sub-Continent* (pp. 363–377). Elsevier. https://doi.org/10.1016/B978-0-323-91545-8.00016-4

JJM. (2024). *Jal Jeevan Mission: Ensuring Tap Water for 15 Crore Rural Families*. Ministry of Jal Shakti. http://pib.gov.in/PressNoteDetails.aspx?NoteId=153255

Kapoor, A., & Anand, M. (2024). *Addressing Groundwater Depletion Crisis in India: Institutionalizing Rights and Technological Innovations*. Economic Advisory Council to the Prime Minister. https://eacpm.gov.in/wp-content/uploads/2024/05/Addressing_Groundwater_Depletion_in_India.pdf

Kaur, T. (2025, April 29). Atal Bhujal Yojana Impact: 2025’s Water Revolution. *Chandigarh UT*. https://chandigarhut.in/atal-bhujal-yojana-impact-water-revolution/

Khandelwal, A., & Monga, A. (2024). Accessing Domestic Water Consumption Patterns in Sonipat Town, Haryana, India. *African Journal of Biological Sciences*, *6*(7). https://doi.org/10.48047/AFJBS.6.7.2024.2581-2595

Krishnan, R., Sanjay, J., Gnanaseelan, C., Mujumdar, M., Kulkarni, A., & Chakraborty, S. (Eds.). (2020). *Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India*. Springer Singapore. https://doi.org/10.1007/978-981-15-4327-2

Kulkarni, A., Sabin, T. P., Chowdary, J. S., Rao, K. K., Priya, P., Gandhi, N., Bhaskar, P., Buri, V. K., Sabade, S. S., Pai, D. S., Ashok, K., Mitra, A. K., Niyogi, D., & Rajeevan, M. (2020). Precipitation Changes in India. In R. Krishnan, J. Sanjay, C. Gnanaseelan, M. Mujumdar, A. Kulkarni, & S. Chakraborty (Eds.), *Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India* (pp. 47–72). Springer. https://doi.org/10.1007/978-981-15-4327-2_3

Kulkarni, A. V., & Karyakarte, Y. (2014). Observed changes in Himalayan glaciers. *Current Science*, *106*(2), 237–244.

Kumar, K. R., Sahai, A. K., Kumar, K. K., Patwardhan, S. K., Mishra, P. K., Revadekar, J. V., Kamala, K., & Pant, G. B. (2006). High-resolution climate change scenarios for India for the 21st century. *Current Science*, *90*(3), 334–345.

Kumar, M. R. (2019). *The Impacts of Urbanization on Groundwater Systems and Recharge*. *04*(05). https://old.rrjournals.com/wp-content/uploads/2020/05/2260-2263_RRIJM190405492.pdf

Kumar Sarangi, A. (2020). Smart Water Leakage and Theft Detection using IoT. *2020 International Conference on Industry 4.0 Technology (I4Tech)*, 46–50. https://doi.org/10.1109/I4Tech48345.2020.9102701

Lakhwan, N., Bharat, D. G. K., & Sarkar, D. S. K. (2024). Climate Resilience in Water Resource Management in India: A Conceptual Framework for Action. *TERI*. https://teriin.org/sites/default/files/2024-09/Discussion_Paper_Climate_Resilience_in_Water_Resource_Management_in_India.pdf

Luo, T. (2018, January 16). 40% of India's Thermal Power Plants Are in Water-Scarce Areas, Threatening Shutdowns. *World Resources Institute*. https://www.wri.org/insights/40-indias-thermal-power-plants-are-water-scarce-areas-threatening-shutdowns

Lutz, A. F., Immerzeel, W. W., Shrestha, A. B., & Bierkens, M. F. P. (2014). Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. *Nature Climate Change*, *4*(7), 587–592. https://doi.org/10.1038/nclimate2237

Majumdar, S. (2021). Back to Growth: Union Budget 2021-22 announcement – Urban Swac... *Invest India*. https://www.investindia.gov.in/team-india-blogs/back-growth-union-budget-2021-22-announcement-urban-swachh-bharat-mission-20

Mall, R. K., Singh, N., Patel, S., Singh, S., Arora, A., Bhatla, R., Singh, R. S., & Srivastava, P. K. (2022). Climate Changes over the Indian Subcontinent: Scenarios and Impacts. In N. Khare (Ed.), *Science, Policies and Conflicts of Climate Change: An Indian Perspective* (pp. 27–52). Springer International Publishing. https://doi.org/10.1007/978-3-031-16254-1_2

Mann, G. (2023, October 6). Saltwater intrusion and drinking water quality. *Smart Water Magazine*. https://smartwatermagazine.com/blogs/graham-mann/saltwater-intrusion-drinking-water-quality

Mehrotra, D., & Mehrotra, R. (1995). Climate change and hydrology with emphasis on the Indian subcontinent. *Hydrological Sciences Journal*, *40*(2). https://doi.org/10.1080/02626669509491406

Mehta, S., & Bhaduri, A. (2021, March 18). Decentralized water resources management. *India Water Portal*. https://www.indiawaterportal.org/drinking-water/decentralized-water-resources-management

Mihir Shah Committee. (2016). *Mihir Shah Committee Report (2016) on Water Reforms in India: A Critique*. Institute For Resource Analysis And Policy. https://irapindia.org/images/irap-Occasional-Paper/IRAP-Occasional-Paper-No9.pdf

Mikucioniene, D., Mínguez-García, D., Repon, M. R., Milašius, R., Priniotakis, G., Chronis, I., Kiskira, K., Hogeboom, R., Belda-Anaya, R., & Díaz-García, P. (2024). Understanding and addressing the water footprint in the textile sector: A review. *AUTEX Research Journal*, *24*(1). https://doi.org/10.1515/aut-2024-0004

Minor Irrigation Census. (2017). *Report of 5th Census of Minor Irrigation Schemes*. https://mowr.nic.in/irrigationcensus/Files/5th-MICensusReport.pdf

Mishra, V., Ambika, A. K., Asoka, A., Aadhar, S., Buzan, J., Kumar, R., & Huber, M. (2020). Moist heat stress extremes in India enhanced by irrigation. *Nature Geoscience*, *13*(11), 722–728. https://doi.org/10.1038/s41561-020-00650-8

MoEFCC. (2019). *Annual Report, 2019-20*. https://moef.gov.in/uploads/2017/06/ENVIRONMENT-AR-ENGLISH-2020.pdf

MoHUA. (1976). *National Mission on Sustainable Habitat 2021-2030*. Ministry of Housing and Urban Affairs. https://mohua.gov.in/upload/uploadfiles/files/NMSH-2021.pdf

Mukherjee, S., Aadhar, S., Stone, D., & Mishra, V. (2018). Increase in extreme precipitation events under anthropogenic warming in India. *Weather and Climate Extremes*, *20*, 45–53. https://doi.org/10.1016/j.wace.2018.03.005

National Water Policy. (2012). *National Water Policy (2012)*. Government of India Ministry of Water Resources. https://nwm.gov.in/sites/default/files/national%20water%20policy%202012_0.pdf

Nidhi, A., & Charan, J. L. (2025). Exploring the Water Crisis and Viability of Unregulated Groundwater in India: An Analysis. *Nature Environment and Pollution Technology*, *24*(1), B4183. https://doi.org/10.46488/NEPT.2025.v24i01.B4183

Niranjana, P. S. (2025, February 22). Conserving wetlands for the future. *The Hindu*. https://www.thehindu.com/sci-tech/energy-and-environment/conserving-wetlands-for-the-future/article69158893.ece

NITI Aayog. (2019). *Composite Water Management Index*. https://niti.gov.in/sites/default/files/2023-03/CompositeWaterManagementIndex.pdf

NITI Aayog. (2021). *Sector Report 2021—Water Resources*. https://dmeo.gov.in/reports-working/sector-report-2021-water-resources

Pant, D. K., Nair, S. K. N., Siddiqui, K. A., Munjal, P., Sapra, M. K., Pande, N., Rawat, T., & Ghosh, P. (2008). *Economic Impact of Interlinking of Rivers Programme*. National Council of Applied Economic Research. https://www.cgwb.gov.in/cgwbpnm/public/uploads/documents/1705647587593353300file.pdf

Panwar, S., & Chakrapani, G. J. (2013). Climate change and its influence on groundwater resources. *Current Science*, *105*(1), 37–46.

PIB. (2013). *Withdrawal of Fresh Water*. https://pib.gov.in/newsite/PrintRelease.aspx?relid=101519

PIB. (2017). *Shortage of Water*. https://pib.gov.in/newsite/PrintRelease.aspx?relid=168727

PIB. (2019). *Water Conservation under MGNREGS*. https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1576612

PIB. (2021). *Water Storage Capacity in Reservoirs*. https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1780931

PIB. (2023). *Exploitation of Groundwater*. Ministry of Jal Shakti. https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=1911222

PIB. (2024). *Per Capita Water Availability*. https://pib.gov.in/pib.gov.in/Pressreleaseshare.aspx?PRID=2002726

Prakash, A. (2025). Melting glaciers is not just an environmental crisis but a humanitarian one. *The Indian Express*. https://indianexpress.com/article/opinion/columns/glaciers-melting-environmental-crisis-humanitarian-9904882/

Qazi, N. Q., Jain, S. K., Thayyen, R. J., Patil, P. R., & Singh, M. K. (2020). Hydrology of the Himalayas. In A. P. Dimri, B. Bookhagen, M. Stoffel, & T. Yasunari (Eds.), *Himalayan Weather and Climate and their Impact on the Environment* (pp. 419–450). Springer International Publishing. https://doi.org/10.1007/978-3-030-29684-1_21

Ravandale, S. (2022, March 21). Celebrating the role of hill women in springshed development and governance. *India Water Portal*. https://www.indiawaterportal.org/groundwater/rainwater-harvesting/celebrating-role-hill-women-springshed-development-and-governance

Ray, K., Pandey, P., Pandey, C., Dimri, A. P., & Kishore, K. (2019). On the recent floods in India. *Current Science*, *117*(2), 204–218. https://doi.org/10.18520/cs/v117/i2/204-218

Reddy, C. S., Jha, C. S., Diwakar, P. G., & Dadhwal, V. K. (2015). Nationwide classification of forest types of India using remote sensing and GIS. *Environmental Monitoring and Assessment*, *187*(12), 777. https://doi.org/10.1007/s10661-015-4990-8

Sachan, D., Kumari, A., & Kumar, P. (2023). *Shifting Velocity of Precipitation Extremes over India under Climate Change*. EGU-16818. https://doi.org/10.5194/egusphere-egu23-16818

Salunke, P., Keshri, N. P., Mishra, S. K., & Dash, S. K. (2023). Future projections of seasonal temperature and precipitation for India. *Frontiers in Climate*, *5*. https://doi.org/10.3389/fclim.2023.1069994

Sharif, M. (2023). *Simulation of Extreme Precipitation Events Using an Improved K-Nearest Neighbor Model* (pp. 381–389). American Society of Civil Engineers. https://ascelibrary.org/doi/10.1061/9780784484852.036

Sharma, A., Patel, P. L., & Sharma, P. J. (2025). Changes in the spatial variability of extreme climate characteristics across the Sabarmati River basin: Past and future. *Gondwana Research*, *143*, 199–213. https://doi.org/10.1016/j.gr.2025.03.016

Sharma, H. (2021, April 7). Explained: What is the Ken-Betwa Link Project; which regions will benefit from it? *The Indian Express*. https://indianexpress.com/article/explained/explained-what-is-the-ken-betwa-link-project-7239885/

Singhal, S., & Ahmad, F. (2025, March 17). Safety in circularity. *Down To Earth*. https://www.downtoearth.org.in/water/safety-in-circularity

Sinha, A., & Sedai, A. K. (2025). National river conservation plan and water pollutants in India. *Economic Analysis and Policy*, *85*, 2192–2206. https://doi.org/10.1016/j.eap.2025.02.031

Steinhübel, L., Wegmann, J., & Mußhoff, O. (2020). Digging deep and running dry—The adoption of borewell technology in the face of climate change and urbanization. *Agricultural Economics*, *51*(5), 685–706. https://doi.org/10.1111/agec.12586

Suchita Awasti. (2021). *Rejuvenation and Conservation of Water Bodies and Open Areas*. Climate Centre for Cities, NIUA. https://niua.in/c-cube/sites/all/themes/zap/pdf/rejuvenation-water.pdf

Suvarna, P. (2020). In this layout, every drop is accounted for. *Deccan Herald*. https://www.deccanherald.com/india/karnataka/in-this-layout-every-drop-is-accounted-for-851674.html

TERI. (2022). *Water – Key Facts for its Sustainable Management in India, World Sustainable Development Summit 2022*. https://www.teriin.org/sites/default/files/2021-06/water-factsheet.pdf

The Economic Times. (2024). *PM Modi targets Congress at Ken-Betwa link event*. https://economictimes.indiatimes.com/news/politics-and-nation/pm-modi-hails-dr-b-r-ambedkars-vision/articleshow/116652748.cms?from=mdr

Tzanakakis, V. A., Capodaglio, A. G., & Angelakis, A. N. (2023). Insights into Global Water Reuse Opportunities. *Sustainability*, *15*(17), Article 17. https://doi.org/10.3390/su151713007

UNDP. (2021). *Equator Initiative Case Studies Local sustainable development solutions for people, nature, and resilient communities*. https://www.equatorinitiative.org/wp-content/uploads/2017/05/Deccan-Case-Study-English-FNL.pdf

Vinayak, A. J. (2025, March 27). Punjab, Haryana, Rajasthan lead in groundwater overexploitation. *BusinessLine*. https://www.thehindubusinessline.com/data-stories/data-focus/punjab-haryana-rajasthan-lead-in-groundwater-overexploitation/article69381032.ece

Vincent, C. J., Supate, A. R., & Desai, N. S. (2017). Efficient Wastewater Management for Sustainable Development: Challenges and Prospects an Indian Scenario. *International Journal of Health Sciences & Research*, *7*(12). https://www.researchgate.net/profile/Clyde-Vincent-2/publication/321759200_Efficient_Wastewater_Management_for_Sustainable_Development_Challenges_and_Prospects_an_Indian_Scenario/links/5a30d1d1a6fdccbf7ef16d17/Efficient-Wastewater-Management-for-Sustainable-Development-Challenges-and-Prospects-an-Indian-Scenario.pdf

Vishnukant Tiwari. (2025, February 24). Why a mega river-linking plan has sparked massive protests in India. *BBC*. https://www.bbc.com/news/articles/c4gwj2qy9pxo

Vishwa Mohan. (2023, February 6). What India is doing to tackle its water crisis. *The Times of India*. https://timesofindia.indiatimes.com/india/what-india-is-doing-to-tackle-its-water-crisis/articleshow/92141578.cms

Woo, S., Singh, G. P., Oh, J.-H., & Lee, K.-M. (2019). Projection of seasonal summer precipitation over Indian sub-continent with a high-resolution AGCM based on the RCP scenarios. *Meteorology and Atmospheric Physics*, *131*(4), 897–916. https://doi.org/10.1007/s00703-018-0612-7

Yadav, M. (2022). South Asian Monsoon Extremes and Climate Change. In P. Saxena, A. Shukla, & A. K. Gupta (Eds.), *Extremes in Atmospheric Processes and Phenomenon: Assessment, Impacts and Mitigation* (pp. 59–86). Springer Nature. https://doi.org/10.1007/978-981-16-7727-4_4

Yakubu, S., Samikannu, R., Gawusu, S., Wetajega, S. D., Okai, V., Shaibu, A.-K. S., & Workneh, G. A. (2025). A holistic review of the effects of dust buildup on solar photovoltaic panel efficiency. *Solar Compass*, *13*, 100101. https://doi.org/10.1016/j.solcom.2024.100101

Zektser, I. S., & Everett, L. G. (2004). *Groundwater resources of the world and their use* (hnd 551.49 UNE 2004). UNESCO; NS/291/6. https://coilink.org/20.500.12592/k0p2q0t

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