STM JOURNALS

Journal of
Water Resource Engineering and Management

ISSN: 2349-4336
Volume 12, Issue 3, 2025
September–December
DOI (Journal): 10.37591/JoWREM

https://journals.stmjournals.com/jowrem

Research JoWREM

Beyond Conventional Purification: India's Journey in Water Technology and Governance

Kailash Narayan[1], Himank Sharma[2,*]

Abstract

India is facing mounting challenges in water availability and quality due to rapid urbanization, industrial growth, climate change, and population pressure. Over the past decade, significant advances have been made in water treatment technologies, driven by increasing demand, stricter environmental regulations, and the need for sustainable solutions. This review critically examines recent technological innovations in water treatment, including membrane-based filtration, advanced oxidation processes, decentralized systems, and nature-based solutions, with a specific focus on their application and scalability in the Indian context. It also evaluates national water policies and government programs such as the Jal Jeevan Mission, National Water Policy (2012), and the Draft National Water Framework Bill (2016), analyzing their impact on the implementation of water treatment infrastructure and sustainable management practices. Despite advancements, persistent challenges such as institutional fragmentation, inadequate funding, and limited public participation hinder effective policy implementation. The paper identifies key gaps in policy coherence and technology adoption and offers strategic recommendations to align India's water treatment framework with long-term environmental and public health goals. By integrating technical progress with policy innovation and inclusive governance, India can move toward more resilient and equitable water resource management.

Keywords: National Water Policy, Jal Jeevan Mission, water, environmental, water treatment of India

INTRODUCTION

Water is an indispensable natural resource vital for sustaining life, economic development, and ecological balance. In India, with a population exceeding 1.4 billion, the demand for clean and safe water has increased exponentially, creating mounting pressure on already stressed water systems. According to India's Central Water Commission (2019), the country accounts for approximately 4% of the world's freshwater resources, but supports nearly 18% of the global population, highlighting a significant imbalance in water availability and consumption. This growing disparity has resulted in widespread water scarcity, contamination, and uneven distribution, affecting agriculture, industry, and domestic sectors alike. Over the last two decades, water quality has become as critical as water quantity. Rapid industrialization and urbanization have led to severe pollution of surface and groundwater resources, with untreated industrial effluents and domestic sewage being the primary contributors. Studies such as Balamurugan et al. (2021) reveal that COVID-19 disruptions further highlight the fragility of water infrastructure and the urgent need for resilient, decentralized systems [1]. Despite national missions and infrastructural expansion, India's capacity to deliver

*Author for Correspondence
Himank Sharma
E-mail: himank.atr@gmail.com

[1]Professor, Department of Humanities and Applied Science, Echelon Institute of Technology Faridabad, Haryana, India
[2]Assistant Professor, Department of Civil Engineering, Echelon Institute of Technology, Faridabad, Haryana, India

Received Date: July 10, 2025
Accepted Date: August 26, 2025
Published Date: August 29, 2025

Citation: Kailash Narayan, Himank Sharma. Beyond Conventional Purification: India's Journey in Water Technology and Governance. Journal of Water Resource Engineering and Management. 2025; 12(3): 12–19p.

universal access to safe water remains constrained by technological and policy shortcomings. In response to these challenges, the Indian government introduced several initiatives aimed at improving water governance and infrastructure. The National Water Policy (NWP), first introduced in 1987 and revised in 2002 and 2012, emphasizes integrated water resource management (IWRM), participatory governance, and sustainability. The Draft National Water Framework Bill (2016) and the Jal Jeevan Mission (2019) represent progressive steps towards ensuring equitable access to water and sanitation, aligning with United Nations Sustainable Development Goal 6 (Clean Water and Sanitation). However, implementation remains inconsistent across states because of institutional fragmentation and financial constraints. Technological advancements have played a pivotal role in shaping modern water treatment strategies. Conventional methods, such as coagulation, sedimentation, and chlorination, are now supplemented or replaced by innovative techniques, such as membrane filtration (UF, RO, NF), UV disinfection, electrocoagulation, advanced oxidation processes (AOPs), constructed wetlands, and bioremediation. These approaches offer improved efficiency, reduced environmental impacts, and greater scalability. However, their success in India depends largely on context-specific customization, cost-effectiveness, and ease of operation, factors that often limit their adoption in rural and underserved regions.

Water treatment in India operates at the intersection of technology, policy, and socioeconomic realities. While metropolitan areas have witnessed the deployment of sophisticated treatment plants, smaller towns and rural villages have often relied on rudimentary or obsolete systems. Furthermore, water governance is complicated by the multiplicity of agencies operating at the central, state, and local levels. Saleth and Dinar (2005) argue that institutional reforms are essential for harmonizing efforts across departments and ensuring policy coherence [2]. The Mihir Shah Committee Report (2016) also emphasized the need to decentralize governance and integrate water, agriculture, and energy policies through a “water-energy-food nexus” framework [3].

A critical issue often overlooked is the pricing and valuation of water. In India, water is predominantly viewed as a public good, resulting in poor cost recovery and inefficient use. Irrigation and domestic water supplies are heavily subsidized, discouraging conservation and investment in infrastructure. Parween et al. (2021) highlight the need for dynamic water pricing policies that balance equity with sustainability. Without addressing these structural inefficiencies, technological upgrades in water treatment may not yield long-term benefits [4].

The interplay between climate change and water resources complicates this scenario. Changes in rainfall patterns, glacial retreat, and the increased frequency of extreme events alter hydrological cycles, increasing the unpredictability of water availability. Levesque et al. (2008) and Wada et al. (2013) underscored the need for adaptive water management systems that incorporate real-time monitoring and predictive analytics [5]. India’s water policy must evolve to account for these new risks and incorporate climate resilience into infrastructure planning and technological deployment [6, 7].

This review aims to synthesize recent technological developments in water treatment within the Indian context, while critically examining the evolving policy landscape. It draws from the national and international literature, government policy documents, and field-level case studies to identify synergies and gaps. The objective is to provide actionable insights into how India can better integrate advanced water treatment technologies with robust, inclusive, and adaptive policy mechanisms [8].

METHODOLOGY

This review adopts a qualitative, integrative approach to analyze recent advances and policy trends in water treatment technologies in India. This methodology combines a systematic literature review, policy analysis, and comparative evaluation to provide a comprehensive understanding of the intersection between technology and governance in the Indian water sector.

Data Collection

Relevant information was gathered from:

- Peer-reviewed journal articles using databases such as ScienceDirect, Springer, and Taylor & Francis.
- Policy documents from the Government of India, including the Ministry of Jal Shakti, Central Water Commission (CWC), National Water Mission (NWM), and Planning Commission archives.
- Institutional reports from international agencies such as the WHO, IWA Publishing, and academic studies relevant to India.
- News portals and expert commentaries (e.g., India Water Portal, Times of India) provide recent developments and ground-level perspectives.

Selection Criteria

The literature selected met the following inclusion criteria:

- Focus on water treatment technologies relevant to India or applicable in the Indian context.
- Examination of national and state-level policies, especially post-2000.
- Peer-reviewed or government-authenticated publications from 2005 to 2024.

Analytical Framework

A thematic content analysis was used to organize findings into key areas:

- Technology types and applications.
- Policy development and implementation trends.
- Institutional and governance challenges.
- Gaps and future needs.

LITERATURE REVIEW

India's water treatment sector has evolved significantly in recent decades, driven by the increasing severity of water pollution, depletion of freshwater sources, and the urgent need for universal access to safe drinking water. This section reviews key technological advancements and policy reforms and assesses their relevance, implementation status, and challenges.

Technological Developments in Water Treatment

India has adopted a range of water treatment technologies classified broadly into conventional and advanced systems. Conventional methods, such as sedimentation, chlorination, and sand filtration, are widespread, particularly in municipal treatment plants. However, they are often ineffective in addressing the increasingly complex chemical and biological contaminants found in Indian water bodies.

Advanced technologies have gradually entered the mainstream, particularly in urban and industrial areas. The most notable features are the following:

- Membrane-based filtration (UF, RO, NF) is widely used in desalination and industrial reuse, but has been criticized for its high energy demands and operational costs.
- AOPs are effective in degrading organic micropollutants, although they are still in the pilot stages in India.
- UV and ozone disinfection have been adopted in select urban systems for chemical-free pathogen removal.
- Electrocoagulation and electrochemical treatment are promising for decentralized treatment, especially in industries such as textiles and tanneries.
- Constructed wetlands and bio-filtration nature-based solutions have gained traction for rural sanitation and urban runoff treatment.

Table 1 presents an overview of the recent water treatment technologies in India.

Table 1. Overview of recent water treatment technologies in India.

Technology	Application area	Benefits	Limitations
Reverse osmosis (RO)	Urban, industrial, desalination	High contaminant removal	High reject water, energy use
UV disinfection	Urban water supply	No chemical residuals	Requires pre-filtration
AOPs (e.g., ozone+H_2O_2)	Industrial effluents	Degrades recalcitrant pollutants	Expensive, complex operations
Electrocoagulation	Rural/Industrial areas	Low sludge generation	Needs stable power, limited scale
Constructed wetlands	Rural sanitation, peri-urban	Low-cost, ecological benefits	Large land area needed

Sources: WHO (2021) [1, 9, 10].

National Water Policy Trends and Programs

India's water governance framework has seen several key policy milestones:

- The National Water Policy (1987, 2002, 2012) emphasized decentralization, conservation, and water pricing but lacked enforceability. The 2012 version includes IWRM and climate change adaptation strategies (MoWR, 2012).
- The Draft National Water Framework Bill (2016) aimed to provide a legally binding national water management structure, but it remains unratified.
- The Jal Jeevan Mission (JJM), launched in 2019, seeks to ensure functional household tap water connections by 2024, focusing on community-based, decentralized treatment models.
- The Namami Gange Mission incorporated in situ water quality monitoring and new wastewater treatment infrastructure along the Ganga River basin.

Despite the policy intentions, the implementation gap remains substantial. Pol (2012) and Iyer (2011) argue that the centralized nature of decision-making and lack of coordination across ministries hinder effective policy deployment. State-level water laws vary widely and often conflict with the national directives [11].

Institutional and Governance Perspectives

Institutional challenges continue to obstruct India's water treatment agendas. Saleth and Dinar (2005) noted the fragmented nature of water institutions and overlapping jurisdictions among central, state, and local bodies. The Mihir Shah Committee (2016) called for institutional restructuring, creating the National Water Commission to integrate surface and groundwater governance [2, 3].

Chowdhury and Behera (2021) highlighted the importance of local institutions in managing traditional water bodies in West Bengal, reinforcing the need for decentralized and culturally rooted approaches [12]. Similarly, Sheth and Iyer (2021) demonstrated successful stakeholder-led water quality initiatives in arid regions of Gujarat [11, 13].

Integration with Climate and Resource Policies

Climate change directly affects water availability and treatment requirements. Wada et al. (2013) showed that human water consumption is a major driver of hydrological droughts [5]. Francés et al. (2017) suggested integrating climate risk assessment with water policy to enhance resilience [14].

India's National Action Plan on Climate Change (NAPCC) includes the NWM, which promotes water use efficiency and conservation. However, critiques by Kumar (2018) argue that technology

adoption under NWM remains uneven, with rural areas lagging in uptake due to a lack of funding and capacity [9].

Gaps in Literature and Practice

While literature covers a wide spectrum of technologies and policies, certain gaps remain:

- Limited empirical studies on the long-term performance of advanced treatment systems in India.
- Scarcity of cost-benefit analyses comparing decentralized and centralized systems in tier-2 and rural areas.
- Few studies have addressed the interlinkage between water pricing and technology adoption at the user level.
- Gender and equity aspects of water treatment access are underexplored.

RESULTS AND DISCUSSION

A review of the existing literature and policy developments reveals several critical insights into how India manages its water treatment landscape at the intersection of technology and governance.

Uneven Technological Penetration

Advanced water treatment technologies are primarily confined to urban municipalities and industrial clusters. Projects under the Smart Cities Mission, such as Pune and Surat, have incorporated membrane-based filtration and IoT-enabled monitoring. In contrast, rural and peri-urban areas primarily depend on outdated or basic methods, such as chlorination or simple filtration, with many regions lacking any treatment facilities [15].

Although the JJM emphasizes decentralized treatment through solar disinfection and biosand filters, its implementation is uneven owing to limited local technical expertise and maintenance support. For example, pilot projects using electrocoagulation in Tamil Nadu showed promise but were discontinued because of operational challenges [16].

Policy-Technology Disconnect

One of the most recurring findings is the disconnection between national policy ambitions and ground realities. While the National Water Policy 2012 promotes IWRM and pollution prevention, enforcement mechanisms remain weak. The Draft Water Framework Bill (2016) still awaits legislative action, reflecting a lack of political prioritization (GOI, 2016) [8]. Similarly, policies that mandate zero liquid discharge (ZLD) for industries have often failed owing to the high cost of compliance and inadequate monitoring. A study by Tingey-Holyoak et al. (2013) highlights that enforcement without capacity building or financial incentives results in non-compliance or superficial adherence.

Institutional Challenges

Lack of institutional coordination remains a major challenge. Different agencies (e.g., Ministry of Jal Shakti, Pollution Control Boards, Urban Local Bodies) often work in silos, leading to duplicated efforts or policy clashes. The Mihir Shah Committee Report (2016) underscored this, calling for a unified National Water Commission that can coherently oversee both surface and groundwater management. At the state and local levels, institutional capacity is uneven. Some states, such as Maharashtra and Gujarat, have developed strong water management frameworks, while others lag due to a lack of political will or budgetary constraints [3].

Community and Decentralized Approaches

Community-led water treatment has emerged as a viable complement to state-led efforts. Case studies from West Bengal and Gujarat show that traditional water bodies and stakeholder engagement can improve water quality outcomes cost-effectively [12]. However, these models remain under supported by formal policies, which tend to favor capital-intensive infrastructure. Integrating such community-

driven initiatives into broader water management plans can enhance resilience, inclusivity, and sustainability.

Climate and Resource Linkages

Climate change impacts on water availability have not yet been fully integrated into most treatment and distribution systems. While the NWM calls for efficiency, actual progress is minimal due to a lack of climate adaptation frameworks within water treatment planning [5, 14].

CHALLENGES AND GAPS

Despite technological advances and progressive water policies, India has faced persistent challenges in the effective treatment and management of its water resources. These challenges are both systemic and localized, cutting across the technical, institutional, and socioeconomic dimensions.

Fragmented Institutional Framework

One of the most pressing challenges is institutional fragmentation in water governance. Multiple agencies at the central and state levels, often with overlapping responsibilities, result in duplication, inefficiency, and policy conflict [2, 3]. There is limited coordination among urban local bodies, State Pollution Control Boards (SPCBs), and water resource departments, severely weakening enforcement and accountability.

Lack of Sustainable Financing

The deployment and maintenance of advanced water treatment systems are capital-intensive. Many municipalities and rural panchayats lack access to sustained funding. Even when capital is available through schemes such as AMRUT or JJM, Operation & Maintenance (O&M) costs are often overlooked, leading to system failure [9, 17].

Technological Incompatibility and Skill Gaps

Imported or high-tech water treatment systems are often unsuitable for Indian conditions, incompatible with existing infrastructure, or too complex for local operators. There is a critical shortage of trained personnel at the grassroots level to manage and maintain these systems [16, 18, 19].

Data and Monitoring Deficiency

Reliable real-time data on water quality and system performance are largely absent or inaccessible. The absence of centralized databases and standard reporting protocols hinders scientific planning and responsive interventions [20, 21].

Social and Equity Barriers

Access to water treatment remains inequitable, especially in marginalized communities and remote villages. Gender dimensions are also poorly addressed, with women bearing the brunt of water insecurity without formal involvement in decision-making [11].

CONCLUSION

India is at a crucial juncture in its water management journey. While the country has made significant strides in recognizing the importance of advanced water treatment technologies and has articulated progressive policy goals, the gap between intent and implementation remains wide. The challenges related to fragmented governance, financial sustainability, technological appropriateness, and social equity continue to hinder progress. However, the growing momentum around decentralized solutions, community engagement, and digital monitoring offers a forward path. Aligning policy frameworks with local needs, building institutional capacity, and fostering inclusive governance are critical for ensuring clean and reliable water access for all. To realize these goals, India must transition from fragmented top-down interventions to integrated, resilient, and people-centric models of water treatment. Only through such a shift can a nation address its current challenges and meet the water security demands of a rapidly urbanizing and climate-vulnerable future.

Recommendations

To bridge the existing gaps in water treatment and align India's policy and practice with the sustainable development goals, the following recommendations are proposed.

Strengthen Institutional Integration

There is a critical need for a consolidated institutional framework that enables synergy among water supply, sanitation, pollution control, and resource management. Establishing a National Water Commission, as proposed by the Mihir Shah Committee (2016), could help streamline efforts by acting as a single coordinating authority across states and sectors [3].

Prioritize Decentralized and Contextual Solutions

Policies should emphasize context-specific, low-cost treatment technologies, especially in rural and peri-urban areas. Solutions such as biosand filters, constructed wetlands, solar disinfection, and local recharge structures have been successful in pilot studies and should be mainstreamed through technical guidelines, financial support, and capacity building [11, 12].

Invest in Training and Human Capital

A large-scale mission-mode program is needed to train local operators, engineers, and technicians in managing modern water treatment infrastructure. This should be integrated with government employment schemes and Public-Private Partnership (PPP) models to improve both sustainability and job creation [16].

Enhance Data Systems and Transparency

The development of a national water quality and treatment dashboard with real-time monitoring, public access, and standardized metrics can significantly improve transparency, regulatory compliance, and citizen engagement. Leveraging IoT and AI-based tools can also help optimize treatment operations [21].

Embed Equity and Community Participation

Women and marginalized groups must be formally included in the planning, implementation, and monitoring of water projects. Building on successful examples of participatory governance can enhance long-term sustainability and local ownership [11, 18].

REFERENCES

1. Balamurugan M, Kasiviswanathan KS, Ilampooranan I, Soundharajan BS. COVID-19 lockdown disruptions on water resources, wastewater, and agriculture in India. Front Water. 2021;3:603531. doi:10.3389/frwa.2021.603531.
2. Saleth RM, Dinar A. Water institutional reforms: Theory and practice. Water Policy. 2005;7(1):1–19. doi:10.2166/wp.2005.0001.
3. Shah M. Water: towards a paradigm shift in the Twelfth Plan. Econ Polit Wkly. 2013 Jan 19;48(3):40-52.
4. Parween F, Kumari P, Singh A. Irrigation water pricing policies and water resources management. Water Policy. 2021;23:130–41. doi:10.2166/wp.2020.147.
5. Wada Y, van Beek LPH, Wanders N, Bierkens MFP. Human water consumption intensifies hydrological drought worldwide. Environ Res Lett. 2013;8(3):034036. doi:10.1088/1748-9326/8/3/034036.
6. Lévesque É, Anctil F, Van Griensven A, Beauchamp N. Evaluation of streamflow simulation by SWAT model for two small watersheds under snowmelt and rainfall. Hydrol Sci J. 2008;53(5):961–76. doi:10.1623/hysj.53.5.961.
7. Pol T. Water Policy leaves a lot to be desired [Online]. DNA India. 2012. Available from: https://www.dnaindia.com/analysis/comment-water-policy-leaves-a-lot-to-be-desired-1655972.

8. Government of India (GOI). Draft National Water Framework Bill. Ministry of Water Resources; 2016.
9. Kumar MD. A critique of Mihir Shah Committee (2016) report on water reforms in India. In: Water Policy Science and Politics. Vol. 1. Elsevier; 2018. p. 83–97. doi:10.1016/B978-0-12-814903-4.00005-1.
10. Tingey-Holyoak JL, Pisaniello JD, Burritt RL, Spassis A. Incorporating on-farm water storage safety into catchment policy frameworks: International best practice policy for private dam safety accountability and assurance. Land Use Policy. 2013;33:61–70. doi:10.1016/j.landusepol.2012.12.011.
11. Iyer RR. National water policy: An alternative draft for consideration. Econ Polit Wkly. 2011;46:201–14.
12. Chowdhury K, Behera B. Institutional dynamics and water resource management: The case of traditional water bodies in West Bengal, India. Int J Water Resour Dev. 2021;38:836–60. doi:10.1080/07900627.2021.1916448.
13. Sheth D, Iyer M. Local water resource management through stakeholder participation: Case study, arid region, India. Water Pract Technol. 2021;16(2):333–43. doi:10.2166/wpt.2021.025.
14. Escribano Francés G, Quevauviller P, San Martín González E, Vargas Amelin E. Climate change policy and water resources in the EU and Spain: A closer look into the Water Framework Directive. Environ Sci Policy. 2017;69:1–12. doi:10.1016/j.envsci.2016.12.006.
15. Suresh S. Intersectoral competition for water between users and uses in Tamil Nadu, India. Front Earth Sci. 2021;9:1–13. doi:10.3389/feart.2021.663198.
16. Mukherji A. Sustainable groundwater management in India needs a water-energy-food nexus approach. Appl Econ Perspect Policy. 2020;44:394–410. doi:10.1002/aepp.13123.
17. Kathpalia GN, Kapoor R. Institutional Structural Changes in the Water Sector. New Delhi: Alternative Futures; 2001.
18. Vyas JN, Nath S. The role of government and the public in water resource management in India. In: Singh P, Singh R, Singh VK, Bhadouria R, editors. Pollutants and Water Management. Hoboken (NJ): Wiley; 2021. p. 339–415. doi: 10.1002/9781119693635.ch16.
19. Rouillard JJ, Benson D, Gain AK. Evaluating IWRM implementation success: Are water policies in Bangladesh enhancing adaptive capacity to climate change impacts? Int J Water Resour Dev. 2014;30(3):515–27. doi:10.1080/07900627.2014.910756.
20. Pawan Jeet, Kumar A, Sundaram PK. Interlinking of rivers: issues and challenges. In: Hromadka TVV II, Rao P, editors. Hydrology. London: IntechOpen; 2020. doi: 10.5772/intechopen.93594.
21. Walmsley N, Pearce G. Towards sustainable water resources management: Bringing the strategic approach up-to-date. Irrig Drain Syst. 2010;24(3–4):191–203. doi:10.1007/s10795-010-9100-z.

