

CLIMATE-RESILIENT WATER INFRASTRUCTURES FOR SUSTAINABLE FOOD, LAND, AND WATER SYSTEMS IN INDIA

INFRASTRUCTURES HYDRAULIQUES RÉSISTANTES AU CLIMAT POUR DES SYSTÈMES ALIMENTAIRES, FONCIERS ET HYDRAULIQUES DURABLES EN INDE

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ABSTRACT

Climate change is intensifying hydrological variability across the Global South, particularly in India, where agriculture, livelihoods, and economic systems remain highly dependent on climate-sensitive water resources. Increasing frequencies of floods, droughts, heatwaves, and compound extreme events are placing unprecedented stress on water infrastructure systems, including dams, irrigation canals, pipelines, reservoirs, urban drainage systems, and hydropower facilities. Existing infrastructure is increasingly unable to cope with changing climatic conditions because many systems were designed using historical hydrological assumptions that no longer reflect future climate realities.

This paper examines the concept of climate-resilient water infrastructure (CRWI) and evaluates its relevance for sustainable food, water, and energy systems in India. The study reviews major climate-induced risks affecting water infrastructure, explores resilience concepts and measurement approaches, and discusses institutional, technological, ecological, and governance pathways for enhancing resilience. Emphasis is placed on irrigation systems, flood management structures, urban water infrastructure, nature-based solutions (NbS), and Managed Aquifer Recharge (MAR) for enhanced resilience. Nature-based Solutions (NbS) together with grey infrastructures are found to provide robust solutions, particularly in management of climatic extremes. Water demand management interventions including efficient water use management, are equally important for climate resilient water systems besides robust supply side interventions.

The paper also highlights policy interventions, integrated water resources management (IWRM), adaptive real-time management systems, and institutional reforms necessary for strengthening climate resilience. It is necessary to plan and upscale such strategies in partnership with potential stakeholders including farmers and NGOs. The study concludes that climate resilience must become an integral component of future infrastructure planning and management in India, requiring coordinated investments in governance, innovation, ecological restoration, and adaptive management.

Keywords: climate resilience, water infrastructure, irrigation, adaptation, India, nature-based solutions, water governance, climate change.

RESUME

Le changement climatique donne lieu à l'intensification de la variabilité hydrologique dans les pays du Sud, en particulier en Inde, où l'agriculture, les moyens de subsistance et les systèmes économiques restent fortement dépendants des ressources en eau sensibles aux effets du climat. La fréquence accrue des inondations, des sécheresses, des vagues de chaleur et des événements extrêmes composés exerce une pression sans précédent sur les infrastructures hydrauliques, notamment les

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barrages, les canaux d'irrigation, les pipelines, les réservoirs, les systèmes de drainage urbain et les installations hydroélectriques. Les infrastructures existantes sont de plus en plus incapables de faire face à l'évolution des conditions climatiques parce que de nombreux systèmes ont été conçus sur la base d'hypothèses hydrologiques historiques qui ne reflètent plus les réalités climatiques futures.

Cet article examine le concept d'infrastructure hydraulique résistante au climat (CRWI) et étudie sa pertinence pour les systèmes alimentaires, hydrauliques et énergétiques durables en Inde. L'étude passe en revue les principaux risques induits par le climat qui affectent les infrastructures hydrauliques, explore les concepts de résistance et les approches de mesure, et discute des voies institutionnelles, technologiques, écologiques et de gouvernance pour renforcer la résistance.

L'accent est mis sur les systèmes d'irrigation, les ouvrages de gestion des inondations, les infrastructures hydrauliques urbaines, les solutions fondées sur la nature (NbS) et la recharge gérée des aquifères (MAR) pour renforcer la résistance. Les solutions basées sur la nature (NbS) ainsi que les infrastructures grises fournissent des solutions robustes, en particulier dans la gestion des phénomènes climatiques extrêmes. Les interventions de gestion de la demande en eau, y compris la gestion efficace de l'utilisation de l'eau, sont tout aussi importantes pour des systèmes d'eau résistants au climat que les interventions robustes du côté de l'offre.

Le document souligne également les interventions politiques, la gestion intégrée des ressources en eau (GIRE), les systèmes de gestion adaptative en temps réel et les réformes institutionnelles nécessaires pour renforcer la résistance au climat. Il est impératif de planifier et de déployer ces stratégies à plus grande échelle en partenariat avec les parties prenantes potentielles, y compris les agriculteurs et les ONG. En fin, l'étude constate la résistance au climat doit devenir une composante à part entière de la planification et de la gestion des infrastructures futures en Inde, nécessitant des investissements coordonnés dans la gouvernance, l'innovation, la restauration écologique et la gestion adaptative.

Mots-clés : Résistance au climat; Infrastructures hydrauliques; Irrigation; Adaptation; Inde; Solutions fondées sur la nature; Gouvernance de l'eau; Changement climatique.

1. INTRODUCTION

Water sector in the global south is facing increased variability and unpredictability because of climate change which is intensifying the water risks. Climate change is altering the hydrological cycle through rising temperatures, changing precipitation patterns, glacier retreat, and more frequent extreme weather events. These changes are creating substantial risks for water infrastructures/systems worldwide, particularly in developing countries where economic systems remain strongly dependent on climate-sensitive sectors such as agriculture and water resources (IPCC, 2021). India is especially vulnerable to climate induced water risks because of its large population, monsoon-dependent agriculture, declining groundwater resources, and rapidly increasing urban and industrial water demand.

The year 2024 was reported as the warmest year on record and the first year in which global average temperatures clearly exceeded 1.5°C above pre-industrial levels (Copernicus Climate Change Service, 2026). Climate projections indicate that warming will intensify hydrological extremes, including floods, droughts, heatwaves, and compound events (IPCC, 2018; IPCC, 2021). These changes pose severe threats to dams, canals, urban water systems, hydropower projects, flood control structures, and groundwater recharge systems and make water management more challenging.

Water infrastructures play a foundational role in supporting agricultural productivity, urban water supply, sanitation, flood protection, drought management, energy production, and ecosystem stability. However, many existing systems were designed based on historical hydrological assumptions that may no longer remain valid under changing climatic conditions (OECD, 2024). Risks are further compounded by inadequate available water storage, old & aging water infrastructures including storage, conveyance and distribution systems, low water use efficiencies, increasing water demand and insufficient integration of climate change and resilience into water management systems.

Climate-resilient water infrastructure (CRWI) refers to systems that are planned, designed, constructed, operated, and managed in ways that enable them to withstand, adapt to, and recover from climate-related shocks and stresses (OECD, 2020). Such systems integrate engineering robustness, adaptive management, environmental sustainability, and institutional resilience.

This paper reviews the concept and significance of climate-resilient water infrastructures/systems with more focus on India. It evaluates major climate-induced risks, resilience concepts and measurement approaches, infrastructure vulnerabilities, governance issues, adaptation pathways, water management imperatives, the role of nature-based solutions together with grey infrastructures and Managed Aquifer Recharge (MAR) for enhanced resilience. The paper also discusses institutional strengthening and policy reforms including partnership with potential stakeholders necessary for achieving sustainable and resilient water systems.

2. WATER INFRASTRUCTURE AND UNDERSTANDING RESILIENCE

Resilience refers to the ability of a system to absorb disturbances, recover from shocks, and adapt to changing conditions while maintaining core functions (IPCC, 2007). In the context of water infrastructure, resilience implies the capacity of systems to continue functioning during and after climate-induced disturbances such as floods, droughts, heatwaves, cyclones, and glacial lake outburst floods.

Several characteristics define resilient infrastructure systems:

- **Diversity:** Multiple water sources and supply pathways reduce dependency on a single source.
- **Redundancy:** Backup systems ensure continuity when one component fails.
- **Flexibility:** Infrastructure operations can adapt to changing conditions.
- **Modularity:** Independent system units reduce cascading failures.
- **Decentralization:** Distributed systems reduce systemic vulnerability.
- **Self-healing capacity:** Systems can detect faults and recover rapidly.

Although resilience and sustainability are closely related concepts, they differ in emphasis. Sustainability focuses on maintaining systems over the long term while minimizing environmental degradation, whereas resilience emphasizes the ability to recover and adapt following disruptions (Mayar et al., 2022).

Measuring Resilience

Measuring resilience remains challenging because resilience is multidimensional and context-specific. Resilience assessments generally consider technological capacity, governance quality, institutional strength, environmental conditions, economic resources, social vulnerability, and adaptive capacity (Carpenter et al., 2010).

Several resilience indices have been developed globally. The Coalition for Disaster Resilient Infrastructure (CDRI) is developing the Global Infrastructure Resilience Index (GIRI), which evaluates infrastructure risks under multiple climate scenarios and hazards such as floods, droughts, and cyclones. Such tools can support evidence-based planning and investment decisions.

3. Climate-Induced Threats to Water Infrastructures

Climate change affects water infrastructure both gradually and suddenly. Long-term warming, altered rainfall patterns, and glacier retreat progressively reduce system performance, while extreme events can cause catastrophic infrastructure failures within hours.

3.1 Flood risks

Floods are becoming more frequent and intense due to increased atmospheric moisture and extreme precipitation events (IPCC, 2021). Floods can overwhelm reservoirs, breach embankments, damage

spillways, erode canal banks, fracture pipelines, and destroy bridges and roads. The 2023 glacial lake outburst flood (GLOF) in the Upper Teesta Basin in India demonstrated the vulnerability of hydropower infrastructure to climate-induced hazards. The event destroyed the Teesta III hydropower project and damaged several downstream structures, causing severe economic and environmental losses. Similarly, the 2018 Kerala floods exposed weaknesses in dam operations, reservoir coordination, and flood forecasting systems.

3.2 Drought and water scarcity

Climate change is increasing evapotranspiration and altering rainfall patterns, thereby intensifying agricultural and hydrological droughts (IPCC, 2021). Droughts reduce reservoir storage, groundwater recharge, hydropower generation, irrigation supplies, and urban water availability. India's agriculture sector consumes nearly 80–85% of total freshwater withdrawals, making irrigation systems highly vulnerable to climate-induced water scarcity (Namara et al., 2023). Haile et al. (2024) projected substantial increases in irrigation water withdrawals under future climate scenarios, particularly in India and South Asia.

3.3 Sedimentation and infrastructure degradation

Higher rainfall intensity, glacier melt, deforestation, and land degradation increase sediment loads in rivers and reservoirs. Sedimentation reduces reservoir storage capacity, impairs hydropower efficiency, blocks canals, and increases flood risk. Many reservoirs in India are losing storage capacity faster than anticipated due to accelerated sedimentation. Infrastructure aging further increases vulnerability because many structures were built decades ago using outdated design standards.

3.4 Urban water infrastructure risks

Urban water systems face multiple climate-related risks, including flooding, water scarcity, sewer overflows, and heat stress. Rapid urbanization and inadequate drainage systems amplify flood risk in Indian cities. Cyclone Fani (2019) disrupted urban water supply systems across Odisha, while extreme rainfall events have repeatedly overwhelmed drainage systems in cities such as Mumbai, Chennai, and Bengaluru.

4. CLIMATE-RESILIENT WATER INFRASTRUCTURE PATHWAYS

The existing and future water infrastructures can be made more resilient if they adapt to the changing circumstances at the right time. Since the future is uncertain, the adaptation programs need to be flexible – they should be able to adapt as the drivers of climate change evolve. The programs should cover a wide range of anticipated climate impacts. Moreover, the adaptation programs should themselves be robust, covering a wide range of anticipated climate impacts.

Promoting CRI will need actions on several interlinked dimensions. Figure 1 highlights the multidimensional actions required to build climate-resilient water infrastructures/systems in India and elsewhere. It underscores six interlinked areas: strengthening laws, policies, and plans; promoting good water governance across scales; adopting integrated water resources management (IWRM); enhancing institutional capacity and skills; upgrading both existing and new infrastructures; and fostering environmental rejuvenation.

Together, these elements provide a comprehensive framework that integrates governance, technical measures, institutional support, and ecological restoration to ensure sustainable and climate-resilient development pathways for the country (Jain et al., 2025).

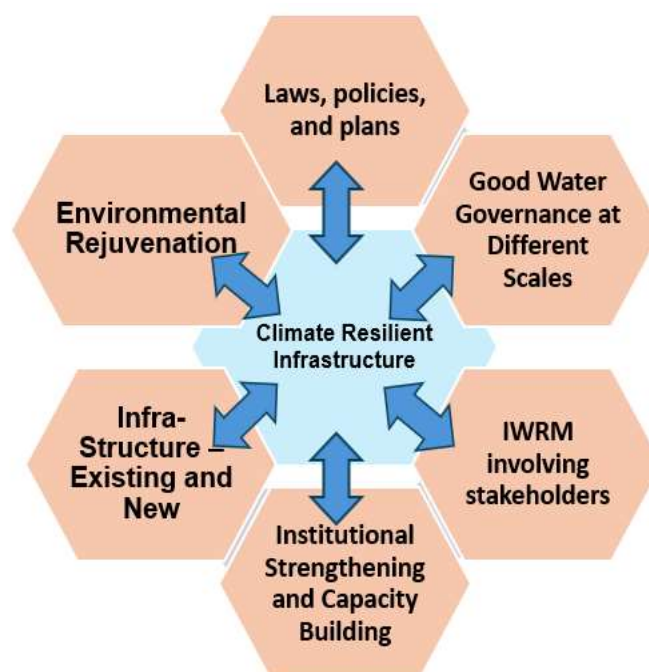


Fig. 1: Actions to develop climate resilient infrastructures and its interlinkages (Source: Jain et al. 2025).

4.1 Irrigation Infrastructure and Climate Resilience

Irrigation is central to India's food security and rural livelihoods. Irrigated agriculture supports higher crop productivity, stabilizes production under climate variability, and reduces poverty (Namara et al., 2023). Irrigation systems face multiple climate-related vulnerabilities, and these include canal breaches during intense rainfall events, reservoir sedimentation reducing storage capacity, reduced water availability during droughts, waterlogging and salinity due to inadequate drainage, damage from floods and soil erosion, and increased evapotranspiration due to rising temperatures. These climate-induced disruptions in irrigation systems directly affect agricultural productivity and food security.

Irrigation infrastructure is increasingly stressed by climate variability, widening supply-demand gap, groundwater depletion, and inefficient water use. Building climate-resilient irrigation systems require strengthening existing infrastructures including their management, modernization and new investments, while managing water demand and supply more efficiently and ensuring long-term sustainability.

4.2 Managing water demand in agriculture

Agriculture in India consumes about 83% of freshwater withdrawals and irrigation efficiency is low (34-38%). As diversion of freshwater to agriculture in future is likely to reduce due to competing demands from other sectors, water demand management is becoming critical for climate resilient water systems, especially when supply side augmentation is limited. Enhancing supply to and Storage of existing water infrastructures is constrained so the resilience can come largely from effective operation and management of the existing systems focused on efficient use and demand management. Governments, both federal and provincial in India, have many programs and policies in place that focus on demand management strategies.

Potential strategies in practice and needing more strengthening include improving water use efficiency at irrigation system level (both on and off farm), crop diversification to less water consuming crops, rationalized cropping patterns rooted to local conditions, drought tolerant crop varieties, modernization of irrigation systems to reduce non-beneficial water losses and promote precision irrigation, and soil-

moisture sensors based irrigation scheduling including application of irrigation demand forecasting and use of artificial intelligence (Sikka et al, 2022). Modernization of irrigation projects in India has demonstrated positive and encouraging results in this direction by increased water use efficiency and water productivity. While planning and designing improvements in water productivity, it has been found that the focus in water stressed areas should be on enhancing economic water productivity. Whereas improving physical water productivity of the crops/farming systems be emphasized in other areas (Amarasinghe et al, 2021).

4.3 Enhanced surface and groundwater recharge

India's per capita water storage capacity remains substantially lower than that of countries such as China and the United States. Expanding, managing and modernizing storage infrastructure, both surface and groundwater storages, therefore remains critical for climate adaptation. Emphasis on both large and small storages including rainwater harvesting and conservation as being scaled up by the Government of India through its catch the Rain program together with integrated and coordinated storage management is to be prioritized. Managed aquifer recharge, rainwater harvesting, and decentralized storage systems can improve water availability during dry periods. Non-conventional water resources and wastewater recycling and use including water circularity need greater emphasis to augment conventional water supply.

4.4 Managed aquifer recharge for building resilience

Managed aquifer recharge (MAR) has emerged as a critical strategy for climate adaptation and building resilient water systems in India, increasingly recognized as a nature-based solution (NbS) that works with natural hydrological processes to enhance water security (Sikka et al., 2020). By replenishing aquifers during periods of surplus surface water, MAR strengthens the buffering capacity of groundwater systems against the growing variability in rainfall and the increasing frequency of droughts, providing farmers and communities with a more reliable water source during dry spells and lean seasons. Given groundwater's unique storage characteristics including minimal evaporation losses, vast storage capacity, and relative insulation from short-term climatic fluctuations, investing in MAR as a component of climate-resilient water infrastructure offers significant advantages over surface storage alone (Alam and Pavelic, 2020). India has championed MAR through multiple national schemes and programs, and there is clear scope for further scaling across diverse hydrogeological settings, from the hard rock aquifer regions of peninsular India to the productive alluvial aquifers of the Indo-Gangetic Plain, where the prerequisites of available aquifer storage, surplus recharge water, and demand for recovered water are widely met (Sikka et al., 2020; Alam et al., 2025).

Beyond augmenting dry-season water availability, MAR can also serve as an integrated flood and drought management tool, simultaneously addressing two of the most damaging climate extremes. Approaches such as Underground Transfer of Floods for Irrigation (UTFI) exemplify this dual function by strategically harvesting and storing excess monsoon floodwater underground, converting what would otherwise be a flood risk into a groundwater resource available for irrigation during the dry season (Alam and Pavelic, 2020). This transforms MAR from a purely supply-side intervention into a broader climate resilience strategy, capable of moderating hydrological extremes at the river basin scale while sustaining agricultural productivity. However, realizing this potential requires MAR to be pursued not in isolation but as part of an integrated approach that combines enhanced recharge with demand-side strategies including improved irrigation efficiency, crop diversification, and robust water governance frameworks.

4.5 Real-Time Adaptive Infrastructure Management

Traditional water infrastructure operations rely heavily on historical hydrological records. However, climate uncertainty requires adaptive and forecast-based management approaches. Real-time management systems integrate weather forecasts, hydrological models, reservoir operations, and demand forecasts to optimize water releases and storage decisions. Although the optimum releases are determined for a finite number of future time periods, they are implemented only for the immediate next

time period. After this period, the next set of observations becomes available, and the entire process is repeated. Adaptive feedback control systems can significantly improve operational resilience under uncertain climatic conditions Fig 2).

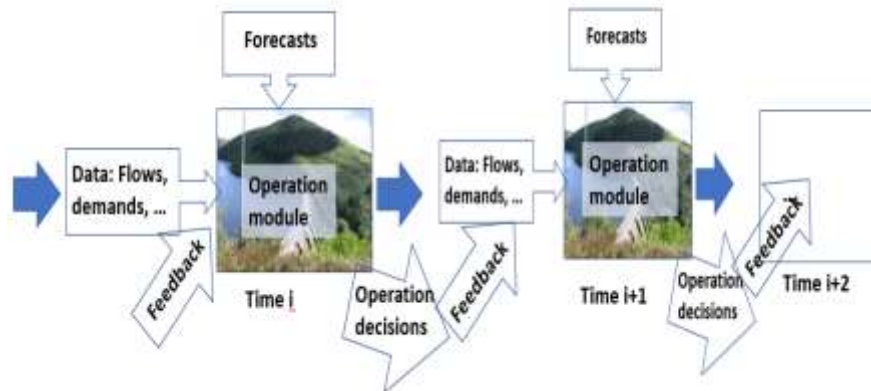


Figure 2. Adaptive feedback control of water-infrastructure using inflow forecasts

4.6 Integrated Water Resources Management

IWRM recognizes that water resources are an integral component of the ecosystem; in addition, water is a natural resource, and a social and economic good. Integrated Water Resources Management (IWRM) promotes coordinated management of water, land, and related resources to maximize economic and social welfare without compromising ecosystem sustainability (Biswas, 2008). It seeks to integrate the management of the physical environment within that of the broader socio-economic and political framework. Adaptive IWRM approaches are increasingly important because climate uncertainty requires flexible and iterative management systems. Basin-scale planning, stakeholder participation, and cross-sectoral coordination are critical for resilient water governance.

With the adoption of the SDGs and recognition of the potential for IWRM, the expectation from IWRM is now much bigger to address multiple scales and multiple stakeholders including local priorities than before to deliver at larger basin scale. Vertical integration has therefore become critical for implementing IWRM as an adaptive strategy. Addressing multiple scales (basin to sub-basins and below where action happens) and multiple stakeholders with many uncertainties and unknowns would require adaptive strategy for change in water resources management for development in a decentralized manner. Integration across scales is critical for ensuring that lessons from local action provide evidence and energy for reform processes, and such vertical integration is critical for implementing IWRM as an adaptive strategy.

4.7 Nature-Based Solutions and Hybrid Infrastructure

Nature-based solutions (NbS) are actions that protect, restore, or sustainably manage ecosystems while addressing societal challenges such as climate adaptation, flood control, and water security (OECD, 2020). NbS differ from conventional gray infrastructure because they are adaptive, regenerative, and multifunctional. They also provide co-benefits such as biodiversity conservation, groundwater recharge, carbon sequestration, and livelihood support.

Restoring floodplains allows rivers to store excess floodwater naturally, thereby reducing downstream flood risk (World Bank & WRI, 2022). Depleted aquifers can be used to store excess floodwater, as demonstrated by IWMI's Underground Transfer of Floods for Irrigation (UTFI) program (Alam et al., 2025). Integrating aquifer recharge with reservoirs enhances water availability, moderates floods, and improves sustainable water management. Urban wetlands, permeable pavements, and green roofs

reduce stormwater runoff and urban flooding while improving groundwater recharge. Mangroves, coral reefs, and coastal wetlands reduce storm surges, coastal erosion, and cyclone impacts. The Bhitarkanika mangrove ecosystem in Odisha demonstrated significant protective benefits during Cyclone Dana in 2024.

NbS should not be viewed as replacements for engineered infrastructure but rather as complementary systems. **Hybrid infrastructure** combining gray and green (Nbs) approaches can improve resilience while reducing long-term maintenance costs. For example, integrating scientifically designed and community-based watershed restoration program with dams can reduce sedimentation, improve water quality, and extend reservoir life.

4.8 Managed Retreat and Adaptive Strategies

Managed retreat refers to the planned relocation of people and infrastructure away from high-risk areas vulnerable to floods, sea-level rise, and coastal erosion (Jain and Karmakar, 2022). India's long coastline and rapidly urbanizing coastal cities face increasing risks from sea-level rise and storm surges. Cities such as Mumbai, Chennai, Kochi, and Visakhapatnam are particularly vulnerable. Temporary evacuation strategies are already widely used during cyclones and floods in India. However, long-term managed retreat may become necessary in highly vulnerable coastal and floodplain regions. International examples such as the Netherlands' "Room for the River" program demonstrate how strategic relocation and floodplain restoration can improve resilience.

5. POLICY, GOVERNANCE AND REGULATORY FRAMEWORKS

Mainstreaming climate resilience in water infrastructure requires enabling laws, policies, and institutional mechanisms. India has introduced several policy initiatives relevant to climate-resilient water infrastructure. The National Water Policy (2012) emphasizes integrated water resources management, water-use efficiency, and basin-scale planning. The Dam Safety Act (2021) established institutional mechanisms for dam surveillance, inspection, and risk management. The Dam Rehabilitation and Improvement Project (DRIP) further aim to enhance dam safety and operational performance. Programs such as the Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), Modernization of Command Area Development (MCAD), and MGNREGS also contribute to resilience by supporting water conservation, agricultural water management, irrigation modernization, and watershed management.

Urban resilience is advanced through initiatives like the Atal Mission for Rejuvenation and Urban Transformation (AMRUT and AMRUT 2.0), which focus on water supply and recharge infrastructure in statutory towns. Rural resilience is supported by the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), which incorporates water conservation and water harvesting structures.

However, policy fragmentation remains a major challenge. Water, agriculture, energy, urban development, and environmental programs often operate independently with limited coordination. Multiple programs in water, food, energy, and environment sectors often function in silos, with limited coordination (Jain et al., 2023). A Nexus approach—ensuring policy coherence, reducing duplication, and enhancing synergies across sectors—can significantly improve outcomes for climate-resilient water infrastructures/systems. It is important to strengthen institutional frameworks by ensuring that water management policies incorporate climate resilience principles by revising existing policies. In sum, India has established a robust legal and programmatic foundation for CRI, but strengthening interlinkages, updating the National Water Policy, and ensuring coherent implementation across scales are necessary steps to enhance resilience in the face of accelerating climate risks.

Good governance is fundamental for resilient infrastructure systems. Effective governance requires:

- Coordination across institutions and sectors
- Transparent decision-making

- Efficient dispute resolution
- Reliable financing mechanisms
- Capacity building and technical expertise
- Stakeholder participation

Institutional fragmentation remains a major obstacle in India's water sector. Strengthening river basin organizations and improving coordination between state and national agencies are essential.

Financing is another critical challenge. Currently, most CRI investments are publicly funded, with public utilities, private actors, and international organizations increasingly contributing to infrastructure development and management. Public investment alone may be insufficient to meet future infrastructure requirements. However, sustainable financing requires reforms in pricing and resource allocation. Innovative financing mechanisms, including green bonds and public-private partnerships, can support climate-resilient investments.

6. FUTURE DIRECTIONS FOR CLIMATE-RESILIENT WATER INFRASTRUCTURE

Future climate-resilient water systems in India will require integrated technological, ecological, institutional, and social approaches.

Key priorities include:

- Modernizing aging infrastructure through rehabilitation and climate-proofing.
- Expanding storage systems using both surface and subsurface approaches, and integrated storage management.
- Water demand management for efficient, wise and rational use of water
- Improving forecasting systems using remote sensing, GIS, and artificial intelligence.
- Strengthening hydrometeorological monitoring networks.
- Mainstreaming climate risk assessment into infrastructure planning.
- Promoting decentralized and modular systems.
- Integrating nature-based solutions with gray infrastructure.
- Enhancing research and development investments in resilient water systems
- Building institutional and technical capacities.
- Improving stakeholder participation and community engagement.

Climate resilience is not to be treated as one-time process but should become a continuous process of learning, adaptation, monitoring, and transformation.

7. CONCLUSION

Climate change is altering hydrological systems and exposing water infrastructure to unprecedented risks. Floods, droughts, sedimentation, sea-level rise, heatwaves, and compound extreme events increasingly threaten irrigation systems, dams, urban water networks, hydropower facilities, and flood-control structures across India.

Climate-resilient water infrastructure offers a critical pathway for ensuring sustainable food, water, and energy security in the face of growing climatic uncertainty. Building resilience requires more than engineering upgrades alone. It demands integrated governance, adaptive management, institutional strengthening, real-time monitoring, ecosystem restoration, and stakeholder participation.

Nature-based solutions provide promising opportunities for enhancing resilience while generating environmental and social co-benefits. Similarly, adaptive management systems and integrated water resources management approaches can improve the flexibility and responsiveness of infrastructure systems. India has already established important policy foundations through initiatives such as the National Water Policy, DRIP, PMKSY, and the Dam Safety Act. However, stronger coordination,

increased investment in research and innovation, improved governance mechanisms, and climate-informed infrastructure planning remain essential.

Ultimately, resilience should be viewed as a dynamic and continuous process rather than a fixed outcome. Climate-resilient water infrastructure will play a central role in protecting livelihoods, sustaining ecosystems, ensuring food security, and supporting long-term socio-economic development in India.

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