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Research Article

Conceptualizing Micro Water Resource Development Plan for Strengthening River Rejuvenation in India

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ABSTRACT

The national water policy of India emphasizes on sustainable water resource development for ensuring food security. In this context, we need to give priority to protect our surface and groundwater resources and efforts must be made to create or renovate the water bodies for enhancing the water storage capacity. Large dams contribute significantly to water storage and irrigation in India. However, they affect the environmental flow of the rivers which is widely sensitized among different stakeholders around the world in recent years. Keeping this in consideration, an attempt is made in this paper to suggest measures and plan for policy support for scenario-wise development of micro water resources in place of some proportion of large dams as an alternative source of water storage for strengthening river rejuvenation. This study provides concept and suggests the methodology for strengthening the national imperative to augment water storage capacity by 2047 by conducting a comparative analysis of contrasting development pathways. It evaluates four scenarios for creating an additional 66 to 94 billion cubic meters (BCM) of storage, ranging from 100% reliance on large dams to a 75% focus on decentralized Micro Water Resources (MWR).

Key words: Micro water resources, River rejuvenation, Large dams

Introduction

Water resource management plays a vital role in sustainable crop production. The management of both surface and groundwater resources is crucial for ensuring food security of India. However, indiscriminate use of water resources has resulted in water stress, which is more acute in some Indian states. The per capita water storage and per capita water availability have been declining due to stagnant water resources and ever-increasing population. The average annual per capita water availability was assessed as 5177 m^3 in the year 1951 which declined to 1816 m^3 in the year 2001 and further to 1544 m^3 in the year 2011 and presently to 1335 m^3 (based on population of 1.4 billion). Similarly, the per capita water storage of India needs to be enhanced from the current level. Hence, we need to intensify our efforts to develop irrigation infrastructure in the form of creation or revival of water bodies, large dams and micro water resources. Enhancing the water use efficiency from current level of 40% to target of 70% by the year 2047 requires integrated efforts in the form of increasing the per capita water storage through dams and micro water resource development, reducing conveyance losses in canal commands, groundwater recharge techniques and expansion of micro irrigation in different potential states of India.

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Benefits of large dams

Large dams are those dams whose height is 15 meters or greater from lowest foundation to crest or a dam between 5 meters and 15 meters impounding more than 3 million cubic meters. Large dams were designed to harness river waters for critical functions such as irrigation for agriculture, generation of clean hydroelectric power, flood control, and providing a stable water supply for a growing population. This engineering-led approach propelled India to become the world's third-largest dam builder, with a hydropower capacity of approximately 46,865 MW in 2023, accounting for about 11% of the country's total power generation capacity.

Negative effects of large dams

This paradigm of development has been increasingly contested due to its significant and often irreversible negative externalities. Ecologically, the construction of large dams has resulted in widespread habitat destruction, fragmentation of river ecosystems, loss of biodiversity, and disruption of animal migration routes. The social costs have been equally profound. Dam projects have led to the displacement of huge people in the project site. Studies indicate that while downstream districts may see an increase in agricultural productivity, the districts where dams are located often experience a rise in rural poverty. Owing to the large surface area, the world's reservoirs lose about 170 cubic kilometers of water to evaporation every year, the equivalent of 7% of all freshwater consumed by human activities (Arora, 2024).

Impact of large dams on environmental flow of rivers

At the heart of the ecological critique is the concept of Environmental Flow (E-flow), defined as the quantity, timing, and quality of water flow required to sustain freshwater ecosystems and the human livelihoods that depend on them. Large dams are the primary disruptors of E-flow. By impounding water and altering natural flow regimes, they fundamentally change the river's hydrology, sediment transport, and temperature, which are critical triggers for aquatic life cycles. This disruption severely impacts the ecological integrity of rivers, diminishes their self-purifying capacity, and leads to the degradation of downstream deltas and floodplains. Hoque *et al.* (2022) reported that the construction of dams and barrages under the Damodar Valley Project have significantly altered the flow duration, flood frequency, and magnitude, which has further threatened aquatic organisms, especially fish diversity and community structure. Mineda *et al.* (2023) noticed that compared with climate change, dams altered most environmental flow metrics. Randell (2022) reported that the large irrigation dams have proven extremely costly in terms of their social and ecological impacts. Owusu *et al.* (2020) emphasized on the need for re-operating existing dams for ensuring restoration of ecosystems and ecosystem services that have already been affected by the construction and operation of large dams.

Recognizing this, the Government of India has initiated policy responses, including the 2018 notification mandating minimum E-flows for the Ganga River and a directive from the National Green Tribunal for states to maintain a minimum environmental flow of 15-20% of the average lean season flow in their rivers. These policies signal a growing acknowledgment that the health of a river is a prerequisite for, not a casualty of, sustainable development.

Need for design of alternative plan

The need for restoration of natural river functions to build ecological and climate resilience is being felt in the recent years throughout the globe and it is intensely evident in Europe which experienced removal of 542 barriers across 23 nations in 2024, resulting in reconnecting over 2,900 km of rivers, demonstrating a continental commitment to reviving waterways. The EU Nature Restoration Regulation, for instance, sets an ambitious target to restore at least 25,000 km of fragmented rivers to a free-flowing state by 2030, primarily through barrier removal.

Reconnecting rivers has been shown to strengthen climate resilience, enhance water and food security, reverse biodiversity loss, restore natural sediment and nutrient flows, and build resilience to floods. In this context, India needs to take initiative for strengthening river rejuvenation through reducing the proportion of large dams in future and to look at alternative options for creating additional water storage in the form of micro water resources.

Tremendous Potential of Micro Water Resources (MWR)

As an alternative to the capital-intensive and socially disruptive model of large dams, Micro Water Resources (MWR) offer a promising pathway. MWR are defined as decentralized, small-scale irrigation and water storage systems, typically with a culturable command area (CCA) of up to 2,000 hectares. This category includes a wide range of structures such as traditional tanks, ponds, check dams, and other rainwater harvesting projects. The inherent advantages of MWR are significant: they have comparatively short completion periods, require lower capital investment, and involve minimal challenges related to land acquisition and population rehabilitation. Furthermore, their distributed nature makes them highly suitable for exploiting small catchments and for conjunctive use with groundwater, helping to recharge local aquifers and stabilize water tables.

The potential of MWR is not merely theoretical; it is being actively demonstrated through large-scale government initiatives. The flagship Mission Amrit Sarovar, launched in 2022 as part of the Azadi Ka Amrit Mahotsav celebrations, exemplifies this approach. The mission's primary objective is to develop and rejuvenate at least 75 water bodies in every district of India, with an initial nationwide target of 50,000 such "Amrit Sarovars". The mission has been remarkably successful, exceeding its initial target by completing over 68,000 Sarovars as of early 2025. A core objective of the mission's success is its emphasis on community participation (Jan Bhagidaari), empowering local communities and Gram Panchayats (village councils) in the planning, execution, and maintenance of these water bodies. This approach provides a robust proof of concept for the feasibility of implementing MWR at a national scale, presenting a viable and sustainable alternative for achieving India's water storage goals.

State-wise and Basin-wise Distribution of Existing Water Storage

Under this backdrop of conceptualizing an alternative plan of MWR, we need to analyze the present status of India's water storage infrastructure, which is dominated by large dams. According to the National Register of Large Dams (NRLD), as of 2023, there are 5,334 completed large dams in the country, with an additional 411 under construction. The total gross storage capacity of these completed dams is approximately 332,361 Million Cubic Meters (MCM), or 332 BCM.

However, the distribution of this critical infrastructure is highly concentrated, reflecting historical development patterns and geographical suitability. A few states host the vast majority of these structures. As shown in Table 1, Maharashtra alone accounts for over 40% of the country's large dams (2,117), followed by Madhya Pradesh (899) and Gujarat (620). In contrast, many states, particularly in the northeast, have very few large dams. This unequal distribution has significant implications for regional water security and equity, as states with fewer large storage structures are more vulnerable to hydrological variability. This existing imbalance underscores the need for a more distributed and equitable approach to future water storage development, a role that MWR is well-suited to fill.

Table 1. State-wise Distribution of Existing Large Dams and Gross Storage Capacity in India

State/UT	Number of Constructed Large Dams	Gross Storage Capacity (MCM)
Maharashtra	2117	50,474.81
Madhya Pradesh	899	35,311.77
Gujarat	620	32,134.26
Chhattisgarh	249	8,982.92
Karnataka	230	37,309.96
Rajasthan	204	16,515.74
Odisha	200	32,529.84
Andhra Pradesh	149	15,920.15
Telangana	168	20,077.36
Tamil Nadu	118	7,195.99
Uttar Pradesh	117	19,058.12
Jharkhand	55	5,881.91
Other States/UTs	391	50,968.63
Total	5334	332,361.46

Note: Data is compiled from the National Register of Large Dams

Concept and Methodology for Scenario classification for Augmenting Storage Capacity by 2047

Scenario planning is a widely used approach for dealing with high levels of uncertainty in water resource management. With an objective of reducing the negative effect of large dams on environmental flow of the rivers which is widely sensitized among different stakeholders in world in the recent years, an attempt is made in this paper to provide concept and methodology for suggesting policy options for scenario wise development of micro water resources in place of some proportion of large dams as alternative source of water storage for strengthening river rejuvenation. This study aims at augmenting water storage capacity of India by the year 2047 (the centenary year of India's independence (Amrit Mahotsav). by conducting a comparative analysis of contrasting development pathways covering four different scenarios.

To analyze the strategic choices for meeting India's future water storage needs, the suggested study aims at evaluating eight distinct scenarios based on the two augmentation targets (66 BCM and 94 BCM) and a varying mix of large dams and MWR. These scenarios are designed to model a spectrum of policy pathways, from a business-as-usual, dam-centric approach (Scenario 1) to a transformative, MWR-focused strategy (Scenario 4). The justification for these targets is rooted in national policy timelines (Azadi Ka Amrit Mahotsav) and historical precedent, providing a robust and relevant basis for projection. For each target, four distinct scenarios were developed, representing a gradient of investment from 100% reliance on large dams to 75% reliance on MWR. This structured approach allows for a systematic evaluation of the trade-offs associated with different policy choices.

A. Total storage capacity through dams in India: 332 BCM; If India targets to increase the water storage capacity by 20% its existing full capacity by 2047 (Amrit Mahotsav year) = 66.4 BCM = 66 BCM

Scenario 1: 100% of 66 BCM through large dams

Scenario 2: 75% of 66 BCM through large dams (49.5 BCM) and 25% through MWR (16.5 BCM)

Scenario 3: 50% of 66 BCM through large dams (33 BCM) and 50% through MWR (33 BCM)

Scenario 4: 25% of 66 BCM through large dams (16.5 BCM) and 75% through MWR (49.5 BCM)

B. If India targets the construction of large dams at the annual growth rate (4.26 BCM per year during 1947-2025) by 2047 (Amrit Mahotsav year): 94 BCM

Scenario 1: 100% of 94 BCM through large dams

Scenario 2: 75% of 94 BCM through large dams (70.5 BCM) and 25% through MWR (23.5 BCM)

Scenario 3: 50% of 94 BCM through large dams (47 BCM) and 50% through MWR (47 BCM)

Scenario 4: 25% of 94 BCM through large dams (23.5 BCM) and 75% through MWR (70.5 BCM)

Meeting these abovementioned targets requires a strategic choice between continuing the historical reliance on large dams and embracing alternative, decentralized approaches. Hence, there is an urgent need to conceptualize the design and composition of micro water resources in major river basins of India which may be achieved through multi-institutional research project (ICAR-Indian Agricultural Research Institute, New Delhi as Lead Centre). The analytical framework of this study is built upon a multi-disciplinary approach, integrating hydrological assessment, scenario planning, economic analysis, and geospatial techniques to provide a comprehensive comparison of large dam and MWR development pathways. This will help in performing a scenario-based comparative analysis of large dams versus MWR for meeting India's 2047 water storage augmentation targets of 66 BCM and 94 BCM and in evaluating the relative economic, ecological, and social costs and benefits associated with each development pathway. At the same time, it will also help in assessing the alignment of these scenarios with national goals for river rejuvenation, climate resilience, and sustainable development and exploring the synergistic potential of integrating MWR with other sustainable technologies, such as renewable energy and efficient irrigation, to strengthen the water-energy-food nexus.

Socio-economic benefits of alternative plan

The higher proportion of micro water resources in alternative plan is expected to result in significant socio-economic benefit as it has huge potential for economic savings for the nation and serving the farmers with better equity of newly created / stored water resources. Large dams are characterized by extremely high upfront capital costs and a history of significant time and cost overruns. While econometric analyses suggest they can be marginally cost-effective in increasing downstream agricultural productivity, they involve huge initial costs. In contrast, MWR projects involve smaller, distributed investments that can be implemented more quickly and often have higher economic rates of return, especially when considering benefits like groundwater recharge and local food security. The farmers in tail end regions of canal commands in India generally experience lesser access to water resources compared to head and mid regions which is matter of concern. However, micro water resources will ensure better equity a they will be designed in several pockets covering all the sections of the farmers.

Furthermore, a focus on MWR directly contributes to achieving several of the United Nations Sustainable Development Goals (SDGs). Most prominently, it supports SDG 6 (Clean Water and Sanitation) by improving local water availability, enhancing groundwater recharge, which secures drinking water sources, and promoting community-based water management. The model of community participation (Jan Bhagidaari) central to MWR implementation strengthens local governance (SDG 16) and empowers women, who often bear the primary responsibility for water collection (SDG 5). By providing a reliable water source for agriculture, MWR also contributes to food security (SDG 2) and boosts rural livelihoods (SDG 8). This multi-faceted contribution makes MWR a highly effective tool for advancing a holistic sustainability agenda.

Conclusion

The large dams will continue to play a role in India's water infrastructure portfolio, a strategic and scaled-up investment in Micro Water Resources (MWR) offers a more resilient, equitable, and sustainable path forward. The suggested concept and methodology for the scenario-wise analysis and design and composition of river basin-wise MWR will provide a clear, science-based foundation for reorienting India's water management strategy aligning with national ambitions and global sustainability commitments. The suggested concept helps in optimal blending of large-scale engineering with nature-based solutions and top-down planning with bottom-up community action, which is essential for securing India's water future aligning with the sustainability development goals (SDGs) of United Nations.

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