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Balkaran Kumar
Research Scholar, University Department of Economics, TM Bhagalpur University, Bhagalpur, Bihar, India

Corresponding Author:
Balkaran Kumar
Research Scholar, University Department of Economics, TM Bhagalpur University, Bhagalpur, Bihar, India

Water resources management and quality monitoring in Bihar: Challenges, Infrastructure and Sustainable Initiatives

Balkaran Kumar

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Abstract
Water resources are fundamental to Bihar's socio-economic development, sustaining drinking water needs, agriculture, industry, and rural livelihoods. This study examines Bihar's extensive surface and groundwater resources, relying on the Gangetic Plains' river systems including the Ganga, Gandak, Kosi, Sone, and others. The research highlights the state's diverse water infrastructure such as canals, reservoirs, tubewells, tanks, and lift irrigation, emphasizing their critical role in irrigation and water management. The distribution and management of water bodies in both rural and urban areas are analyzed using recent census data. Ensuring water quality remains a major challenge due to chemical contamination by arsenic, fluoride, and iron, which affects millions in rural Bihar. The Public Health Engineering Department's comprehensive water quality monitoring protocol and surveillance system, combined with field-level initiatives and capacity building efforts, are key responses to this crisis. Further, the paper reviews major initiatives by the Department of Water Resources including the Ganga Jal Apurti Scheme, Tal Development Plan, rubber dam constructions, river inter-linking projects, and flood management programs. These projects aim to restore ecological balance, augment water availability, improve irrigation, and enhance flood resilience. The study underscores the holistic approach taken by Bihar to address water quantity and quality issues through infrastructural development, environmental conservation, and community participation. This integrated water resource management is essential for Bihar's climate adaptation, sustainable growth, and improved public health.

Keywords: Water resources, water quality monitoring, irrigation infrastructure, river inter-linking, flood management

1. Introduction
Water is the lifeblood of Bihar's economy and environment, underpinning agriculture, industry, and human well-being in a state where over 85% of the population depends on farming (Yadav, 2020) [7]. Spanning the fertile Gangetic Plains, Bihar's water resources comprise an intricate network of surface and subsurface systems. Major rivers including the Ganga, Gandak, Kosi, Sone, and their tributaries are fed by the south-west monsoon, replenishing both canals and groundwater aquifers. Yet, this abundance is tempered by pronounced seasonal variability: monsoon deluges trigger destructive floods that affect more than 70% of Bihar's landmass annually, while pre-monsoon dry spells strain irrigation and drinking supplies (Sinha *et al*., 2012; Sharma, 2019) [4, 6].
Compounding these quantity challenges, water quality concerns pose serious public health risks. Extensive testing has revealed that over 30,000 rural wards are afflicted by chemical contamination primarily arsenic, fluoride, and iron exposing nearly 4.8 million households to unsafe water and heightening the burden of waterborne diseases (Singh *et al*., 2021; Kalra *et al*., 2012) [5, 2]. In response, the government has established a multi-tiered monitoring network of laboratories and field test kits, aiming to detect and remediate contamination swiftly. Nonetheless, infrastructure gaps persist: although 968 canals irrigate 2.76 million hectares and nearly 46,000 distinct water bodies are recorded across the state, only half of Bihar's cultivable area currently receives dependable irrigation (Department of Water Resources & Department of Minor Water Resources, Government of Bihar, 2023).

This study synthesizes secondary data from the Bihar Economic Survey, departmental reports, and the First Census Report on Water Bodies to assess the extent and efficacy of existing water resource infrastructure, water quality management protocols, and recent policy interventions. By examining both the spatial distribution of water assets and the institutional frameworks governing their use, the research aims to identify strategies that integrate infrastructural development, community-based management, and ecological conservation. The goal is to inform resilient, sustainable water governance that can withstand Bihar's climate pressures while equitably meeting agricultural, industrial, and domestic needs.

2. Review of Literature

- **Water quality assessment and contamination studies:** Kumar *et al*. (2025) [3] conducted a comprehensive assessment of groundwater quality in Patna district using the Water Quality Index (WQI) method, specifically the Canadian Council of Ministers of the Environment approach. Their study analyzed secondary data from 2004-2020 to evaluate physicochemical parameters and spatial-temporal trends. Results indicated that while most samples fell within permissible limits, some locations showed elevated pH, electrical conductivity, hardness, alkalinity, chloride, and nitrate levels, suggesting localized contamination from natural and anthropogenic sources. The study found that 76% of samples were categorized as fair to excellent, while 24% were marginal to poor, highlighting the need for regular monitoring and sustainable groundwater management to ensure safe drinking water access.
- **Arsenic Contamination and Health Risk Assessment:** Singh *et al*. (2021) [5] investigated arsenic exposure in the Indo-Gangetic plains of Bihar, focusing on the Ganga-Meghna-Brahmaputra basin. Their research revealed that out of 38 districts in Bihar, 18 districts reported high arsenic contamination in groundwater, affecting over 80% of rural drinking water sources. The study found that while older alluvium surfaces were relatively free from hazardous arsenic levels, the flood plain surfaces contained several localized pockets with arsenic concentrations ranging from 50 to over 500 µg/L. The research identified specific depth control mechanisms where aquifers within the 12-75 meter depth range were yielding arsenic, emphasizing the geomorphological and depth-related factors controlling arsenic occurrence in the region.
- **Irrigation Infrastructure and Water Resources Development:** Yadav (2020) [7] examined the development of Bihar through irrigation management, highlighting that the state's irrigation schemes are classified into major, medium, and minor categories. The study noted that Bihar has 27 major and 163 medium completed irrigation schemes, with another 19 major and 31 medium schemes under construction. Despite having about 40,000 minor surface irrigation works and extensive groundwater infrastructure including 600,000 shallow tube wells, Bihar's gross irrigated area of around 50% remains relatively low compared to other states. The research emphasized the potential for participatory irrigation management and the need for conjunctive use of surface and groundwater resources to enhance water use efficiency and achieve sustainable agricultural development.
- **Institutional Framework for Flood Management: Sinha *et al*. (2012) [4]:** Conducted a comprehensive study on strengthening the institutional framework for flood and water resources management in Bihar. Their research identified that Bihar is one of the five most flood-prone states in India, with floods affecting about 6.88 million hectares of land out of 9.416 million hectares (73.06%). The study revealed significant institutional challenges undermining Bihar's ability to cope with annual floods, including decision-making deficits, inadequate staff skills, and delays in maintenance. The research emphasized that structural measures alone are insufficient and recommended integrated approaches combining structural and non-structural measures, including floodplain management policies and improved institutional performance.
- **Sustainable Water Resource Development and Management:** Sharma (2019) [6] analyzed sustainable water resource development in East Champaran district of Bihar, emphasizing the role of natural resource management in national development. The study highlighted that Bihar faces significant environmental challenges due to climate change, affecting water resources, agriculture, food security, and human health. The research noted that Bihar's location at the crossroads of wet eastern coastal regions and dry continental western plains causes regional variations in rainfall distribution and makes the state vulnerable to both droughts and floods. The study advocated for integrated social, ecological, and economic approaches to address water resource challenges and promote sustainable development.
- **Water Quality Monitoring and Community Health:** Kalra *et al*. (2012) [2] assessed water quality using the Water Quality Index for groundwater in Koilwar block of Bhojpur district, Bihar. Their study analyzed 60 water samples from ten different villages, considering 11 water quality parameters including temperature, pH, total hardness, and iron content. The research demonstrated the application of WQI as an effective tool for converting complex water quality data into easily understandable information for water quality assessment and management. The study contributed to understanding localized water quality variations and provided a framework for community-based water quality monitoring in rural Bihar.

3. Objective of the study

The objective of this study is to analyze the status, distribution, and management of water resources in Bihar, focusing on both surface and groundwater availability. It aims to assess the existing water infrastructure, including irrigation systems and water bodies, and evaluate the challenges related to water quality, especially contamination issues affecting rural areas. Further, the study seeks to review the initiatives and schemes implemented by the Public Health Engineering Department and the Department of Water Resources for water quality monitoring, conservation, flood management, and sustainable utilization. By synthesizing secondary data from governmental reports and surveys, the research intends to provide a

comprehensive understanding of Bihar's water resource dynamics and offer insights into effective water management strategies for climate resilience, agricultural productivity, and public health improvement in the state.

4. Research Methodology

The research methodology adopted in this study is primarily based on the analysis of secondary data obtained from credible and authoritative sources. The data has been sourced from the Bihar Economic Survey, as well as reports and statistics provided by the Department of Water Resources and Department of Minor Water Resources, Government of Bihar. Additionally, important information has been drawn from the First Census Report on Water Bodies published by the Ministry of Jal Shakti, Government of India (2023), and water quality data from the Public Health Engineering Department (PHED), Government of Bihar. This method enables a comprehensive understanding of water resources, water bodies distribution, and water quality management in Bihar by synthesizing existing quantitative data and official records.

5. Water Resources in Bihar

Water resources play a vital role in ensuring the availability of drinking water for both humans and animals, while also supporting key economic sectors such as agriculture, fishing, and industry. These resources form the backbone of the state's socio-economic development, as they not only sustain livelihood but also contribute to food security and rural employment.

Bihar is well-endowed with both surface water and groundwater resources, which are primarily replenished through its numerous rivers, their tributaries, and seasonal rainfall, especially during the south-west monsoon. Being a significant part of the Gangetic Plains, the state hosts important rivers such as the Ganga, Gandak, and Kosi in North Bihar, and the Sone, Phalgu, Punpun, Sakari, and Chanan in South Bihar. The interwoven network of these river systems underscores the strategic importance of water resources in Bihar's ecological and economic landscape.

Table 1: Status of Surface Water Structures in Bihar (2022)

Type	Number	Area (in hectares)
Canals	968	2,764,864
Reservoirs	26	217,560
Tubewells	776	115,546
Tanks (Ahar Pyne, Pond, Check Dam)	319	43,509
Lift Irrigation	38	2,934

Source: Department of Water Resources and Department of Minor Water Resources, Government of Bihar

Table 1 explain Surface water structures in Bihar, play a crucial role in supporting the state's vast agricultural sector and aiding water management. Canal systems are the most prevalent, with 968 canals serving an impressive area of over 2.76 million hectares. Reservoirs, although fewer in number, cover a substantial area of around 217,560 hectares. Tubewells and tanks, including Ahar Pyne, ponds, and check dams, are also important contributors, collectively irrigating significant tracts of land across the state. Lift irrigation, though limited in extent compared to other structures, offers vital support in areas where water must be elevated for distribution. The variety and distribution of these water structures reflect Bihar's comprehensive approach to utilizing both traditional and modern methods of irrigation. Canals and reservoirs form the backbone of large-scale irrigation, while tube wells and tanks provide localized water availability, especially in regions where surface water may be seasonally scarce. Efficient management and maintenance of these structures are essential for ensuring sustainable agricultural productivity and meeting rising water demands for domestic and industrial use. This diversity enhances Bihar's resilience against water shortages and supports its socio-economic growth.

Distribution of Water Bodies in Bihar (2018-19)

Table 2: A. Types of water bodies

SI. No.	Particulars	Number of Water Bodies
1	Ponds	35,027
2	Tanks	4,221
3	Lakes	2,693
4	Reservoirs	2,126
5	Water Conservation Schemes/ Percolation tanks/Check dams	312
6	Others	1,414
	Total	45,793

Source: First Census Report on Water Bodies, Ministry of Jal Shakti, Government of India (2023)

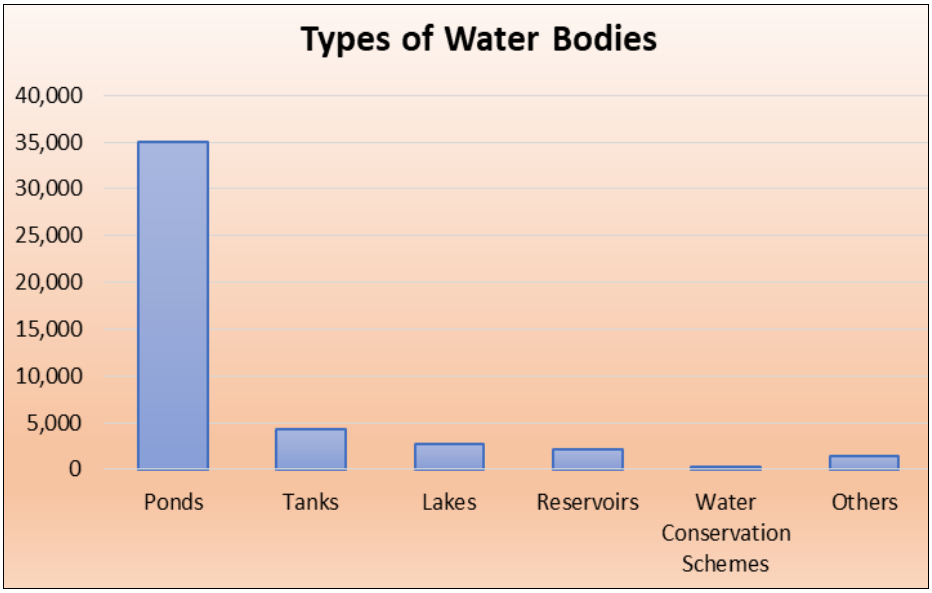
Bihar's landscape is enriched by a diverse array of water bodies, as evidenced by the census data from 2018-19. Ponds constitute the majority, with over 35,000 across the state, serving as vital sources for irrigation, aquaculture, and local water needs. Tanks, lakes, and reservoirs also contribute significantly to water storage and management, while specialized water conservation structures such as percolation tanks and check dams enhance groundwater recharge and the overall resilience of the state to seasonal changes in water availability.

The distribution of these water bodies is overwhelmingly rural, with more than 43,800 out of the total 45,793 water bodies located in rural areas. This pattern highlights the central role water bodies play in supporting agricultural practices, village life, and local economies. Urban areas possess comparatively fewer water bodies, underlining a potential area for development in urban water management and conservation infrastructure. The comprehensive mapping and utilization of these water resources are crucial for sustainable development and climate adaptation in Bihar.

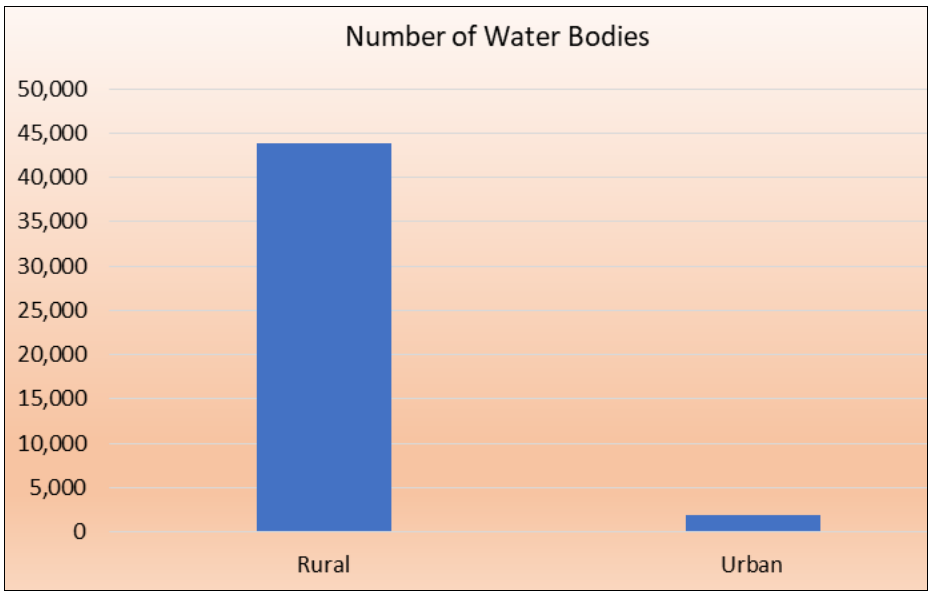
Table 3: B. Location of water bodies

SI. No.	Location	Number of Water Bodies
1	Rural	43,831
2	Urban	1,962

Source: First Census Report on Water Bodies, Ministry of Jal Shakti, Government of India (2023).



The majority of water bodies in Bihar are located in rural areas, with 43,831 out of a total 45,793 situated outside urban centers, while only 1,962 are found in cities and towns. This overwhelming rural presence highlights the state's dependence on traditional water resources for agriculture and local livelihoods. It also complements the earlier data showing the diverse types of water bodies such as ponds, tanks, and reservoirs that are predominantly established to meet the demands of rural communities, further emphasizing the importance of sustainable management for rural development and resilience.



6. Status of water quality in rural Bihar (2022-23)

Ensuring safe drinking water is a major challenge in Bihar's rural areas due to widespread chemical contamination. The Public Health Engineering Department (PHED) has implemented a Water Quality Monitoring Protocol, which mandates regular testing for arsenic, fluoride, and iron contaminations. This system aims at early detection, timely intervention, and transparent sharing of results with local residents. The protocol involves monthly tests for arsenic and fluoride in affected areas, quarterly assessments for iron, and routine checks in other wards, helping authorities respond proactively to contamination events. The current status of rural wards affected by water quality issues is detailed in the table below.

Table 4: Status of water quality affected rural wards in Bihar (2022-23)

Chemical Contamination	Affected Wards	Affected Households (in lakh)	Wards Completed	FHTC[1] Given (in lakh)
Arsenic	4,709	6.98	461	6.74
Fluoride	3,789	4.67	3,780	4.64
Iron	21,709	36.03	21,282	35.13
Total	30,207	47.68	29,743	46.51

Source: Public Health Engineering Department (PHED), Government of Bihar

[1] FHTC refers to Functional Household Tap Connection

The data reveals that iron contamination is by far the most prevalent issue, affecting 21,709 rural wards and over 36 lakh households, with 21,282 wards having completed remedial measures and 35.13 lakh households provided with functional tap connections. In contrast, arsenic and fluoride affect fewer wards 4,709 and 3,789 respectively but still pose significant health risks to nearly 12 lakh households combined. The response to both contaminants includes substantial progress, particularly for fluoride, where remediation has been completed in over 99% of affected wards.

Overall, the state has completed interventions in 29,743 out of 30,207 affected wards and provided tap water connections to 46.51 lakh households. This reflects Bihar's commitment to improving rural water quality and access despite serious contamination challenges. The ongoing monitoring protocol and high coverage of functional tap connections are vital steps towards safeguarding public health and promoting safe water access for all rural residents.

7. Schemes of the public health engineering department for water quality monitoring and management

- **Water Quality Monitoring Infrastructure:** The Public Health Engineering Department (PHED) of Bihar has established a comprehensive water quality monitoring and surveillance system. This includes a State Level NABL-accredited Water Quality Testing Laboratory in Patna, 38 District Water Quality Testing Labs (11 of which are NABL accredited), 75 Sub Divisional Water Quality Testing Labs, and 9 Mobile Water Quality Testing Labs. The department has operationalized a protocol for water quality testing and reporting. Further, on-the-spot surveillance is carried out by trained pump operators at water supply schemes. Regular testing is mandated monthly in arsenic and fluoride-affected wards, quarterly for iron-affected wards, and at least once every four months in non-affected wards.
- **Community-Based Water Quality Surveillance:** At the grassroots level, Field Test Kits (FTKs) are distributed to Gram Panchayats to test parameters such as pH, hardness, alkalinity, chlorine levels, and nitrate. Specialized kits for iron, arsenic, and fluoride testing are also included. One pump operator in each Gram Panchayat is trained and registered on a centralized Water Quality Management Information System to report test results. Additionally, H2S vials are used for bacteriological testing of drinking water pre- and post-monsoon. Sanitary surveys of drinking water sources are coordinated by Panchayati Raj Department technical assistants, who inspect water sources twice a year and submit reports via mobile applications to the PHED portal for timely corrective action.
- **Capacity Building and Training:** PHED has set up a fully equipped Water Quality Laboratory at its Training cum Research Centre 'PRANJAL' to provide hands-on training and orientation for laboratory staff. The Quality Council of India supports these efforts by conducting technical sessions aimed at building the capacity of chemists and lab assistants involved in water testing and quality assurance.
- **Monitoring of River Ganga's Water Quality:** The Bihar State Pollution Control Board (BSPCB) regularly monitors the water quality of the River Ganga at 34 locations and its tributaries and ponds at 70 locations throughout the state. The monitoring indicates elevated bacterial contamination (Total Coliform and Faecal Coliform), mainly due to sewage and domestic wastewater discharged from cities on the riverbanks. However, other parameters like pH, dissolved oxygen (DO), and biochemical oxygen demand (BOD) remain within prescribed limits, indicating the water supports aquatic life and wildlife. BSPCB also monitors wastewater and effluent discharged from industrial units and sewage treatment plants, analyzing thousands of samples annually to ensure environmental compliance.

This structured scheme on multiple levels reflects Bihar's robust and evolving approach toward safeguarding water quality, ranging from advanced laboratory infrastructure and field-level testing to ecological monitoring of critical water bodies like the Ganga. This holistic strategy is essential for addressing both chemical and biological contamination challenges impacting public health and environmental sustainability in the state.

8. Initiatives of the department of water resources in Bihar

- **Ganga Jal Apurti Scheme:** Bihar faces severe environmental challenges including droughts, floods, groundwater depletion, and drinking water shortages, particularly in the southern part of the state. To counter these issues and restore ecological balance, the Department of Water Resources has implemented the Ganga Jal Apurti Scheme. This scheme pumps surface water from Maranchi village in the Patna district during the monsoon period and transports it underground to storage reservoirs. These reservoirs provide treated water to cities like Gaya, Bodh Gaya, Rajgir, and Nawada, benefiting both human populations and the local ecosystem by recharging groundwater and restoring water flow at religious sites.
- **Tal Development Plan and Gayaji Dam:** The Department has also focused on improving water management in the Tal area comprising Patna, Nalanda, and Lakhisarai districts. This includes constructing embankments, weirs, check dams, and box culverts, alongside deepening reservoirs and desilting drainage channels aimed at enhancing aquatic life and fish production. Another key project is the Gayaji Dam, India's longest rubber dam near the Vishnupad temple in Gaya, designed to store monsoon water and release it year-round to alleviate water scarcity and conserve the Falgu river ecosystem.
- **Intra-state River Inter-linking and River Rejuvenation:** An ambitious Intra-state River Inter-linking Project aims to connect rivers like Kosi-Mechi and Gandak-Noon-Bayan-Ganga for better flood management and irrigation by transferring surplus water to dry areas. Additionally, rejuvenation projects such as the one for the old Lakhandei river focus on restoring water channels and improving irrigation availability in affected districts through inter-linking old and new streams, channel construction, and desiltation.
- **Flood Management and Structural Development:**

The Department also undertakes flood management measures like construction of embankments, sheet piling for erosion control, and shoal removal to protect riverbanks. Projects under the Bihar Kosi Basin Development Project (BKBDP) include slope restoration and embedding modern techniques to enhance river embankment protection. A Physical Modelling Centre at Birpur is being set up with World Bank support to facilitate model testing of rivers and foster technical expertise locally.

- **Irrigation Expansion and Infrastructure Strengthening:** Several infrastructure projects are underway, including the construction of a barrage on the Kamla river, and raising and strengthening embankments along the Kamla Balan river to prevent floods and safeguard millions of residents. Phased projects to raise embankments and protect agricultural land from flooding are being actively implemented with significant budgetary investment and outreach across multiple districts.

These comprehensive, multifaceted initiatives demonstrate Bihar's dedicated approach to sustainable water resource management, integrating ecological conservation, flood control, irrigation enhancement, and climate resilience for the benefits of its population and environment.

9. Policy Recommendations

- **Strengthening Infrastructure and Maintenance:** To ensure reliable water distribution, it is imperative to upgrade and maintain existing irrigation networks. Regular desilting of canals and water bodies, alongside scheduled repairs of embankments and check dams, will enhance conveyance efficiency. Allocating dedicated budgets for preventive maintenance, and employing digital monitoring tools to track structural health, can reduce downtime and water losses. Additionally, expanding minor irrigation works such as community-managed ponds and lift irrigation units will diversify supply options and improve resilience against monsoon variability.
- **Enhancing Water Quality Management:** A state-wide roll-out of rapid testing kits at the Gram Panchayat level should be paired with mobile laboratories for remote sample analysis. Strengthening the Water Quality Management Information System (WQ MIS) with real-time data dashboards will facilitate early warning and targeted interventions. Implementing tiered treatment solutions ranging from community filtration units in high-risk areas to household reverse osmosis systems where contamination persists will reduce exposure to arsenic, fluoride, and iron. Capacity building for pump operators and local health workers on water treatment and hygiene practices will further bolster community-led surveillance.
- **Promoting Integrated Water Resource Governance:** Establishing multi-stakeholder Water User Associations (WUAs) across river basins can foster participatory decision-making and equitable resource allocation. These WUAs should include representatives from agriculture, industry, and municipal sectors to coordinate supply-demand balancing. An integrated water policy that aligns the Public Health Engineering Department, Water Resources Department, and Pollution Control Board under a common governance framework will streamline project implementation. Incentivizing conjunctive use of surface and groundwater through tariff reforms and subsidy realignment will encourage efficient utilization and groundwater recharge.

10. Conclusion

In light of Bihar's extensive water infrastructure and the critical challenges identified, this study underscores the state's concerted efforts to ensure water security and quality. With 968 canals irrigating 2.76 million hectares and over 45,793 water bodies 95.7% of which are rural Bihar has built a robust foundation for agricultural productivity. Yet, chemical contamination remains a pressing concern: 21,709 rural wards are affected by iron contamination alone, impacting 36.03 lakh households, while arsenic and fluoride jointly affect nearly 12 lakh more. The Public Health Engineering Department's monitoring protocol bolstered by 38 district labs and community-based Field Test Kits has facilitated remedial measures in 29,743 wards and delivered functional tap connections to 46.51 lakh households, achieving a 98% intervention completion rate in affected areas.

Complementing these quality interventions, the Department of Water Resources has launched transformative initiatives such as the Ganga Jal Apurti Scheme, Tal Development Plan, and intra-state river inter-linking projects to augment supply, restore ecological balance, and bolster flood resilience. These projects, alongside flood management works under the Bihar Kosi Basin Development Project and capacity-building at the PRANJAL laboratory, reflect a holistic management strategy that integrates traditional practices with modern technologies. Continued focus on urban infrastructure enhancement, emerging contaminant monitoring, and institutional strengthening will be vital to sustaining Bihar's progress toward climate-resilient, equitable, and sustainable water resource management.

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