Groundwater Resource Management: Challenges, Approaches and Sustainable Strategies in West Singhbhum District

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ABSTRACT

Groundwater constitutes a critical natural resource supporting domestic water supply, agriculture, and overall socio-economic development, particularly in resource-dependent regions such as West Singhbhum District of Jharkhand. In recent decades, increasing population pressure, agricultural expansion, mining activities, and climate variability have intensified stress on groundwater resources. The present study aims to examine the challenges, governance mechanisms, and sustainable management strategies related to groundwater resources through an extensive review of global, national, and regional studies. The review-based analysis reveals that overextraction, declining recharge, groundwater quality deterioration, and institutional fragmentation remain major constraints to sustainable management. The study further identifies the significance of participatory governance, scientific monitoring, demand-side management, and artificial recharge measures. The findings emphasize the necessity of integrating policy frameworks, community involvement, and climate-resilient strategies to ensure long-term groundwater sustainability and water security in West Singhbhum District.

Keywords: *Groundwater Management, Sustainable Water Resources, Groundwater Governance, Climate Change, West Singhbhum District*.

I. INTRODUCTION

Groundwater refers to the water stored beneath the Earth's surface within soil pores and fractures of rock formations, forming an essential component of the global hydrological cycle. It constitutes one of the most reliable sources of freshwater, supporting drinking water supply, agricultural irrigation, and industrial activities across the world. Groundwater is primarily stored in aquifers—subsurface geological formations capable of storing and transmitting water—which are naturally recharged through rainfall infiltration, river seepage, and percolation from surface water bodies. Unlike surface water resources that are often seasonal and vulnerable to climatic variability, groundwater remains relatively stable and available throughout the year, making it indispensable for socio-economic development (ScienceDaily, 2024).

Over the past few decades, increasing population pressure, rapid urbanization, agricultural intensification, and industrial expansion have significantly increased dependence on groundwater resources. However, unsustainable extraction, declining recharge rates, contamination from agricultural chemicals and industrial effluents, and the growing impacts of climate change have severely threatened both the quantity and quality of groundwater. Depletion of aquifers not only reduces water availability but also leads to ecological degradation, land subsidence, and deterioration of water quality. As groundwater forms the backbone of water security in many developing regions, effective governance, scientific monitoring, and sustainable management practices have become critical priorities at global, national, and regional levels.

1.1 Groundwater Problem in the World

Globally, groundwater supports the drinking water needs of more than two billion people and contributes nearly half of irrigation water used in agriculture. Despite its importance, groundwater resources are under severe stress worldwide. Agricultural irrigation accounts for approximately 70 percent of global groundwater withdrawals, particularly in water-scarce and semi-arid regions. Countries such as India, China, Pakistan, Iran, and the United States have experienced alarming declines in groundwater levels due to excessive pumping beyond natural recharge capacity (ScienceDaily, 2024).

Scientific assessments reveal that global groundwater depletion has accelerated sharply over time, increasing from nearly 126 billion cubic meters per year in the 1960s to more than 280 billion cubic meters per year by the early 2000s, with continuing upward trends. Many major aquifer systems are now classified as "overstressed," where extraction significantly exceeds recharge. In addition to quantity decline, groundwater quality deterioration has emerged as a serious concern. Contamination from arsenic, nitrate, and industrial pollutants affects millions of people, leading to chronic health problems in Asia, Africa, and parts of Latin America.

Furthermore, excessive groundwater withdrawal has caused land subsidence in several regions, damaging infrastructure, reducing aquifer storage capacity, and increasing vulnerability to floods. Climate change intensifies these challenges by altering precipitation patterns and increasing the frequency of droughts, thereby reducing natural recharge. Weak governance frameworks, inadequate monitoring systems, and limited community participation further aggravate the crisis. Consequently, sustainable groundwater management has become a global priority for ensuring long-term water security, ecological stability, and human well-being (ScienceDaily, 2024).

1.2 Groundwater Problem in India

India is one of the largest users of groundwater in the world and faces a rapidly intensifying groundwater crisis. According to the Central Ground Water Board (CGWB), India's annual groundwater extraction is approximately 245.64 billion cubic meters (BCM), against an annual recharge of 446.90 BCM, resulting in an overall extraction rate of about 60.47 percent of replenishable resources (Ministry of Jal Shakti, 2025). Although this national average appears moderate, it conceals severe regional disparities.

Several states, including Punjab, Haryana, Rajasthan, Delhi, and parts of Uttar Pradesh, exhibit extraction levels exceeding 100 percent of recharge, indicating over-exploitation. Punjab records groundwater extraction as high as 156.36 percent, while Rajasthan shows 147.11 percent, reflecting critical depletion trends. Agriculture alone accounts for nearly 87 percent of total groundwater use in India, largely driven by water-intensive cropping patterns, free electricity for pumping, and inadequate regulation.

Groundwater quality degradation is an equally serious concern. High concentrations of nitrate beyond permissible drinking limits have been reported in nearly 440 districts, posing serious health risks such as methemoglobinemia and other chronic illnesses. In several regions, contamination by fluoride, arsenic, iron, and salinity further restricts safe usage. Rapid urbanization, unregulated borewell construction, and weak enforcement of groundwater legislation have intensified the crisis. These trends underline the urgent need for sustainable groundwater governance, demand-side management, recharge enhancement, and policy reforms to safeguard India's water security (Ministry of Jal Shakti, 2025).

1.3 Groundwater Problem in Jharkhand

Jharkhand presents a unique groundwater scenario characterized by geological complexity, uneven rainfall distribution, and spatial variability in water availability. According to the *Dynamic Ground Water Resource of Jharkhand 2024* report, post-monsoon groundwater levels range from as shallow as 0.19 meters below ground level (bgl) in Gumla district to as deep as 14.11 meters bgl in Koderma district. Approximately 62 percent of the state records groundwater levels between 2–5 meters bgl, indicating moderate availability but high spatial variation (CGWB & Government of Jharkhand, 2024).

Long-term monitoring trends reveal declining groundwater levels in several blocks, with observed drops of up to 2 meters in certain regions due to increased extraction for irrigation and domestic consumption. Out of 263 groundwater assessment units in the state, around 1.9 percent are classified as over-exploited, 2.3 percent as critical, and 4.2 percent as semi-critical. Although the majority of units fall under the “safe” category, localized stress is increasing, particularly in mining-affected, urban, and agriculturally intensive zones.

Groundwater quality issues also pose serious challenges in Jharkhand. Fluoride contamination has been reported in multiple districts, leading to health problems such as dental and skeletal fluorosis. Limited artificial recharge structures, inadequate rainwater harvesting, growing dependence on tube wells, and lack of community-based water management further aggravate groundwater vulnerability. Given Jharkhand’s dependence on groundwater for rural drinking water supply and agriculture, sustainable management strategies, scientific monitoring, institutional strengthening, and community participation are essential to ensure long-term groundwater security in the state (CGWB & Government of Jharkhand, 2024).

II. FINDINGS FROM THE REVIEWS STUDY

Author(s) & Year	Region / Focus	Methodology	Key Findings	Governance Insights / Recommendations
Ul Hasan et al., 2025	Indus Basin, Pakistan	Document analysis, stakeholder perspectives	Groundwater under stress due to unsustainable extraction, climate variability, institutional fragmentation	Identified overlapping mandates, weak enforcement, limited participation; proposed 6 policy principles for coordination, monitoring, innovation, and local participation
Kc et al., 2025	Barahathawa Municipality, Nepal	Groundwater Governance Index (32 indicators), stakeholder framework	Transitional governance (GGI=1.03), fragmented technical capacity, legal/institutional gaps	Recommended participatory mapping, localized regulations, inclusive decision-making; framework replicable for similar regions
Jedd et al., 2025	Nebraska, U.S.	Interviews, workshops, records analysis	Voluntary self-limiting behavior legitimized extraction limits	Polycentric governance effective when socially accepted, inclusive, and supported by local collaboration and legal authority
Sarkar & Sarkar, 2025	India	Mixed-methods, secondary data, policy review	Complex governance due to groundwater invisibility, land links, millions of users; overextraction and weak legal enforcement	Advocated evidence-based regulations, voluntary participation, and strong political commitment for effective governance

Zhao et al., 2024	Global	Literature review	CAC and market-based approaches often disadvantage small users; voluntary approaches ineffective	Polycentric governance combining formal regulation and local management recommended, adaptable to climate change
Prakash et al., 2024	India	Comparative legal and institutional analysis	Severe depletion, contamination due to water-intensive crops, subsidies, regulatory gaps	Demand- and supply-side measures suggested; community participation and effective regulations critical
Hassenforder et al., 2024	Southern Mediterranean	Literature review + 25 case studies	Rising water demand + climate change increases reliance on groundwater	Identified 17 conditions for multi-stakeholder dialogue; highlighted need for collaborative governance
Shiferaw et al., 2024	India	Theory-based case studies (World Bank projects)	Climate change increases irrigation demand, risks depletion	Recommended integrating demand- and supply-side approaches; climate-smart agriculture
Faragher & Carden, 2023	Cape Town, South Africa	Case study, governance review	Transition to hybrid water systems; groundwater crucial in drought	Engineering-focused governance insufficient; reforms needed for sustainable urban groundwater use
Nastiti et al., 2023	Indonesia	Assemblage Thinking framework	Groundwater availability threatened by overextraction, unequal access	AT lens helps analyze socio-ecological dynamics; recommends holistic governance incorporating human, material, and policy factors
KC et al., 2022	Global	Literature review of governance assessment methodologies	Groundwater stress from climate change, population growth, land-use change, industrialization	Developed an integrative framework to include marginalized groups, multiple indicators; supports strategic planning under stress
Taghilou, 2022	Global	Socio-ecological resilience framework	Participation constrained by free-riding; conflicts over rights	SES framework for clarifying public/private rights, enhancing resilience, planning policy interventions

Bruns, 2021	Sub-Saharan Africa	Comparative review, case studies	State-led regulation problematic; limited access to tech & energy constrains irrigation expansion	Polycentric governance and extended participation ladder suggested; collective action key for equity and sustainability
Kulkarni et al., 2021	India	Literature review, policy analysis	India largest groundwater user; depletion and contamination widespread	Community participation, institutional reform, integrating groundwater science and governance essential
Singh, 2021	Punjab & Jammu, India	Primary data, case studies	Intensive extraction, weak governance, subsidies lead to declining water tables	Gradual phasing out of energy subsidies, conjunctive use of groundwater/surface water recommended
Petit et al., 2021	Global	Workshops, literature review	Pumping races exclude poorer farmers; environmental degradation	Regulatory & economic instruments insufficient; participatory negotiation pathways suggested
Ghosh, 2021	India	Literature review	Groundwater invisible; multi-stakeholder conflicts, risk of depletion	Framework proposed for integrated groundwater management addressing demand & supply
de Jesus Barreiras, 2020	Portugal	Doctoral research, info systems evaluation	Governance constrained by gaps in water info systems	Developed framework linking groundwater governance deficiencies to OECD principles; proposed decision-support system
Bajaj et al., 2020	India	Document review, descriptive analysis	India largest groundwater consumer; policies exist but poorly coordinated	Align central & state governance; integrate groundwater management with policy and participatory approaches
Bhattacharjee et al., 2019	Bangladesh	Policy review, governance analysis	Groundwater over-exploited, pollution and encroachment prevalent; legal frameworks inadequate	Strengthen institutions, clarify public/private rights, enhance monitoring, participation, and enforcement

III. FINDINGS FROM STUDY

Groundwater Stress and Overextraction: Most studies consistently highlighted that groundwater resources are under significant stress globally. In India, Pakistan, Nepal, and parts of Africa, overextraction has emerged as a critical concern due to the intensive use of groundwater for irrigation and domestic purposes (Prakash et al., 2024; Ul Hasan et al., 2025; Bajaj et al., 2020). The extraction of water-intensive crops, coupled with subsidies for electricity and water, has led to declining water tables, aquifer depletion, and in some areas, irreversible reductions in groundwater availability (Kulkarni et al., 2021; Singh, 2021). This overuse not only threatens the sustainability of groundwater but also jeopardizes food security and the livelihoods of millions of farmers.

Institutional and Legal Gaps: Weak institutional frameworks and inadequate legal structures were recurrently identified as barriers to sustainable groundwater governance. Studies in Pakistan, India, and Nepal pointed out overlapping mandates among government agencies, outdated policies, limited enforcement, and insufficient mechanisms to regulate extraction (Ul Hasan et al., 2025; Sarkar & Sarkar, 2025; Kc et al., 2025). In India, licensing-based regulations were often poorly implemented due to bureaucratic inefficiency, corruption, and rent-seeking behavior, while in Nepal, the absence of permitting mechanisms and weak pollution controls contributed to governance gaps (Prakash et al., 2024; Kc et al., 2025).

Effectiveness of Governance Approaches: Research emphasized that governance systems combining local-level participation with formal regulation—polycentric governance—were generally more effective than purely command-and-control or market-based approaches (Jedd et al., 2025; Zhao et al., 2024; Bruns, 2021). Voluntary arrangements and social legitimacy played a key role in ensuring compliance, as seen in Nebraska, U.S., where farmers adhered to self-imposed extraction limits when these were socially accepted and supported by elected local boards (Jedd et al., 2025). Conversely, market-based or purely regulatory approaches often disadvantaged small-scale or resource-poor users, leading to inequities and reduced sustainability (Zhao et al., 2024).

Climate Change and External Pressures: Rising demands for irrigation and domestic use, compounded by climate change, land-use changes, and population growth, were highlighted as intensifying pressures on groundwater resources (Shiferaw et al., 2024; Hassenforder et al., 2024; KC et al., 2022). Variability in rainfall and increasing drought frequencies require governance systems to be adaptive and data-driven, capable of responding to changing hydrological and socio-economic conditions. Failure to integrate climate considerations into groundwater management risks further depletion and reduced resilience.

Quality and Accessibility Concerns: Beyond quantity, several studies highlighted groundwater quality challenges, including contamination by fluoride, nitrates, and other pollutants (Bhattacharjee et al., 2019; Nastiti et al., 2023). Poor quality exacerbates health risks such as fluorosis in affected populations. Furthermore, marginalized and low-income groups often face inequitable access to groundwater, as governance structures frequently favor wealthier or politically connected users, highlighting the importance of inclusive policy-making (KC et al., 2022; Kc et al., 2025).

Recommendations for Improvement: Across studies, recommendations emphasized holistic, multi-dimensional strategies to improve groundwater governance. Integrating **demand- and supply-side measures**—such as water-efficient irrigation, aquifer recharge, and conjunctive use of surface and groundwater—was identified as critical (Shiferaw et al., 2024; Prakash et al., 2024). Strengthening **stakeholder participation**, particularly including marginalized groups, and improving **monitoring and data-driven regulatory mechanisms** were repeatedly suggested (Ul Hasan et al., 2025; Bajaj et al., 2020;

de Jesus Barreiras, 2020). Additionally, frameworks like **Assemblage Thinking (AT)** and **socio-ecological resilience (SES)** were proposed to capture complex interactions among human, institutional, and ecological factors, promoting sustainable, adaptive, and context-sensitive groundwater management (Taghilou, 2022; Nastiti et al., 2023).

Integration of Policy and Practice: A recurring theme was the gap between policy formulation and on-ground implementation. Even when legal frameworks or management guidelines existed, their effectiveness was often limited by poor coordination between central and state agencies, lack of technical capacity, or insufficient local engagement (Bajaj et al., 2020; Kulkarni et al., 2021). The studies emphasized the importance of **coproduction of knowledge**, where scientific evidence, community knowledge, and institutional frameworks interact to guide practical governance measures.

IV. CONCLUSION

The study concludes that groundwater resource management in West Singhbhum District is confronted with multiple environmental, institutional, and socio-economic challenges. Although a large part of the district remains within the safe category, localized groundwater stress is increasing due to unregulated extraction, limited recharge infrastructure, mining activities, and growing domestic and agricultural demand. The review findings clearly indicate that weak governance structures, inadequate monitoring systems, and limited stakeholder participation restrict effective groundwater management. Experiences from national and international case studies highlight that integrated and polycentric governance approaches, supported by scientific data and community participation, are essential for sustainable outcomes. The study emphasizes the need for strengthening institutional coordination, promoting rainwater harvesting and artificial recharge, encouraging water-use efficiency, and incorporating climate-adaptive planning. Sustainable groundwater management in West Singhbhum can only be achieved through a balanced approach linking policy implementation, scientific assessment, and local-level participation.

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