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ASSESSING GROUNDWATER DEPLETION AND ITS SOCIO-ENVIRONMENTAL IMPACTS: A CASE STUDY OF JODHPUR, RAJASTHAN, INDIA

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Abstract: *Groundwater constitutes the principal source of freshwater in arid and semi-arid regions of the world, particularly in India, where seasonal rainfall variability and limited surface water availability constrain sustainable development. Rajasthan, one of India's most water-stressed states, faces acute groundwater depletion, with Jodhpur district emerging as a critical hotspot of over-extraction and declining water security. The findings reveal a persistent decline in groundwater tables often exceeding 1-2 meters annually in over-exploited blocks primarily driven by intensive agricultural irrigation, unregulated urban expansion, climate variability, and institutional weaknesses in groundwater governance. The paper concludes that restoring groundwater balance in arid zones requires a synthesis of traditional water-harvesting knowledge, scientific resource assessment, community engagement, and institutional reform to ensure long-term water security and socio-ecological resilience.*

Keywords: Ground water Depletion, Arid Regions, Socio-Environmental Impacts, Water Management

Introduction

Groundwater has emerged as the most dependable and strategically important freshwater resource for arid and semi-arid regions across the globe, particularly in contexts where surface water availability is limited, highly seasonal, or climatically uncertain. According to UNESCO (2022), groundwater supplies nearly 50 percent of global drinking water demand and supports approximately 40 percent of irrigated agriculture, underlining its central role in food security, public health, and economic stability. Unlike surface water systems, groundwater offers a buffering capacity against climate variability, making it especially vital in dryland environments. However, its relative invisibility, open-access nature, and weak regulatory frameworks have rendered it highly vulnerable to over-extraction and long-term depletion. India represents one of the most groundwater-dependent countries in the world. The expansion of tube-well irrigation since the Green Revolution has transformed agricultural productivity but has also intensified pressure on aquifer systems. Currently, groundwater contributes approximately 62 percent of irrigation water and nearly 85 percent of rural drinking water supply in the country (Central Ground Water Board, 2020). This scale of dependence has placed India among the largest global extractors of groundwater, with depletion rates exceeding natural recharge in many regions. Recent national assessments indicate that a significant proportion of India's aquifers are under severe stress, raising serious concerns about long-term water security, agricultural sustainability, and rural livelihoods.

The groundwater crisis is particularly acute in the western Indian state of Rajasthan, which is characterized by low and erratic rainfall, high evapotranspiration losses, frequent droughts, and geologically constrained aquifer systems. The state receives an average annual rainfall of less than 500 mm, much of which is highly variable across space and time. According to CGWB assessments, more than 60 percent of groundwater assessment units in Rajasthan are classified as over-exploited or critical, indicating extraction levels far in excess of recharge capacity. This unsustainable trajectory has resulted in rapidly declining water tables, increasing energy costs for pumping, and deterioration in groundwater quality, including salinization and fluoride contamination. Within this broader regional context, Jodhpur district located on the eastern margin of the Thar Desert offers a particularly compelling case for examining groundwater depletion. The district's arid climate, fragile hydrogeology, and heavy reliance on groundwater for domestic, agricultural, and urban uses have made it one of the most water-stressed regions in Rajasthan. Over the past few decades, Jodhpur has witnessed rapid population growth, agricultural intensification through borewell-based irrigation, and accelerated urban expansion driven by infrastructural development and rising living standards. These processes have substantially altered groundwater extraction recharge balances, leading to persistent declines in water tables across much of the district. Equally significant has been the institutional and socio-cultural shift in groundwater use patterns. Traditional community-managed water systems such as baoris, johads, and tankas that historically promoted collective stewardship and enhanced local recharge have gradually been replaced by privately owned deep tube wells. While this transition has increased short-term water access for individual users, it has eroded collective responsibility and weakened informal norms regulating groundwater use.

As a result, groundwater depletion in Jodhpur is no longer simply an environmental phenomenon but a deeply embedded hydro-social crisis, manifesting in agricultural distress, livelihood insecurity, social differentiation, and growing inequalities in access to water. Against this backdrop, the present study seeks to assess groundwater depletion in Jodhpur through a systematic examination of its temporal trends, underlying drivers, and socio-environmental consequences. By adopting a secondary data–based case study approach, the paper aims to generate insights into the complex interactions between hydrogeological constraints, human interventions, and governance structures in an arid-region context. More broadly, the study contributes to ongoing debates on groundwater sustainability in India's drylands and offers evidence-based insights to inform policy interventions that reconcile ecological integrity with human development objectives, particularly under conditions of increasing climate uncertainty.

Study Area: Jodhpur District, Rajasthan

Jodhpur district is located in western Rajasthan, India, on the eastern periphery of the Thar Desert, and occupies a strategically important position within the arid and semi-arid transition zone of north-western India. Geographically, the district extends between 26°00′ to 27°37′ North latitude and 72°55′ to 73°52′ East longitude, covering a vast geographical area of approximately 22,850 km², which makes it one of the largest districts in Rajasthan in terms of spatial extent. Its location at the interface of desert and semi-arid environments renders it particularly sensitive to climatic variability, water scarcity, and land degradation processes. The district shares its boundaries with Bikaner and Nagaur districts to the north and northeast, Pali to the south, Jaisalmer to the west, and Barmer to the southwest, situating it within a larger arid belt characterized by extreme hydro-climatic constraints. The physiography of Jodhpur is largely defined by undulating sandy plains, isolated rocky outcrops, and low-lying pediplains, interspersed with dune systems that are more prominent in the western and north-western parts of the district. These landforms exert a strong influence on surface runoff, infiltration capacity, and groundwater recharge potential.

From a hydrogeological perspective, Jodhpur is dominated by hard-rock aquifer systems, primarily comprising sandstone, limestone, rhyolite, shale, and granite formations. These geological units possess limited primary porosity, with groundwater occurrence largely confined to secondary porosity in weathered zones, fractures, and joints. Consequently, aquifer storage and recharge capacities are inherently low and spatially heterogeneous. Groundwater depths vary widely across the district but have increased substantially over time, with water levels in several locations now extending beyond 80-100 meters below ground level, indicative of chronic over-extraction. Demographically, Jodhpur district supports a population of approximately 3.69 million (Census 2011), with a significant proportion residing in rural areas and depending directly or indirectly on agriculture and allied activities. Land use is predominantly agricultural, with rain-fed farming supplemented by groundwater irrigation. Major crops include bajra, wheat, mustard, guar, cumin, and pulses, many of which are increasingly reliant on tube-well irrigation due to rainfall uncertainty. Rapid urban growth, particularly in Jodhpur city, has further intensified domestic, commercial, and industrial demand for groundwater. Historically, the district developed innovative indigenous water-harvesting systems, such as baoris (stepwells), tankas, johads, and talabs, which played a crucial role in capturing monsoon rainfall, sustaining base flows, and enhancing groundwater recharge. However, the widespread adoption of deep tube wells, coupled with inadequate regulation, has led to the gradual neglect of these traditional systems. As a result, the district currently exhibits a growing mismatch between groundwater extraction and recharge.

Climate and Rainfall

Jodhpur experiences an arid to semi-arid climate marked by extreme temperature variability. Summer temperatures frequently exceed 48°C, while winter minima may fall below 05°C. The district receives an average annual rainfall of 350-400 mm, nearly 90 percent of which occurs during the southwest monsoon (July-September). High inter-annual rainfall variability and frequent droughts severely restrict reliable surface water availability, intensifying dependence on groundwater resources (IMD, 2022).

Geology and Hydrogeology

The hydrogeology of Jodhpur is dominated by hard rock formations such as sandstone, limestone, rhyolite, and granite, which possess limited primary porosity. Groundwater storage is largely confined to secondary porosity developed through fractures and weathered zones. Consequently, aquifer recharge is slow and spatially uneven. CGWB data indicate that groundwater levels in several blocks now exceed 80-100 meters below ground level, reflecting severe over-exploitation.

Demography, Land Use and Economy

According to the Census of India (2011), Jodhpur district has a population of approximately 3.69 million, making it one of the populous districts in western Rajasthan. The demographic structure of the district is predominantly rural, with a substantial proportion of the population residing in villages and small settlements dispersed across an arid landscape. Population density remains relatively low in comparison to humid and semi-humid regions of India; however, the pressure on natural resources particularly groundwater is intense due to environmental constraints and livelihood dependence on climate-sensitive activities. The district's economy is largely agrarian, with agriculture and allied activities constituting the primary source of livelihood for a significant share of households. A large proportion of the workforce is engaged as cultivators, agricultural labourers, and marginal farmers, many of whom are highly vulnerable to climatic variability and water scarcity. Landholdings in the district are predominantly small and marginal, which further limits farmers' capacity to absorb risks associated with crop failure, declining productivity, and rising irrigation costs. Land-use patterns in Jodhpur are shaped by arid environmental conditions and limited water availability. A substantial share of the cultivated area is under rain-fed agriculture, making cropping systems highly dependent on the southwest monsoon. However, increasing rainfall uncertainty and frequent dry spells have encouraged a gradual expansion of groundwater-based irrigation, particularly through tube wells and borewells. Groundwater irrigation has become crucial for ensuring crop security during drought years and for supporting winter (rabi) cultivation.

The dominant crops in the district include bajra (pearl millet) a traditional drought-resistant crop alongside wheat, mustard, guar, cumin, and pulses. While crops such as guar and bajra are relatively suited to arid conditions, the expansion of water-intensive crops like wheat and mustard has significantly increased pressure on groundwater resources, especially during the rabi season when surface water availability is minimal. The dependence on groundwater irrigation for these crops has contributed directly to declining water tables and increased energy consumption for pumping. In recent decades, Jodhpur city has experienced rapid urbanization driven by population growth, expansion of educational and industrial activities, tourism, and infrastructure development. This urban expansion has led to a sharp rise in domestic, commercial, and industrial water demand, much of which is met through groundwater abstraction. The proliferation of private borewells, both authorized and unauthorized, has further intensified extraction, often without adequate monitoring or recharge mechanisms. The interaction between rural agricultural demand and urban water consumption has created increasing competition for limited groundwater resources. Urban users backed by greater financial capacity are often able to access deeper aquifers, while rural communities, small farmers, and marginalized groups face growing water insecurity. This emerging water-use inequity underscores the socio-economic dimension of groundwater depletion in Jodhpur, highlighting the need for holistic land-use planning and integrated water resource management that accounts for both rural livelihoods and urban development pressures.

Water Resources Context

Historically, Jodhpur district developed a highly adaptive and locally grounded water-management system tailored to the extreme arid conditions of western Rajasthan. In the absence of perennial rivers and with erratic monsoonal rainfall, communities evolved indigenous rainwater harvesting and storage practices that maximized the efficient capture, storage, and recharge of limited precipitation. Key among these systems were baoris (stepwells), johads, tankas, nadis, and man-made lakes, which together formed a decentralized and interconnected hydrological network across rural and urban landscapes. Baoris (stepwells) played a particularly significant role in urban and peri-urban areas, serving as multi-purpose structures that provided potable water, moderated micro-climates, and functioned as social and cultural spaces. Tankas underground cisterns commonly found in households were designed to collect rooftop runoff, ensuring year-round drinking water security. Johads and nadis acted as shallow earthen or masonry embankments that captured surface runoff during the monsoon, facilitating groundwater recharge while supporting livestock and agriculture. Larger lakes and reservoirs, such as those historically constructed around Jodhpur city, regulated surface runoff and sustained water availability during prolonged dry periods.

These traditional systems were characterized by community ownership, collective maintenance, and an inherent understanding of local topography and hydrogeology, which ensured sustainability over centuries. Importantly, they functioned not merely as storage structures but also as effective recharge mechanisms, enhancing groundwater levels and maintaining base flows within aquifers. The integration of land use, water conservation, and social norms created a resilient water economy well suited to arid environments. Over the past few decades, however, the region has witnessed a profound transformation in water-use practices. The widespread adoption of deep tube wells and electrically powered pump sets, particularly since the late twentieth century, has fundamentally altered the local water regime. Groundwater abstraction has become increasingly individualized, privatized, and demand-driven, severing the historical linkage between extraction and natural recharge. Easy access to pumping technology and subsidized electricity has encouraged excessive withdrawal, often without regard to aquifer limits or long-term sustainability.

This technological shift has led to the systematic neglect and physical deterioration of traditional water-harvesting structures. Many baoris and johads have fallen into disuse, been encroached upon, or suffered from siltation and pollution. As these structures ceased to function, their vital role in groundwater recharge diminished, resulting in a reduced replenishment of aquifers. Consequently, the imbalance between groundwater extraction and recharge has grown more pronounced, accelerating water table decline across much of the district. Apart from this, centralized water supply schemes and tanker-based systems in urban areas have reinforced dependence on groundwater while weakening community-level stewardship. The erosion of traditional knowledge systems and collective governance mechanisms has undermined local capacity to manage water resources sustainably. In this context, groundwater depletion in Jodhpur is not merely a hydrological issue but also represents a loss of cultural and institutional resilience. The current water resources context in Jodhpur thus reflects a transition from ecologically attuned, community-managed systems to technologically intensive and poorly regulated extraction regimes. Understanding this historical shift is essential for framing sustainable groundwater management strategies. Revitalizing traditional rainwater harvesting structures complemented by modern scientific assessment and policy support offers a critical pathway for restoring groundwater recharge, enhancing water security, and building long-term resilience in this arid region.

Methodology: This study employs a qualitative and descriptive research design based exclusively on secondary data analysis. Given the scale of the study and the availability of authoritative datasets, secondary sources provide a robust foundation for longitudinal and comparative analysis.

Data Sources: Key data sources include:

- Central Ground Water Board (CGWB) reports and groundwater assessments
- Rajasthan State Ground Water Department district-level data
- Census of India (2011) demographic and socio-economic statistics
- IMD rainfall and climate datasets
- NITI Aayog policy reports
- Peer-reviewed academic journals
- Reports from UNDP, UNICEF, and NGOs
- Credible national and regional media reports

Limitations: The absence of primary field data and high-resolution GIS analysis limits micro-level spatial interpretation, though cross-verification across multiple sources enhances reliability.

Groundwater Depletion: Trends and Causes

Groundwater assessments conducted by the Central Ground Water Board (CGWB) consistently indicate that a majority of groundwater assessment units (blocks) in Jodhpur district fall under the "over-exploited" category, signifying that annual groundwater extraction substantially exceeds natural recharge. In several blocks, the stage of groundwater development exceeds 150 percent, reflecting an unsustainable extraction recharge imbalance. Such conditions are symptomatic of chronic groundwater stress and pose serious risks to long-term water availability. Long-term monitoring data reveal a persistent decline in groundwater levels across much of the district. Since the early 1990s, groundwater levels have declined at an average rate of approximately 1-2 meters per year, with significantly steeper declines observed during extended drought periods. In many locations, wells that once accessed groundwater at shallow depths are now defunct, and borewells routinely extend beyond 80–100 meters below ground level. The spatial pattern of depletion is uneven, with the most severe declines occurring in agriculturally intensive rural areas and in peri-urban zones surrounding Jodhpur city, where competing agricultural and urban demands converge. The drivers of groundwater depletion in Jodhpur are multidimensional, reflecting the interaction of environmental constraints, socio-economic pressures, technological change, and governance limitations.

Agricultural over-extraction remains the dominant driver of groundwater decline. Due to the unreliability of monsoon rainfall and the absence of adequate surface water sources, farmers have increasingly relied on borewell-based irrigation to stabilize crop yields. The expansion of rabi crops particularly wheat and mustard has significantly intensified seasonal groundwater withdrawal. While some traditional crops, such as bajra and guar, are relatively drought-resilient, the growing emphasis on water-intensive and market-oriented cropping systems has placed excessive pressure on aquifers. Additionally, subsidized or free electricity for agricultural pumping has reduced the marginal cost of extraction, encouraging overuse. Urban expansion and construction activities represent a rapidly growing source of groundwater demand. Jodhpur city has experienced accelerated urban growth driven by population increase, tourism, industrial activity, and infrastructural development. Urban water supply systems rely heavily on groundwater, supplemented in some areas by tanker-based extraction. Construction activities often involve unauthorized borewells and temporary pumping, further exacerbating aquifer depletion. The concentration of deep wells in urban and peri-urban areas has led to localized cones of depression, affecting nearby rural users and shallow wells.

Climate variability and declining recharge have compounded extraction pressures. Jodhpur's rainfall is not only low but also highly erratic, characterized by short-duration high-intensity events interspersed with prolonged dry spells. Such rainfall patterns generate rapid surface runoff but limited infiltration, reducing effective groundwater recharge. Recurrent drought years further diminish recharge potential and accelerate groundwater decline. Rising temperatures and high evapotranspiration rates associated with climate change are likely to worsen this imbalance by increasing crop water demand and reducing soil moisture retention. Weak regulatory enforcement and policy fragmentation have significantly constrained sustainable groundwater management. Although legal frameworks exist for borewell registration and groundwater regulation in Rajasthan, enforcement remains uneven due to limited institutional capacity, data gaps, and political sensitivities. Groundwater governance is further weakened by fragmentation among multiple agencies responsible for water resources, agriculture, energy, and rural development, resulting in poor coordination and inconsistent implementation of conservation measures.

Underlying these structural issues is a cultural perception of groundwater as a private resource. Since groundwater is accessed through privately owned wells, users often perceive extraction rights as linked to land ownership rather than collective aquifer sustainability. This perception promotes competitive drilling, deeper wells, and a "race to the bottom," where individuals seek to secure water for themselves in anticipation of future scarcity. The absence of a shared understanding of groundwater as a common-pool resource has undermined collective action and long-term planning. In combination, these factors have produced a trajectory of unsustainable groundwater use in Jodhpur. The observed depletion trends underscore the urgent need for integrated and participatory groundwater governance that addresses not only technical and regulatory dimensions but also socio-cultural and economic drivers shaping water use behavior.

Socio-Environmental Impacts

Socio-Environmental Impacts of Groundwater Depletion

Groundwater depletion in Jodhpur has generated a complex set of interlinked social and environmental consequences, reflecting the deep integration of water resources with livelihoods, health, ecosystems, and regional development. In an arid region where groundwater serves as the primary buffer against climatic uncertainty, declining aquifer levels have intensified vulnerability across social groups and ecological systems.

Social Impacts: Drinking Water Insecurity

The decline in groundwater levels has significantly undermined access to safe and reliable drinking water, particularly in rural and peri-urban areas of Jodhpur. According to CGWB and Rajasthan State Ground Water Department reports, a large proportion of habitations in the district are classified as water-stressed or partially covered during dry seasons. As shallow aquifers dry up, drinking water sources increasingly depend on deeper borewells or tanker supply, which is costly and unreliable. UNICEF (2016) notes that in several districts of western Rajasthan, households often receive potable water only once every few days during summer months, forcing reliance on unsafe or distant sources.

Rising Irrigation Costs and Farmer Indebtedness

Groundwater depletion has led to a substantial increase in the cost of irrigation, as farmers are compelled to drill deeper borewells and invest in higher-capacity pumps. CGWB data indicate that average well depths in over-exploited blocks of Rajasthan have increased by 30-50 meters over the last three decades, significantly raising capital and energy costs. The increased electricity consumption for pumping despite subsidies has contributed to mounting farm expenses, while declining water availability has reduced crop productivity during drought years. Studies on agrarian distress in Rajasthan (Sharma & Rathore, 2018) highlight that groundwater scarcity has intensified farmer indebtedness, particularly among small and marginal farmers who lack the financial capacity to deepen wells or shift to water-efficient technologies. Crop failures resulting from water stress further exacerbate income instability, reinforcing cycles of poverty and vulnerability.

Migration and Livelihood Disruption

Water scarcity has emerged as a key driver of seasonal and permanent migration from rural Jodhpur to urban centers within and outside the district. NSSO and Census-based analyses indicate that migration from arid and semi-arid regions of Rajasthan is strongly correlated with drought frequency and declining groundwater availability. Households dependent on agriculture and livestock are often forced to seek alternative livelihoods in construction, informal services, and low-wage urban employment, leading to social dislocation and erosion of traditional livelihood systems.

Gendered and Socially Differentiated Impacts

Groundwater depletion disproportionately affects women, children, and marginalized communities. Women bear the primary responsibility for water collection in rural households, and declining water availability has increased the time, physical effort, and opportunity costs associated with accessing drinking water. UNICEF (2016) reports that in water-scarce regions of Rajasthan, women may spend two to four hours per day collecting water during peak scarcity periods. Marginalized social groups including landless laborers and scheduled caste households are particularly vulnerable, as they depend on common water sources or public supply systems that are increasingly unreliable.

Environmental Impacts

Policy Responses and Governance Challenges

In response to accelerating groundwater depletion, both the Government of India and the Government of Rajasthan have introduced a range of policy initiatives, regulatory frameworks, and community-oriented programs aimed at improving groundwater sustainability. While these efforts signal a gradual shift from supply-centric engineering approaches toward demand management and participatory governance, their overall effectiveness in arid districts such as Jodhpur remains constrained by institutional, technical, and socio-political challenges.

Major Policy Initiatives

Atal Bhujal Yojana (ABHY)

The Atal Bhujal Yojana, launched in 2019 with World Bank support, represents a significant policy transition toward community-led groundwater management in India. The scheme focuses on improving groundwater governance in identified water-stressed districts through behavioral change, institutional strengthening, and data-driven decision-making. Core components include:

- Preparation of Water Security Plans at the gram panchayat level
- Promotion of water budgeting and crop-water alignment
- Incentivizing reduced extraction through performance-linked funding
- Strengthening groundwater monitoring networks and data transparency

In Rajasthan, including parts of western districts, ABHY has facilitated greater awareness of groundwater status among select communities. However, its coverage remains limited relative to the scale of groundwater stress. In districts such as Jodhpur, where aquifers are deep, heterogeneous, and already severely depleted, behavioral change alone is insufficient without parallel economic incentives, technological support, and regulatory enforcement.

Jal Swavalamban Abhiyan (JSA)

The Jal Swavalamban Abhiyan, initiated by the Government of Rajasthan, seeks to enhance water self-sufficiency through rainwater harvesting, catchment treatment, recharge structures, and revival of traditional water bodies. The program has contributed to the construction and renovation of lakhs of water conservation structures across the state, including anicuts, check dams, tankas, and baoris. In Jodhpur, JSA has demonstrated localized improvements in surface storage and shallow groundwater recharge, particularly in years of favorable rainfall. Studies by state agencies and independent researchers indicate short-term rises in post-monsoon water levels near recharge structures. However, these gains often remain spatially fragmented and temporally fragile, especially in drought years when recharge is minimal and extraction continues unchecked.

Governance and Implementation Challenges: Limited Institutional Coordination

Groundwater governance in Rajasthan is characterized by institutional fragmentation across multiple departments, including water resources, groundwater, agriculture, energy, and rural development. Policy objectives often operate in isolation for example; water conservation initiatives are undermined by electricity subsidies that incentivize continuous pumping. The absence of a unified governance framework integrating water energy agriculture linkages reduces policy coherence and effectiveness.

Inadequate Monitoring and Data Gaps

Although groundwater monitoring networks have expanded, data density and resolution remain insufficient, particularly at the village and aquifer scale. CGWB observation wells provide valuable long-term trends but are often too sparse to capture localized variability in hard-rock and alluvial aquifers found in parts of Jodhpur. Limited real-time monitoring and weak enforcement of borewell registration further constrain regulatory oversight, allowing uncontrolled extraction to persist.

Regulatory Weakness and Enforcement Constraints

While Rajasthan has introduced legal provisions for groundwater regulation, enforcement remains politically and administratively challenging. Groundwater continues to be treated de facto as a private property linked to land ownership, making restrictions on extraction socially contentious. Efforts to regulate drilling depth, pump capacity, or abstraction volumes face resistance from farmers and urban stakeholders alike, particularly in the absence of viable livelihood alternatives or compensation mechanisms.

Behavioral Change and Social Acceptance

Programs such as ABHY emphasize behavioral change, yet altering long-established water-use practices is a slow and complex process. In regions facing acute scarcity, individual users often prioritize short-term water security over collective sustainability. Additionally, awareness initiatives frequently fail to reach women, tenant farmers, and landless laborers groups that are most affected by groundwater depletion but least involved in decision-making processes.

Role of Community-Based and Traditional Approaches

Revival of traditional water management systems including baoris, johads, tankas, and community-managed tanks has shown considerable promise in strengthening local water resilience. These systems not only enhance recharge but also foster collective ownership and stewardship, addressing the social dimensions of groundwater governance. Case studies from western Rajasthan demonstrate that villages with functional traditional systems and active local institutions exhibit relatively lower dependence on deep borewells and tanker water. However, such initiatives often remain limited in scale and continuity, dependent on short-term project funding or civil society leadership. Without sustained policy support, technical guidance, and integration into formal planning processes, their long-term impact remains constrained.

Way Forward: Bridging Policy and Practice

The experience of Jodhpur highlights that groundwater sustainability cannot be achieved through isolated interventions. Effective governance requires:

- Integrated policy frameworks linking groundwater management with agriculture, energy, and urban planning
- Scaling up community-based institutions with legal recognition and financial support
- Strengthening monitoring systems through aquifer-level mapping and real-time data
- Aligning incentives toward water-efficient crops, technologies, and practices
- Revitalizing traditional knowledge systems alongside modern hydrogeological science

In essence, while initiatives such as Atal Bhujal Yojana and Jal Swavalamban Abhiyan mark important paradigm shifts, their success in districts like Jodhpur will depend on sustained institutional commitment, inclusive governance, and the political will to move from short-term water security toward long-term groundwater sustainability.

Salinization and Groundwater Quality Deterioration

One of the most critical environmental consequences of groundwater depletion in Jodhpur is the deterioration of groundwater quality. As water tables fall, deeper and more mineralized groundwater is increasingly tapped, resulting in higher concentrations of total dissolved solids (TDS), salinity, fluoride, and nitrate. CGWB groundwater quality assessments for Rajasthan indicate that significant areas of Jodhpur exhibit salinity levels above permissible drinking water limits, rendering groundwater unsuitable for both drinking and irrigation. Salinization not only affects crop yields but also leads to long-term soil degradation, reducing agricultural productivity.

Drying of Wetlands, Stepwells, and Traditional Water Bodies

Declining groundwater levels have severely affected traditional water bodies, including baoris, tanks, and seasonal wetlands. Many stepwells that once maintained perennial or semi-perennial water supplies now remain dry for most of the year. The loss of base flow from aquifers has resulted in the shrinking or complete disappearance of these water bodies, undermining their ecological, cultural, and recharge functions. Studies from western Rajasthan highlight that the decline of traditional water systems has weakened local hydrological resilience and increased dependence on external water sources (UNDP, 2019).

Loss of Biodiversity and Ecosystem Services

Groundwater depletion has also led to a decline in biodiversity, particularly in and around wetlands, grasslands, and agro-ecosystems. Reduced water availability affects native vegetation, forage resources, and wildlife habitats, disrupting ecological balance. The loss of ecosystem services such as micro-climate regulation, soil stabilization, and support for livestock further exacerbates vulnerability in dryland communities.

Synthesis

Collectively, the social and environmental impacts of groundwater depletion in Jodhpur reflect a reinforcing feedback loop, wherein environmental degradation intensifies social vulnerability, and socio-economic pressures further drive unsustainable resource use. These impacts underscore that groundwater depletion is not merely a technical or hydrological concern but a multi-dimensional sustainability challenge, with profound implications for equity, livelihoods, and ecological integrity in arid regions.

Policy Responses and Governance Challenges

Initiatives such as Atal Bhujal Yojana and Jal Swavalamban Abhiyan represent important shifts toward participatory groundwater governance. However, limited institutional coordination, inadequate monitoring, and insufficient behavioral change constrain their effectiveness. Community-based approaches and revival of traditional systems have shown promise but require scaling and sustained policy support.

Discussion

The case of Jodhpur demonstrates that groundwater depletion in arid and semi-arid regions cannot be adequately understood or addressed through a purely hydrological lens. Rather, it represents a hydro-social crisis, in which environmental constraints interact with socio-economic inequalities, technological transitions, institutional weaknesses, and entrenched patterns of resource use. While natural scarcity and climatic variability form the biophysical backdrop of water stress in western Rajasthan, the magnitude and persistence of groundwater decline in Jodhpur are largely the outcome of human decision-making and governance structures.

Groundwater Depletion Beyond Physical Scarcity

Jodhpur's hydrogeological setting characterized by low rainfall, high evapotranspiration, and limited recharge potential predisposes the region to water stress. However, similar arid environments across the world exhibit markedly different groundwater outcomes, depending on governance regimes and social organization. The sustained decline of 1-2 meters per year observed in Jodhpur indicates that extraction patterns have systematically exceeded the ecological limits of aquifers for several decades, pointing to structural rather than episodic failure. The transition from community-managed surface-based water systems to atomized, technology-driven groundwater extraction has fundamentally altered human–water relations in the region. Borewell technology, subsidized energy, and weak regulation have enabled users with greater financial capacity to access deeper aquifers, marginalizing smallholders and landless households. This has transformed groundwater from a shared survival resource into a contested and unequal commodity, reinforcing socio-economic stratification.

Governance Failures and Institutional Mismatch

The findings reveal a significant mismatch between ecological scale and governance scale. Groundwater aquifers function as common-pool resources that transcend administrative boundaries, yet management remains fragmented across departments and jurisdictional units. Programs such as Atal Bhujal Yojana promote participatory water governance, but their effectiveness is constrained by limited spatial coverage, short project cycles, and the absence of enforceable extraction controls. Moreover, policy emphasis has largely remained skewed toward supply-side interventions such as recharge structures while insufficient attention is given to demand management, cropping pattern transformation, and regulation of abstraction. In regions like Jodhpur, where recharge potential is inherently limited, reliance on recharge-centric solutions risks creating a false sense of security and may even encourage further extraction, a phenomenon widely described as the "rebound effect."

Socio-Economic Inequities and Differentiated Impacts

The Jodhpur case highlights that groundwater depletion produces uneven social outcomes, disproportionately affecting women, small farmers, pastoral communities, and urban poor populations. Those least responsible for extraction are often the most vulnerable to its consequences. Increased time burdens for water collection, loss of agricultural viability, rising indebtedness, and migration underscore the social costs of unsustainable groundwater use.

These patterns mirror findings from other arid and semi-arid regions of India such as Bundelkhand, Marathwada, and parts of Gujarat where groundwater decline has been linked to agrarian distress, rural out-migration, and deteriorating human development indicators. Thus, Jodhpur should not be viewed as an isolated case but as part of a broader national groundwater crisis.

Role of Local Knowledge and Collective Action

An important insight emerging from the study is the potential of community-based institutions and traditional water systems to address both ecological and social dimensions of groundwater depletion. Historical practices in Jodhpur, centered on baoris, johads, and tankas, were embedded in local ecological knowledge and collective norms of water sharing. Their marginalization has not only reduced recharge but also weakened social mechanisms for restraint and cooperation. Where community-led initiatives have been revived, evidence suggests improved water security, heightened awareness of aquifer limits, and greater willingness to adopt demand-side measures. However, such approaches remain constrained by broader political economic structures and require formal policy recognition, capacity building, and financial continuity to be scalable and durable.

Implications for Policy and Sustainability Transitions

The Jodhpur experience reinforces the argument that sustainable groundwater management in India's drylands requires a paradigm shift from treating groundwater as an infinite private resource to recognizing it as a finite common requiring collective stewardship. Policies must move beyond techno-managerial fixes and incorporate social equity, behavioural change, and institutional accountability as core components. Localized, aquifer-specific planning; inclusion of marginalized voices in decision-making; alignment of agricultural incentives with water availability; and integration of traditional systems with scientific groundwater monitoring are essential for long-term sustainability. Importantly, groundwater governance must be embedded within broader development and climate adaptation strategies, particularly in the context of increasing climate variability. In sum, the Jodhpur case underscores that groundwater depletion is not merely an environmental challenge but a developmental and governance challenge. Addressing it effectively demands an integrated, inclusive, and demand-side-focused approach one that aligns human aspirations with the ecological realities of arid landscapes and resonates with wider efforts toward sustainable and equitable development in India's dryland regions.

Conclusion

Groundwater depletion in Jodhpur represents a critical convergence of environmental vulnerability, socio-economic stress, and governance insufficiency in an arid and climatically fragile region. The sustained decline of groundwater levels, driven by prolonged over-extraction, limited natural recharge, and increasing climatic variability, has emerged as one of the most pressing challenges to the district's long-term sustainability. As the preceding analysis demonstrates, groundwater stress in Jodhpur is not an isolated hydrological issue but a multidimensional crisis affecting agricultural productivity, livelihood security, public health, and ecological resilience. The over-reliance on deep borewell–based extraction, coupled with weak regulatory enforcement and fragmented institutional arrangements, has progressively undermined the viability of aquifers that once ensured water security in the region. For agrarian communities, declining groundwater has translated into rising irrigation costs, declining crop yields, farmer indebtedness, and increasing dependence on climate-sensitive livelihoods. Simultaneously, urban expansion and growing domestic water demand have intensified competition over an already scarce resource, exacerbating social inequities between rural and urban users and between socio-economic groups.

Environmental consequences further compound these challenges. Aquifer depletion has disrupted soil water interactions, accelerated land degradation and salinization, and contributed to the drying up of traditional water bodies such as baoris and lakes systems that once supported both biodiversity and social cohesion. These changes have weakened critical ecosystem services in a region already exposed to desertification risks and climate extremes, thereby reducing the adaptive capacity of both natural and human systems. The findings strongly suggest that addressing groundwater depletion in Jodhpur requires a fundamental shift in water governance paradigms. Supply-oriented and infrastructure-heavy solutions alone are insufficient in a landscape with limited recharge potential. Instead, integrated, demand-side-focused strategies must be prioritized, including regulation of abstraction, promotion of water-efficient cropping patterns, participatory water budgeting, and the revival of traditional rainwater harvesting and recharge systems. Programs such as the Atal Bhujal Yojana and Jal Swavalamban Abhiyan mark important steps in this direction but must be strengthened through sustained institutional support, transparent monitoring, and meaningful community participation.

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