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HYDROGEOLOGICAL EVALUATION AND MANAGEMENT OF GROUNDWATER RESOURCES IN CHURU DISTRICT, RAJASTHAN: EMERGING CHALLENGES IN AN ARID REGION

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Abstract: *Groundwater, a critical resource constituting over 97 percent of Earth's liquid freshwater, is vital for sustainable development, supporting agriculture, drinking water, and industrial needs. Effective management is essential to mitigate over-extraction and contamination, particularly in arid regions. In Churu District, Rajasthan, over-exploitation and poor groundwater quality due to high salinity, fluoride, and nitrate levels threaten water security and agricultural productivity. Located in the arid Rajasthan Plain, Churu spans 16,830 km² with a population of 2,039,547, relying heavily on groundwater for 90 percent of drinking and 60 percent of irrigation needs. This study aims to assess groundwater quality, evaluate management practices, and propose sustainable conservation strategies tailored to Churu's hydrogeological and socio-economic context. Data from the Central Ground Water Board (CGWB), including hydrogeological surveys, water level records (2017), and quality analyses (2016), alongside agricultural statistics (2013–14), were analyzed using GIS-based mapping and GEC'97 norms. Findings reveal a critical groundwater development stage (92.59 percent), with blocks like Rajgarh (374.96 percent) and Sujangarh (131.73 percent) over-exploited, and quality issues rendering water unsuitable in many areas. Localized recharge efforts show limited success, but declining water levels and contamination persist. The study underscores the need for artificial recharge structures, modern irrigation techniques, and community-driven governance to ensure sustainability. These findings offer a replicable framework for managing groundwater in arid regions, informing policy and stakeholder actions to balance human and environmental needs.*

Key words: Groundwater Management, Water Quality, Sustainability, Churu District, Over-Exploitation

Introduction

Groundwater, often termed the “invisible resource,” has historically served as the cornerstone of water security for millions across the globe. Its subterranean nature allows it to act as a buffer against the volatility of surface water systems, especially in regions marked by climatic extremes. Globally, it supports nearly half of all drinking water needs and irrigates about 40 percent of the world’s agricultural land (UNESCO, 2022). Yet, this essential resource is being depleted at unsustainable rates. A pioneering study by Gleeson et al. (2012) estimated that around one-fifth of the world's major aquifers are undergoing long-term depletion. This overextraction is not just a function of need it reflects a pattern of development that has prioritised short-term gains over long-term sustainability, often underpinned by the absence of robust groundwater governance mechanisms (Villholth, 2013). In many water-scarce countries, particularly those in the global South, groundwater has evolved from being a supplementary resource to a primary source. The Indian context exemplifies this transition in both scale and urgency. India, despite being home to just over 18 percent of the world’s population, accounts for nearly 25 percent of global groundwater withdrawals (World Bank, 2010; Wada et al., 2010). This dependence was magnified during the Green Revolution when tubewell-based irrigation was aggressively promoted to ensure food security. While the policy succeeded in increasing agricultural yields, it also entrenched a model of high-volume groundwater extraction supported by subsidised electricity and a lack of regulatory oversight (Shah, 2009). The result is a paradox: groundwater has become both a driver of rural prosperity and a source of looming ecological distress.

Current assessments paint a sobering picture. According to the Central Ground Water Board (CGWB, 2021), more than 70 percent of India’s groundwater assessment units fall into 'semi-critical', 'critical', or 'overexploited' categories. These classifications are based on the ratio of annual extraction to annual replenishment and point to a structural imbalance that is growing more acute. In certain areas, particularly in northwestern India, water tables are declining by more than one metre per year (Rodell et al., 2009). Yet, the response to this crisis has often been reactive rather than anticipatory. Institutions have struggled to keep pace with the growing complexity of the problem, which intersects with agriculture, energy, health, and climate change. The challenge is not only one of quantity. Groundwater quality across India is deteriorating in tandem with declining levels. Geogenic contaminants such as fluoride and arsenic, along with anthropogenic pollutants like nitrate, heavy metals, and pesticide residues, are increasingly common in aquifers used for drinking and irrigation (Singh et al., 2018; Amini et al., 2008). For instance, high fluoride exposure, which affects bone health, is prevalent in Rajasthan, Andhra Pradesh, and parts of Gujarat, while arsenic contamination is a chronic issue in West Bengal and Bihar. Nitrate, often leached from fertilisers and poor sanitation systems, has been linked to methemoglobinemia or ‘blue baby syndrome’ in infants (UNICEF, 2014). These health risks are particularly severe in rural and peri-urban regions where groundwater remains the only viable source of water.

In this context, the western Indian state of Rajasthan represents an extreme but telling case. Arid in climate and vast in area, Rajasthan accounts for 10.4 percent of India’s geographical area but holds just 1.16 percent of its surface water and 1.72 percent of its groundwater reserves (Government of Rajasthan, 2010; CGWB, 2020). The state is heavily reliant on groundwater, with over 90 percent of drinking water and more than 60 percent of irrigation needs met through aquifers. However, most of these aquifers are under severe stress. CGWB (2021) reports that over 80 percent of administrative blocks in Rajasthan are classified as overexploited or critical. This pattern of unsustainable use is compounded by erratic rainfall (300–600 mm annually), high evaporation rates, and poor surface storage capacity. Historically, Rajasthan developed innovative indigenous systems for rainwater harvesting, including johads, baoris, tankas, and kunds, which not only recharged local aquifers but also served as symbols of decentralised water governance (Agarwal & Narain, 1997). However, the advent of mechanised pumping technologies and the decline in community-based management have led to the erosion of these systems. Studies by Jain et al. (2018) show that while some of these traditional structures have been revived under government programmes like MNREGA, their integration into a larger aquifer management framework remains weak and poorly monitored. Churu District, located in the Shekhawati region of northwestern Rajasthan, embodies the hydrological and institutional challenges discussed above. Geographically situated in the Thar Desert, Churu experiences low recharge potential and high evapotranspiration, making groundwater not only the most relied upon but also the most threatened resource. Spanning over 13.85 lakh hectares, the district houses over two million people, the vast majority of whom are dependent on groundwater for drinking, agriculture, and livestock rearing (Census of India, 2011). According to hydrogeochemical studies conducted by Kumar et al. (2019), nearly 77 percent of groundwater samples from the district exhibit electrical conductivity above 3.0 dS/m indicative of high salinity. Sodium Adsorption Ratio (SAR) values range from 0.05 to 68.11, significantly limiting the water's suitability for irrigation. Moreover, fluoride concentrations in certain areas reach as high as 13.25 mg/L, far exceeding the World Health Organization's safe limit of 1.5 mg/L (Sharma, Kumar, & Singh, 2021). Similarly, nitrate concentrations have been recorded up to 196.24 mg/L, surpassing BIS guidelines and posing significant health risks.

The human impacts of this degraded groundwater regime are significant but often underreported. Villages in Churu frequently rely on tanker-supplied water during dry months, and the burden of water collection falls disproportionately on women and children. Agricultural productivity is also in decline, with farmers either shifting to less water-intensive crops or abandoning cultivation altogether. Yadav et al. (2014) highlight that poor water quality, combined with unpredictable availability, is contributing to distress migration in several blocks of the district. Groundwater management is crucial for ensuring the sustainability of this vital resource, which constitutes over 97 percent of the Earth's liquid freshwater and supports drinking water, agriculture, and industrial activities (Rekha et al., 2024). Effective management practices are necessary to prevent over-extraction, contamination, and degradation of aquifers, which can lead to severe ecological and economic consequences (Rekha et al., 2024; Anand & Kumar, 2016). Innovative technologies, including AI-driven models, enhance decision-making by enabling real-time monitoring and identifying vulnerable areas for targeted interventions (Borgohain et al., 2024). Furthermore, multi-objective hydro-economic modelling can optimise groundwater use while balancing agricultural profitability and energy consumption, demonstrating that sustainable practices may require trade-offs, such as a reduction in agricultural profits to maintain groundwater levels (Afshar et al., 2020). Overall, a participatory governance framework that integrates ecological, economic, and social dimensions is crucial for achieving long-term groundwater sustainability.

The problem of groundwater depletion and contamination is particularly pronounced in Churu District. Studies indicate that 77 percent of groundwater samples in the region exhibit electrical conductivity (EC) exceeding 3.0 dS m^{-1}, indicating high salinity, while sodium adsorption ratios (SAR) range from 0.05 to 68.11, rendering much of the water unsuitable for irrigation (Kumar et al., 2019). Additionally, fluoride levels (0–13.25 mg L^{-1}) and nitrate concentrations (1.29–196.24 mg L^{-1}) frequently exceed World Health Organization (WHO) and Bureau of Indian Standards (BIS) limits, contributing to non-carcinogenic health risks in 71–78 percent of samples (Khan & Sharma, 2007)). These quality issues, combined with a declining groundwater table due to over-pumping for irrigation, threaten the sustainability of water resources in Churu, impacting both rural livelihoods and urban water security (CGWB, 2020). The significance of this research lies in its focus on Churu District as a microcosm of the broader groundwater crisis in arid regions. With groundwater levels declining in 38 percent of Rajasthan's districts between 2000 and 2021 (CGWB, 2021), and limited studies addressing localized management strategies for Churu, this paper fills a critical gap in the literature. The findings are expected to inform policymakers, local communities, and stakeholders about integrated approaches combining traditional practices, such as Chauka rainwater harvesting systems, with modern interventions like artificial recharge structures. Ultimately, this study contributes to the broader discourse on sustainable water management in water-scarce regions, offering a replicable framework for balancing human needs with environmental conservation in arid ecosystems.

Rajasthan, occupying 10 percent of India's geographical area, holds only 1.16 percent of the country's surface water and 1.70 percent of its groundwater resources, making it heavily reliant on groundwater for domestic, agricultural, and industrial needs (Government of Rajasthan, 2010). The Central Ground Water Board (CGWB) (2020) reports that groundwater meets approximately 90 percent of drinking water and 60 percent of irrigation demands in the state, with 80 percent of its districts classified as overexploited or critical in terms of groundwater extraction. Overexploitation is driven by intensive agricultural practices and low recharge rates due to the arid climate, with annual rainfall averaging 400–600 mm in most districts (CGWB, 2021). Studies highlight a significant decline in groundwater levels, with 38 percent of Rajasthan's districts reporting a drop of 0.2–0.4 meters per year between 2000 and 2021 (CGWB, 2021). Additionally, contamination by fluoride, nitrate, and salinity has rendered groundwater in many areas unsuitable for consumption or irrigation, exacerbating water scarcity (Singh et al., 2018).

Groundwater management in Rajasthan integrates traditional and modern approaches to address scarcity and quality issues. Traditional rainwater harvesting systems, such as the Chauka system, have been effective in capturing runoff in barren lands, enhancing recharge by up to 5 percent in localized areas. Modern interventions include artificial recharge structures like check dams, recharge shafts, and anicuts, often supported by government programs such as the Mahatma Gandhi National Rural Employment Guarantee Act (MNREGA) (CGWB, 2020). Community-based management has gained traction, with initiatives like Bhujal Jankaars (community water monitors) promoting participatory groundwater governance in rural Rajasthan (Birkenholtz, 2017). The Rajasthan State Water Policy (2010) prioritizes water allocation for drinking over irrigation and encourages recharge structures, but implementation is hindered by weak enforcement and lack of clear property rights for groundwater (Government of Rajasthan, 2010). Case studies, such as the Arvari River basin, demonstrate the success of community-driven recharge efforts, with groundwater levels rising by 1–2 meters in managed watersheds (Davies et al., 2016). However, upstream-downstream conflicts and inequitable access to recharge benefits remain challenges.

Despite the growing body of research, several gaps persist in the study of groundwater management in Churu District. First, while regional studies on Rajasthan's groundwater are abundant, few focus specifically on Churu's unique hydrogeological and socio-economic context, limiting the applicability of generalized findings (Khan & Sharma, 2007). Second, there is a lack of comprehensive studies integrating water quality, quantity, and management practices to propose localized, sustainable solutions for Churu (Kumar et al., 2019). Third, the effectiveness of traditional practices like Chaukas in Churu remains understudied, with most research focusing on other Rajasthan districts. Finally, there is limited exploration of community engagement models, such as photovoice or participatory GIS, to enhance local awareness and ownership of groundwater management (Birkenholtz, 2017). Addressing these gaps requires a multidisciplinary approach that combines hydrogeological analysis, community participation, and policy evaluation tailored to Churu's arid environment. The growing stress on groundwater in India's arid and semi-arid regions has prompted a surge in research focused on sustainability, quality, and governance. While studies often highlight large-scale depletion, there remains a pressing need to understand localised contexts, especially in districts such as Churu, where hydrogeological, climatic, and socio-economic factors intersect in complex ways. Much of the existing work points to the alarming pace of groundwater depletion across northwestern India. Upadhyay, Ketholia, and Pandey (2018), using satellite data, identified this region as one of the most severely affected globally, where abstraction significantly outpaces natural recharge. Building on these findings, Scanlon et al. (2012) noted that irrigation remains the primary driver of depletion, with limited attention paid to alternative cropping patterns or water-saving technologies. Although such macro-level analyses are valuable, they often overlook district-level dynamics that are crucial for designing effective interventions.

Technological progress has begun to reshape how groundwater resources are monitored and managed. For instance, the use of GRACE satellite data by Frappart and Ramillien (2018) provided detailed insights into groundwater changes across India, while more recent efforts by Sheikhi, Ashrafi, and Nikoo (2023) have introduced artificial intelligence-based models capable of forecasting depletion zones by integrating rainfall, land use, and socio-economic indicators. These tools, though promising, are still evolving and require more robust field validation, particularly in less-researched areas like Churu. In terms of groundwater quality, the problem is no longer limited to isolated contaminants. Studies show that combinations of fluoride, nitrate, and heavy metals are increasingly found in the same aquifers, which can amplify health risks (Adimalla, 2020; Garg, Singh, & Poonia, 2021). Tiwari and Singh (2016) argue for the development of risk-based indices that incorporate both chemical and microbial parameters to assess the full scope of potential health hazards. Meanwhile, Narain (2018) draws attention to the fact that water-related health burdens are not evenly distributed. Women, who often manage household water collection and use, are more exposed to contaminated sources, yet remain marginalised in decision-making processes related to water governance.

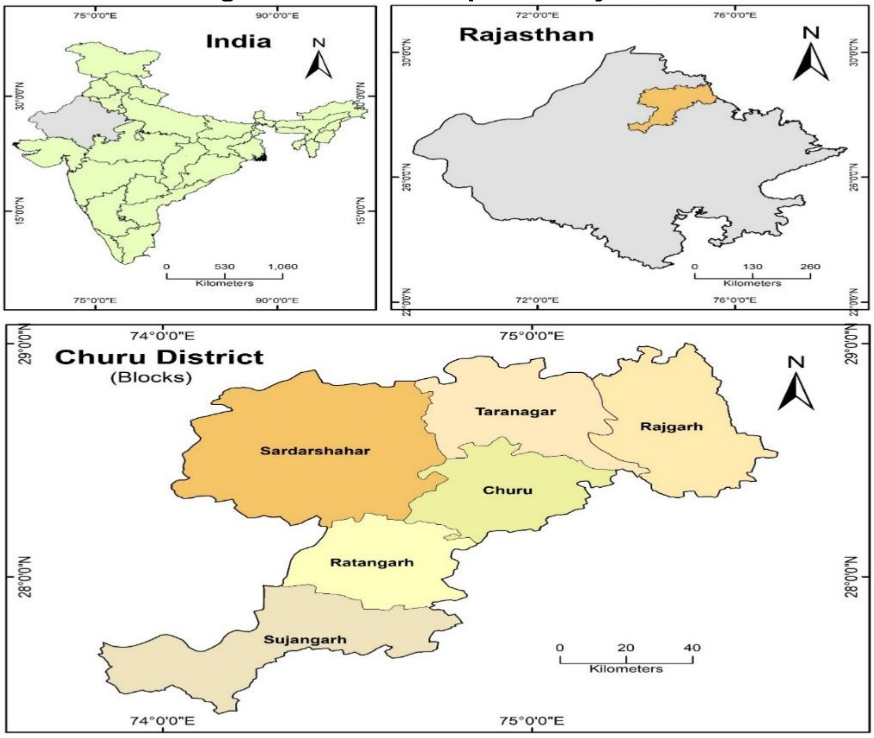
There is also a growing recognition that technological fixes alone are insufficient. Institutional and community-based approaches have emerged as important elements of sustainable groundwater management. Ostrom's (1990) theory of common-pool resources highlights how local rules, trust, and collective action can succeed where formal regulation fails. On the policy front, hydro-economic frameworks have gained attention for their potential to balance water use with financial viability. Konikow and Kendy (2005) advocated for demand-side regulation through pricing and usage permits. Afshar, Tavakoli, and Khodagholi (2020) demonstrated through modelling that optimising groundwater use often involves trade-offs, including potential reductions in short-term agricultural profits to ensure long-term water availability. These models offer practical tools for decision-makers but are rarely implemented due to political and institutional constraints. Climate change adds another layer of complexity. Mall et al. (2006) and Roy, Sharma, and Jha (2018) have shown that rising temperatures and irregular rainfall patterns are likely to reduce natural recharge, especially in sandy soil regions like Churu. The vulnerability of shallow aquifers to drying out during extended droughts has already been observed in several districts. Gleeson et al. (2020) argue for the development of resilience-oriented aquifer management, which combines scientific data with community inputs to adapt to uncertain hydrological futures. Altogether, the literature makes it clear that managing groundwater in arid regions requires more than just increasing recharge. A successful strategy must integrate technological tools, community knowledge, economic planning, and an understanding of local social dynamics. The present study draws on these broader insights to explore the groundwater challenges in Churu District, offering a locally grounded perspective to a problem of national importance.

Study Area

Churu District, situated in the northeastern part of Rajasthan, India, covers an area of 16,830 square kilometers, representing 4.92 percent of the state's total area. Located between 27°24'00" to 29°00'00" North latitudes and 73°40'00" to 75°38'00" East longitudes, it is bordered by Hanumangarh to the north, Bikaner to the west, Nagaur to the south, Sikar and Jhunjhunu to the southwest, and Hissar district of Haryana to the east. The district comprises seven tehsils Sujangarh, Sardarshahar, Rajgarh, Churu, Ratangarh, Taranagar, and Bidasar and six administrative blocks, with 899 villages. As per the 2011 census, the population is 2,039,547, with 1,463,312 rural and 576,235 urban residents. The region experiences a dry climate, receiving an average annual rainfall of 369.60 mm (2006–2016), predominantly during the southwest monsoon from late June to mid-September. The Kantli River, an ephemeral drainage system, flows from Jhunjhunu in the southeast and dissipates near Rajgarh, active only during high rainfall.

Geomorphologically, Churu is characterized by extensive sand dunes and isolated hard rock hillocks, with a gentle slope toward the north or northwest and elevations ranging from over 500 meters to below 230 meters above mean sea level. Soils include aeolian sand dunes in the north, desert soils in the south, red desert soils in a southern-western belt, and saline soils in low interdunal areas with poor drainage. Geologically, the district is divided into the Sikar and Bikaner basins by NNE-SSW faults, with the eastern Sikar basin featuring eroded Pre-Cambrian crystalline basement and the western Bikaner basin preserving thicker Palana Series and Marwar Supergroup sediments. Aquifers include unconsolidated Quaternary alluvium, semi-consolidated Palana sandstone, and consolidated Bilara limestone and Nagaur Group rocks, with yields varying from meager to 1,121 liters per minute. Groundwater quality and availability are critical concerns, with alkaline water predominant and issues like high electrical conductivity (265–10,000 µS/cm), fluoride (up to 10.3 mg/l), nitrate (up to 1,124 mg/l), and iron (up to 6.93 mg/l) affecting usability. Depth to water levels in 2017 ranged from 5.66 to 66.85 mbgl pre-monsoon and 6.66 to 64.10 mbgl post-monsoon, with declining trends in some areas due to over-exploitation. The stage of groundwater development is 92.59 percent (2013), with blocks like Rajgarh (374.96 percent) and Sujangarh (131.73 percent) over-exploited, while Sardarshahar (39.79 percent) is safe. Total replenishable groundwater resources are 141.8221 MCM, with a net availability of 134.7310 MCM and a gross draft of 124.7477 MCM. Hydrogeological studies by the Central Ground Water Board, including borehole drilling (1965–67) and monitoring since 1972, highlight over-exploitation and quality issues, necessitating artificial recharge, watershed development, and modern irrigation techniques to ensure sustainable water management in this arid region.

Fig 01: Location Map of Study Area



Database and Methodology

Database

The research on the groundwater scenario in Churu District, Rajasthan, relies on a comprehensive dataset compiled from multiple authoritative sources, primarily the Central Ground Water Board (CGWB) and the State Ground Water Department, Rajasthan. The primary data sources include systematic hydrogeological surveys conducted by the CGWB, exploratory drilling records from 1965–67 (34 boreholes) and 1971–74 under the United Nations Development Programme, and reappraisal hydrogeological surveys covering the entire district. Water level data were obtained from 43 National Network Hydrogeological Stations established by the CGWB, with measurements taken four times annually since 1972. These stations, along with key wells inventoried during surveys and piezometers from the State Ground Water Department, provided data for depth to water level maps for pre-monsoon (May 2017) and post-monsoon (November 2017), as well as seasonal water level fluctuations and decadal trends (2007–2016). Groundwater quality data, including electrical conductivity (265–10,000 µS/cm), fluoride (0.01–10.3 mg/l), nitrate (0.56–1,124 mg/l), iron (0.005–6.93 mg/l), and pH (7.27–8.46), were sourced from CGWB's pre-monsoon 2016 analyses.

Additional data on land use, irrigation, and crop patterns were derived from the Rajasthan Agriculture Statistics (2013–14) and District Agriculture Statistics (2013–14), detailing net sown area (1,153,316 ha), total cropped area (1,354,565 ha), and irrigation by sources such as tubewells (64,949 ha), other wells (34,449 ha), and canals (7,334 ha). Geological and hydrogeological information, including aquifer characteristics, was compiled from CGWB reports, which describe unconsolidated (Quaternary alluvium, aeolian sand), semi-consolidated (Palana Series sandstone), and consolidated (Bilara limestone, Nagaur Group) formations. Groundwater resource estimates, calculated as per the Groundwater Estimation Committee (GEC'97) norms, were jointly provided by CGWB and the State Ground Water Department, reporting annually replenishable resources (141.8221 MCM), net availability (134.7310 MCM), and gross draft (124.7477 MCM) for 2013. Landsat imagery studies supplemented drainage and geomorphological data, particularly for the Kantli River's course. All data were cross-verified for consistency and reliability, ensuring a robust foundation for analysis.

Methodology

The methodology adopted for this study integrates quantitative and qualitative approaches to assess the groundwater scenario in Churu District. Hydrogeological data analysis involved mapping depth to water levels using pre- and post-monsoon 2017 data from CGWB's National Hydrograph Stations and inventoried wells. Spatial interpolation techniques were applied to generate depth to water level maps (Figures 3 and 4) and seasonal fluctuation maps (Figure 5) using Geographic Information System (GIS) tools. Long-term water level trends were analyzed by computing decadal pre-monsoon water level changes (2007–2016) to identify areas with rising (up to 25 cm/year) or declining (up to 25 cm/year) trends (Figure 6). Groundwater quality was evaluated by analyzing chemical parameters (pH, electrical conductivity, fluoride, nitrate, and iron) from pre-monsoon 2016 data, with spatial distribution maps (Figures 7–10) created to highlight areas exceeding permissible limits, such as fluoride in Rajgarh and nitrate across multiple blocks.

Groundwater resource assessment followed the GEC'97 methodology, which excludes saline and hilly areas, to estimate annually replenishable resources, net availability, gross draft, and stage of development (92.59 percent overall, with block-wise variations). Aquifer characterization was based on CGWB's exploratory drilling and pumping test data, detailing specific yields (0.5–7 percent) and transmissivity (2.5–1,024 m²/day) for different formations. Agricultural and irrigation data were analyzed to correlate groundwater draft with irrigation patterns, focusing on tubewell and well-based irrigation. Recommendations for groundwater management, including artificial recharge and conservation strategies, were formulated by integrating hydrogeological findings with land use and climatic data, emphasizing sustainable practices like check dams, watershed development, and modern irrigation techniques. The study ensured data triangulation by cross-referencing CGWB, State Ground Water Department, and agricultural statistics, enhancing the reliability of conclusions drawn regarding over-exploitation, quality issues, and management strategies.

Results and Discussion: Groundwater Scenario

Depth to Water Level

The analysis of groundwater levels in Churu District, based on data from 43 National Hydrograph Stations and inventoried wells, reveals significant spatial and temporal variations. Pre-monsoon (May 2017) depth to water levels ranged from 5.66 to 66.85 meters below ground level (mbgl), with shallower levels (<35 mbgl) observed in Sardarshahar, Ratangarh, Rajgarh, and parts of Sujangarh blocks. Deeper levels (>20 mbgl) were prevalent in the northern and southern parts of the district. Post-monsoon (November 2017) levels varied from 6.66 to 64.10 mbgl, with notable improvements in Sujangarh (6.66 mbgl minimum). Block-wise details are presented in Table 1, highlighting the variability across the district.

Table 01: Depth to Water Level (2017)

Block	Pre Monsoon		Post Monsoon	
	Min.	Max.	Min.	Max.
Churu	18.94	43.16	21.64	43.50
Rajgarh	12.51	51.86	9.98	49.78
Ratangarh	27.85	48.15	27.88	59.68
Sardarshahar	28.76	66.85	29.11	60.63
Sujangarh	5.66	9.10	6.66	64.10
Taranagar	7.81	15.50	8.87	12.80

Source: Central Ground Water Board (CGWB) and the State Ground Water Department, Rajasthan

The shallower water levels in Sujangarh and Taranagar suggest better recharge potential, likely due to proximity to the Kantli River's influence, while deeper levels in Sardarshahar indicate heavy groundwater extraction. The post-monsoon rise in water levels reflects monsoon recharge, though the persistence of deep levels in some areas underscores over-exploitation.

Water Level Fluctuation

Seasonal water level fluctuations (May to November 2017) indicate a rise of more than 4 meters in Rajgarh, Sardarshahar, central Churu, northwestern Ratangarh, and parts of Sujangarh, attributed to monsoon recharge. Conversely, a decline of up to 2 meters was observed in central and northern parts of the district, likely due to continued groundwater withdrawal outpacing recharge. These fluctuations highlight the dependency on monsoon rainfall and the uneven distribution of recharge across the district.

Long-Term Water Level Trends

Analysis of decadal pre-monsoon water level data (2007–2016) shows a rising trend of up to 25 cm/year in the southwestern and northern parts, possibly due to localized recharge efforts or reduced extraction. However, a declining trend of up to 25 cm/year dominates the majority of the district, reflecting over-exploitation driven by agricultural and domestic demands. This declining trend is particularly concerning in blocks like Rajgarh and Sujangarh, where groundwater development is significantly overexploited.

Groundwater Quality

Quality of Shallow Groundwater

Groundwater in Churu District is predominantly alkaline, with pH values ranging from 7.27 to 8.46. Quality issues, including elevated electrical conductivity (EC), fluoride, nitrate, and iron, were observed in various blocks, impacting suitability for drinking and irrigation.

Electrical Conductivity

Electrical conductivity ranges from 265 to 10,000 µS/cm at 25°C, with most areas falling between 750 and 3,000 µS/cm. Higher EC values (>3,000 µS/cm) were recorded in northern Sujangarh and central-northeastern parts, indicating saline groundwater unsuitable for most uses. Lower EC (750–1,500 µS/cm) in parts of Churu, Taranagar, and Sardarshahar suggests relatively fresher water.

Fluoride

Fluoride concentrations range from 0.01 to 10.3 mg/l, with high values (exceeding the permissible limit of 1.5 mg/l) in Rajgarh, Sardarshahar, Ratangarh, and Sujangarh. The highest concentration (10.3 mg/l) was observed in Rajgarh, posing health risks such as fluorosis.

Nitrate

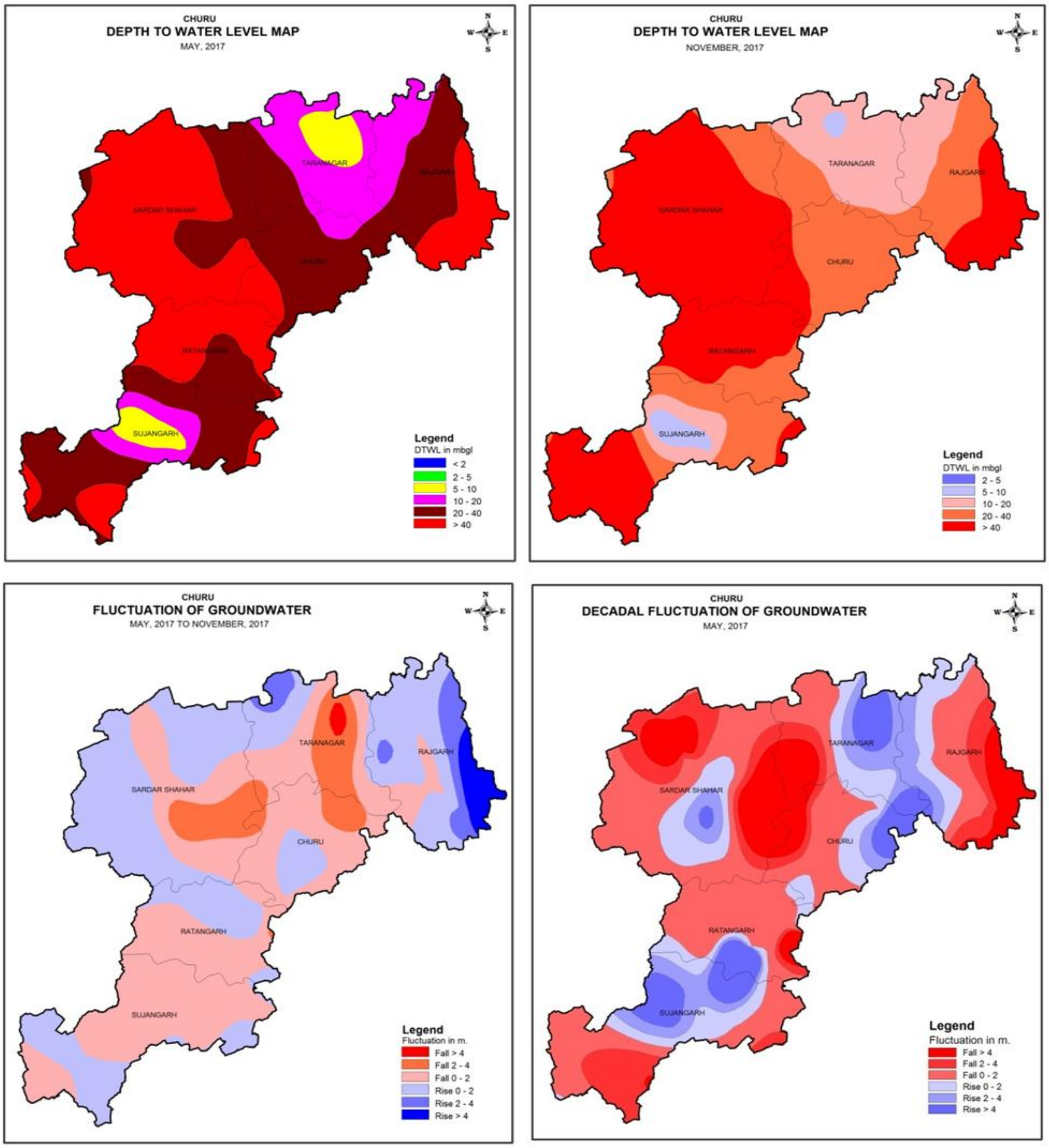
Nitrate levels, ranging from 0.56 to 1,124 mg/l, exceed the permissible limit of 45 mg/l in nearly all blocks. Extremely high concentrations (1,120–1,124 mg/l) were recorded in Bidasar and Dhirawas, likely due to agricultural runoff and poor sanitation practices, increasing risks of methemoglobinemia.

Iron

Iron concentrations are generally within the permissible limit of 1 mg/l, but elevated levels (up to 6.93 mg/l in Sardarshahar) were observed in Bamboo (2.53 mg/l), Binasar (3.63 mg/l), and Sardarshahar. These levels can affect water taste and usability.

The prevalence of quality issues, particularly high fluoride and nitrate, underscores the need for targeted treatment and monitoring to ensure safe water supply. Salinity in northern areas further limits groundwater usability, necessitating alternative water sources or desalination.

Figure 02: (a) Depth to water level (May 2017), (b) Depth to water level (November 2017), (c) Seasonal water level fluctuation map (May-November, 2017), (d) Decadal pre-monsoon water level trend map (May 2007 – 2016)



Groundwater Resources

Groundwater resource estimation, conducted using GEC'97 norms, indicates annually replenishable resources of 141.8221 million cubic meters (MCM), with a net availability of 134.7310 MCM and a gross draft of 124.7477 MCM as of 2013. The overall stage of groundwater development is 92.59 percent, classifying the district as critical. Block-wise estimates are presented in Table 2.

Rajgarh (374.96 percent) and Sujangarh (131.73 percent) are over-exploited, indicating severe stress on groundwater resources, while Sardarshahar (39.79 percent) remains safe due to lower extraction rates. The high draft in Rajgarh and Sujangarh is driven by intensive irrigation, reflecting the district's heavy reliance on groundwater for agriculture.

Table 02: Block-Wise Replenishable Groundwater Resources (As of 2013)

Block	Annually Replenishable Resource (MCM)	Net Annual Availability (MCM)	Annual Draft for Irrigation (MCM)	Annual Draft for Domestic & Industrial Use (MCM)	Gross Annual Draft (MCM)	Stage of Development (percent)	Category
Churu	10.3453	9.8280	4.1412	4.5045	8.6457	87.97	Semi-critical
Rajgarh	8.1631	7.7549	24.3456	4.7320	29.0776	374.96	Over-Exploited
Ratangarh	28.4327	27.0110	15.0300	5.0651	20.0951	74.40	Semi-critical
Sardarshahar	59.3164	56.3507	15.8100	6.6138	22.4238	39.79	Safe
Sujangarh	35.5645	33.7863	40.1310	4.3745	44.5055	131.73	Over-Exploited
Taranagar	0.0000	0.00	0.00	0.00	0.00	0.00	--
Total	**141.8221**	**134.7310**	**99.4578**	**25.2899**	**124.7477**	**92.59**	**Critical**

Source: Central Ground Water Board (CGWB) and the State Ground Water Department, Rajasthan

Status of Groundwater Development

The stage of groundwater development (92.59 percent) indicates near-full utilization of available resources, with no scope for further development in most blocks. Over-exploitation in Rajgarh and Sujangarh is exacerbated by low rainfall (369.60 mm annually) and increasing urban and agricultural demands. Rising trends in some areas suggest localized recharge efforts, but declining trends in major parts highlight unsustainable extraction. The reliance on tubewells (64,949 ha irrigated) and other wells (34,449 ha) underscores groundwater's critical role in irrigation, contributing to the high draft.

Groundwater-Related Issues and Problems

Over-exploitation is the primary issue, with all blocks except Sardarshahar exceeding 100 percent development, leaving no scope for additional groundwater abstraction. Quality issues, including high fluoride, nitrate, and salinity, further constrain usability, particularly in Rajgarh, Sujangarh, and Sardarshahar. Declining water levels, especially in northern areas, threaten long-term sustainability, while saline ingress risks contaminating freshwater aquifers due to over-extraction. These challenges are compounded by limited surface water availability from the ephemeral Kantli River and inadequate recharge infrastructure.

Groundwater Management Strategy

Groundwater Development

Given the over-exploited status of most blocks, further groundwater development for irrigation or industrial use is unsustainable. Exploratory drilling in unexplored areas could help refine aquifer parameters, but strict regulation of new abstraction structures is essential to prevent further depletion.

Water Conservation and Artificial Recharge

To address over-exploitation, artificial recharge structures like check dams, anicuts, and nala bunds should be constructed at hydrogeologically suitable sites to enhance monsoon recharge. Surface water reservoirs, such as ponds and tanks, can serve dual purposes of storage and recharge. Modern irrigation techniques, including drip and sprinkler systems, and cultivation of less water-intensive crops are recommended to reduce draft. Watershed development and soil conservation projects can further mitigate runoff losses and improve recharge.

The results highlight Churu District's critical groundwater situation, driven by over-exploitation and quality degradation. The high stage of development (92.59 percent) and block-specific over-exploitation (e.g., Rajgarh at 374.96 percent) reflect unsustainable extraction, primarily for irrigation, which accounts for 99.4578 MCM of the total draft. The declining water level trends in major areas, coupled with quality issues like high fluoride and nitrate, pose significant challenges for water security. Sardarshahar's safe status offers limited scope for development, but salinity risks must be addressed. The spatial variability in water levels and quality suggests the need for localized management strategies. Artificial recharge and conservation measures, supported by modern agricultural practices, are critical to restoring groundwater balance. However, the effectiveness of these interventions depends on community awareness and regulatory enforcement to curb over-extraction and promote sustainable water use.

Conclusion

The comprehensive analysis of Churu District's groundwater scenario reveals a critical state of over-exploitation and quality degradation, driven by heavy reliance on groundwater for irrigation and domestic needs in an arid region with limited surface water. With an overall groundwater development stage of 92.59 percent as of 2013, and blocks like Rajgarh (374.96 percent) and Sujangarh (131.73 percent) classified as over-exploited, the district faces significant challenges in sustaining its water resources. Declining water levels, particularly in northern and central areas, coupled with quality issues such as elevated fluoride (up to 10.3 mg/l), nitrate (up to 1,124 mg/l), and electrical conductivity (up to 10,000 µS/cm), limit the usability of groundwater for drinking and agriculture. The predominance of alkaline water and localized high iron concentrations further exacerbate these challenges. Despite some areas showing rising water level trends due to recharge efforts, the overall declining trend underscores the urgent need for sustainable management. The district's hydrogeological framework, characterized by unconsolidated Quaternary alluvium, semi-consolidated Palana Series sandstone, and consolidated Bilara limestone and Nagaur Group formations, highlights variable aquifer yields and quality, with salinity posing a significant constraint in western areas. The reliance on tubewells and wells for irrigating 64,949 and 34,449 hectares, respectively, has intensified groundwater draft, particularly in over-exploited blocks. The ephemeral Kantli River and low annual rainfall (369.60 mm) limit natural recharge, making artificial recharge structures like check dams, anicuts, and ponds essential for restoring groundwater storage. Modern irrigation techniques, such as drip and sprinkler systems, and cultivation of salt-tolerant, less water-intensive crops are critical to reducing draft and improving water use efficiency.

To ensure long-term water security, Churu District requires a multi-faceted management strategy, including strict regulation of new groundwater abstraction, construction of recharge structures at hydro-geologically suitable sites, and promotion of watershed development and soil conservation. Public awareness campaigns on water conservation and sustainable practices are vital to address over-extraction and quality issues. While Sardarshahar offers limited scope for further development due to its safe status, careful monitoring is needed to prevent salinity ingress. The findings underscore the need for integrated water resource management, combining scientific interventions with community participation, to mitigate the risks of groundwater depletion and contamination, ensuring sustainable water availability for Churu's agricultural and domestic needs.

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