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Groundwater governance under climate change in India: lessons based on evaluation of World Bank interventions

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ABSTRACT

Groundwater is the single largest source of water for irrigation and domestic use in India. Climate change further exacerbates the threat of depletion, reducing food security and increasing the vulnerabilities of resource users. Governance is complicated by externalities associated with its attributes as an invisible and fluid resource which create problems of rivalry and exclusion. Based on theory-based case studies for evaluation of selected World Bank projects, we analyse challenges for groundwater governance and identify factors that contribute to depletion. It highlights the need for integrating and balancing demand and supply-side approaches, including water-efficient irrigation and climate-smart practices.

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Introduction

Under the changing climate, access to irrigation water is vital for improving food security for the poor and rural small-scale producers, especially in the semi-arid regions with uncertain rainfall patterns. In recent years, climate change has further strengthened this nexus through recurrent droughts and increased water stress for agriculture and other uses. India is one of the large countries in the world facing high levels of water stress (WRI, 2020). Groundwater plays a central role in improving water and food security and reducing rural poverty in India. Groundwater is the single largest source of irrigation and household water use serving 85% of domestic water supply in rural areas, 45% in urban areas and more than 60% of irrigated agriculture (CGWB, 2019). This indicates that in addition to food security, drinking water security of nearly 1 billion Indians is at risk on account of India's groundwater crisis (Kulkarni et al., 2015). Since the 1960s, the extraction of groundwater accelerated significantly as the number of borewells increased from 1 million to over 20 million (CGWB, 2019). As groundwater abstraction exceeds natural replenishment, accessible aquifers are reaching unsustainable levels of exploitation in several parts of the country – especially in the north-western and southern peninsular regions. The deepening scarcity of groundwater is amplified by climatic

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change (including erratic rainfall, droughts and high temperatures), impacting the hydrological cycle and putting additional stress on available water resources, water quality and threatening livelihood security (Azhoni et al., 2017; Shiferaw et al., 2008; World Bank, 2010).

Several studies have established the strong linkages between food security, climate change and access to water, especially groundwater (Foster et al., 2015; Reddy et al., 2021; Turrall et al., 2011). Climate change's impacts on agriculture are mostly transmitted through extreme events and water resources that affect agricultural production (Figure 1). As groundwater is the single largest source of irrigation in India, our emphasis will be on groundwater resources. Groundwater-based investments in tube wells for irrigation were critical in securing crop productivity growth for major staples (rice and wheat) during the green revolution period (Foster et al., 2015). Of late, climate change is impacting agricultural productivity (and food security) through reduced water availability and quality. Changes in the magnitude and distribution of precipitation have not only increased the demand for irrigation water but also reduced the groundwater recharge. This is more evident in the drought-prone regions where the effect on crop yields is significant (Devineni et al., 2022; Reddy et al., 2021; Shiferaw et al., 2008). Monitoring, measurement and sustainable management of the scarce resource is further complicated by its attributes as an invisible and fluid subterranean resource which also create problems of rivalry and exclusion (United Nations, 2022).

Increased dependence on groundwater coupled with more intensive land use and agricultural production practices (e.g., multiple cropping using irrigation and modern inputs) have adversely impacted groundwater tables, accelerating depletion and affecting water quality, including for drinking water (Reddy et al., 2018). A number of studies have tried to identify the drivers of groundwater depletion in India. These studies have argued that mandatory regulatory policies (power regulation, credit regulation, etc.) per se are not effective in reducing groundwater depletion (Devineni et al., 2022; Kumar et al., 2022), but also indicate that social regulation through participatory groundwater governance based on collective action can be more effective (Kulkarni et al., 2015; Reddy et al., 2021). While demand management interventions (such as pricing, water-efficient technologies, etc.) by themselves have not always proved to be effective without associated

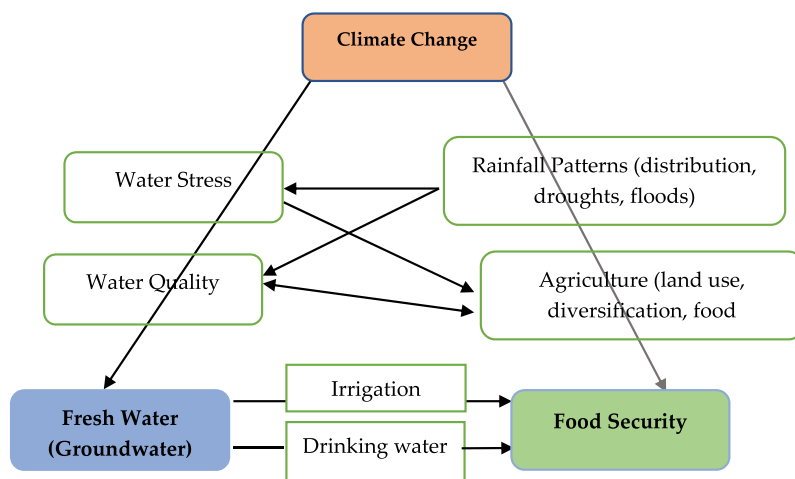


Figure 1. Simplified framework of the climate, water (groundwater) and food security nexus.

improvements on the supply side, improvements in groundwater in some regions are attributed to large-scale surface irrigation projects and improved precipitation that reduce dependence on groundwater resources (Bhanja et al., 2017; Kumar & Perry, 2019). Thus, demand and supply-side interventions have limited impact when implemented independently.

In order to address the increasing depletion and vulnerabilities of resource users (including food security for the poor and rural producers), a number of initiatives for improved groundwater management, governance and sustainable use are being explored (Molle & Clossas, 2016, 2019a, 2019b; Clossas & Molle, 2016; Msangi, 2021). While some of these initiatives are funded by state governments, others are financed by the World Bank and other multilateral financial institutions and donors. Whilst most initiatives in India have been small in scale (Reddy et al., 2014), some state governments (e.g., Gujarat, Rajasthan) are taking interest in scaling up relatively more effective interventions.

This study assesses the complexity of groundwater governance and management challenges at local levels and how different interventions supported by the World Bank have contributed to reducing overexploitation and vulnerabilities to climate shocks (e.g., food security for resource dependent households). It contributes to the existing literature and provides new insights that deepen current understanding of the effectiveness of development interventions using comparative theory-based case studies conducted in multiple villages in three water-stressed states in India (Rajasthan, Andhra Pradesh and Telangana) where long-term World Bank-supported programmes have been implemented. The case studies also provided insights into terms of lessons and policies for groundwater governance in India. The deep-dive case studies across locations and projects are used to identify the underlying factors that enhance effectiveness in improving groundwater management and livelihoods. These factors include: (1) institutional capacity and governance arrangements at the local level; (2) government commitment and policies to address the agriculture–energy nexus; (3) availability and uptake of water-efficient irrigation technologies and climate-smart agricultural practices; and (4) provision of incentives to support adoption of improved technologies and practices.

Based on this evidence, we argue that a combination of supply- and demand-side interventions are more effective in addressing groundwater depletion, reducing vulnerabilities as well as improving the resilience of rural communities in the face of climate change. Along with integrated demand- and supply-side interventions, participatory institutions are critical for enhancing groundwater governance at the local level and play an important role for the success of interventions in reducing depletion and improving sustainable use and livelihoods for resource users.

The remainder of the paper is structured as follows. The next section assesses the depletion of groundwater in India and the World Bank's response to address it. The third section describes the methodology for case studies. The fourth section discusses the main findings. The fifth section presents the final takeaways in terms of concluding thoughts, lessons and policy implications. Limitations of the study are also described in this final section.

Groundwater depletion in India

Governance issues and depletion

The nationwide assessment by the Central Ground Water Board (CGWB) in 2022 revealed a steady increase in the stage of groundwater extraction (SGWE) (annual exploitation as ratio of renewable supplies) from 58% in 2004 to 63% in 2017, which declined slightly to 60% in 2022 (Table 1). Of 7089 assessed units, the CGWB classified 14% (compared with 17% in 2017) of groundwater blocks as 'Over-exploited' (extraction exceeding 100% of the natural replenishment), 4% as 'Critical' (extraction reaching about 90–100% of utilizable resources), 12% as 'Semi-critical' (extraction in the range of 70–90% of utilizable resources), leaving 67% of groundwater assessment units as 'Safe' (CGWB, 2022). Although this needs to be confirmed through continued monitoring, there is an improvement in the national groundwater situation between 2017 and 2022 which is reflected in the decline in areas under 'Critical' and 'Over-exploited' categories.¹

The situation of groundwater depletion is particularly alarming in three major regions of the country accounting for over 84% of 'Critical' and 'Over-exploited' groundwater blocks (Table 2 and see Appendix 1 in the supplemental data online). These regions are: (1) the Northwest (parts of Punjab, Haryana, Chandigarh, New Delhi, and Uttar Pradesh); (2) Western (parts of Rajasthan and Gujarat); and (3) the Southern Peninsular (parts of

Table 1. Groundwater potential and depletion in India, 2004–22.

Groundwater resources assessment	2004	2009	2011	2013	2017	2022
Annual replenishable groundwater resources (bcm)	433	431	433	447	432	438
Net annual groundwater availability (bcm)	399	396	398	411	393	398
Annual total ground water demand (bcm)	231	243	245	253	249	239
Stage of groundwater extraction (SGWE) (%)	58	61	62	62	63	60
Total assessed units (<i>n</i>)	5723	5842	6607	6584	6881	7089
Safe (%)	71	73	68	69	63	67
Semi-critical (%)	10	9	11	10	14	12
Critical (%)	4	3	3	4	5	4
Over-exploited (%)	15	14	16	16	17	14
Saline (%)	1	1	1	1	1	2

Sources: CGWB (2019, 2022).

Table 2. Threat of groundwater depletion by region in India, 2022.

Regions	Stage of groundwater extraction (%)	Categorization of assessment units (blocks/mandals/talukas)						National share of critical and over-exploited (%)
		Total units (No.)	Safe (%)	Semi-critical (%)	Critical (%)	Over-exploited (%)	Saline (%)	
Northwestern	153	633	15	8	7	69	0	38
Western	54	617	77	13	2	6	3	4
Southern Peninsular	51	2817	65	14	4	15	3	42
Central	65	1317	69	19	4	7	0	12
Northern Himalayan	27	38	95	5	0	0	0	0
Eastern	44	1457	85	7	3	1	5	4
Northeastern	10	162	99	1	0	0	0	0
Islands	26	48	88	4	0	6	2	0
Total	60	7089	67	12	4	14	2	100

Source: CGWB (2022).

Andhra Pradesh, Karnataka, Tamil Nadu, Telangana and Puducherry), where groundwater reserves are limited due to properties of dispersed hard-rock aquifers. The southern region accounts for about 42% of the 'Critical' and 'Over-exploited' blocks in the country, followed by the Northwest region (38%) and the Western dry region (4%) (Table 2).

Governance is a key factor for sustainable use of groundwater as a largely invisible, poorly understood and fluid resource prone to public good externalities. Although groundwater is a common pool resource like surface water, the installation of a borewell grants users the rights to exploit the scarce resource. But this also creates negative externalities on other users. Without proper regulation, these externalities associated with the de facto open-access resource give the well-owners a strong economic incentive to accelerate extraction. Climate change and the inequitable access to public water systems by farmers and urban households further accelerate extraction (World Bank, 2010). The situation is even more profound in drought-prone areas. The availability of modern pump technologies along with rapid rural electrification and government support for the 'green revolution' to increase food security since the 1960s ignited growing investment in tube wells across the country. Agriculture and energy policies designed to address the needs of the past are, however, inappropriate to address current challenges and continue to accelerate groundwater depletion. One study estimated that a 10% increase in the average power subsidy in India is likely to induce 6–7% increase in groundwater extraction rates (Badiani & Jessoe, 2018).

The inadequate governance of groundwater and its growing depletion is reducing resilience and increasing vulnerability of farm communities to climatic shocks. Studies indicate that a 1 m drop in the groundwater table will reduce food grain production by 8% and cash crops by 5% (Sekhri, 2013). The power subsidies for agriculture further undermine energy supply and financial sustainability of public power utilities, further increasing the fiscal burden of the state governments (Shah et al., 2008; World Bank, 2010). Nevertheless, given the invisible nature of the resource, groundwater depletion has not received sufficient attention until recently. Political sensitives in regulating groundwater use for millions of small-scale farmers and concerns for national food security and poverty reduction have often limited direct government involvement in improving resource governance.

The World Bank's response to address the groundwater depletion

The concern over groundwater depletion and inefficient water use from groundwater mining in India was recognized since 2005. However, the World Bank's country strategy (2005–08) did not propose any specific programmes or strategies to tackle the depletion challenge. The subsequent country strategy (2009–12) (World Bank, 2010) proposed solutions through the World Bank's support for irrigation, water supply, energy, transport and water resources. This paved the way for various analytics to investigate the groundwater governance challenges in the country. It proposed some actions intended to make incremental improvements to curb the worsening depletion problem within the context of the existing institutional framework (World Bank, 2010).²

Until recently, the activities to support groundwater management continued to be embedded within broader operations aiming at water sector restructuring, rural water supply and sanitation, watershed management, irrigation and competitiveness, and

water-bodies restoration. Based on the 2018 country strategy, the World Bank supported participatory groundwater management (PGM), which aims to promote more resource-efficient, inclusive, and diversified growth in the rural sector.

Since 2018, the World Bank's programme enlarged its groundwater operations through financial and knowledge services. In June 2018, the World Bank approved the Atal Bhujal Yojana – National Groundwater Management Improvement Program (Abhy-NGMIP) – a dedicated groundwater-focused programme, the largest of its kind in the world – with US\$900 million total cost, including a US\$450 million bank loan. The World Bank has also initiated a dialogue with key institutions and stakeholders to address the underlying policy and incentive issues that accelerate non-sustainable use and depletion of groundwater.

Methods

Sustainable management of groundwater often requires transdisciplinary approaches involving hydrogeology, biophysical sciences and socio-economics to address demand and supply-side constraints. Successful groundwater governance also involves a combination of instruments or approaches (e.g., incentive or market-based and regulatory instruments; Molle & Closas, 2019a, 2019b; Msangi, 2021). The actual combinations of interventions or instruments to address groundwater depletion may vary depending on the hydrogeology, bio-physical, socio-economic and policy contexts. The World Bank projects often deploy different interventions that aim to address supply- and/or demand-side constraints. The evaluation of these interventions in India was conceived using transdisciplinary approaches in an effort to better understand their effectiveness, the drivers of success and the constraints. Given the growing challenges of groundwater depletion and the policy interest to address it, the evaluation aimed to offer lessons that could help improve future policies and programmes in India.

The methodology for data collection was designed based on specific groundwater management activities supported by the World Bank and completed through different projects. The case studies were focused on two major regions affected by high levels of groundwater depletion: (1) Western arid states (Rajasthan) and (2) the Southern peninsular states (Telangana and Andhra Pradesh). In Rajasthan, the case study focused on the Rajasthan Agricultural Competitiveness Project (RACP), implemented during March 2012 and June 2020, and had a significant component for groundwater management. Four case study villages supported by RACP in four 'Over-exploited' category clusters representing districts of Ajmer, Alwar, Jaipur and Sawai Madhopur were selected. These villages were purposively selected to capture the main groundwater intervention typologies supported by RACP: *watershed-focused approach* (Bichun/Mokhampura and Bansur) and *groundwater-focused approach* (Bonli and Peesangan). The watershed approach mainly included supply-side interventions to increase recharging of groundwater or conserve surface water (e.g., farm ponds). This was supported by incentives to encourage adoption of water-efficient micro-irrigation systems (MIS) through mini-sprinklers and drips and a shift to more water-efficient crops. In the groundwater-focused approach, similar water-efficient irrigation and cropping practices were supported along with monitoring of the groundwater table but without interventions to increase recharging. The different management plans are summarized in Appendix 2 in the supplemental data online.

In the Southern peninsular states, the case study focused on two World Bank projects: the Water Sector Improvement Project (WSIP) implemented during June 2010 and July 2018 and the Community Based Tank Management Project (CBTMP) implemented during April 2007 and July 2016. One district was purposively selected as the case study for the WSIP: Nalgonda district in Telangana. Five cases were purposively selected for the wider CBTMP interventions: two districts in Telangana (Mahabubnagar and Medak) and three districts in Andhra Pradesh (Prakasam, Kadapa and Kurnool) (see Appendix 3 in the supplemental data online for details). In Telangana, all three selected districts represent drought-prone areas under threatened groundwater categories: Medak ('Over-Exploited'), Nalgonda ('Critical') and Mahabubnagar ('Semi-critical'). In Andhra Pradesh, the three districts represented the 'Over-exploited' (Prakasam), 'Semi-critical' (Kurnool) and 'Safe' (Kadapa) blocks. All the case studies, except Nalgonda that focused on the role and contributions of the PGM approach, have strong tank and groundwater linkages while some (e.g., Kadapa) received canal water transfers to refill the tanks.

In the WSIP and CBTMP districts, both projects implemented relatively similar supply- and demand-side technical interventions to improve groundwater management. On the supply side, CBTMP tank rehabilitation primarily aimed to use surface water for irrigation to augment groundwater while also indirectly recharging aquifers. Similarly, WSIP focused on installation of groundwater recharge shafts and renovation of existing water storage structures and construction of check dams for recharging groundwater. On the demand-side, WSIP provided various awareness and learning activities for PGM, including building local capacity for participatory groundwater monitoring and crop water budgeting, while discouraging drilling of new borewells and encouraging adoption of MIS and less water-intensive crops (LWICs). For CBTMP, the activities included participatory groundwater monitoring, awareness and capacity building, promotion of MIS and LWICs and water sharing – but did not actively discourage drilling of new borewells.

In each case study, data were collected using an underlying theory of change on programme interventions and hypothesized pathways and success factors to impact formulated based on synthesis of global evidence (see the next section). Respondents at multiple levels were interviewed followed by site visits and discussion and interviews with resource users and local institutions implementing activities on the ground. The evaluation team conducted a detailed assessment of project activities, achievements and challenges through rapid appraisal tools, namely, focus group discussion (FGD), key informant interviews (KIIs), transect walks and interactions with individual farmers and water user groups. Semi-structured instruments were used to conduct FGDs, KIIs with village institutions and officials involved in implementing the programme. Data collected at each case study site included: (1) the socio-economic and biophysical characteristics of the target villages; (2) the groundwater and natural resource degradation issues before the project; (3) trends in the number of different types of wells and their functionality; (4) the main project interventions on the demand and supply-side; (5) the role and functioning of local institutions; (6) changes in the cropping patterns, use of water saving technologies and intensity of groundwater utilization; (7) the effectiveness of the interventions in reducing groundwater depletion, improving economic productivity, reducing household vulnerabilities to drought and water stress in the areas; and (8) the realized distributional impacts for vulnerable groups (e.g., women, landless and youth).

Analytical framework

In order to assess and evaluate the effectiveness of the interventions, a ‘theory of change’ (ToC) is developed presenting the hypothesized relationships and pathways linking selected interventions with expected outcomes based on the synthesis of global evidence from a structured review of the existing literature (Msangi, 2021). The ToC approach has increasingly become a key component of the methodological toolbox of sustainability science (Oberlack et al., 2019). This serves as an organizing framework for undertaking theory-based case studies and benchmarking the evidence when assessing the effectiveness of complex interventions and the success factors and it enhances project planning, monitoring and evaluation (Dhillon & Vaca, 2018). The ToC considers context (including socio-ecological and economic factors) to enhance the understanding as to why some interventions work in a given context but not in another and it helps develop a nuanced understanding of how interventions could be scaled to wider target areas (Blamey & Mackenzie, 2007). It can also help in creating a dialogue between policymakers and evaluators about the way policy initiatives work on the ground and the expected positive impacts and outcomes of adopting different approaches (Mason & Barnes, 2007).

The detailed ToC for the evaluation and the case studies are presented in Figure 2. Based on a synthesis of existing empirical evidence, it conceptualizes the drivers of groundwater depletion including the absence or unclear property rights, incoherent or inadequate policy environment, and demographic factors that increase pressure on groundwater resources. Climate variability and change in recent years has further exacerbated resource degradation and the resulting vulnerabilities.

Given the complexity of the issues involved to improve groundwater management, the ToC outlines a more holistic approach including demand- as well as supply-side interventions that are scientifically sound (backed by data and monitoring support). Demand-side interventions include policies to manage or regulate water use or technological approaches that improve the efficiency of water use. Stakeholder support and participation of local communities and institutions such as water-user associations that facilitate access and use rights are key to regulate demand. Supply-side interventions mainly include investments in watershed management, physical infrastructure, namely, rain-water harvesting, tank rehabilitation, etc. Besides, livelihoods-based interventions are critical for attaining broader community participation.

Uptake of better groundwater management interventions is facilitated by improved awareness and scientific knowledge of the communities, especially the risks associated with poor resource management. This in turn provides a conducive environment for drawing lessons and builds political will towards integrated and inclusive groundwater policies to enhance sustainability. Increased policy support facilitates investments in piloting and demonstrating these practices and scaling them up.

Conceptually, such awareness through local demonstrations and adaptive learning would bring behavioural changes at different levels that could strengthen downstream (farm and community level) commitment and upstream political will towards sustainable resource management practices in the long run. At the resource user level, the intermediate and long-term outcomes would be in the form of sustainable groundwater management practices; increased productivity and incomes that enhance livelihoods; reduced vulnerabilities to groundwater depletion; and enhanced resilience to climate

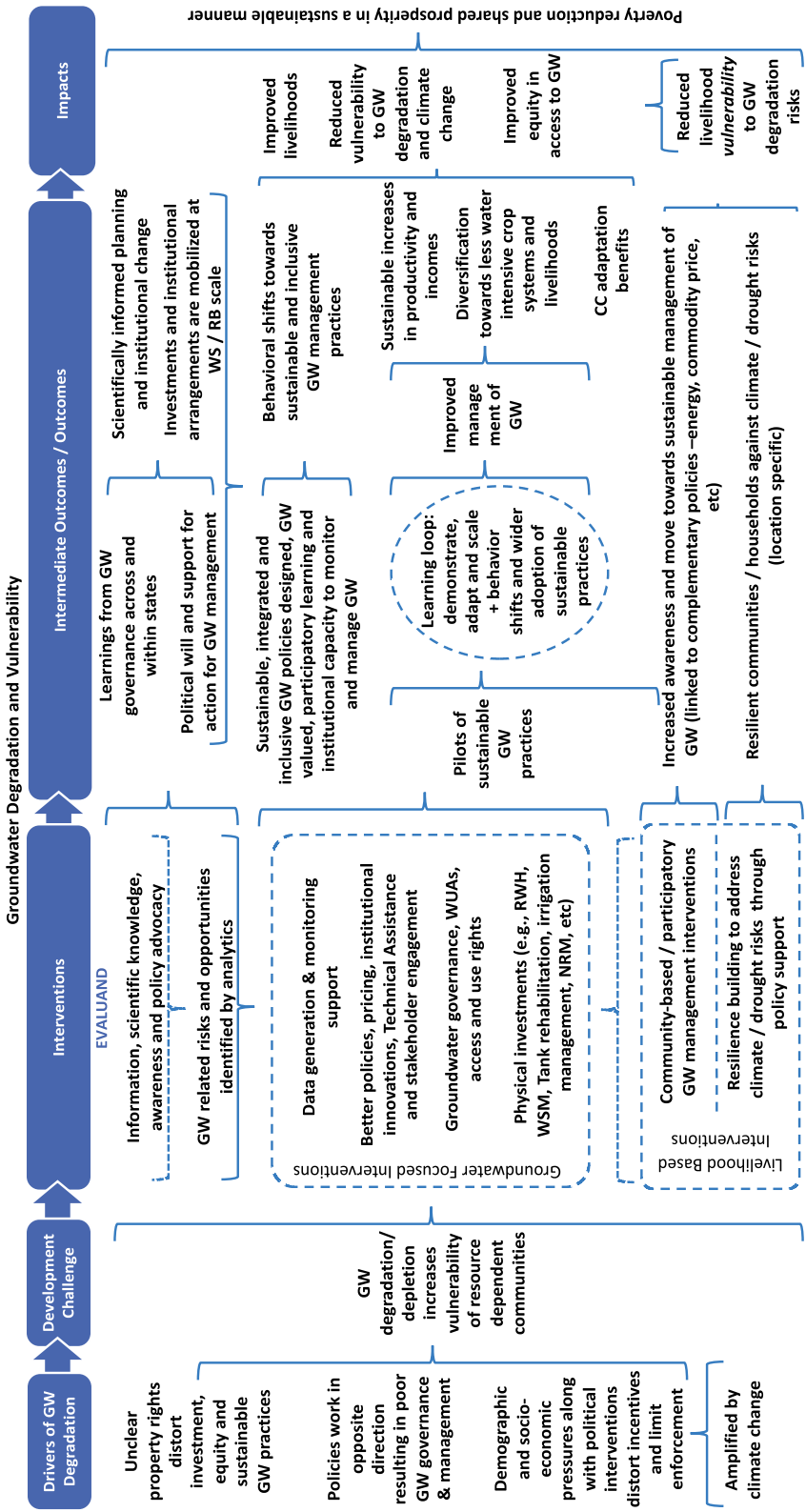


Figure 2. Theory of change for the analysis of the effectiveness of interventions in reducing groundwater depletion and associated vulnerabilities.

change. At the community level, the interventions are expected to improve local institutional capacity for resource governance and enhance resilience to climatic risks. Depending on the extent of improvements made, the long-term impacts may also include sustainable rural livelihoods and poverty reduction.

However, the success of the interventions in achieving the intended outcomes and their sustenance is likely to be affected by a spectrum of conditioning factors. These include the suitability of technical interventions, resource governance arrangements and financial incentives (World Bank, 2021). Resource management practices include technologies and climate-smart management practices adapted to local socio-ecological conditions. Governance arrangements include resource use rights (e.g., devolution of groundwater use rights to communities), policies and regulations.

Results

This section discusses the results from the evaluation based on the selected case studies focusing on the effectiveness of addressing resource depletion, improving farm productivity, resilience and reducing vulnerabilities as well as identifying the success factors.

Main findings from Rajasthan

Effects on groundwater depletion

The case studies from Rajasthan show that the overall effectiveness of RACP interventions to address groundwater depletion has been modest (Figures 3 and 4). In three clusters except Bichun, farmers relied entirely on groundwater as the source of irrigation before and after RACP. The number of borewells (before and after the project) increased on average by 48%, while the percentage of households owning borewells increased by 39%. The largest changes were in Bichun, a water-scarce dryland area targeted through the watershed management approach, where the number of borewells increased from just 15

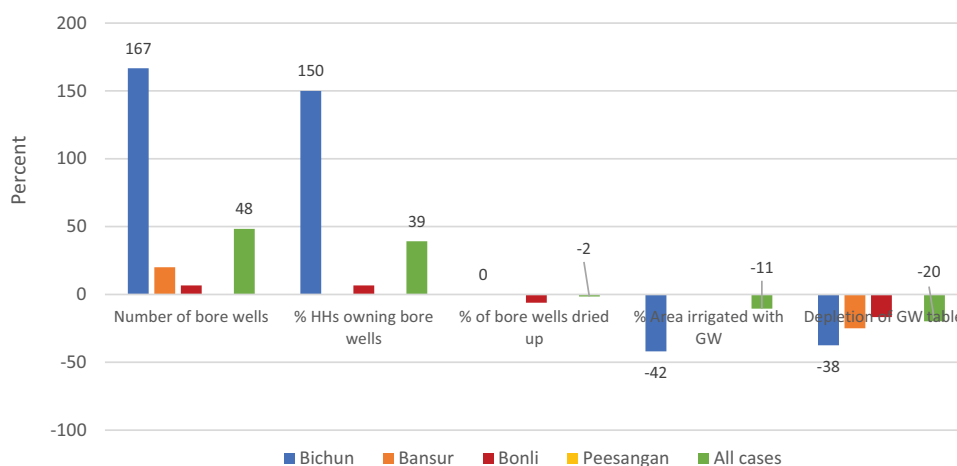


Figure 3. Groundwater depletion in selected Rajasthan Agricultural Competitiveness Project (RACP) villages, Rajasthan (% change, 2012–19).

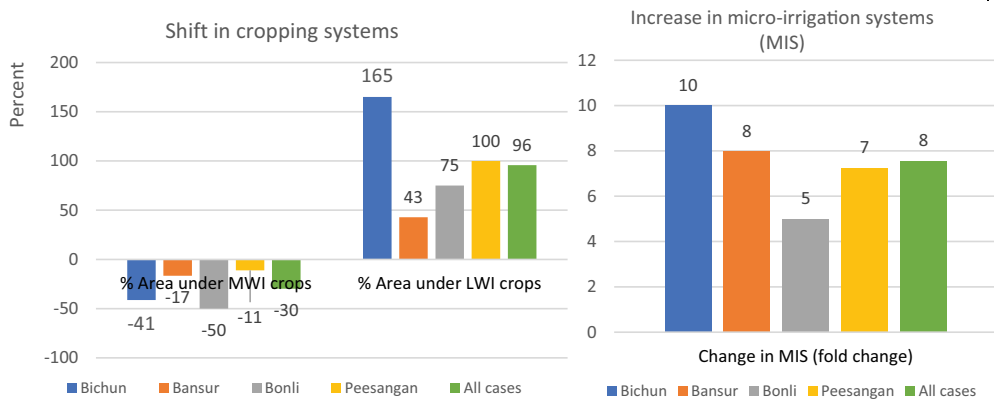


Figure 4. Shift in cropping systems and micro-irrigation systems (MIS) in project villages, Rajasthan, 2012–19.

to about 40 as farmers expected to develop irrigation – but poor water quality limited its further development. The increase in the number of borewells indicates challenges in regulating groundwater exploitation in threatened areas, except in the over-exploited blocks (e.g., Peesangan). A positive impact of the RACP interventions was the decline in area irrigated (%) with groundwater by 11% on average – but the decline reached 42% in Bichun because of increased conjunctive use of surface water (farm ponds) for irrigation.

The case studies showed that better rainfall conditions in recent years have helped ease the pressure on groundwater in recent years both through conjunctive use and increased replenishment of the water table. Although depletion was not reversed (i.e., recharge exceeding extraction), the rate of decline in the water table has decreased by 20% across villages (Figure 3). The overall effect in reducing depletion ranged from 17% in Bonli to 25% in Bansur and 38% in Bichun. In all four clusters, demand-side interventions such as MIS and polyvinylchloride (PVC) conveyance pipes helped reduce evapotranspiration losses. Non-drought years offer the potential to increase recharge using supply-side interventions and the watershed management approach. This indicates how climatic conditions could deter or enable improved management of groundwater resources.

Another important factor was project's support for LWICs (fruits and vegetables), and the uptake of MIS. The percentage area under LWICs on average increased by 96% (ranging from 43% in Bichun to 100% in Peesangan), while there is an eight-fold increase on average in the cropping area under MIS (Figure 4). These demand-side interventions enabled a shift towards more water-efficient and climate-smart cropping practices, while the area under more water-intensive (MWI) cropping declined by about 30%.

The case studies also revealed interesting patterns on the groundwater–energy–agriculture nexus. RACP has been supporting off-grid solar pumps with intention to ease state power subsidies. However, the interim effect of subsidizing solar pumps seems to have the unintended effect of accelerating depletion. Given the low marginal cost of pumping, the off-grid solar pumps in some villages (e.g., Bansur) are lowering the local price of irrigation water.³ This indicates that unless solar pumps are connected to the main grid and farmers are able to sell the surplus power, this could accelerate depletion. This is

consistent with other evidence indicating that without proper regulation subsidized off-grid solar pumps could accelerate depletion and fail to address the water–energy nexus (Bassi, 2015; Reddy et al., 2018; Shah et al., 2018).

Effect on land productivity

The case studies showed increased short-term productivity of field crops, vegetables and livestock, which also led to increases in farm income. This was possible partly due to expansion in the irrigated area and improvement in crop yields, which have ranged from 20% to 50% since 2012. In Peesangan, household incomes increased by about 20–40% for all irrigators and by 30–40% for farmers who adopted efficient MIS (sprinklers and drip irrigation). Farmers attributed the changes to timely and uniform irrigation, surface water harvesting through farm ponds, installation of drip- and mini-sprinklers with leak-proof pipes. This was further enhanced through the adoption of improved varieties, targeted application of fertilizers and the diversification towards high-value crops (e.g., guava and flowers).

Reducing vulnerability

The interventions seem to be moderately effective in reducing the short-term vulnerability of the community to water stress. The discussions in the sample villages indicated that not all resource users were benefiting from the project – the number of farmers benefiting from the project was about 40% in Bichun, 80% in Bansur, 88% in Bonli and 70% in Peesangan.⁴ The landless households were not direct beneficiaries, but they also received some benefits through short-term project employment. Nevertheless, increases in access to irrigation water were associated with higher productivity and incomes, which improved food and nutritional security for beneficiaries. The increased availability of groundwater allowed farmers to diversify production to high-value products (e.g., fruits, vegetables and flowers) as well as livestock products. While beneficiaries were limited in some villages (e.g., 40% in Bichun), improvement in livelihoods contributed to reduced distress migration out of target areas. However, the long-term effect on vulnerability to climate shocks could be negative if groundwater depletion is not reversed.

These findings are in line with other studies that showed that neither small-scale supply-side interventions nor regulatory interventions were effective in checking groundwater depletion (Kumar & Perry, 2019; Reddy et al., 2021). Earlier studies also show that supply-side interventions such as watershed development and rainwater harvesting structures could result in water stress downstream, while upstream on-site effects could be positive (Batchelor et al., 2003; Ray & Bijarniya, 2006). Similarly, the effectiveness of crop diversification on groundwater uses and farm incomes will depend on several factors, including access to markets and food prices (Devineni et al., 2022; Reddy & Reddy, 2020). The long-term impacts on vulnerability to climate change will depend on the extent to which the interventions would help enhance sustainable use or reduce groundwater dependence.

Main findings from Telangana and Andhra Pradesh

Effects on depletion reduction

The interventions in these areas were generally not able to reverse groundwater depletion as the groundwater table (depth to the water table) on average declined by 115%.

This is also reflected in the increase in the percentage of dried-up borewells. The exceptions are Kadapa and Nalgonda where the water table has remained stable or improved (Figure 5). The results in Nalgonda show the possibility of reversing depletion through supply- and demand-side interventions coupled with efforts for regulating drilling of new wells. In Kadapa, the effect was mitigated through transfer of canal waters to fill the tanks, which contributed to recharging of the aquifers and improved the groundwater table by 83% – showing the value of conjunctive use when surface or canal water is available to ease dependence on receding groundwater. The main drivers of accelerated depletion in the other cases include the unregulated drilling of borewells and share of households owing borewells, and the increase in area irrigated with groundwater.

The density of borewells on average increased by more than fourfold (422%) while the percentage of households owning borewells increased by 87%. Consequently, compared with the situation before the projects, the area irrigated with groundwater on average increased by 44% – leading to increased depletion of the water table (115%). The level of depletion is highest in Prakasam where the density of borewells increased from 40 to over 400, followed by Kurnool (from 30 to 275) and Medak (from 100 to 300) since 2007. This was further exacerbated by climatic risks – frequent droughts and poor inflows into the tanks which reduced conjunctive use and replenishment.

On the positive side, compared with the situation before the projects, the small-holder farmers have increasingly shifted to LWICs (the change in the percentage area allocated to LWICs increased from 44% in Mahabubnagar to 313% in Medak). The percentage area irrigated using efficient MIS also increased (ranging from five-fold in Kurnool to 50-fold in Mahabubnagar and Prakasam) (Figure 6). However, the effectiveness of these shifts in reversing groundwater depletion was limited due to unregulated use (increased drilling of borewells) and frequent droughts. The Nalgonda case shows a success story where the pilot village ‘Graduated’ from ‘Critical’ to almost ‘Safe’ category after the PGM model contributed to improved local governance and regulation of drilling new wells and high adoption of water-efficient and climate-smart

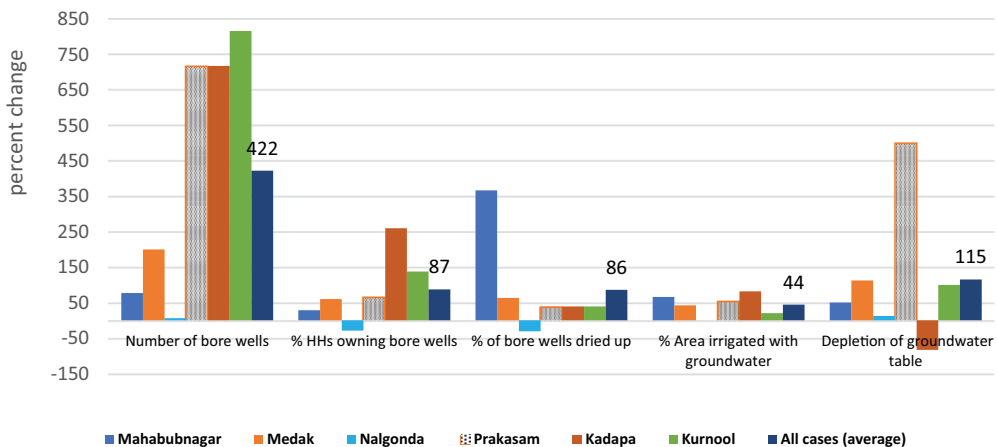


Figure 5. Groundwater depletion in project districts in Telangana and Andhra Pradesh (% change, 2007–19).

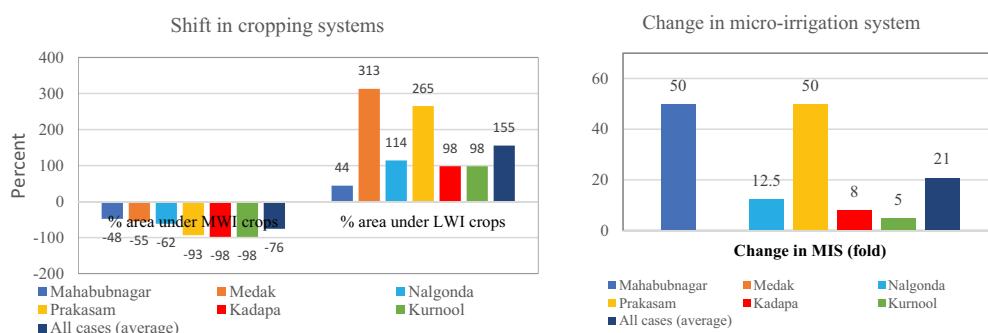


Figure 6. Shift in cropping systems and micro-irrigation systems (MIS) in project districts, in Telangana and Andhra Pradesh, 2007–19.

agricultural practices.⁵ The PGM enabled systematic aquifer mapping to identify sites for effective recharging, building of check dams with recharge shafts, and increased adoption of LWICs and water-efficient MIS.

This compares with other districts where farmers reported an improvement in water availability and groundwater recharge, especially in Kurnool, but the unregulated use led to a declining water table (e.g., by 50% in Mahabubnagar and by 500% in Prakasam – with well depths reaching over 300 m). Hence, tank restoration was unable to reverse depletion because of the unabated drilling of wells – leading to the expansion of irrigated area in the already water-stressed districts. Periods of poor rainfall that leave the tank reservoirs with minimal stored water accelerated depletion as farmers desperately tried to reach deeper into the ground, partly enabled through the free or subsidized supply of power for agriculture.

Effects on agricultural productivity

The increase in crop productivity and farm income was higher in Telangana. This effect seems to be associated with access to groundwater and its efficient use through micro-irrigation methods and water efficient crop choice. In particular, crop diversification through reduction in more water-intensive crops (MWIC) such as paddy in favour of LWICs (such as cotton and groundnut) allowed increase in land and water productivity and income. In contrast, similar interventions accomplished only a modest increase in agricultural productivity and farm incomes in Andhra Pradesh. Although the transition to LWICs such as cotton and maize (from paddy) occurred, consecutive droughts affected the effectiveness of the interventions. The heightened water stress led to an increase in local water prices (from Rs.60 (US\$0.86) to Rs.100 (US\$1.40)/h for LWICs). Although quantitative evidence was not collected by the projects, the case studies suggested that similar productivity increases were not observed in the non-project villages mainly because shifts to LWICs and adoption of MIS were limited or non-existent.

Effects on vulnerability

Over the 12 years, the tanks in many targeted villages were not able to store water. On average, the tanks were filled for about one in three years but did not store any water during one in four years (Figure 7). For example, in Mahabubnagar and

Nalgonda (not shown), the tanks did not store any water for about 25% of the time, but the integrated interventions helped reduce the short-term vulnerability to drought. In Kurnool (not shown), tanks stored water to overcome consecutive droughts, reducing the negative effects on livelihoods. This not only reduced out-migration but also saw an in-migration of agricultural labour for harvesting cotton and chilies. The adaptive capacity of households improved through a combination of income diversification and social welfare programmes.

In Medak where tanks filled only twice in 12 years and the shift to LWICs and the adoption of MIS was modest, vulnerability to drought has increased. In Kadapa, which received canal water transfers to fill the tanks, climate variability did not affect tank filling much and the shift to high-value LWICs was successful, but this also reduced area traditionally used for staple crops such as paddy, millet, pulses and fodder crops and affected food security of farm households.

Overall, when the tanks fail, farmers entirely depend on groundwater resources for irrigation which often leads to over pumping and depletion of borewells. The interventions did not reduce the vulnerability of households that did not own borewells, who had to rely on erratic rains or have to rely on government welfare schemes or seasonal and permanent migration, and casual farm labour. For example, in Medak, income from non-farm employment accounted for 35% of household income for borewell-owner farmers and up to 67% for those without borewells.

Though the AP and Telangana case studies results are broadly consistent with those in Rajasthan, they demonstrate the value of integrating demand- and supply-side interventions. While large-scale irrigation projects (e.g., canal irrigation) are effective in recharging



Figure 7. Filling of tanks in project districts, Telangana and Andhra Pradesh over 12 years, 2007-2019, showing vulnerability to drought in selected semi-arid districts in India.

groundwater when compared with small-scale interventions such as rainwater harvesting structures and watershed development (Kumar & Perry, 2019), participatory institutions and social regulation could enhance the adoption of water conservation interventions and help equitable access to groundwater (Reddy & Reddy, 2020). The Nalgonda case study demonstrated that science-based interventions integrating supply- and demand-side interventions coupled with participatory institutions could be more effective in addressing climate risks that accelerate groundwater scarcity (Reddy et al., 2018).

Role of state and national policies

In this section, we discuss the different policies and regulatory instruments at the state and national levels that contribute to or counter the effectiveness of the interventions in reducing groundwater depletion. While several states provide power and agricultural subsidies that accelerate depletion, they tend to vary across states (see Appendix 4 in the supplemental data online for details of the different policy instruments in India).

Regulatory policies

To restrict further development of groundwater in water-stressed states, national and state policies sanction direct controls in highly over-exploited blocks which are 'Notified' by the Central Ground Water Authority (CGWA) of India and/or endorsed by the state. Regulatory restrictions involve the following types of sanctions: no new groundwater structure should be constructed in the area without obtaining 'No Objection Certificate'; electricity connections should not be available to operate the pumps; and institutional credit for groundwater development will not be available. In the early 2000s, the states of Telangana and Andhra Pradesh introduced a key regulation through the Land, Water and Trees Act (WALTA) that aimed to regulate the drilling of new borewells through registration and licensing. The case studies, however, showed that enforcement of WALTA regulations is generally a challenge although slightly more effective in Andhra Pradesh than in Telangana.

Supply-side groundwater management policies

Over half a century, India has relied on watershed development and management as the main supply-side instrument across the country to achieve diversified water resources-related objectives, including recharging of groundwater aquifers. In Rajasthan, two of the case study clusters adopted watershed management as the key instrument. In Andhra Pradesh and Telangana, at least 50% of the case study villages had watershed programmes implemented at some point over the previous three decades. However, the policy interest on watershed programmes seems to have waned recently partly because of its merger with the Prime Minister's Farm Irrigation Scheme (PMKSY) (with the exception of some states). While it is imperative to regulate water use and demand, moving away from watershed programmes that replenish aquifers could have adverse effects on groundwater availability and its sustainable use in the semi-arid regions.

Demand-side groundwater management policies

The energy policies of the states impactfully shape the demand for groundwater. In January 2018, Telangana was the first state in the country offering unregulated free

power around the clock to farmers. As a result, Telangana has become a leader among the southern states in per capita power consumption, arguably at the cost of its groundwater resources in the long run.⁶ On the other hand, although Andhra Pradesh is a power-surplus state, it provides restricted free power to irrigation pumps for 9 h/day and also started the work on *rural feeder segregation* to separate domestic and commercial use from agriculture supplies. The case studies showed that even regulated power supply could lead to the depletion of groundwater. Free and unregulated access to power for pumping groundwater is likely to accelerate depletion, especially when the relevant supply- and demand-side approaches are not being implemented.

Rajasthan offers a better policy alternative in regulating demand. The *rural feeder segregation* has been completed and the state aims to provide uninterrupted power to all domestic, commercial and industrial consumers while regulating the supply of power to agriculture. Farmers are provided 6.5–7 h of subsidized power daily for one-third of the tariff for domestic power. Accordingly, power for pumping groundwater is metered, priced and regulated through the rural feeder segregation, and farmers are increasingly willing to pay for metered and subsidized power. This has helped ease the overall demand for power while also reducing the pressure on groundwater resources.

Power subsidies, in general, have aggravated groundwater depletion by inducing increased demand for water in all the regions. The combination of electricity subsidies, other farm input subsidies, agricultural output price policies and the effects on farm revenues drive the underlying incentives that influence farmers' irrigation water consumption. There is an inverse relationship between electricity price and demand for groundwater, which in turn influences farmers' irrigation water consumption as well as their cropping choices and irrigation decisions. As a result, the electricity subsidies that lower the price of electricity for pumping lead to the expansion of water-intensive crops largely driven by the low cost of groundwater use for irrigation (Badiani & Jessoe, 2018). Such expansion occurs because the low or subsidized private cost of irrigation does not reflect the real scarcity value of water under unregulated use of the common-pool groundwater resource and its growing depletion. In addition, water-intensive crops such as paddy and sugarcane also benefit from favourable price policies that encourage planting of these crops, often legacies from the green revolution era which focused on improving the domestic availability of staples. Thus, past electricity and agricultural price policies that accelerate groundwater depletion go against the objective of water conservation and sustainable use. Along with rural feeder segregation (discussed above), some studies have suggested progressive pricing of electricity based on the total amount of agricultural use to support sustainable management of groundwater (Singh et al., 2014). Unless these underlying policy distortions (both national and state levels) are addressed, it would be difficult to create an enabling policy environment to address the groundwater crises in India (Badiani & Jessoe, 2018; Shiferaw et al., 2008; World Bank, 2021).

Several states are also supporting solar power in an effort to reduce electricity subsidies. In Rajasthan where solar pumps (off-grid) are already operational in several villages, this new approach could accelerate depletion as farmers who have surplus water and power could use the solar pumps to sell groundwater at low prices. While off-grid solar power could reduce the supply of subsidized power to farmers and the associated fiscal

burden to the states in providing electricity subsidies, it may not contribute to reversing depletion of groundwater unless supported by governance arrangements to regulate water use or connected to the main grid to allow farmers sell surplus solar power to power companies. As an alternative to direct power subsidy, Andhra Pradesh and Telangana are exploring the grid-based solar power option using available village common lands. This is partly premised on the idea that the off-grid solar power increases the subsidy burden to the states while also imposing limitation on the power of the irrigation pumps (i.e., less than 5 hp that mainly work in shallow aquifers and irrigate less area). Public investments in grid-based solar power generation are hence expected to support high-capacity motors, as they are connected to the main grid which supplies electricity to the villages. The challenge with this approach is that grid-linked solar power generation often requires a large surface area (e.g., using degraded common lands or state-owned lands in villages), while use of high-capacity pumps could also accelerate depletion. States such as Gujarat are also setting up solar panels on water bodies. While grid-linked solar systems could be viable and cost-effective when compared with individual solar power subsidies to farmers, additional safeguards are needed to prevent undesirable effects on groundwater and to make the model bring sustainable benefits to farmers (e.g., by helping them diversify into power supply or 'solar farming' rather than relying on climate-prone agricultural activities).

Other demand-side policies currently implemented at different levels across states include: (1) subsidies for efficient irrigation and water use technologies (e.g., drips, PVC pipes, sprinklers); (2) bank credit restrictions for reduced spacing distance between the wells; (3) incentives for conservation agricultural practices (e.g., system of rice intensification paddy in several states); (4) short-duration paddy and basmati varieties for water saving and high returns in several states; and (5) extension support for rain-fed and less water-intensive crops (Gulati et al., 2019). Future policies for sustainable groundwater management in threatened areas should consider repurposing and redirecting existing subsidies that accelerate depletion (e.g., power subsidies) to such instruments that promote conservation and sustainable use.

Institutional arrangements for reducing depletion

Institutions are the bridges between policies and implementation, especially in the context of participatory governance for effective coordination of recharging efforts and demand management at the local level (Ma'Mun et al., 2020; Young, 2009). While a community-based groundwater management approach (e.g., PGM) is gradually gaining momentum in India, groundwater institutions remain largely informal and ineffective in improving governance. These institutions need to be strengthened and linked with the formal institutions that have a well-defined role in resource management, that is, groundwater departments and village *panchayats*.

In addition, the inter-sectoral coordination of natural resource management policies at all levels between land, water, agriculture and energy is key for addressing the nexus issues. Several sector ministries run numerous departments and poorly coordinated programmes and policies that make it difficult to improve groundwater management (Azhoni et al., 2017). For example, water resource activities, including tank rehabilitation, groundwater and watershed development, are run usually through different departments

at the state level. Similarly, tank rehabilitation and watershed programmes are carried out in parallel by separate departments despite the spatial interdependence which can hamper effectiveness.⁷

Conclusions, policy implications and limitations

Conclusions

Groundwater is the key resource to sustain economic growth and poverty reduction. However, it remains a largely invisible, undervalued and poorly understood resource for proper governance and sustainable use. The interdependence of users on common aquifers creates a problem of rivalry and exclusion that undermines private incentives for sustainable management. Over the past decades, many of the World Bank's operations initially focused on sectoral economic development issues, and often left groundwater nested under a broader water sector umbrella, making it difficult to identify effective approaches to address the underlying governance challenges. It was often affected negatively through irrigation and rural development projects that increase abstraction while watershed management projects aim to increase availability on the supply side. Some recent interventions, however, aim to directly improve groundwater governance for sustainable use. Given the growing threat of depletion, this study draws from deep-dive case studies in severely affected regions to provide insights and lessons on how tailored interventions help improve governance and reduce overexploitation of groundwater in India.

In terms of effectiveness, the case studies in Rajasthan show that RACP interventions had a positive but modest effect in reducing groundwater depletion. The findings from case studies in Telangana and Andhra Pradesh, however, showed that the interventions did not have significant effects in reducing depletion. Access to water often improved food and livelihood security for the rural resource users in the short term, but vulnerabilities to climate change remain until depletion is reversed for sustainable use. The main factors limiting effectiveness in reducing depletion include governance challenges related to unregulated drilling of borewells and expansion in area irrigated with groundwater. The case studies showed that World Bank projects have supported demand-side approaches through water-efficient irrigation and cropping practices, while watershed management played a key role on the supply side.

The experience in both Rajasthan and Nalgonda (Telangana) show the potential for slowing down or reversing the depletion of groundwater when the projects support supply- and demand-side approaches to enhance replenishment, while also regulating further drilling and extraction through participatory groundwater governance at the local level. When combined with demand-side interventions, conjunctive use of surface water (or canal water where available) and regulations to control well-deepening or drilling of new borewells has the potential to improve the groundwater table and check over-exploitation. However, climate change and frequent droughts impede such conjunctive use and replenishment and facilitate depletion.

Policy implications

The findings from these case studies provide the following lessons and implications for future policies:

- Integrated approaches that make real and positive changes in augmenting supply and reducing demand are key to sustainable management of groundwater. Supply-driven approaches that disregard demand management or demand-side approaches that exclude replenishment will not be effective. In addition, local interventions such as rainwater harvesting or watershed development need to be conceived as part of landscape or basin-wide approaches (e.g., water transfers) to enhance scale and address spatial interdependence.
- Conjunctive use of surface and groundwater and enhanced coordination between watershed development and water storage programmes (e.g., tanks) are key to ensure synergy and complementarity that enhances effectiveness. Such interventions need comprehensive policies backed by appropriate institutional arrangements.
- Market-oriented approaches that improve the relative returns to climate-smart production through improved supply and affordability of inputs and technologies (e.g., drip irrigation) and better access to markets (e.g., minimum support prices) for water-efficient crops could contribute to the sustainable use of groundwater. In this context, reducing market distortions at all levels could be critical for sustainable groundwater management.
- Community-centred and incentive-based approaches are better able to deal with groundwater depletion. While strict metering of water use is not feasible due to multiple reasons, participatory governance approaches that strengthen local institutions and empower communities could improve groundwater governance.
- Electricity pricing is critical for sustainable management of groundwater. However, most states currently provide highly subsidized power to farmers for various reasons. The long-run negative impacts are already evident in the water-stressed regions, as groundwater tables decline and more wells dry up. Therefore, designing appropriate policies for electricity as well as price policies to encourage low water intensity and climate-resilient crops that bring diverse benefits (e.g., water, food and nutrition security) and implementing them through community-based institutions could pave the way for sustainable groundwater use.
- Addressing the water–energy–agriculture nexus requires better coordination of policy, market and regulatory measures from national to local levels. In water-stressed regions, unregulated access to off-grid solar power or the free supply of power for irrigation or price support for water-intensive agriculture will accelerate depletion. Grid-linked solar power systems, rather than promoting independent solar pumps, could be more effective in addressing vulnerabilities in areas of distress. However, innovative approaches are needed to support farmers to diversify into sustainable and non-farm activities, including solar power generation, in ways that will reduce pressure on groundwater.

Limitations

Despite efforts to enhance the overall validity of the study, the findings are based on a few in-depth case studies from three Indian states where World Bank projects have been implemented. This is likely to limit external validity to other states where different socio-ecological and economic conditions prevail. In addition, the assessment relies mostly on mixed evaluation methods with limited systematic quantitative data to assess outcomes across locations without adequate counterfactuals. Due to problems of measurement, the assessment is also based on the analysis of short-term results associated with World Bank interventions which do not control for weather-related effects and, hence, may not provide robust evidence on long-term sustainability outcomes for groundwater resources.

Notes

1. This study did not collect data after 2019 and, hence, cannot determine if some of these changes are related to programme interventions. However, the CGWB suggests that good continuous rainfall (which typically contributes about 61% of the annual replenishment) and better management and conservation practices have contributed positively (CGWB, 2022).
2. Such measures include: (1) targeted regulation of groundwater use; (2) building capacity and adjusting the role of state groundwater institutions; (3) promoting conjunctive use in agriculture; (4) technical and political solutions to power pricing; and (5) integrating groundwater in urban water supply planning (World Bank, 2010).
3. Some farmers owning subsidized solar pumps were selling groundwater at lower prices, that is, IRS50/h in January 2020 (US\$0.65), about half the regular local water price of IRS90/h (US \$1.30).
4. In Bichun, groundwater quality was poor and did not allow irrigation development. In Peesangan, tourism provided additional income and growing markets for local produce.
5. In Nalgonda, the number of wells remained unchanged since 2007 at 180 wells (15 open and 165 borewells). Following the WISP PGM pilot, the area has almost moved from 'Critical' (before the project (SGWE > 98%) to 'Safe' category (SGWE ≤ 70%) (GoTS and MoWR, 2019).
6. During the field visits in January 2020, the evaluation team observed that some farmers were running pumps continuously – some pumping groundwater into the stream with the intention to recharge borewells downstream (e.g., Nalgonda), while others were pumping water into an open well (e.g., Mahabubnagar).
7. Without proper coordination, watershed development could obstruct water flows to downstream tanks (Ray & Bijarniya, 2006) making tank renovation less relevant (e.g., Mahabubnagar case study in Telangana).

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