Challenges and issues of groundwater management in India

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This study reviews groundwater status and management based on the existing literature regarding its resource endowment, hydrogeology, challenges and issues of management and policy suggestions for India. Efficient management requires decoupling groundwater rights from land-ownership rights, changes in electricity pricing and metering, aquifer-based plans for storage and replenishment, and empowerment of participatory irrigation management for local management. Issues of water–food–energy nexus, climate change, carbon footprint of groundwater extraction and virtual water trade are also important for ensuring sustainable management of groundwater resources.

Keywords: Carbon footprint, groundwater management, hydrogeology, virtual water trade, water–energy–food nexus.

GROUNDWATER has become the cornerstone of India's food and drinking water security. The country's endowment of surface and groundwater resources is 690 billion cubic metres (BCM) and 432 BCM respectively[1]. Despite being scarce, groundwater accounts for 64% of irrigation, 85% of rural water and 45% of urban water supply[2]. The reasons for preferring groundwater range from poorly defined property rights to misplaced incentives[3,4]. On an aggregate level, groundwater extraction has been on an upward trend since 2009 (ref. 1). It has led many districts/blocks in the country to move from safe to overexploited category. The over-extraction of groundwater is also accentuated by natural factors such as climate change, aquifer type and agro-climatic zone[5–7]. India is expected to have average water availability of 1341 m^3 per capita per year by 2025 and would be categorized as a water-stressed country[1]. Table 1 gives the water level and groundwater depletion for a few major states in the country as of 2022.

The endowment and replenishment of groundwater resources are not uniformly distributed across India. These are affected by hydrogeology, climatic conditions, cropping patterns and groundwater replenishment sources[8,9]. Due to variations in the endowment of groundwater and the heterogeneity of land features, several State and Central Government policies have been implemented to address the challenges of groundwater management in a localized manner. Some State Government policies, such as Jyoti Gram Yojana (JGY) of Gujarat and Pani Bachao Paise Kamao (PBPK) of Punjab, have been successfully reduced groundwater depth to some extent[10]. The Central Government has implemented the Model Bills and National Water Policies with a legal framework for setting up institutions and infrastructure for groundwater management[11].

The classification based on water scarcity does not consider water contaminated with fluoride, arsenic and other harmful pollutants. About 120 million people (9% of the Indian population) are reported at risk of fluorosis due to fluoride contamination in groundwater[12]. Water contamination can further aggravate water and food security problems.

The relationship between groundwater deterioration and food production is bidirectional. While groundwater depletion implies impending food scarcity, the current food production patterns have also significantly contributed to groundwater exploitation. India's major agricultural products (rice and wheat) are water-intensive[4] and groundwater usage has been increasing steadily due to electricity subsidies[2] (approximately 2.5 times the requirement of millets[13]). However, withdrawing electricity subsidies or strict groundwater rationing could lead to food scarcity[13]. Therefore, the issues related to food security, water conservation and energy subsidies must be tackled simultaneously to ensure socially optimal outcomes.

This study aims to provide a holistic overview of groundwater status and review the major policies, challenges and recommendations for sustainable groundwater management in India.

Overview of groundwater in India

Hydrogeological setting

The hydrogeological setting of a region plays a crucial role in the water retention and replenishment capacity of the aquifer system. The prominent hydrogeological settings in India are the hard-rock and soft-rock formations[1,4,9]. The hard-rock formations (consolidated formations) occupy

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Table 1. Groundwater depletion in key Indian states

State	Percentage of groundwater extraction (overall)	Categorization*
Delhi	101.4	Overexploited
Gujarat	53.39	Safe to semi-critical
Haryana	134.56	Overexploited
Karnataka	64.85	Safe to semi-critical
Kerala	51.68	Safe
Maharashtra	54.99	Sami-critical
Punjab	164.42	Overexploited
Rajasthan	150.22	Overexploited
Tamil Nadu	82.93	Critical
Uttar Pradesh	68.83	Semi-critical to overexploited

*Categorization according to the Central Groundwater Board, GoI.
Source: Adapted from Ministry of Jal Shakti, GoI report, 2022.

two-thirds of the surface. They create aquifers with low water retention and permeability, and thus low replenishment capacity. The soft-rock formations (unconsolidated formations) are found in the Indo-Ganga–Brahmaputra plains, coastal deposits across the east coast and aeolian deposits in the northwestern plains of India. These formations create aquifers with significant water retention capacity.

Groundwater availability

As of 2017, the extractable groundwater resources (total available minus discharges) were 393 BCM. The states situated on the soft-rock aquifers, such as Punjab, Uttar Pradesh, Haryana, West Bengal, Odisha and Tamil Nadu, have the highest replenishable groundwater resources[8].

For understanding the extent of groundwater exploitation, it is crucial to analyse the stage of groundwater utilization. A value of 100% implies groundwater extraction being equal to the annual groundwater recharge, while that greater than 100% indicates extraction exceeding its replenishment. Out of 6607 assessment units, those with more than 100% stage of utilization are mostly concentrated in Rajasthan, Tamil Nadu, Haryana, Punjab, Delhi and Karnataka[8]. Units with a higher stage of utilization fall under the semi-critical (stage of utilization between 70% and 90%) and critical (stage of utilization between 90% and 100% zone). Between 2002 and 2016, Gujarat witnessed an increase in groundwater level, whereas Rajasthan witnessed a declining trend[14]. In most South Indian states, groundwater level has either improved by 1–2 cm/yr, or remained stable since 2013 (ref. 14).

A crucial aspect of groundwater availability is the source of groundwater recharge, which includes rainfall, return flow from irrigation, canal seepage, recharge from tanks and ponds, etc. Rainfall accounts for 67% of groundwater recharge and is the primary source for most states, except those on soft-rock formations. Punjab and Haryana have high groundwater recharge rates, sourced by factors other than rainfall during monsoon season in the Indo-Gangetic Plains[8]. Figure 1 presents a source-wise contribution to annual groundwater recharge across the Indian states.

Groundwater usage

Groundwater is used for irrigation (89% of groundwater utilization), domestic consumption and industrial production (11% of groundwater utilization)[2]. In the last few decades, the use of tube-wells has been significantly higher than that of tanks, canals and other wells[2]. Increased use of tube-wells for groundwater extraction is coupled with reduced surface water usage and increased electricity consumption in the agricultural sector[2]. The literature shows that groundwater is extracted during the post- and pre-monsoon seasons in North and Central India to provide irrigation mainly to rice and wheat crops[15,16]. Arunachal Pradesh uses almost all its extracted groundwater for domestic and industrial purposes[8] (Figure 2).

Groundwater contamination

Groundwater in India is polluted due to human and animal waste, fertilizer application and industrial run-off[8]. Overexploitation of coastal aquifers has led to salinization due to seawater intrusion in parts of Gujarat and Tamil Nadu[8]. Arsenic is present in the Indo-Ganga–Brahmaputra alluvial terrain (including West Bengal, Uttar Pradesh and Punjab) and the hard-rock areas of Chhattisgarh and Karnataka. As of 2015, 20 states have reported groundwater fluoride concentration above the permissible limit[9].

Groundwater measurement

For groundwater monitoring and measurement, the Central Ground Water Board (CGWB), Government of India (GoI), has a network of 23,125 observation wells across the country as of March 2017 (ref. 2). However, the number of monitoring wells and sampling frequency are inadequate considering the spatial variability and heterogeneity

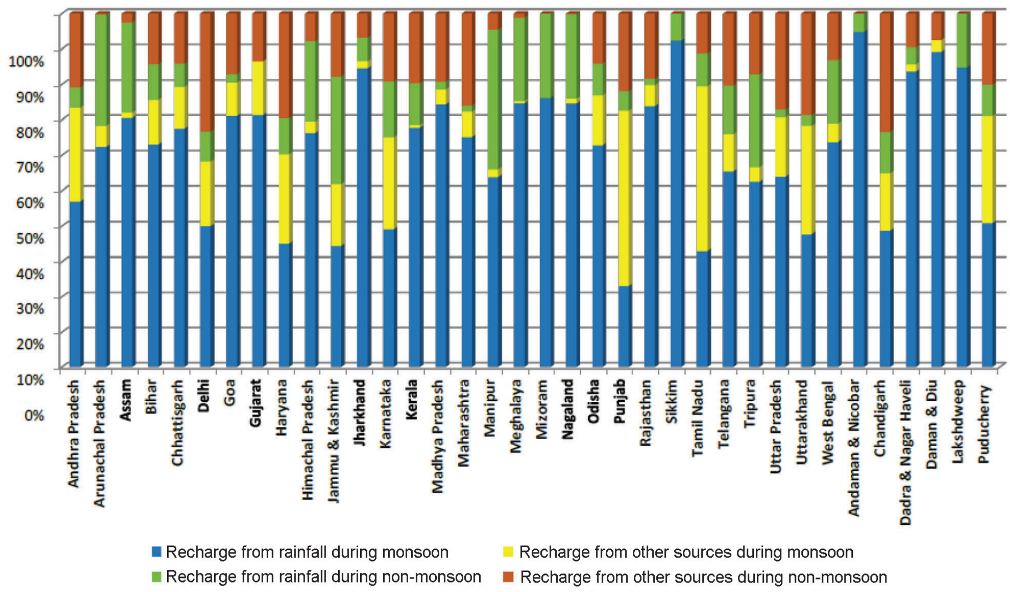

Figure 1. Sources of groundwater recharge across India (source: CGWB, GoI, 2020).

of the hydrogeology of aquifers. An alternative measure of groundwater depth is the Gravity Recovery and Climate Experiment (GRACE) satellite imaging. It captures data for all regions. However, the accuracy of these data needs to be verified against the *in situ* observations of soil moisture, evapotranspiration, groundwater level and streamflow[6].

Issues and challenges of groundwater management

Heterogeneity of land and aquifer features

There is heterogeneity in hydrogeology, especially in the hard-rock and mountain systems. These heterogeneities in aquifers affect the groundwater depth and quality. The total replenishable groundwater resource is 398×10^9 m^3, with 60% restricted to the northern alluvial region (20% of the land mass)[9]. There is spatial variability in the groundwater level and replenishment within the northern alluvial region due to differences in sediment routing systems and regional climate[17]. The aquifer heterogeneity also implies inequity in resource endowment and usage within a village[18]. The groundwater overuse aggravates inequalities amongst the users and can lead to conflicts related to various water uses[19]. Sustainable groundwater management requires a better understanding of the heterogeneous factors such as endowment, recharge and usage of groundwater, along with anthropogenic and climatic conditions[6].

Changes in demographic features

Groundwater is the primary source of irrigation, and therefore, the backbone of food security. The country's population is forecasted to be 1.63 billion by 2051, which would increase the demand for food and hence the pressure on groundwater resources[6,20]. Dietary patterns are also changing due to rising incomes, liberalization and demographic transitions[21]. The per capita consumption of sugar, dairy, meat, vegetables and fruits is projected to increase[22], and such a shift in diet will have a larger water footprint and lead to greater exploitation of groundwater resources (Table 2).

Invisibility and exclusivity of groundwater resource

Groundwater is an invisible and fugitive resource, which leads to competition and conflicts between different stakeholders[18]. Increasing industrialization and urbanization further fuel the water demand causing more conflicts. The Indian property rights do not exclusively state the groundwater ownership and club it with the land ownership rights, converting the common pool resource into private property and giving significant power to landowners over groundwater and excluding user rights of the landless. Thus, the landowner can dig or drill a well, extract groundwater and even dump waste that might degrade or contaminate the groundwater. The land and well ownership are highly skewed and combining groundwater rights with the land rights leads to inequality in groundwater access[23–25].

Groundwater overexploitation increases the water-drawing cost and reduces water yield. The system is skewed towards benefitting large landowners with finances to drill deeper wells or degrade groundwater quality through wilful contamination. Groundwater depletion can have cascading effects, as overexploitation in a region may result in deeper groundwater levels in an adjacent basin. It can cause

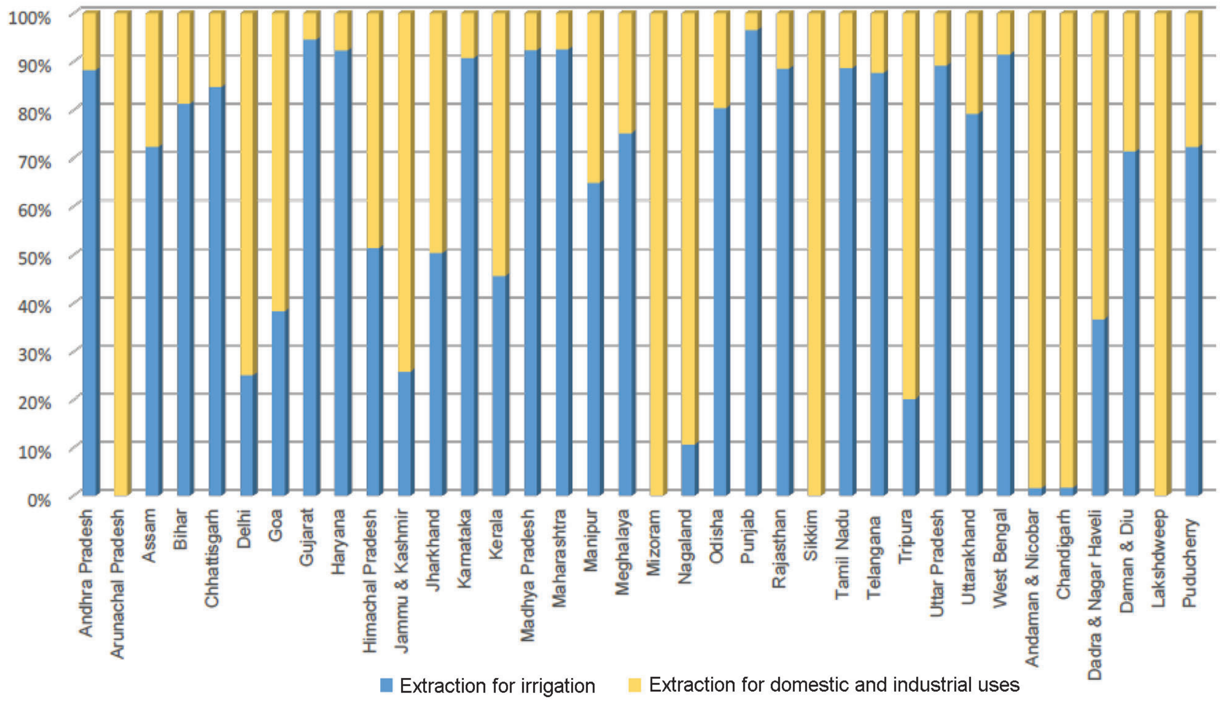

Figure 2. State-wise irrigation draft versus domestic and industrial draft (source: CGWB, GoI, 2017).

Table 2. Water footprint of Indian dietary patterns

	Water footprint	
Dietary pattern	Green (l/capita/day)	Blue (l/capita/day)
Rice and low diversity diet	2209	566
Rice and fruits	2683	640
Wheat and pulses	2492	836
Wheat, rice and oil	2636	883
Rice and meat	2776	677
All	2531	737

Source: Adapted from Green *et al.*[49].

stream-flow decline near pumping areas and have a persistent effect in the downstream regions[26,27]. Therefore, groundwater resource degradation can threaten resource sustainability base in a much larger geographical area[28].

Misplaced incentives

A reason for the continued groundwater overexploitation is the existence of policies and subsidies that directly or indirectly incentivize groundwater usage. The incentives for choosing water-intensive crops, despite recurring water shortages, come from three sources: the minimum support prices (MSPs) for certain crops, the common property nature of groundwater resources, and subsidies for electricity usage and tube-well installation[3]. MSP and the Public Distribution System (PDS) led a new agrarian movement, where mid-sized farmers pushed for higher MSPs and input subsidies[2,29]. With the increasing use of electricity for pumping groundwater, the cost of metering and billing also increased. Further, collusion among the farmers and shared-meters made the payment collection challenging[2]. Consequently, most State Electricity Boards (SEBs) moved to flat tariffs in 1970, which reduced the marginal groundwater pumping cost to near zero and resulted in political tie-ups[30]. Lastly, the surface water-based irrigation infrastructure, such as canals, could not develop at an adequate rate to support the increase in crop production due to bureaucratic and design failures. It pushed mid-sized and large farmers to apt for private groundwater pumps[2].

Water–energy–food nexus

In response to the 1965–66 famine, GoI initiated the green revolution, a system of policies and initiatives for ensuring food security, which pushed for food security at the cost of water and energy resources[2]. Recent studies report that food production has a high negative correlation with the groundwater level and a high positive correlation with electricity consumption[31]. These results indicate a water–energy–food (WEF) nexus.

FAO defines WEF nexus as the inter-linkage of water, energy and food security. The conceptual framework for dealing with this nexus identifies climate change, dietary changes, population growth, etc. as the drivers. The framework also calls for the identification and involvement of all stakeholders to solve these issues simultaneously.

The effective power tariffs combined with volumetric rationing of groundwater could address the unsustainable abstraction levels[32], with Gujarat's JGY (implemented in 2003) being a good example. JGY provided separate electricity feeder lines to irrigators, enabling effective rationing of groundwater usage to 8 h/day (ref. 33). Other suggestions for tackling the nexus are as the following:

(a) Providing farmers incentives to produce less water-intensive, nutritionally rich cereals[2]. This could lead to a reduction in irrigation demand and emissions[34].
(b) Demand-side interventions, such as micro-irrigation technologies, laser levels, on-farm agricultural water management measures, etc. These have been successful in reducing on-farm water usage[2]. However, when the farmers used the saved water for expanding irrigation, the aggregate water savings became zero and the overall water usage increased[35].
(c) Supply-side interventions, such as on-farm water harvesting. These had significant impacts on water availability on a local scale. This positive impact does not extend to the total groundwater availability, as these interventions only accomplish reallocation of water among users situated on the same aquifer[2].

Several unintended spin-off technologies have considerably accelerated groundwater extraction[36]. Subsidizing solar-energy pumps may be similar to the power subsidy because operating costs after the initial investment are minimal[37].

Climate change

Climate change affects rainfall and frequency, with repercussions for the local environment. It is expected that climate change will significantly alter India's hydro-climatic regime. There might be a higher intensity of precipitation and a larger number of dry days in a year. More likelihood of increased frequency of extremely wet rainy seasons will lead to increased run-off[38]. These changes reveal that the *kharif* (monsoon season) crops will face more risk of floods and droughts. During the *rabi* season and especially summer crops, there might be enhanced evapotranspiration, needing more frequent irrigation[39].

Political considerations

Electricity-powered tube-wells are the predominant source of irrigation for most farmers, and their welfare is linked to the electricity tariff for agricultural usage. The flat power tariff system with near-zero electricity pricing creates a 'free power illusion' among the farmers and reduces the marginal cost of pumping groundwater[30]. This tariff system has led to consistent financial loss for many SEBs (especially in parts of western and southern India). A pan-India study using panel data found that a 10% reduction in electricity subsidies can reduce the losses incurred by SEBs and groundwater extraction by 5.4%. However, it would also lead to a 12% fall in farmers' income[40].

The possible loss in farmers' welfare and strong signals in favour of more electricity access, by the demands for longer hours of daily power supply and more farm power connections, have provided incentives for retaining the populist policies related to electricity tariff and supply[30]. It has been shown that conditional on mid-term elections, electricity prices continue to decrease in the year preceding a scheduled election[40].

Legal framework

The management of the within-state water resources is scheduled under the State List, and the management of inter-state water resources is scheduled under the Union List. The legislation does not mention groundwater separately and considers it part of 'water supplies' or 'irrigation'. Consequently, groundwater becomes a state subject, making the management of inter-state aquifers a tricky affair[41].

The groundwater property rights treat the resource as private property under the Easement Act, 1882. The judicial strictures give the property owners the right to overexploit the groundwater resources under their land and state that no penalties would be placed on them for overextraction[11]. There are other policies aimed at the management of groundwater resources. The Water (Prevention and Control of Pollution) Act, 1974 was enacted to prevent water pollution due to industrial emissions. It contains regulations to prohibit pollutant discharge in water bodies, including wells. However, after an amendment in 1978, the state governments were not required to have state-wide compliance with the rules. The Water Act of 1974 did not specify groundwater as a separate issue from surface water. The provisions for the management of groundwater were made in the Environment (Protection) Act, 1986. The Environment Act set up an authority to monitor the quality and quantity of water resources (groundwater and surface water), promote rainwater harvesting, etc.[41]. It also set up the Central Ground Water Authority (CGWA), a key institution for groundwater management[11].

The Central Government prepares Model Bills related to groundwater management for enactment and implementation by the state governments[41]. The first Model Bill was passed in 1970 and was updated in 1992, 1996, 2005 and 2011 (ref. 11). The initial Bill aimed at empowering state governments to restrict the installation of new groundwater extraction methods. It was unsuccessful due to lack of cooperation from the state governments[41] and a top-down regulation system that introduced control on groundwater usage by individual owners, but did not account for the need of aquifer-level protection measures[11]. The subsequent revisions focused on including groundwater used for drinking and domestic purposes, exempting small and marginal farmers from obtaining permits, rainwater harvesting for groundwater replenishment, and mandating the creation of groundwater authorities under the state governments[42]. Even with these revisions, the Bill failed to achieve the targets[41].

The Model Groundwater (Sustainable Management) Bill, 2017 aims at integrating the surface and groundwater management, aquifer conservation and developing a bottom-up regulation framework. It addresses issues such as the nexus between water management and food security, different regulations for different groundwater use, and the right to water, health and environment of the citizens. This Bill is a first step in the right direction for groundwater management, as it has a more holistic approach to groundwater conservation and would give more power to the local authorities to choose groundwater preservation techniques. The latter feature can boost the participation of local authorities in groundwater conservation. However, its success depends on its adoption by the state governments, the setting up of strong local institutions, and the decoupling of political incentives and groundwater management[11].

The state governments have their own policies and regulations for groundwater management. The Punjab Government has been against the Model Bill, stating that it has a negative impact on the farmers. It has implemented policies for crop diversification, electricity supply control and micro-irrigation[43]. Some other states have implemented policies for rationing electricity, regulating groundwater usage and promoting solar energy for groundwater usage. These policies, such as JGY, Punjab's Paani Bachao Paise Kamao, and West Bengal's electricity pricing and solar-powered tube-well schemes, have had some success[2,10,11]. Only Maharashtra and Karnataka have regulatory policies based on the Model Bill. Although the regulatory framework has been successfully set up in these states, the enforcement of the regulations could be challenging due to the number of existing groundwater wells[44].

Institutional issues

Table 3 provides a summary of the four major institutions for groundwater management based on data from the Ministry of Jal Shakti and the 2009 status report of the Ministry of Water Resources (MoWR), GoI. These institutions suffer from inadequacies in tackling groundwater overexploitation due to the lack of statutory powers, low community involvement in management schemes, bureaucracy, lack of political will and inefficient usage of human resources. These issues also extend to the state-level institutions, with additional challenges in coordinating between various State and Central Government authorities[43].

Given the importance of community-based groundwater management, participatory irrigation management (PIM) has come to the forefront. It aims to involve groundwater users in various aspects of groundwater management, especially in storage, distribution, cropping pattern and intensity[45]. There are concerns regarding the overall efficiency of PIM due to lack of political and financial support, uncertainties regarding water delivery and availability, lack of technical knowledge regarding aquifers and irrigation systems, etc.[45].

Water trade and carbon footprint of groundwater economy

Informal water markets play a crucial role in the Indian agricultural sector. While these markets may lead to increased agricultural productivity[46], they can also contribute to local food insecurity and unemployment[47].

Virtual water (VW) is the water consumed for producing agricultural and industrial products. The trade in such products leads to the trade of VW embedded within them. India is a net exporter of groundwater; it exported about 25 km^3 of water embedded in its agricultural exports in 2010, equivalent to the water demand of nearly 13 million people[48]. An increase in VW export will lead to a further decline in groundwater resources.

There is substantial inter-state VM trade in India. The main cereals traded in 2010–11 were rice and wheat. The estimated VM inter-state trade was 153.4 km^3, with groundwater and surface water accounting for 35% of this trade. The majority of inter-state cereal trade occurred through the PDS. As the PDS aims at maximizing the operations of MSP policy, it is not surprising that PDS trade is more dependent on overexploited groundwater than non-PDS cereal trade[49].

Abstraction of groundwater contributes to carbon emissions due to the pumps used to extract water and through carbon dioxide (CO_2) released from bicarbonate in the extracted groundwater. The deep tube-wells have a considerable carbon footprint. The total annual CO_2 emission from groundwater in India is estimated at 2–7% of the total annual CO_2 emissions[50]. Another estimate shows that groundwater irrigation contributes around 8–11% of total carbon emission[51]. The CO_2 emissions due to groundwater pumping are much higher than bicarbonate extraction in India. The CO_2 emission can be reduced using solar and wind-powered pumping systems and by improving the pumping efficiency[50].

Table 3. Central Government agencies for groundwater management

Institution (year constituted)	Main functions and responsibilities
Central Ground Water Board (1954, restructured in 1972)	• Technical advice for groundwater resource management and development • Systematic hydrogeological surveys • Monitor national hydrograph observation wells • Training activities related to groundwater • Review regulation of groundwater management • Develop infrastructure for and carry out rainwater harvesting and artificial recharge of groundwater
National Water Resources Council (1983)	• Lay down the National Water Policy and review it from time to time • Assist in resolution of inter-state water conflicts • Review major water development plans • Recommendations for development of water resources
Ministry of Jal Shakti (2019, supersedes Ministry of Water Resources), GoI	• Development and regulation of the India's water resources • Perspective of water planning and coordination concerning diverse water uses • Lay down policies and programmes for development and regulation of the India's water resources
Central Groundwater Authority (1997)	• Regulation and control of groundwater development and management

Policy suggestions

The potential disaster of groundwater scarcity requires a restructuring of electricity pricing, infrastructural development for its storage and aquifer replenishment, participatory groundwater management and remodelling the legal framework[11,52–54]. Further, avenues for better metering and delivery of electricity for agricultural use, the use of solar energy, conjunctive use of surface and groundwater, and the WEF nexus are important considerations for the long-term success of the policies[2,55].

Ryan and Sudarshan[52] developed a series of models for the rationing of commons for Rajasthan farmers and found that the de facto policy regime led to a 12% loss in annual household income. They attributed it to inefficient and over-extraction of groundwater, leaving smaller amounts available to efficient farmers. They also studied the effects of using Pigouvian pricings as opposed to rationing and found that such reforms are not Pareto efficient as they are biased towards large farmers. The study concludes that rationing is the better policy option because it increases social welfare despite decreasing the social surplus. Another study focused on the arid regions suggested that the optimal groundwater management regime (in terms of social costs and benefits) would require the state governments to pool and conserve groundwater resources[53]. Therefore, the literature favours policies for the rationing and pooling of groundwater resources.

Sidhu *et al.*[54] compared the advantages and disadvantages of flat and metered tariffs. They found that flat tariffs have lower administrative costs and better welfare outcomes for small farmers, but fail to provide incentives for groundwater conservation and judicious electricity use. These optimal usage features are fulfiled by metered pricing. The authors suggested a hybrid pricing structure that charges pump owners a fixed flat rate based on the pump size along with per-unit pricing. Gulati and Pahuja[55] also suggested a series of policy changes to deliver electricity and energy price subsidies to the agricultural sector. The suggested policies include feeder segregation at the village level, minimum energy supply guarantee for farmers, and smart metering and subsidy delivery using ICT. The identified stakeholders include farmers, rural non-agricultural consumers, power sector employees, elected representatives, the government, power distribution companies, urban consumers and lenders/investors for the power sector. The authors showed that an optimal policy would aim to improve the payoffs of farmers and power distribution companies, and target to at least keep the payoffs of the remaining stakeholders constant in the short run[55].

From a legal perspective, Cullet[11] emphasized the importance of adapting the Model Bill before its adoption by a state legislature to ensure that the policies implemented are fine-tuned to the unique features of the state. For meaningful mitigation of the groundwater crisis, he recommended restructuring the property laws to decouple groundwater from landownership, development and empowerment of local-level groundwater management agencies, and customization of the groundwater management policies based on the unique features of a region.

From a review of the literature and analysis thus far, we make the following policy suggestions:

(a) Groundwater management should happen at the regional level, as factors such as soil type, water usage and extraction, etc. can change rapidly even within a state. Therefore, a centrally governed policy is not optimal.

(b) Developing local authorities and groups for groundwater conservation would help align the conservation efforts with the soil type, rainfall and climate of a region, even within a state. Further, local authorities may be able to monitor the implementation of conversation policies at lower administrative costs. These local authorities could be set up at the district or taluka level.

(c) Along with district-level authorities, village/Panchayat-level participatory management groups would help resolve disputes regarding groundwater distribution and rationing. A village could come together and create a common pool/reservoir for groundwater, and also discuss its usage/rations within the community. The village/Panchayat-level participatory management groups should work under the guidance of the local authorities to ensure that the groundwater resources of the entire region are improved.

(d) A hybrid pricing system would help transfer the increasing marginal cost of deeper wells to the end users. At the same time, due to a part of the tariff being a fixed price based on pump size, there would be lesser administrative costs.

(e) The legal framework around property ownership should be changed so that groundwater rights are no longer linked with land ownership. Further, any new Bills for groundwater conservation should include provisions for giving administrative powers to local authorities.

(f) Finally, the problem of the food–water nexus can be resolved by expanding the food procurement basket to include nutrition-dense crops with low irrigation requirements, such as millets. This would give farmers an additional monetary benefit to move away from wheat and paddy production.

Keeping in mind the above policy suggestions, CGWB's 2021 master plan for artificial recharge of groundwater appears to be a step in the right direction. To ensure that the artificial recharge set-up is appropriate for a particular block, the Board has initiated plans based on aquifer type, climate conditions and local groundwater issues. The master plan aims to develop 110 lakh artificial recharge and water conservation structures, with a budget estimate of INR 79,178 crores.

Conclusion

Groundwater over-extraction can have disastrous effects on drinking water and food security. There may be a food shortage in the near future along with a drinking water shortage, especially in urban areas. Further, the current electricity pricing system for groundwater pumps contributes to overexploitation of groundwater and may lead to losses in the power sector and an energy crisis (WEF nexus). There are several challenges related to groundwater management. The most frequently cited challenge is the combination of near-zero electricity pricing for agricultural use and MSP for water-intensive crops, providing incentives for overexploitation of groundwater. A related concern is the grouping of groundwater rights with land ownership, which enables the exploitation of a common property resource (groundwater). VM trade, climate change and demographic changes are also affecting groundwater.

Efficient groundwater management requires reforms in the energy sector and the legal framework. Electricity pricing and rationing, along with the promotion of solar energy can reduce groundwater exploitation and carbon emissions. The legal framework should be remodelled to decouple groundwater from landownership, empower PIM, and develop policies focused on aquifer level groundwater management. Lastly, conjunctive use of surface and groundwater is important.

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Received 18 August 2021; revised accepted 28 June 2022

doi: 10.18520/cs/v123/i7/856-864