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Regulating agricultural groundwater use in arid and semi-arid regions of the Global South: Challenges and socio-environmental impacts

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Abstract

Groundwater forms the basis for millions of rural and urban livelihoods in the Global South. Its use for irrigation has spurred widespread socio-economic development in various areas but has also led to aquifer overdraft and related socio-environmental impacts. This article presents common challenges that agricultural groundwater regulation faces in the areas of intensive use. It shows the main approaches that have been used to try to regulate and control groundwater use. These revolve mostly around direct regulation by the state; different forms of co-management between groundwater user groups and state agencies; and incentives aimed at reducing agricultural groundwater use. This review analyzes why in many contexts, these mechanisms have not led to more sustainable aquifer use. Finally, the article brings to highlight the important challenges this poses in terms of socio-environmental sustainability.

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Groundwater, Governance, Irrigation, Water policy, Socio-environmental sustainability.

Introduction

Groundwater is the invisible, subsurface part of the hydrological cycle and in the past 80 years it has become the primary source of water for domestic, urban, agricultural, and industrial uses in many countries; especially in arid and semi-arid regions [24,56,68]. This is due to its easy accessibility with tube wells, high water quality and interannual reliability as compared to surface water bodies [55]. The operation and maintenance of tube wells is highly flexible compared to surface water infrastructure providing individual and collective users with water on-demand (just-in-time) at relatively low costs. This has propelled its widespread use for irrigation. For farmers, its use has enabled increased crop productivities and diversification, transforming rural economies, and significantly improving the food security and livelihoods of millions around the world, while proving to be an effective strategy to increase the resilience of agriculture in view of climate change induced climatic variability [24,54]. Groundwater is a “horizontal” resource, meaning that “farmers [and other users] located above an aquifer can sink wells independently of each other over a significant areal extension” ([69]: 156). The attractiveness of this water source coupled to accessible drilling and pumping technologies has led to the intensive use of aquifers around the world and especially in semi-arid regions such as southern Europe, Northern Africa, the Middle East, Pakistan, parts of India and China, northern Mexico, the coasts of Peru and Chile and the south-west of the USA [17]. This leads to widespread and decentralized groundwater access through individually owned and operated wells making it hard to pinpoint by whom-, how-, in which quantities—and where water is being used.[1] In arid and semi-arid areas, this easily leads to situations where pumping exceeds aquifer recharge, which presents important socio-environmental challenges [16,27].

Faced with severe aquifer depletion and/or to prevent it from occurring, many governments have tried to develop a broad diversity of mechanisms aimed at regulating and controlling groundwater extractions [30,56,59,62]. In this literature review, which is based on the analysis of key review publications as well as several documented case studies of groundwater governance in arid and semi-arid regions of the Global South,[2] I present the

[1] Although important advances have been made with remote sensing techniques which are becoming increasingly cheap and easily accessible [52].

[2] The Global South here includes an analysis of countries in South America (including Mexico), Africa, the Middle East, Asia and Spain. The latter is included because of the valuable experiences of groundwater management.

most commonly used mechanisms that have been put in place as well as the challenges that the implementation of these mechanisms face from a socio-environmental sustainability perspective[3] [12,49].

Governmental regulation, subsidies and supply augmentation

Policies and interventions that aim to advance (more) sustainable groundwater use in intensively used aquifers often include a mix of the following policy objectives: (a) controlling the drilling of new wells and the deepening of existing ones; (b) controlling and regulating water abstractions from the aquifer with the use of wells; (c) preventing pollution and water deterioration of aquifers; (d) guaranteeing the safe use of groundwater in view of increased water pollution threats; and (e) in view of the above sometimes increasing the resource base of aquifers through water transfer and/or managed aquifer recharge.

For controlling and regulating the drilling of new wells, the deepening of existing ones as well as for regulating water abstractions from aquifers a first step is to identify who is drilling/deepening the wells, who owns/uses the wells, and how much water is being extracted by the wells in use. In order to achieve this, around the world, governments have created systems based on governmental permits and licenses for drilling companies as well as for water users [45]. Since the 1980s, many countries established new systems of permits or reactivated existing regulations with new amendments [10,28,39]. Of course in every country the frameworks are different and come from distinct historical, cultural, legal, and institutional legacies that relate back to precolonial, colonial, and post-colonial pasts. Additionally every region has a different and very specific climatic and geohydrological uniqueness that brings with it specific challenges especially in the current context of climate change.

In most areas of intensive agricultural groundwater use such as central and northern Mexico, coastal Peru and Chile, many areas in Northern Africa, the Middle East, Pakistan, India and northern China the large number of wells, the large number of (un)registered drilling companies, and the widespread drilling that takes place on a day-to-day basis, makes it very hard to create an up-to-date license/permit registry system for the administration, regulation and control of agricultural groundwater use (see for instance the study by Shah et al. [54] for India [67], the study by Qureshi et al. for Pakistan [28]. the study by Hoogesteger et al. for Mexico [8,41], the studies by Azizi et al. and Mirnezami et al. for Iran [18], the study by Dalin et al. for coastal Peru [19], the study by Donoso et al. for Chile). Based on a literature review [46] identified several factors that undermine the efficiency of groundwater use monitoring and the enforcement of the existing legal framework in many countries.

First of all, they point to the fact that in most countries state agencies do not have sufficient resources (staff, vehicles, budget, training, equipment) to monitor and regulate groundwater use as their administrative units sometimes have thousands of users dispersed over large areas. This makes the implementation of sanctions wellnigh impossible, while also de-legitimizing the (moral) authority of the agencies. This lack of legitimacy is often compounded by the widespread lack of transparency and often selective application of the regulations within the groundwater regulatory agencies. In amongst others India [54,57], Jordan [2], Mexico [61,65] and Algeria [5] bribing, fraud and corruption of officials at different levels in the regulatory agencies seems common practice. Complicating things further, there are many countries where the regulatory agencies have limited legal faculties to effectively deal with users that do not comply with the regulations. The result is that even if fines or other sanctions (such as well closures) are given, the legal means to force their payment are not there or are too slow. Incidents of the use of violence/force by organized users vis-à-vis bureaucrats/inspectors in rural areas also greatly undermines regulatory efforts of the state in many countries.

Another stumbling block for controlling groundwater extractions is the metering of individual groundwater use. Many countries have made the installation of water meters on deep tube wells compulsory (i.e. Mexico, Peru, Chile, Jordan, Morocco, Spain). However, the high costs of the installation of water meters and the ingenuity of users in bypassing and tampering with the water meters, let alone the registration of extracted volumes, makes efforts to monitor and control groundwater use transient [46]. Finally, the use of political power, networks, and personal relationships with and within the government enables the economic and ruling elite to bypass and/or informally arrange and legalize (the often lucrative) groundwater use and drilling permits through extra-legal means. In contexts of high economic and political power differences such as in many countries in the Global South, therefore implementation of the law and administrative control runs the risk that above all the "illegal wells and expired permits" of smallholders and communities get fined and closed; while the "(extra)legal wells and permits" of the economic and political elite are respected [3,11,31].

For politicians and state agencies it is far more attractive to work through incentives such as subsidies on irrigation modernization (mostly to drip) [4,34]; Hoogesteger, 2017) and infrastructural interventions for augmenting total water supply. Measures for water supply augmentation include inter-basin water transfers

[3] Transboundary aquifer management arrangements are not analyzed in this review though we recognize that these specific cases merit attention.

[48]; waste-water treatment and re-use [6]; sea water desalinization [60]; and managed aquifer recharge schemes [22]. Context specific combinations of these measures have proven effective in advancing aquifer sustainability where they have been combined with consistent state regulation and control; mostly in relatively small aquifers with a limited amount of users [44].

Groundwater co-management

An alternative and complement to state regulation that has been widely promoted is the collective management of groundwater—self-regulation or local-level governance. In the early 2000s, the World Bank recommended frameworks to promote the development of aquifer management organizations [70,71]. However, within these guidelines the question of what powers should be held by an aquifer management organization versus higher-level authorities is not explicitly addressed. In reality, there is always a combination of state-led and community-centered governance that often goes hand in hand with a sharing and contestation over powers and responsibilities between (organized) local resource users and state agencies [23,26].

A complicating factor in groundwater management is that it is difficult to organize aquifer users and develop social control over groundwater pumping [64]. The "invisible" and "individualized" character of groundwater makes it difficult to determine who is pumping how much and to monitor reductions in extractions. It is only after prolonged periods of pumping that their combined actions result in aquifer declines. Even if a strong collective aquifer co-management structure is constituted and reductions in groundwater extractions are agreed on, it takes a long time before an aquifer stabilizes and the pumpers see any reward for their restraint [30].

Molle and Closas [44] based on a review of 12 cases of aquifer management councils from around the world (Mexico, Jordan, Tunis, Morocco, New Zealand, France, Australia, USA) identify the following key aspects that mark the effectiveness of arrangements for co-management of aquifers (see also [1]. First, the number of groundwater users sharing the aquifer and possibly the adverse effects of drawdown is of course a key feature. Their analysis suggests that a few hundred, even up to a thousand users might be a "manageable" number for co-management arrangements. A second characteristic is social homogeneity and high levels of trust and reciprocity among users [37,38]. Conversely, in cases where groundwater users have divergent interests and big power differences exist among uses, it is hard to identify shared objectives and joint strategies withing the users organizations [64,65].

It has proven difficult for user organizations to advance agreements and/or policies that lead to reduced pumping from aquifers such as metering, declaring illegal wells, drilling bans, pumping quotas, crop prohibitions, penalties for illegal practices or disincentives such as water and energy pricing amongst others [58,63]. Such measures usually curtail access to groundwater and with it the benefits to users. Therefore, for instance in Mexico, groundwater users committees have focused on policies that are attractive to its members such as arranging subsidies for irrigation technology, supporting farmers with the legal and administrative tasks of their groundwater concessions and electricity subsidies, while lobbying for the interests of the groundwater users vis-à-vis state agencies [31]. In other cases user based organizations' focus on supply augmentation strategies such as managed aquifer recharge (see for instance the study by Fernández-Escalante et al. [25] for Ica, Peru [9]; the study by Basel et al.for Oaxaca, Mexico) or supply augmentation though inter-basin transfers [48] or wastewater reuse [64].

User based organizations for aquifer management are usually stuck within a balancing act in which on the one side they need to be able to bind their constituency by offering benefits to the users, while on the other they have to remain accountable and legitimate vis-à-vis state agencies and the legal framework in which these need to operate. A review of diverse "successful" cases [44] suggests that establishing co-management arrangements is easier where the recovery, or at least stabilization of aquifer levels is a credible objective and where the threat of state intervention to curtail groundwater use through the implementation of regulations is real. Such contexts have been identified mainly in cases in countries in the global north (Spain, Japan, the United States of America and in New Zealand and Australia). Other factors that have been identified are [42,53]: a credible threat or opportunity (social or hydrological) that incentivizes users to collaborate; accountability mechanisms; transparency with regard to the rationale behind the measures; the distribution of costs and benefits; the data/models used to devise the measures; and legal empowerment of the organizations. Enabling or constraining many of these factors is the question of mandate, legitimacy and funding of these organizations to make them operational and functional. Up until now most of the examples of functioning organizations relates to cases where these are legally and financially supported by state agencies [44].

Socio-environmental implications of aquifer declines

The rise and expansion of agricultural groundwater use has brought a lot of socio-economic development and wealth to rural areas in various regions in the Global South. Millions of smallholder farmers have increased food-security and incomes while also becoming an important source of year-round agricultural labor [55]. However, in many regions the widespread ineffectiveness of regulatory, co-management and incentive based strategies to advance more sustainable groundwater use results in a continued race to the bottom of the aquifers. This race to the bottom leads to the following processes [30]:

Out-pumping the poor

When groundwater levels drop, pumping costs increase and wells need to be deepened or repositioned. Those that cannot afford these costs lose their access to groundwater and related livelihoods and often leads to poverty, increased proletarianization, migration and related marginalization [29,50].

Buying out smallholder irrigators

Access to groundwater strongly depends on the political economy of production. In countries with smallholder farming systems depending on groundwater, richer farmers pumping out poorer farmers is common, but mostly unintentional and related to the dynamics of a common pool resource. In areas with industrial agriculture, lucrative agricultural commodity chains tend to establish firm control over groundwater by playing the legislative system, acquiring pumping permits via extra-legal means and buying out the smallholders (see for Chile [14,47]; Peru [18,40], Mexico [28], Jordan [2,36], India [11,54,57]). Similarly cities, industry and mining tend to acquire the groundwater resources they need through legal and illegal means and mostly at the cost of the weakest groundwater users such as rural communities and smallholder irrigators [13,21,43,66].

Diffuse socio-environmental consequences

In coastal aquifers, over-pumping can lead to salinity intrusion, in the long-term rendering the aquifer useless. Land subsidence is a common occurrence in areas of intensive groundwater use, and leads to high social costs due to breaks in drainage pipelines, damages to houses and roads and increased risk of flooding. Over-pumping can also have very serious groundwater quality impacts as the cases of arsenic in Bangladesh and West Bengal [7] and arsenic and fluor in most of central and northern Mexico [32,33] show. Other environmental consequences include drying springs, reduction of river base flows and desiccation of groundwater dependent wetlands with adverse effects on related livelihoods. These socio-environmental consequences are diffuse and impact the livelihoods, public health and wellbeing of wide segments of a population; especially the rural poor and marginalized.

Conclusions

Groundwater has become the cornerstone of many agricultural socio-ecologies in arid and semi-arid regions of the world. However, because of the centrality of this resource for many regional (especially rural) economies, its regulation aimed at advancing more sustainable aquifer use levels is extremely challenging. A broad literature review that necessarily misses many of the nuances and context specificities of the different governance arrangements in areas of intensive groundwater use in arid and semi-arid regions, shows that bribes, corruption, fraud, vested political interests, the politically unpopularity of regulatory measures, the economic and political power of large farmers and often the uncertainty of hydrological data coupled to underfinanced regulatory state agencies and legal loopholes form important challenges that hamper efforts aimed at reducing agricultural groundwater use. Though many forms of co-management aimed at involving organized groundwater users have been tried in arid and semi-arid areas of the Global South, many of these initiatives have not led to more sustainable groundwater use due to the difficulty of forming aquifer users collectives, underfunding of users organizations, unclear delineation of legal status and responsibilities, and lack of effective cooperation with state agencies. The result is widespread aquifer draw down coupled to a gradual accumulation of groundwater in the hands of economically and politically powerful producers, industry, mining and cities, while rural communities and smallholder farmers increasingly lose their access to groundwater and/or are exposed to declining groundwater quality and other adverse effects. The few examples in the Global North where important advances have been made towards more sustainable groundwater use point at contexts in which strong and consistent state regulations, transparency, co-management, and substantial financial investments to compensate those whose water access is reduced have been achieved. Therefore important question marks have to be raised around the short- and long-term tradeoffs of sustaining the highly consumptive groundwater irrigation sector in water stressed aquifers. This is especially so in contexts where a rather small number of large agricultural producers consume the lion's share of groundwater resources. Curbing their groundwater consumption will imply, legal, institutional, economic, and political transformations as well as challenging powerful vested interests, but is in many contexts an imperative to reach aquifer stabilization and ensure long term aquifer sustainability in both quantity and quality.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

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