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Transformations to groundwater sustainability: from individuals and pumps to communities and aquifers

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If the success of agricultural intensification continues to rely on the depletion of aquifers and exploitation of (female) labour, transformations to groundwater sustainability will be impossible to achieve. Hence, the development of new groundwater imaginaries, based on alternative ways of organizing society-water relations is highly important. This paper argues that a comparative documentation of grass-roots initiatives to care for, share or recharge aquifers in places with acute resource pressures provides an important source of inspiration. Using a grounded anti-colonial and feminist approach, we combine an ethnographic documentation of groundwater practices with hydrogeological and engineering insights to enunciate, normatively assess and jointly learn from the knowledges, technologies and institutions that characterize such initiatives. Doing this usefully shifts the focus of planned efforts to regulate and govern groundwater away from government efforts to control individual pumping behaviours, to the identification of possibilities to anchor transformations to sustainability in collective action.

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Introduction

Over the past half century, a 'groundwater revolution' [1] has occurred: a shift from using relatively easily available

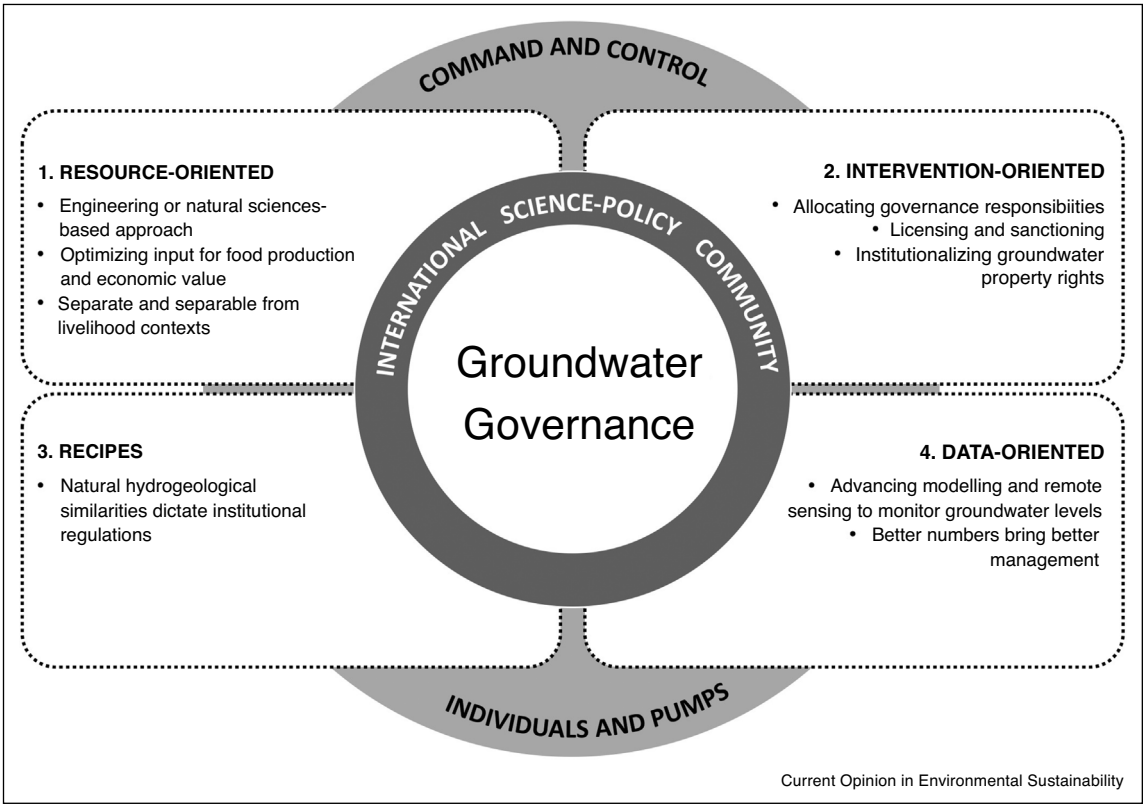
shallow subsurface waters to using much deeper underground waters that are not always replenishable. This shift happened by replacing often centuries-old technologies for capturing and distributing or storing groundwater (wells, qanats, drains, pozas) with new — ever better and cheaper — technologies for drilling, pumping and conveying water. In agriculture — which is the focus of this paper — the availability of groundwater has allowed the expansion of agricultural frontiers [2] by extending irrigated areas and making farming possible in arid places. Currently, some forty-two percent of the world's irrigated lands is irrigated with groundwater [3].

Both scientific scholarship and policy statements, underscore the strategic importance of tapping into previously inaccessible groundwater reserves for realizing present-day and future global water, food security and climate resilience ambitions [4–8]. Yet, they also, and somewhat paradoxically, draw attention to the overexploitation and pollution of aquifers [9,10]. Analyses point out how the intensified use of groundwater for agriculture results in rapidly falling groundwater tables, declining water quality, increased rates of saltwater intrusion and land subsidence, while also drying up natural water bodies like wetlands and rivers with detrimental effects to biodiversity. Excessive groundwater pumping may also irreversibly destroy or reduce underground storage capacity as well as damage hydraulic connections between surface and groundwater systems [11].

Governing groundwater is notoriously challenging, with widespread scholarly agreement that past and current attempts are disappointing or ineffective [12••,13–15]. This is because groundwater is invisible, making it difficult, cumbersome and often expensive to determine and monitor quantities available. It is also because groundwater flows are connected to other water flows — surface, rain and subsurface — and because there are different types of groundwater, with some being easier to re-charge than others. An additional complexity is that groundwater is a common pool resource with high subtractability, meaning that one person's use can change the availability or quality for other current or future users. However, unlike other common pool resources, the need for infrastructure to access the water increases the potential for excludability. There are two types of tensions here: between individual and collective interests and between short-term gains and longer-term sustainability [16,17].

Figure 1 summarises how recent reviews on groundwater governance [12••,13,18,19,15] display strikingly similar lines of argumentation and conclusions, something that

Figure 1



Focus areas of international scholarship on groundwater governance.

can perhaps be attributed to the fact that most groundwater governance scholarship appears to come from just a few international research centres (such as IWMI, FAO, IGRAC, OECD). Writings are resource-oriented and intervention-oriented and assume that governing groundwater is primarily a public concern. Most studies are geared towards the formulation of generic guidelines (glossing over socio-ecological differences), clearly anchor prescriptions (or recipes) in the assumption that similar hydrogeological conditions warrant similar institutional or governance arrangements, and place faith in the use of ever more advanced modelling and remote sensing techniques to better know and manage groundwater. Overall, a 'tragedy of the commons' reasoning prevails, with attention focusing on what governments can do to either curb the greed of individual extractors through licensing and sanctioning, often in combination with efforts to institutionalize property rights, or to increase supply through advanced technological means such as inter-basin transfers, or desalinization [13].

In the rest of this paper, we make a plea for pluralizing groundwater governance scholarship. We argue that there is merit in complementing the current focus on government efforts to better regulate and control extraction, with efforts to document and learn from community initiatives to care for, share or recharge the aquifers they depend on for livelihoods and incomes.

Transformations to groundwater sustainability

Our project, Transformations to Groundwater Sustainability (T2GS), brings together a network of scholars, activists and practitioners with backgrounds in critical social science, engineering and hydrogeology, who work in different countries on water-related themes. Through the project, we aspire to contribute to the anti-colonization and pluralization of groundwater scholarship [20,21•,22]. The purpose of anti-colonization is to trace how current groundwater crises are caused by or intrinsic to particular models of agricultural intensification (and development) – those premised on systematically undervaluing water (and the environment more broadly) as well as labor (much of it from women).

Anti-colonization importantly includes developing sensibility to how prevailing scientific ways of knowing (measuring, thinking about, imagining) and managing groundwater originate in, or help legitimate such unsustainable models of farming and development. Pluralization is a necessary parallel move to anti-colonial critique. It consists of looking beyond accepted science-based expertise and solutions to (re-)appreciate and learn from the wisdoms, technologies and institutions that communities have devised — often based on generations of living in a territory — or are experimenting with to protect, recharge, access and share groundwater.

Pluralization also entails developing new circuits and ways for knowledges to travel. We are interested in finding ways of joint learning that do not depend on grand theorizations and the adoption of single idioms, and resist the pressures for equivalence, commensuration and coherence that often come with a desire for global comparison and universality. We propose to instead cherish pluriversality: allowing many knowers, knowledges and versions of groundwater to co-exist, learning from and living with, rather than overcoming, differences [23–25]. Doing this means developing awareness of the many translations needed to contrast and compare what happens in one place to what happens elsewhere. In our collaborations in the project, we actively experiment with different ways of doing this. We for instance organize monthly online workshops, make podcasts, encourage social scientists to learn about hydrogeology and hydrogeologists to learn about critical social science and feminism, and we jointly search for the shared origin of dominant groundwater imaginaries, tracing how these resonate in the study cases. We have also started to make use of drawings to capture the complexities of community groundwater practices in the different places where we study. We use these drawings as a horizontal tool for interpretation and critical reflection. An example is a drawing based on the study carried out by the Indian team in Randullabad (Figure 2). The making of, comparing, and joint conversations about these drawings allow discussions to emerge about different ways of understanding groundwater injustices, inequalities and governance challenges. Experimenting with different ways of representing, comparing and translating experiences, ideas and findings is proving to also be a joyful way to start practicing care and solidarity in how we learn and develop knowledge: attempting to make sure that all voices, experiences and stories matter.

Guiding our efforts is a conscious attempt to shift the current emphasis in groundwater governance scholarship from command and control — aiming to regulate the pumping behaviour of individuals — to an approach which recognizes and supports the care of communities for aquifers [27,28•] through identifying and assessing forms of solidarity and collective action [27,29]. In addition to mobilizing feminist and anti-colonial thinkers to help do this [23,26•,29,30••,31••,32••,33,34], we are interested in a broader 'return to practice' [35,36] and take the idea of hydrosociality [37,38] seriously. An important premise that guides our efforts is that lessons about possibilities to use, care for and share groundwater in ecologically wise and socially just ways need to be empirically anchored in the actual practices of those engaging with groundwater on a day-to-day basis: diggers, artisans, farmers and dowsers, to just name a few.

The remarkable existence of community-based initiatives and engagements with groundwater in India,

Figure 2

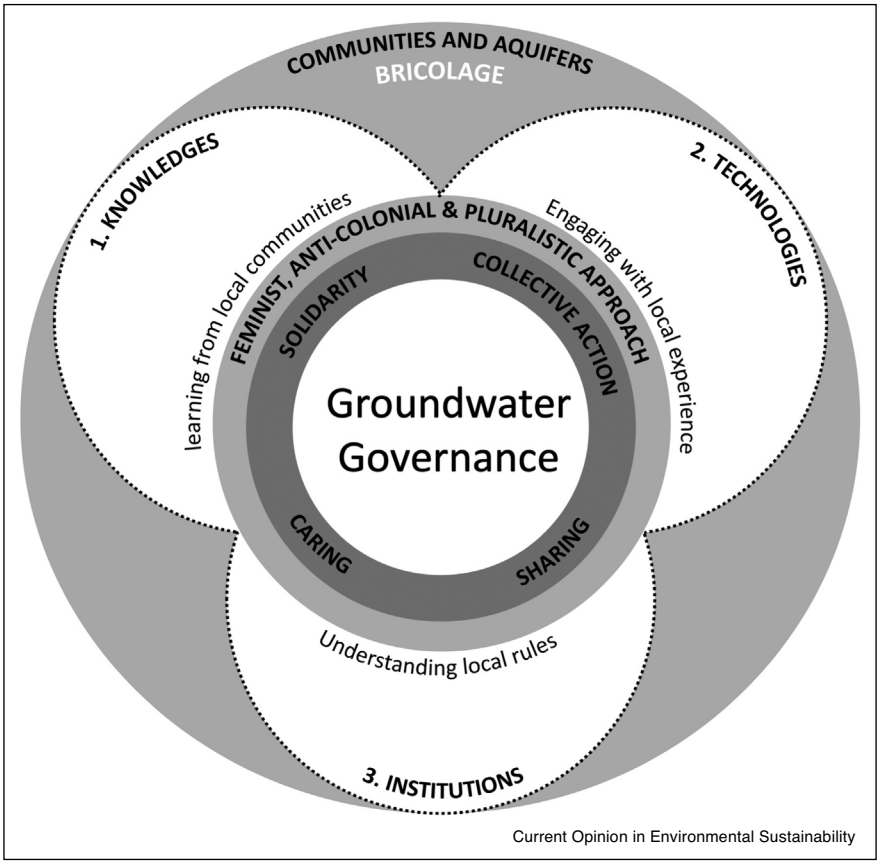
The Participatory Groundwater Management Initiative in Randullabad, India. (Co-produced by Uma Aslekar, Dhaval Joshi, Rucha Deshmukh and Cristian Olmos Herrera).

Algeria, Morocco, Tanzania, Chile, Peru, USA, Zimbabwe, Syria forms a source of inspiration and starting point of our exercise. These initiatives consist of people who, sometimes with outside support, organize to capture, share, re-charge or protect groundwater in places where threats of depletion and pollution are particularly acute.[1] Their collective action is catalyzed by direct experiences of harm caused by declining water availabilities or deteriorating qualities, a sense of territorial belonging, or a connection to place [36,39•]. Such efforts to defend groundwater reserves and longstanding practices of stewardship counter narratives of the 'tragedy of the commons', demonstrating that degradation and depletion of the resource is not inevitable, as farmers may be motivated to cooperate to avoid these risks. Especially where state-initiated programmes of agricultural intensification actively promote the exploitation of aquifers for profit — such as in Morocco, parts of India, and Peru — the continued existence of such grassroots initiatives shows that processes of modernization are never complete or uniform. The question of whether these initiatives indeed represent examples of more environmentally sustainable and socially equitable forms of groundwater governance, or whether they instead consist of more temporal and perhaps fragile socio-political compromises [2] is central to our conversation and analysis [40]. In this sense our approach is agnostic; our investigations are not based on an assumption that community initiatives are 'better' (more sustainable or just) than government-initiated ones. In one of the cases we study, in Ravangaon (India), female farmers are for instance quick to point out how the unsustainability of current groundwater practices is importantly caused by macro-policy orientations that are difficult to change at their level. Our hope is that serious critical attention to and engagement with what communities do — learning from the wisdoms, technologies and institutions that they have devised or are experimenting with to protect, recharge, access and share groundwater or resist its depletion — will widen and pluralize ideas about how to generate transformations to groundwater sustainability beyond currently accepted science-based solutions. It may also provide inspiration for new groundwater imaginaries, cosmologies or moral ecological rationalities [41] of engaging with neighbors, future generations, water itself and more-than-humans dependent on water.

We used an ethnographic approach as the empirical starting point for the documentation and analysis of the identified community initiatives. To allow positioning ourselves in academic as well as policy debates, we pragmatically divided this effort into three broad, loosely defined, and intertwined categories: *knowledges*, *technologies* and *institutions* (*see* Figure 3). We remain sensitive to the connections between these categories: It is through technologies such as wells and pumps, for instance, that

[1] The Supplementary material to this article contains ten short narratives about the ongoing action-research projects happening in each of the project sites.

Figure 3



The Groundwater Governance framework of the Transformations to Groundwater Sustainability project (T2GS).

people learn and obtain knowledge about fluctuating water levels and qualities.[2] As we show in more detail below, technologies also co-determine how water is distributed (the rules of use). In writing about and sharing our findings, in the pluralizing and feminist spirit of the project, we try treating different knowledges and technologies in horizontal ways, avoiding the a priori judgment of some as intrinsically better or advanced and others as backward or primitive. In particular, the often-used distinction between scientific knowledges and local or indigenous knowledges is one we treat with caution. After all, *all* knowledges come from somewhere and are based on specific experiences [38,42]. The term *bricolage* (or tinkering) is an important conceptual-methodological device to help do this. It expresses that actual practices of using and governing water often consist of technologies, knowledges and institutions that are patched together and always in-the-making, instead of fixed and rationally or scientifically designed [43–45]. A bricolage lens allows to see the flexible adaptations and hybridizations that make groundwater governance arrangements work in particular contexts. These are never innocent, but laden with meaning and imbued with power relations. Indeed, power and meaning weave through our three themes, helping to understand how change happens, and how it is shaped to benefit some and not others [44].

In what follows, we use inspiring material from the literature to further explain and illustrate our approach in each of the three categories: knowledges, technologies and institutions.

Knowledges, technologies and institutions

Knowledges

In this first category, we are interested in how local communities appreciate, know and deal with fluctuating qualities and quantities in their everyday dealings with groundwater. Such knowledge may be the result of generations of accumulated experience and observation by

[2] See Chitata, in the Supplementary material.

those whose lives depend on using groundwater [46], and often forms part of wider cosmologies — ways of being in and making sense of the world [47]. Creative ways of knowing groundwater for instance include the innovative 'water towers' that young farmers in Algeria use to establish whether or not they can irrigate [48], as well as the participatory groundwater assessment and recharge methods developed by ACWADAM in Maharashtra [49]. The *pozas* used by mango farmers on the desert coast of Peru likewise provide an example of their intimate knowledge about assessing and dealing with water scarcity and fluctuating availabilities; knowledge that is embedded in ways of farming and living [46,50••]. In Ghana, embodied ways of knowing served as a useful tool for understanding groundwater governance for irrigation during the dry season [51].[3] Place-specific practices of assessing groundwater quantities and qualities may differ from accepted temporal or spatial boundaries used in scientific assessments [62], or even challenge those practices or technologies widely heralded as sustainable, for instance relating to conservation agriculture [52]. Knowledges of farmers often form part of very specific ways of dealing with the ecological and climatological characteristics of their fields and plots; they demonstrate how they are adapted and attuned to micro-specificities. This contrasts with the pressures of 'modern' agriculture to specialize and homogenize [53].

In documenting and assessing groundwater knowledges we are interested in finding out how prevailing technical and scientific understandings of groundwater can be complemented, or perhaps challenged, by other ways of knowing groundwaters and aquifers. Tracing the resonances, gaps and frictions between different knowledges constitutes an important starting point for doing this. We mobilize insights from Science and Technology Studies (STS) [54–58] to help treating the knowledges embedded in the experiences and routines of groundwater users as equally legitimate as the understandings of engineers, agronomists and hydrogeologists. An important lesson from STS is that which and whose knowledge travels, gains authority or prevails in making decisions is not just a question of accuracy, but also one of politics, history and culture [59,37,60,61].[4] In Chile, for instance, the state water resources agency used a supposedly scientific hydrological assessment done in response to concerns of overexploitation of an aquifer to underpin water allocation decisions in accordance with its own interests, further endorsing existing unequal patterns of resource use [62]. In Peru, mining companies dismissed indicators used by local residents to appreciate water quality, labelling these as vernacular or anecdotal. Mining companies instead put forward their own quantitative technical assessments [63]. Groundwater's invisibility, and the overall difficulty of accurately assessing the dynamics of flows and stocks, creates a lot of room for such disagreements. Indeed discussions about (ways to measure) availabilities and qualities often themselves become part of contested claims and power struggles [37].

Critically examining and, where needed, challenging forms of segregation and hierarchy in knowing groundwater — such as those between natural sciences and social sciences; between knowledge originating in the majority world and that coming from the minority world; between experts and practitioners — is a necessary component of the pluralization we strive for, as is the cultivation of critical awareness about how claims of scientific objectivity or neutrality may themselves be expressions of power [64]. Here it is important to appreciate that practical assessments of availabilities, both by scientists and by users, often combine — rearrange and hybridize — different knowledges and ways of knowing. It is, for instance, interesting how hydrogeologists may call in the help of dowsers when prospecting for water [65].

Technologies

Technologies for measuring, accessing, distributing or recharging groundwater form the material expression and articulation of, but also co-shape, society-water interactions. Technologies-in-use often represent a palimpsest of accumulated experience [66], with technologies — pumps and wells — often also providing people with a means to assess (fluctuations in) groundwater levels.[5] Building on a long tradition of scholarship about how technologies are social, cultural and political [67], and in line with the larger argument of the paper on the pluralization of groundwater scholarship, we examine how particular (combinations of) technological artefacts and infrastructures make some forms of knowing, access, care, organization and distribution possible, and others more difficult. Particular technologies may go accompanied, or be associated with, particular institutions and cosmologies. For instance, in Morocco shallow wells were associated with a (slow) world of parsimony and water scarcity, whereas deep tube-wells are associated with a (quick) world of abundance [68,69••]. More generally, in

[3] Also see the narratives of Dominguez *et al.* (Peru), Saidani (Algeria), Peterson *et al.* (USA), Aslekar *et al.* (India), Bossenbroek *et al.* (Morocco), Dajani (Syria), de Bont *et al.* (Tanzania) and Chitata (Zimbabwe) included in the Supplementary material for examples of 'local' groundwater knowledges.

[4] See Peterson *et al.* (Supplementary material) who explore links between groundwater pollution, unsustainable agricultural practices, and public health in California. Farmworkers built networks with activists, administrative and scientific groups to advocate for clean drinking water. Also see Olmos Herrera (Supplementary material) for a case study of the Atacama Desert, where large-scale mining not only alters water flows, but also challenges the *cosmovisión* of local communities with devastating ecological effects.

[5] In the Zimbabwe narrative in the Supplementary material, Chitata *et al.* show how people can assess groundwater levels by the sounds and vibrations of their pumps.

irrigation the shift to groundwater use often happens through a shift from collective surface canal irrigation systems to individually owned and used tubewells. In canal irrigation systems, water flows can easily be seen, changed and contested. With a shift to individual tubewells, pumps and underground pipes, flows become invisible, making it harder to discuss how water is distributed, cared for and shared [63].[6] This process of technology-driven individualization of water use and management neatly matches popular ideologies of privatization and *laissez-faire* economics [64,17,71] which inform idea (s) of farming as profit-maximizing entrepreneurialism. Because one person's use of tubewells reduces availability of groundwater for others, the technology also reorganizes the distribution of water [70••]. The fact that only those with means can afford to invest in drilling deeper tubewells may mean that they become 'water lords'. For the less well-to-do, water sources may become contaminated and wells may run dry.[7] Technology and ideology together make the attribution of responsibilities for such unequal distributions of water [72] and for the depletion of groundwater difficult, as these are both invisible (and naturalized) and ascribed to the workings of anonymous markets and multiple (non-specified) users or polluters. Ironically reinforcing this is the phenomenon that many devices (e.g. industrial tube-wells, pumps, drip irrigation systems and engines) used in groundwater are associated with progress, themselves having become the symbols of more modern ways of farming and living.

In this way, tracing how the access to, and distribution of, groundwater is mediated by technologies and critically re-visiting the normative associations that surround (ed) their development, promotion and use allows exposing and questioning the power asymmetries and processes of marginalization they reproduce or bring into being [73]. How this happens is often full of surprises and contingencies, as technologies are seldom as 'fixed' as they may seem. Individuals and communities often display creativity in (re)crafting and (re) designing technologies and infrastructural configurations through *bricolage*. In the process, they re-distribute and re-define water as well as power in subtle ways [74,75,43,76•,77••,72,78].[8]

In addition to technologies for accessing and distributing groundwater, technologies for the managed recharge of aquifers are particularly interesting as these seem to provide promising examples of collective forms of care that promote the circularity of water.[9] They are often based on reviving age-old community practices. Whether these indeed represent forms of water stewardship and solidarity cannot be assumed, but needs careful investigation [79].

Institutions

Our third avenue of inquiry is about understanding how the rules and norms that shape practices of accessing, sharing and caring for groundwater emerge or change, often in interaction with socio-environmental histories,[10] technologies and political-ecological contexts. Pluralization entails learning from these multiple, imbricated, and constantly in-the-making institutions. Although many agree that groundwater should be treated as a common pool resource (with multiple individuals being able to access and use it and, in the process, reducing the quantity or quality available to others), this is made difficult as the boundaries of the resource are often not precisely known. The fact that most groundwater is accessed through individually owned tubewells (with water rights often being based on land rights) makes groundwater governance *de facto* a combination of private ownership within a larger open access regime. The resulting institutional puzzle becomes even more complex because of how groundwater and surface water are interconnected, with the two often being regulated by different norms, technologies and laws [16]. Such connections may entail issues with local communities that are not using groundwater themselves but are harmed by its overexploitation by others. Hence, the springs or rivers they make use of may dry up, or there may be damage to wetlands or pastures.

This complexity makes the existence of successful institutions for caring for, and sharing of, groundwater something that is remarkable. Institutional theorizing about the commons has indeed often mobilized groundwater examples [80]. These show the endurance and flexibility of groundwater institutions. Examples for instance show how groundwater institutions build on institutions to manage surface water, as in the emblematic Huerta de Valencia irrigation system in Spain. Here, irrigators integrated groundwater and treated waste water with surface water flows over the past thirty years [81]. We build on

[6] See Chitata *et al.* (Supplementary material). In Zimbabwe, more 'efficient' irrigation infrastructure, designed by engineers, interrupted the relation of irrigators with groundwater with potential negative effects on how the community will protect groundwater.

[7] The Supplementary materials provide some narratives that illustrate this: Peterson *et al.*, Bossenbroek *et al.*, Dajani, Olmos-Herrera.

[8] See de Bont *et al.* (Supplementary material) who highlight how in Tanzania, know-how from artisanal mining kickstarted the emerging groundwater economy.

[9] See Saidani; Dominguez *et al.*, Kulkarni *et al.*, and Aslekar *et al.*, (Supplementary material). Newly established smallholders in Algeria's Sahara and agribusinesses in Peru increasingly use secular recharge infrastructure adapted from nearby communities. However, this has led to water inequities with the very communities who invented these technologies. In Maharashtra, India, a local community designs rules and develops infrastructure to recharge and share groundwater.

[10] See Kulkarni *et al.* (Supplementary material). Women farmers in a village in Maharashtra explain how wider state-promoted trajectories of agricultural intensification, associated with new technologies and crops, have made farming and groundwater increasingly unsustainable. These women have few, if any, means to resist or change this.

theorizations of groundwater institutions as emblematic examples of how common property resources can or should be managed, as these help shift the emphasis from individual to collective interests and from short-term gains to longer-term sustainability. Yet, we also complement and sometimes challenge existing theorizations with those that pay more attention to power and politics [44,47] and highlight 'the commons' as something relational, that is, alive and socially constructed [82]. Norms and rules-in-use emerge in the interplay between what are often considered distinct 'formal' and 'informal', 'customary' and 'state-sanctioned' arrangements, and they are animated by power relations [83]. They are often embedded in wider social relations [84],[11] cosmologies or moral-ecological rationalities that have historically evolved and are only partly the result of conscious design processes.

Conclusions

Transformations to groundwater sustainability in agriculture are unlikely to happen when governments continue promoting forms of agricultural intensification that systematically undervalue people and ecosystems. A systematic, feminist and anti-colonial critique of such exploitative and destructive ways of farming is therefore a necessary starting point in attempts to do groundwater governance differently. Such a critique highlights the ways in which the historical, social, and infrastructural practices in various places are moulded by racial, capitalist and colonial legacies. It comes with a questioning of the science that supports such water-intensive and exploitative farming models. Critique is not enough, however. Imagining and doing groundwater differently also requires pluralizing the conceptual vocabularies to make sense of, imagine and engage with groundwater.

Initiatives of people who come together to jointly access, share and care for groundwater — often going against pressures to overextract — form an important source of inspiration here. Documenting and understanding such initiatives forces attention away from the design of government efforts to regulate and control the pumping behaviour of individuals, towards the appreciation of and support for collective caring, recharging and sharing efforts around aquifers. Bringing into focus the many flexible adaptations and collaborations which people involved in such efforts engage in and experiment with to live and deal with fluctuating availabilities and qualities of groundwater in dynamic market contexts, draws attention to hitherto underexplored ways of knowing, accessing and sharing it. It also helps creating sensitivity to the mundane work that goes into restoring, sustaining, or improving aquifers, and provides a strong reminder of how part of the motivation for engaging in such work stems from historical attachments to territories and people.

Documenting and assessing the knowledges, technologies and institutions that characterize community initiatives around groundwater forms the basis for creating new groundwater conversations and learnings. Important questions here are how and whether they provide inspirations for broader transformations to groundwater sustainability, and how the actions of communities in one place can be made useful elsewhere. Comparisons across heterogeneous communities sometimes require difficult translations and simplifications. To avoid getting trapped in one single language, we suggest nurturing and thinking with differences, learning from each other's idioms so that no one remains the same as they were at the beginning. Also, in tracing patterns across initiatives and distilling lessons for transformations to sustainability, it is important to remain attentive to the fact that water is a deeply contested resource, the governance of which is always thick with politics [37]. This also means that actual governance arrangements for groundwater, even when community-based and characterized by care for the aquifer and for each other, will often be negotiated, necessitating suboptimal compromises that may not be to everyone's full satisfaction.

[11] See Bossenbroek *et al.* (Supplementary material). Young community members recognized that groundwater in the vicinity of oases in Morocco was depleted due to profit-oriented watermelon production by outsiders. The community affirmed ownership of this subterranean resource, excluded the outsiders, and themselves engaged in cash cropping.

Conflict of interest statement

Nothing declared.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.cosust.2021.03.004.

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- •• of outstanding interest

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