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Sharing Difficult Waters: Community-Based Groundwater Recharge and Use in Algeria and India

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ABSTRACT: The intentional recharge and use of aquifers for drinking, domestic use and irrigation is one of the most elaborate community initiatives in groundwater governance. Communities deal with difficult waters like flash floods and runoff for short periods, and for more prolonged periods with dry spells that prompt frugality in water use. These collective systems have been challenged in recent decades by the massive development of individual boreholes; these have emerged in connection with intensive groundwater-based agriculture and have led to unsustainable groundwater exploitation. This article analyses how communities have been confronted with, and have resisted, such challenges in recent times. It focuses on two long-standing and functional community aquifer recharge and use systems, one in Algeria (M'Zab Valley) and the other in India (Randullabad, in the state of Maharashtra). We show that sharing such difficult waters requires, first, practice-based and shared knowledge of the complex interactions between the surface and groundwater that is collectively owned by the community; second, robust collective action to maintain and operate the common infrastructure that is undergoing continuous adaptation to the particular socionatural conditions of a specific area; and, third, adaptive institutions to carefully balance available water resources and their frugal use. Our analysis shows that community governance of groundwater is embedded in social norms and meanings and that these are expressed in the frugal use of scarce resources and/or the continuous challenging of irresponsible water use when it threatens domestic water supply. These community initiatives can represent sources of inspiration for ecologically sustainable and socially equitable forms of groundwater governance, even in very challenging situations.

KEYWORDS: Water sharing, irrigation, knowledge, institutions, infrastructure, Algeria, India

INTRODUCTION

In recent decades, there has been a sustained worldwide interest in managed aquifer recharge. It is considered to be a water management strategy to, "maintain, enhance and secure stressed groundwater systems and to protect and improve water quality" (Dillon et al., 2019: 1). The capture of seasonal high flows and their channelling into aquifer recharge allows for increased local groundwater storage to offset subsequent dry season water scarcity; it can also potentially mitigate flooding (Bouwer, 2002; Pavelic et al., 2021). However, despite the increasing attention on managed aquifer recharge (as distinct from natural recharge), its contribution is estimated at only 2.4% of groundwater withdrawals (Dillon et al., 2019). It is therefore important when interrogating the sustainability of groundwater use to jointly analyse aquifer recharge and its subsequent use. However, there have been very few empirically grounded studies on functional, long-standing water recharge and use systems (ibid).

Floodwater harvesting for irrigation, in particular through spate irrigation, and domestic water supply through, for example, cisterns are old practices that were developed in various regions of the world; some date back several centuries (Mehari et al., 2007; Beckers et al., 2013). While these long-standing floodwater systems all interact intensely with groundwater systems, there has been less attention to community initiatives around floodwater systems that were designed and constructed to intentionally recharge aquifers for use during droughts (Pavelic et al., 2012). Examples of such systems include the *pozas* in Peru (Domínguez Guzmán et al., 2017), the *ooranies* in India (Sakthivadivel, 2007), the floodwater-sharing system in the M'Zab Valley in Algeria (Saidani et al., 2022), the collection of run-off by infiltration through the *chirle* system in the Karakum Desert in Turkmenistan (Fleskens et al., 2007), and subsurface channels to recharge the aquifer along the Wuhe River (Wang et al., 2014).

Intentional groundwater recharge and use systems often deal with difficult waters that come suddenly; these typically include flash floods and runoff that accompany intense precipitation during, for example, monsoons, and then disappear for long periods of time, prompting frugality in the use of water. These waters may cause devastating widespread inundations; however, by storing them in invisible underground aquifers with complex water dynamics they can be used during prolonged dry periods if well managed. We argue in this paper that sharing the use of these difficult, capricious waters in a sustained manner over the long run requires: (1) water recharge and use infrastructure and technologies that are adapted to the particular socionatural conditions of a specific area (Varisco, 1983); (2) robust collective action and institutions to develop, maintain and operate such labour intensive water systems while carefully balancing the available water resources and their use (Mehari et al., 2007); and (3) practice-based and shared knowledge of the complex interactions between surface and groundwater (Pakhmode et al., 2003). Importantly, in community aquifer recharge and use systems that deal with difficult waters, the meaning of water is associated with notions of sharing of, and caring for, a precious source of life in an often-hostile environment (Zwarteveen et al., 2021). This calls for a prudent use of water, since the next flood or runoff may be months or years away. Water has to be provided to all community members, who in turn will need to contribute to keeping the recharge and use system alive.

This shared approach to flood and runoff water management has been challenged by the massive individual access to groundwater that has accompanied cheaper and easier-to-use technologies; drilled boreholes and installed pumps have made groundwater a major source of water for intensive agriculture (Margat and Van der Gun, 2013). Individual access to groundwater released farmers from hierarchical or collective constraints related to the sharing of water from state or community-managed irrigation systems. This new freedom entailed the possibility of intensive, often unsustainable, groundwater mining for entrepreneurial agriculture (Schlager, 2007; Kuper et al., 2016). These individual initiatives often happen in the context of a particular state discourse that values – and thus subsidised – intensive groundwater use, while portraying 'traditional' systems as inefficient and prone to 'losses' to the environment from surface water channels (Fernald et al., 2015). Traditional systems, more generally, are also associated with 'backward' subsistence farmers who contribute little or nothing to national objectives of food production (Akesbi, 2011). Individual over-pumping threatens the resource base, yet intensive agriculture is part of a potent social imagery of profitable and modern farming that is attractive to many farmers. Environmentally, this has led to abandoning sustainable practices in favour of less sustainable systems that are capable of providing greater quantities of water (Lightfoot, 1996).

This article analyses how long-standing community initiatives engaged in intentional recharge of groundwater aquifers have, in recent times, been confronted with, and resisted, the consequences of the massive new individual access to groundwater, which is often encouraged by national agricultural and water resources development programmes. Our analysis is based on two case studies of long-standing and functional community-managed water recharge and use systems, one in Algeria (M'Zab Valley) and the other in India (Randullabad, in the state of Maharashtra). Through this article, we aim to foreground and appraise community initiatives that have been collectively designed and adapted to ensure a better balance between available groundwater resources and their use in the face of contemporary challenges. These examples of community groundwater initiatives that combine intentional recharge and floodwater sharing can inspire ecologically sustainable and socially equitable forms of groundwater governance. This is especially relevant in an era when increasing floods, drought, and pollution will make waters more and more difficult to manage in such a way that they satisfy the ever-growing needs of society. These initiatives, however, also need to be supported and protected by policies, as community aquifer recharge and use is hard work and is regularly undermined by policy interventions. We document these cases in order to contribute to the enrichment of mainstream literature on groundwater governance; we bring in the different grassroots approaches and experiences to open up debate on transformations to groundwater sustainability (Zwarteveen et al., 2021).

THE IMPORTANCE OF SHARING IN COMMUNITY IRRIGATION SYSTEMS

In community irrigation systems, sustainability is guaranteed through the central notion of 'sharing', that is, holding in common for the mutual benefit of all (Riaux, 2006). At first glance, this notion relates primarily to water sharing between the irrigators; however, the question of what exactly is shared needs some unpacking, since an irrigation system is, "simultaneously a hydrologic, engineering, farming and organizational system" (Coward, 1980: 16). This means, first, that the irrigators need to collectively take care of the water source in a sustainable manner, such that it remains available to, and sharable with, others, including future generations (Mol et al., 2010; Domínguez Guzmán et al., 2021). These practices of care for the source of water often relate to both its quantitative and qualitative aspects; the former includes maintaining the flow rate that is feeding the irrigation system and providing water to meet the needs of livestock and domestic use, while the latter involves protecting the water source from pollution.

Second, unpacking the 'sharing' of water requires attention to its engineering dimension. This refers to the co-ownership of the irrigation infrastructure by irrigators who are involved physically and/or financially in its design, development and maintenance (Coward, 1986; Mollinga, 2001). The rights of water users are often linked to their contributions to the infrastructure's upkeep. In our case, the infrastructure pertains to structures for water recharge (diversion, transportation and infiltration of floodwater and runoff) and water use (mainly wells and channels to store and lead the water to the fields).

The third aspect of sharing in an irrigation system is that water supply and demand are intimately linked. Cropping patterns, in particular, are often governed by explicit or implicit community agreements, including prohibitions on the introduction of new crops (for example, perennial crops or water-consuming summer crops) or plans to extend the irrigated surface area; both of these may generate conflicting water demands. An interesting example of the coordination of cropping patterns and water demand in community irrigation systems is documented by Lansing and Kremer (1993). It relates to how Balinese farmers organise the fallow periods of rice terraces so that they balance the contrasting objectives of pest control (which privileges a uniform fallow period) and water sharing (a staggered fallow period). A community irrigation system also often caters to multiple water uses, including for domestic use, livestock and irrigation. In such cases, the irrigators, and often the community at large, collaborate in the careful balancing of water availability and quality in order to supply multiple uses (Vos et al., 2020). This sharing of water beyond those who hold formal 'rights' to the irrigation system subscribes to a community-level notion of caring, particularly when it includes domestic water supply (Domínguez Guzmán et al., 2021; Idda et al., 2021; Archidiacono et al., forthcoming).

A fourth component of water sharing has to do with the organisational arrangements in irrigation systems. These 'irrigation institutions' ensure the carrying out of the critical activities in an irrigation scheme, which include water allocation and distribution, system maintenance, and conflict management (Ostrom, 1990; Vos et al., 2020). These collective arrangements are co-constructed and are invented and instituted to overcome specific common difficulties (Cleaver, 2017). Such rules are frequently adapted when particular contextual issues arise in either water supply or demand; their aim is to cope with specific shocks and to manage the ensuing community interactions (Mahdi, 1986). It is this capacity to adapt to change that gives these systems their robustness (Cifdaloz et al., 2010; Idda et al., 2021).

The case studies presented here relate to elaborate community initiatives around managing groundwater. These initiatives were aimed at reinforcing the natural cycle of aquifer recharge and then using that water for irrigation, livestock and domestic consumption. These difficult waters require robust collective action and collectively devised infrastructure. Extensive and embodied knowledge (see Cleaver et al., 2023, this issue) is also required to understand the functioning of the system and to respond to its changing needs and its hydrological and environmental conditions. This includes detailed knowledge on the pathways of water, discharges, flood levels, volumes to be shared, quality of water, and geological lineaments. This knowledge often emerges through intimate interactions between the people and the water; it is frequently mediated by infrastructure and embedded in broader understandings of socionatural relations (Iwaniszewski, 2009; Chitata et al., 2021). The knowledge often becomes collectively owned by the community, though it is regularly shaped and constrained by gender and class relations. Moreover, for the system to persevere, this knowledge needs be passed on to subsequent generations and needs to be shared as much as the water itself; however, it must also be continuously adjusted to new circumstances. Idda et al. (2021) show interesting examples of how practice-based knowledge of the maintenance of *foggara* (qanat) irrigation systems is transmitted to young people in oasis communities in Algeria's Sahara. This shared knowledge is part of a larger irrigation culture; it is also a key element of resilience when irrigators confront disturbances, unexpected events, or changing climate (Fernald et al., 2015).

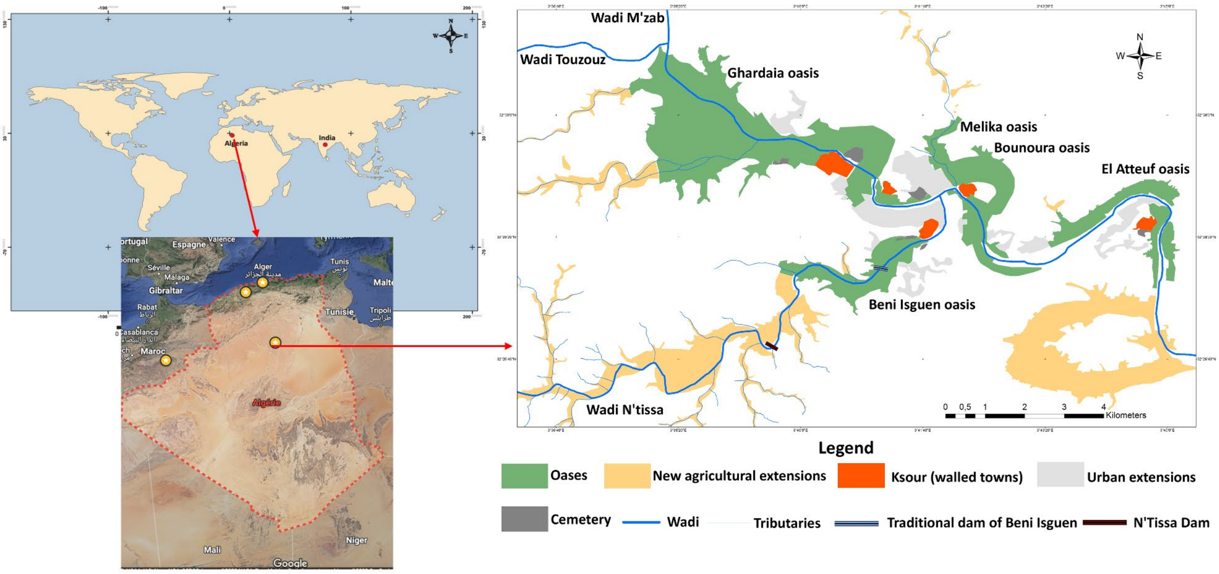
PRESENTATION OF THE TWO CASE STUDIES

The two case studies presented in this article are located on two different continents and exist in radically different physical, cultural and social contexts. What they have in common is that they concern functional, intentional, community-based aquifer recharge systems and that water sharing is at the heart of these systems. Both case studies are inspiring because there is a renewed interest by communities in sharing scarce waters. Both also show that hard work is needed to keep the system functional in the face of multiple threats. Policy interventions related to agriculture and irrigation are not always conducive to the sustainability of these systems. Our analysis is embedded in a historical understanding of the trajectory and of the contemporary practices in these systems.

General background of the case studies

The first case study concerns the M'Zab Valley in Algeria's Sahara. This valley comprises five fortified towns, each associated with a palm grove (Figure 1). Two agricultural landscapes coexist in the valley. The first is comprised of ancient palm groves that are served by community-managed irrigation systems (1500 ha). The second is made up of the new agricultural extensions that were created from the 1980s onwards (1550 ha); these are located on the periphery of the oases and consist of a more entrepreneurial type of agriculture that sources its water from individual boreholes. These peripheral extensions have been inspired in part by state-sponsored agricultural development schemes that have been implemented 100 to 250 km to the south of the M'Zab Valley (Bisson, 2003; Hamamouche et al., 2018). For this study, we consider the community-managed water recharge and use system of this valley's Beni Isguen oasis, which covers an area of 186 hectares (ha), with 855 ha of agricultural extensions.

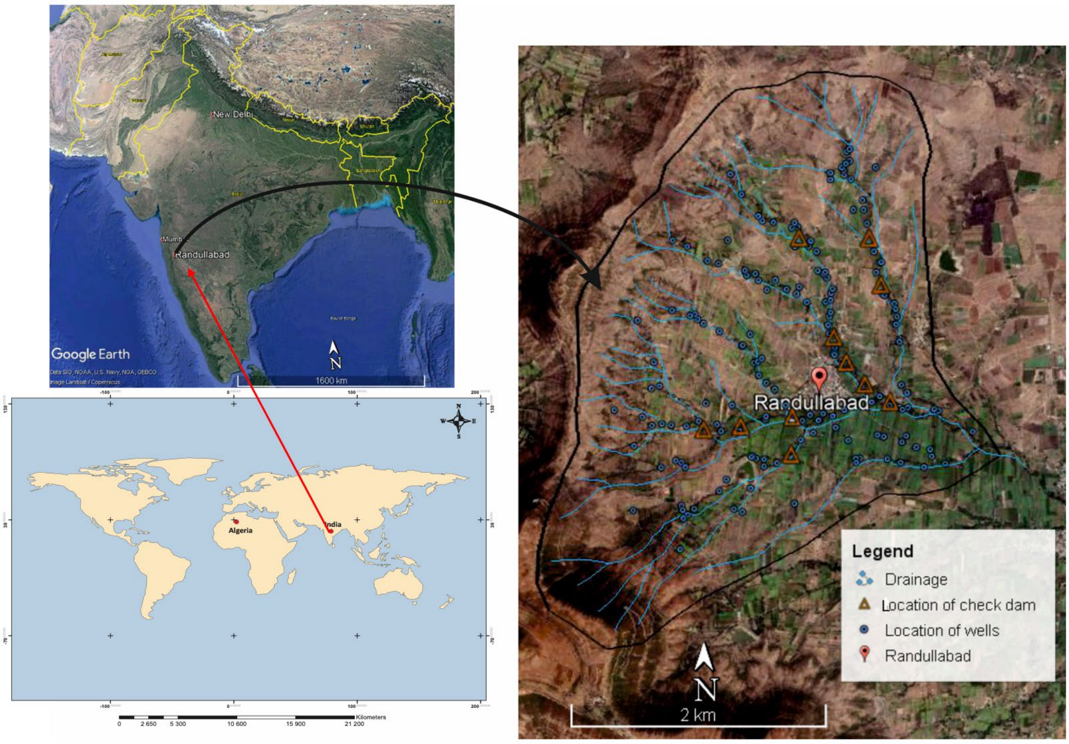
Figure 1. Map showing the oases and agricultural extensions of the M'Zab Valley in Algeria.



The climate is arid, with a dry and hot summer that extends from April to September and a mild winter from October to March. The area receives irregular torrential rains, with a total of about 81 mm of precipitation per year. From the 13th century onwards, the oasis community, as part of the larger M'Zab Valley urban desert civilisation, developed a sophisticated hydraulic system. It channels occasional flash floods in Wadi Tissa (0-3 per year) and runoff from surrounding hills to recharge the aquifer thus inserting the water into local use loops (Saidani et al., 2022). The infrastructure is developed, operated and maintained through a tight social organisation. For several centuries, the community system was robust enough to adapt; in the 20th century, however, it proved vulnerable to rapid and profound change. These changes have included: increased pumping of the aquifer for drinking water and agricultural development schemes; rapid urbanisation; and the increased mobility of community members engaging in other economic sectors. However, the dual problem of flood damage plus water scarcity in the agricultural extensions motivated the community to renew its interest in the recharge system; thus over the past two decades it has been engaged in a campaign for its restoration.

The second case study focuses on a community water recharge and use scheme in Randullabad in the state of Maharashtra (Figure 2). The participatory groundwater management programme that was launched in 2008 has built on decades-old community practices of water harvesting and of the sharing of water from collective wells. It aimed to curb the unsustainable drawing up of groundwater by individual boreholes. It stands out as an example of coupling knowledge on hydrogeology with local-level decision-making, and together generating a watershed development programme that is shaped by the way groundwater is understood, accessed and shared by the community.

Figure 2. Map showing the water infrastructure in Randullabad, in the state of Maharashtra, India.



Randullabad is a small village located in the rain shadow area of the Western Ghats of the Indian state of Maharashtra. The village is totally dependent on groundwater for drinking water, domestic use and agriculture. There is no perennial river or stream passing through the village and it is dependent on approximately 190 shallow dug wells for irrigation. About half of the existing wells in Randullabad were dug about 40 years ago. Each well was dug by three to four farming families and the water is still shared among the well owners through informal agreements. In many neighbouring communities, the drilling of deep borewells has led to serious groundwater overexploitation; observing this, the village governing council decided in early 2000 to put a complete ban on drilling borewells in the village. As a result, in the last 20 years not a single borewell was drilled in the village. Randullabad started facing water scarcity even so, due to changes in rainfall patterns and intensification of cropping systems. The community decided to implement a watershed development and management programme to improve groundwater recharge, with the support of external organisations. Practice-based and embodied ways of knowing groundwater among members of the local community were complemented by a scientific understanding of groundwater dynamics; these were combined in a programme to implement sustainable groundwater use.

Research methodology: How we engaged with communities

We started our work in Beni Isguen with an investigation of two very contrasting, but co-existing, agricultural landscapes. One of these was the oasis created in the 13th century, which had a functioning ancestral community recharge and water use system; the other was comprised of the new state-sponsored agricultural development schemes. The latter were located about 100 to 250 km away in the localities of Mansoura, Hassi Fehal and El Menia. They consisted of intensive farming systems that were based on pumping from deep aquifers. The two formed a strong contrast, the oasis being a frugal community water system and the agricultural development schemes following a 'mining' logic, managed by investors, using large amounts of water and producing high levels of emissions (Saidani et al., 2022). During our exploratory interactions, community members questioned these unsustainable forms of agriculture. At the same time, however, we identified agricultural extensions at the periphery of the oasis that had been developed by community members employing more diversified and entrepreneurial farming systems. These extensions were served by collective boreholes into the deep aquifer or by individual boreholes into the phreatic aquifer; in some cases, floodwater was used to recharge the aquifer; this was surface water that would otherwise have flowed downstream to the Beni Isguen oasis. These peripheral extensions were inspired both by the community water system and by the more distant development schemes (ibid).

The first part of our work took place in the oasis. It was aimed at collecting historical and technical information on transformations of the community water recharge and use system. We conducted 30 semi-structured interviews, including with members of the oasis community, farmers active in the respective landscapes, sellers of agricultural inputs, members of civil society organisations, community water stewards, and members of the local administration. The interviews, along with field observations and joint visits with community members and water stewards, focused on the history of the water-sharing system, its social organisation, the ancestral practices governing it, and the adaptation of these practices. In our dialogue with community water stewards, we also used so-called spoken maps; these are a form of "participatory mapping" (Collard and Burte, 2014) which helped them to explain the functioning of the water recharge and use system and the multiple pathways of water inside the oasis.

The second part of the fieldwork was aimed at understanding the farming systems of the peripheral extensions, identifying, mapping and analysing the links with the ancestral system of the oases. We also visited the distant agricultural development schemes and had interactions with the investors and farm staff to understand these farming systems.

The village of Randullabad is dependent on groundwater for irrigation and domestic uses, as the surface water streams only carry water for four to six months. The falling groundwater table explains the community's interest in the water and soil conservation project, which included managed aquifer recharge; its implementation was proposed by an NGO working in Maharashtra, with support from an agricultural cooperative bank. This project was part of an integrated programme for the rehabilitation of watersheds that was implemented between 2008 and 2012 through Village Watershed Committees.

The watershed development programmes were conventionally implemented using a ridge-to-valley approach. The hydrogeological component was seldom considered while planning interventions for groundwater recharge, although the understanding of aquifers is crucial to identifying potential recharge areas. To better plan and implement recharge activities, the project called on the Advanced Center for Water Resources Development and Management (ACWADAM), which is an NGO working on aquifer-based groundwater management in India and to which one of the authors belongs. The idea was to develop a systematic village-based data collection system for more effective implementation of the water management programme. Initially, ACWADAM conducted training on monitoring and hydrogeological data collection with the community resource persons who were part of the Village Watershed Committee. These people, with the help of the ACWADAM team, mapped the geology and, over three years, collected data on water level, weather, water quality, and cropping, as well as socio-economic data. This helped in delineating aquifer systems in the village and identifying potential groundwater recharge areas for building recharge structures like check dams, percolation tanks, and continuous contour trenches. In Randullabad, the Village Watershed Committee developed certain protocols for water recharge, as well as for drinking water, domestic use and agriculture; these protocols aimed to strike a sustainable balance between *how much is available* and *how much can be used.*

SHARING OF WATERS IN BENI ISGUEN

An elaborate and enduring community water recharge and use system

A coherent set of infrastructures for direct and indirect recharge

Floodwater from Wadi N'Tissa passes through the new agricultural extensions upstream from the oasis (Figure 1); it then arrives at a *thissenbadh* (flood distributor) that divides the volume of water into three parts. The first part is diverted to the irrigation of private gardens, following small streets and canals that feed several sectors of the oasis. Inside the sectors, the water enters the gardens through *kua* (intakes), whose width is proportional to the number of palm trees in the garden (Figure 3). Garden owners thus indirectly recharge the aquifer through spate irrigation; when the water reaches the end of the garden, the overflow exits through *tenfass* (openings) and flows back to Wadi N'Tissa.

The second part of the water from the distributor is directed to the recharging of recharge wells, or *abar baluàa* (lit. swallowing well). Water is injected through an opening in the shaft 30 cm above ground level (Figure 4). These wells are located in places where the rock is fractured and thus they directly recharge the aquifer.

Figure 3. Intakes (*kua*) to gardens in the oasis of Beni Isguen.

Source: Photo by Amine Saidani (2022).

The third part of the floodwater continues in the wadi. It is joined by excess water from the first two parts and then is stopped downstream of the oasis by an *ahbass* (dam). The reservoir thus created enables aquifer recharge and the sediment is later extracted for soil amendment. In case of big floods, the excess water will overflow the dam and will continue on to other oases located on Wadi M'Zab.

Along the contours of the surrounding hills, there are also *saregue* (small stone walls) to capture runoff water and then channel it to gardens or to the canals, and then to the recharge wells.

Figure 4. A recharge well, locally called *abar baluàa* (lit. swallowing well) in the oasis of Beni Isguen.

Source: Photo on the left by Kacem Djadi (2006), photo on the right by Amine Saidani (2021).

Shared wells to access the aquifer

The community uses groundwater that is drawn up through 300 wells spread within the 186 hectares (ha) oasis. Most of the wells are situated in the alluvium of the valley, while a minority has been installed in the surrounding limestone. Inside some wells, a chamber has been built to increase the storage capacity of the well; some underground galleries have also been constructed to drain more water to the wells. Most of the wells are only for water use, but 61 of them are also used for aquifer recharge. According to a member of the *Umana Essayl* (collective of water stewards), "this double role depends on the porosity of the rock". The wells are used for irrigation, livestock watering, and domestic water. Groundwater is distributed through a network of small open canals that run throughout the oasis following the natural slope.

For centuries, the construction of a well to a depth of 10 to 50 metres in alluvium and hard rocky soil was considered a difficult task, indeed a project for life. Due to this difficulty and considering the many descendants of the original well owners, most wells are shared by up to 15 families. In the past, water was extracted with animal traction and a goatskin bag attached to a *dalu* (rope). The advent of mechanical pumping in the 1950s and the electrification of the oasis in the 1990s led to technical and institutional adaptations around access to, and use of, water. Collective access to wells was maintained, however, with each family equipping the collective well with their own submersible pump.

Collective action to ensure the continuity of the managed water recharge and use

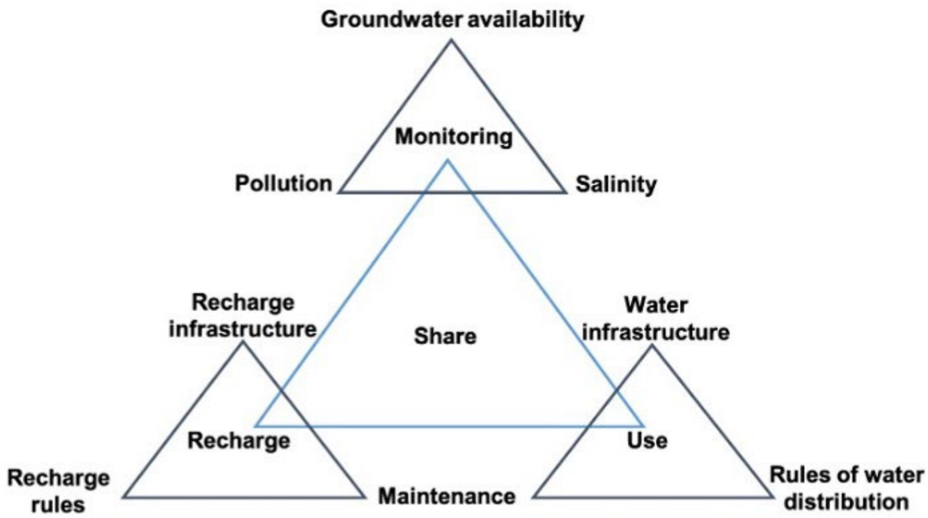
To maintain the integrity of this system and to satisfy the community's basic needs, a set of community rules (*orf*) was put in place; these were adjusted over time and with experience to most effectively govern this water-sharing system. These norms are upheld by the Umana Essayl, the customary water stewards who operate as a collective. The main roles of this collective are to manage the community water recharge and use system, to preserve the oasis, and to resolve conflicts over water and land within the oasis.

The Umana Essayl operate under the aegis of the *Azzabas* (religious authorities), who are responsible for the spiritual, moral and social life of the city and who typically intervene in case of disagreements or conflict. The Umana Essayl also interact with the secular authority; this is represented by the *Achiras,* constituted by social groups of the various families that form the *Djamaa* (Assembly of Elders). They further interact with the *Umana El Umrane* who manage issues related to urbanisation and housing. Together, these authorities must ensure the application of the orf on the ground, its adaptation to new problems, and its transmission to new generations.

The notion of sharing is at the heart of the hydraulic system

The hydraulic system is known locally as *thazoni uamane* (water sharing). This system of water sharing has several requirements; these include: collective monitoring and protection of the resource base; operation and maintenance of the collective and individual infrastructure; balancing of water supply and demand; and adaptation and transmission of the organisational arrangements (Figure 5).

Figure 5. A graphical representation of the *thazoni uamane* (water-sharing system) of the Beni Isguen oasis.



Note: The figure is based on field observations and interviews.

We unpack here the different dimensions of sharing in this community hydraulic system, echoing Coward's (1980) comprehensive definition of an irrigation system. First, the hydrological dimension of the system relates to sustaining collectively the resource base, that is, the quantity and quality of the water collectively stored in the aquifer. This means sharing the effort of performing the recharge when flash floods or runoff arrive. Operating the recharge is a complex task that is carried out under the supervision of the Umana Essayl, building on their extensive and embodied knowledge of the recharge process (see also Cleaver et al., 2023, this issue). They direct the water initially to the gardens for spate irrigation, then to the recharge wells (by which time there is less silt in the floodwater), and finally towards the downstream dike. When a flood is announced, they check the flood distributor at the entrance of the oasis to make sure that it is working properly and that it is not obstructed. Other members of the Umana Essayl collective stand further downstream in the oasis; when the flood arrives at their level, they give the signal to open the channels leading to recharge wells. Some members of the Umana, accompanied by garden owners, check that the floodwater irrigates all gardens as not all families are interested in receiving this muddy water. The Umana may decide to close the flood distributor when the irrigation is done and the recharge wells are saturated. They take great care to evacuate the surplus flood water to avoid damage to houses and gardens. Umana are therefore at the same time operators carefully handling the recharge process, experts with embodied and practice-based knowledge, and mediators who enforce the rules and handle minor conflicts. The larger community interacts closely with the Umana; its members also engage in monitoring available water resources, which they do by keenly observing water levels in wells after floods and during times of drought. Collectively, they have gained profound vernacular knowledge on groundwater dynamics. Traditionally, water quality was also a concern, particularly its salinity as salt concentration increases with decline in the water table.

The second component of a shared community hydraulic system is that a large part of the recharge and flood protection infrastructure is common property; this is particularly true in the case of the dike, the primary and secondary flood channels, and the recharge wells. These are maintained through the financial and physical contributions of the different households, as organised by the Umana Essayl. Most groundwater use infrastructure belongs to, and is maintained by, the families operating them, including collective wells, pumps, and groundwater channels. Groundwater is exploited through collective wells that are shared by several families. Each irrigator has water rights that correspond to time spent in well construction or to their financial contribution. After the installation of electric submersible pumps, the per-pump volume increased from 1-1.65 litres per second (l/s) to 2-3 l/s. This, in addition to the fragmentation of water rights due to split inheritance, prompted rights holders to redefine the water turns of those owning the up to 15 pumps that could be sharing the same well. Two to three pumps can run at the same time in winter, but only one pump at a time can run in the peak periods of summer.

The third aspect of a shared community hydraulic system relates to the fact that the farming systems of the oasis are governed by social norms that promote the frugal use of scarce groundwater resources. The water rights of irrigators are based on the number of palm trees that they are historically entitled to grow, which limits water demand. An elderly member of the Umana Essayl named Bessaid tells us that,

> The west side of the oasis has more than 300 openings which ensure the distribution of water to the gardens. The sharing of water to the gardens is done based on the size of the stone of a specific date variety. The water is not distributed randomly, every opening has a well-defined size, for example 6 or 7 cm. The flood water can also pass through several gardens, so everyone benefits from the flood water.

More fundamentally, however, there are a host of internalised norms related to notions of frugality and solidarity underlying the practices of irrigators. All irrigators are required, for example, to maintain the irrigation system at the plot level and to irrigate during floods, thus contributing to recharging the groundwater. Outside of the flood period, irrigators are expected to be very frugal in their water use.

Fourth, the Umana Essayl ensure that water-sharing rules are applied and, when needed, adjusted. They interact with the different religious and secular community authorities in case of conflicts or major decisions. Perpetuating water-sharing rules is essentially based on oral tradition that has been transmitted by the Umana from father to son since childhood through involving their children in water issues. Djabir explains that,

> my father took me with him as soon as I reached the age of 7 (…). I even spent the night in the watchtowers to watch for the arrival of a flood (…). [T]hese years spent with my father enabled me to take over from him when his health no longer allowed him to be part of the Umana Essayl (…). I do the same with my two older boys, aged 20 and 14 respectively (…). During the holidays and at weekends, I take them with me to the palm grove (…). [U]nfortunately, they have never witnessed a major flood since the last one was in 2008.

Brahim, Djabir's 14-year-old son, leads other children in knowledge-sharing sessions on the traditional irrigation system and meteorology as part of his *kechafa* (scout) activities.

The fifth and final aspect of sharing a community-level hydraulic system involves knowledge of the functioning of the elaborate recharge and groundwater use system. To preserve and properly manage the aquifer, the Umana share this knowledge with other community members through frequent interactions. Mohamed, who is a member of an environmental association, explains to us that, "just as past generations thought of leaving a water reserve for the present generation (…), [w]e, as the present generation, must think of leaving a water supply for future generations".

Different challenges to the water-sharing system in the 20th century

In the 20th century, the community water system of Beni Isguen began to be confronted with a number of challenges. For centuries, because the state was historically absent, the Djamaa (Assembly of Elders governing the tribes) constituted the main administrative council of the M'Zab Valley. This assembly gradually lost its influence during the 20th century, however, as local authorities representing the state progressively interfered with the management of local issues. This has resulted in various challenges for the oasis. An example of this is the polluting of the groundwater that has followed from the urbanisation of the oasis, the multiplication of individual houses and tourist lodges, and the state-led development of drinking water supply and sanitation networks, which together have produced more wastewater in the oasis. Water that is pumped from the deep aquifer is now delivered directly to households, and flush toilets and showers have replaced the traditional dry sanitation toilets. Historically, these toilets were used to collect faecal nutrients with which to fertilise the soil (Bekaddour et al., 2021). Recent work on a sewage system channelling wastewater to distant treatment plants is being met with scepticism by the local community; its members regularly observe leakages in the drinking water network and are concerned about similar leaks in the sewage network. Encouraging dry sanitation toilets and designing a local water treatment plant are alternative solutions proposed by the community.

The community in Beni Isguen was also confronted with other environmental issues. An environmental association was created in 1989 following a social mobilisation to prevent the state from setting up a toxic waste sorting centre. The success of the operation, which was highly publicised in the media, enabled it to become a key player in environmental issues. It then carried out operations to rehabilitate several recharge and traditional wells. This further success gave the Umanas Essayl the idea of regaining their influence and official status through creating an association that would oversee the maintenance of the hydraulic network and the rehabilitation of the wells. Since the various customary organisations, including the Umana Essayl, have no legal status in the eyes of the state, the idea was to motivate a more formal dialogue at the state level and thus to qualify for financial support. The state recognises its role and importance within society but is not able to directly finance its activities. However, so far, the formal association has played only a minor role in operational issues, which continue to rely on customary organisations.

The urbanisation of the oasis and the fragmentation of oasis gardens due to the process of inheritance has resulted in problems with maintaining the integrity of the water-sharing system. Wells had to be increasingly shared and in some sectors the sharing system had to be remodelled; in other sectors, this led even to the destruction of *seguias* (canals) and the clogging or collapse of wells. This was compounded by the emancipation of sharecroppers who had played an important role in the development and maintenance of the hydraulic system through servile labour. They were now able to engage in economic activities in other sectors, rendering the upkeep of infrastructure more difficult (Bisson, 2003). A fine point can be put on this by the fact that in 2019 only 26 of the 61 recharge wells identified in Beni Isguen were functional.

In the 1980s, the high pressure on land and water in the oasis led some community members to create farms on the outskirts of the old oasis, extending its agricultural space. This new land was most often appropriated informally by oasis inhabitants and then – because the state wanted to facilitate access to agricultural land to achieve national food security – it was subsequently regularised under the 1983 land law. These extensions are located upstream of the oasis and thus use surface water that would otherwise be available to the oasis (Figure 1). Some families that got focused on the more dynamic farming in the extensions also lost interest in maintaining their gardens in the oasis.

Finally, in the early 2000s, the inhabitants asked the state to build a dam upstream of the oasis to protect its new houses from flooding, and in 2008 the N'Tissa Dam was completed (Figure 1). This shows how floods that had been considered beneficial were increasingly being seen as causing disasters (Côte, 2002). The dam has changed the way the Umana organise their water sharing, allowing them to spread out the sharing of the floodwater over time. The release of floodwater is now controlled by opening the four gates of the dam, which allows them to direct the water according to their needs. In 2017, the Umana decided to build two recharge wells at the entrance of the oasis to improve the recharge, particularly in the event of low flooding.

Renewed interest in the managed water recharge and use system

In the extensions

The migration of farmers from the oasis to the extensions has not been without difficulties. They were initially devoid of basic infrastructure such as roads and electricity, and farmers faced problems of water shortage; therefore, like their ancestors, they appropriated the land near tributaries to benefit from floodwater and runoff, in addition to drilling individual boreholes to tap groundwater from the phreatic aquifer. The latter is not sufficient to meet their needs, however, particularly in dry periods. Some farmers dug several boreholes to increase the volume of water drawn with electrical connections (electric meter) that are often several hundred metres away from these boreholes. These increasingly expensive options have led them to exploit the deep Albian aquifer (not recharged by the wadi). However, accessing this aquifer requires a significant investment and farmers have made requests to the agricultural service for assistance in the construction of boreholes. Between the end of the 1990s and 2021, six deep boreholes for collective use were implemented by the state. Users have tried to adopt the principles of water sharing by placing a volumetric meter at the entrance to each farm, on the basis of each user's water rights; however, conflicts over the management and maintenance of these wells have meant that currently only three boreholes are functional.

The difficulties in accessing groundwater have prompted farmers in the extensions to increase aquifer recharge, inspired by the existing oasis water-sharing system but also by recent technological advances. Farmers have undertaken a variety of individual water projects, including: (1) building weirs in the tributaries of Wadi N'Tissa to enhance infiltration; (2) building trenches to divert and channel floodwaters to their farms; (3) building terraces on their plots that are separated by *rebtat* (small walls) to slow down the floodwater and avoid damage, and thus to recharge the water table by percolation and retain sediment; and (4) constructing recharge wells for direct aquifer recharge.

Inside the oasis

Farmers in the extensions have been inspired by the oasis recharge system, but oasis farmers have also been inspired by the technologies used in the extensions. Each family, for example, now has its own pump and electrical connection and farmers have adopted drip irrigation technology.

More generally, over the past two decades there has been a renewed interest in the water-sharing system. In 2008, the M'Zab Valley experienced a devastating flood that submerged the valley and caused enormous damage to water infrastructure and to cities, especially Ghardaia. Urbanisation and obstruction of the wadi beds contributed to the damage, but this is difficult to address due to the blurring of responsibilities between the state and the community. Farmers, on the other hand, also benefited from the rise in groundwater caused by the flood. This further proved the importance of maintaining the sharing system. In parallel, this catastrophe generated an influx of national and international funding for the rehabilitation of the water-sharing system and the safeguarding of the *k'sar* (fortified town).

In March 2020, when lockdown measures were announced due to COVID-19, several villages in the M'Zab Valley were repopulated, as people who had migrated to work as wage earners or traders returned to their home villages. They resumed agricultural activities and restored some of the palm groves. The population increase and the intensification of agricultural activities put pressure on the scarce water resources of the oasis. This motivated the community to start a campaign to restore the irrigation system, which had long been in disrepair. According to Djabir, who is part of the Umana Essayl, "The lockdown measures coupled with the absence of floods is a good opportunity to clean our wells and seguias to prepare for a future flood in order to renew the water reserve for several years". The Umana Essayl gathered donations to start maintenance work as part of a *tuiza* (collective effort); the work included rehabilitating 22 recharge wells, cleaning hundreds of metres of canals, and removing the sediment accumulated in front of the dike. In the process, functionality was restored to 75% of the recharge wells in the oasis.

The 'COVID rehabilitation campaign' was impressive in its scale and swiftness; however, there have also been other efforts to improve the recharge system. In 2017, the Umana converted two private irrigation wells in the new extensions into recharge wells; they were chosen for their strategic location, being at both the entrance to the oasis and on the edge of the main wadi. A several-metre-long weir was installed in the middle of the wadi to divert part of the floodwater towards the wells, in which openings had been made so that the diverted water could infiltrate. In 2008, a bigger dam was constructed by the state upstream of the oasis (Figure 1). This dam, combined with the two new recharge wells built by the community, allow the Umana to (when flooding is less) direct water towards the two recharge wells to raise the water table, or (with heavier flooding) send it towards the gardens and the recharge wells of the oasis.

SHARING OF WATERS IN RANDULLABAD

Sharing groundwater for domestic purposes and for agriculture through collective decisions

The story of Randullabad resonates with India's story of groundwater use. More than 80% of India receives four months of monsoonal rain, between June and October. Part of this water recharges the aquifer and is drawn upon in the remaining eight months for various uses including drinking and agriculture. In Maharashtra and in many other states of India, large dug wells with a diameter of 3 to 6 metres (Figure 6) have been used for centuries for tapping the shallow groundwater of the unconfined aquifer during the dry period (Sakthivadivel, 2007). Most of these were community wells that were primarily used for drinking water. Agriculture was dependent mainly on rain and irrigation was possible only in proximity to surface water sources like dams and canals. India's groundwater resource development began in the mid-1960s; it was aimed mainly at achieving food security in the wake of consecutive famines (Shah, 2009). Until then, in villages like Randullabad farmers used to practice rainfed agriculture, growing crops like millet, pulses and food grains. Limited crops were grown in winter, using only soil moisture. In the 1960s and 1970s, the shallow wide community wells were increasingly used by farmers to store water, which they then used for irrigation during the dry season.

Figure 6. A typical large-diameter dug well in Randullabad that was constructed in the 1960s and 1970s.

Source: Photo by ACWADAM (2010).

In a rocky area like Randullabad, it is quite challenging for a small-scale farmer who is cultivating one or two acres to dig a well that is 4 to 6 metres in diameter and 10 to 15 metres deep. Farmers would therefore join forces and select land for digging a well on the basis of their mutual understanding. These farmers would contribute to the cost and/or the labour of well digging. About half of the existing wells in Randullabad were dug in the 1960s and 1970s. For many decades, water was lifted from these dug wells using the bullock-powered *mhot (*Persian wheel) system. Most of these older wells were dug by three to four farming families and the water was shared among the well owners through informal agreements; more recently constructed wells, in contrast, are mainly shared among family members. Over the last six or seven decades, the community has also learned about the principle of intentional recharge and have made the link between intentional recharge and water availability from wells. A severe drought occurred in 1971/1972, and two years later the Irrigation Department constructed a groundwater recharge structure. The community was not involved in its construction, but they helped the engineers identify a suitable site for recharge based on their local knowledge and wisdom. The structure was designed to recharge the groundwater, and direct water withdrawals were not allowed; instead, farmers could lift water from nearby wells.

In the 1980s, farmers started using mechanised pumps to abstract water from their wells, first with diesel engines and later with submersible pumps. The technology came with a cost and farmers again depended on their traditional informal water user groups for sharing related expenses, including electricity bills. Each of these wells has a single 3-5 horsepower (hp) pump that is used by all the farmers for irrigating their land. In 2013, out of about 350 ha of irrigated land in Randullabad, around 200 ha (57%) was irrigated through shared wells (Aslekar et al., 2013). Indeed, most of the land owned by small and marginal farmers is irrigated through arrangements from shared wells.

In the early 1990s, borewell drilling rigs made their entrance into many of Maharashtra's villages. Submersible pumps enabled groundwater users to pump water from virtually any depth below the ground. Digging a well in a hard rock area is an expensive affair, and a well of 5 m in diameter and 15 m in depth costs about Rs. 5 lakhs (US$6130), while drilling a borewell is an easy and affordable option for medium and small landowners, costing Rs. 1 lakh (US$1225) for a 100 m deep borewell. Farmers also lose less land when drilling a borewell than when digging a large-diameter dug well. They thus started drilling borewells as a lucrative option for irrigation, while shifting at the same time to more profitable crops. Many farmers in villages near Randullabad changed their traditional cropping pattern from millets and food grains to vegetables and sugarcane, which required more water but yielded good financial returns. Aquifers in hard rock areas, however, have limited storage capacity compared to those in alluvial areas or sedimentary terrain, and as you go deeper the storage capacity of the aquifer decreases. Borewells in hard rock generally have no, or limited, casing. A 100-metre-deep borewell with only 3 to 6 metres of casing will likely tap groundwater from multiple shallow and deep aquifers in its vicinity. This over-abstraction of groundwater by deep borewells has led to a decline in the volume of water contained in shallow aquifers – the same aquifers from which dug wells were tapping their drinking water. Perennial village wells turned seasonal and started running dry in drought years, threatening the community's drinking water security. This was evident in many villages of western Maharashtra in early 2000.

Bharat Jagtap, then a member of the Village Watershed Committee, observed that in the hope of tapping water farmers were drilling increasingly deeper, wasting money on borewells that were not yielding sufficient water. At around this time, the state government launched the Adarsh Gaon Yojana (Ideal Village Scheme), which supported villages in undertaking water and soil conservation initiatives. Randullabad's Gram Panchayat (Village Council), which was the community's grassroots-level democratic institution, decided to participate in this initiative. One of the criteria by which a village was selected for the scheme was that it put a ban on borewells; convinced by Jagtap, who was also a member of the Gram Panchayat, the community agreed to do so and a decision to that effect was obtained from the Gram Panchayat. Since then, not a single borewell has been drilled in Randullabad for irrigation. The Gram Panchayat faced several challenges in implementing the ban, as boreholes are cheaper than dug wells and as water demand had increased due to a booming agricultural economy; it was, however, able to successfully mediate a few conflicting situations that arose after the ban.

Pressure on groundwater due to market 'pull'

The mid-1990s to the early 2000s was the period of economic reforms and liberalisation in India. The winds of change reached Randullabad in the mid-2000s. Farmers in the village were approached by a multinational potato chip manufacturer to grow potatoes; this led to large-scale potato cultivation (Figure 7). The village annually produces approximately 50 trucks of potatoes, which are mostly sold to a single company under a long-term agreement. By 2009, more than 40% of farmers were growing potatoes during the rainy season. The company offered assured rates for produce of desirable quality and helped farmers procure seeds, fertilisers and pesticides. Farmers, however, did not have access to a reliable water supply.

Figure 7. Potato production in Randullabad.

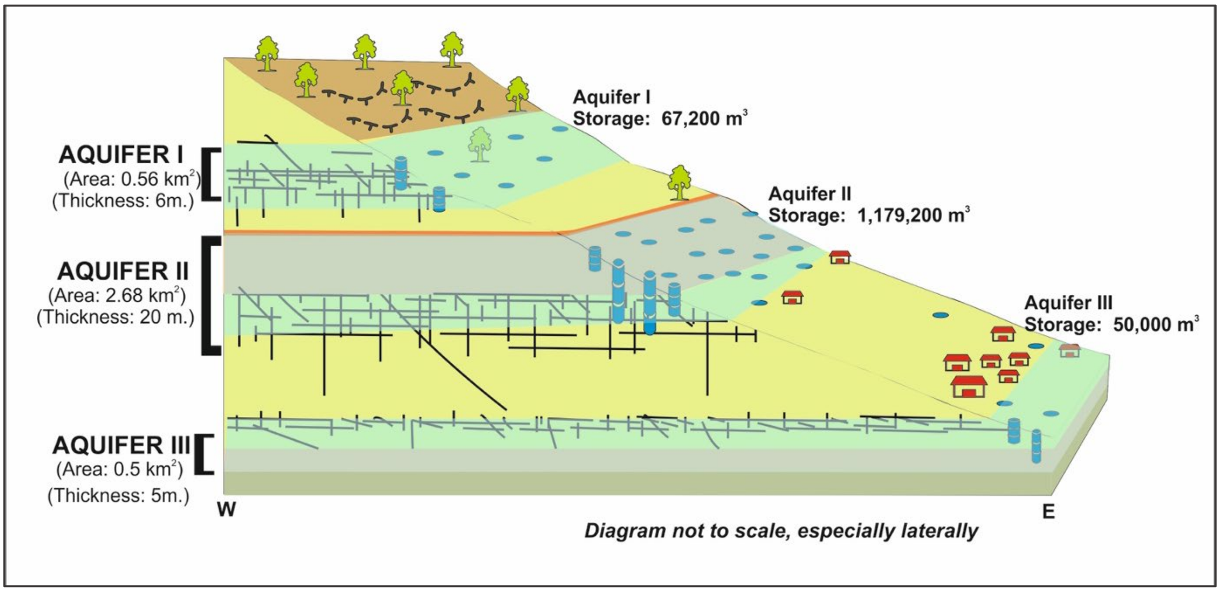
Source: Photo by ACWADAM (2011).

Randullabad has experienced a change in its rainfall pattern over the last 20 to 25 years, with longer dry spells (more than 40 days) during the monsoon season. The fast-growing crops need water during this time and farmers are thus compelled to pump water from wells even during the rainy season, which they would otherwise have left for use during the dry season. During drought years, the situation worsens. In 2003, there was a drought in Maharashtra during which Randullabad faced acute drinking water scarcity. People had to purchase drinking water and water for domestic use. Agriculture was badly affected; farmers had to migrate to nearby areas in search of work and many had to suspend the education of their children. In 2008, the community was approached by an NGO working on a four-year watershed programme; the severe drought that Randullabad had experienced was a strong stimulus for its Gram Panchayat and the community as a whole to participate. A Village Watershed Committee was constituted which, together with the NGO, decided to involve scientists in the implementation of the watershed development plan; in this way, ACWADAM got involved.

Collaboration and knowledge-driven community actions

The recharge programme was implemented using a participatory groundwater management approach that included institutional capacity building at the village level, local data collection, and preparation of data for decisions by the Gram Panchayat. The study helped map aquifer systems in the village and identify the potential groundwater recharge areas for constructing recharge structures such as check dams. Some inherent limitations, however, constrain recharge interventions in hard rock terrain, in particular the aquifer's limited storage capacity. The Village Watershed Committee collected hydrogeological data in the form of well-water levels, rainfall, and in situ water quality. With the help of experts from the NGOs, this data was analysed and discussed with the community. During the implementation of the programme, the Village Watershed Committee, and more generally the community members, became increasingly aware of the potential and the limitations of managed recharge in connection with groundwater use. In other words, the programme provided villagers progressively with a solid, practice-based understanding of Randullabad's hydrologic system (Figure 8).

Figure 8. Aquifer systems in Randullabad.



Source: Aslekar et al. (2013).

The first challenge of the groundwater management programme was to create a balance between the recharge of the aquifer and its discharge through abstraction from pumping and base flow. The community showed that it was able to achieve this balance. In 2012/2013, for example, the total recharge to the three aquifers (see Figure 8) was 712,560m^3. The abstraction from pumping was 627,750m^3, while discharge in the form of base flow was 12,000m^3. The total discharge from the aquifer was thus 639,750m^3, which was 11% lower than the recharge, leading to a rise in the water table.

The second challenge was to provide a sense of community co-ownership of the recharge and water use infrastructure. The recharge infrastructure consisted mainly of continuous contour trenches or scattered trenches; these had to be protected from damage by grazing cattle, who could also harm the vegetation, grasses and shrubs that had been planted in the area to prevent soil erosion. The committee also encouraged the sharing of wells and the use of low-flow water pumps to limit over-abstraction of groundwater (Table 1).

The third challenge was to reason the farming systems in the village to avoid creating a water demand that would systematically overexploit the available groundwater. Since crops such as sugarcane and banana were not traditionally grown in the village, the main challenge was to manage the available water for crops like potatoes, tomatoes, peas, beans and food grains. There were also some individual challenges to the groundwater management programme. A former head of the local governing body recounted that,

> In the summer of 2012, a farmer decided to expand his poultry farm and for that he wanted to drill a borewell. We all tried to persuade him against drilling. However, he was quite adamant and called the drilling rig. By then, the whole Panchayat had assembled to resist this move. At that time, I decided to call the Block Development Officer from the government and requested her to intervene in the matter. The officer intervened and stopped the drilling as it was against the resolution passed by our Gram Panchayat. We organised a meeting at 11 pm at the Gram Panchayat office and amicably decided to give this farmer extra water, through the water supply scheme at extra cost. The farmer too, dropped the idea of drilling a borewell in the larger interest of the village.

The principal challenge, however, was to ensure the sustainability of the water recharge and use programme even after the withdrawal of the NGO that was implementing it. The community was left with the questions of: how to continue preserving the balance between water recharge and use, how to maintain the collective infrastructure, how to restrain demand, and how to sustain the balance within the managed recharge and use system. In response to these challenges, the Village Watershed Committee and the NGOs jointly decided to develop several protocols governing groundwater recharge and use (Table 1). The protocols were shared with the community during the Gram Panchayat's general meeting with the villagers. No formal resolution was passed in the village council regarding the implementation of the protocols, but that has not so far made them vulnerable. The idea behind the protocols was to develop knowledge-based systems where the community makes decisions based on shared data and facts. The 11 protocols were developed for the village's water safety, security and sustainability. Table 1 briefly explains the recommendations and challenges faced during the implementation of these protocols.

Table 1. Groundwater management protocols developed for Randullabad, with recommendations and challenges faced during implementation.

Protocol	Recommendations to community members	Challenges faced during implementation
Hydrogeology in watershed programmes	Locate watershed structures for recharge and discharge on the basis of hydrogeological studies	Farmers in the groundwater recharge area were initially reluctant to give up their lands for construction of check dams
Recharge area protection	Protect recharge area by fencing 45 hectares (ha) of land	The ridge area of the village is common land that is used for grazing animals; the animals damage the recharge trenches and plantations in the area
Pump capacity regulation	Encourage farmers to use low horsepower (hp) pumps, as pumping rate should match the natural capacity of the aquifer to release water into the wells	Farmers in Randullabad use low-capacity pumps because well yields are limited; hence, there were very few challenges to the protocol
Regulation of distance between wells (drinking-water well protection)	Do not locate irrigation well within 75 metres of a drinking-water well, as pumping within this distance can affect the availability of drinking water	Reinforcement was not problematic because the Maharashtra Groundwater Act (1993) for the protection of drinking water prohibits construction of irrigation wells within 500 metres of drinking-water wells
Depth regulation of wells	No irrigation well in the village should be deeper than the drinking-water well	The security of drinking water is critical to the village and so villagers adhered to the rule
Regulation of agricultural water requirement	Reduce water use by adopting water-saving techniques like drip and sprinkler irrigation and not growing water-intensive crops	Reluctance to adopt drip irrigation arose initially as it is expensive, with high recurring costs; the sprinkler is relatively cheap but it can only be used during initial crop stages; the watershed committee made drip irrigation mandatory for horticulture and promoted sprinklers for food grains and vegetables; water-intensive crops (sugarcane, bananas) are traditionally not grown, hence there was not much resistance to this protocol
Groundwater sharing through community participation	Community should continue sharing wells and should strengthen water user groups	New wells are individually owned wells; land near the ridge line has been newly developed by people within or outside the village who are digging individual wells; however, the cost of digging a new well is high, therefore their numbers are limited
Drinking water quality monitoring	Fluoride was found in hand pumps that were tapping deep aquifers; these sources should thus not be	There is limited awareness about the water quality issue in the community; testing is usually done by outsiders like

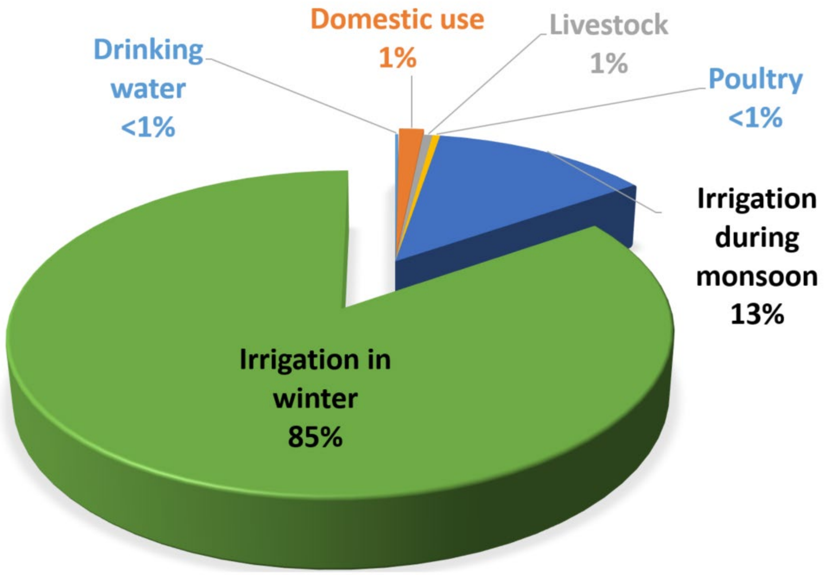
	used for drinking and regular water quality monitoring should be done	NGOs or government authorities; regular monitoring of sources is not done by the community; testing kits are expensive
Regulations to control overexploitation	Borewell drilling should be banned to control groundwater overexploitation and preserve confined aquifers	This decision had already been taken by the Randullabad Gram Panchayat earlier on; the main challenge is with people who are newly developing their lands and have the financial resources to drill a new borewell; there are also occasional challenges from individual farmers
Groundwater monitoring to understand water availability	There should be on-going monitoring of at least groundwater levels, rainfall, and simple water quality parameters	One watershed committee member is voluntarily monitoring hydrogeological parameters; however, there is no backup for him and little accountability
Community awareness for groundwater use	Scientific findings, information and data should be shared with the community	After the withdrawal of NGOs, information sharing is more on economic activities and less on groundwater dynamics

While developing these protocols, priority was given to providing drinking water to all community members throughout the year. Even though the drinking water demand in Randullabad is less than 1% of the overall water demand (Figure 9), its supply can only be safeguarded by regulating all other water uses during the monsoon period and during winter irrigation. Rules on depth of wells were critical, as were regulations on distance between wells. A piped distribution system was developed by the Village Watershed Committee so that every household received tap water every alternate day or on a schedule that depended on the availability of water in the drinking-water well. Operation and maintenance of groundwater recharge structures, such as regular desilting of percolation tanks, is necessary for ensuring the effectiveness of recharge. This was ensured to some extent by the protocols for protection of the recharge area and by hydrogeological inputs in watershed activities. The well-sharing protocol, the regulations to control pump capacity, and the regulations to control overexploitation of groundwater helped to control the demand for groundwater. The key to community participation is the constant engagement and sharing of information about the resource; the protocol for sharing scientific findings, information and data ensures that critical parameters are monitored and shared within the community.

DISCUSSION: SHARED INFRASTRUCTURE, INSTITUTIONS, PRACTICES AND KNOWLEDGES FOR SHARED WATER

The analysis of two long-standing and functional community initiatives, one in Algeria (M'Zab Valley) and the other in India (Randullabad, in Maharashtra), shows how communities have made conscious and active links between aquifer recharge and groundwater use. Sharing difficult waters when they are in excess due to floods and runoff, and intentionally storing them in aquifers, allows for droughts to be endured. Dillon et al. (2019: 3) label community-managed aquifer recharge as "unintentional" and as "inadvertently" recharging the aquifer "as a by-product" of irrigation or soil and water conservation; we show, on the other hand, how communities intentionally recharge aquifers and then manage the (frugal) use of groundwater.

Figure 9. Groundwater use in Randullabad (India) for various purposes.



The case studies show that sharing difficult waters is hard work, that it is not without conflict, and that it is frequently undermined by water and agricultural policies that are not tailored to the coherence and intricacies of collective aquifer recharge and use systems. Typically, the state considers surface and groundwater resources to be distinct; it responds to social unrest by providing more water resources in the short run, for example through the transfer of surface water or the provision of treated wastewater, and it stimulates agricultural ambitions beyond the scope of available water resources (Zwarteveen et al., 2021). It is therefore not surprising that such community systems frequently face challenges; these can include: unsupportive or even disruptive policy interventions such as the implementation of a drinking water supply system that increased the sewage in Algeria's Beni Isguen Oasis; the emergence of entrepreneurial forms of agriculture; economic opportunities in other sectors; and the availability of cheap technology that allows for individual tapping of groundwater. The two cases presented here, however, provide a striking tale of resilience; they illustrate how a community can manage to put in place the necessary water reserves that can see them through prolonged droughts.

We showed that communities share practice-based knowledge of the hydrological cycle as it concerns their aquifer system. They are also able to maintain and operate common recharge and use infrastructure and have a common understanding of the farming systems that are compatible with sustaining the resource base. We further observed the adaptive nature of institutions that carefully balance available water resources and ensure their (frugal) use. In this, the communities in our case studies have shown many of the intrinsic social norms and values of communal irrigation systems around the world (see Aubriot, 2022).

Water sharing in community-managed water recharge and use systems requires, first, extensive, embodied and collectively shared knowledge about the complex interactions between surface and groundwater; this is needed to balance long-term water supply and demand. In Beni Isguen, this knowledge is embodied in the Umana Essayl, the customary collective of water stewards. Their historic and constantly updated knowledge is practice-based and is the fruit of a long-term engagement with groundwater. As the Randullabad case shows, knowledge possessed by local community members can be usefully confronted to scientific knowledge. Members of the Village Watershed Committee interacted frequently with scientists over a period of more than 10 years during the implementation of a watershed programme. Scientific knowledge did not remain theoretical or general; rather, it was jointly and practically verified over the course of these many years, for example, during droughts in recent years when the village had uninterrupted access to domestic water.

Shared knowledge informs the way that infrastructure is designed and maintained and how to make the institutions governing water systems more effective. Knowledge also emerges from the embodied encounters of community members with groundwater, mediated by infrastructure and institutions. This shared knowledge, as part of a larger irrigation culture, is a key aspect of the resilience that can be drawn upon when irrigators are faced with disturbances, unexpected events, or climate change (Fernald et al., 2015). As much as the water itself, shared knowledge must be passed on to subsequent generations.

The second component of effective water sharing is the existence of a coherent set of infrastructures to manage recharge and water use systems. These infrastructures, which have generally been developed progressively, also need a lot of attention to maintain their integrity. The design and upkeep of shared infrastructure for recharging aquifers and groundwater use is generally labour intensive and must be regularly adapted to changing conditions (Mahdi, 1986). The construction of a state-sponsored dam upstream of the oasis of Beni Isguen, for example, changed the extent and timing of floods, prompting water experts to install new recharge wells upstream of the oasis. The choice of the location was contested by other community members, but only the longer-term performance of these new wells will show if the decision was correct.

The third important aspect of water sharing – something that is often forgotten when studying irrigation systems – is that there must be agreement within the community as to what farming systems and practices will lead to water demand that is compatible with sustaining the resource base, including for future generations (Coward, 1980). In Randullabad, this meant curtailing some of the ambitions of certain community members who were interested in increasing their water use for profitable farming activities. In Beni Isguen, water sharing is done on the basis of the number of palm trees that different households are supposed to grow, thus limiting individual ambitions. Farmers from Beni Isguen who were interested in diversifying their farming systems left the oasis for agricultural extensions that were located upstream from it. These farmers implemented an oasis agriculture that was inspired by long-standing environment-friendly practices (Saidani et al., 2022). They use inputs and irrigation water frugally through careful agricultural and irrigation practices and they have created local water loops through water recharge and use practices; they thus *care* for water. These extensions widen the scope of the water-sharing debate. They draw attention to the fact that the efforts of individuals in leaving the oasis and engaging with more entrepreneurial ways of farming are not based on short-term material gains or on controlling water for their own sake; rather, they are engaging in a broader, shared vision of the necessity of caring for water and for one another. Having said this, the farmers of the extensions are using water that would have in the past flowed downstream to the oasis and, increasingly, there is a call from oasis residents for a sharing agreement on available floodwater.

Fourth, carefully balanced water sharing requires robust collective action to maintain and operate the common infrastructure and adaptive institutions. Our analysis shows that these community-managed systems also depend on, and involve, other actors, including NGOs, the state and politicians; it would thus be wrong to ignore, "broader governance processes and power dynamics" (Whaley and Cleaver, 2017: 56). This was one of the reasons the Village Watershed Committee in Randullabad involved the local government body in the managing of the recharge and water use system. The Beni Isguen water stewards, similarly, created a formal association in an effort to reinforce the dialogue with the state. These community systems need to be supported and protected by policies, as it is hard work to keep them functional.

CONCLUSION

This paper draws attention to the important historical and contemporary work of communities sharing groundwater in arid environments. Our work consisted of carefully documenting and analysing communities in Algeria and India where initiatives around intentional aquifer recharge and frugal water use were underway. Aquifer recharge is done with difficult waters such as floodwaters or runoff. Such sudden, capricious and elusive waters can create havoc but, when conveniently stored in aquifers, they are at the origin of livelihoods in the arid environments of our case studies. Water thus, "produces both the transience of the moment, and the enduring connections of landscape and history" (Mosse, 2003: 299). These communities have put in place everyday collective practices for sharing the knowledge, institutions and technologies necessary to sustain groundwater governance. This governance is underlain by common values and social norms of solidarity and sobriety.

The communities in our case studies show a clear sense of caring for the aquifers they share. They have contributed to their creation, have been active in resisting their overexploitation by individuals, and have worked to sustain the collective effort of aquifer recharge. In sustaining these aquifers, they have shown emotional engagement through, for example, resistance when community members or the state endangered the aquifers; they have also engaged themselves practically through their everyday efforts (Mol et al., 2010; Domínguez Guzmán et al., 2021). Their care for aquifers is also about being able to pass them on to future generations; in the Algerian case this is explicitly claimed by the water stewards, and in the community in India by the Village Watershed Committee. Both communities have progressively created a groundwater commons (sharing, after all, means 'having in common') which should be considered a "living process" that has been forged through the "social practices of communing, [that is,] acts of mutual support, conflict, negotiation, communication and experimentation that are needed to create systems to manage shared resources" (Bollier, 2020: 349). Sharing difficult waters therefore is, and has always been, an important practice, one through which people have forged strong relations with groundwater and with each other that can now help them deal with contemporary challenges.

As mentioned by Molle and Closas (2017: 14), "pure" forms of state-centred or community-based groundwater governance are hard to find. Our case studies are no exception to this. The empirical evidence of the cases reported here shows how communities carefully, under very challenging and rapidly changing circumstances and with profound knowledge on aquifer dynamics, organise themselves around groundwater to sustain and share it. The cases also show how communities engage dynamically with 'outside' parties in the sustained care of their aquifers. In the process, they resist unsupportive or even obstructive meddling, they enrol interesting allies, they collect opportune funds and subsidies, and they constantly negotiate their place in a myriad of formal and informal institutions. In these arid environments where groundwater constitutes such a vital resource, outside parties such as the state, NGOs and scientists are thus actively and variously engaged; this is, of course the case in the vast majority of community-based water systems (Aubriot, 2022). Even in state-centred groundwater governance systems, however, and even when communities are (formally) excluded from groundwater governance, individual practices and community social norms matter, for example in cases of "illegal" withdrawing of water from the aquifer (Kuper et al., 2016). It thus makes sense to seek active community involvement in groundwater governance in order to work towards transformations of aquifers towards sustainability.

Beyond the quantitative sharing of groundwater that is discussed in this paper, one of the major issues that emerges is the pollution of groundwater through domestic or industrial wastewater and the use of fertilisers and pesticides in agriculture (Dillon et al., 2019). Since the communities in our case studies have been in the habit of monitoring water resources over the long run, they are generally sensitive to this issue. In Beni Isguen, for instance, the community created an environmental association to resist the construction of a toxic waste sorting centre in their locality. Their social mobilisation was motivated by their long-term view of sharing of, and caring for, water across generations. Monitoring water quality, however, is a complex issue; it requires laboratory analyses that are costly and difficult to carry out without outside support. This shows the added value of enrolling scientific and technical partners to support this process, as was done in Randullabad.

Different "variants of care" can be observed when carefully studying communities that deal with difficult waters (Domínguez Guzmán et al., 2021: 14); similarly, as we have shown in this paper, there are numerous ways of sharing waters that can be made visible by analysing the knowledge, technologies and institutions that characterise such dealings. Making visible and conceptualising such grassroots initiatives can help challenge conventional ways of studying groundwater governance (Zwarteveen et al., 2021). These multiple ways of sharing of and caring for groundwater, however, need to be "attended to, cherished, differentiated" as "there is a risk that they will disappear" (Domínguez Guzmán et al., 2021: 14). Caring for, and sharing, groundwater are everyday practices, but they are hard work to sustain in the face of the massive increase over the last decades in (individual) access to groundwater, unhelpful state interventions, and attractive individual profits. The values and social norms related to caring and sharing, however, are precisely what will be required to improve, restore and sustain living aquifers around the arid world. Community initiatives thus represent sources of inspiration for ecologically sustainable and socially equitable forms of groundwater governance, even in particularly challenging situations.

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