Conjunctive Use of Canal Water and Groundwater

An Analysis Based on Farmers' Practices in Ravangaon, Maharashtra

Bhat, S.; Kulkarni, S.; Deshmukh, R.; Bhopal, S.; Zwarteveen, M.; Sumbre, S.

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Conjunctive Use of Canal Water and Groundwater: An Analysis Based on Farmers' Practices in Ravangaon, Maharashtra

Sneha Bhat

Society for Promoting Participative Eco-System Management (SOPPECOM), Pune, India; bhatsneha@gmail.com

Seema Kulkarni

Society for Promoting Participative Eco-System Management (SOPPECOM), Pune, India;
seemakulkarni2@gmail.com

Rucha Deshmukh

Advanced Center for Water Resources Development and Management (ACWADAM), Pune, Maharashtra, India;
ruchadeshmukh@ymail.com

Sachin Bhopal

Society for Promoting Participative Eco-System Management (SOPPECOM), Pune, India; svbhopal99@gmail.com

Margreet Zwarteveen

Water Governance Department, IHE-Delft, Delft, and Geography, Planning and Inclusive Development, University of Amsterdam, The Netherlands; m.zwarteveen@un-ihe.org

Simran Sumbre

Advanced Center for Water Resources Development and Management (ACWADAM), Pune, Maharashtra, India;
sumbresimran@gmail.com

ABSTRACT: This article examines what happens when canal water is combined with groundwater. It does so by documenting the complex web of practices that are emerging around accessing, storing and transferring water in the command area of irrigation systems in Ravangaon, a village in Maharashtra, India. From mainly accessing water through field channels that are fed by the public surface irrigation system, farmers have moved to using pumps and siphons to transport water from the canal either directly to their fields or to wells and ponds for storage. Their practices are shaped by hydrogeology – most notably the location and storage capacity of the aquifer in relation to canals and farmers' plots - as well by the political economy – most notably their relative dependence on water-intensive crops like sugarcane. Access to water has largely become a function of one's ability to invest in advanced pumping, transporting and storage facilities. In line with other scholars, we conclude that the conjunctive use of canal water and groundwater makes it difficult, if not impossible, to trace and monitor actual water use patterns. This means that water distribution increasingly escapes formal and public forms of regulation and control. The article ends with a reflection on what this means to the advancement of water sustainability and justice.

KEYWORDS: Conjunctive use, tinkering, canal irrigation, water governance, Maharashtra, India

INTRODUCTION

Throughout India, the ever-increasing availability of affordable pumping technologies has drastically changed modes of accessing water, including in command areas of public irrigation systems. From relying on gravity flows that transport water through canal minors, sub-minors, outlets and field channels, many farmers now access water by pumping it either directly from canals or from wells. Water levels in the wells fluctuate with, or may even partly depend on, water flow in the canals; this effectively turns canals for irrigation into recharge canals (Shah, 2011; Singh, 2006; Selvarajan, 2002; Thakkar, 1999: 19). Which farmers construct wells, as well as the location and number of the wells they construct, is partly a function of their ability to mobilise the necessary resources; this is in turn affected by their skill in navigating the system to access subsidies and/or other kinds of government support. Their position at the intersection of wealth, caste and gender relations importantly co-determines this ability.

This paper uses the case of Ravangaon to think about the dynamics of such changes and to reflect on their implications for water management and governance. We situate our analysis in the broader conversation about conjunctive use and management of water and, more specifically, in the question of how to measure, trace and account for water and money when different sources of both are mixed and combined. We anchor the paper in a documentation of farmers' practices of accessing, storing and using water. In Ravangaon, as in many other irrigated areas of Maharashtra, what farmers do, and why they do it, is importantly determined by the political economy of sugarcane. It is for this reason that we include a brief history of sugarcane in the area as background to our analysis of contemporary water practices.

CONJUNCTIVE USE: CONTROL OR TINKERING?

'Conjunctive use' can refer to a range of situations where water from different origins is combined (see Foster et al., 2010; Shah, 1990; Shah et al., 2006). Here we use the term for farmers who use wells that are directly or indirectly few by canal water as an on-demand irrigation system. They often do this because canal water is both inadequate and unreliable.

A quick – and admittedly not very systematic or comprehensive – search and review of the literature[1] suggests that most scholars write about conjunctive water use from an often-implicit identification with managers, whose institutional responsibilities and powers are usually not specified. Their main concern is one of optimisation, with authors focusing on how to most rationally and efficiently organise the allocation of water when canal water is combined with groundwater. The studies consider the combining of different sources of water as a potentially useful strategy for using large-volume natural groundwater storage to either 'buffer' water-supply availability or to confront some of the serious problems of groundwater salinisation and soil waterlogging on alluvial plains (cf. Foster et al., 2010: 3; see also Sharma and Minhas, 2005; Laghari et al., 2012). Simulation models seem to be the method preferred for this type of investigation, with simulations showing what *could* be achieved if management of waters was 'rationalised' (see Singh, 2012. These studies discuss and help imagine ideal type situations; they sketch futures in which waters are combined to meet a variety of goals, mostly related to productivity or 'more crop per drop'. They treat conjunctive use as if it were something that can be planned and designed, a treatment that hinges crucially on the (belief in the) possibility of somehow tracing, and accounting for, how and where water flows.

The study that we present here differs in three ways from these more typical studies on conjunctive water use. First, our study starts from an explicit identification with farmers and with organisations such

[1] We used the keywords 'conjunctive use' and 'irrigation' in Scopus, limiting the search to the last 10 years. Conducting this search on 25 January 2023 yielded 167 articles, 147 of which made use of the terms 'optimisation' or 'model(ling)'. We reviewed the abstracts of the 20 most-cited articles; we also scanned the others to ascertain whether these included studies of actual conjunctive use practices, but found none.

as ACWADAM and SOPPECOM,[2] which are interested in helping farmers improve their management of water and other natural resources. In addition to concerns around productivity and efficiency, ACWADAM and SOPPECOM care about the longer-term sustainability of water, as well as about the equity (or justice) of its distribution. ACWADAM has a long track record of helping communities know, manage and recharge their aquifers by, among other things, engaging in participatory aquifer mapping exercises. SOPPECOM engages with, and develops, a range of actions to make water available to those without formal rights or without the funds to invest in pumps and wells, many of whom are (low caste, widowed) women.

The second way in which our study differs is that we do not start from the ideal-typical, that is, from imagining a future on the basis of optimisation modelling; rather, our study is anchored in actual conjunctive use practices. This importantly stems from the realisation that proposals for improving (ground) water management need to be anchored in what farmers are already doing (cf. Shah, 2011). We document how conjunctive use happens in practice; we show how and why farmers combine different water sources in canal irrigation systems and we assess how this changes water flows and allocations. Surprisingly, there have been few others who look at what farmers are actually doing. In India, many water professionals and scholars with whom we interacted in the last 10 years or more acknowledge the widespread practice of conjunctively using groundwater and canal water in command areas of irrigation systems. Tushaar Shah, one of India's most well-known (ground) water experts, admits that, "pump irrigation from groundwater wells as well as directly from canals is rampant in Indian systems, leaving surface irrigation systems reconfigured and their command areas redrawn" (Shah, 2011: 73). This 'conjunctive reality', however, is not much talked about in water or irrigation studies. It is also minimally acknowledged or reported in official statistics, something that may relate to the fact that recorded information on any given irrigation (or irrigated) area often only indicates the 'initial' or 'dominant' water source (cf. Foster et al., 2010). Foster et al. (ibid) note that in 14 of 23 large-scale irrigation canal command areas in the arid terrain of Pakistan, less than 50% of the water applied to fields is derived from the canal system, with most of the rest coming from groundwater and the remainder from rainfall. Likewise, in the Indian states of Punjab and Uttar Pradesh, over 70% of the irrigation water supply is derived from wells, with part of the remaining 30% coming from groundwater that has seeped from irrigation canals, and another minor amount coming from aquifer reserves.

The third difference of our study from most studies on conjunctive use logically follows from the first two, in that we are much less optimistic than most others about the possibility of effectively steering, planning and controlling the conjunctive use of water. The shift from open canals to underground flows and pipes and from publicly to privately owned and managed systems, makes it difficult to trace or account for water. Accurate water distribution via monitoring and regulation is of course difficult even when not using water conjunctively. It is almost a given in canal irrigation systems that head-end farmers routinely over-appropriate water in order to grow crops that were not anticipated when designing the system (see Mollinga, 2003); indeed, the very unreliability of the canal water supply is often what prompts farmers with land in tail-end areas to resort to groundwater. Increasingly, however, the availability and affordability of pumping technologies is enticing many farmers to substitute dependence on often not very reliable canal rotations with individually owned pumps and wells. The proliferation of

[2] The Advanced Center for Water Resources Development and Management (ACWADAM) is a non-governmental organisation that conducts research on water resources; it focuses particularly on the science of groundwater, with an emphasis on sustainable and equitable management. ACWADAM's participatory groundwater management approach is an innovative paradigm for managing India's groundwater resources (see http://www.acwadam.org); see also ACWADAM 2016. The Society for Promoting Participative Ecosystem Management (SOPPECOM) is a non-profit, non-governmental organisation that works in the area of natural resource management, primarily in rural areas SOPPECOM is committed to 1) the principles of sustainable and rational use of natural resources; 2) equity and social justice in the distribution of benefits, especially to disadvantaged sections such as Dalits, the landless and women; and 3) democratic and decentralised governance of these resources (see www.soppecom.org; see also Kulkarni, 2003; Paranjape and Joy, n.d.).

wells and pumps in and around the command areas of public irrigation systems and the conversion of irrigation canals into recharge canals further calls into question the belief in, and dreams of, 'controlling water'; it also troubles conventional ideas about what irrigation management is or should be (Shah, 2011).

Rather than using a lens of control, therefore, we propose that metaphors such as 'tinkering' and 'bricolage' (Cleaver, 2002, 2012; Benouniche et al., 2014)[3] may be more appropriate for describing and explaining what goes on when different waters are combined in an irrigation system. Tinkering[4] refers to quick fixes or forms of making-do; it is a patching together of materials from different sources to solve a problem-at-hand, or the creative navigating or bypassing of rules to suit one's own purpose. Using the term helps reveal and create acceptance of the many ways in which the 'behaviour' of water deviates from, or eludes, formal or public plans, designs and laws. Attention to tinkering also usefully sheds doubt on the existence of identifiable centres of power (that is, formally appointed managers and operators) before the analysis. Use of the term creates room for accepting that actual water flows will always be the partially contingent outcome of interactions and negotiations between a range of human and more-than-human actors, only some of whom have formal responsibilities. By shifting attention away from idea(l)s about how water should be distributed or managed before the empirical investigation, attention to tinkering relaxes beliefs in the possibility of rationally designing, controlling and 'fixing' water; it makes room for imagining other ways of managing it (cf. Kemerink-Seyoum et al., 2019; Chitata et al., 2021).

METHODS

This paper's authors have a long association with Ravangaon village. Different action-research projects have allowed us to become firsthand witnesses of the social and hydrological changes the village has experienced over the last 15 years. Our initial intervention in the village, in 2006, focused on widowed and separated women farmers; it set out to understand the reasons for their singlehood. Detailed interviews with women and the extensive fieldwork carried out during this period constituted our initial introduction to the village dynamics. Some of the village residents with whom we engaged in discussions around irrigation indeed became our colleagues, working with us as researchers and community mobilisers. One villager began working with us in 2003 and continued to do so for almost a decade supporting research on canal water management and helping analyse the performance of water users associations and practices of watershed management. A few others became actively engaged in the present study; they helped monitor wells and borewells, introduced the research teams from SOPPECOM and ACWADAM to the community, and helped the researchers understand the political economy of the village. Already during our initial engagements with farmers in Ravangaon, we noticed how many used groundwater as a main or complementary source of irrigation. Every time we visited the village, more wells had been dug, most of which were directly fed by canal water. A more systematic study of the canal command areas in Ravangaon became possible as part of the joint learning process that was initiated by the Transformations to Groundwater Sustainability (T2GS) project (Zwarteveen et al., 2021).

The objective of the study in Ravangaon was to understand the relationship between groundwater and surface water in the canal command area. We made efforts to map water sources, aquifers and wells, and our study also focused on documenting emerging water access, storage and use practices. We were interested in combining an understanding of what farmers do with water and why, with an understanding of hydrogeological dynamics; our goal was to develop a grounded socio-hydrogeology of Ravangaon.

[3] Perhaps the Indian equivalent would be the term *jugaad*. One of the reviewers of this paper alerted us to the existence of a wider debate about this term in the scholarly literature about India (see Birtchnell, 2011). It is not our aim here to engage with this literature or this debate.

[4] Here we use the terms 'tinkering' and 'bricolage' interchangeably. The terms do have different scholarly legacies, though and can have slightly different meanings depending on where and by whom they are mobilized.

To that end, we complemented what we already knew about Ravangaon and its inhabitants with the surveying and monitoring of dug wells and borewells. We conducted focus group discussions (FGDs), in-depth interviews and canal transect walks; we also engaged in village-level consultations and carried out geological mapping, aquifer delineation and a socio-economic survey. Combining these different methods meant going back and forth between different data sets and sources of information to allow insights from one to inform the others. Information gained from FGDs and interviews, for example, was crucial for mapping the aquifers; these maps, in turn, determined the sample selection for the socio-economic household survey. Table 1 presents details of the main methods used.

Table 1. Methods used in the study of Ravangaon.

Method	Objective	Details
Dug well and borewell mapping survey	To gauge the extent of groundwater development in the village and patterns of groundwater use	207 dug wells and 227 borewells Data was gathered about: year of construction; water use from the source; water transfers to (in the case of dug wells), and from, the source; GPS coordinates of the wells
Focus group discussions (FGDs)	To understand (shifts in) agriculture and water use practices	FGDs with: large and small farmers, women's labour groups, marginal farmers from the Scheduled Caste community, and migrant workers who come to cut sugarcane in the village
In-depth interviews	To understand the details of water access, use and storage practices in relation to crops and land use	With men and women farmers Most of the interviews – especially those with women – were conducted informally, often while they were at work on the land Interviews were sometimes also conducted in more than one sitting, after reflection on the data that had previously been collected
Transect walks	To understand the situation of canal water distribution	Observations about the condition of outlets, field channels, and the ways water was extracted from the canal
Well monitoring	To understand the impact of the canal on aquifers in the village	18 village wells were monitored between April 2019 and March 2022 Water levels were measured once a month Rule for selection: no exogenous water supply
Aquifer mapping	To understand groundwater use patterns in the village	Different aquifers in Ravangaon were identified; storativity and transmissivity of each identified aquifer were also calculated

Secondary data collection	To gather relevant data about agriculture and water use in the village	Command area maps, cadastral maps, water release data from the canal, and revenue records for all the village plots
Sample household survey	To understand agriculture and irrigation practices in the village at scale	122 landowning households Sample selection: variety in terms of location of lands vis-à-vis aquifers and canal commands 122 households (14% of the village total) As per the 2011 census, total land owned by these households was 21% of the net sown area
Village-level consultation in April 2019	To discuss the study with the village community	Around 50 participants in the village consultation
Dissemination workshop in September 2022	To disseminate the key findings of the study	Discussions about the study, and key findings

RAVANGAON: SOME BACKGROUND AND CONTEXT

Ravangaon village is part of Daund block, in the Pune district of Maharashtra; it is located 80 km southwest of the city of Pune, on the national highway that connects the cities of Pune and Hyderabad. This location means that the village has relatively good access to markets, employment opportunities, education and other facilities. The village has 856 households, most of whom belong to the Dhangar (Shepherd) caste. Although classified as Nomadic Tribes (NTs), Dhangars have been settled in Ravangaon for generations. Members of Scheduled Castes (SC) comprise 14% of Ravangaon's population, and some households belong to Other Backward Classes (OBCs) and General Castes. Although there are SC households that have land, many are landless and depend on wage work. For most households, agriculture is the main source of livelihood, though a few people are employed at nearby factories as contract labourers.

Sugarcane

Sugarcane is the main crop grown and irrigated in Ravangaon, and its political economy importantly shapes hydrosocial relations (Mollinga, 2014). The predominance of sugarcane in a relatively dry region is remarkable as it is a perennial crop with a high water requirement (1700-2500 mm through its growth cycle of 11-17 months). Farmers' preference for sugarcane is the outcome of a particular history (see Tozzi et al., 2022). In the late 19th and early 20th century, the British began to build water infrastructure in the rain shadow areas of the state mainly to provide employment and food; the investment in irrigation was thus a response to recurring famines and droughts. The uptake of the newly created infrastructure and water sources was low, however, with farmers using water only during dry spells to protect their food crops. To generate revenue and to justify its investment in water infrastructure, the Irrigation Department began to encourage the cultivation of more profitable and water-intensive crops. In this way, sugarcane gradually became the crop of choice in the 20th century, this single crop generating a large part of the British revenues. Sugarcane's profitability explains why much of it is grown in prime command areas, even where the average rainfall is between only 500 and 700 mm. Today, the cultivation and processing of sugarcane assumes an important place in Maharashtra's political economy, with sugarcane growers and sugar factory owners having formed strong alliances with politicians to protect their interests (Datye et al., 2004).

This is also true in Ravangaon. *The* Imperial *Gazetteer of India* of 1885 reports that Ravangaon village had less than 2 hectares (ha) of sugarcane; at that time, food crops dominated village farmland. Today, most of these local crops have disappeared to make room for sugarcane, the expansion of which has accelerated in the past decades. Between 2000 and 2015, the area under sugarcane in the Daund block doubled from 22% to 44% of the total cropped area and its share of the irrigated area increased from 29% to 68% (Government of India, Department of Agriculture & Farmers Welfare, n.d.). Sarika, a woman farmer in her late 40s*,* reflects on this shift, saying that,

> This is my natal as well as marital village. When I was young, we used to cultivate only half acre of sugarcane, as irrigation was limited. We sold our sugarcane to cane crushing units in the village. There used to be six such units in our village, and most people sold their sugarcane there. We used to cultivate food crops, mainly traditional and hybrid sorghum. Now with eight sugar factories in the area, most people cultivate sugarcane, with other crops like maize and onion as intercrops (Interview with Sarika, Ravangaon, 6 December 2019).

Most sugarcane growers are small and marginal farmers. Our Ravangaon household study showed that 79% of all households cultivate sugarcane, with many of them (39% in 2021/2022) not growing any other crop and only 7% cultivating *jowar* (sorghum). In conversation, farmers explained that they liked sugarcane because it was a low-risk high-gain option. The fixed prices set by the Central Government and the additional incentives from the state of Maharashtra make sugarcane a reliable income source. The presence of sugar factories in the village also makes it easy to obtain agricultural credits, including loans for new irrigation infrastructure, because loan repayments can be deducted from sugar factory payouts. Loans may also be provided through the village credit society, whose members usually have strong political ties with sugar factory owners. Sugar factories also arrange the migrant labour for harvesting and transport; for many farmers, this is important as they face difficulties mobilising labour at the village level. Farmers mentioned that sugarcane is a sturdy crop that can withstand delays in water supply; many also considered sugarcane to be a high status crop. As one farmer explained,

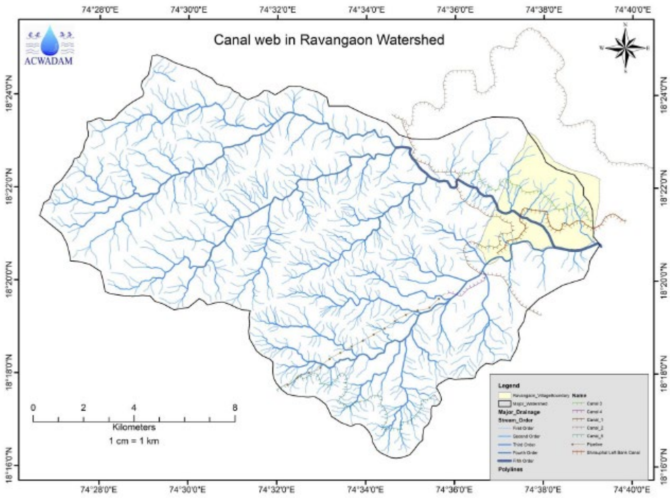
> The farmers who cultivate sugarcane over three-four acres of land and have a borewell drilled (…), have better and easier chances of finding a girl to marry their sons. There are several men over the age of thirty in the village, who are unmarried owing to a lack of (…) assets like sugarcane farming and individual borewells (Interview with Keshav, 2 August 2019).

Once farmers have ventured into sugarcane, it is difficult for them to opt out; they are forced to continue growing it by their political and financial dependence on sugar factory owners. A marginal woman farmer, Asha, noted that the decision to transition to food crops could not be taken on an individual basis; as she put it, "I can't shift to food crops unless other farmers do it, too. If my field is the only one with jowar or pulses then birds will not leave anything behind" (Interview with Asha, Ravangaon, 23 July 2021).

Public irrigation

As per the 2011 Census, the total geographical area of Ravangaon is 1452 ha, of which the net sown area is 1058 ha; of this sown area, about 500 ha is irrigated. Ravangaon is located in the drought-prone area of Maharashtra, with the Daund block receiving an average annual rainfall of only 477 mm, as measured over a period of 116 years (1901 to 2017) (Government of Maharashtra, Department of Agriculture. n.d.).

Figure 1. Location of Ravangaon in the watershed.



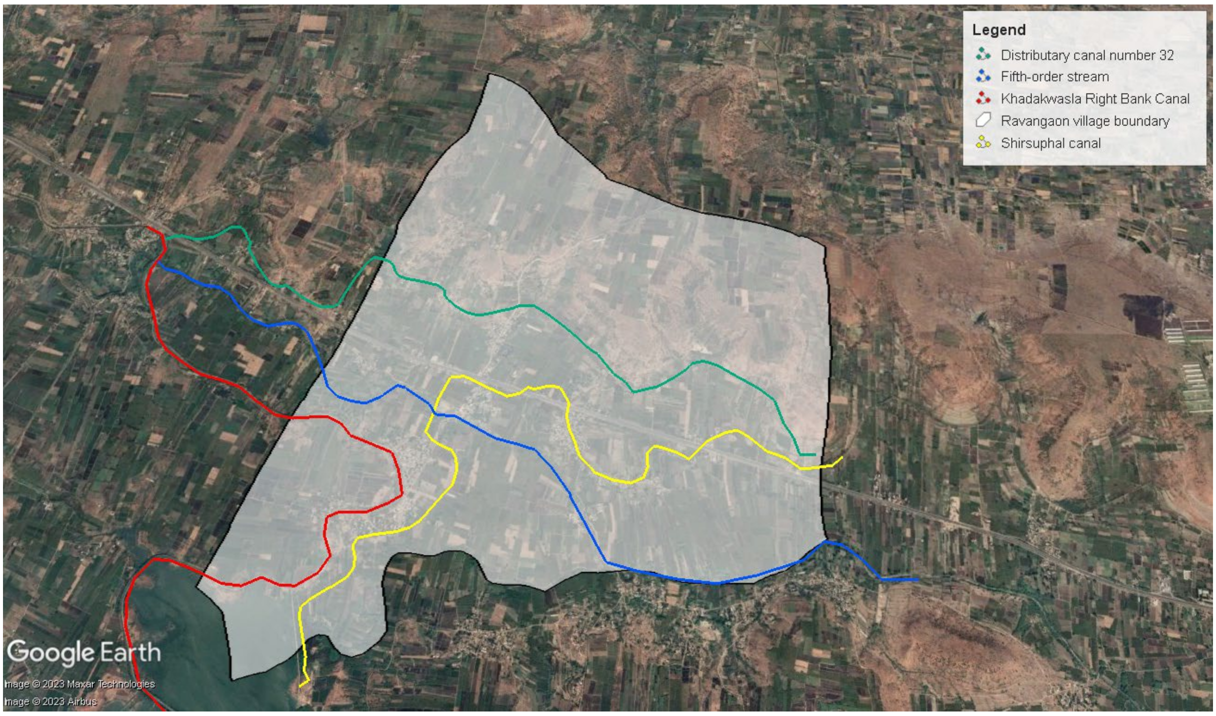
Ravangaon is strategically located at the outlet of the watershed. A fifth-order stream passes through the village, with a catchment of over 195 km^2. During monsoons, a large volume of water flows through this stream. In recent years, people have noticed that the stream runs dry immediately after monsoon rains, possibly because of the check dams that have been constructed upstream as part of state-sponsored watershed schemes.

Ravangaon is located in the command area of two distributaries that branch from the right bank canal (RBC) of the Khadakwasla dam, a major irrigation system that serves over 10,000 ha. The Khadakwasla project comprises four dams: the Temgarh (104 Mm^3), Panshet (301 Mm^3), Varasgaon (362 Mm^3), and Khadakwasla (55 Mm^3). The Khadakwasla reservoir was part of the British investment in irrigation in the 19th century, which they undertook as a response to recurring famines and droughts. Captain Fife, after whom Khadakwasla Lake was originally named, surveyed the area and recommended that a canal system be built from the Mutha and Nira rivers instead of spending effort on the smaller lakes and reservoirs that dotted the district. The Khadakwasla project was sanctioned in 1868, and the construction work that was carried out in 1876/1877 provided employment to many people in the area. Water for irrigation was first released in 1878. The old right bank canal (RBC) of the Mutha River from (then) Lake Fife serves Ravangaon and other villages. The left bank canal (LBC) of the dam largely serves the domestic water needs of Pune city and a few neighbouring towns, while also increasingly catering to the industrial area of the district. The 2019/2020 water audit report of the Khadakwasla irrigation complex in fact notes that almost 60% of the water is intended for non-irrigation uses, while the actual figure may be even higher (Government of Maharashtra, Water Audit reports 2003-04 to 2019-20). Ravangaon also benefits from the 19th century Shirsuphal tank (an artificially created lake). The construction of this tank was completed around the same time as was the Mutha canal that branches from Lake Fife. Its construction provided employment to people of the area during the severe drought of 1864. As reported in *The Gazetteer*, of the total command area of 1800 ha, about 300 ha was located in Ravangaon village. The Shirsuphal tank is now largely dependent on water released from the RBC of the Khadakwasla dam; its catchment area has diminished considerably due to several upstream water infrastructure projects. One minor canal branches out from the tank and irrigates about 235 ha in Ravangaon.

At present, distributary canal number 32 of the Khadakwasla RBC – which is also referred to as the New Mutha Right Bank Canal (NMRBC) and was built in the 1970s – passes through four villages, including Ravangaon. As per the data provided by the Water Resources Department of the Government of Maharashtra, the total command area of this distributary is 1069 ha. Ravangaon is located at the head of the distributary and 326 ha of the village are served by it. The local waterman – the person responsible for releasing and regulating the canal water at the farm level – reported that an additional distributary was supposed to be irrigating another part of the village but was destroyed several decades ago. The water from the RBC is released into the fifth-order stream that passes through the village. Together with the 235 ha that is served by the Shirsuphal tank, the total area commanded by public irrigation in Ravangaon is 561 ha.

A Google Earth map (Figure 2) shows the dense network of canals and the fifth-order stream that also receives surplus water from the Khadakwasla dam. The map indicates that a major part of Ravangaon's area benefits from public sector irrigation.

Figure 2. Map of the canal network in Ravangaon.



Source: Google Earth maps (n.d.).

Expansion of groundwater

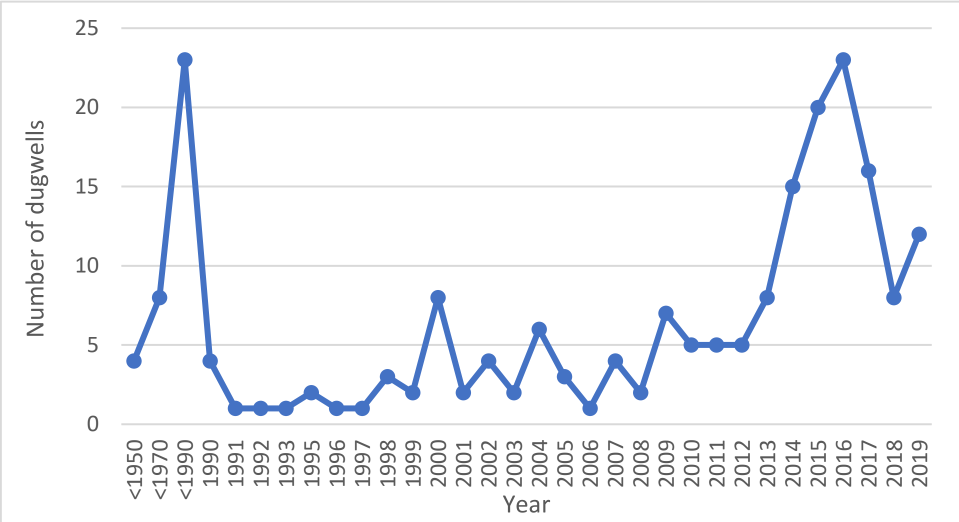
The last 10 years have seen a rapid expansion in the use of groundwater for irrigation. In 1870, there were just four dug wells in the village.[5] As a result of the mapping survey and the transect walks with villagers in 2019/2020, we arrived at a current total of 207 dug wells and 227 borewells,[6] although it is likely that we missed some. More than half (54%) of the borewells were constructed in the last 10 years. Most of the new wells are located in the command area of distributary canal number 32 and the Shirsuphal canal, although farmers have also taken advantage of the new possibilities for pumps and wells to start irrigating outside of the former command area, which accounts for the gradual expansion of the Ravangaon irrigated area. Figures 3 and 4 show the sharp increase in dug wells and borewells after

[5] *The Gazetteer* describes the wells that were used for irrigation as circular, 8 to 10 feet in diameter (2.5 to 3 metres) and 20 to 50 feet deep (6 to 15 metres). The water was lifted by a *mot* (a leather or iron container), which was operated by a pair of bullocks (Government of Maharashtra, 1885).

[6] Drilling borewells is easier than constructing dug wells as it requires less money, time and land.

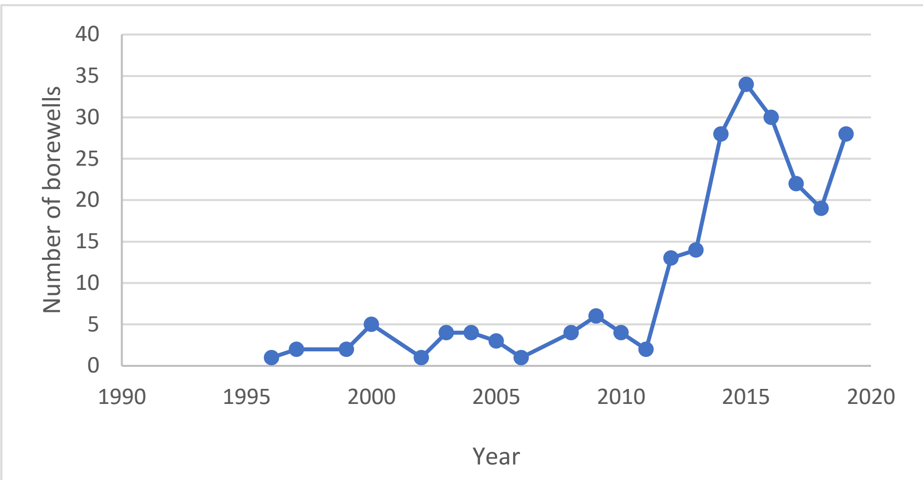
2010, which is when canal rotations began to decline from 5-7 to 3-4 per year. The temporal drops in the number of borewells that can be seen in Figure 4 happen in years when the rainfall is good and when enough canal water is released to allow farmers to recharge their dug wells and borewells.

Figure 3. Temporal growth of dug wells (N = 207).



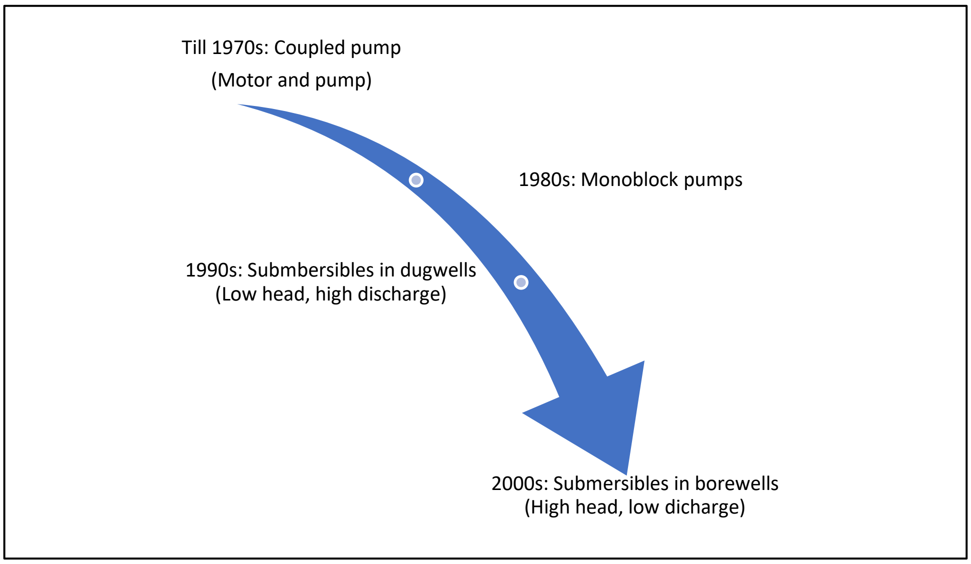
The first borewell was drilled in 1995 and had a depth of 45 metres. Over time, the depth of borewells gradually increased, till they reached 110 metres in 2018. This suggests that farmers in Ravangaon are increasingly drawing water from the confined deeper aquifer systems. Not all drilled borewells yield water, however, and some borewells only supply water for one or a few seasons and then dry up. Farmers then remove the motor from the old borewell and install it in a newly drilled borewell. Even when a borewell provides water for only a single season, however, farmers still think the expenses of drilling it are justified; their priority is saving the sugarcane crop. The cost of dug wells (US$4500-5000) is four to five times higher than the cost of drilling borewells (US$1000-1500). The low cost of borewells is mainly because the technology for drilling them is easily available and fuel is subsidised; dug wells, on the other hand, use costly human labour.

Figure 4. Temporal growth of borewells (N = 227).



Over the years, the source of the power for pumping water shifted from animals to diesel engines to electricity. Until the 1970s, farmers used coupled pumps (motor engines and pumps); however, with electrification in the 1980s, they started to instead use monoblock pumps. From the beginning of the 1990s, low head, high discharge submersible pump sets became common in dug wells, and today they are the most prominent dug well pumping device. Farmers with borewells used submersible pumps for abstracting water; these are generally high head, low discharge pumps. Farmers admitted that they could only afford to use pumps because they do not always pay electricity bills and because electricity is often subsidised; that is, some farmers constructed their own unmetered electricity connections to power their pumps, and electricity bills are also often waived by those with political power as a way to 'buy' political loyalty and support. This appears to have become less common in recent years, however, with farmers now even receiving retroactive electricity bills. To avoid high electricity costs, farmers are increasingly turning to solar-powered pumps, even though the power generated is often not enough to transport water across a long distance. Government subsidies are now available for their purchase. In 2022, we counted more than 50 farmers with solar pumps, a sharp rise from 2019 when only a few farmers had them.

Figure 5. Timeline of pump technologies for groundwater abstraction in Ravangaon.



Aquifer mapping

To better understand how the dense network of wells and borewells that we revealed through the well-mapping survey relates to groundwater dynamics, we engaged in a mapping of the aquifers. Aquifer mapping uses a combination of geologic, geophysical, hydrologic and chemical field and laboratory analyses to characterise the quantity, quality and sustainability of ground water in aquifers. Systematic aquifer mapping helps understanding the geology of aquifers, their hydrologic characteristics, as well as water levels in the aquifers and how they change over time. Such an understanding, in turn, is useful for monitoring groundwater extraction and use (Government of India, Central Ground Water Board. n.d.).

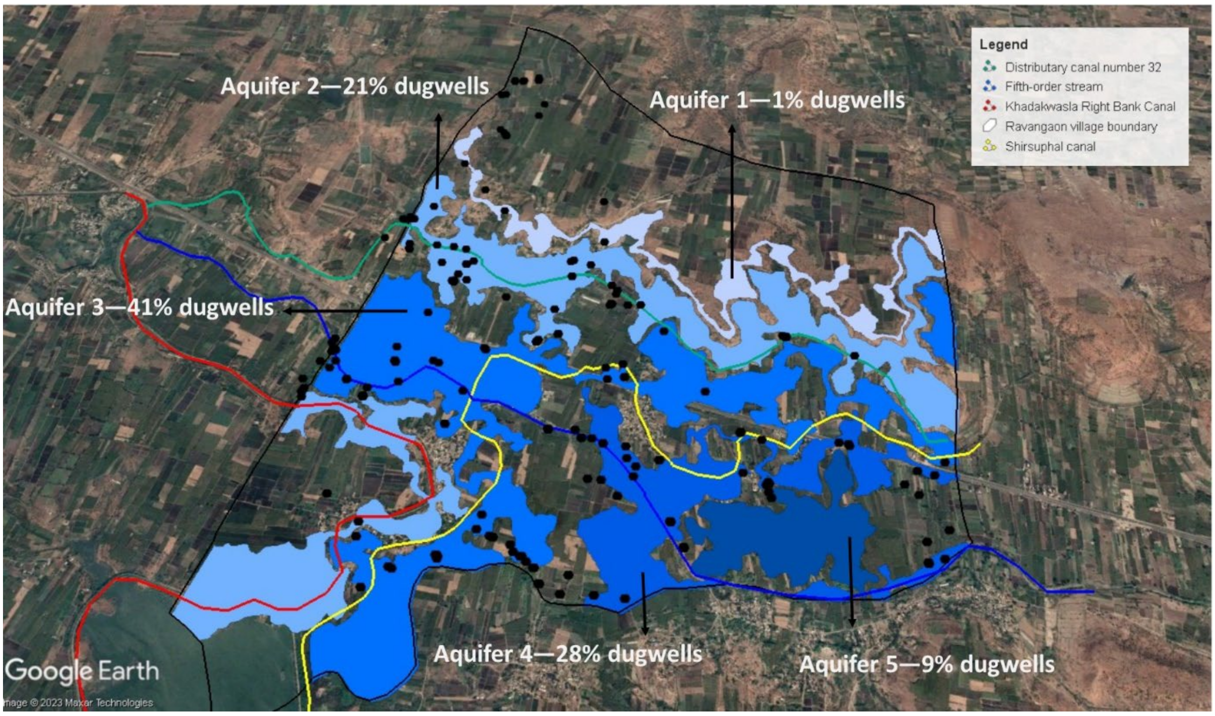
Our mapping of the aquifer, which was preceded by a geological study of the village, showed that there are five main aquifers within the village boundary. Geologically, they consist of two types of basaltic formations: compact basalt and vesicular amygdaloidal basalt. These five aquifers are separated by impermeable layers of rock. Each of the aquifers has a slightly different capacity for storing and transmitting groundwater, but storage is generally very limited. Table 2 shows the storage capacities of the different aquifers. Aquifers 2, 3 and 4 are the main aquifers within the village boundary; they have a comparatively high storage capacity.

Table 2. Storage capacity of aquifers within the village boundary.

Aquifer number	Storage capacity in cubic metres (m^3)	Storage capacity (millimetres)	Storage capacity (% of total capacity)
1	3759	<1	1
2	109,550	8	35
3	157,500	11	50
4	44,135	3	14
5	2455	<1	1

A limited storage capacity means that the aquifers transmit water but farmers need to use their dug wells to store it, using them as sumps. Farmers dig these wells in and around the command areas of the canals and the stream, which receive their water from the main canal of the dam.

Figure 6. Location of surveyed dug wells from well-mapping and aquifer survey.



Source: Google Earth maps (2022).

From canals to wells

According to farmers, one important reason for their preference for pumps and wells is the ever-larger intervals between canal water rotations. They remembered the 1990s, when there were eight or nine rotations a year; now, they told us, there are only three. Farmers attributed this to an increased competition over water, with ever more water being diverted to Pune city, to industries in the area, and to agriculture in other parts of the command area. The water audit reports[7] brought out by the Maharashtra Water Resources Department indeed show that around 60% of the water from the Khadakwasla complex is being used for non-irrigation purposes, that is, for domestic and industrial water needs. The reduction in the number of rotations means that the interval between one rotation and the next increases, forcing farmers to find alternative sources of water. Asha, a woman farmer in her mid-40s who grew up in Ravangaon and lives there still as a married woman, said that,

> Twenty-five years ago, there used to be water in the canal all the time, but it has substantially decreased over the years. Now we only get three rotations in a year. So, we have to invest in wells, and borewells and lifts. We often don't have enough money, so we take crop loans, or mortgage our jewellery, or sell the livestock (Interview with Asha, Ravangaon, 23 July 2021).

Sarika, another woman farmer, explains how the expanded use of wells is gradually making it ever more difficult to use flow irrigation; according to her,

> No one takes water by flow irrigation these days. People have not kept the sub-minor canals. They are full of grasses which led to water losses. The grass also made movement of tractors and bullock carts in the field difficult. The irrigation officials said they will get them cleaned, but that never happened. So, when the number of rotations decreased, farmers stopped maintaining the field channels. So for the last ten years or so, we have been using siphons to draw water from the canal (Interview with Sarika, Ravangaon, 6 December 2019).

Data from the Irrigation Department for the years 2015/2016 to 2019/2020 indeed shows that in most years there are only four or five water rotations. During drought years the number of rotations goes even further down, to only two or three. It is in these years that the number of dug wells and borewells also increases.

Table 3. Number of rotations for distributary canal number 32 from 2015/2016 to 2019/2020.

Year	Kharif	Rabi	Summer	Total rotations including kharif	Total rotations, rabi and summer
2015/2016	1	1	0	2	1
2016/2017	2	2	2	6	4
2017/2018	1	2	2	5	4
2018/2019	0	2	1	3	3
2019/2020	2	2	1	5	3

Canal water is accessed in multiple ways and is stored in wells that effectively function as sumps or storage wells. The reduction in the number of rotations has meant that the sump wells now get filled only a few times per year. This has prompted farmers along the canal to both increase the number of storage or sump wells as well as multiply the sources from which they lift or siphon canal water to fill them. Increasingly, farmers also invest in drilling borewells in order to tap into deeper aquifers and transfer from these into wells or ponds. As discussed earlier, the canal system is poorly maintained and the outlets are completely destroyed. Water can thus be accessed only through the ground or through direct lifts from the canals or the minor tank.

[7] For details refer to Water Audit reports from 2003 to 2020 https://wrd.maharashtra.gov.in/Site/1182/Water-Audit-Report.

PRACTICES OF ACCESSING, TRANSFERRING AND STORING WATER

Today, with the exception of a small area served by the Shirsuphal canal, all farmers have stopped making use of flow or gravity irrigation to irrigate their crops. They instead rely on individually owned wells and borewells as sources of irrigation water, sometimes combining these with other methods such as direct lifting (pumping) or siphoning of water from canals into their fields or into wells. An increasing number of farmers have even started digging wells close to the canal (or stream), sometimes buying small plots of land specifically for this purpose; this acts as an easy way to appropriate canal water through percolation and siphoning. Some farmers have also drilled shallow dug wells inside the Shirsuphal minor irrigation tank, allowing them to benefit from percolated water in summer when the tank is dry. Accessing water in this way entails engaging in negotiations with officials and making deals them. Farmers, for instance, need to convince the canal inspector to allow them to pump or siphon water directly from the canal, something that is not formally allowed. As one woman farmer explained,

> We have to give regular bribes to the water inspector. For every water rotation we have to give Rs300-500 (US$4-5) to them. Otherwise when 'the squad' comes to inspect then they will not warn us. A squad of officials visits now and then the minor irrigation tank in the village, to check what are the problems with the flow of the water, and then they cut our motor pumps. If we give them bribes, they warn us that the squad is coming, and we can remove our motor for the time being. If we don't give them money, then they will cut our connection, take our motor, and break our pipeline (Interview with Asha, 28 July 2019).

Farmers engage in similar shady deals with officials to obtain electricity at cheaper rates or to avoid paying electricity bills.

In this section, we focus more closely on how different farmers combine technologies, water sources and rules to secure their access to irrigation water. We do this by presenting the stories of five different farmers.

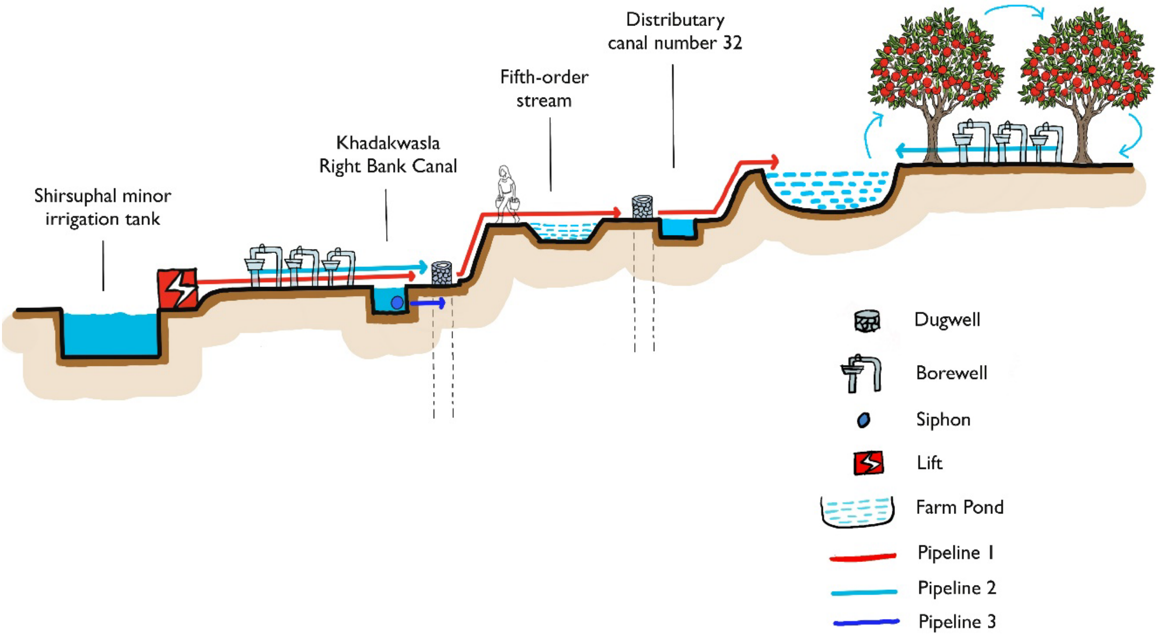
Vijay belongs to the Dhangar community. He has been politically active in the local village assembly. His family owns 8 ha of land outside of the command area. Before purchasing this land in the late 2010s, he had 2 ha of land located in the command area of the irrigation system. He decided to sell it, however, as it no longer had secure and stable water access and therefore yielded too little income to meet the needs of his joint family. Vijay's choice to buy a larger area of land with the money he had earned from selling his plot in the command area was also affected by the fact that his younger brother had yet to get married. Having a larger landholding, Vijay hoped, would improve his brother's marriage prospects. Since purchasing this land, Vijay has developed an intricate network of pumps, wells, pipelines and siphons to get water from the RBC to his new fields, where he is one of the few farmers to grow pomegranates[8] (Interview with Vijay, Ravangaon, 2 August 2019).

Vijay first constructed a dug well (dug well-1) in a small plot that he had purchased specifically for the purpose in the command area of distributary canal number 32. He then drilled five borewells in his field, three of which are currently working. As he still needed more water, he constructed one more dug well (dug well-2) and three more borewells near the village stream. These were constructed on the encroached village common land, which many farmers are using for this purpose. He also installed a siphon in the Khadakwasla RBC, using it to bring water to dug well-2. The distance from the siphon to the dug well is long, approximately half a kilometre (km), which is why water from dugwell-2 is first transferred to dugwell-1 before being transported to the field. To allow the dug wells to collect as much water as possible, Vijay wants to make sure that they are empty when the canal carries water. He thus

[8] At the time that Vijay purchased his new lands, several farmers were shifting from sugarcane to pomegranates, as the latter crop yielded a good price on the market. Pomegranates also require less water. At the time of our research, however, pomegranates had become less popular; prices had declined and the risk of pest attacks and weeds had increased the cost of pesticides and weedicides. In one-year cycle of pomegranate, weedicides are applied twice, and pesticides are applied twelve times, cost of which along with the fertilisers is around 610 USD.

also constructed a farm pond with a storage capacity of five million litres. In the summer of 2018, and despite this intricate setup, he still did not have enough water to irrigate his pomegranates. He thus decided to also lift water from the Shirsuphal tank into dug well-2, transporting it across an approximate distance of about 2 km. He uses PVC pipes of 13 cm in diameter to transport water. These are buried about a meter underground, making them difficult to steal.

Figure 7. Vijay's water infrastructure.



Source: Drawing by Cristian Olmos Herrara, co-produced by Rajendra Deshpande, Sneha Bhat, and Seema Kulkarni.

There are many farmers like Vijay who have developed networks of pipelines to transfer water. When they have to lay the pipelines through the lands of other farmers, as they often do, they need to negotiate with them. Those farmers through whose land the pipes are laid usually agree, as they too depend on the agreement of others to lay their own pipelines. Farmers make sure to lay pipelines when there are no crops in the field. If an existing pipeline is damaged during the process, then the farmer laying the pipeline must bear the cost of the repair. Vijay and others who lift water from the canal sometimes have disagreements with farmers who lift water directly from the tank, though no serious incident was reported. Most often there is an understanding among those farmers who can afford the required infrastructure.

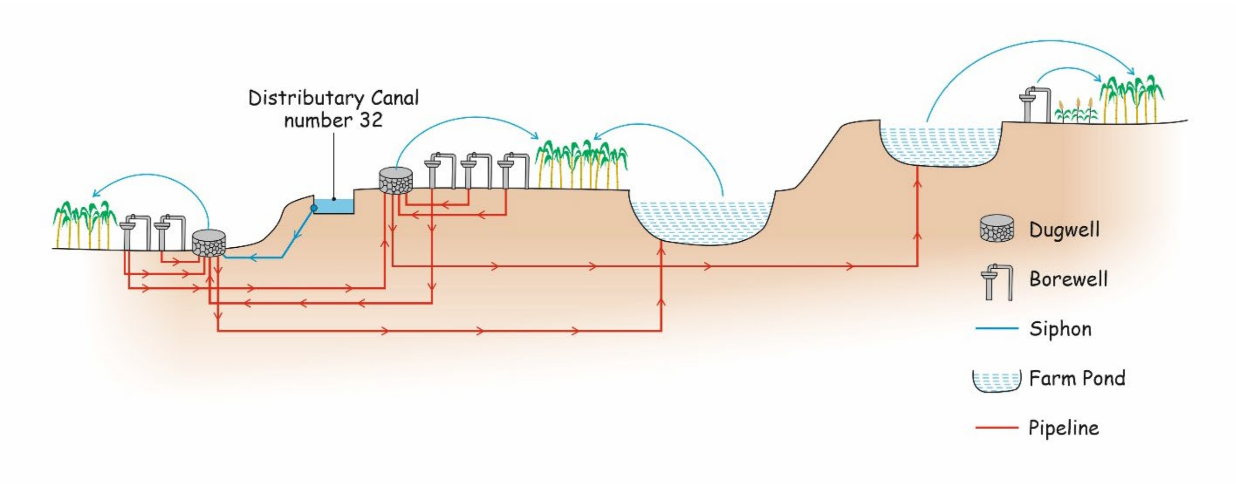
To develop his complex system of accessing, transporting and storing water, Vijay has invested around Rs5 million (US$60,000) over the last 10 years. This is in addition to the purchase of land for water, which cost about US$200,000. He mortgaged gold and took loans from multiple sources including the credit cooperative, the bank, and moneylenders. He used his position as a member of the local village assembly to negotiate access to larger amounts of credit. Doing this is much more difficult for most other farmers.

Vijay's story is about transferring water to land outside of the original command area. The story of Prakash, however, who also belongs to the Dhangar community, is one in which he and his family continued irrigating within the command area while also gradually expanding irrigation on land outside of it. Prakash's family has 7 ha of land, divided into three plots. One of these is in the command area of distributary canal number 32, and two of them are outside of the command area. Prakash and his family have bought the 4 ha of land outside of the command area in the last decade. Like Vijay, Prakash developed an intricate and interconnected network of dug wells, borewells and farm ponds to allow water to be accessed and stored, and then transferred to the different plots to supply the crop water requirements. He cultivates sugarcane and fodder crops. Apart from agriculture, the family also derives income from running a hardware shop in the village and from the salaries of two family members. These other sources of money helped mobilise the funds for investing in water infrastructure.

Table 4. Prakash's water infrastructure.

Plot number	Area (ha)	Location	Water infrastructure
1	1	In the command area of distributary canal number 32; the wells are recharged during canal rotations	• 1 dug well (dug well-1) • 2 functioning borewells from which water is transferred to both dug well-1 and dug well-2, depending on the need of each dug well • Siphon from distributary canal number 32 (200 metres) directly into the field
2	2	Outside of the canal command area, but close to the canal; this gives the location advantage of percolation from the canal Aquifer-2	• 1 dug well (dug well-2) • 5 horizontal borewells connected to dug well-2 • 3 functioning borewells from which water is transferred to both dug well -1 and dug well-2, depending on the need of each dug well • 1 farm pond (farm pond-1) into which water is transferred from dug well-1 and dug well-2 during canal rotations
3	4	Outside of the command area; the location is not geologically favourable for wells	• A farm pond (farm pond-2) into which water is transferred from dug well-1 and dug well-2 throughout the year, as that is the main source of irrigation for this land • 1 borewell

Figure 8. Prakash's water infrastructure.



Source: Drawing by Rajendra Deshpande, co-produced by Sneha Bhat and Seema Kulkarni.

Mahesh also belongs to the Dhangar community. His family's land is divided into four plots, three in Ravangaon village and one in the neighbouring village of Nandadevi. His lands in Ravangaon are located in the command area of the Shirsuphal canal. Until around 2003, Mahesh could irrigate lands with flow irrigation, making use of his rotational turns. Since then, however, canals have gradually deteriorated, making flow irrigation ever more difficult. This is why he has developed a system that combines siphons, wells and borewells. Mahesh shares the ownership of these wells and borewells with relatives who also farm and who have plots adjacent to his own. They thus share the costs as well as the water from the wells and borewells. Other farmers also engage in such sharing arrangements, the precise details and rules of which vary among farmers and also depend on the nature of their relationship with one another. One of the dug wells, for instance, is shared among three farmers, Mahesh, his brother, and a third farmer who is not related to them but who has adjacent land. Whenever an expense is incurred, it is divided in half, with one half borne by Mahesh and his brother and the other half by the third farmer.

Table 5. Mahesh's water infrastructure.

Land number	Area (hectares)	Location	Water infrastructure
1	0.27	In the command area of Shirsuphal canal, in Aquifer-4	• 1 borewell shared by 6 farmers. • 1 siphon from Shirsuphal canal directly into the field, 200 metres from canal to the field
2	0.36	In the command area of Shirsuphal canal, not favourable in terms of groundwater	• 1 dug well (dugwell-1) which is in a small nearby plot, shared by 3 farmers • 1 borewell, shared by 6 farmers • 1 siphon from distributary canal number 32, about 300 metres from the canal
3	0.27	In the command area of Shirsuphal canal, not favourable in terms of groundwater	• 1 borewell, shared by 6 farmers • 1 siphon from distributary canal number 32, pipeline extends from plot number two to plot number three

Mahesh owns 2 ha of land in the neighbouring village of Nandadevi. There, in the summer of 2019 (a low rainfall year), he invested in a lift from Shirsuphal tank together with five other farmers who owned adjacent land. This additional investment was required to procure enough water to irrigate their sugarcane for the three summer months, as their wells and borewells did not have sufficient water. They placed a motor in the tank, and when the water level of the tank receded they dug a small well inside the tank area; this provided them with additional water for a few more days. The farmers share a common pipeline up to a certain point, after which it branches off to their individual fields. Mahesh invested around Rs100,000 (US$1200).

The story of Kavita contrasts sharply with that of Prakash and Vijay. Kavita is a Scheduled Caste woman farmer and agricultural labourer who cultivates land that she jointly owns with her husband and his family members. Their 0.8 ha of land is located outside the command area of distributary canal number 32. Her family does not have the social, political or financial resources to lift, transport or store water. This means that she can only cultivate during the monsoons, when she grows jowar or millet. For the rest of the year, she depends on daily wages from agricultural and construction labour. Kavita is perhaps less indebted than Vijay and Prakash, but she does face the anxiety of having to find enough wage work to feed herself and her family throughout the year.

Suresh is a smallholder Dhangar farmer. He has one hectare of land in the command area of Shirsuphal tank, although the land no longer receives water through flow irrigation. To access water, he depends on one shared dug well and one shared borewell, both of which do not supply enough water to sustain water-intensive crops throughout the year. He thus recently had to abandon sugarcane when it did not survive the heat of the summer. His cropping pattern now depends on rainfall.

The five cases discussed above show that accessing water in Ravangaon hinges on the ability to mobilise the funds to invest in technologies and infrastructure, including dug wells, borewells, siphons, pipelines, ponds and (solar) pumps. This ability, importantly, is a function of political connections; these are needed both to obtain loans (including from sugar factories) and to leverage government schemes for farm ponds, solar pumps, drip irrigation, pipelines, etc. Vijay's case exemplifies this. He is part of the Gram Panchayat and he has very close connections with people in the credit cooperative who helped him with procuring loans for water infrastructure. Accessing water also hinges on buying and selling land to acquire a smart combination of plots. Those with least access to funds and with fewer political connections, like Kavita and Suresh, are forced to entirely abandon the cultivation of water-intensive commercial crops such as sugarcane. Even those with the necessary capital and connections, however, need to continuously engage in practices of political, technological and financial jugaad in order to be able to continue farming; they need to constantly be shifting plots and water sources in order to maintain the level of water security that is needed to grow sugarcane or other crops that earn enough to justify the huge investment and to allow for the repayment of loans.

DISCUSSION AND CONCLUSIONS

In Ravangaon, like in many command areas of India's public canal irrigation systems, farmers' increased use of dug wells and borewells signals as much a shift in how water is accessed and distributed as an increase or intensification of water use. 'Public water' is water that is captured, transported and distributed thanks to public investments in canal infrastructures; it is meant to support the public good. The net effect of the expansion of wells in Ravangaon, however, is that this public water is now increasingly diverted into interconnected private systems of dug wells, borewells and farm ponds. This prompts a de facto individualisation of water access as well as a de facto subsidisation of those farmers who already are relatively more successful, thereby sharpening water-based inequities and disparities (see Srinivasan and Kulkarni, 2014; Kulkarni, 2018). The particular characteristics of aquifers collectively shape how this process is unfolding. The aquifers in Ravangaon can transmit and transport canal water, but they have little storage capacity. The term 'conjunctive use' is perhaps not the most accurate here, as it suggests that farmers combine groundwater with canal water. In fact, canal waters percolate and seep through the aquifer and farmers then collect, transfer and store it in their wells for eventual use on their farms.

The state-supported political economy of sugarcane is key to explaining why this happens. On the one hand, state- and national-level policies encourage everything that increases profits per drop of water; this is part of an overall strategy of economic growth that hinges importantly on the intensification of agriculture. On the other hand, members of the political class have forged close connections and alliances, or indeed sometimes overlap, with sugar mill owners. The political and economic prioritisation of sugarcane is not likely to change in the near future, given that its economic importance is increasing in tandem with the growing interest in its by-products and in its use for ethanol production (Lee et al., 2020). This means that there will continue to be strong political and financial pressure on farmers to continue growing sugarcane, even in water-stressed regions of the state. Growing this crop makes farmers vulnerable to the volatility of markets for food and agricultural inputs. Already now in Ravangaon, many households face difficulties in repaying loans. Incomes, after debts are settled, are often barely enough to meet direct needs. This is why many women also try to grow some subsistence crops or engage in backyard dairy or poultry activities; indeed, it is often such activities by women that sustain the daily needs of households. The incomes from commercial agriculture are thus effectively freed up to repay debts, to pay for the next season's inputs, and/or to enable further investments in water-related infrastructure.

In addition to the water requirements of sugarcane and other commercial crops, the expansion of groundwater in Ravangaon is also closely linked with the growing insecurity of canal water. Many farmers are choosing to substitute dependence on fewer and less-reliable canal rotations with individually owned pumps and wells. These indeed offer a significant level of autonomy and control, making farmers less dependent on coordinating with other farmers and canal operators to devise and implement rotation schedules. The flip side of this increase in individual autonomy and water security is a reduction in the collective care of water and its distribution. Because they no longer rely on flow irrigation, farmers have less incentive to clean and maintain the minor canals. This is becoming a self-reinforcing spiral, for if minor canals are not well kept, flow irrigation becomes difficult if not impossible; this, in turn, forces more and more farmers to find other ways of accessing water. Because there is less need for collaboration and collective investment, existing mechanisms of sharing and caring for each other may also be crumbling. Shah refers to this as replacement of the "irrigation community" by a "scavenging irrigation economy" (Shah, 2011: 80). This was predicted as long ago as 1919 by Harold Mann, who was Director of Agriculture in the Bombay Presidency. According to Mann,

> Following a great concentration of effort, capital and water on one single crop (…) we have created conditions of things which are very risky for all but the most financially stable of the cane growers. A year's lack of success places them in the hands of financiers, from which they can only hope to escape by growing again the same crop. In the meantime, the expenses required to get a first-class crop has been getting greater and greater and hence the chance of a man [sic] who once made anything by a brilliant success from any particular crop has become less and less (cited in Tozzi et al., 2022).

The situation is thus that, with public waters being increasingly accessed through private networks, socio-economic inequities are widening. Only a few farm households succeed in generating a reasonable farm income; most others struggle to make ends meet. At the same time, the ecological and health impacts of the intensification of agriculture are becoming ever more apparent, including salinisation and decreased water quality. It has become more important than ever to ensure that public investments in water are directed to supporting the longer-term well-being of people and ecosystems, instead of only supporting the short-term profits of those who are already better off. It has never been more difficult, however, to regulate, plan and account for where, and to whom, water is flowing. This extreme difficulty is precisely because of how public canal waters partly 'disappear' underground, effectively allowing them to elude existing forms of control. This is not just happening in Ravangaon, but also in many other command areas of India's public irrigation systems. How then to plan for, or help bring about, a more sustainable and just water future?

Shah (2011) suggests merging canal systems with emerging private water networks as a way of learning to live with the present reality of conjunctive use. This includes managing irrigation canals as the recharge canals that they have in effect become, thereby making smart use of underground water storage potential. By learning from what farmers are already doing, perhaps they can be enlisted as partners in a process by which irrigation agencies carry out the more limited role of delivering bulk water to pre-designated points in the command area, with farmers then organising themselves to pay a volumetric water charge (ibid: 84). This is an interesting suggestion and is in line with the 'tinkering' approach that we proposed. One could argue that what is already happening is moving in that direction; that is, farmers are entering into informal agreements with canal inspectors, paying them to be allowed to take water directly from the canal. Formalising such arrangements may help to better plan and account for how public waters are distributed; however, it does little to safeguard the longer-term sustainability of the aquifer and may further worsen distributional inequities.

The questions that therefore remain are how to ensure that waters are equitably shared and how to ensure that their future availability (and that of the livelihoods and ecosystems that depend on them) is not compromised by current uses. Finding answers to these questions is all the more difficult when there are few shared incentives to care for either the aquifer or each other. While our analysis does not yield an easy solution, the activities and experiences of ACWADAM and SOPPECOM do suggest that there are two important components of a path to more sustainable water governance. The first is a sustained critique of the state- and national-level prioritisation of so-called high-value water-intensive crops. Both ACWADAM and SOPPECOM, often together with other activist groups and critical researchers, actively engage in such critiques through, for instance, their involvement in high-level debates. The second component of a more sustainable path is the long-term engagement with, and support of, local *experiments* (tinkering) of farmers and communities in their efforts to co-develop more sustainable and less water-intensive farming practices (based on, for example, agro-ecology) and new forms of collective action around water. In this regard, the workshop that was organised to present and discuss the findings of this study with members of the village community was promising. Many of those present acknowledged that current irrigation practices were quite unsustainable and there was a broad consensus around the need to transition away from the monocropping of sugarcane. Farmers articulated the need to diversify their cropping basket and to grow sugarcane only on a small part of the farm as a cash crop. There was also a lot of interest in better understanding the aquifers and in aligning irrigation and cropping patterns with their longer-term sustainability. This study thus forms only the start of a gradual process of joint learning and indeed tinkering. There is no guarantee of success; it is clear, however, that if there are indeed successful outcomes they will hinge on the anchoring of the process in real people and real problems.

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