The multiple uses of water derived from managed aquifer recharge systems in Kenya and India

Abstract

'Multiple-use services' (MUS) takes into account the fact that households use water for both domestic and for productive uses. This paper is the first to determine how managed aquifer recharge (MAR) systems are a form of MUS. Two cases were studied in India and in Kenya. In the Kenyan case, sand dams are the form of MAR, and in India check dams and infiltration ponds of various scales are used. Through observations, interviews, and water quality data, it is possible to describe how the communities access the water from these infrastructures in multiple ways for different uses, according to their water needs and the characteristics of the different access points. MAR involves harvesting rainwater and retaining run-off water into the dry season thus increasing the amount of available water and enabling diversification of water uses. It should therefore be considered as an option by water managers aiming to develop water resources meeting both the domestic and productive needs of communities.

INTRODUCTION

'Multiple-use services' (MUS) is an approach that takes into account the fact that households use water for both domestic and productive uses, and indeed that there are many different productive uses for water (Adank 2006). Although some water supply programmes formally adopt MUS principles nowadays (van Koppen *et al.* 2008), there is still a recognition that MUS chiefly happens in 'self-supply' situations where households end up managing their water supply rather than relying on communal or municipal services (Adank 2006; Hall *et al.* 2014). Three categories of MUS are: 'domestic-plus', which is the supply of additional water to the household for productive use; 'irrigation-plus', which add-ons to irrigation supplies that make it possible to use water for domestic or other productive uses; and 'MUS-by-design' where a participatory process is used to match available water sources to users' needs and priorities (Hall *et al.* 2014).

Managed aquifer recharge (MAR) processes aim at intentionally enhancing water infiltration into aquifers providing storage for subsequent recoveries or environmental benefits. The MAR types include surface-spreading methods such as infiltration ponds, excess irrigation, well injection, in-channel modifications (e.g. check dams and sand dams), induced bank filtration, and enhanced storage (subsurface dams) (Sprenger *et al.* 2017). Although predominant in Europe, MAR has particular utility in semi-arid areas where water supplies are precious (Gale 2005) and thus is spreading worldwide (Stefan & Ansems 2018).

There have been a few studies where MAR has been considered as part of a MUS approach. For example, Meijera *et al.* (2006) studied an irrigation canal in Sri Lanka and found that water leakage from the canal recharged the aquifer and, therefore, increased the amount of water available in shallow wells dug next to the canal which is used for domestic use and in home gardens. This water is preferable due to the high salinity and fluoride content of the deeper boreholes. Sakthivadivel (2007) states that there are over 500,000 tanks in peninsular India that are providing groundwater recharge to multiple-use wells nearby or to even dig in the tank bunds or tank floors. Senzanje *et al.* (2008) studied the multiple uses of water in four communal dams in Limpopo in South Africa and found that for drinking and cooking, farmers preferred using water from boreholes and that this water was also indirectly from the dams as the dams recharged the groundwater. The examples highlight the importance of holistic community-led intervention approaches.

Gale (2005) stresses the need to consider the water use priorities of communities when planning MAR schemes, and a few studies have listed out the different types of benefits MAR can bring to communities, but without formalising it as a MUS approach. For example, Lasage *et al.* (2008) listed the benefits of sand dams in Kitui County in Kenya to include domestic use, irrigation, and brick production. Parimalarenganayaki & Elango (2016) found a check dam in Tamil Nadu in India is used for agriculture, bathing, cattle watering, and recreation.

The formulation of this manuscript was prompted by a series of observations made during a hydrogeological study in Kenya from May to July 2017 (Quinn *et al.* 2019). During that study, visits to three sand dam sites occurred almost daily to collect water level and quality data. The researcher also observed the daily activities of the communities using the sand dam and in particular, how different water abstraction methods were applied for different uses.

In this paper, we explore in detail whether MAR systems could help to facilitate MUS. We take two case studies from Kenya and India. Both are characterised by MAR systems from which communities access the water in multiple different ways for multiple different uses, according to different factors including water quality and where the water source is located. By understanding how their water needs map onto the characteristics of the different access points, this study can help water managers from different sectors to collaborate to better integrate MAR into water resource plans to meet both domestic and productive needs in rural communities.

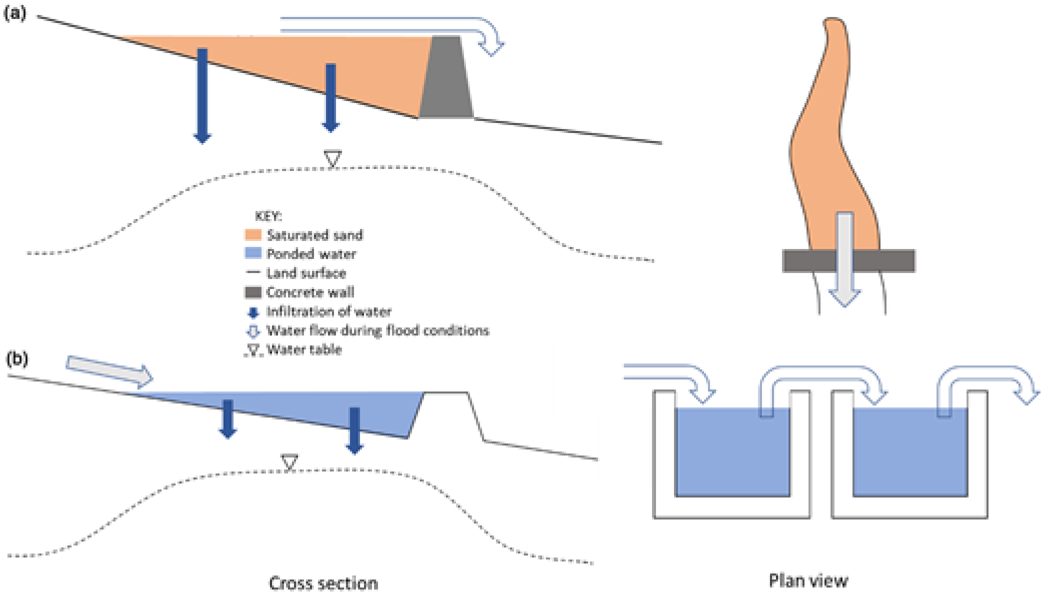
METHOD

Sand dams in Makueni County, Kenya

In Makueni County, Kenya, there are two rainy seasons: the first between March and May (long rain) and the second between November to December (short rain), with very little rainfall in between; overall the area is classified as semi-arid (Gichuki 2000). To ensure the sustainability of water supplies into the dry season, sand dams have been constructed. A sand dam is a concrete wall constructed across a seasonal riverbed. When the river is inflow in the rainy season, sand and water accumulate behind the dam wall and settle to form a small sand aquifer (Lasage *et al.* 2008). Although water is retained in the trapped sand, it also leaks into the surrounding aquifer and hence sand dams can be classified as an MAR (Quinn *et al.* 2019). This is illustrated in Figure 1. There are over one thousand MAR systems Kenya that are used to supply water to rural and to urban areas and they are starting to be disseminated elsewhere in the world (Ritchie *et al.* 2021). For this study, three dams were selected from those constructed by the Africa Sand Dam Foundation (ASDF), and had to (a) contain sand and water at the end of the rainy season, and (b) be within 30 km of the researchers' base at the town of Mtito Andei, which allowed daily visits to the sand dams for monitoring. The dams (herein identified by ASDF numbers) were all constructed over a week with the sand deposited during the year after the dam was built. In all of them, a hand pump is located near to the wall to allow the abstraction of water from a covered well. At Dam 106, there is pooled water located directly downstream of the dam wall. Upstream of the study area, the river channel branches off to several narrower tributaries; open wells used for small-scale household farms are located along these branches. There are no permanent scoop holes. About 600 m upstream, there is another large sand dam with a hand pump. At Dam 167, a stream runs from the rock located under the base of the dam wall. A scoophole is positioned about 300 m upstream of the dam. Dam 211 is situated on the tributary of a larger river with a saline low flow throughout the dry season. No pooled water or leakage was observed downstream of the dam wall.

Locals reported that the dam had originally leaked but that the remediation work completed the previous year had stopped it. A scoophole is located relatively close to the dam wall. Approximately 700 m upstream of the dam there is another smaller sand dam without a hand pump.

Figure 1



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(a) Diagram of a sand dam in cross-section and plan views. (b) Diagram of a Chauka in cross-section and plan views.

The village of Laporiya, Rajasthan, India

Laporiya is a village located in the Dudu block of Rajasthan, at 90 km from Jaipur, the state capital. As farming is the predominant activity, water scarcity and droughts are common, making the livelihoods of inhabitants difficult (Dasgupta *et al.* 2014). Traditionally, pearl millet, sorghum, maize, moth bean, pulses, gram, cotton, paddy and wheat are grown in Rajasthan, and goats, sheep and cows are bred for dairy and wool (Planning Commission 2006). During drought years, agriculture can be hard and, with the lack of work, many young people migrate to cities or other states seeking better living conditions. Water quickly became a critical resource and rainwater harvesting was proposed by village residents as a solution to fight against water scarcity. In Laporiya, this started with the rehabilitation of a broken traditional reservoir, which grew into a new water management model (Ashoka 2013). Gram Vikas Navyuvak Mandal Laporiya (GVNML), an NGO created by a villager, Laxman Singh, who started to mobilise the inhabitants to work together and launched a campaign for change. After several years of work, the organisation implemented a Chauka system. A Chauka consists of rectangular and shallow three-sided compartments constructed with earth bunds (maximum depth of 23 cm). Built-in succession, Chaukas collect rainwater that infiltrates into the ground and recharges the aquifer (Figure 1). In a parallel paper, the authors have evaluated that each year the Chauka system causes an additional 5% of rainfall to be recharged into the aquifer, compared to that of the recharge on a similar area with no Chaukas (Yadav *et al.* 2004 under review). In addition, Chaukas attenuate land erosion, and retained water allows the village to be more resilient to drought and creates a better environment for the cattle and goats to pasture on (Dasgupta *et al.* 2014). This rainwater harvesting system was designed by Laporiya's inhabitants and, while acclaimed locally, it provoked some disapproval from the Indian Government (Ashoka 2013). The Government encouraged the construction of contour bunds and disdained the villagers when they said it was not appropriate for Laporiya. Inhabitants observed that bunds in the region sped up the water flow, directing it to the stream, instead of slowing the flow and allowing water to percolate into the ground (Anand 2017). However, after witnessing the failure of contour bunds in surrounding villages and gaining the support of Anupam Mishra, a member of Gandhi Peace Foundation and figure of authority regarding traditional water systems, Laporiya's residents decided to continue with their idea, and now have a model for more than 50 villages in their vicinity (Ashoka 2013). The village also has ponds of various scales (smaller nadis and larger talabs) and check dams that are used both for aquifer recharge and surface water storage, contingent on the permeability of the underlying soil. These are common throughout Rajasthan, although the exact number is unknown; in neighbouring Gujarat, it is estimated to be 75,000 (Dashora *et al.* 2018). Finally, there are open wells and boreholes with hand pumps.

Bias in site selection

We must acknowledge the sampling bias of the work. The two locations were selected as they were field sites for hydrological studies where MAR seemed to be working well. They were not selected to be either typical or good MUS examples. Laporiya is an award-winning example of local water management and is not typical of villages in Rajasthan. The sand dams were selected to be 'successful' and there are others in the vicinity that contain either no sand or no water at the end of the rainy season. At Laporiya where formal interviews were conducted, there was bias in the selection of the respondents and interview translation as this was done by the implementing NGO. Some more negative views on the system may have been missed or lost in translation. In Kenya, data was collected through serendipitous observations rather than formal interviews so some of the views of the community, and alternative water uses at other times of year may have been missed.

Data collection: interviews and observations

In Kenya at Dam 167, detailed observations were made of all abstraction activities on two separate days: one approximately 1 month into the dry season, the second after 2.5 months into the dry season; both recorded in a fieldwork diary. When these observations were presented to the implementing NGO, they were surprised by the wide range of different uses of the water from sand dams, beyond what they had previously documented. They realised that they had been underestimating the benefits that communities realised from the sand dams. This prompted the research team to conduct a more formal study in the second site, Laporiya.

In Laporiya, semi-structured interviews were conducted with different stakeholders in July 2019, as shown in Table 1. The interviewees described what each water source was allowed to be used for and how the sources were managed. Farming and non-farming village residents were interviewed to get a broad perspective on livelihoods. The results from these interviews were interpreted applying a qualitative analysis of a speech with NVivo 12 (QSR International, 2018). Each interview was transcribed and encoded following the themes identified for the interviewee's category and then analysed through a grounding theory analysis (Corbin & Straus 1990) to identify patterns (during, between, and after interviews) following the 'data analysis spiral' described by Creswell (2013). As opposed to linear approaches, qualitative data analysis is a circular process of collecting, organising, describing, interpreting, and finally representing data. Every interview, recording or other pieces of data must go through these steps and be integrated into the circle process. The themes were identified by a recurrence of apparition within the different interviewees' speeches. After a theme was identified, exhaustive research of the subject was performed, meaning that the theme was broached with all participants until no new information on that theme was collected. The circular approach and exhaustive research should catch all relevant information and data of the interviews (Corbin & Straus 1990).

Table 1

Number of interviews and focus groups conducted in Laporiya

Respondent type	Number of respondents interviewed	Number of focus groups run
Farmers	20	
Village residents	5	
GVNML (local NGO)	1	
Ground Water Board	2	
Village committees		2
Neighbouring village committee members		1
Gram Panchayat		1
Women's groups		1

After obtaining consent from the interviewees, their answers were recorded before being transcribed into the software NVivo 12. The interviewees were given a week for withdrawal, a period after which their recording would be entirely anonymised and processed, thus impossible to identify and remove from the software. Ethical approval was obtained for the research from the Cranfield University Research Ethics Scheme, no. CURES/8272/2019.

Data collection: water quality

To sample water to measure its quality, in scoop holes, water was first scooped with a sterile cup until the water appeared clear. For covered wells, water was pumped for 30 s before taking water samples. For open water sources, including all types of ponds, a sterile cup was used to skim the sample from the water's surface. Finally, for open wells, the local method of water abstraction was used (plastic bucket attached to a rope) to collect samples. The collected water was transferred to 125 mL sterilised plastic bottles. Conductivity was measured with handheld probes (Fisherbrand Traceable Conductivity/TDS Meter Pen). In Kenya, two samples were tested at each abstraction location at two sampling timepoints (May 2017 and July 2017), and the mean was taken. In Laporiya, a single value was taken at each of two sampling timepoints (September and October 2019). A mean was calculated across all sample time points and sites, which were 21 open wells, one check dam, four nadis, and one pond.

The measurement of TTC was performed with portable DelAgua testing kits in Kenya only, which use the membrane filtration method (University of Surrey 2004). If two valid colony counts resulted i.e. both Petri dishes were readable, and neither exceeded 100 counts (the number at which counting inaccuracies are likely to be introduced), the count from the larger volume sample was used. If two equal volumes were taken, the mean was used. The data presented here are a mean of all the values collected at duplicate at two sampling timepoints (May 2017 and July 2017 in Kenya).

RESULTS

Sand dams in Kenya

[Table 2](#) shows what water from each source was used for, and the associated water quality data. It is clear that people choose water for drinking based on taste (salty vs sweet). For example at Dam 167, the handpump is not used for drinking, while the scoop hole is. Conductivity measured at the scoop hole was lower than the WHO limit for the conductivity of 1.5 mS/cm (WHO 2004) as opposed to the handpump which is over the WHO limit. However, the consequence is that people are drinking water that is of higher microbiological risk, although no health data was collected during this study. In addition, the time taken to scoop water increased throughout the dry season. During the observation on 9 June 2017, on average 4.6 L were abstracted per minute however this decreased dramatically towards the middle of the season to 2 L/min on 20 July 2017. The majority of abstraction from both the handpumps and scoop holes from all the dams occurs in the morning by women and in the evening by children who have returned from school.

Table 2

Uses for each water source and associated quality data for sand dams in SE Kenya

		Handpump	**Scoop hole**	**Dow**
Dam 106	**Uses**	• Household cleaning • Personal hygiene • Drinking (start of the dry season only)	Not present	• •
	Conductivity (mS/cm)	1.1		1.4
	TTC (counts/100 mL)	*0.25*		Too r
Dam 167	**Uses**	• Household cleaning	• Household cleaning • Drinking • Cooking • Personal hygiene	• • • •
	Conductivity (mS/cm)	*3.7*	1.1	*3.6*
	TTC (counts/100 mL)	*22.5*	*100*[a]	*47.5*
Dam 211	**Uses**	• Household cleaning • Personal hygiene • Cooking • Drinking (start of the dry season only)	• Household cleaning • Personal hygiene • Cooking • Drinking	No p
	Conductivity (mS/cm)	*2.3*	0.4	
	TTC (counts/100 mL)	*4*	*75*	

The values in italics are over WHO (2004) guidelines.

[a]One of the July measurements was too many to count.

Two of the hand pumps were locked and only community members who had contributed both financially and physically to the dam construction were allowed to have a key. In the case of Dam 211, this led to the construction of a scoop hole not previously present before the construction of the sand dam. Beyond the padlocking of the pumps, abstraction was not formally controlled by the community.

Sand dams are primarily designed intended to provide water to communities for domestic and irrigation purposes (Maddrell & Neal 2013). In these dams, however, there is a variety of productive uses, including fishing, brick making, and washing services which have never been reported before. Informal conversations with community members revealed that the water ponded under the dam was one of the most valued benefits of having a sand dam.

Laporiya

There are two types of ponds: the talabs, and the naadis; talabs are the biggest. The three talabs are worshipped as they are of utmost importance for the life of the village. A ritual of brotherhood is renewed each year in November after a foot march through the village when villagers take an oath to protect and take care of the talabs (not polluting the water with household waste and participating in the repairs of the bunds). Talabs work mostly quite well, but buildings and walls can block the water draining from the surrounding land into the talabs. These structures are mostly constructed by the government and many of the villagers want to remove them so the talabs can work better. Two of the talabs are designed for groundwater recharge as well as animal watering. The third one, the biggest, can also be used for irrigation, only if it has sufficient water and approval from the village committee. Once the pond is full, connected water canals are opened. First, the lands closer to the pond are irrigated, and then the further ones, following the gravity flow in the water canals. Sometimes lands furthest from the pond do not receive water every year. Conflicts surrounding irrigation from the pond are solved at a village meeting where elders of the village from each caste gather and discuss to solve a problem. Sometimes, lower castes do not have a representative, but they have a say in the decisions and can send someone in the meeting to defend their interests. The farmers with fields closest to the talab want to stop any abstraction (even by themselves) and even deepen the talab so that it would recharge their wells better (although this might not be hydrologically true).

Nadis are smaller ponds, designed mainly for animal watering, as they are constructed in areas with impervious soil, but groundwater recharge happens in small quantities. There are several nadis in the village, located in the common pasture lands to ensure easy access for all animals. These are primarily for goat and cattle watering. Sometimes the government comes to construct nadis, but in the past, they have done these on permeable soil so the water was not retained. The local NGO, GVNML, has better local knowledge in this respect and is frustrated that they cannot communicate better with the government.

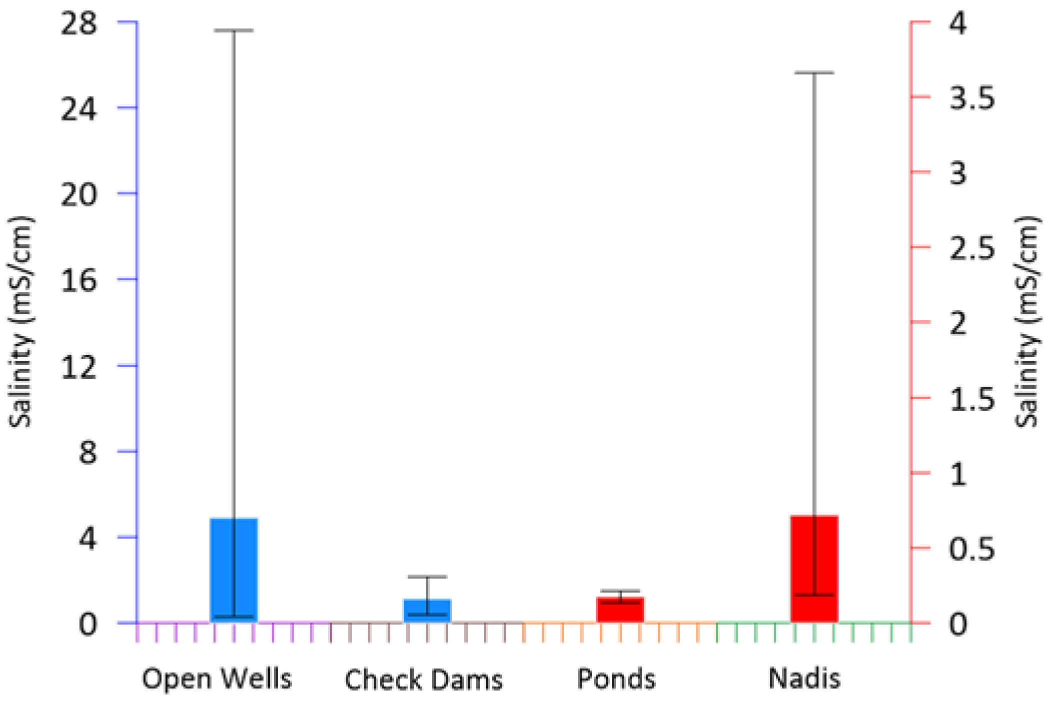
Four check dams were constructed on the seasonal stream surrounding the village, and the water they store is used for irrigation and to recharge the downstream wells, further away from the village's ponds. Notwithstanding, water is pumped occasionally for irrigation, mostly during dry spells, or when water is available in winter for the cash crops. Farm ponds, mostly privately owned by groups of farmers, were constructed on the outskirts of the village, far away from the talabs and nadis, for irrigation purposes.

Roof rainwater harvesting structures were installed in some houses. These collect rain and store it in underground water tanks for later use, principally for domestic purposes, and occasionally for animal watering.

A public water supply is also available, but not always reliable ('a few hours every other day' according to an interviewee). This water supply comes through a pipeline from the Bisalpur dam located in the Dudu block, around 110 km from Laporiya. An estimated 60–70% of the houses in Laporiya have a tap connection. This pipeline was constructed by the government and local maintenance is done by a person designated by the Gram Panchayat, the representative of government at a village level. The water tariff is 100 rupees/month (approximately US$1.40).

There are common open wells, located on the village's pasture lands. These lands are owned by the Government, but villagers have the right to use them. The common drinking wells are designated for domestic drinking use only, although a limited number of people can take water from them. Access to these wells is regulated by caste so that higher castes and lower castes use separate wells. The wells are identical but separated by less than 100 m. There are also private open wells, owned by individuals, however as shown in Figure 2, these are usually producing water that is too salty to drink so are used for irrigation. The large error bars in Figure 2 indicate the huge range in salinity encountered. The common drinking water production wells (one is shown in Figure 1) are the only non-salty water sources in the village, alternatively, people buy water from tankers that they store in underground tanks.

Figure 2



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Salinity measurements in the different water sources in Laporiya, a mean taken from water samples from September and October 2019. The blue bars refer to the left and (blue) axis and the red bars refer to the right hand (red) axis. Please refer to the online version of this paper to see this figure in colour: http://dx.doi.org/10.2166/washdev.2022.177.

The Chaukas collect rainwater that percolates into the ground and, during intense rainfall, overflowing water will run off to fill a nadi. Chaukas are built in the village's pasture lands; they increase the soil moisture so grasses and trees grow which can be grazed by animals. The grazing has strict rules: after the monsoon season, the big cattle, such as cows and buffaloes, have first access to the grazing area, then the smaller animals like goats and sheep. However, some villagers would like the rules to be applied more strictly.

Table 3 summarises responses from the interviews to show the uses of each water source. According to GVNML's representative, the objective is to capture every drop of rain falling in the village. This has led to water availability all year, even in winter, when the demand is the highest (rabi seeds, or winter crops, are usually the cash crops, like wheat). All drinking, domestic, and animal water needs have been met by the system for the last decade, and these are prioritised by common agreement between the villagers. However, interviews revealed that bad monsoon years lead to less water availability, not always enough for all lands owned by the farmers. In this case, they usually reduce their cropping areas or switch to less water-demanding crops, depending on the water levels observed in the wells.

Table 3

MAR structures and their primary and secondary water uses in Laporiya

Structures	Domestic use (cooking, bathing, washing)	Drinking	Irrigation	Animal watering
Pond	√	×	√	√√
Nadi	×	×	×	√√
Check Dam	×	×	√√	√√
Chauka	×	×	×	×
Open well	√√	√	√√	√

√√ – Primary use.

√ – Secondary use.

× – No use.

DISCUSSION

In these two examples, it seems that MAR has facilitated the retention of water close to the community, instead of letting seasonal rain drain away to bigger rivers and eventually reach the oceans. This additional water resource is providing water for income-generating activities such as laundry services, brickmaking, fishing, and multiple crops per year, with the minimum impact on existing groundwater resources. Providing water for productive use through deep-well drilling can strongly deplete groundwater levels as has been observed in the agricultural regions of India, China, and the USA (Aeschbach-Hertig & Gleeson 2012). Although the data presented here only documents the current situation without comparison to before the construction of the MAR structure. Lasage *et al.* (2008) did a study of the impacts of sand dams 10 years after construction with an additional control community with no sand dams and found measurable increases in farmers' income, achieved partly through diversification of activities. In Rajasthan, the demand for the Chaukas to be replicated in other villages is a testament to the impact it is having (Ashoka 2013). Sand dams have also been replicated in thousands across Kenya and in 12 other countries across the world (Ritchie *et al.* 2021).

The more surprising finding is the way different water abstraction points are used to supply water for different purposes. While the water is all coming from the same shallow aquifer, the abstraction method seems to depend a lot on the location of the intended use. For example, motorised pumps in open wells supply water for irrigating nearby fields. Similarly, there is no point in trying to pump and in carrying water for animals that can easily walk themselves to a pond. In neither location are drinking troughs provided which collect run-off water from handpumps so that animals can drink, as is recommended in MUS systems (van Houweling *et al.* 2012; Hall *et al.* 2014). Domestic water is usually sourced close to the house; the salinity also has a big control on which abstraction point is used, over and above any microbiological contamination risks (Quinn *et al.* 2018). It is unknown how aware the water users are of the risks of drinking water from unprotected sources.

The extent to which abstraction of water for different uses is regulated is considerable in Laporiya and happens somewhat in Kenya with locked handpumps. In Laporiya, the strict regulation and respect engendered for water seem to contribute to the success of the system, for example ensuring the most efficient use of water, with irrigation water only being allowed for winter crops in years of plenty, large animals feeding at the Chauka fed pastures first and protection of the talabs. Taking a comprehensive perspective on water use and claims over water resources is termed as water tenure approach and is advocated by the FAO (Hodgson 2016). Hutchings *et al.* (2016) made a similar observation in Bihar, India, where indigenous communal practices of good upkeep resulted in better environment, safeguarding individual household wells.

The location of water strongly determines the uses, even if the source and infrastructure themselves are neutral. There is potential for planners working in domestic and productive uses to collaborate on the same water resources and ensure water is available for multi-purpose use. This has been documented in Limpopo, South Africa (van Koppen *et al.* 2020) and together these examples provide a blueprint for future collaborative water planning and building on community-scale realities.

CONCLUSIONS

The two studied MAR systems have evolved to provide the communities with multiple uses of water. Overall, MAR is harvesting rainwater and retaining run-off water into the dry season thus increasing the amount of available water and enabling diversification of water uses. Water that needs to be carried to the house for domestic purposes may be preferentially sourced from close to the house even if the microbial quality is compromised. Wells for irrigation will be constructed close to the fields and will benefit from recharge and form the MAR structures.

Water managers who are keen to either formally adopt a MUS approach, or who are otherwise keen to increase community livelihoods by increasing water availability should consider if MAR is an option. Some structures require a specific type of geography, like sand dams which need seasonal rivers carrying a high sediment load, and a rocky riverbed on which dams can be constructed. However, surface-spreading methods can be applied more ubiquitously, where there is a shallow aquifer.

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