CRANFIELD UNIVERSITY

MATTHIEU CARRIERE

Impact of Rainwater Harvesting in Rural Rajasthan: An Assessment

SCHOOL OF WATER, ENERGY AND ENVIRONMENT
Water and Sanitation for Development

MSc
Academic Year: 2017 - 2018

Supervisor: Dr Alison Parker
Associate Supervisor: Dr Kristell Le Corre Pidou, Dr Basant Yadav
September 2018

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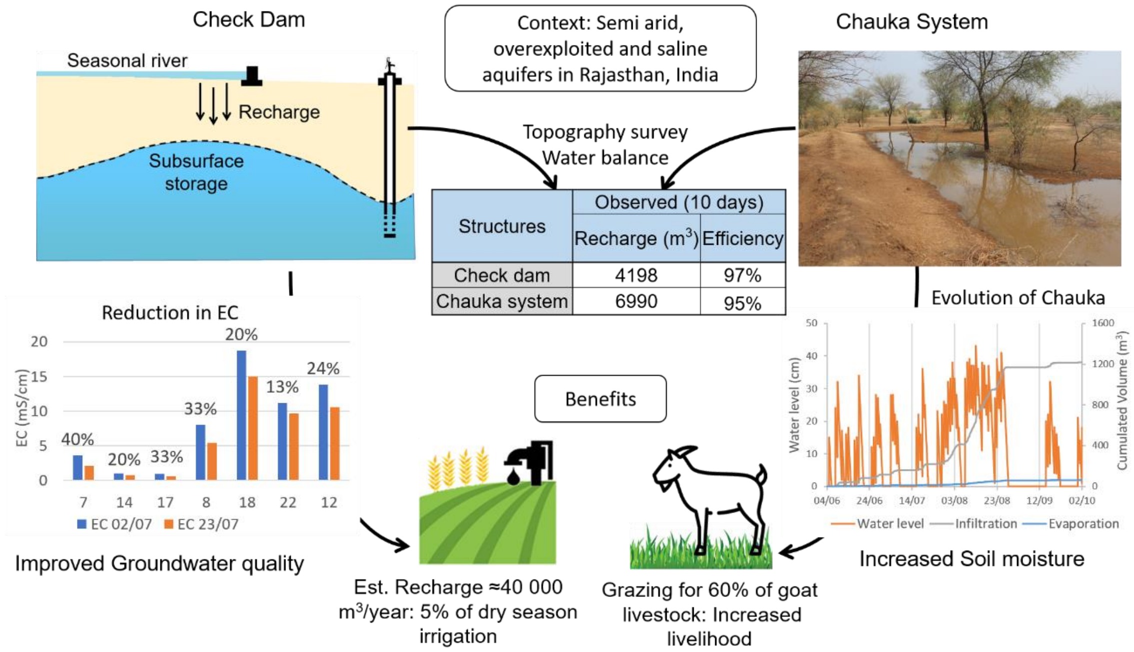
This thesis is submitted in partial fulfilment of the requirements for the degree of Master of Science.

Graphical Abstract



Abstract

The Green Revolution and the associated boom in groundwater use for irrigation have led to increasingly depleted aquifers in several parts of India. Rainwater Harvesting structures have been heavily promoted by state and federal governments as a Managed Aquifer Recharge technique, to increase the proportion of the abundant monsoon run-off that percolates. However, their impacts on their environment and on the communities they serve are not properly understood. This study focused on two different structures in a village facing water shortages, fluoride contamination and salinity issues: a check dam and a series of chaukas (small enclosure made of earthen dykes). It intended to assess their effects on groundwater level and quality as well as on livelihoods. Surface water balances conducted during the early days of the monsoon showed high infiltration efficiencies ranging from 95% to 97%, with a decreasing trend. Due to their large surface and small capacity, chaukas are unlikely to have any effect on aquifers. However, their primary benefit is to increase soil moisture, which provides grazing for 60% of the village's goat livestock. The check dam infiltrates an estimated 40 000 m^3 during an average monsoon, which supports about 5% of the dry season agriculture. Water quality improved, with salinity being reduced by 13% upstream of the structures, and up to 40% in their vicinity. Fluoride levels are lower near the structures, though still above the 1.5 mg/L guideline value for drinking water. The studied structures showed modest but still noticeable local impacts, but their connections with upstream and downstream areas, as well as the effects of the numerous ponds in the village remain to be investigated.

Keywords: Rainwater Harvesting, Managed Aquifer Recharge, Semi-arid area

Acknowledgements

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List of Abbreviations:

CGWB	Central Ground Water Board
EC	Electrical Conductivity
FAO	Food and Agriculture Organisation
GVNML	Gram Vikas Navuyak Mandal Laporiya
MAR	Managed Aquifer Recharge.
NASA	National Aeronautics and Space Administration
RWH	Rainwater Harvesting
TIN	Triangulated Irregular Network
UN	United Nations
WHO	World Health Organisation

Impact of Rainwater Harvesting in Rural Rajasthan: An Assessment

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The Green Revolution and the associated boom in groundwater use for irrigation have led to increasingly depleted aquifers in several parts of India. Rainwater Harvesting structures have been heavily promoted by state and federal governments as a Managed Aquifer Recharge technique, to increase the proportion of the abundant monsoon run-off that percolates. However, their impacts on their environment and on the communities they serve are not properly understood. This study focused on two different structures in a village facing water shortages, fluoride contamination and salinity issues: a check dam and a series of chaukas (small enclosure made of earthen dykes). It intended to assess their effects on groundwater level and quality as well as on livelihoods. Surface water balances conducted during the early days of the monsoon showed high infiltration efficiencies ranging from 95% to 97%, with a decreasing trend. Due to their large surface and small capacity, chaukas are unlikely to have any effect on aquifers. However, their primary benefit is to increase soil moisture, which provides grazing for 60% of the village's goat livestock. The check dam infiltrates an estimated 40 000 m^3 during an average monsoon, which supports about 5% of the dry season agriculture. Water quality improved, with salinity being reduced by 13% upstream of the structures, and up to 40% in their vicinity. Fluoride levels are lower near the structures, though still above the 1.5 mg/L guideline value for drinking water. The studied structures showed modest but still noticeable local impacts, but their connections with upstream and downstream areas, as well as the effects of the numerous ponds in the village remain to be investigated.

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Word Count: 7986 words

1. Introduction

Groundwater has become a source of water of critical importance with about half of the freshwater abstracted in the world coming from aquifers (Morris et al., 2003). The United Nations (UN) has estimated that about two billion people rely on groundwater for drinking purposes (UN World Water Assess Programme, 2003). The increased use of groundwater for agriculture in the past decades also dramatically increased food security and livelihood for billions of people (Shah et al., 2007).

India is particularly dependant on groundwater: its use has increased exponentially since the 1950s, soaring from 20 km^3/year to 251 km^3/year in 2010 (Food and Agriculture Organization (FAO), 2016; Shah, 2007), making it the world's greatest groundwater abstracter, surpassing the USA and China combined (FAO, 2016). It is estimated that India generates 9% of its GDP from groundwater abstraction (Mudrakartha, 2007). As it is more flexible and reliable than the public water service, 85% of the rural population and 60% of the irrigated agriculture have become dependent on groundwater. This trend has been bolstered by decreasing capital costs and generous public energy subsidies (World Bank, 2010). Because of this ever-increasing use of groundwater, the Central Ground Water Board (CGWB) classified 16% of India's aquifers as overexploited and an additional 3% as in a critical state (2015). Sheetal (2012) reported local water table level drop by up to 16 m between 1980 and 2010, while Sarah et al. (2014) mentioned, in several states, decline rates of 1 to 2 m/year since 2000. Such declines impact profoundly small-scale farmers relying on groundwater for irrigation (Singh et al., 2002; Zaveri et al., 2016).

As signs of aquifer over-exploitation started to accumulate in the 60s, Managed Aquifer Recharge (MAR), or Artificial Recharge, emerged as a way to alleviate some of the pressure on the groundwater resources (Sakthivadivel, 2007). The UN Environment Programme (1998) defined it as "*the planned, human activity of augmenting the amount of groundwater available through works designed to increase the natural replenishment or percolation of surface waters into the groundwater aquifers*".

In India, where rainfall patterns are highly variable, rainwater harvesting (RWH) has been used for centuries. Applied to MAR in India, the principle is to store a fraction of the vast volume of run-off generated during the monsoon, increasing its residence time and allowing it to percolate to depleted aquifers. It has received growing attention from both governmental and civil institutions and was streamlined in the 90's (Sakthivadivel, 2007). In the latest version of its Master Plan for Artificial Recharge to Ground Water, the CGWB (2013) ambitions to build a total of 11 million recharge structures, totalising a recharge capacity of 85.5 Billion cubic meters per year. This would account for 34% of the total groundwater abstraction in India in 2010 (FAO, 2016).

Many different structures can be built for RWH in arid to semi-arid environments. Check Dams (small dams typically built, in MAR application, across ephemeral rivers) are one of the most common, with the CGWB (2013) aiming at building almost 300 000 of them. Very localised solutions also exist, such as the Chaukas in Rajasthan, a system developed by a local community organisation, Gram Vikas Navuyak Mandal Laporiya (GVNML). A Chauka is a small enclosure, usually about 2 000 m^2, built across a gently sloping area by placing earthen dykes on three sides. Figure 1 shows the layout of a typical Chauka. They are designed to hold up to 22cm of water when full that slowly infiltrates in the soil and are built in series so that each one overflows in the next one. Excavation trenches are kept to increase infiltration. Practitioners consider that the main hydrological impact of chaukas is to increase and maintain soil moisture rather than recharging the aquifer themselves. This increase, combined with seeding, provides the community with grazing areas for several months a year, which increases livelihood. Additional benefits include erosion control, increase in biodiversity and improved living environment (GVNML, 2007).

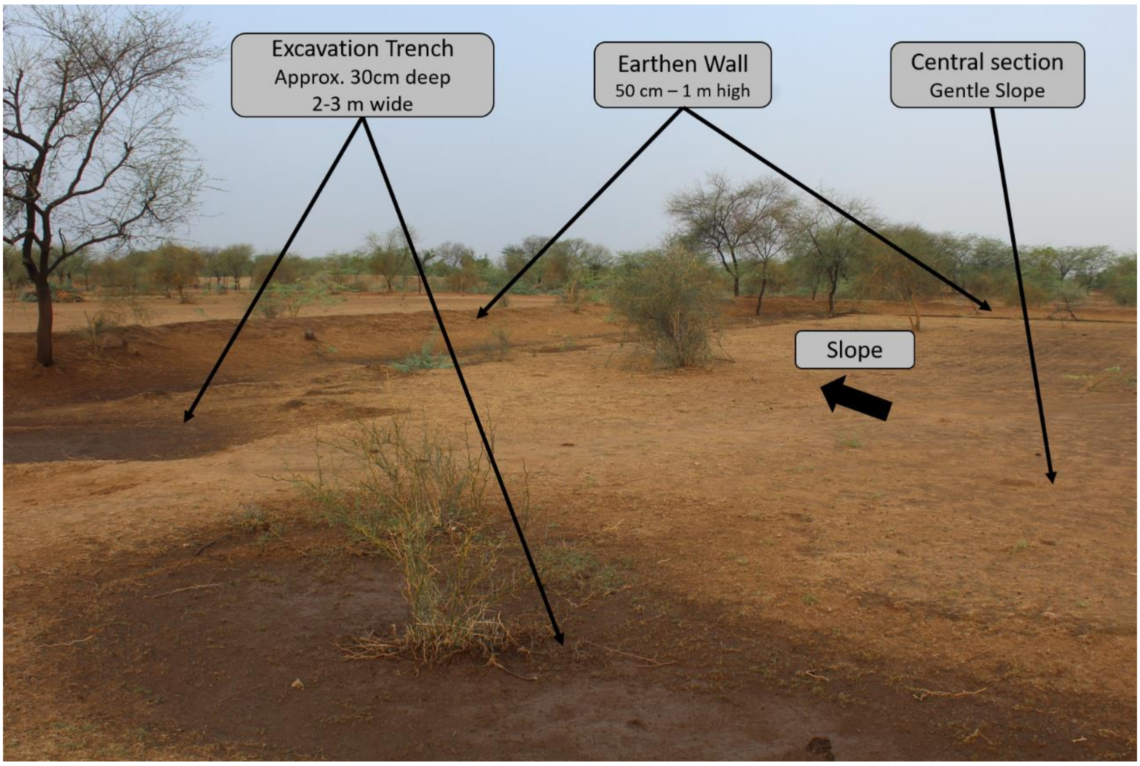

Figure 1: Typical chauka layout

Despite the extensive implementation of RWH structures for MAR in India, referred to as the "Groundwater recharge movement" (Sakthivadivel, 2007), further scientific research is necessary to fully understand the impacts of such structures on their environment. A growing number of studies investigated the ability of the most common RWH structures, such as check dams and infiltration ponds, to infiltrate water into the ground. Many researchers concluded that RWH's efficiency (the proportion of impounded water that actually infiltrates) was typically around 60% (Boisson et al., 2014, 2015; Massuel et al., 2014; Parimalarenganayaki and Elango, 2015, 2018), which contrasts with the 97% estimated by the CGWB (Dhiman et al., 2011). Muralidharan et al. (2007) showed using tritium tracers that check dams could increase rainfall infiltration from 5%-8% under natural conditions to 27%-40%. However, at watershed scale and depending on the intensity of rainfall, RWH structures may have a negative impact because of enhanced evaporation due to water being impounded for longer periods than under natural conditions. These researches remain scarce compared to the number of existing structures and focus mainly on hard-rock aquifers.

Other critical topics have been much less studied. A literature review by Renganayakiparimala and Elango (2013) showed a globally positive impact of check dams on groundwater quality, reducing the concentration of toxic ions by providing a dilution effect. However, Boisson et al. (2015) point out that MAR can enhance the effects of anthropogenic contamination, and may also increase rock-water interaction. Fluoride contamination, mostly geogenic, is of particular importance in India, with 19 out of the 29 Indian states having reported fluoride levels above the World Health Organisation (WHO) guideline value of 1.5 mg/L (Dhiman et al., 2012). Bhagavan and Raghu (2005) confirmed the diluting effect of RWH for fluoride in Andhra Pradesh. However, Brindha et al. (2016) showed mixed impacts depending on groundwater levels, and simulations by Marie et al. (2014) yielded both accumulation and decrease, depending on the period: no consensus has yet been reached.

Few researchers have investigated the socio-economic impacts of RWH structures. A review of the existing papers (Renganayakiparimala and Elango, 2013) highlighted increased livelihoods thanks to a strengthened and more reliable irrigated agriculture, and to a lesser extent increased animal grazing. Women also spend less time fetching water, but potential inequalities in water distribution require an integrated approach to ensure communities' adhesion. Chaukas have never been studied in the published literature, and as they operate on a much smaller scale than typical RWH structures, little is known about their behaviour and impacts.

Two RWH structures, a chauka system and a check dam in Laporiya, Rajasthan were studied for three weeks at the beginning of the rainy season. In this study, their impact on their physical and human environment was evaluated: their recharge capacity was quantified, the potential beneficial impact on water quality was investigated and their role in the water and livelihood system of the community was defined.

2. Material and Methodology

2.1 Description of the study area:

Laporiya is located within Rajasthan, the driest state of India: 91% of the water used for drinking is abstracted from the ground (Dashora et al., 2017). Almost two-thirds of the state's aquifer are classified as overexploited, which amounts to 45% of India's total (Dhiman et al., 2012). The most important source of groundwater recharge in Rajasthan is rainfall, of which 90% falls during the monsoon, between June and September (Yadav, et al., 2016). Rainfall in Laporiya is 493 mm per year and is subject to important interannual variations, with a standard deviation of 205 mm (Singh et al. , 2012). The area has been classified as semi-arid, as over a year, rainfall represents less than 50% of potential evapotranspiration (Von Maltitz et al., 2018). Laporiya's aquifer is included in the overexploited section of Rajasthan.

Laporiya is a village of 1,764 inhabitants in Jaipur's district, where agriculture is the primary source of livelihood for 87% of the workforce (Ministry of Home Affairs, 2011). GVNML has been conducting work with the local population for decades, including social mobilisation, supervision of water management and livelihood programs and upkeep of the chaukas.

May 2014 data from the National Hydrograph Stations shows that the area experiences groundwater contamination. Results up to 4.8 mg/L of fluoride and 56 mg NO_3/L of nitrate have been measured within 20 km of the site (Yadav et al., 2016). These values are above the WHO guidelines of 1.5 mg/L for fluoride, and 50 mg NO_3/L for nitrate (Gordon et al., 2008).

The chauka system covers an area of 0.247 km^2 of which 60% is occupied by the 61 individual enclosures forming the system (Figure 2). Three chaukas, shown in colours, were selected for detailed study.

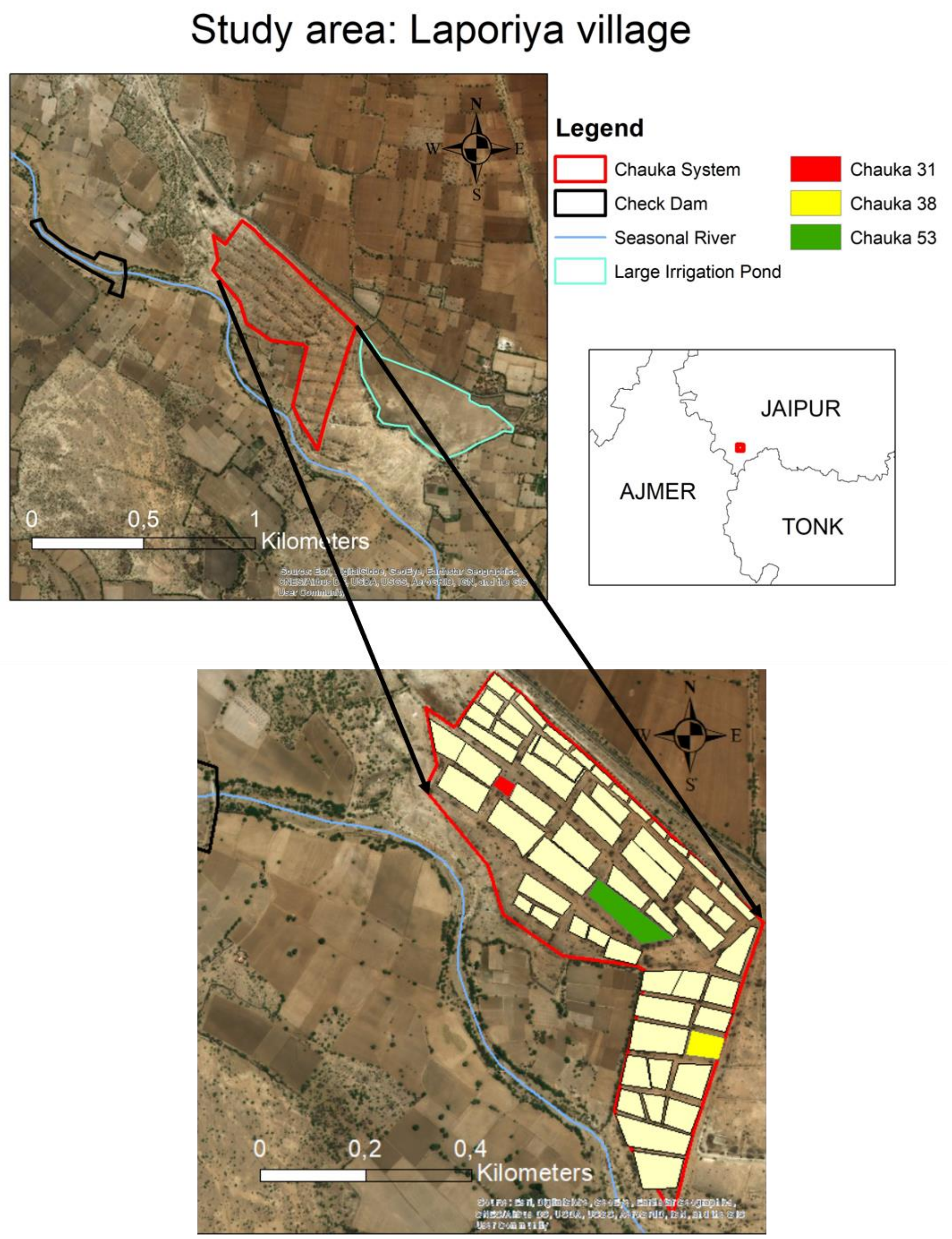

Figure 2: Map of the study area

The check dam, located on an ephemeral river, has a crest 38.5 m long and 1.70m high and controls an area of roughly 0.03 km^2. (shown with the 'Check Dam' item in Figure 2) up to 500m upstream. Under the supervision of GVNML, several ponds were created within the village boundaries to store water, which were not directly studied.

2.2 Data collection

2.2.1 Field Measurements

A topographic survey was conducted using a dumpy level (model Topcon AT-F6) coupled with a Garmin GPSMap CS76X unit. The density of elevation points was adapted to the variation in topography: in the check dam more were taken near the wall where the surface was more irregular. In the chaukas, the dykes and the excavation trenches were thoroughly surveyed, while the more regular central section required fewer data points.

Water depths were regularly measured in the structures after rainy episodes, using iron sticks as marks. Water levels were measured in open wells, using a Pocket Dipper (Groundwater Relief, 2014). Precipitation data were acquired from GVNML, which monitors daily a plastic rain gauge in their Laporiya office, 2 km away from the site. Evaporation rates were measured using a metal evaporation pan.

2.2.2 Social Surveys

People living near the structures were surveyed using a pre-tested, anonymous questionnaire. Water sources and uses in the village were determined, as well as the uses and benefits of the RWH structures, particularly of the chauka system. Participants were also asked about perceived water quality issues, as well as water management in the area, and alternate sources of water. Farmers using groundwater were asked specific questions to better assess their use of irrigation and its seasonal variation. The questionnaire can be found in Appendix A. 39 households were surveyed throughout the village, representing about 23% of the village population. Due to time constraints, and lack of formal household lists, haphazard sampling was used to select the households for interview, under the supervision of GVNML staff. Location and times were varied, to minimise potential biases (Sapsford, 2007). GVNML staff assisted with translation.

More in-depth interviews were also conducted with the director of GVNML. The role of the organisation in the community, their projects and their knowledge of local hydrology and water quality issues were discussed.

2.2.3 Chemical Analysis

26 samples were taken from open wells, boreholes, impounded rainwater and the public water supply on July 2nd. Three weeks later, seven samples were taken from the same set of points to measure the impact of the early monsoon on water quality. Samples were tested on the field for different parameters, namely Dissolved Oxygen, pH, temperature, ORP using a Hanna HI98196 multiparameter probe. Electrical Conductivity (EC) was measured using a Fisherbrand Traceable Conductivity meter pen (all measures were taken with a 20°C reference).

A Palintest 7100 photometer was used with Palintest tablet reagents to perform chemical analysis on the field for Nitrate, Nitrite and Fluoride. Some samples were out of range (for nitrate particularly) and required dilution, which was done with triple-distilled water.

2.3 Data Analysis

2.3.1 Topography

Triangulated Irregular Network (TIN) models were created after projection of the elevation points on the WGS-1984 UTM 43N coordinate system. Small adjustments (less than a meter) to some point coordinates were made based on field observations and measures when the precision of the GPS unit was not sufficient. The surface and volume of water impounded for different water levels were computed using the Raster Calculator and Zonal Statistics tools (with a one-centimetre step).

The watershed of the area was computed using the Hydrology toolbox of ArcMap 10.5, based on a digital elevation model produced by the Shuttle Radar

Telescope Mission (version 3), accessed through the National Aeronautics and Space Administration's Earthdata engine (NASA, 2000).

2.3.2 Water Balance

Based on the results of the topographic surveys, surface water balances were computed after rainy events using Eq. 1 (Boisson et al., 2015; Massuel et al., 2014):

$$I_{SW} = \Delta V_{wat} + P + Q_{net} - E - U_{comm} \qquad \text{Eq. 1}$$

where I_{SW} (m^3) is the estimated infiltration, ΔV_{wat} (m^3) the variation of the volume of water stored in the structure, P (m^3) the precipitation falling on the structure, Q_{Net} (m^3) the net surface inflow which was measured subtracting surface outflows from the surface inflows. E (m^3) the evaporation of the water impounded, and U_{comm} (m^3) the direct abstraction of surface water by the community and animals.

U_{comm} was assessed through the social surveys, observation on the field, and key informant interviews. ΔV_{wat} was derived from the gauge measures and the TIN models. E and P were computed using Eq. 2 and Eq. 3:

$$E_i = \frac{K_{e,i}}{1000} * \frac{S_{wat,i} + S_{wat,i-1}}{2} * \Delta t_i \qquad \text{Eq. 2}$$

$$P_i = p_i * S_{tot} \qquad \text{Eq. 3}$$

Where p_i (m) is the amount of precipitation between the two measurements, S_{tot} (m^2) the total surface of the structure, $K_{e,i}$ (mm/h) the evaporation rate, $S_{wat,X}$ (m^2) the surface of impounded water on measurement X, and Δt_i (hour) the duration between measurements i-1 and i.

On dry days without inflow or outflow, Eq. 1 could be used, and the amount of infiltration was derived. This water balance method fails to estimate precisely the amount of infiltration when there is a net inflow of water to the structures which keeps the depth of water constant (Oblinger et al., 2010). Several methods exist to overcome this issue, such as estimating the inflow to the structure from rainfall data by phi method (Oblinger et al., 2010) or using a curve number method

(Glendenning et al., 2012). However, the lack of adequate data and the short length of this study did not allow for an efficient use of these methods. Another option is to derive an empirical relation between infiltration and the average depth of water between two consecutive measures on dry days (Biswas et al., 2017; Sharda et al., 2006). However, due to the limited availability of data, the method described by Boisson et al. (2014) and Dashora et al. (2017) was used. Effective infiltration rates were computed by dividing the amount of infiltration by the average surface of impounded water and were used in wet conditions. Infiltration amounts were then computed according to Eq. 4:

$$I_{SW} = \frac{r_{\text{infil}}}{1000} * \frac{S_{wat,i} + S_{wat,i-1}}{2} * \Delta t_i \qquad \text{Eq. 4}$$

where r_{infil} is the infiltration rate (mm/h). A representative value was chosen among those available and used to compute the amount of water recharged on rainy days, and the net inflow was derived using Eq. 1.

Surface water balances methods estimate the amount of water which infiltrates into the soil, but not necessarily which recharges the aquifer. A fraction of the infiltrated water restores soil moisture near the surface. There can be underground seepages, forming wet areas downstream of a dam or a dyke because of lateral movements of water. This can happen to or from the structures and prevents a part of the infiltrated water from recharging the aquifer (Boisson et al., 2014).

2.3.3 Water Level Fluctuation

Water level fluctuation is a common method to quantify the amount of recharge which reaches the aquifer (Boisson et al., 2014; Glendenning and Vervoort, 2010):

$$R_{GW} = \Delta_H * A * S_y + Q_{Abs} \qquad \text{Eq. 5}$$

where R_{GW} (m^3) is the recharge from the water level fluctuation (groundwater) method, Δ_H (m) the average change in the water level, A (m^2) the surface of the study area, S_Y (%) the specific yield of the aquifer and Q_{Abs} (m^3) the amount of water abstracted from the aquifer.

Two piezometric maps were interpolated using Inverse Distance Weighting on ArcMap 10.5 and processed with Map Algebra to compute the average variation of groundwater level, Δ_H. The aquifer in the area is almost exclusively alluvium and aeolian sand (Geological Survey of India, 2002) whose specific yield was taken as 9% (Dhiman et al., 2012). Due to their proximity and to the presence of several other RWH structures (mainly ponds), it was impossible to differentiate the individual influence of each structure. The water level fluctuation method was used to quantify the total recharge, which was then compared with the amount infiltrated from the studied structures.

2.3.4 Numerical Model

A simple computational model was created based on measured performances to estimate the impact of the chauka system during a typical rainy season (June to Mid-October). Each surveyed chauka was studied individually. The model accounts for evaporation from the open water and infiltration to the soil. It is based on Eq. 1, with the difference that in the model, infiltration amount (calculated from observed infiltration rate) were used to compute variation in the volume of water. Chaukas were allowed to overflow when their computed volume exceeded their maximal volume V_{max} (m^3). It was assumed that all the water coming in the chauka was from rain falling directly on it, not from run-off, as this was the case during the study. It was assumed that if a rain event was strong enough to generate run-off within the chauka, then all the chaukas would overflow and all run-off would leave the system. Figure 3 presents the model.

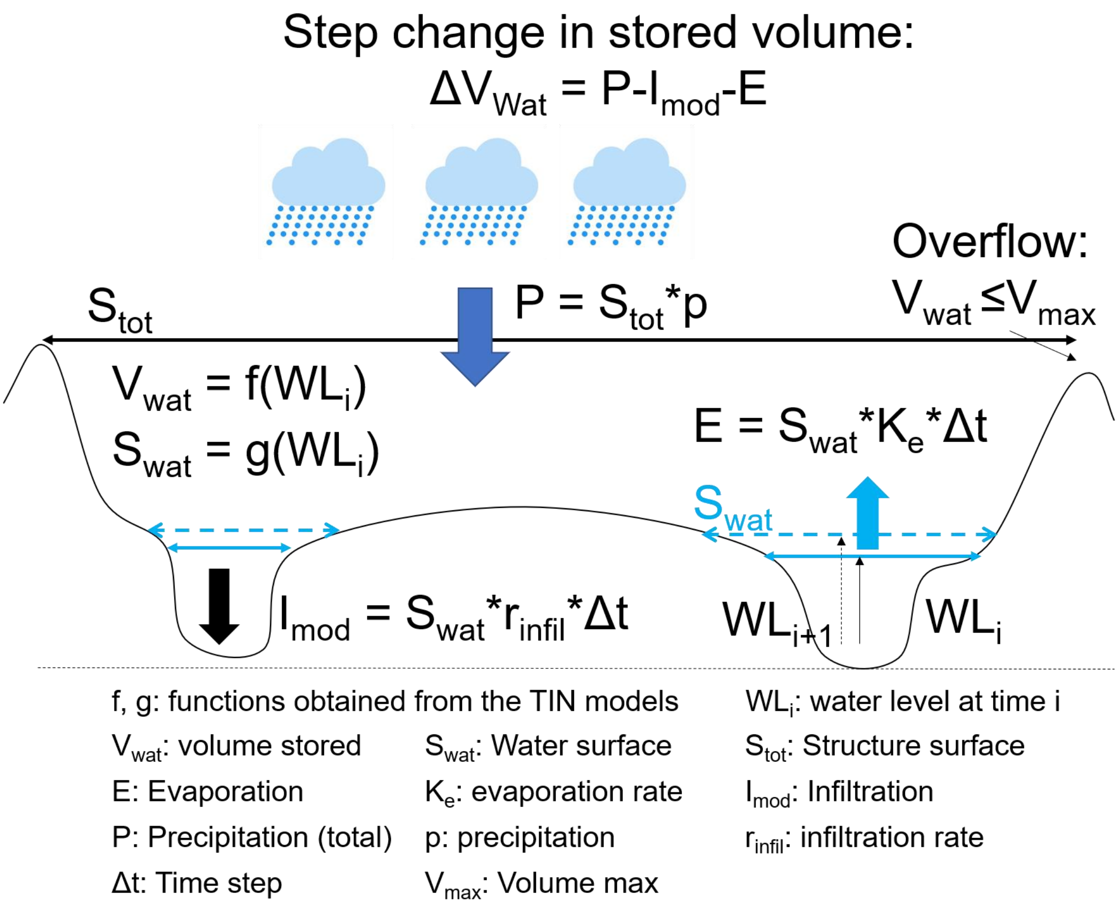

Figure 3: Computational model of chaukas (Cross-section view)

Rainfall inputs of the monsoon 2004 in Jaipur district, representative of the average monsoon between 2001 and 2011, were used as inputs (Singh et al., 2012). The actual evaporation from the open water was computed using Hargreaves's equation (Hargreaves and Samani, 1985), based on FAO (Brouwer and Heibloem, 1986) and India Meteorological Department (2015) data. A coefficient of 1.5 was used to convert the reference crop evaporation to open water evaporation. The evaporation coefficient K_e was kept higher during daytime (6 am to 6 pm) and lower at night, with the daily average being equal to the value obtained using Hargreaves's equation. A constant infiltration rate was chosen from those computed with the surface water balance. The time step Δt was one hour. The relations between water level, surface and volume of impounded water were obtained from the TIN models. Rainfall was assumed to fall at midnight, which was coherent with field observations.

This model could not be applied to the check dam, as a relation between precipitation and inflow to the structure could not be derived. As mentioned earlier, there was not enough data to calibrate a proper curve number or a simple phi coefficient, and the presence of other RWH structures upstream of the check dam added complexity to the situation.

2.3.5 Extrapolation to the Chauka system

The area of each individual chauka was measured using satellite imagery and field observation. Any quantity measured or computed for the studied chaukas (Q_{Sample}) was extrapolated to a quantity for the entire chauka system (Q_{System}) by applying Eq. 6:

$$Q_{System} = Q_{Sample} * \frac{A_{System}}{A_{sample}} \qquad \text{Eq. 6}$$

3. Results

3.1 Hydrology

3.1.1 Hydrology of the area

The check dam controls a watershed of 135.7 km^2. As illustrated in Figure 4, it overflows into a seasonal river that flows along the chauka system. A larger check dam is on the river, roughly 3 km upstream in Gagardu village. The chauka system is fed by the overflow of a series of ponds, which are themselves fed by a secondary overflow of the second check dam, west of the chauka system. The drainage system of the road that follows the northern side of the chauka flows to a large irrigation pond located within Laporiya. This irrigation pond overflows south-west of the chauka system, into the river.

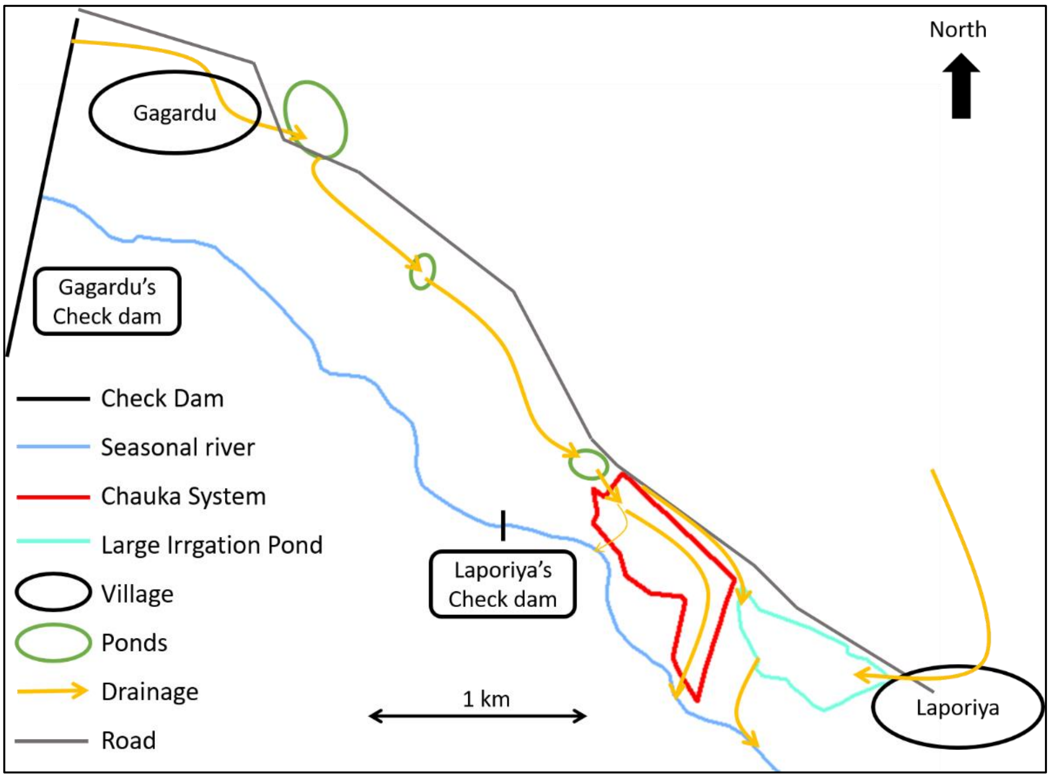

Figure 4: Hydrology of the area

3.1.2 Topography

The check dam, when at full capacity, holds 13 740 m^3 of water, spread over an area of 19 200 m^2. Most of this water is stored on the sandy riverbed, but two adjacent fields can also be flooded and contain 11% of the water impounded. Figure 5 shows the characteristics of the check dam (water level measured from the lowest point in the area).

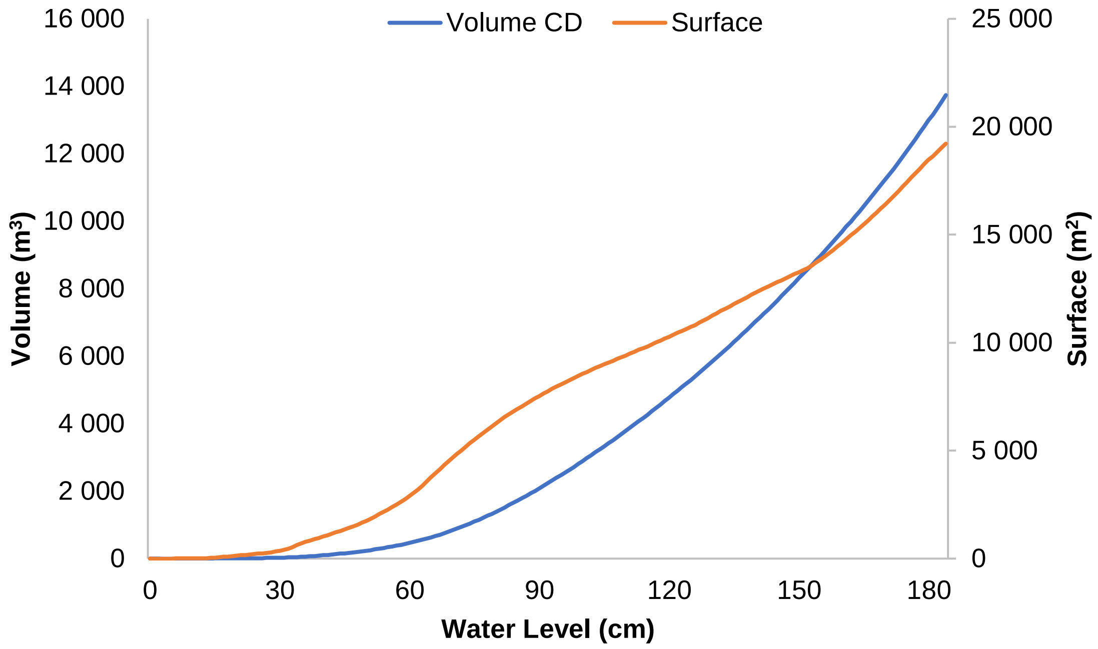

Figure 5: Check Dam Surface and Volume curves

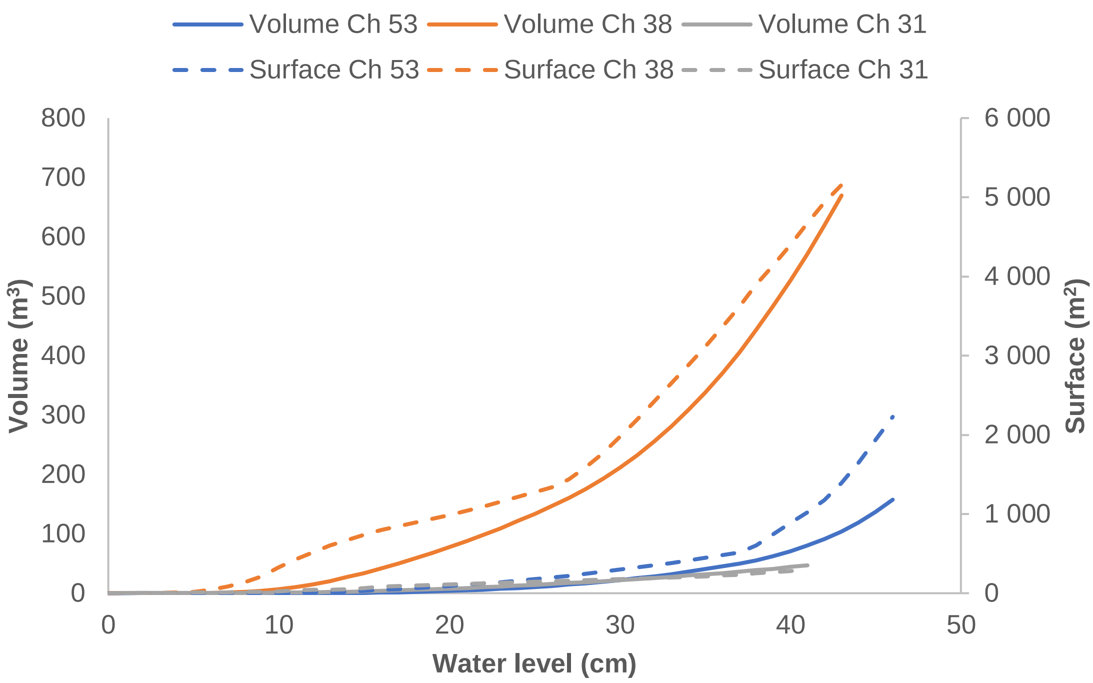

Figure 6: Chaukas Surface and Volume curves

The surveyed chaukas covered a wide array of size, with capacity ranging from 47 m^3 (chauka 31) to 670 m^3 (chauka 38). Figure 6 shows the volume and surface curves of the surveyed chaukas. All curves show an increase in slope with water level, which is due to the trenches being filled up, and the central section starting to be flooded. The total capacity of the chauka system could be estimated using Eq. 6. When all the 61 chaukas are full, the system would hold approximatively 10 000 m^3 of water.

3.1.3 Water Balance

The study took place in June and early July 2018, during which only two significant rain events happened. The first event was a 54 mm rain in the early morning of June 25th. There was no more rain until the chaukas ran dry. The second set of measurement was taken between June 29th and July 2nd with 67 mm of rain during this period (from June 28th to 30th). Because of rain between two measures, it was necessary to compute total infiltration based on observed infiltration rate on June 30th, as described in section 2.3. In the chaukas, the total infiltration was estimated using the infiltration rate of the previous observation, which was close to the observed average over the study period. For the check dam, the average infiltration rate was taken, based on the observation on the first event (12.8 mm/h) and after June 30th (3.1 mm/h). The chosen rates are shown in Table 1.

The water impounded in the structures is not directly used by the community. Hence, U_{comm} was taken as null in Eq. 1. Table 1 summarises the performances of the different structures as calculated with Eq. 1. Detailed results and measured evaporation rates can be found in Appendix B. Infiltration rates for the chauka system are averages of the chaukas'. For logistical reasons, the water level on June 29th (first day of the second event measures) could not be taken for chauka 53, which explains why its infiltration is so low. This value was excluded from the extrapolation for the entire system. For both events, the research team could not get to the site right after the rain. Some water was also left in the structures after the last measure, particularly in the check dam (2 500 m^3). Hence, a part of the infiltration following these rain events was not captured, and these figures are underestimated.

Table 1: Results of the water balance, as per Eq. 1

Structures	Event 1		Event 2		Infiltration Rate (mm/h) (Eq. 4)
	Recharge (m^3)	Efficiency	Recharge (m^3)	Efficiency	
Check dam	410	97%	3788	97%	8,0
Chauka 31	22,9	96%	30,0	95%	5,1
Chauka 38	104,0	95%	204,8	95%	4,6
Chauka 53	43,3	96%	11,0	97%	6,2
Chauka system (Estimated with Eq. 6)	2411	96%	4579	95%	5,3

Note: Average evaporation rate was 6.9 mm/d.

All structures had very high infiltration efficiency rates (defined as the ratio of water infiltrated over the total water impounded). Though it is a very rough estimate, it can still be observed that for a small amount of water, the chauka system was able to infiltrate much more water than the check dam. However, on the second event which only had slightly more rain, the check dam stored and infiltrated a much greater amount of water, reaching the level of the chaukas. A possible explanation would be that the run-off that reaches the check dam is more controlled by upstream structures, which need to fill up first, than the chaukas, which are mainly fed by direct rainfall.

3.1.4 Water Level Fluctuations

Water levels in nearby open wells were monitored prior to the first rainfall event (June 23rd), and after the second rainfall event (July 2nd). The water level in the open wells was about 15m higher near the MAR structures than near the village, located downstream. As shown in Figure 7, data on change of water level were available on an area covering 1.5 km^2 from downstream of the check dam to the outskirts of the village. The greatest increase in water level happened near the irrigation pond which is east of the chauka system. Eq. 5, with an average water level increase of 1.93m, showed a total recharge of approximatively 256 000 m^3. As there were few abstractions from the aquifer, Q_{Abs} was neglected. During this period, the check dam infiltrated about 1.6% of the total recharge. For comparison, the chauka system infiltrated the equivalent of 2.7% of the total recharge. However, the depth of water (4.7 cm, considering an area of 149 000 m^2) which was infiltrated from the system may not contribute significantly to the aquifer recharge but contributed to near-surface moisture.

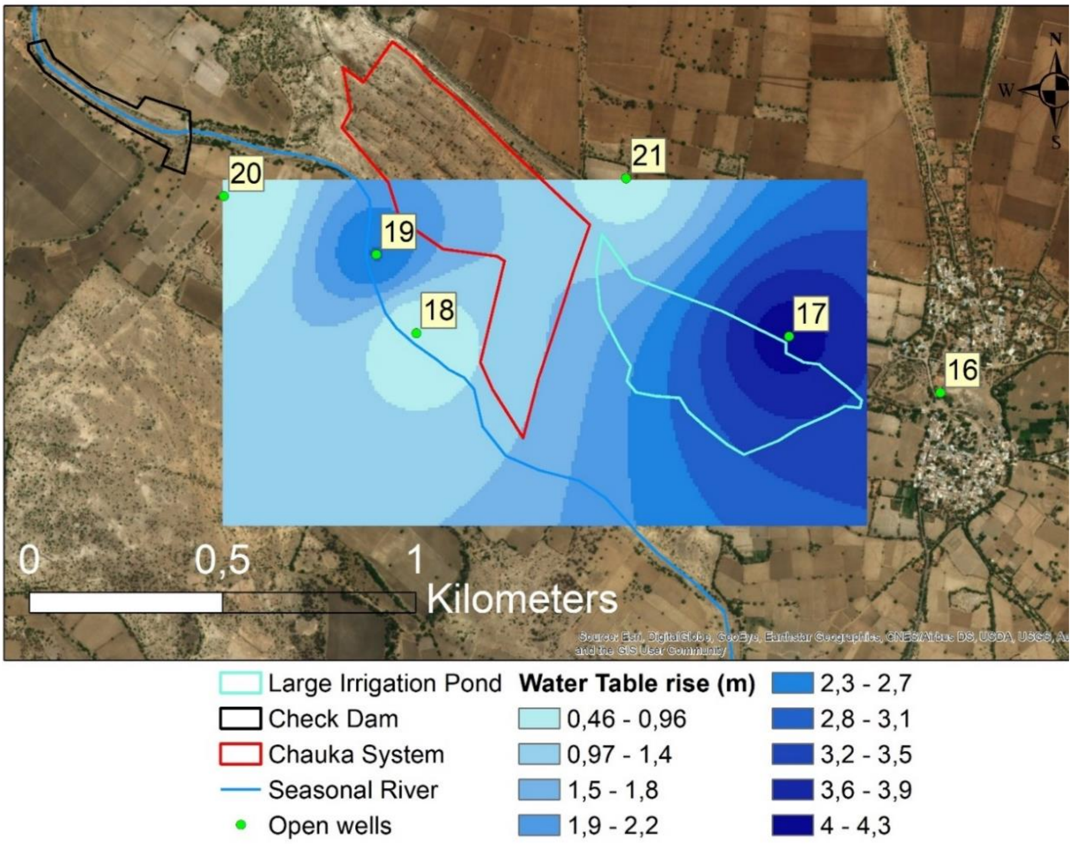

Figure 7: Increase in water table level between June 23rd and July 2nd

3.1.5 Modelling of the Monsoon

The model yielded an estimate of the infiltration and evaporation of the chauka system during the entire rainy season. The infiltration rates shown in Table 1 were used in the model, as they were a good intermediate between the higher initial values, and the lower ones observed for low water levels. It was applied to the three studied chaukas, and then extrapolated to the entire system. The model revealed that a typical rain event of 30-40mm remained impounded in the chaukas for 1.5 or 2 days. This was confirmed by the field observations. The evolution of water level and infiltrated volume in chauka 53 is shown in Figure 8.

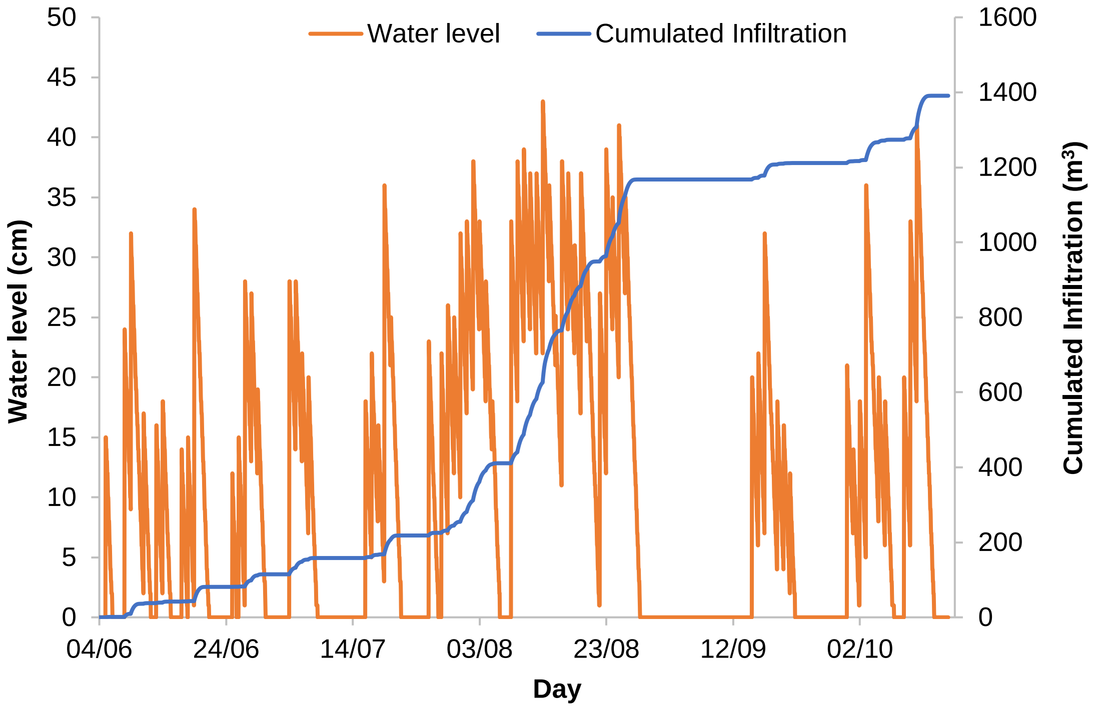

Figure 8: Modelled evolution of water level and infiltration in Chauka 53

According to the model, Chauka 53 infiltrated about 1400 m^3 of water during the monsoon. Chauka 31 and 38 infiltrated 475 m^3 and 3150 m^3 respectively, with an average infiltration efficiency of 94.6%, slightly lower than the observed 95.2%. The calculated evaporation rates for the model with Hargreaves's equation (7.8

mm/d on average, 10.2 mm/d in June) were higher than measured in the field (6.9 mm/d), which explains the lower efficiency of the model. For the entire chauka system, infiltration would be 71 000 m^3. The model could not be applied to the check dam, due to limited data availability. However, with the simplistic assumption that infiltration would be proportional to rainfall during the rainy season (about 450 mm, based on an average year), the check dam would infiltrate about 42 000 m^3 of rainwater (based on the second observed rain event, and including the 2500 m^3 which were still impounded on July 2nd).

3.2 Water Quality

3.2.1 Salinity

High levels of salinity in the groundwater were observed, with EC values ranging from 900 to 19 000 µS/cm on July 2nd. As shown in Figure 9, salinity levels are much higher away from the MAR structures (points 12 and 13) than nearer to them. The sample point 18 (open well) showed an isolated high level of salinity of 18 000 µS/cm. High nitrate levels (40.8 mg NO_3/L, the highest level recorded in an open well), the presence of nearby fields, and the absence of any protective wall would suggest contamination by irrigation run-off. The lowest conductivity levels were observed near the large irrigation pond. Sample points 16 and 7, which are located close to a smaller pond also have lower levels.

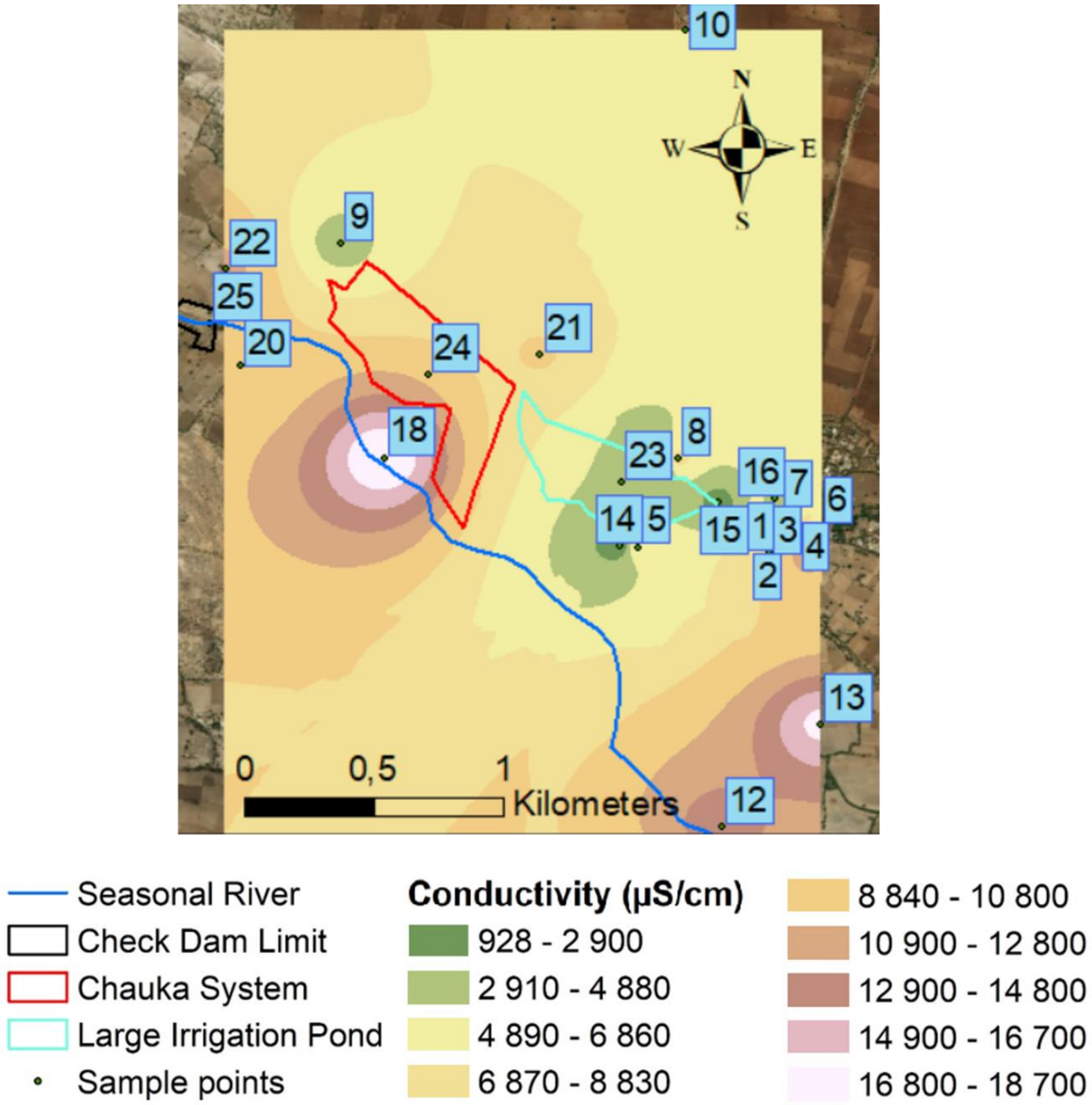

Figure 9: Conductivity on July 2nd

The evolution of EC was measured during the second sampling campaign. Figure 10 shows the results for the seven points that were sampled during the second campaign, ordered by proximity to a RWH structure. All sample points showed a reduction in their salinity levels, ranging from 13.2% to 39.9%. The sample with the lowest reduction (point 22) is located upstream of the MAR structures, while the samples with the highest reduction (7, 8 and 17) are located near irrigation ponds. However, sample point 13 which is the furthest away from any MAR structures has slightly higher reduction than sample point 14, which is just by the large irrigation tank.

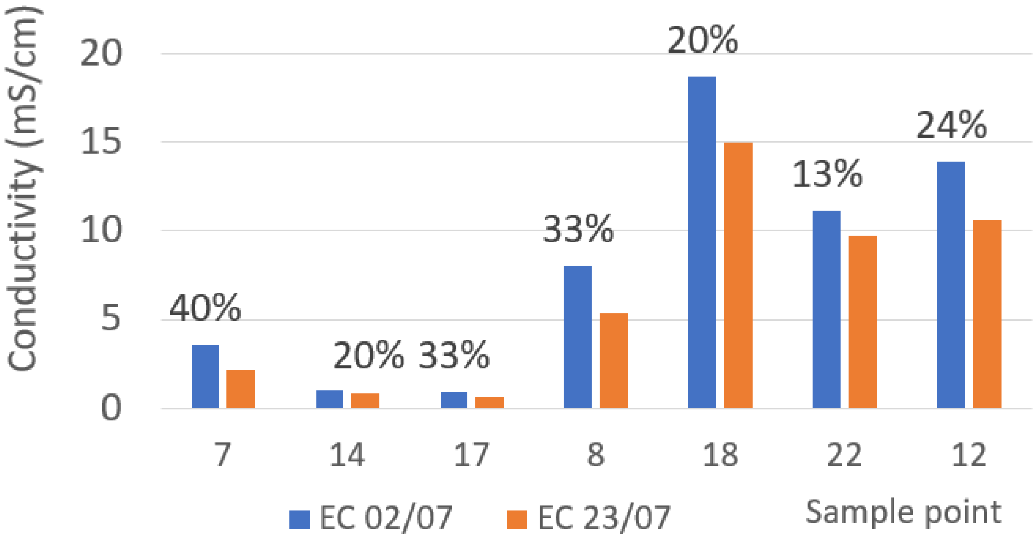

Figure 10: EC measures and corresponding reduction (as percentage)

3.2.2 Fluoride contamination

Fluoride contamination was also confirmed in the village, with an average value of 5.6 mg/L, way above the guideline value of 1.5 mg/L for drinking water. Fluoride follows a similar location pattern as salinity, with higher values found upstream and away from MAR structures, and lower values nearer. The lowest levels were also found close to the ponds. As seen in Figure 11, there is a correlation between the salinity and the fluoride content with a coefficient of correlation of 83%, which is strongly significant with 25 sample points.

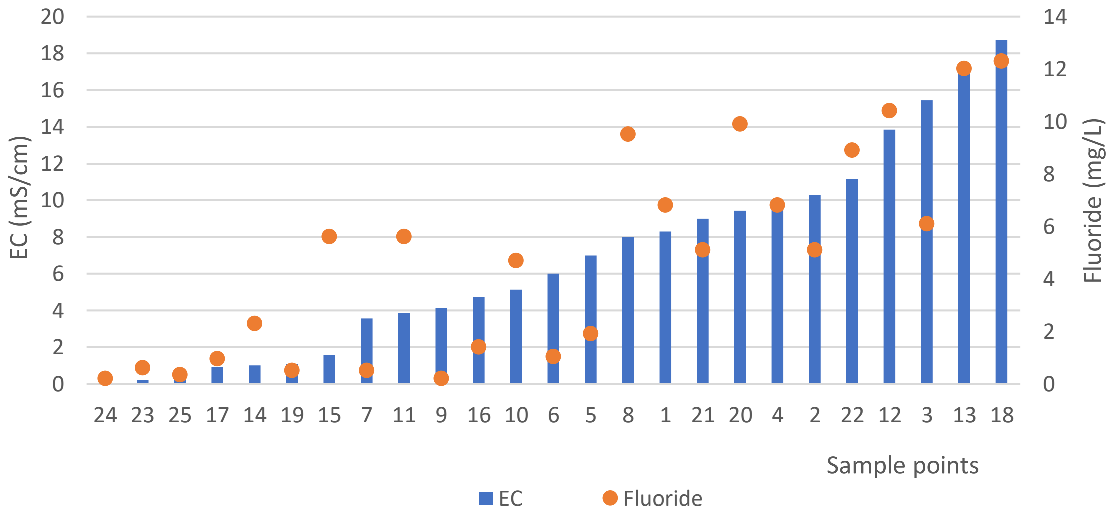

Figure 11: EC and Fluoride on 02/07

As for salinity, fluoride levels in the water impounded in the structures was very low: sample 23 was taken in the large irrigation ponds, sample 24 in the chauka 38, and sample 25 in the check dam.

The salinity and fluoride levels, as well as the increase in water level, suggest a higher impact from the ponds than from the check dam. Unfortunately, the second set of samples could not be tested for fluoride to confirm this hypothesis. However, reduction within the same range as conductivity can reasonably be expected.

Detailed results for these three parameters can be found in Appendix C.

3.3 Social Surveys

3.3.1 Water for domestic use

A public water supply scheme from the government provides piped water to most households. Water comes from a large reservoir, 150 kilometres away from the village and is typically available for 30 minutes once every other day. Most of the people surveyed (87%) were preferentially using tap water for domestic uses, particularly to drink. This number is consistent with GVNML's assessment that 295 out of 320 families in the village had access to a piped supply, sometimes shared between a few households. However, the public supply is unable to cover the needs of a typical household. The community hence resorts to other sources of water for other activities like washing, bathing, watering animals etc. About half of the village uses a communal open well (sample point 14, Figure 9) 500 meters away from the village, but only 13% use it as their main source of drinking water.

Rainwater harvesting at a domestic scale is also implemented in the village, with 44% of the people surveyed using a roof water harvesting system, typically connected to an underground cemented tank. Roof water harvesting requires a cemented house. GVNML supported the implementation of roof water harvesting by helping 20 families below the poverty line accessing a government scheme covering the upgrade cost of their house, and by financially supporting the building of cemented tanks for these families. Half of the households surveyed are equipped with at least one cemented tank, whose capacities vary from 5 to 20 m^3. These tanks are used to store rainwater, but also tap water. The village committee also owns a 5 m^3 tanker which can be hired by villagers to fill up their tank: 40% of the village use that service. Finally, about 30% of the village use boreholes at least occasionally though not for drinking.

3.3.2 Perceived water quality issues

Figure 12 shows the perceived water quality issues in the village. The most reported issue was salinity, occurring mainly in open wells and boreholes. The operator of the village piped supply sometimes uses the communal open well to feed the network, when the government supply is unavailable for too long. Complaints linked to this situation were classified in Figure 12 as 'Open wells'. A few villagers complained about fluoride in groundwater. Two of them own a private borewell which was sampled and turned out to be contaminated with fluoride (5.1 and 6.8 mg/L). This shows that there is at least some level of awareness about this issue. One person mentioned the formation of solid particles when preparing tea (with milk) with water from a borewell. This might be due to the precipitation of calcium fluoride, but the phenomenon was never observed, and no samples could be taken to confirm it.

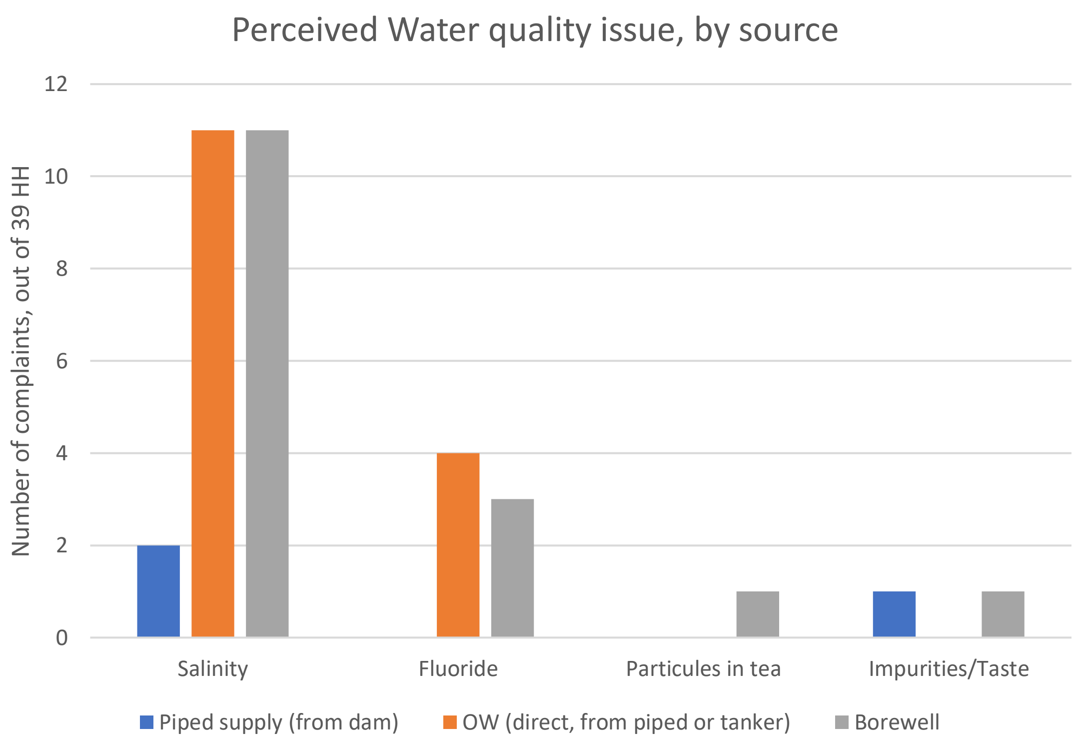

Figure 12: Perceived Water quality issue, by source

3.3.3 Water for agriculture

Agriculture in the area is mainly reliant on rainfall during the monsoon season (June-September). The proportion of land irrigated during the dry season (October-June) was surveyed: results are shown in Figure 13. Despite the numerous RWH structures and the irrigation ponds, only 377 acres (24% of the total cultivated land) were irrigated after the end of rainy season. Similarly, the owners of open wells/borewells used for irrigation reported a decrease in the duration of use of 82% between the end of a monsoon and the beginning of the next one. This reduction is dictated by water availability, not by power supply (most pumps in the area are diesel pumps), with wells typically being depleted within one hour of pumping in summer.

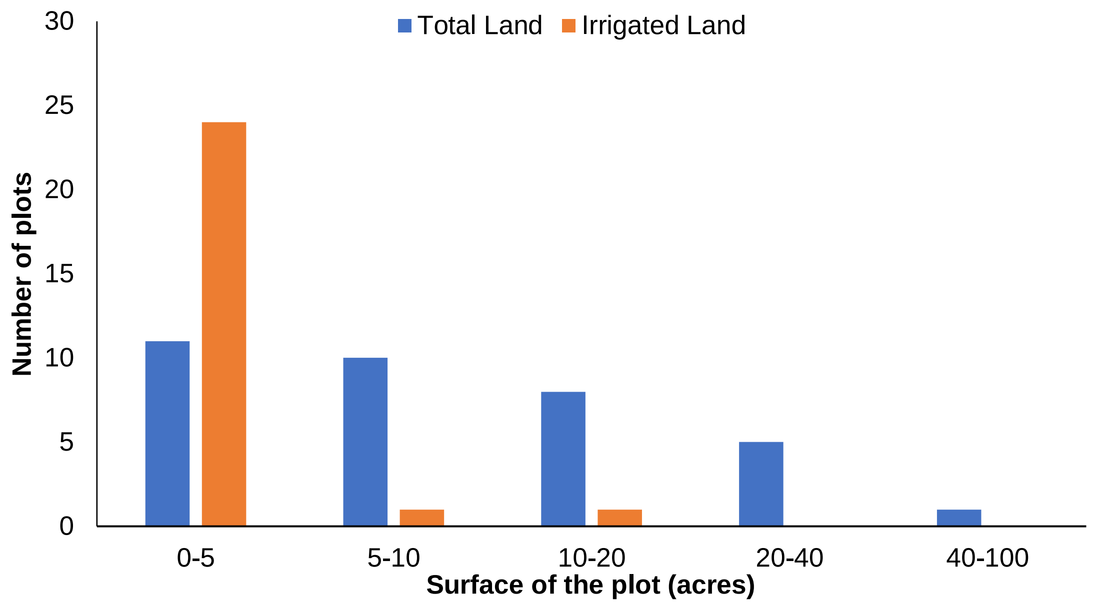

Figure 13: Cropping plots

3.3.4 Chaukas

Finally, people were asked about their perception of the MAR structures. Since people usually had no direct interactions with the check dam, the questionnaire focused on the chaukas. The presence of GVNML staff was necessary for translation, but this might have biased some answers: 38 out of 39 people surveyed declared that the chaukas were useful or very useful to the community. Every person surveyed knew about the existence of the chaukas. The only direct use of the system by the community is for animal grazing. There is no direct use of the water impounded within the chauka (except by wildlife): outside of their home, people water their animals at the dedicated ponds, which are fitted with animal basins. Chaukas are also used for village meetings.

About 80% of the community considers that the milk production in the village has increased due to the grazing areas which became available in the chauka system with soil moisture increase. One elder mentioned that it increased by a factor of 100, but there is no evidence of such a figure. More than half of the sampled households mentioned a general increase in the vegetation cover in the area, including medicinal herbs which were initially not present in the village. Nine people (23%) mentioned an increase in water level in nearby wells, and six (15%) an increase in water quality.

72% of the village population participate in the upkeep of the chauka, which can take two forms. People spontaneously engage in small-scale, unsupervised voluntary work when noticing a need for a minor fix. Besides, GVNML and the village committee organise larger scale work: large terracing operations, cleaning up of animal waste, eradication of invasive plant species. Such work benefited from the National Rural Employment Guarantee Act, which allowed GVNML to provide a salary to the villagers.

4. Discussion

As explained in section 1, several researchers reached the conclusion that the infiltration efficiency of RWH was about 60%, including in alluvial aquifers similar to Laporiya's. However, higher values are sometimes found for check dams: Glendenning and Vervoort (2010) reported a dam with an efficiency of 92%. Though chaukas have never been studied, they can grossly be considered as percolation tanks with a higher surface-to-depth ratio. Some outliers also exist for these, with observed values of 30% (Muralidharan and Athavale, 1998) and 85% (Glendenning and Vervoort, 2010).

Results found in this study are much higher, ranging from 95% to 97%. There are several potential explanations for this. The above-mentioned works have lasted for at least a complete season (monsoon season and the recession period during which the structures empty), and some lasted for several years to capture interannual variations. This study covered a much shorter period, 10 days with rain, at the beginning of the monsoon, which comes with different conditions.

Evaporation rates can explain some of the difference between the results of this study and in the literature. The water balances were conducted shortly after the rain. A comparison between measured evaporation rate on June 18th (no rain) and June 30th (just after the rain) shows very different rates, respectively 11.9 and 5.3 mm/d, measured over a 24h period. The factors responsible for this difference are well known: lower temperature, lesser radiation due to cloud cover, higher relative humidity after the rain (Allen et al., 1998). Low-evaporation periods are probably over-represented in our study because it focused on the few days that followed rain. If a longer period had been considered, a higher mean evaporation rate, and hence lesser efficiency would have probably been measured, closer to what can be found in the literature. Increasing the mean evaporation rate from 6.9 to 10 mm/d in the water balance would have yielded efficiencies between 92% and 96%.

Infiltration rates tend to decrease over time, as was observed in both structures. Dry soils have a suction effect, due to capillary actions and absorption which disappears as moisture increases (Mays, 2010). Preferential paths can appear in the soil through cracks formed during a dry period, as this was the case near the dam wall. As water content increases, clay present in the soil will tend to swell, reducing these preferential flows and decreasing soil permeability (Boisson et al., 2014). Higher initial infiltration rates lasted for a higher proportion of time in our short study than in a typical study where they are of marginal importance, which can explain the higher observed efficiency. Long-term variation of infiltration rate, due for instance to aquifer saturation or siltation, which did not happen in our study, are also reported in some of the reviewed papers, further preventing infiltration and reducing efficiency (Glendenning and Vervoort, 2011). A wide range of long-term infiltration rate values can be found in the literature. Gale (2006) measured a rate of about 9 mm/h in one of his studied check dams, decreasing to 3 mm/day with time, but values as low as 1 or 2 mm/h are prevalent both for check dam and percolation tank (Boisson et al., 2015; Dashora et al., 2017; Glendenning and Vervoort, 2010). These values, lower than the observed ones, illustrate these effects and explain the differences.

Choosing an appropriate infiltration rate for the chauka model was then of great importance. Unlike percolation ponds, chaukas (or at least their central section, which represent most of their surface) alternate between flooded and dry periods in a matter of a day, as they hold so little water. During an intermediate dry period, soil moisture will partly evaporate, restoring higher initial infiltration rate for the next rain event. Hence, a lower infiltration rate as observed in the last measures on July 1st and 2nd (1-3 mm/h) would not be representative of their behaviours. Initial rates, as explained before, could not be observed. However, knowing the amount of rain that generated them and under the model's assumption that only rain falling directly on the chaukas was impounded, initial levels can be estimated. Then, Eq. 1 can be applied to get a theoretical value of the initial infiltration rate. For the rain event of June 25th, whose timing could be determined, this gave infiltration rates of about 10 mm/h. Similarly, such rates would not be representative of the chaukas. Hence, the chosen values, between 4.6 and 6.1 mm/h, are reasonable intermediates.

This idea does not apply to the check dam, which stays under water for the entire monsoon. If a similar model was to be applied to it, a low infiltration rate, probably of 3 mm/h as was observed on July 1st and 2nd, should be applied. However, such a rate was not coherent with the amount of rain that fell on June 30th, even assuming that only the immediate surrounding of the dam (30 000 m^2) contributed to the run-off. Therefore, it was not used for the application of Eq. 4 and a larger intermediate value was used.

As mentioned in section 3.2.2, salinity and fluoride levels, as well as water level, suggest that the ponds in the village, used as surface water reservoirs rather than recharge structures, have a larger impact than the check dam. However, the location of the sampling points was not perfect: the wells near the ponds were very close (a few meters away) or even within the ponds, whereas the two wells closest to the check dam were 200 m away. This value is higher than the radius of influence of 64m that was determined by Palanisami et al. (2005), and hence the effect of the check dam on groundwater quality and level might be hidden by the absence of wells in its vicinity. Hence, definitive conclusions cannot be drawn because of these biased well locations. Taking samples after the infiltration of the entire monsoon's run-off could show a higher impact of the check dam, as more water would be allowed to percolate. However, a better solution would be to install a monitoring borewell in the immediate proximity of the check dam, to provide observations comparable to the ones of the ponds.

This illustrates a point which has been discussed on several occasions in the literature: studying recharge structures at a local scale only provides limited insights (Boisson et al., 2015; Glendenning and Vervoort, 2011). All RWH structures have an impact on downstream areas, which is especially important in an area with several structures as in Laporiya. Fully understanding the hydrological impact of RWH in an area requires to be able to differentiate between mere reallocation of rainwater resources between two adjacent structures, and net benefits which would be run-off loss prevented at a basin, state or even national scale. Such considerations were out of the range of this short assessment but were still perceived in the probable impact of Gagardu's check dam on Laporiya's check dam response to the first rain event.

Most of the population drinks from the piped supply which does not present any health risk due to fluoride (fluoride level was 1.2 mg/L). However, the most prevalent alternative option for drinking water is the communal well (sample point 14) whose fluoride level of 2.3 mg/L is higher than WHO guideline value (Gordon et al., 2008), even if it remains under the village's average. Hence, the small fraction of the population which regularly drinks from the communal well might be exposed to potential health risks. These risks are limited as 2.3 mg/L is still under other guidelines, such as the American maximum contaminant level of 4.0 mg/L (Environmental Protection Agency, 2018), and other exposure routes, such as food, should be considered to assess them (Gordon, Callan and Vickers, 2008).

The impact of RWH structures on the community's public health through improved water quality is probably very limited. However, thanks to the hydrological study and the social surveys, the impact on livelihoods could be estimated. There are about 225 goats in Laporiya. Assuming a goat represents 0.15 animal unit (Waller, Moser and Anderson, 1986), and that an animal unit requires 1.8 acres of grazing (Natural Resources Conservation Service, 2009), the chaukas would sustain about 60% of the village's total for several months a year (the availability of grazing in the chaukas throughout the year was not surveyed). This is particularly significant for the poorest families, not owing lands and with smaller herds, which can use the chaukas for free. However, if compared to the village's entire livestock, mainly composed of cows and buffalos which usually graze on fodder from fields, the amount of grazing area provided would be much less important.

75% of farmers practising irrigation during the dry season cultivate wheat. Over a growing period, wheat requires about 550mm of water (Brouwer and Heibloem, 1986), or 2 225 m^3 per acre. It was estimated that the check dam infiltrated about 42 000 m^3 of water during a monsoon season. This would represent 19 acres of irrigated land, about 5% of the village's total. This percentage, however, does not account for the less important summer irrigation. The four dams studied by Dashora et al. (2017) support about 16% of the dry season agriculture in their respective village: a similar proportion, though at a scale 20 times larger. However, for lack of water and despite the numerous MAR structures and irrigation ponds, agriculture during the dry season remains a small fraction of what it is during the monsoon. As pointed out by Boisson et al. (2014), increased recharge from potential new MAR projects might thus barely result in increased abstraction for irrigation. Without any demand-side intervention, the usual goal of MAR in India to reduce the long-term decline of the water level is unlikely to be met here.

5. Conclusion

The impact of two RWH structures on their environment has been studied in a semi-arid area. Both the chauka system and the check dam had a modest but still noticeable impact on the area and its community. However, the benefits they provide are of different nature. Due to its large spatial extent, and relatively small capacity, the chauka system is unlikely to have any significant impact on the groundwater level or quality. Yet, it is a structure well integrated within the community, which contributes to environment quality and increased livelihoods through animal grazing. A detailed socio-economic study would be necessary to accurately quantify this impact. The check dam contributes a roughly-estimated 40 000 m^3 of groundwater infiltration throughout the monsoon, supporting 5% of dry season agriculture. There was clear evidence of improved water quality through dilution effect due to groundwater recharge. However, the relative contribution of the check dam and others RWH structures in the village could not be determined because of the short duration of the study and biased sample points location.

The findings of this quick assessment would be strengthened by a longer-term study of at least a year. Its features should include a study of the RWH ponds which exist in the village, whose impact might be similar or greater to check dam's, drilling monitoring boreholes near the check dam, and considering interactions with upstream and downstream structures to assess larger-scale impact.

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Appendices

Appendix A: Questionnaire for Social Survey

Questionnaire Survey for Assessing Water Use

GENERAL:

How many people are there in your household?

WATER USE

1) Where do you collect water for household/domestic use (drinking, cooking, bathing, laundry)?

☐ Borehole ☐ Domestic Rain Water ☐ Piped Water (owned)

☑ Water Kiosk ☐ Surface water ☐ Open Well ☐ Piped water (shared)

☐ Other (***specify***)

2) If you collect water from boreholes, how many active boreholes do you use? **(Ask for specific location)**

3) Do you use water for other purpose?

☐ Yes ☐ No

If Yes, for which activity?

☑Irrigation ☐ Cattle ☐ Vegetables/Gardening ☐ Other (specify)

If cattle: How many animals do you have?

<u>Piped Water:</u>

4) Is water always available at the tap?

☐ Yes ☐ No

   a. If not
      a. In a typical day, for how many hours do you have water?
      b. Does it change with season?

b. If yes, do you have to limit the quantity of water you take? By how much and for how long?
c. If yes, do you use other sources of water?

5) Do you provide water to other households? If yes, for how many people, and how much water per week?

<u>Non-piped Water:</u>

6) What kind of container do you use to collect water and how big is it?

Type of container [ ] Approximate Vol ([ ]

7) How many of these containers does your household collect each day?

8) How far from your household is the water point?

9) Is water always available at this water point?

☐ Yes ☐ No

If not, during the last 12 months, when was water not available?

If yes, do you have to limit the quantity of water you take? By how much and for how long?

10) Have you ever used water from a MAR structure (Chauka/Check Dam)? ***(water extracted directly from the structure)***

☐ Yes ☐ No

11) Do you have a rainwater tank?

☐ Yes ☐ No

If yes, what is the volume?

WATER QUALITY

12) Do you encounter water quality issues?

☐ Yes ☐ No

If yes, which kind of issue? ***(Specify)***

☐ Salinity ☐ Odour ☐ Colour

☐ Taste ☐ Issues with tea making/cooking ☐ Other

13) When do you notice this issue(s)?

☐ All the time ☐ A few months a year ☐ A few days a year ☐Rarely

At which period does it usually happen?

14) Do you think it has an impact on your health?

☐ Yes ☐ No

If yes, could you develop?

WATER MANAGEMENT

15) Is there a water fee collected?

☐ Yes ☐ No

If yes, how much is it, and to whom is it paid?

16) **(If tap water):** If there is a problem with your water connection:

a. Who can you ask to repair it?
b. How long does it take?
c. Do you have to pay for repair? How much?

CHAUKA

17) Do you know what the chaukas are?

☐ Yes ☐ No

18) Does your household use the chaukas?

☐ Yes ☐ No

19) If yes, what for?

☐ Animal Grazing ☐ Irrigation ☐ other (specify)

20) Would you say the chaukas are useful for the village?

☐ Very useful ☐ Useful ☐ Not so useful ☐ Useless

If useful, how do they benefit the village?

21) Do you take part in maintaining the chaukas, or any other RWH structure?

☐ Yes ☐ No

22) If yes:

a. Who decide when to do maintenance?
b. Are you paid for this work? If yes, by whom?
c. How frequently is maintenance done?

WATER FOR IRRIGATION:

23) How much land do you cultivate?

24) What water source do you use for irrigation?

☐ Pond ☐ Open well ☐ Borehole ☐ Canal ☐ Other (specify)

25) When do you usually irrigate your land?

☐ During the monsoon (Kharif) ☐ After the monsoon (Rabi) ☐ Pre-monsoon (Summer)

26) How much land do you irrigate?

27) Which kind of crop do you irrigate? (ask for different seasons)

28) Do you have a motor pump for your water source? If yes, how powerful is it?

29) For how long do you let your pump on (hours per day), for each season?

30) Do you have another water source for irrigation? If yes, please specify (type, location, volume abstracted…)

31) Is water always available at this water point?

☐ Yes ☐ No

If not, during the last 12 months, when was water not available?

If yes, do you have to limit the quantity of water you take? By how much and for how long?

32) How much does the water level drop between the end of a monsoon, and the beginning of the next one?

Appendix B: Water Balance

These tables give the detailed results of the water balance for every set of measurements that have been taken. Green cells indicate results that have been obtained with Eq. 4 (June 30th). A sum up of these tables can be found in section 3.1.3.

B-1: Check Dam Results

Table A-1: Check dam water balance results

Check Dam											
Day	Time	Water level (m)	Surface (m^2)	Volume (m^3)	Evap rate (mm/h)	Time step (h)	Evap (m^3)	Infiltration (m^3)	Infiltration %	Infiltration rate (mm/h)	Rain inflow (m^3)
25/06	09:45	0,6	2908	463							
25/06	19:15	0,47	1500	185	0,49	09:30	10,26	267	96,3%	12,8	
26/06	06:00	0,33	539	42	0,10	10:45	1,10	142	99,2%	13,0	
Total						20:15	11,36	410	97,3%	12,8	
29/06	16:00	1,14	9748	4171							
01/07	09:15	1,04	8913	3238	0,20	41:15	77,0	3079	97,6%	8,0	2223
01/07	17:10	1,02	8735	3061	0,50	07:55	34,9	142	80,2%	2,0	
02/07	09:40	0,95	8066	2473	0,15	16:30	20,8	568	96,5%	4,1	
Total						65:40	132,7	3788	96,6%	6,4	2223

B-2: Chauka 31 Results

Table A-2: Chauka 31 water balance results

Chauka 31											
Day	Time	Water level (m)	Surface (m^2)	Volume (m^3)	Evap rate (mm/h)	Time step (h)	Evap (m^3)	Infiltration (m^3)	Infiltration %	Infiltration rate (mm/h)	Rain inflow (m^3)
25/06	09:45	0,365	229	35,1							
25/06	19:15	0,285	166	19,5	0,49	09:30	0,92	14,7	94,1%	7,8	
26/06	06:00	0,235	134	11,2	0,10	10:45	0,16	8,2	98,1%	5,1	
Total						20:15	1,08	22,9	95,5%	6,6	
29/06	18:45	0,325	195	30,4							
30/06	19:00	0,24	137	12,7	0,20	24:15	0,80	20,4	96,2%	5,1	3,6
01/07	09:15	0,2	114	7,7	0,08	14:15	0,14	4,9	97,1%	2,7	
01/07	17:10	0,17	91,7	4,6	0,50	07:55	0,41	2,7	86,9%	3,3	
02/07	09:40	0,14	51,6	2,4	0,15	16:30	0,18	2,0	91,9%	1,7	
Total						62:55	1,5	30,0	95,1%	3,8	3,6

B-3: Chauka 38 Results

Table A-3: Chauka 38 water balance results

Chauka 38											
Day	Time	Water level (m)	Surface (m^2)	Volume (m^3)	Evap rate (mm/h)	Time step (h)	Evap (m^3)	Infiltration (m^3)	Infiltration %	Infiltration rate (mm/h)	Rain inflow (m^3)
25/06	09:45	0,25	1273	134							
25/06	19:15	0,185	917	63,2	0,49	09:30	5,10	65,4	92,8%	6,3	
26/06	06:00	0,135	636	23,8	0,10	10:45	0,83	38,6	97,9%	4,6	
Total						20:15	5,93	104	94,6%	5,5	
29/06	18:45	0,3	1973	211,2							
30/06	19:00	0,17	847,4	49,89	0,20	24:15	6,84	158	95,9%	4,6	3,5
01/07	09:15	0,13	601	20,6	0,08	14:15	0,83	28,5	97,2%	2,8	
01/07	17:10	0,095	268,5	5,2	0,50	07:55	1,72	13,6	88,8%	4,0	
02/07	09:40	0,05	16,2	0,2	0,15	16:30	0,35	4,7	93,0%	2,0	
Total						62:55	9,7	205	95,5%	4,1	3,5

B-4: Chauka 53 Results

Table A-4: Chauka 53 water balance results

Chauka 53											
Day	Time	Water level (m)	Surface (m^2)	Volume (m^3)	Evap rate (mm/h)	Time step (h)	Evap (m^3)	Infiltration (m^3)	Infiltration %	Infiltration rate (mm/h)	Rain inflow (m^3)
25/06	09:45	0,37	512,3	50,09							
25/06	19:15	0,28	244,3	16,65	0,49	09:30	1,76	31,68	94,7%	8,8	
26/06	06:00	0,21	108,5	4,79	0,10	10:45	0,19	11,67	98,4%	6,2	
Total						20:15	1,95	43,34	95,7%	7,9	
30/06	19:00	0,255	185,4	11,33							
01/07	09:15	0,185	72,1	2,56	0,08	14:15	0,15	8,63	98,3%	4,7	
01/07	17:10	0	0,0	0,00	0,50	07:55	0,14	2,42	94,4%	8,5	
Total						22:10	0,3	11,0	97,4%	5,2	

B-5: Evaporation Rate

Table A-5 shows the measured evaporation rate during the study.

Table A-5: Evaporation rate

Period	Evaporation rate (mm/h)	Period	Evaporation rate (mm/h)
18/06 11:47		25/06 08:25	
18/06 14:00	1,1	25/06 10:50	0,2
18/06 15:04	1,0	25/06 17:00	0,6
18/06 15:53	0,8	25/06 21:15	0,3
18/06 17:07	0,9	30/06 13:00	
18/06 18:19	0,6	30/06 20:00	0,3
18/06 19:55	0,5	01/07 08:10	0,1
19/06 05:30	0,2	01/07 12:00	0,2
19/06 11:30	0,5	01/07 17:00	0,3
19/06 13:21	1,1	02/07 05:15	0,2
19/06 14:10	0,5	02/07 19:00	0,3
19/06 15:27	0,6		
19/06 17:55	0,7		

Appendix C: Water level and quality results

The following table gives the results of the Fluoride and Salinity tests that have been conducted on July 2nd, as described in section 3.2. Conductivity levels on July 23rd are also included.

Table A-6: Water quality and level

Number	Type	PL 23/06 (m)	PL 01/07 (m)	EC 01/07 (µS/cm)	EC 23/07 (µS/cm)	F (mg/L)
1	BW			8286		6,8
2	BW			10286		5,1
3	BW			15429		6,1
4	BW			9857		6,8
5	BW			7000		1,9
6	BW			6000		1,04
7	BW			3571	2146	0,5
8	BW			8000	5400	9,5
9	BW			4143		0,2
10	BW			5143		4,7
11	OW		338,41	3857		5,6
12	OW	339,15	340,62	13857	10600	10,4
13	OW		338,15	17286		12,0
14	OW		341,39	1014	810	2,3
15	OW		333,32	1557		5,6
16	OW	325,77	329,21	4714		1,4
17	OW	336,80	340,82	914	611	1,0
18	OW	344,47	344,92	18714	15000	12,3
19	OW	343,85	346,52	1100		0,5
20	OW	344,19	344,27	9429		9,9
21	OW	344,60	345,33	9000		5,1
22	OW		346,15	11143	9671	8,9
23	Surface			229		0,6
24	Surface			100		0,2
25	Surface			286		0,3

PL stands for piezometric level, EC for electrical conductivity, F for fluoride, BW for borewell and OW for open well.