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The impact of intensive farming systems on groundwater availability in dryland environments: A watershed level study from Telangana, India

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ABSTRACT

Intensification of agriculture in India has increased food self-sufficiency. However, it has also led to unwanted environmental impacts, particularly the increased pressure on groundwater resources. These impacts are most severe in the dryland regions of the country. Therefore, this paper aims to understand the impact of intensified forms of agriculture on the availability of water resources in a dryland watershed in Telangana, India. To achieve this, we first assessed the water use of three main farming systems in the study region. We then calculated the water balance at the watershed level to understand the agricultural impact on groundwater availability within the watershed. The three farming systems studied were the crop without livestock system (CWL; 48% of households), the crop-dairy system (CD; 38% of households), and the crop with small ruminants system (CSR; 6% of households). The results indicated that the CD system used the highest quantity of water (19,668 m^3/household/y), followed by the CSR (8645 m^3/household/y) and CWL (4403 m^3/household/y). CWL and CD systems comprise 86% of the households, making these systems the largest water users. Finally, the water balance of the whole watershed showed a deficit of – 13.9 Mm^3/y. Cultivation of water-demanding non-dryland crops, increased specialization of farming systems, and management practices in current farming systems are the factors causing over-utilization of water and subsequent groundwater depletion. We also realize that the current policy environment and other drivers such as decreasing landholdings and market forces, also induce increased water use in production. We, therefore, conclude that there is a need to promote agro-ecologically suitable farming strategies, improve the existing technological options and introduce new policies that reduce the over-use of water resources for sustainable agricultural production in dryland regions.

1. Introduction

Transitions in farming systems are occurring rapidly worldwide due to increasing population, income growth, urbanization, and development policies (Reardon et al., 2019). Such transitions are also happening in India, where extensive traditional mixed farming systems are transitioning towards intensive farming systems (Amjath-Babu and Kaechele, 2015; Kuchimanchi et al., 2021a). These intensive farming systems are characterized by high use of inputs such as land and water, specialize in crop or livestock production as the primary income source, and are market-oriented (Udo et al., 2011; Oosting et al., 2014; Kuchimanchi et al., 2021b). While intensification of agriculture in India has increased food self-sufficiency, it has also led to rapid changes in agricultural land use and affected water availability and water use. Landscape changes have led to high precipitation runoff, low groundwater infiltration, and increased groundwater use for irrigation, particularly in dryland environments (Thomas and Duraisamy, 2018; Duraisamy et al., 2018; Jain et al., 2021).

India is the world's largest groundwater user (Jain et al., 2021; Paria et al., 2021), using around 230 km^3 of groundwater per year (World

Abbreviations: CWL, Crop without Livestock; CD, Crop with Dairy; CSR, Crop with Small Ruminants; AOT, Average Operational Time; APD, Average Pump Discharge; WS-1, Watershed -1; TLU, Tropical Livestock Units; NRDWP, National Rural Drinking Water Program; IMD, Indian Metrological Department.

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Bank, 2012). According to Rosegrant et al. (2009), about 65% of that groundwater is used to produce half of the country's food. However, the prospects of climate change indicate a negative impact on the future availability of water resources and a threat to India's food security (Kumar and Kumar, 2013; IPCC, 2014). Sixty percent of India is classified as dryland, i.e. arid and semi-arid (UNCCD, 2010), where water is already scarce. The continued growth of intensive agricultural production in these regions (Kuchimanchi et al., 2021 a,b), coupled with growing water demand from population growth and industrial sectors, is likely to result in severe water scarcity in India in the near future (Kumar and Kumar, 2013).

The impact of agricultural production on the use of water resources in India has been studied from a range of perspectives and using different methods, such as crop-livestock water productivity (Jayanthi et al., 2000; Singh et al., 2004; Blümmel et al., 2009; Haileslassie et al., 2011; Clement et al., 2011; Bekele et al., 2017), surplus water use in farming and growing water scarcity in dry regions (Batchelor et al., 2003; Bouma and Scott, 2006; Bharucha et al., 2014), and water resource auditing and/or modeling at watershed level (Perrin et al., 2012; Ariyama et al., 2019; Singh and Saravanan, 2020). All these studies deliberate on the impact of excessive water use at a landscape or regional level or analyze crop-livestock water productivity, water use, and water availability at a watershed level in isolation. Hence, to our knowledge, there are no studies that look at coupled interactions between water use by different farming systems at the farm level and its relation to the water availability at the watershed level in India.

Therefore, the current paper aims to understand the impact of water use by current dominant forms of intensified agriculture on the availability of groundwater resources in a dryland watershed in Telangana, India. To achieve this, we first assess the water use of the three main farming systems in the study region. We then calculate the water balance at the watershed level to understand the agricultural impact on groundwater available within the watershed. Gaining insight into water use by the different farming systems, their practices, and their effect on water availability could help anticipate future water scarcity and, therefore, better planning (Kuchimanchi et al., 2021a, 2021b; Kuchimanchi et al., 2022). In the discussion section, we reflect on the possible social and economic implications of the current developments in farming systems on water resource availability in dryland regions.

2. Material and methods

2.1. Background and study area

The current study was a part of a larger research project that studied the transition of farming systems, covering aspects of characterization of emergent farming systems, assessment of their economic performance, and analysis of their vulnerability to climate change (Kuchimanchi et al., 2021a, 2021b, Kuchimanchi et al., 2022). The research project was conducted in two watersheds: the *Rangareddy* and *Nagarkurnool* districts in the southern state of Telangana, India (Fig. 1), covering a sample of 3006 households (HHs; 46% of the total population) in both watersheds.

The watersheds fall in a drought-prone area (Manickam et al., 2012). The annual rainfall is 500–700 mm, distributed around the South-West (June to September) and the North-East (October to November) monsoon seasons. The aridity index of the region is $0.2 \leq AI < 0.5$ (Ramarao et al., 2019) and is therefore classified as semi-arid. The mean temperature in the area varies from 43 °C in May to 13 °C in December. The length of the growing period for crops ranges from 120 to 150 d/y. The watersheds are situated in the agro-ecological sub-region 7.2, characterized by deep loamy and clayey mixed red and black soils with medium to very high available water holding capacity (Gajbhiye and Mandal, 1983). These soils are classified as Group-B soils which have a minimum infiltration rate of 3.8–7.5 mm/h. The water transmission of such soils is identified as moderate rate, ranging from 0.15 to 0.30 mm/h (US SCS soil classification standards, SCS, 1956). The geology of the study region is dominated by crystalline basement rock (Archaean granite and Gneiss). A region with this type of geology is characterized by low porosity or sediment and has a low ability to store water.This results in frequent failures in both installation of borewells and water withdrawal after the installation.

Farming systems in both watersheds have similar characteristics (Kuchimanchi et al., 2021a; Kuchimanchi et al., 2022), and therefore the current study was conducted only in watershed 1 (WS-1; Fig. 1). The total geographic area of WS-1 is 9463 ha, covering four villages and a population of 1820 households (HHs), of which 1688 HHs (92%) were into agriculture-based livelihoods. The average farm size in the region is 1.0 ha, and the average herd size is 1.6 Tropical Livestock Units[1] (TLU) (Government of India, 2011; Kuchimanchi et al., 2021a).

Within WS-1, *Thalakondapalle* was chosen as the representative village for data collection (Table 1). Although five farming systems were present in the village, data collection was limited to the three farming systems providing consistent income from agriculture (Kuchimanchi et al., 2022), i.e. the Crop without Livestock (CWL), Crop with Dairy (CD), and the Crop with Small Ruminants (CSR). These systems covered 92% of the HHs in the region. A brief description of the three farming systems under study is provided in Table 2 (for further information, see Kuchimanchi et al., 2022).

2.2. Framework of analysis and data collection

In this study, a watershed is the unit of analysis. It is considered a social-ecological entity wherein the farming systems and people constitute the social component, and the watershed and its natural resources comprise the ecological component (Ostrom, 2009; Reddy and Syme, 2015). Fig. 2 shows the framework for data collection and analysis that was followed to calculate the water balance in the study watershed. In brief, we first collected data about agricultural water use at the farm level by conducting a longitudinal survey for the three main farming systems in the region.

Second, we collected data on domestic water use by HHs at the watershed level using secondary data sources. Agricultural and domestic water use together comprise of the water consumed by all HHs at the watershed level. Third, we used secondary data sources to estimate water availability at the watershed level. Finally, we calculated the water balance at the watershed level by subtracting the water consumed (WC) from the water available (WA).

2.3. Data collection of water use in different farming systems at the farm level

We estimated the water use at HH level for the different farming systems by first quantifying the total amount of water extracted by borewells per HH for farming and second by conducting a longitudinal study. To quantify the water extracted by borewells we needed to calculate the average operation time (AOT) and average pump discharge (APD) of borewells used by the HHs in the region. The AOT was obtained through the longitudinal study for all three seasons. For the APD, however, we used standard pump discharge values for monsoon, winter and summer as provided by the manufacturers. These values were computed using the pump's head capacity curve method. This is a common method used to compute expected discharge values when pumping test data are not available (Qureshi et al., 2003; Konikow, 2010). In addition to this, we also accounted for the underlying aquifer conditions based on regional delineation of principal aquifers by Central Ground Water Board (2012) as the yield rate of the aquifer limits the amount of groundwater that can be pumped. Further to this, as ground water levels are really low in the summer season and it may be

[1] Where 1 TLU = average live weight of 250 kg therefore 1 adult cow = 0.7 TLU, 1 adult buffalo = 1.5 TLU, sheep/goat =0.1 TLU

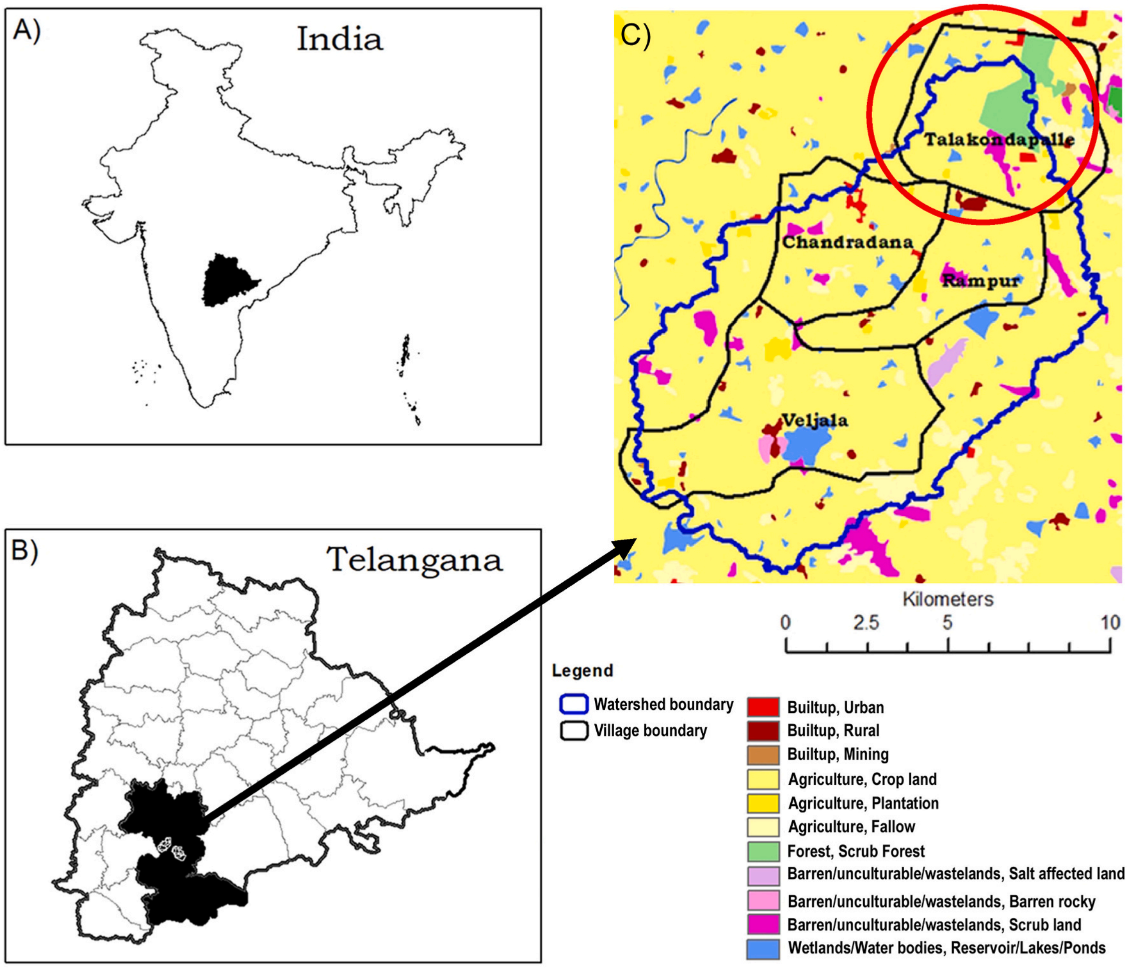

Fig. 1. (A) Location map of the study region in India. (B) The study region is within the state of Telangana. (C) The study watershed and the representative village *Talakondapalle* (circled) overlayed on land use and land cover base. Source: Ortho rectified Resourcesat-2 Data from LISS-III sensor of 3 seasons pertaining to 2015–16 (Monsoon season-Kharif: Aug-Oct, Post-monsoon-Rabi: Dec-Mar, Pre-Monsoon-Zaid: Apr-May).

Table 1
Distribution of households in farming systems across four villages in WS-1.

Villages	Farming systems					Total
	Crop Without Livestock	Crop with Dairy	Crop with Small Ruminants	Landless With Livestock	Crop With Diverse Livestock	
Thalakondapalle*	304	232	32	22	1	591
Chandradana	189	193	16	10	1	409
Rampur	147	102	8	85	0	342
Veljal	195	115	13	16	7	346
	835	**642**	**69**	**133**	**9**	**1688**

Source: Kuchimanchi et al., 2021a, Kuchimanchi et al., 2022; * is the selected village for the study.

inaccurate to use standards, we cross-verified the discharge rate by physically conducting pumping tests in the region. The pumping tests were in line with the standard values for summer provided by the manufacturers, hence validating the approach (see supplementary table for details). Hence, based on the pumps owned by farmers in the region the standard discharge rate was estimated to be 6.5 l/s in monsoon, 4.5 l/s in the winter and 1.0 l/s in the summer.

For the longitudinal study, 75 HHs (i.e. 25 HHs per farming system) were randomly selected from the full HH list of the representative village *Thalakondapalle* (i.e 591 HHs). The HH sample for the study was finalized after the selected HHs expressed their willingness to participate. Those declining to participate were replaced by new HHs until a sample of 25 HHs per farming system was reached. We also controlled the distribution of castes and farm size among selected HHs to ensure that the sample was representative of the total regional population. If the representation of one of these groups/categories was lacking, we substituted a randomly selected HH from the overrepresented group. Further details regarding the procedure and criteria to select HH can be found in supplementary material.

After selecting the HHs, the longitudinal study was performed using a structured questionnaire between August 2015 and August 2016. The questionnaire was field-tested and amended before use. The final version for the actual data collection was then printed into booklets. Farmers were trained on how to fill the booklet with the data required.

Table 2
General characteristics of the farming systems under study in WS-1.

	Crop Without Livestock (CWL)	Crop with Dairy (CD)	Crop with Small Ruminants (CSR)
Farmers (n)	835	642	69
Average land size (ha)	1.3	2.1	2.4
Average herd size (TLUs)			
Large ruminants	0	3.4	0
Small ruminants	0	0	5.5
Distribution per farm size[1]			
Marginal (<1 ha)	35%	13%	16%
Small (1–2 ha)	38%	30%	19%
Medium (2.01–4 ha)	21%	45%	42%
Large (>4 ha)	6%	12%	23%
Cropping characteristics	Rain-fed, Limited irrigation, Monocropping	Irrigated, Mixed cropping	Rain-fed, Limited irrigation, Monocropping
Crops	Cotton, Maize	Rice, Pulses, Vegetables, Green fodder	Cotton, Maize, Groundnut
Dominant livestock species	Native poultry (subsistence)	Large ruminants: crossbred/exotic cattle/buffalo	Small ruminants
Crop - livestock practices	Intensive practices	Intensive, specialized technologies	Intensive, specialized technologies Depend on common lands for grazing
Farm infrastructure	Traditional/basic	Use farm machinery	Traditional/basic

Source: Kuchimanchi et al., 2022; [1] Based on a wealth ranking assessment done by the implementation agency in the region.

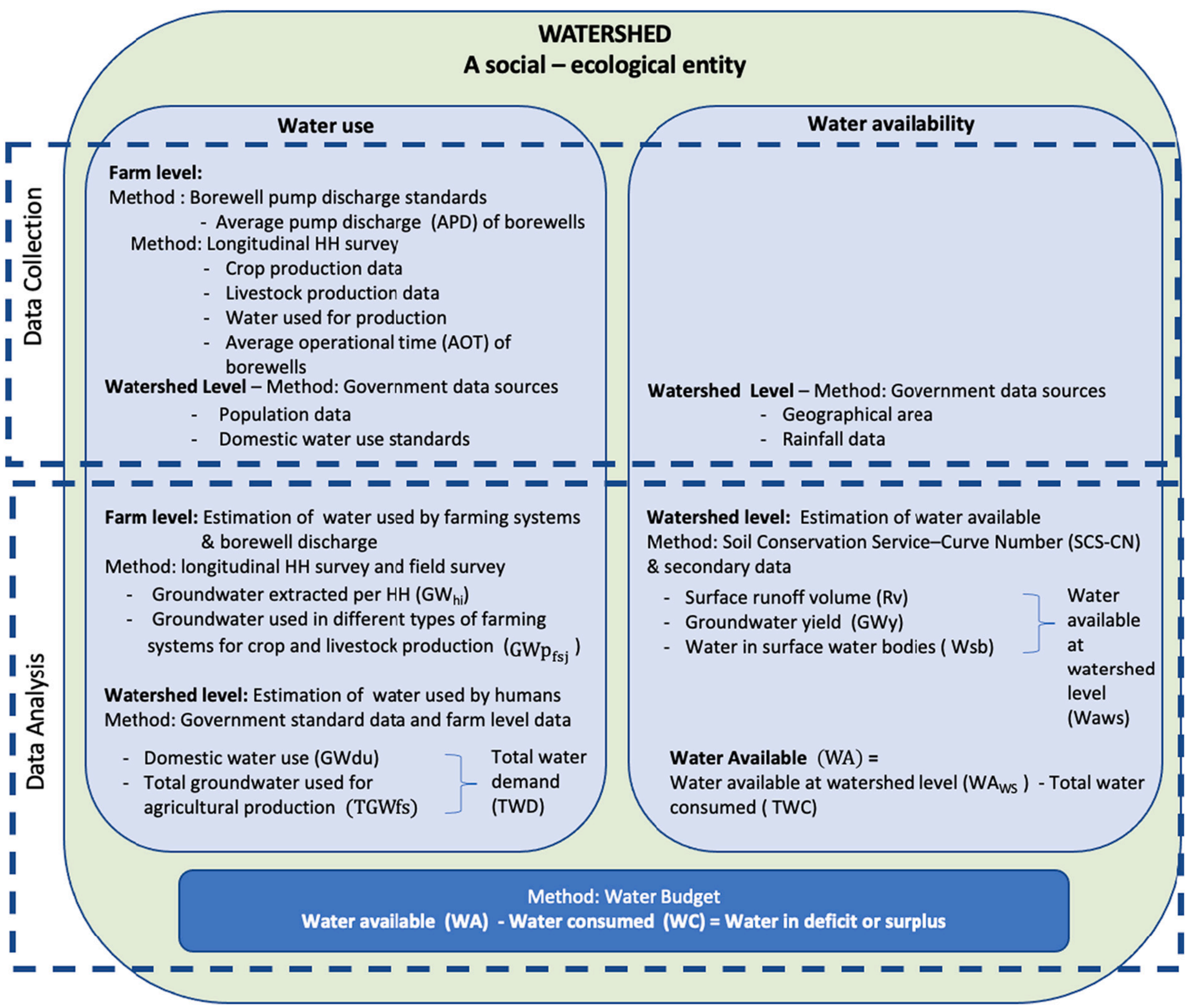

Fig. 2. Framework for data collection and data analysis.

The data collection process was monitored fortnightly by data collectors and once a month by the first author of this manuscript to ensure accuracy, consistency and to assist the farmers in data collection. The data collected in the booklets were as follows:

- General HH Profile – Respondent name, farm typology (i.e. CWL, CSR, CD system), and land size

- Crop data – types of crops grown during each agricultural season, the area for each crop and green fodder (ha), the area under irrigation (ha), and crop yield (kg).
- Livestock data – type of livestock owned (cattle: indigenous, cross-bred, exotic, bullocks; buffalo: indigenous and graded; sheep, goat), physiological stage of animal (i.e. young/adult, dry, heifer, in milk), herd size, total milk produced (l/d/ animal) and animals sold per household (type and number).
- Water-use data: borewells owned and used (n), time of pumping h/d, water storage structures used (i.e. water troughs and tubs, utensils), and their sizes (l).
- Water used for livestock production, i.e. drinking and animal management (e.g. cleaning and cooling animals) for large and small ruminants (l/d).

Groundwater from borewells was used as drinking water for animals, as surface water bodies in the region were dry. Therefore, the water consumed by animals for drinking was calculated by estimating the water capacity of the containers (e.g. troughs, plastic tubs or drums, steel utensils) used to provide water to animals in each HH. This was done by giving water to the animals by type (large or small ruminants) in different physiological stages (dry and in milk) to determine the exact water intake. This value was then multiplied by the times the animals were provided with water per day. This procedure was done daily every other week during the longitudinal study. In the case of small ruminants, in the summer season, when borewells were completely dysfunctional on their farms, shepherds leased borewells from other farmers in the region who were willing to share water resources. The same procedure given above was followed. Further, to avoid duplication, care was taken that water from permanent water tanks on the farms, though owned by very few HHs (i.e. only 12 out of 25 HHs in the crop-dairy system) was not used for drinking water. This was also reconfirmed by farmers as stored water was not provided to the animals.

2.4. Data collection of domestic water use at the watershed level

The domestic water use, including water used for cooking, bathing, sanitation needs, and washing clothes by HHs (i.e. 55 l/d/person), was derived from secondary government data sources - the government census data (2011) for population details and the National Rural Drinking Water Program (NRDWP) guidelines (Government of India, 2013).

2.5. Data collection of groundwater use and availability at the watershed level

The groundwater availability in the region was estimated using secondary data sources. The average rainfall data in the region was obtained from the Indian Meteorological Department database (accessed in 2018). Data regarding the total geographical area (e.g. runoff water, see section 2.6.3) and predominant land categories in the region was obtained from the government census (2011). We assumed that water stored in surface water bodies was 20% of the surface runoff in the region. This was based on ground realities found in Kuchimanchi et al. (2021a), field visits that indicate shallow depth, and literature on potential evapotranspiration for the region (Rao et al., 2012). Similarly, as the crops were flood irrigated in the region calculating return flow from irrigation is required to estimate the water balance in the region. However, the irrigation return flow (RF) varies crop and season wise, and is influenced by several factors like: the overuse of borewells for irrigation, gneissic aquifer system, high evapotranspiration, uncertainty of water pumping discharge rate, irrigation time and crop choices (Naghedifar et al., 2018) or stages of crop growth, soil texture and depth (Jafari et al., 2012). Therefore, in this study we have used a calculated safe estimate of 20% irrigation return flow coefficient based on study by Dewandel et al. (2008) which is approximately 30 km from the current study site.

2.6. Calculations

Using the data from the longitudinal study and the secondary data, we calculated the groundwater consumption and availability in the study watershed in four steps: 2.6.1) estimating water consumed in different farming systems at the farm level, 2.6.2) estimating domestic water use at the watershed level, 2.6.3) estimating groundwater availability at the watershed level, and finally, 2.6.4) calculating the water balance at the watershed level. As the watershed covers four villages, these calculations were also done at village level using the same method to understand the variation in water use and groundwater available across villages.

2.6.1. Estimating water used in different farming systems at the farm level

Using the average operation time (AOT) and average pump discharge (APD) (see section 2.3), the total groundwater extracted per HH (GW_{hji}) was determined. Here the difference in the number of active borewells owned by HHs was the main factor determining the total groundwater extracted per HH (GW_{hji}). Therefore the general equation for this is:

$$GW_{hji} = AOT_j^{*}\, APD^{*}\, n_{hi} \tag{1}$$

Where:

GW_{hji} = the groundwater extracted by all active borewells per HH h in farming system j in season i (l/d)

AOT_j = the annual average operational time of borewells per HH in farming system j (h/d).

APD = the average pump discharge per borewell (l/h)

n_{hi}= number of active borewells owned by HH h in season i (longitudinal study)

h = the farms/households in farming system j

j = the type of farming system i.e. *CWL, CD or CSR*

i = season (monsoon - 20 weeks, winter – 20 weeks, summer – 12 weeks)

a) Estimation of water use in the different farming systems

After estimating the groundwater extracted per HH we calculated how the water extracted is used for crop and livestock production by the different farming systems under study. The equation therefore is:

$$GWp_{hji} = GWlp_{hji} + \left(GWcp_{hji} - RF\right) \tag{2}$$

Where:

GWp_{hji} = the groundwater used for agricultural production in HH h in farming system j in season i (l/d)

$GWlp_{hji}$= the groundwater used in HH h for livestock production in farming system j in season i (l/d)

$GWcp_{hji}$ = the groundwater used for crop production in HH h in farming system j in season i (l/d).

RF = irrigation return flow which is estimated to be 20% of the total water applied for crop irrigation as return flow (Dewandel et al., 2008)

h = the farms/households in farming system j

j = the type of farming system i.e. *CWL, CD or CSR*

i = season (monsoon – 20 weeks, winter – 20 weeks, summer – 12 weeks)

in the above eq. [2] *$GWlp_{hji}$* was calculated by:

$$GWlp_{hji} = ADWa_{hji}{}^{*}na_{hji} + ADWy_{hji}{}^{*}ny_{hji} + GWfm_{hji} \tag{2.1}$$

Where:

$GWlp_{hji}$ = the groundwater used for livestock production in HH h in farming system j in season i (l/d)

$ADWa_{hji}$ = the average drinking water for an adult animal in HH h in farming system j in season i (l/animal/d)

$ADWy_{hji}$ = average drinking water for a young animal in HH h in farming system j in season i (l/animal/d)

na_{hji}= the average number of adult animals in HH h in farming system j in season i (n)

ny_{hji}= the average number of young animals in HH h in farming system j in season i (n)

$GWfm_{hji}$ = the groundwater used for farm management in HH h in farming system j in season i (l/d)

h = farms/households in farming system j

j = the type of farming system i.e. *CWL, CD or CSR*

i = season (monsoon – 20 weeks, winter – 20 weeks, summer – 12 weeks)

And $GWfm_{hji}$ per HH was calculated by:

$$GWfm_{hji} = \sum_{k=1}^{n} VWS_{khji} * NSE_{khji} \tag{2.1.1}$$

Where:

$GWfm_{hji}$ = the groundwater used for farm management in HH h in farming system j in season i (l/d)

VWS_{khji}= the volume of water in storage structure k in HH h in farming system j in season i (l/d)

NSE_{khji} = the number of times storage structure k is emptied in HH h in farming system j in season i (n/d)

k = the storage structures used to store water during season i

h = farms/households in farming system j

j = the type of farming system i.e. *CWL, CD or CSR*

i = season (monsoon - 20 weeks, winter – 20 weeks, summer – 12 weeks)

$GWcp_{hji}$ per HH is calculated by:

$$GWcp_{hji} = GW_{hji} - GWlp_{hji} \tag{2.2}$$

Where:

$GWcp_{hji}$ = the groundwater used for crop production in HH h in farming system j in season i (l/d)

GW_{hji}= the groundwater extracted in HH h in farming system j in season i (l/d) (Refer to eq.[1]above)

$GWlp_{hji}$ = the groundwater used for livestock production in HH h in farming system j in season i (l/d)

b) Estimation of water use for farming at the watershed level

Once the water use in different farming systems was determined, the total water used in agricultural production in all farming systems i.e. TGW_{fs} was calculated at the watershed level. For the systems under study, i.e. CWL, CD, and CSR, farm-level data from the longitudinal study was used. To determine the distribution of HH in a particular farming system we used the proportions described in Kuchimanchi et al. (2022). That study covered the same area and nearly 50% of the population, and determined that 48% of HH belonged to CWL system, 38% to CD system, 6% to CSR system. The remaining 8% belonged to Crop with diverse livestock (CWDL) and to Landless with livestock (LWL). The same farm-level data from the longitudinal study were used to quantify water use in these systems. This was possible as the CWDL had a similar cropping pattern. For livestock, the data on herd size was taken from a previously conducted HH survey done by Kuchimanchi et al. (2021a, 2022). The average water requirements for the different livestock species were used from the current study. We considered these distributions of HH per farming system and governmental census data (2011) to extrapolate to watershed level. For HHs with non-agricultural activities, only domestic water use was accounted for. Hence, TGW_{fs} is calculated by:

$$TGW_{fs} = \sum_{j=1}^{5} GWp_{fs_j} \tag{3}$$

And GWp_{fs_j} is:

$$GWp_{fs_j} = \sum_{i=1}^{3} GWp_{ji} * d_i * n_j \tag{3.1}$$

Where:

TGW_{fs} = the total groundwater used in all farming systems at the watershed level (l/y)

GWp_{fs} = the groundwater used for agricultural production by all HHs of farming system j at the watershed level (l/y)

GWp_{ji} = the average groundwater used for agricultural production in a HH h in farming system j in season i (l/d)

d_i = days per season i i.e. *140 days in monsoon, 140 days in winter, and 85 days in the summer*

n_j = total number of households in farming system j

h = farms/households in farming system j (source: Government population census, 2011)

j = the type of farming system i.e. *CWL, CD, CSR, CWDL, LWL*

I = season (monsoon – 20 weeks, winter – 20 weeks, summer – 12 weeks)

2.6.2. Estimating domestic water use at the watershed level

Similarly, the total water used for domestic use per year (GW_{du}) was calculated by multiplying the total population in the watershed (i.e. 15,952) by 55 l/person/d according to the standard prescribed by NRDWP guidelines (2013).

2.6.3. Estimating water availability at the watershed level

The Soil Conservation Service–Curve Number (SCS-CN) method (SCS, 1956; Mishra and Singh, 2003, Singh, 2017) was used to estimate water availability within a watershed based on the rainfall received in the region. While this method was initially developed to estimate direct runoff from rainfall in particular events (e.g. storms) (USDA, 1956), posterior developments and modifications have allowed the model to be applicable to long-term hydrological simulations (e.g. seasons or years) (Mishra and Singh, 2004; Singh, 2017). We follow the approach suggested by Singh (2017). This method is based on an empirical approach to the relationship between rainfall (P) and ground conditions of the watershed (soils, management, and antecedent moisture content). The formula is provided below:

$$Q = \frac{(P - Ia)^2}{(P - Ia + S)} \tag{4}$$

$$S = (25400/CN) - 254 \tag{4.1}$$

Where:

Q = runoff depth is the runoff that directly enters the stream immediately after the rainfall, it includes surface runoff, prompt interflow, and rainfall on the surface of the stream (mm)

P = average rainfall, i.e. *687 mm for the last 5 years using daily rainfall data obtained from Indian Metrological Department (2018) (mm)*

I_a = initial abstraction, i.e. *0.3 mm under Indian conditions (Singh, 2017) (mm)*

S = maximum potential retention, i.e. *84.6 mm (US SCS soil classification standards) (mm)*

CN = 75 given the soil type, land use and cover, antecedent moisture content of the watershed as per the US SCS soil classification standards, (Singh, 2017))

Note: As the whole of the watershed has similar land use and land cover and the major land type is agricultural lands (seeFig. 1for reference), the Ia and S values were considered the same for the whole watershed

Once the runoff depth (Q) is calculated, the runoff volume (RV) and groundwater recharge[2] (GW_R) were calculated. The empirical formulas for these are:

$$RV = 1000 * H_0 * F \tag{5}$$

Where:

RV = runoff volume is the total amount of water expected in a given period of time (in this case, season) in the catchment (in this case, a watershed) (m^3/y)

[2] Source: https://calculator.agriculture.vic.gov.au/fwcalc/information/determining-catchment-yield-for-planning-farm-dams

H_0 = runoff depth. In this study, as rain gauge data was not available, the value of H_0 = Q in eq. [4] (mm)

F = Area (ha)

$$GW_R = (C*A*P/10) + \mathrm{RF} \tag{6}$$

Where:

GW_R = is part of the runoff that gets infiltrated into the ground and reaches the groundwater storage in the soil (m^3)

C = runoff coefficient is identified as 7.5 It is an empirical value obtained based on the Ia, considering the soil type (red sand – loam soil) in the watershed which falls in Group B (USDA-SCS soil classification, Singh, 2017)

RF = return flow during irrigation of crops in the region estimated in eq.2

A = area of the watershed (ha)

P = rainfall (mm)

2.6.4. Estimating the water balance at the watershed level

A water balance (WB) was then calculated using the following equation from above:

$$WB = WAws – TWC \tag{7}$$

Where WAws:

$$WAws = GW_R + Wsb \tag{7.1}$$

And TWC:

$$TWC = TGWfs + GWdu \tag{7.2}$$

Where:

WB = the water balance at the watershed level, i.e. *water in surplus or deficit (l/d)*

WA_{WS} = the water available at watershed level (groundwater + water in surface water bodies) (l/d)

TWC = total water consumed (l/d)

GW_R = Groundwater recharge (m^3) (Eq. [6])

Wsb = water in surface water bodies (m^3) assumed to be 20% of total surface water runoff in the watershed based on evapotranspiration values of the region (Rao et al., 2012) and ground realities as per Kuchimanchi et al. (2021a)

GWdu = the domestic water use (l/d) (section 2.6.2)

TGWfs = the total groundwater used by all different farming systems in the watershed (l/d) is done by extrapolation using government census population data (Eq. [3])

Note: l/d is presented in m^3/y in Table 4.

3. Results

3.1. Estimating water use in different farming systems in the region

Based on the pump discharge standards the average pump discharge values for borewells in the region was determined as 23,400 l/h in the monsoon season, 16,200 l/h in the winter and 3600 l/h for the summer seasons. These values were used as the standard to calculate the total water extracted by borewells per HH per season. Though electricity in rural areas was available only for seven h/d, the study showed that the average time borewells pumped water was 1.5 h/d during the monsoon season as the rainfall compensated for reduced irrigation and pumping time. For the winter and summer seasons, however, the average pumping time was 3.2 h/d.

The longitudinal study on water use at the farm level by the three farming systems revealed the following (Table 3):

CWL system ($n = 25$): HHs in this system owned 0.9 (SD 0.3) borewells on average, which were functional only in the monsoon season. The average area under crops was 1.3 ha (SD 1.1 ha) per HH during the study year. The crops grown by these HHs were predominantly maize and cotton. The total water used for crop production was 4403 m^3 (SD 1624 m^3) per HH.

CSR system ($n = 25$): HHs in this system owned an average of 1.7 (SD 0.7) borewells, a few of which were also functional in the winter season. Hence, some HHs in this system cultivated crops for two seasons per year. The average cropped area per HH was 1.2 ha (SD 1.5 ha) in the monsoon season and 1.2 ha (SD 0.5 ha) in the winter season. The main crops grown were maize and cotton in monsoon and groundnut in the winter season. The total water used per HH was 8645 m^3 (SD 3731 m^3) for crop and small ruminant production per year.

In this region, farmers used groundwater from borewells to provide drinking water to their animals because the surface water bodies were almost nil. The water consumption for adult sheep and goats was estimated to be 4.6 and 4.8 l/d in the monsoon and winter seasons and 5.9 l/d in the summer season. For lambs or kids, the values were 1.4 l/d in monsoon, 2.3 l/d for winter, and 3.9 l/d for summer. Therefore, the total drinking water was estimated to be 122 m^3 (SD 86.8 m^3) per HH for an average herd size of 83.2 (SD 56.6) TLUs per HH.

CD system (n = 25): HHs in this system had the highest number of

Table 3
Farm characteristics and average (SD) water use per farm per year of the three farming systems in the study watershed.

	Monsoon (Jun-Sept)	Winter (Oct-Feb)	Summer (Mar-May)	Total
Crop Without Livestock system	N = 25			
Borewells in working condition (#)	0.9 (0.3)	–	–	
Area under crops and green fodder (ha)	1.3 (1.1)	–	–	
Water for crops[1] (m^3/y)	4403 (1624)			
Total groundwater used for farm production (m^3/y)	**4403 (1624)**			**4403 (1624)**
Crop with Small Ruminants system	N = 25			
Borewells in working condition (#)	1.7 (0.7)	1.0 (1.0)	–	
Area under crops and green fodder (ha)	1.2 (1.5)	1.2 (0.5)	–	3.0 (2.0)
Water used for crops[1] 2 (m^3/y)	3510 (1284)	5022 (2360)	–	8523 (3645)
Average herd size (TLUs)	87.2 (61.1)	88.8 (62.9)	74.1 (45.7)	83.2 (56.6)
Water used for livestock (m^3/y)	35.3 (25.5)	49.2 (33.1)	37.9 (28.2)[2]	122 (86.8)
Total groundwater used for farm production (m^3/y)	**3545 (1258)**	**5071 (2393)**	**37.9 (28.2)**	**8645 (3731)**
Crop with Dairy system	N = 25			
Borewells in working condition (#)	4.0 (2.9)	3.2 (1.8)	1.2 (1.9)	
Area under crops and green fodder[1] (ha)	1.2 (1.2)	1.2 (0.5)	1.1 (0.5)	3.5 (2.2)
Water for crops and fodder (m^3/y)	8951 (5143)	9020 (4597)	826 (281)	18,797 (10021)
Herd size (TLUs)	8.6 (5.0)	7.9 (5.3)	5.9 (5.1)	7.4 (5.1)
Animals in milk (#)	5.0 (3.0)	4.0 (3.1)	4.0 (3.1)	4.3 (3.1)
Unproductive animals (#)[3]	5.5 (3.0)	6.9 (5.1)	6.5 (5.4)	6.3 (4.5)
Drinking water for animals (m^3/y)	63.2 (47.7)	52.8 (49.8)	46.7 (35.7)	163 (134)
Water used for maintenance (m^3/y)	68.7 (269)	278 (460)	361 (403)	708 (1132)
Water used for livestock (m^3/y)	132 (316)	331 (510)	408 (438)	871 (1265)
Total groundwater used for farm production (m^3/y)	**9083 (5459)**	**9351 (5107)**	**1234 (719)**	**19,668 (11286)**

[1] Water used excludes return flow from irrigation.
[2] Borewells are leased from other farmers in the region.
[3] Unproductive animals include calves, dry animals, and bullocks.

borewells, 4.0 (SD 2.9). Some borewells were in working conditions throughout the year, i.e. 3.2 (SD 1.8) in the winter and 1.2 (SD 1.9) borewells in the summer season. These HHs were into crop and dairy production, and the total groundwater usage per HH was estimated to be 19,668 m^3 (SD 112865 m^3). A large share of this water was used to irrigate perennial green fodder. The food or cash crop cultivation (such as rice, maize, cotton, and vegetables) was limited to the monsoon season in the study year. The total cropped area per HH was 3.5 ha (SD 2.2 ha) for the whole year. The cropped area was dedicated to green fodder production in the winter and summer seasons. Farmers further indicated that winter and summer season crops were planned based on groundwater availability as they preferred to divert water for dairy production during these seasons.

In dairying, water was mainly used as drinking water for animals and livestock management activities such as cleaning and cooling animals in the summer. However, survey data indicated that only 48% of the HHs in the sample used water for the latter. Hence, from the total water used by the CD system (i.e. 18,797 m^3), only 871 m^3 (SD 1265 m^3) was used as drinking water for animals and livestock management activities.

Fig. 3 shows the drinking water estimates for different cattle across breeds and physiological states. Among the dairy cattle breeds, the exotic cattle had the highest estimates of drinking water, followed by the crossbreds. We also found that a high amount of water was used for young animals, such as heifers, calves, dry animals, and non-dairy cattle like bullocks (See Table 3). The herd size per HH ranged from 4 to 32 animals and averaged at 7.4 (SD 5.1) TLUs per HH. Of this herd size, an average of 4.3 (SD 3.1) animals were in milk, while 6.3 (SD 4.5) animals were unproductive.

3.2. Impact of different farming systems at the watershed level

Table 4 presents the estimates of the domestic water use, the water used by the different farming systems, and the water availability at the village and the watershed level. The water balance table indicates that the water is in deficit at the village and watershed levels. The water balance at village level, however, differed between villages. This variation can be attributed to variation in proportion of farming systems between villages (see Table 1) and the population density in the villages. The high water deficit at the watershed level is explained by i) the excess water consumption by farming systems; ii) the region's high surface runoff volume (47.8 Mm^3/y) which also accounts for the high evapotranspiration in the region (1500–1950 mm); iii) and the low infiltration[3] capacity of water into the ground (i.e. 13.4 Mm^3/y with return flow) due to the region's geology (classified as the peninsular gneissic complex, i.e. hard rock formation), and the land use and cover (which is predominantly croplands) that further aggravate surface runoff.

4. Discussion

This study, coupling the water use in different farming systems and the water balance at different scales (i.e. farming system, village, or watershed), provides a more complete understanding of the water available and the water consumption in the region.

Among the three systems, the CD system used the highest water (19,668 m^3/HH/y) compared to the CSR (8645 m^3/HH/y) and CWL (4403 m^3/HH/y) systems. The livestock systems used more water than the CWL system, mainly to produce green fodder in the CD system and for the cultivation of other commodity crops (e.g. groundnut) in the CSR system (see Tables 2 and 4). Groundnut production in CSR system can complement small ruminant production, since crop residues are used as feed (Heuzé et al., 2017). However, green fodder production in the CD system is a dedicated feed crop for dairying only, which increases the water footprint of the system. The groundwater abstraction rate by all farming systems in the region is more than the recharge rate of the watershed, resulting in a water deficit (see Table 4). The CD and CWL systems were the largest water users because of the high water demand, but also because they constituted 86% of the HHs in the region.

This study suggests that there is a possible over-utilization of water in the region, which is caused by three factors. First, there is a high focus on cultivating non-dryland crops such as rice, cotton, fruits, and vegetables. The cultivation of these crops not only directly increases the use of water in the region but also reduces the availability of crop residues for livestock. The shortage of crop residues, for instance, has made the CD system to cultivate green fodder and invest (up to 80% of farming costs) in fodder from external markets (Kuchimanchi et al., 2022). Hence, the reduced availability of crop residues increases water use within the region and contributes to high virtual water use for fodder production outside the region (Kumar and Singh, 2008; Harika et al., 2015). Second, increasing farm intensification and specialization imply reduced circularity in agriculture and sub-optimal integration of crop-livestock production within and between farms in the region (Kuchimanchi et al., 2021a; Kuchimanchi et al., 2022; Oosting et al., 2021). For instance, the CD system uses a large share of water to grow dedicated feed crops for livestock, such as green fodder (Table 3). In less specialized systems, this high-water footprint is often lower as the feed for livestock comes partly from crop residues grown on the same farm (e.g. CSR system) or from other farms in the region without livestock (e.g. CWL system). Third, certain management practices in the farming systems lead to high water use. For example, in the CD system, we found HHs having large herd sizes with many replacement animals, i.e. calves and heifers (Table 3), which comprised almost 60% of the TLUs per HH. Although keeping a large herd has benefits (e.g. manure availability or income from the sale of animals), a high number of female calves and heifers that take two years or more to become productive also require water resources. Similarly, in crop production, HHs in the region adopted management practices that increased or squandered water use. For instance, the higher use of inorganic fertilizers due to the lack of manure (Kuchimanchi et al., 2021a) causes soil hardening and loss of soil carbon levels, particularly in course textured semi-arid soils (Pahalvi et al., 2021). In dryland environments, both soil hardening and low soil carbon reduce the soil's water holding capacity, necessitating more irrigation (Plaza-Bonilla et al., 2015). In addition to this, the free power supply in the region also promotes unfavourable irrigation practices by farmers, such as flood irrigation when not needed. Further small and marginal farmers, are a majority in the region. This results in lower adoption of conservative measures or cover crops due to small land holdings and economic factors which also contributes higher water run-off.

The suggested over-utilization of water resources may have resulted in water scarcity. As a coping strategy, most HHs (i.e. the CD and CWL systems) have limited crop production to one season per year (Table 3), because borewells in the region do not function across the year and there is considerable variation in borewell pump discharge for summer (2000–5227 l/h) (see supplementary material). These findings also signify that over-utilization of water has led to groundwater scarcity in the region, which is in line with Sishodia et al. (2016) and the Central Ground Water Board (2017 & 2019). In addition to this, the high presence of croplands in the area (Kuchimanchi et al., 2021a) is another significant factor that causes groundwater depletion as it leads to high runoff due to a low vegetation cover (present study, Thomas and Duraisamy, 2018; Duraisamy et al., 2018). This phenomenon is illustrated in the water balance (Table 4), which shows a high runoff volume of 47.8 Mm^3 while the groundwater recharge was only 13.4 Mm^3 and only 6.9 Mm^3 is captured in surface water bodies at the watershed level. These findings not only indicate the region's low groundwater recharge potential, but also show that the region's ability to meet the water requirements for the current production systems might have been exceeded.

[3] Sukhija et al., (1996), show that the natural direct groundwater recharge in semi-arid regions of India with crystalline basement rock or peninsular gneissic complex is 3–15% of the rainfall in the region

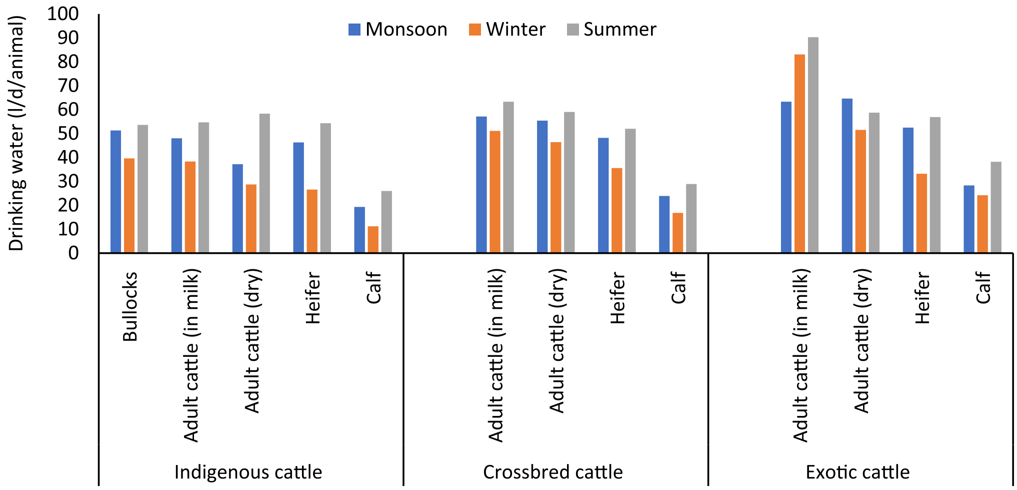

Fig. 3. Average drinking water for large ruminants (l/d/animal).
(Source: Longitudinal study 2015–16)

Table 4
Water Balance of the four villages and the watershed.

	Thallakondapalle	Chandradana	Rampur	Veljal	Total at WS
WS area in the village (ha)	2718	1897	1604	3244	9463
Population (n x1000)	5157	2352	3255	5188	15,952
Average rainfall over 5 years (mm/y)	687	687	687	687	687
Runoff volume[1] (Mm^3)	13.7	9.6	8.1	16.4	47.8
Groundwater Recharge[2] (Mm^3)	4.3	2.5	2.2	4.5	13.4
Water available (Mm^3/y)					
Surface water runoff	9.4	7.1	5.9	11.9	34.3
Water in surface water bodies[3]	1.9	1.4	1.2	2.4	6.9
Water not available as ground or surface water for farm production[4]	7.5	5.7	4.7	9.5	27.5
Water available for use (groundwater recharge + surface water bodies)	6.2	3.9	3.4	6.9	20.2
Water Use (Mm^3 /year)					
Domestic water use	0.10	0.05	0.03	0.07	0.25
Water used for farm production[5]					
Crop Without Livestock	2.5	1.0	1.3	3.0	7.8
Crop with Small Ruminants	0.5	0.2	0.2	0.4	1.2
Crop with Dairy	8.5	4.7	4.0	7.7	24.9
Other farming systems	0.0	0.0	0.0	0.1	0.1
Total Water Consumed (TWC) (Mm^3)	***11.5***	***6.0***	***5.5***	***11.2***	***34.2***
Water Balance (Deficit/Surplus) (Mm^3)	***−5.4***	***−2.1***	***−2.1***	***−4.3***	***−13.9***

[1] Runoff Volume is the total amount of water expected in a given period of time (in this case, season) in the catchment (in this case, a watershed).
[2] Groundwater recharge is part of the runoff that gets infiltered into the ground and reaches the groundwater storage in the soil. This also includes the return flow from irrigation of crops which is estimated to be 20% of the total ground water applied for irrigation.
[3] Assumption is that only 20% of the total surface water available is stored in surface water bodies as they are few and evapotranspiration in the region is high.
[4] Is the water stored as soil moisture, evapotranspiration (1500–1950 mm/y), transpired by vegetation, and other surface runoff not captured as groundwater or in surface water bodies.
[5] Extrapolated to the total number of households in the villages using government population census data based on the percentage of households per farming system in the sample.

The high water-demanding practices leading to groundwater use and depletion, both in the region and across India, can be related to socio-economic conditions of farming communities, market demand, access to credit, agricultural and infrastructural subsidies, and development policies. Kuchimanchi et al. (2021b) showed that small landholdings and market demand for certain agricultural commodities impose farming strategies that are water-demanding on rural HHs to earn better incomes (e.g. cash or vegetable crops and dairy farming). Financial and credit systems may also promote such water-demanding farm production pathways through loans to farm ventures with assumed cash flow and repayment capacity (Ripoll Bosch and Schoenmaker, 2021; Kuchimanchi et al., 2022). Along with these, policies supporting smallholder agricultural production can unintentionally worsen the situation further (Shiferaw et al., 2008; Fishman et al., 2015; Sishodia et al., 2016; Mitra et al., 2022). For example, subsidies on power supply, irrigation infrastructure, and agricultural intensification accelerated land-use change and excessive water pumping in dry regions when coupled with market demand for specific agricultural produce, as they are usually water-demanding. Similarly, despite the large-scale promotion of water-efficient systems (drip and sprinklers) in India, Fishman et al. (2015) show that the potential of these systems to reduce the excessive extraction of groundwater is reduced due to the simultaneous increase in irrigated area. Lastly, the watershed development program[4] could also be contributing to the same issue due to incoherent program design. The

[4] India's most extensive development program for drylands focused on improving rural livelihoods through enhancing agricultural productivity by increasing the availability of surface and groundwater for agricultural production

program, on one hand, promotes agricultural intensification that is water-demanding. This is counterproductive to the other aim of the program, which is to promote soil moisture conservation measures that increases water availability in a region. Similar findings have been reported by Batchelor et al. (2003), Joshi et al. (2004), and Bouma and Scott (2006).

The situation described above may be the case in other dryland states of India, as the same policies and development programs are implemented. Jain et al. (2021) further state that increasing groundwater depletion is expected to reduce cropping intensity by 68% in already groundwater-depleted regions. Hence, if current water-demanding agricultural pathways continue, India's food security might be in jeopardy and needs to be addressed. The further expansion or intensification of agriculture may also aggravate the social implications linked to depleting natural resources such as compromised incomes, high dependence on markets for inputs and feed, and increased indebtedness, all inducing marginalization and vulnerability to climate change reported in studies by Shiferaw et al. (2008), Taylor (2013) and Kuchimanchi et al. (2021a, 2021b, 2022). Vaidyanathan (2006) and Chinnasamy et al. (2019) have even found a link between groundwater depletion and farmer suicide-prone zones in some southern Indian states, where groundwater is the only source of irrigation for agricultural production. These insights imply that dryland watersheds have ecological limits. Agricultural production, therefore, needs to be determined by the region's water resources carrying capacity to mitigate the risk of desertification as reported in other dryland regions of the world (United Nations, 2011; IPCC, 2019).

Considering the above, the promotion of suitable farm strategies, modifying existing technological options and introducing new policies to reduce the over-use of water resources in food production is warranted. Farming strategies include the promotion of circularity in agricultural systems towards efficient use of natural resources (Muscat et al., 2021; Oosting et al., 2021); advocating feed and animal management options that are suitable to dry regions (e.g. control of herd size and structure, with optimal replacement strategies, choice of feed types and quality, improve animal health care and suitable animal breeds and purposes) (Descheemaeker et al., 2009; Kebebe et al., 2015; Tamou et al., 2018); or accentuate agronomic practices that maximize soil carbon levels and water holding capacity (e.g. soil and crop residue management, use of organic manures, and suitable cropping system designs) (Plaza-Bonilla et al., 2015; Giller et al., 2021).

The technological options involve the improvement of existing water conservation and use measures (e.g. watershed development, inland lake restoration, farm ponds, water-efficient systems) as water scarcity continues to grow, implying that the current measures may be inadequate. The first suggestion is to make climate science-based alterations in watershed development measures for better capture of surface runoff. This is needed as climate change is predicted to significantly influence the timing and magnitude of runoff, eventually impacting water supplies, water quality, and aquatic ecosystems of a watershed (Marshall and Randhir, 2008). The second would be to mainstream community engagement approaches and tools[5] in existing local governance structures to facilitate communities to manage their natural resources.

Regarding policies, we realize the necessity for a range of new policies targeting sustainable agricultural production in dryland regions. These policies entail, for instance, the introduction of regulatory guidelines for the use of land and water resources (Shiferaw et al., 2008; Plaza-Bonilla et al., 2015; Sishodia et al., 2016; Khair et al., 2019); policies that incentivize the up-take of technologies and farm strategies for water conservation (Fishman et al., 2015; Shao and Chen, 2022; Mitra et al., 2022; World Resources Institute, 2021); or region-specific agricultural commodity pricing and favorable financial and credit systems that promote the adoption of agro-ecologically suitable crop-livestock production (Harding et al., 2021; Ripoll Bosch and Schoenmaker, 2021). It is expected that such policies will address the unregulated use of water, reduce the over-utilization of water, and support suitable dryland farm development pathways.

This research aimed at gaining insight into how water is consumed in the study area by different farming systems, and what could be the implications of farming system development at watershed level. In the methodology, we combine different quantitative methods. One of the methods applied is the SCS-CN method, to estimate the runoff in the watershed. This method was initially developed to estimate direct runoff from rainfall in particular events (e.g. storms) and in particular locations in the United States of America (SCS, 1956). The convenience of the model, however, made it popular and was rapidly modified, improved and adapted for other locations (Ponce and Hawkins, 1996; Garen and Moore, 2005; Ajmal and Kim, 2014; Bartlett et al., 2016) and for long-term studies, such as seasons or years rather than particular events (Mishra and Singh, 2004; Singh, 2017). This method has also been adapted to suit Indian conditions (suggested by the Ministry and Agriculture, Govt. of India, 1972 in Singh, 2017). However, the method is still subject to criticism due to the several adaptations and because its oversimplification may compromise the accuracy of the results (see references above). Further, as the study used several quantitative methods and combined several data sources - the assumptions and the generalities introduced in some of the calculations may lead to bias in the final figures presented. For instance, the study uses governmental data and standards (e.g. population census, water pump discharge standards provided by pump manufacturers) may not be exact. The assumptions and the methods applied for runoff and irrigation return flow may also result in a higher runoff or a lower recharge value underestimating the total water available. Therefore, future in-situ measurements and groundwater monitoring system studies will be required to refine the water balance equation. However, despite these issue, the values still fall within an acceptable range of other similar studies. For instance, literature indicates runoff values to be high in arid and semi-regions due to the geology and high evapotranspiration rates (Rao et al., 2012). According to Sukhija et al. (1996), the natural direct groundwater recharge in semi-arid regions of India with crystalline basement rock or gneissic complex (such as in this study watershed) is 3–15% of the rainfall in the region (while our estimate is approximately 10% without return flow). Other studies in semi-arid regions also indicate low recharge, which is also the cause of high runoff (Rejani et al., 2015; Surinaidu et al., 2021). Although the results are similar to the findings in studies quoted above, results of this study should be considered as indicative rather than in absolute terms.

5. Conclusion

While intensification of agriculture has shown its benefits, particularly in increasing total food production, we also find that agricultural intensification in water-limited environments may lead to long-term social and ecological effects. In this study, we find that the current farming systems seem to use more groundwater than the region can infiltrate, likely causing groundwater depletion. Of the three main farming systems studied, the CD system used the most water for production, followed by the CSR system and the CWL system. However, the widespread presence of the CWL and CD farming systems in the region (comprising 86% of HHs) makes them the highest water users in the region. The main factors leading to the over-utilization of water by these systems were the cultivation of water-demanding non-dryland crops, increased specialization of farming, and current agricultural management practices. The estimation of water use at the farm and the availability of groundwater at the watershed level shows that sustainable farming in dryland regions will need to be developed based on the

[5] https://www.indiaobservatory.org.in/tool/clarthttp://fes.org.in/sourcebook/groundwater-game-practitioners-manual.pdfhttps://wotr-website-publications.s3.ap-south-1.amazonaws.com/76_WOTR_CoDriVE_Visual_Integrator_0.pdf

region' water resources carrying capacity. We also realize that a range of factors aggravates groundwater use and depletion, such as socio-economic conditions of farming communities, market demand, access to credit, agricultural and infrastructural subsidies, and development policies. Hence, efforts towards promoting farm strategies and policies that reduce the over-use of water resources is required for sustainable agricultural production in dryland regions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

General data can be shared on resquest. However, authors choose to keep household level data confidential

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crsust.2022.100198.

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