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Research Article

Food-Water-Energy Nexus in Arid Region: An Analysis from Jaisalmer District of Western Rajasthan

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ABSTRACT

Drastic change in land use pattern in the Indian Thar desert has been observed during last few decades, especially in extreme arid region with annual rainfall <200 mm. More specifically, a significant increase in irrigated area in Jaisalmer district has been observed. As a consequence, number of electrified wells and tubewells used for irrigation purpose has increased during last few decades. All these have led to over-exploitation of ground water for irrigation purposes. In this study, we have tried to analyze the spatial pattern of ground water depletion in Jaisalmer district during last 15 years and its influence on energy and food security vis a-vis environmental pollution. Data on depth of ground water table of 117 wells in Jaisalmer district both during pre- and post-monsoon seasons of 1995, 2004, 2008 and 2009 were used along with statistical data on irrigated area under wells and tubewells. The average depth of ground water table was 42.64 m in 1995, which increased to 45.85 m in 2009. The annual rate of ground water depletion was 0.20 m. Overall, total annual energy consumption for irrigation in Jaisalmer was estimated at 277×10^6 MJ. Annual consumption of this energy for operating electric-operated submersible pumps indirectly leads to a GHG emission of 63.71 Gt CO_2 equivalent. It is imperative that irrigated agriculture in Indian Thar desert is highly water and energy intensive, and both these resources are becoming scarce. A sustainable approach for water and energy management in arid agriculture is therefore very essential.

Key words: Water consumption, Crop production, Irrigation, Food demand, Solar energy, Renewable energy

Introduction

Indian Thar desert lies at western part of India covering four states, Rajasthan, Gujarat, Punjab and Haryana with an area of 0.32 million km^2. Drastic change in land use pattern in the area has been observed during last few decades especially in region with annual rainfall <200 mm. Area under rainfed cultivation in Jaisalmer district increased by 332% during last 30 years, but net irrigated area increased from a meager of only 110 ha during 1980-81 to 156897 ha during 2009-10 (CAZRI, 2008). All these expansions in cultivated area were mostly at the expense of rangelands, which were dominated by high value fodder grasses like *Lasiurus sindicus* and *Cenchrus cilliaris*.

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In arid agricultural production systems, low, erratic and uneven rainfall combined with irrational land use and scarce water resources have made the agricultural production highly unstable and meagre. Rodell *et al.* (2009) reported that groundwater withdrawals for irrigation and other uses are depleting the groundwater reserves of the Indian states of Rajasthan, Punjab and Haryana @ 4.0±1.0 cm yr^{-1} equivalent height of water, or 17.7±4.5 km^3 yr^{-1}. Nationally, groundwater accounts for 50–80% of domestic use and 45–50% of irrigation purpose (Mall *et al.*, 2006). However, the response of groundwater to meteorological conditions is much slower compared to surface/near-surface components of terrestrial water cycle (Changnon *et al.*, 1988). The residence time of ground water ranges from months in shallow aquifers to a million years or more in deep desert aquifers (Sturchio *et al.,* 2004). Because of this fact, once the dynamic equilibrium of groundwater is disturbed in the arid regions, recovery process would be rather slow and the disturbances of higher magnitude can even threaten the existence of these aquifers. In arid regions, where people depend on groundwater for domestic needs and irrigation, withdrawals can easily surpass net recharge leading to groundwater depletion (Postel, 1993). Increased use of groundwater owing to population growth and agro-economic development is exerting tremendous pressure on the available groundwater resources. The present study is an attempt to analyse the groundwater depletion pattern in Jaisalmer district over last one decade, and its relation to energy consumption, GHG emission and food security of the region.

Materials and Methods

Study area

The study was carried out in Jaisalmer district, which is located in western Rajasthan and lies between 26°4′ and 28°23′ N, and 69°20′ and 72°42′ E in the Great Indian Thar Desert (Fig. 1). The geographical area of the district is 38,401 km^2 and 34% of this area is stony and rocky. The district is extended by 270 km in east-west and 186 km in the north-south direction, and is bounded by Bikaner on the north, Indian boarder on the west & south-west, Barmer and Jodhpur on the south, and Jodhpur and Bikaner districts on the east. On the basis of exposed rock formations and subsurface data, the sedimentary sequences of the district could be classified into 4 major basins, viz. Jaisalmer, Lathi, Birmania and Nagaur basin. The groundwater occurs in almost all formations, but the quantity and quality varies according to rock types. Lathi and Parewar sandstone form very promising ground water aquifers wherein it occurs under semi-confined and unconfined conditions.

Fig. 1. Location of Jaisalmer district in the Indian Thar desert and the wells and tubewells in Jaisalmer district used in the present study

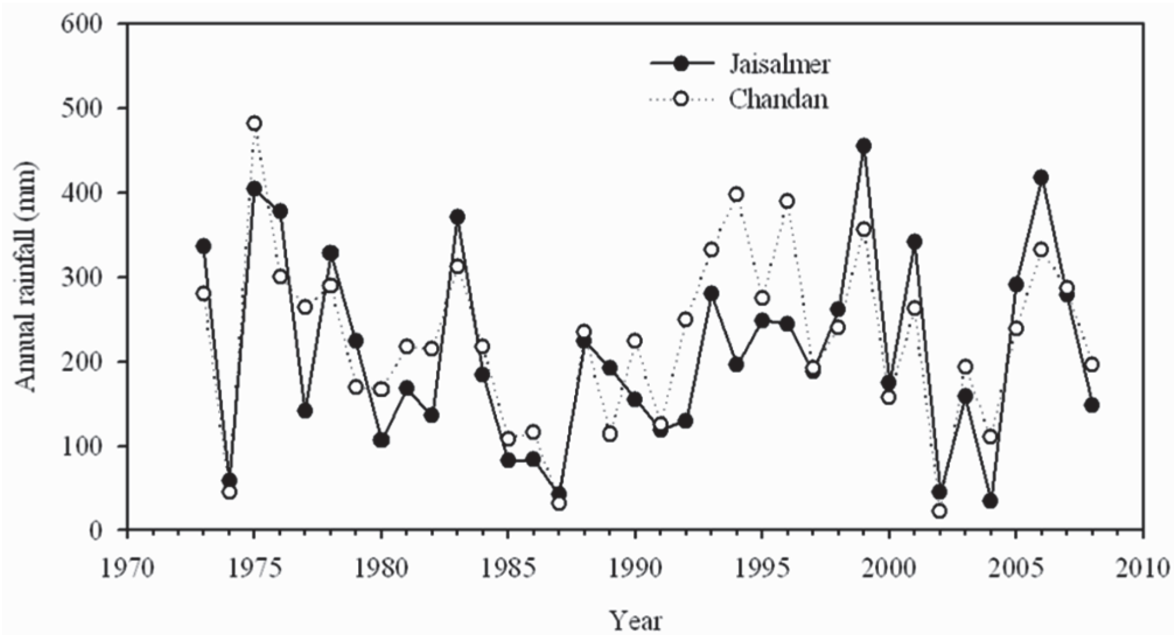

Fig. 2. Long-term annual rainfall at two locations of Jaisalmer district, Jaisalmer and Chandan (Data source: Daily meteorological data of Jaisalmer and Chandan station, CAZRI, Jodhpur from 1981 to 2009)

Average annual rainfall at the Jaisalmer and the Chandan site was 196 and 213 mm, respectively, with less than 10 rainfall events per annum. Major portion of the rainfall occurs during June–September (Fig. 2). It has been critically observed that annual rainfall variation follows a cycle of 4–5 years. The mean diurnal variation of temperature is 14-16°C. Mean maximum and minimum temperatures vary from 40-42°C (occasionally touching 48-50°C), and 3-10°C, respectively, with occasional frost (-2 to -4°C) associated with western disturbances.

Data source

Data on irrigated area in Jaisalmer district both during *kharif* and *rabi* season pertaining to 1980-81 to 2008-09 periods were obtained from the official website of the Department of Agriculture, Govt. of Rajasthan. Data on number of electrified wells and tubewells used for irrigation purpose was also collected from the same source. Data on groundwater depth from 117 wells at Jaisalmer district were collected from groundwater department of Jaisalmer district during the period from 1995 to 2009 (Fig. 1). Both pre- and post-monsoon data of groundwater were collected for the year 1995, 2004, 2008 and 2009.

Data analysis

Annual withdrawal of groundwater for irrigation purpose was calculated after considering the following average parameters from field observations: motor output rating of submersible pump used for irrigation is 20 hp, discharge pipe diameter is 65 mm, total head is 54 m, discharge is 960 L min^{-1} and the method of irrigation is sprinkler system. It was assumed that the radius of influence of one sprinkler nozzle is 6 m and maximum number of sprinkler nozzles to be operated at a single run is 15. Both water and electricity consumption for irrigation purpose were calculated based on the average of irrigated area over last 5 years and considering 26% of irrigated area under tubewell command area in the district. Major crops under irrigated conditions were considered as *Cuminum cyminum* (cumin), *Planta goovata* (isabgool), *Brassica sp* (mustard), *Cicer arientinum* (chickpea), *Arachis hypogea* (groundnut) and *Triticum aestivum* (wheat). Minimum number of irrigations for these crops was taken as 6, 5, 6, 3, 15 and 8, respectively.

Table 1. Irrigated area under major crops in Jaisalmer district and the number of irrigation for each crop

Crop	*Irrigated area (ha) during 2009-10	*Average irrigated area (ha) during last 5 years ending on 2009-10	Minimum number of irrigation to be given during crop growth period
Cumin	10330	7847	6
Isabgool	21276	9197	5
Mustard	34660	75637	6
Gram	52675	44953	3
Groundnut	9241	6619	15
Wheat	10768	10007	8

*About 26% of total irrigated area is under tubewell/well in Jaisalmer and rest is under IGNP canal command area

(Source: http://www.krishi.rajasthan.gov.in/Departments/Agriculture/)

Greenhouse gas emission was calculated with the average emission factor of 0.82 kg CO_2 equivalent per kWh electricity consumption (CEA, 2009). Temporal change in groundwater depth was studied through statistical average of 117 wells for a year. Surface map of groundwater depth was prepared through variogram analysis followed by ordinary kriging.

Results and Discussion

Food demand and associated changes

Escalating human population in Jaisalmer (population density increased from 13 km^{-2} during 2001 to 17 km^{-2} during 2011, demands additional food. In Jaisalmer, an additional 21.5 Kt of cereals, 5.6 Kt of oilseeds, 3.9 Kt of pulses and 15.7 Kt of vegetables yr^{-1} were required to meet the food demand during last decade, considering the per capita requirement of cereals, oilseeds, pulses and vegetables as 400, 100, 70 and 280 g day^{-1}, respectively. All these have forced the farmers to cultivate crops to meet the basic food requirement, even in energy and water scarce situations, which can be realized from Fig. 2, depicting the area under *rabi* crops in Jaisalmer during last three decades.

A major portion of irrigated areas in Jaisalmer district (73.85%) lies under command area of Indira Gandhi Nahar Project (IGNP). However, number of electrified wells and tubewells used for irrigation increased from a handful in 1980-81 to 2257 in 2007-08 (data from 2002-03 to 2007-08 are presented in Fig. 2). Gross irrigated area under wells and tubewells in the district was recorded as 50,123 ha during 2007-08. Using statistical data on average acreage of major crops under irrigation during last few years (Table 1), annual withdrawal of groundwater through wells and tubewells for irrigation purpose was estimated as 295 million m^3 (MCM).

Groundwater withdrawal for food production

Recharge of groundwater through rainwater during monsoon was almost negligible in most of the wells (Fig. 3). Post- and pre-monsoon difference was negative indicating recharge for few wells in 1995 mostly in Sankra block of Jaisalmer, however, it was negligible in 2008. Annual rainfall was 238.1 and 290.3 mm in Jaisamer and Chandan, respectively in 1995, but was 148 and 195.8 mm in 2008, indicating better recharge in 1995. Year 2008 was a drought year. It could also be observed that in Sankra block, post- and pre-monsoon difference was found positive, indicating the withdrawal for life saving irrigations during *kharif* seasons. Therefore, continuous withdrawal of groundwater for irrigation and other livelihood activities led to a fast rate of depletion of ground water resources. The average depth of ground water table was 42.64 m in 1995, which increased to 45.85 m in 2009. The annual rate of groundwater depletion was 0.20 m yr^{-1} (Fig. 3). Spatial pattern of groundwater depletion in terms of per cent change

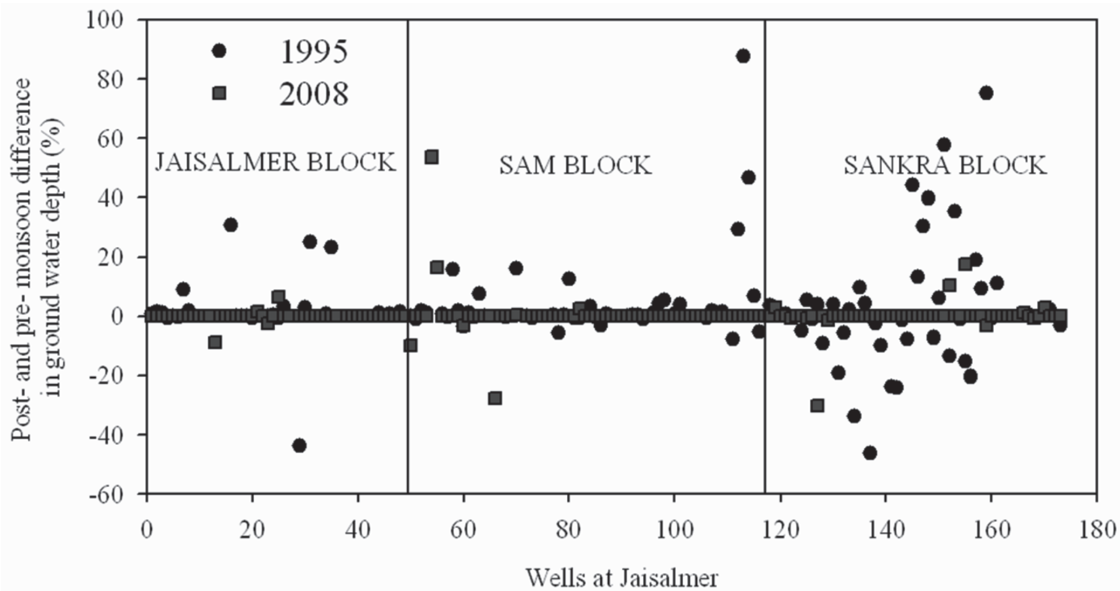

Fig. 3. Post- and pre-monsonn difference in groundwater depth below ground level during 1995 and 2008 in Jaisalmer district

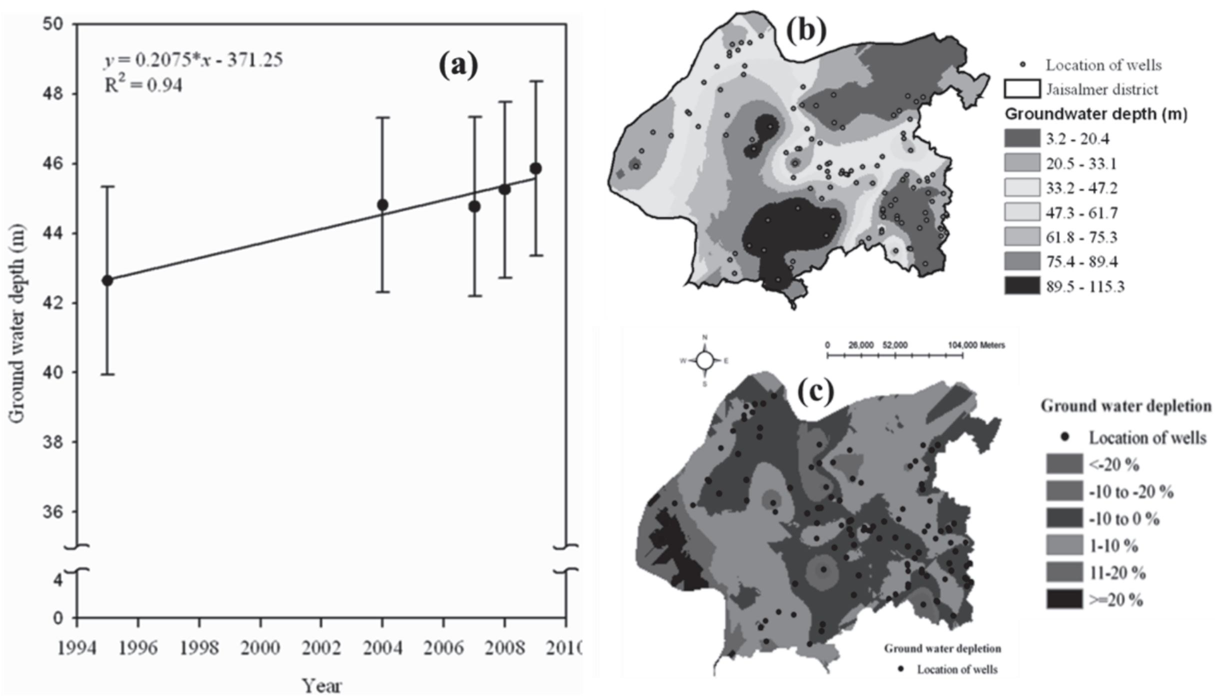

Fig. 4. Ground water depletion pattern in Jaisalmer district, a) depletion trend during 1995-2009, b) spatial pattern of ground water depth in 2009 and c) spatial trend of change in ground water table during the period from 1995 to 2009; negative value indicates increase in water table depth below ground level

in depth of water table during the period from 1995 to 2009 was also prepared (Fig. 4). Central and southeastern portion of Jaisalmer district was found with overall depletion of groundwater table, where agricultural activities have been intensified during last two decades. Rangelands with scattered sand dunes are dominant land use system at western part of Jaisalmer district and hence, rise in ground water table instead of depletion has been observed.

Energy consumption GHG emission for irrigation

Apart from the depletion of groundwater, irrigation through electrically operated tube wells and tubewells also led to huge consumption of energy and emission of greenhouse gasses (GHGs). About 40% of global CO_2 emission is reported to contribute by electricity and heat generation processes. On an average, energy consumption of major crops for irrigation purpose in Jaisalmer district was calculated as 7412, 6177, 7412, 3706, 18531 and 9883 MJ ha^{-1} for cumin, isabgool, mustard, chickpea, groundnut and wheat. Energy consumption for irrigation under each crop was calculated by multiplying the total duration (h) of irrigation per ha with area under each crop and average capacity of motor used for irrigation (kW). Total duration of irrigation was obtained from minimum number of irrigation for each crop as given in Table 1 and about 23 h of irrigation to cover 1 ha. Overall, total annual energy consumption for irrigation in Jaisalmer district was estimated as 277×10^6 MJ. Moreover, annual consumption of this energy for operating electrically operated submersible pumps indirectly leads to a GHG emission of 63.71 Gt CO_2 equivalent.

Conclusions

Irrigated cultivation in extreme arid situation of the Indian Thar desert is highly water and energy intensive, whereas both these resources are becoming scarce. Therefore, a sustainable approach for water and energy management in arid agriculture is very essential. Emphasis should been given to harvest and conserve surface rain water as well as to recharge groundwater. Moreover, water for irrigation purpose need to be used judiciously after considering the soil water retention characteristics and soil moisture depletion pattern. Renewable energy sources like solar and wind energy may be exploited to supplement the energy demand because both these resources are available in plenty in the region. Solar photovoltaics operated pumps are now readily available in market and need to be used in large number for irrigation purpose and obviously by utilizing the harvested rain water in surface reservoirs.

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