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Evaluating the effectiveness of water infrastructures for increasing groundwater recharge and agricultural production – A case study of Gujarat, India

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ABSTRACT

Groundwater for agricultural purposes is of utmost importance in the Indian state of Gujarat. To augment existing agricultural water resources, the Gujarat Government invested in many large-scale and small-scale water infrastructures (WI). In order to increase water storage and groundwater recharge and to justify further investments in WI, a better understanding on the impacts of past WIs is needed. This study uses data from NASA's Gravity Recovery and Climate Experiment (GRACE), along with soil moisture data from the Global Land Data Assimilation Systems, to estimate water storage before and after the intensification in the investment in WIs. In addition, Normalised Difference Vegetation Index (NDVI) data from the Moderate Resolution Imaging Spectrometer (MODIS) sensor was used to show changes in seasonal cropped areas during the same period. The analysis of data showed that the water storage in the state was estimated to be 24 BCM in 2003–2004 and 30 BCM in 2010–2011, an increase of 29% pre and post WI intensification. The Pixel Crop Duration Index (PCDI) indicated an increase in cropped area (at district level) in 2010–2011 when compared with 2003–2004 period, by 30% on yearly basis and about 80% during non-monsoon period. Results also indicates a significant net increase in water storage (by 5890 M m^3 after water used for crop intensification) and increase in agricultural crop area (by 63,862 km^2) in Gujarat during the period of intensification in infrastructures for water storage and groundwater recharge. Results also indicate that some districts have higher net water storage (compared to 2003), however the cropped area duration - PCDI has not increased much (e.g., Valsad and Navsari). The findings of this study can increase the understanding of the potential of WIs and provide valuable guidance for increasing cropped area in high water storage regions of Gujarat.

1. Introduction

Groundwater is the most important source of freshwater in many regions of the world, especially so in India (Rodell et al., 2009; Chinnasamy and Agoramoorthy, 2015). However, due to unsustainable practices in groundwater extraction and variability in monsoon rainfall, groundwater storage is depleting at alarming rates across the country (Central Ground Water Board, 2014; Groundwater Resource Estimation Committee, 2009). As a result, India has emerged as the largest consumer of groundwater in the world, with estimated annual withdrawals of 230 km^3 (Central Ground Water Board, 2011, 2014; Groundwater Resource Estimation Committee, 2009). This high withdrawal rate is alarming and unsustainable in a country where livelihoods depend predominantly on agriculture. If water conservation measures are not immediately undertaken to ensure sustainable usage and increase natural recharge rates, many regions in India will face a reduction in agricultural production (and loss of employment), increased distress, migration and a decrease in fresh water supplies, leading to extensive socio-economic stresses.

Gujarat, a north-western state in India (Fig. 1), has more than half of its total land area devoted to agriculture (Shah et al., 2009), with 64% of the state classified as arid or semi-arid. Agriculture in Gujarat is highly dependent on the southwest monsoon. However,

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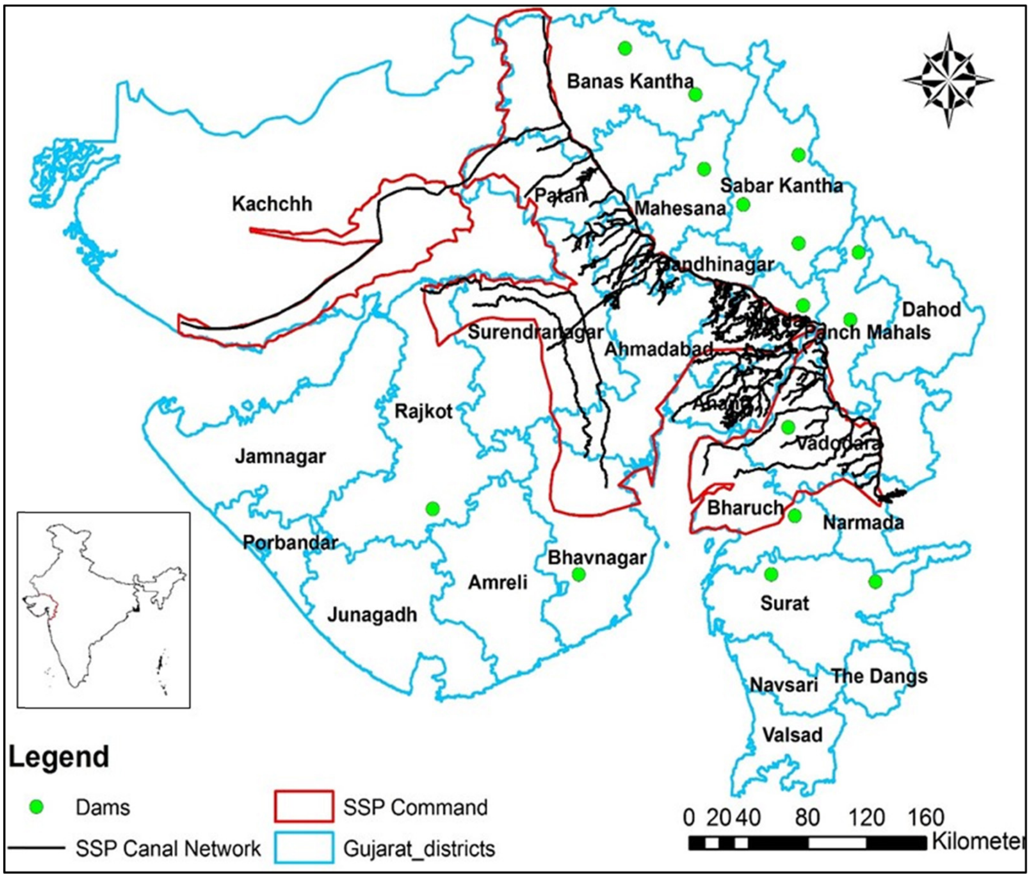

Fig. 1. Sardar Sarovar Project (SSP) and other important dam locations in Gujarat. Shown are designed command area (red outline), SSP canal (black line) and major dams (green dots). Inset shows the location of Gujarat in India. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

the monsoon rainfall has not only been insufficient in many areas; it has been extremely erratic over the past decade (Shah et al., 2009). With the bulk of rain being confined to just three months of the year i.e. July, August and September, growing crops during the remaining nine months is solely dependent on irrigating from surface and groundwater resources. As a result, the state has witnessed a 13% increase in groundwater overdraft for irrigation during 2004–2009 (Central Ground Water Board, 2011). Increasing groundwater overdraft is a growing problem and the situation is further worsened due to low natural groundwater recharge rates (fractured geology) and unpredictable variations in monsoonal rains (Shah et al., 2009). Expansion and strengthening of irrigation resources and enhancing groundwater recharge have therefore been one of the central aims of the Gujarat government for driving the agricultural growth in the state (Shah et al., 2009).

Among the Indian states that aim to enhance irrigation resources, Gujarat has taken a greater interest in augmenting water resources and has invested in a variety of water infrastructures (WI), ranging from dams, check dams, percolation tanks and infiltration ponds (Central Ground Water Board, 2014; Shah et al., 2009). The agricultural sector in Gujarat has been growing at 9% per annum since the last decade and much of its success has been attributed to strengthened irrigation systems that have helped in improving the cropping intensity (Swain et al., 2012; Gulati et al., 2009). Among the 17 major and 169 medium irrigation projects in Gujarat, Sardar Sarovar Project (SSP) is credited to be the lifeline of agricultural development in the past decade. Despite heavy focus on canal irrigation projects the role of groundwater irrigation in the agrarian success of Gujarat cannot be ignored since tubewells are estimated to be irrigating around 3,000,000 ha/year. The construction of approximately 500,000 check dams (Govt. of Gujarat, Check Dam Patrak-2, 2014)), farm ponds and boribunds have been considered highly successful in the regions of Kutch, Saurashtra (central Gujarat) and parts of north Gujarat, which have traditionally suffered from low and erratic rainfall and early withdrawal of the monsoon (Shah et al., 2009). As a result, the aforementioned regions have been able to secure the *Kharif* crops against early withdrawal of the rains and have sufficient water to irrigate the next crop (Gulati et al., 2009; Shah et al., 2009).

1.1. How effective is groundwater recharge?

Even though many irrigation projects in Gujarat are claimed to be successful, questions arise as to why this success could not be replicated in other states of India. For example in Rajasthan, a neighbouring state of Gujarat, many watershed interventions failed to have an impact on the agricultural water situation (Shah et al., 2013; Shah, 2010). In addition, many installed check dams are defunct and this is increasing socio-economic stress on the local farmers who invested in the construction of the check dams. There is a constant struggle by the government to choose between reservoir recharge and managed aquifer recharge and the cases of defunct check dams have placed a question mark on the need of artificial structures for recharge (Shah et al., 2009). Hence, it is imperative to understand and quantify the impact of the irrigation projects in Gujarat so that the investments are justified. Such improved understanding can aid in the formulation of successful watershed intervention projects elsewhere in India, and in other