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Spatio-temporal analysis of irrigation infrastructure development and long-term changes in irrigated areas in Upper Kharun catchment, Chhattisgarh, India

Navneet Kumar[a,*], Bernhard Tischbein[a], Mirza Kaleem Beg[b], Janos J. Bogardi[a]

[a] Center for Development Research (ZEF), University of Bonn, Germany
[b] Chhattisgarh Council of Science and Technology, Raipur, India

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ABSTRACT

The Upper Kharun Catchment (UKC), which is part of the new State Chhattisgarh formed in 2000, features considerable population growth, expansion of urban areas and dynamic changes in irrigation infrastructure as well as irrigation practices (spatial extension, temporal intensification, increasing use of groundwater as source) for meeting the increasing food demand. Water intensive rice is the major crop of the area. UKC has a comprehensive canal irrigation system which provides the link to water supply from reservoirs fed from areas outside the UKC. However, water provision for irrigation via the canal system for irrigation is restricted to only post-monsoon season. As a consequence, groundwater remains the only source of irrigation water in summer and winter seasons. Improved electricity facilities and subsidy on groundwater pumping have triggered an enormous increase in groundwater withdrawals. Remote sensing satellite images along with ground observed data were used in this study to spatially identify the areas with canal and groundwater irrigation. Results reveal that in 2011, around 50% of the area of the UKC benefits from canal irrigation, whereas 29.8% area is irrigated by groundwater. Around 103 villages in the UKC have no canal infrastructures. 216 villages in UKC are considered as 'hotspot areas' because of high groundwater withdrawal (irrigated area exceeding 75 ha per village), There has been threefold increase in groundwater irrigated area in UKC between 1991 and 2011. The upward trend of groundwater use indicates an alarming situation towards over-exploitation and creates the need to provide and analyze data on the use of groundwater resources in the area in order to detect past and to estimate future trends referring to groundwater withdrawals. These data are a prerequisite for enabling careful and foresightful management of groundwater resources especially at spatially identified hotspot areas towards ensuring sustainable management of this resource.

1. Introduction

Agriculture is by far the biggest consumer of water in India. More than 85% of India's freshwater is withdrawn by agriculture alone and, according to the Ministry of Water Resources, it is expected that the irrigation needs will increase by 56% by the year 2050, while the demand for drinking water will double and the water demand for energy production will increase 16 fold (Asian Development Bank, 2003). Irrigation systems in India rely on canal and groundwater.

According to Agricultural Census, 2010–11, India's total area under irrigation is 64.7 million hectares. Tube well irrigation contributes to 45% of total share followed by canal irrigation (26%). Despite of heavy investment in canal infrastructure creation, the Indian government has not been able to reduce the groundwater depletion. The area irrigated with groundwater (and its share of total irrigated area) shows an increasing trend over time (Chatterjee, 2012; Szakonyi and Urpelainen, 2013). Three major reasons drive this trend: (i) rather low canal irrigation efficiency, inadequate and unreliable supply hinder actually full or appropriate utilization of the canal irrigation potential; (ii) subsidies in electricity and development in groundwater pumping devices ease groundwater use as an option to overcome the gap (according i) between actual and potential usage of irrigated lands; (iii)

* Corresponding author at: Center for Development Research (ZEF), University of Bonn, Walter-Flex-Straße 3, 53113, Bonn, Germany.
E-mail addresses: nkumar@uni-bonn.de, navneet2206@gmail.com (N. Kumar), uls203@uni-bonn.de (B. Tischbein), mkbaig77@gmail.com (M.K. Beg), jbogardi@uni-bonn.de (J.J. Bogardi).

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groundwater-based irrigation is seen as an option for agricultural production during periods when canal systems are not operated.

India has emerged as the biggest consumer of groundwater in the world, with estimated annual withdrawals of 230 km^3 (CGWB, 2014). Groundwater irrigation in India covers more than 50% of total irrigated area, responsible for 70% of agricultural production and providing livelihood for 50% of the Indian population (World Bank, 1998; Shah, 2010). This extremely high groundwater withdrawal rate is depleting aquifers across the country, and declining water table at faster rates than ever before. In fact, the rates of depletion in India are probably the highest in the world (Aeschbach-Hertig and Gleeson, 2012). This trend towards unsustainable water management is especially alarming in a country where livelihoods mainly depend on (irrigated) agriculture and groundwater resources are needed to meet the increasing demand for drinking water (Rodell et al., 2009; Tiwari et al., 2009; Livingston, 2009; Shah, 2009; Fishman, 2011; Devineni et al., 2013; and Russo et al., 2013). Given this situation, there is an urgent need to immediately take appropriate measures to strengthen sustainable management of groundwater via either reducing withdrawals or enhancing recharge rates; otherwise several regions in India will face a drastic reduction in agricultural production, loss of employment and socio-economic stresses.

There is huge uncertainty in the actual area irrigated, the location of irrigated areas, and the irrigation strategies (water sources, timing and intensity of use), which leads to uncertainties in estimates of actual water use by irrigation and in turn contributes to mis-management of water resources. In India, the irrigated areas are reported based on census data collected at village level, later aggregated to block, district, State and National level (Reddy et al., 2006). Such a process is highly labor extensive and time consuming and the quality of the compiled data is not always reliable (Biggs et al., 2006; Droogers, 2002). However, advancement in satellite remote sensing offers a tremendous potential for continuous monitoring and mapping of irrigated areas due to the availability of satellite imageries at different spatio-temporal scales (Lenney et al., 1996; De Fries et al., 1998; Lobell et al., 2003; Thenkabail et al., 2005, 2009; Ozdogan and Gutman, 2008; Alexandridis et al., 2008).

The mapping of spatio-temporal dynamics of irrigated areas is a key to understand the drivers of change and spatially identify and locate the 'hotspot' regions at high risk of over-exploitation due to extensive and unsustainable groundwater irrigation. The mapping of canal infrastructure explores the areas where the potential benefits of canal system are still not reached and also reveals the gaps or bottlenecks in the irrigation systems.

Chhattisgarh state is known as the rice bowl of India. Traditionally, rice is grown as a single main monsoon crop. Yet, there is an increasing tendency towards taking rice up as a winter and or summer crop at sites where sufficient groundwater is available to meet the water demand. Rice is grown in basins which are permanently or at least for a high share of the vegetation period flooded with a water layer. As a consequence, the gap between rainfall and crop-water requirements plus losses by percolation and seepage has to be matched by irrigation water input. Therefore, rice cultivation is requiring a high amount of water which is supplied either by canals from reservoirs or withdrawn from groundwater sources.

The Upper Kharun Catchment (UKC) is a part of Chhattisgarh State featuring high population growth, considerable expansion of urban areas, ongoing industrialization, and dynamic changes in irrigation practices (extension, intensification, and increasing use of groundwater) for meeting the rising food demand. UKC has a comprehensive canal irrigation system which provides the link to water supply from reservoirs fed from runoff generated outside (upstream) the UKC and enables conveyance and distribution of irrigation water within the UKC. However, water provision for irrigation via the canal system for irrigation is restricted to only post-monsoon season (September to November). During the summer and winter seasons, the irrigation water demand of crops can be met by groundwater resources only. According to the (CGWB) report 2012, the expansion of groundwater irrigated areas in Chhattisgarh increased 6-fold from 2001 to 2010 and as a result, groundwater resources are at the risk of being over-exploited for irrigation purposes at least in parts of the Chhattisgarh.

The local people stick to their traditional practice of paddy cultivation, which is highly water demanding. Moreover, the Government of Chhattisgarh is providing subsidies for electricity to pump groundwater for paddy cultivation. The practice of over-exploitation of precious groundwater resources may lead to a major water crisis in the near future, and therefore careful management is essential and as prerequisite, reliable information on trends regarding withdrawals and recharge by percolation and seepage is needed.

This study aims at a detailed spatial analysis of the development of irrigation infrastructure (canal and groundwater irrigation systems) and to spatially detect changes in the irrigated areas in the UKC at decadal year time steps (1991, 2001 and 2011). As detailed and direct information on water quantities used in the irrigation schemes is missing, information on the spatio-temporal development of irrigated areas provided by this study can be used as a starting-point towards more comprehensive modeling and assessment of (irrigation) water balances. Based on the spatio-temporal dynamics of irrigated areas, extensive groundwater irrigated area with less recharge from percolation losses in irrigation canals was identified. The output of the study can be beneficially used for: (i) enhancing the understanding of usage of canal and groundwater for irrigation in terms of spatio-temporal trends, (ii) detecting eventual 'hotspot areas' (sites with a high risk towards groundwater-overexploitation), (iii) providing input into surface water and groundwater modeling. Thus, a contribution towards facilitating appropriate, adaptive and integrated land and water resources management in the study area is undertaken.

2. Study area

The study area Upper Kharun Catchment (UKC) is a part of the Seonath sub-basin (a tributary of Mahanadi river basin). It lies between 20° 33′ 30″ N – 21° 22′ 05″ N latitude and 81° 17′ 53″ E – 81° 45′ 17″ E longitude. UKC covers an area of approx. 2486 km^2 and stretches across Raipur, Durg and Dhamtari districts of Chhattisgarh State, India. The topography is flat with an elevation difference of 198 m over a distance of around 90 km from south to north (Fig. 1). UKC is situated in Chhattisgarh Plains Zone, and experiences three typical Indian seasons, namely winter, summer and monsoon. The climate is tropical (hot and humid type) and average annual rainfall amounts to 1100 mm. The UKC covers diverse land-use types, i.e., urban, rural, agricultural, forest and industrial areas. The majority of the study area is agricultural land (77.6%). The main crop grown in the area is paddy (rice). Four major soil types are found in the UKC namely, Alfisols (loam also known as Dorsa), Vertisols (clay also known as Kanhar), Entisols (sandy loam also known as Bhata) and Inceptisols (sandy clay loam also known as Matasi). The discharge measuring station Patharidith located at northern part of UKC is defining the study area. UKC was selected as study site, because it represents a typical (in terms of processes) and drastic (in terms of the magnitude and dynamics of the processes) example of regions confronted with (i) rapid land use dynamics (including highly water-demanding extension and intensification of irrigation), (ii) limited water resources becoming even more variable due to climate change, and (iii) being the home of a population with (irrigated) agriculture providing livelihoods.