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Climate-smart tank irrigation: A multi-year analysis of improved conjunctive water use under high rainfall variability

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ABSTRACT

Although water harvesting is receiving renewed attention as a strategy to cope with increasing seasonal and inter-annual rainfall variability, many centuries-old local water-harvesting reservoirs (tanks) in India are rapidly deteriorating. Easy access to groundwater is seen as one of the major threats to their maintenance and functioning. Potentially, however, conjunctive use of water from rain, tanks and groundwater reserves, supported by proper monitoring, could improve the resilience and productivity of traditional tank irrigation systems. To date, few quantitative multi-annual analyses of such climate-smart systems have been published. To redress this, we assess the sustainability of a rehabilitated tank irrigation system, by monitoring all inputs and outputs over a period of six years (12 cropping seasons). Our results show that during the period considered, improved conjunctive use resulted in a more stable cropping intensity, increased economic water productivity and higher net agricultural income. Groundwater tables were not negatively affected. We argue that improved conjunctive use can considerably reduce the vulnerability of tank irrigation to rainfall variability and thus is a valuable strategy in light of future climate change.

1. Introduction

India faces severe seasonal and regional water shortages in the coming decades. Demand from agriculture, by far the biggest water user, is increasing, to support the growing and increasingly affluent population (National Academy of Agricultural Sciences, 2009). At the same time, availability of water is under pressure due to climate change and overexploitation of groundwater resources (Biemans, 2012; Rodell et al., 2009). Although average total rainfall over the Indian subcontinent is likely to remain unchanged, the variability in rainfall is expected to increase (Kumar et al., 2011; Mathison et al., 2013). In a monsoonal climate that is already erratic and highly seasonal in nature, this increased variability due to climate change will further impact water availability.

In order to cover periods of shortages, farmers in India have for thousands of years been constructing so-called tanks[1] to harvest and store rainfall and surface runoff (Gunnell et al., 2007; Von Oppen and Subba Rao, 1987). Serving more than 20% of cropped area in southern states, tank irrigation is still one of the major strategies for coping with rainfall variability. In tank irrigation systems, water is harvested during the monsoon and used during the subsequent dry season. It is a flexible system, in which the volume of water stored in the tank at the end of the monsoon determines what and how much area farmers crop. Although this does not guarantee a stable year-to-year production and income, farmers prevent loss of investments by making timely adjustments to the cropping plan and allocation of resources. Besides their primary purpose as a source of water for irrigation, tanks also have important secondary purposes, such as the provision of drinking water, flood mitigation and water for livestock and fish production (Palanisami and Easter, 1983; Palanisami and Meinzen-Dick, 2001).

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[1] Artificial lakes, generally with earthen embankment dams, for harvesting and storing surface runoff after heavy rainfall.

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Despite their advantages, many tank irrigation systems have fallen into disrepair during the past 50 years (Kajisa et al., 2007; Palanisami and Meinzen-Dick, 2001; Sakurai and Palanisami, 2001): throughout India, the cropped area supported by tank irrigation has declined from 19% in the 1950s to 4% at present. The main causes of this decline have been (i) centralization of water management, whereby the state took over the responsibility of communal tanks, which led to an institutional breakdown with severe implications for maintenance schemes and the collection of water charges (Palanisami and Easter, 1983; Von Oppen and Subba Rao, 1987); (ii) siltation and encroachment of farming onto the tank bed, both symptoms of institutional breakdown and a higher population pressure (Dasog et al., 2012; Easter and Palanisami, 1985; Gunnell and Krishnamurthy, 2003; Palanisami and Meinzen-Dick, 2001) and (iii) access to cheap and easily available canal water and groundwater (Dasog et al., 2012; Kajisa et al., 2007; Sakurai and Palanisami, 2001). While tank irrigation declined, irrigation with groundwater rose sharply in India: it now accounts for almost 60% of the irrigated area. Farmers with access to groundwater have less incentive to contribute to the communal maintenance of the tank once it has deteriorated (Sakurai and Palanisami, 2001). They prefer the rapid return on investments in boreholes rather than contributing to the rehabilitation of the tank system. The resulting free-riding undermines the runoff harvesting, storage and distribution capacity of the tank system.

Groundwater also offers opportunities to enhance the performance of the tank system, however, by providing additional storage capacity to buffer seasonal and inter-annual shortages in rainfall and tank water (Ranganathan and Palanisami, 2004). Conjunctive use – maximizing the yield of water resources by the coordinated management of supplies of surface water and groundwater – is a well described concept in large-scale surface water supply systems (Bredehoeft and Young, 1983; Burt, 1964; Tsur, 1990), but empirical evidence on its benefit for tank irrigation and rehabilitation is limited. Early evaluation of tank rehabilitation programmes focussed largely on the merits of participatory execution (ADB, 2006; Gunnell & Krishnamurthy, 2003; Palanisami & Easter, 1983; Von Oppen & Subba Rao, 1987). It mainly described how well programmes were executed and their internal efficiency, rather than their efficacy in terms of achieving the desired effect. Recently, Dasog et al. (2012) and Reddy and Behera (2009) followed a more quantitative approach, comparing yields and improvements to livelihoods before and after rehabilitation, but without paying specific attention to changes in water use. To our knowledge, no longitudinal empirical studies have been reported in which conjunctive use of water from rain, tanks and groundwater reserves has been monitored over several years, thus taking into account the high inter-annual variability in rainfall.

Our aim is to assess the sustainability of improved conjunctive use of rainfall, tank water and groundwater in a tank irrigation system. We base our assessment on primary data collected over a period of 6 years, comprising 12 cropping seasons. During this period, all water inputs and yield outputs of a single tank irrigation command area were measured at farm and tank level in an extensive monitoring campaign as part of a tank rehabilitation project. The performance of the tank system was assessed using three indicators; cropping intensity, net agricultural income and economic water productivity. Whether groundwater resources were used sustainably was assessed by groundwater level observations. Section 2 explains the monitoring approach and three indicators used and gives a short background description of the study site and the rehabilitation measures implemented during the monitored period. In Section 3 we present the annual performance of the tank irrigation and the impact on groundwater levels. The paper concludes with a discussion on the observed changes and the wider relevance of our findings.

2. Methodology

2.1. Study area

Our case study area is a tank irrigation site near the village of Musilipedu, approximately 45 km east of the town of Tirupati, in the Yerpedu Mandal[2] of Chittoor District, in the state of Andhra Pradesh, India (79°42′E and 13°36′N). The region is mostly influenced by the north-east monsoons (October–December) and, to a much lesser extent, by the south-west monsoons (June–September). Average annual rainfall at Tirupati is 988 mm (1975–2006 period) with a high inter-annual variability not only in quantity (238 mm standard deviation), but also in the number of low and high-intensity rainfall events.

The Musilipedu tank is a non-system tank, fed solely by rainfall in its catchment area, with no connections to other tanks, upstream or downstream. The area upstream of the tank, i.e. the tank's catchment area, is approximately 740 ha. When full, the tank covers 54 ha; the irrigated area is 188 ha (Fig. 1). The tank has two compartments, separated by a low bund. When both compartments are full, excess water can flow over two surplus weirs into the Swarnamukhi River. Irrigation water from the tank can be diverted into the tank command area through a culvert, closed by a gate. It is then diverted by gravity from the main channels into a tertiary system consisting of field channels dug by the farmers.

The distribution of the tank water is managed by the WUA. Only farmers who own land can become members. The WUA farmers number 223, with an average land holding of 0.6 ha. In the Kharif cropping season (1 June–15 October) only a portion of the command area is cultivated, mainly with groundnuts and rice, and the limited rainfall during the south-west monsoon is supplemented by groundwater irrigation. During this season the tank remains empty. The area cropped in the Rabi cropping season (15 October–15 March) largely depends on how much water has accumulated in the tank during the north-east monsoon (September–November) at the start of the season. The main crop cultivated is paddy rice. Supplementary irrigation from groundwater is applied, especially at the end of the growing season and in the tail ends of the irrigation canals. From April to June the entire command area is left fallow, except for a small area cropped with sugarcane.

In common with the trend throughout India, groundwater use in the Musilupedu tank irrigation site has steadily increased in recent decades. Groundwater is abstracted from a shallow aquifer which is replenished during the monsoon, after which groundwater levels rise to near the soil surface. Although the initial investment required is substantial, boreholes are cheap to exploit (fuel and electricity are subsidized), reliable (under the farmer's own control) and efficient (water is available when and where needed). In Andhra Pradesh, electricity is provided for free to farmers, though only for several hours a day, with power cuts occurring regularly. 54% of the 223 farmers had access both to groundwater and tank water, 42% relied on tank water alone and 8% used only groundwater. The average farm size of farmers with access to both groundwater and tank water was, at approximately 1 ha, more than twice that of farmers with only tank water.

During the monitoring period the Musilipedu tank was rehabilitated using standard funds from the District Collector with further support from the FAO.[3] The rehabilitation entailed both institutional improvements, such as enhancing the empowerment of the WUA, and technical and agronomical improvements. To augment

[2] A mandal is an administrative division in India, above which is the district and below which are the villages.

[3] FAO, with the Dutch Government, funded the APWAM project, an 8-year project on improving water productivity in irrigated agriculture in Andhra Pradesh.