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Mapping agricultural responses to water supply shocks in large irrigation systems, southern India

Trent W. Biggs[a,*], Pardhasaradhi Gangadhara Rao[b,c,1], Luna Bharati[d,2]

[a] Department of Geography, 5500 Campanile Drive, San Diego State University, San Diego, CA 92182, United States
[b] International Water Management Institute-India, c/o ICRISAT, Patancheru, Andhra Pradesh, India
[c] Department of Civil and Environmental Engineering, The University of Melbourne, Room D402, Victoria 3010, Australia
[d] International Water Management Institute, Nepal, Department of Irrigation Building, Room # 427 and 428, Jawalakhel, Lalitpur, Nepal

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ABSTRACT

Irrigated agriculture experienced a water supply shock during a drought in southern India in 2002–2003. In this paper, hotspots of agricultural change were mapped and put in the context of hydrology and water management. Time series of MODIS imagery taken every eight days before (2001–2002) and during (2002–2003) the supply shock were combined with agricultural census data to document changes in cropping patterns in four large irrigation projects in the downstream sections of the Krishna and Godavari River basins (total command area 18,287 km^2). The area cropped in rice in the four irrigated command areas decreased by 32% during the drought year, and rice production in the two districts that experienced the largest flow reductions fell below production levels of 1980. The irrigation project that showed the largest change in double cropped area (−90%) was upstream of the Krishna Delta. In the Krishna Delta, large areas changed from rice–rice to rice–gram double cropping. Historical water management contributed to the vulnerability of rice production to drought: the main reservoir in the system was drained to dead storage levels by the end of each growing season over 1968–2000, with little carryover storage. The land cover change maps suggested that the lower Krishna Basin has experienced a "hard landing" during basin closure, and revised management strategies that account for the new flow regime will be required to maintain agricultural production during droughts.

1. Introduction

Irrigation projects may be vulnerable to water supply shocks that occur during droughts or after irrigation development upstream. A growing number of irrigation systems located in the downstream parts of large rivers are expected to experience water shortages as river basins become over-allocated (Falkenmark and Molden, 2008). In a closed river basin, where all available surface water has been allocated, new diversions for irrigation projects upstream necessarily decrease water availability downstream. Basins undergoing closure can experience either a "hard" landing, with large changes in land cover during dry years, or a "soft" landing, where management interventions support sustained crop production through a drought. Determining whether basins are experiencing hard or soft landings is important for developing management strategies designed to identify and mitigate the impact of closure on downstream irrigated areas.

Irrigated command areas can be viewed as social–ecological systems (SESs) (Lankford and Beale, 2007; Walker et al., 2004) where human activities depend on water fluxes that are in turn affected by those activities. The vulnerability of SES has three components: adaptive capacity, sensitivity, and exposure (O'Brien et al., 2004). Sensitivity is defined as a change in system function for a given exogenous perturbation, and exposure is the probability of occurrence of the perturbation. Social–ecological systems adapt to variability in resource supply (Adger, 2006; Carlson and Doyle, 2002; Luers et al., 2003; Smit and Wandel, 2006), but the systems may then be sensitive to exogenous perturbations larger than the range to which the system adapted. Mapping "hot spots" in SESs that are sensitive and exposed to exogenous change (Alessa et al., 2008) is important for understanding how system services, such as food production and farmer livelihoods, are affected by variability and changes in resource availability. Understanding the sensitivity of irrigated SESs to exogenous shocks is vital for anticipating the effects of upstream irrigation and climate variability on food production.

One measure of the sensitivity of irrigation systems is the change in cropping systems and agricultural production observed during

* Corresponding author. Tel.: +1 619 594 0902; fax: +1 619 594 4938.
E-mail addresses: tbiggs@mail.sdsu.edu (T.W. Biggs), p.teluguntla@pgrad.unimelb.edu.au (P. Gangadhara Rao), L.bharati@cgiar.org (L. Bharati).
[1] Tel.: +91 40 30713071.
[2] Tel.: +977 1 5542306/35382; fax: +977 1 5535743.

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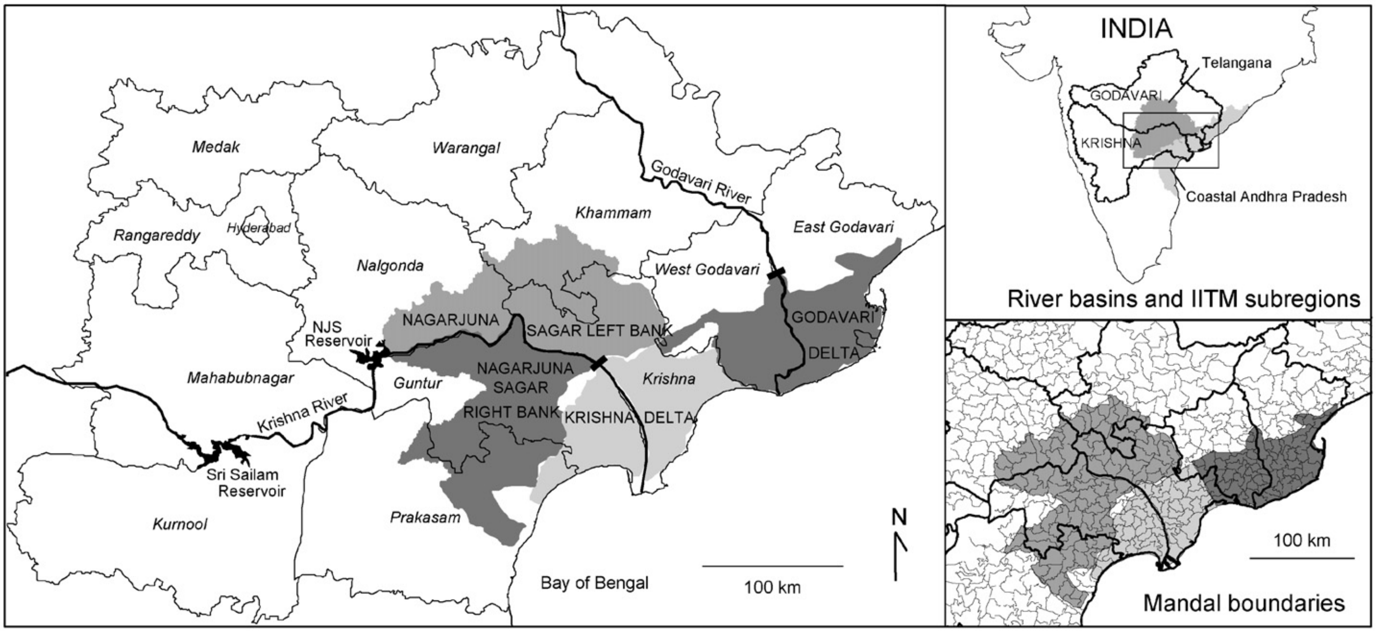

Fig. 1. Location map of the four study irrigation systems in southern India. In the main panel, the clear polygons and italicized labels are the district boundaries. The upper right inset indicates the river basin boundaries (Godavari and Krishna) and two meteorological subregions from the Indian Institute of Tropical Meteorology (IITM). The lower right inset shows the *mandal* and district boundaries on the irrigated command areas. The irrigated command areas were delineated from satellite imagery, unpublished reports from the irrigation districts, and district land use maps.

water supply shocks. Shocks can include reduced rainfall (meteorological drought), soil moisture stress (agricultural drought), reduced canal flows or reservoir storage (hydrological drought), and restricted access to water due to economics or lack of political power (socioeconomic drought) (Heim, 2002; Mollinga, 2001). Census data may be used to quantify changes in cropped area in large administrative units (5000–20,000 km^2), but identification of changes in individual irrigated command areas requires data with higher spatial resolution. India has small administrative units (*mandals*, 80–600 km^2) but data are often not readily available for all places and years. As an alternative, remote sensing has been used to map crop type (Badhwar, 1984; Lobell et al., 2003), crop yield (Ferencz et al., 2004; Lobell et al., 2003; Pinter et al., 2003), change in cropped area (de Beurs and Henebry, 2004) and vulnerability of yields to temperature fluctuations (Luers et al., 2003). Time series of the normalized difference vegetation index (NDVI) have been used to map irrigated areas (Biggs et al., 2006; Gaur et al., 2008; Wardlow et al., 2007), detect changes in land cover in non-agricultural areas (Lunetta et al., 2006), and map long-term (decadal) changes in irrigated areas (Thenkabail et al., 2007). Remote sensing has been used to detect interannual changes in irrigated crops in irrigation systems (Gaur et al., 2008), and census data may be combined with remote sensing data to map irrigated areas in heterogeneous landscapes (Biggs et al., 2006).

In this paper, cropping patterns were mapped during an average year (2001–2002) and a drought year (2002–2003) in four large irrigation projects of southern India that cover 1.8 million hectares. Cropping patterns were mapped using time series of satellite imagery at eight-day temporal resolution. Long-term data on rainfall, canal flow, and district-level crop production put the drought year in historical context. Census data in small administrative units (*mandals*) were used to relate the MODIS change maps to the area planted in specific crops. The questions addressed include: how and where did the water supply shock of 2002–2003 impact cropped area and rice production? Did past management of the irrigation systems enhance or limit their sensitivity and exposure to fluctuations in water supply?

Table 1
Water allocation and irrigated command areas in the lower Godavari and Krishna Basins.

	Water allocation (MCM)[a]	Designed command area (km^2)	Total geographical area
Godavari Delta	7463	4100	7005
Krishna Delta			
Left bank	–	2948	3739
Right bank	–	2284	3266
Total	5102	5232	6934
Nagarjuna Sagar			
Left bank	–	4200	9378
Right bank	–	4755	9600
Total	7957	8955	18,978
Total	20,522	18,287	32,917

[a] Water allocation data for Krishna Delta and Nagarjuna Sagar Projects are from the Krishna Water Disputes Tribunal, cited in D'Souza (2006).