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# Adaptability of Irrigation to a Changing Monsoon in India: How far can we go?

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**Title:** Adaptability of Irrigation to a Changing Monsoon in India: How far can we go?

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Agriculture and the monsoon are inextricably linked in India. A large part of the steady rise in agricultural production since the onset of the Green Revolution in the 1960's has been attributed to irrigation. Irrigation is used to supplement and buffer crops against precipitation shocks, but water availability for such use is itself sensitive to the erratic, seasonal and spatially heterogeneous nature of the monsoon. Most attention in the literature is given to crop yields (Guiteras, 2009; Fishman, 2012; Auffhammer et al, 2011) and their ability to withstand precipitation shocks, in the presence of irrigation (Fishman, 2012). However, there remains limited evidence about how natural weather variability and realized irrigation outcomes are related.

We provide new evidence on the relationship between monsoon changes, irrigation variability and water availability by linking a process based hydrology model with an econometric model for one of the world's most water stressed countries. India uses more groundwater for irrigation than any other country, and there is substantial evidence that this has led to depletion of groundwater aquifers. First, we build an econometric model of historical irrigation decisions using detailed crop-wise agriculture and weather data spanning 35 years from 1970-2004 for 311 districts across 19 major agricultural states in India. The source of agricultural data comes from the Village Dynamics in South Asia database at the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT). Weather data is sourced from the only long term continental scale daily observationally gridded precipitation and temperature dataset called APHRODITE (Asian Precipitation- Highly Resolved Observational Data Integration Towards Evaluation of the Water Resources), that captures the spatial extent of the monsoon across the Himalayas, South and South-East Asia, and the Middle East in great detail. We use panel data approaches to control for unobserved and omitted variables that can confound the true impacts of weather variability on irrigation. Exploiting the exogenous inter-annual variability in the monsoon, our multivariate regression models reveal that for crops grown in the wet season, irrigation is sensitive to distribution and total monsoon rainfall but not to ground or surface water availability. For crops grown in the dry season, total monsoon rainfall matters most, and its effect is sensitive to groundwater availability but differentially so for shallow dug wells and deep tube wells. The historical estimates from the econometric model are used to calculate future irrigated areas using three different bias-corrected climate model projections of monsoon climate for the years 2010 – 2050 under the strongest warming scenario ( business as usual scenario) RCP-8.5 from the CMIP5 (Coupled Model Intercomparison Project) models. These projections are then used as input to a physical hydrology model, such as the Water Balance Model, that tracks water use and exchange between the ground, atmosphere, runoff and stream networks. This enables us to quantify supply of water required to meet irrigation needs from sustainable sources such as rechargeable shallow groundwater, rivers and reservoirs, as well as unsustainable sources such as non- rechargeable groundwater. Preliminary results show that the significant variation in monsoon projections lead to very different results. Crops grown in the dry season show particularly divergent trends between model projections, leading to very different groundwater resource requirements. By combining the strengths of the economic and hydrology components, this work highlights potential sustainable or unsustainable water use trajectories that different regions within India will face.