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Agricultural adaptation to drought in the Sri Lankan dry zone

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ABSTRACT

Droughts affect more people than any other natural disaster. Drought severity is not merely a function of precipitation; it emerges from a web of interrelations between human and natural systems. The impacts of drought are equally complex, shifting across temporal scales, economic sectors, and regions. Even in regions with similar hydroclimatic characteristics, there is tremendous variation in the effects of drought. This study combines satellite imagery, geospatial data, and qualitative data to identify the multi-scalar factors that drive variations in agricultural responses to drought. We analyzed eleven years of remotely sensed imagery to identify agricultural areas in which cultivation occurred during an extreme drought in Sri Lanka. We visited a subset of these communities and conducted interviews with officials and farmers to identify the factors that influenced agricultural adaptation. Results suggest that though structural factors such as infrastructural capacity and physical environment significantly affect agricultural adaptation, dynamic factors such as local control of water supply, perceived risk, community cohesion, and farmer experience explain significant variation in the adaptive capacity of agricultural systems.

1. Introduction

Drought is a recurring and complex phenomena that substantially affects both human and natural systems. On average, drought affects more people and causes more economic damage than any other natural disaster (Wilhite & Vanyarkho, 2000). Recent studies suggest that in many regions of the world the spatial extent, likelihood, and duration of droughts will increase in the future (Dai, 2013; Touma, Ashfaq, Nayak, Kao, & Diffenbaugh, 2015). Drought arises from an interaction between reduced rainfall (meteorological drought), soil moisture stress (agricultural drought), reduced canal flows or reservoir storage (hydrological drought), and restricted water access caused by economic factors or political power (socioeconomic drought) (Heim, 2002). Regions with similar infrastructural, institutional, and physical characteristics may manifest markedly different responses to similar drought events (Swain et al., 2014).

Drought has particularly severe effects on agricultural systems (Lesk, Rowhani, & Ramankutty, 2016). The complex social and ecological processes that interact to generate agricultural responses to drought include management paradigms and governance, cultivation patterns, decision-making processes, information availability and access, infrastructure, and environmental factors (Meinzen-Dick, 2007; Ostrom, 2009). A system's adaptive capacity, or the ability of a system to prepare for stresses and changes in advance or adjust and respond to the effects caused by the stresses, emerges from complex interactions between these processes at multiple scales and levels (Engle, 2011; Gibson, Ostrom, & Ahn, 2000; Smit & Wandel, 2006). Adaptive systems have high adaptive capacity and exhibit the potential for structural change (Cash et al., 2006), facilitate coordination and deliberation amongst stakeholders (Lebel, Garden, & Imamura, 2005), foster social learning through critical self-reflection (Pahl-Wostl et al., 2007), and realign decision-making to natural scales (Moss & Newig, 2010). A community's adaptive capacity is a function of both local processes and the larger systems in which these processes are embedded (Cash et al., 2006; Smit & Wandel, 2006).

To capture these cross-scale interactions, we combined remotely sensed and qualitative data to identify the structural and dynamic determinants of agricultural adaptation. Structural variables are those that are slow to change such as jurisdictional boundaries, infrastructural capacity, relative location within the irrigation network, and physical environment. Dynamic factors change quickly and at smaller scales. These factors include

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community dynamics, political influence, resource control, market constraints, and perceptions of risk. Larger, slowly changing, structural factors (i.e. institutions and infrastructure) set the conditions within which the smaller, dynamic processes (i.e. political influence, resource control, market fluctuations, and perceptions of risk) operate; conversely, an aggregation of smaller dynamic processes can generate changes in structural variables (Giddens, 1984; Gunderson, 2001).

This paper focuses on the processes of agricultural adaptation that took place in rural Sri Lanka in response to a severe drought in 2014. The 2014 drought is estimated to have affected the livelihoods of over one million Sri Lankans. 58 percent of the country had completely insufficient water to cultivate during the 2014 dry season (World Food Program, 2014). We analyzed satellite imagery to measure variations in agricultural responses to drought and identify a subset of agricultural communities with similar structural characteristics (i.e. agroecological region, storage capacity, command area, number of farming families, institutional jurisdiction) but different cultivated extents. We conducted key informant interviews in eight of these communities to identify the factors, both structural and dynamic, that influenced variations in cultivated extent during the drought. By linking analyses of remotely sensed and qualitative data, we developed a rich, cross-scalar understanding of the factors that influenced agricultural adaptation to drought.

2. Background

Sri Lanka is an island nation off of the southeastern coast of India. The nation experiences two monsoon seasons annually. The northeast monsoon lasts from October to December and brings nearly two-thirds of annual rainfall to Sri Lanka; the southwest monsoon lasts from May to October and brings rain primarily to the southwestern region of the island. This rainfall pattern divides the island into a wet and dry zone (Fig. 1) and creates a distinct wet and dry cultivation season.

For over 1000 years, farmers living in the dry zone have constructed small reservoirs, locally known as *tanks,* to store wet season water for dry season cultivation. Today, the dry zone is dotted with over 11,250 "minor" tank systems (Imbulana, Wijesekera, & Neupane, 2006). Due to low tank storage capacities, variations in rainfall, and growing population, farmers in these systems frequently experience water scarcity during the dry season (Shah, Samad, Ariyaratne, & Jinapala, 2013). To address these challenges, in the 1960s the Sri Lankan government began construction of a network of massive irrigation systems that diverted the waters of nation's largest river, the Mahaweli Ganga, through a system of centrally managed reservoirs, hydropower plants, and over 10,000 km of canals (Withananachchi, Kopke, Withanachchi, Pathiranage, & Ploeger, 2014). In the 1970s, the government created the Mahaweli Authority of Sri Lanka (MASL) and charged the institution with the implementation and management of these new "major" irrigation systems (Zubair, 2005). The MASL offered perpetual leases to government-owned plots of land in the MASL systems. Farmers who resettled the land received 2.5 acres of paddy land and 0.5 acres of homestead (Takesada, Manatunge, & Herath, 2008). By the end of 2012, the MASL had resettled over 166,000 families onto 250,000 acres of irrigated land (Withananachchi et al., 2014). Today, these irrigation systems contribute significantly to the Sri Lankan economy, producing over 800,000 metric tons of paddy annually (MASL, 2014) and generating enough power to meet 40% of Sri Lanka's energy demand (Manthrithilake and Liyanagama, 2012).

Over 40 institutions and legislative acts govern water use in Sri Lanka (Manthrithilake and Liyanagama, 2012). Minor irrigation systems fall under the jurisdiction of the Department of Agrarian Development and are primarily managed by the farmers themselves. The MASL and Irrigation Department (ID) share the management of major irrigation systems. Prior to each season, a group of national officials from the Ceylon Electricity Board, the Department of Agriculture, the ID, and the MASL meet to determine seasonal inflows to each major system reservoir. The group produces a Seasonal Operating Plan (SOP) that specifies the first and last date of water issues for each system, proposed cultivated extents, expected energy generation, and monthly diversion volumes for each major irrigation system. Within each major irrigation system, water release from reservoirs along main canals is managed by system-level MASL or ID officials. Farmers are grouped by field canal into farmer organizations (10–15 farmers) that are responsible for field-level water rotations and canal maintenance.

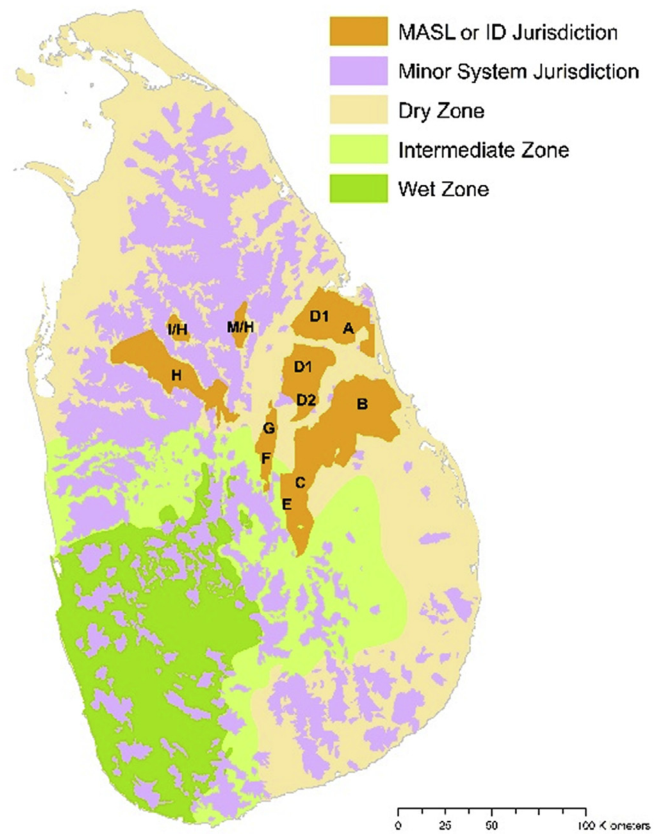

Fig. 1. Water management regimes and agroecological zones of Sri Lanka. The jurisdictional boundaries of minor irrigation systems are shown in purple below. These systems cover most of the island. Major irrigation systems managed by the MASL and ID are shown in orange. These systems are named using letters (i.e. System H, System B, System MH), which are displayed on each system in the figure. The majority of the major irrigation systems fall in the dry region of the country. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Methods

3.1. Remote sensing analysis

Many studies have used remotely sensed metrics of vegetation health to monitor agricultural responses to drought (Brown, Reed, Hayes, Wilhite, & Hubbard, 2002; Peters et al., 2002; Thenkabail, Gamage, & Smakhtin, 2004). We use the Enhanced Vegetation Index (EVI) to measure regional variations in the effects of drought on