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High-resolution spatial assessment of population vulnerability to climate change in Nepal

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ABSTRACT

Current, spatially explicit, and high-resolution assessments of population vulnerability to climate change and variability in developing countries can be difficult to create due to lack of data or financial and technical capacity constraints. We propose a comparative, multiple-approach framework to assess the spatial variation of population vulnerability to climatic changes using several high-resolution variables related to climate, topography, and socioeconomic conditions with an objective to detect the spatial variability of climate vulnerability in Nepal. Nepal is one of the most vulnerable countries to the effects of climate change due to frequent climatic hazards and poor socio-economic capacity. We used a climate vulnerability index (CVI) approach to derive climate vulnerability maps at the one-kilometer resolution and test an additive and a principal components-based composite method of data aggregation. In this work, we attempt to answer three questions. 1) How do different methods of assessment inform the spatial variation of the climate vulnerability in Nepal? 2) How do different variables interact to shape climate vulnerability in Nepal? 3) What proportions of the population in Nepal are vulnerable to climatic disasters and why? Our analysis uncovered significant spatial variations in population vulnerability to climate change across Nepal, with the highest vulnerability being experienced by the High Mountain region followed by the regions in the lower elevations. We find that although the lack of adaptive capacity is the biggest cause of population vulnerability to climate change in Nepal, a resilient community is shaped by both biophysical and socioeconomic characteristics. By performing an iterative sensitivity analysis of our thirteen variables both at the aggregate level (nationally) as well as at the more disaggregated (physiographic region) level, we contribute to identifying important, multi-scalar driving factors for vulnerability that can be employed as leverage points for lowering vulnerability at different scales. After performing analyses at multiple regions, we conclude that region-specific variable selection is needed for more detailed assessments and in order to prioritize adaptation strategies at scales that go beyond the hierarchy of administrative divisions.

1. Introduction

Climate vulnerability is the tendency of a system to be adversely affected by climate due to its inherent susceptibility to harm and lack of capacity to adapt to variability and changes (Field et al., 2014). There are many approaches to studying climate related hazards, their impacts, people's resilience, and the resultant vulnerability of various population groups. These approaches are evolving as more information is being gathered and missing links are being identified (Pricope, Pardo, & Lopezz-Carr, 2013). Earlier approaches focusing only on climatic perturbations have more recently shifted towards the understanding and quantification of links among climate perturbations and stressors, internal and external biophysical characteristics, and internal and external socioeconomic characteristics (Füssel, 2007). Consequently, climate vulnerability is defined as a function of exposure, sensitivity, and adaptive capacity where exposure is typically conceptualized as the character, magnitude, and rate of climate variation, sensitivity as the system's susceptibility or harm associated with environmental and social changes, and adaptive capacity as a system's capacity to deal with and respond to exposure and sensitivity (Adger, 2006;

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Field et al., 2014). No matter the approach, climate vulnerability is always a function of the place and scale of assessment, interconnections among different systems, and interactions between and among system components (O'Brien, Sygna, & Haugen, 2004; Turner et al., 2003). In this work, we conceptualize population vulnerability as the characteristics or emergent properties of a system stemming from the interaction of various biophysical and socioeconomic factors and aim to understand the behavior of different factors influencing vulnerability and create spatially explicit maps of vulnerability resulting from multiple interacting factors in Nepal.

Although many regions of the world are exposed to climatic hazards, climate vulnerability defined by the type and intensity of hazard, the susceptibility of the system, the size of affected populations, and capacity to recover are greatly defined by the locations where they occur (Tucker et al., 2015). For instance, coastal regions are different from mountains; warmer regions have different climatic hazards than cold regions; the sensitivity of forested lands is different than that of settlements (Turner et al., 2003). Socioeconomically, some communities are better prepared for climatic hazards with sufficient resources and infrastructure available to them via social or institutional networks, while some are not (Turner et al., 2003). As a result of unique interactions of different biophysical and socioeconomic variables, different levels of vulnerability will thus characterize different places (Tucker et al., 2015; Turner et al., 2003).

The Intergovernmental Panel on Climate Change (IPCC)'s fifth assessment has concluded that global climate change is an imminent threat to many communities as there is clear scientific evidence of increasing greenhouse gasses, warming atmosphere and oceans, diminishing amount of snow and ice and rising sea levels (Pachauri et al., 2014). Every year, millions of people are being affected and trillions of dollars' worth of property values are being lost to different climatic hazards, such as floods, landslides, cyclones and hurricanes (Dai, 2012; Hallegatte, 2015; Jongman, Ward, & Aerts, 2012; Peduzzi et al., 2012; Petley, 2012). Some research is indicating that the magnitude, frequency, and intensity of these disasters have been increasing and can be partially attributed to global climate change (Confalonieri, Marinho, & Rodriguez, 2009; Hallegatte, 2015). Global climate change coupled with increasing population in many parts of the world have resulted in an increased number of people affected and higher loss of property due to climatic hazards (Amendola, Linnerooth-Bayer, Okada, & Shi, 2008; Guha-Sapir et al., 2012), rendering many regions and major sections of population increasingly vulnerable to climate-related hazards. In this work, we assess population vulnerability to climatic variability and change for communities living in Nepal using different climate vulnerability indices and aim to unravel the relative contribution of different variables in the quantitative representation of vulnerability.

Nepal is a small country in South Asia, lying along the Himalayan range. People are vulnerable to climate change due to the fragile nature of the landscape, extreme climatic conditions in most of the region, recurrent climatic hazards, people's low economic capacity, political conflicts, and a lack of good governance. There are three general types of climate-related hazards that typically recurrently affect the Himalayas region- hydrological hazards such as storms, cloudbursts, floods, landslides, mudflows, and avalanches; climatologic hazards such as droughts and related hazards such as extreme temperatures and wildfire; wind and thunderstorms and related disasters like lightning (Pathak, Gajurel, & Mool, 2010). A recent analysis of historical disaster data shows that the frequency and intensity of disaster events are increasing in Nepal (Aryal, 2012) concurrent with sustained population increase.

Climate change effects are more intense in this region compared to the rest of the world (Shrestha & Aryal, 2011; Shrestha, Wake, Mayewski, & Dibb, 1999). Recent research reports the significant change in temperature, precipitation and vegetation phenology between 1982 and 2006- with 0.06 degree centigrade per year increase in average temperature, and 6.52 millimeters per year increase in total precipitation- in the Himalayas (Shrestha, Gautam, & Bawa, 2012). Temperature and precipitation trend analyses of Nepal from 1975 to 2006 using weather station data show general trends of increasing temperature over most of the country, while different parts of Nepal experience differential trends in precipitation (Marahatta, Dangol, & Gurung, 2009). A review by the International Center for International Mountain Development (ICIMOD) reports that there is not any significant trend in precipitation, but there is a general increase in temperature across the Himalayas with higher warming trends in the high altitude area (Singh et al., 2011).

The effects of climate change in Nepal are not homogenous and might depend on factors like topography, remoteness, people's dependency on climate-related occupations like agriculture and animal husbandry, accessibility, infrastructure, and economic capacity. The only existing spatial assessment of climate vulnerability for Nepal was performed by a government team at the district level (Ministry of Environment, 2010). However, in Nepal, most of the districts are heterogeneous with the highly variable landscape, climate, and socioeconomic status (District Nepal, 2016). Therefore, a district-only based approach leaves out a lot of potentially critical information like varied population density, different climatic conditions, wide-ranging dominant occupations, heterogeneous topography, and accessibility within the individual districts (Bhuju et al., 2013; McDowell, Ford, Lehner, Berrang-Ford, & Sherpa, 2013).

Given the unavailability of national level high-resolution assessments of climate vulnerability, this study analyzes climate vulnerability in Nepal at a one-kilometer resolution using multiple datasets. In this work, we try to answer following questions. 1) How do different methods of assessment inform the spatial variation of the climate vulnerability in Nepal? 2) How do different variables interact to shape climate vulnerability in Nepal? 3) What proportions of the population in Nepal are vulnerable to climatic disasters and why?

2. Methods

2.1. Study area

Nepal is a small country with an area of 147,181 square kilometers and a total population of about 28 million (CBS Nepal, 2016). The livelihoods of people are primarily dependent on rain-fed subsistence agriculture while remittances are the main source of Gross Domestic Product (World Bank, 2016). It is one of the least developed countries, ranking 145th globally, in a recent assessment of Human Development Index (UNDP, 2015).

Nepal lies between India and China (Fig. 1a) along the Himalayan mountain range, a geologically dynamic, ecologically fragile and socioeconomically underprivileged region of the world (Ives & Messerli, 1989). The Himalayas rise in altitude from a few meters from sea level to the world's highest peak, Mount Everest (8848 m). Nepal is divided into five major physiographic regions- Tarai (below 600 m), Siwalik (100–2000 m), Hill (20–3500 m), Middle Mountain (700–4100 m) and High Mountain (1800–8800 m) (Fig. 1b) on the basis of elevation (LRMP Nepal, 1986; Shrestha, Shrestha, Chaudhary, & Chaudhary, 2010).

Although globally the climate system of Nepal falls in the subtropical zone, there is high variation in climate with a subtropical climate in the lowland Tarai and alpine climate in the High Mountain region (Marahatta et al., 2009). The average precipitation