PROGRESS REPORT

URBAN GROWTH, LAND-USE CHANGE, AND GROWING VULNERABILITY IN THE GREATER HIMALAYA MOUNTAIN RANGE ACROSS INDIA, NEPAL, AND BHUTAN

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1. Introduction

The overarching objectives of this project are to **1) characterize and quantify LCLUC associated with urban settlement change, and 2) assess the vulnerability of these urban settlements to hazards** in the Hindu Kush Himalaya (HKH) study region of Nepal, India, and Bhutan. Since the start of the project, our team made progress in three key research areas:

1) Determining how and where are urban settlements changing;
2) Creating a database archive of the frequency, magnitude, and duration of the four dominant natural hazards— earthquakes, fires, floods, and landslides—to better understand how they vary over time and space in the region; and
3) Gathering socio-economic data for the region to determine the sensitivity of the socio-economic system to different stressors.

2. Research Activities

2.1. Determining how and where are urban settlements changing

We have started the 30-meter resolution change analysis for the 41 contiguous scenes (Figure 1) for the entire Landsat TM archive (1984-present) using the Continuous Change Detection and Classification Algorithm (CCDC) (Zhu & Woodcock 2014) and an associated Python package called Yet Another Time Series Model (YATSM) which allows parameterization of the 9.3 version of the CCDC algorithm and includes infrastructure for mapping results (Holden & Woodcock, personal communization).

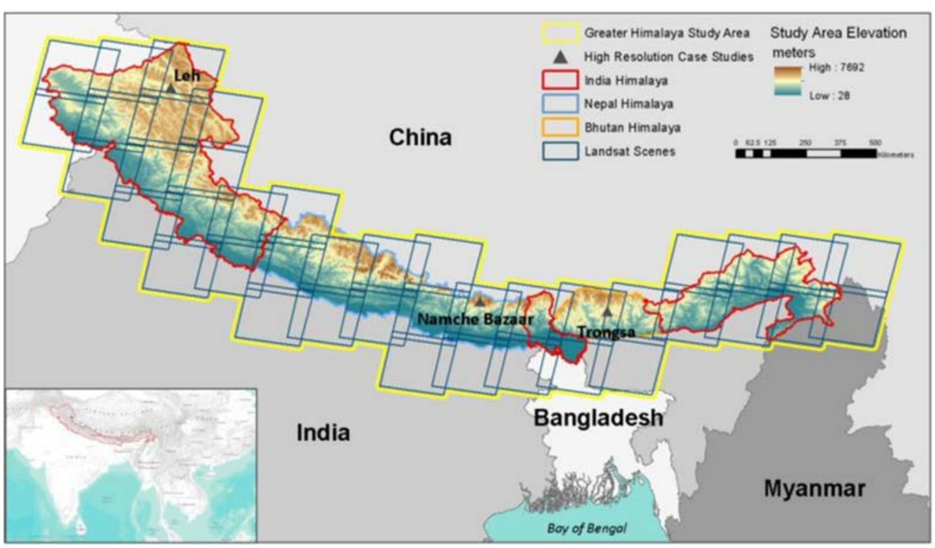

Figure 1: We define the *Greater Himalaya Study Area* as the contiguous Himalaya mountain arc from the northwest India state of Jammu and Kashmir, through Himalaya Nepal, the India state of Sikkim, Himalaya Bhutan, and Arunachal Pradesh in northeast India.

Our preprocessing workflow and data storage system is established and the algorithm is currently running on the High-Performance Computing cluster (HPC) at Yale University. Preliminary results show pixel-level time series trajectories as well as change maps throughout the region (Figures 2 & 3).

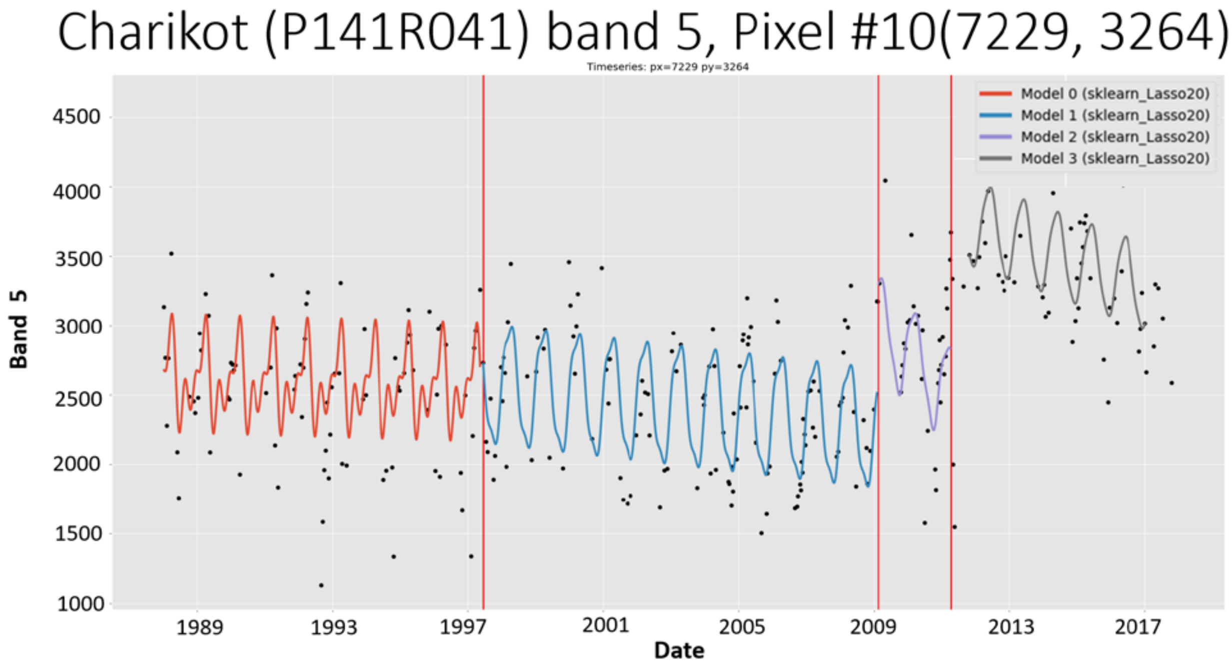

Figure 2: Structural breaks (red vertical lines) indicate abrupt changes in the times series signaling significant land cover changes.

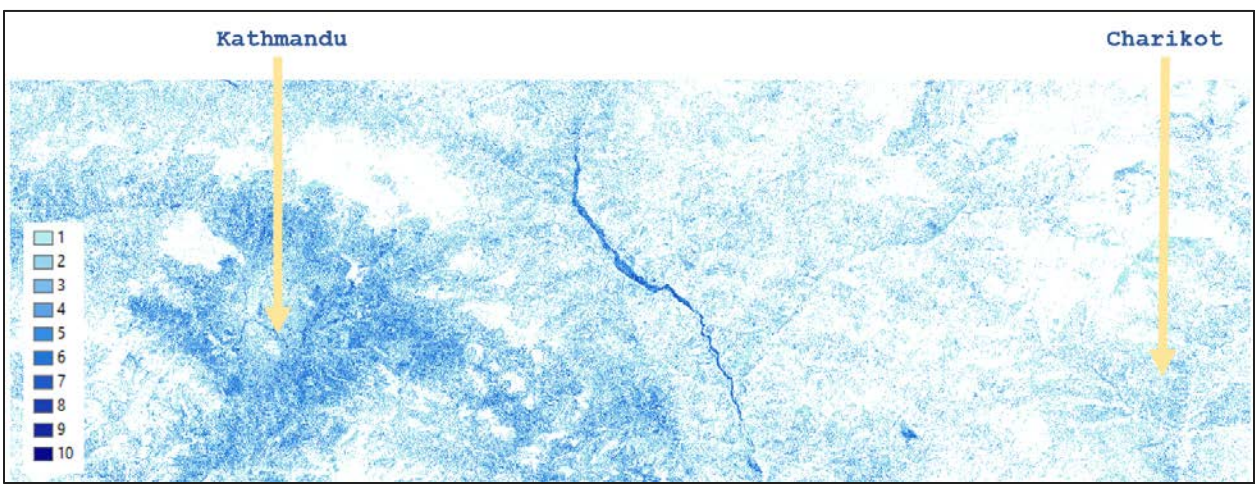

Figure 3. Preliminary results showing the number of abrupt changes (breaks) per pixel from 1984-2017

We have begun topographic correction of the Collection 1, Level 2 Landsat imagery using 1 Arc-Second Global Shuttle Radar Topography Mission (SRTM) data. Currently, we are testing different topographic correction methods—mainly C-correction, Minnaert correction, and empirical-statistical methods on a topographically heterogeneous region of the Himalaya—a

Landsat scene for path 141, row 041 (Teillet et al. 1982, Riano et al. 2003). We are also working to determine the optimal resolution of Digital Elevation Model (DEM) data to use for Landsat imagery topographic correction. Very preliminary results show visual improvement using the C-correction method (Figure 4). Quantitative measures of topographic correction method effectiveness are now beginning.

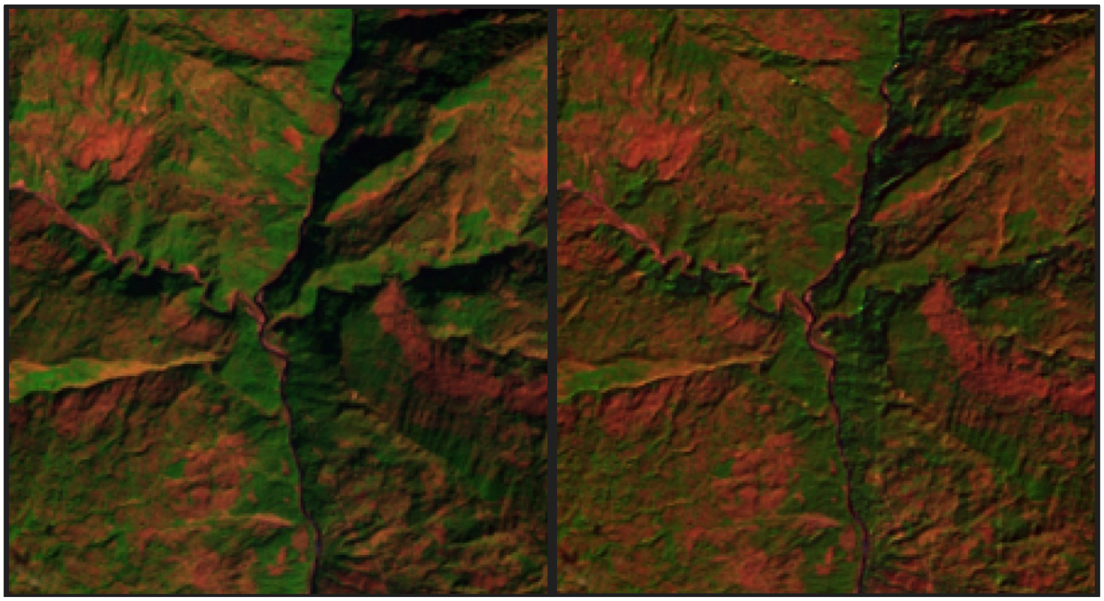

Figure 4. Image on the right is the original, uncorrected image. Image on the left has been topographically corrected using the C-correction method and the 1-Arc Second SRTM DEM.

During December/January 2017/2018, we traveled to 2 of our 3 field sites, to Almora, India and Charikot, Nepal. During this trip, we recorded oral and written land use histories for approximately 20 sites per location to assess the accuracy of our implementation of the Yatsm/CCDC algorithm.

2.2. Creating a database archive and mapping the frequency, magnitude, and duration of the four dominant natural hazards— earthquake, fire, flood, and landslides—to better understand they vary over time and space in the region

We have collected and assessed global data sources for the four dominant natural hazards—earthquakes, fires, flood, and landslides—in the study region (Table 1). Figure 5 illustrates a representative sample of the data in the region.

Table 1. Data sources for biophysical stressors. All datasets are at the Global level unless otherwise noted.

Data #	Type	Detail	Temporal Data Availability	Data Description	Source
			-	Global Seismic Hazard Map	(Giardini et al. 1999)

1	Biophysical Stressor	Earthquakes	1900 – 2012	Global Historic Earthquake Events Data	(Bondár et al. 2015)
			1973 – 2007	Atlas of ShakeMap	(Allen et al. 2008, 2009)
			-	ISC-GEM Global Instrumental Earthquake Catalog (Version 5.0)	International Seismological Center
			-	ANNS Comprehensive Earthquake Catalog (ComCat)	USGS
			2013	National Action Plan for Earthquake Safety and Health Facilities (Bhutan)	Asian Disaster Reduction Center
			2011	Earthquake joint Rapid Assessment for Recovery, Reconstruction, & Risk Reduction (Bhutan)	Royal Government of Bhutan & the World Bank
2	Biophysical Stressor	Fires	2001– Present	Global MODIS Active Fire Product	(Giglio et al. 2003)
			2001 – Present	Global MODIS Burned Area Product	(Roy et al. 2005)
			2012 – Present	Global VIIRS Active Fire Product	(Schroeder et al. 2014)
3	Biophysical Stressor	Floods	2009	Bhutan Flash Flood Report	UNDP
			1985 – Present	Global Active Archive of Large Flood Events	(Brakenridge 2010)
4	Biophysical Stressor	Landslides	-	Digital Elevation Model	SRTM-derived global 1 Arc- Second Product
				Landslide Occurrence Data	ICIMOD, Yale Himalaya Initiative
				Global Landslide Catalogue	NASA
5	Biophysical Stressor	all	2005	Disaster Management Analysis (Bhutan)	(Levaque 2005)
			1995 & 2015	Country Reports (Bhutan)	(Lotay 2015)
			2009	Joint Rapid Assessment for Recovery,	Royal Government of Bhutan, World Bank,

				Reconstruction and Risk Reduction (Bhutan)	& United Nations
			2011 – Present	Incident Maps (Nepal District Level Reports)	Government of Nepal Disaster Risk Reduction Portal
			2015 – 2018	Hazard News Repository (Nepal)	Government of Nepal Disaster Risk Reduction Portal

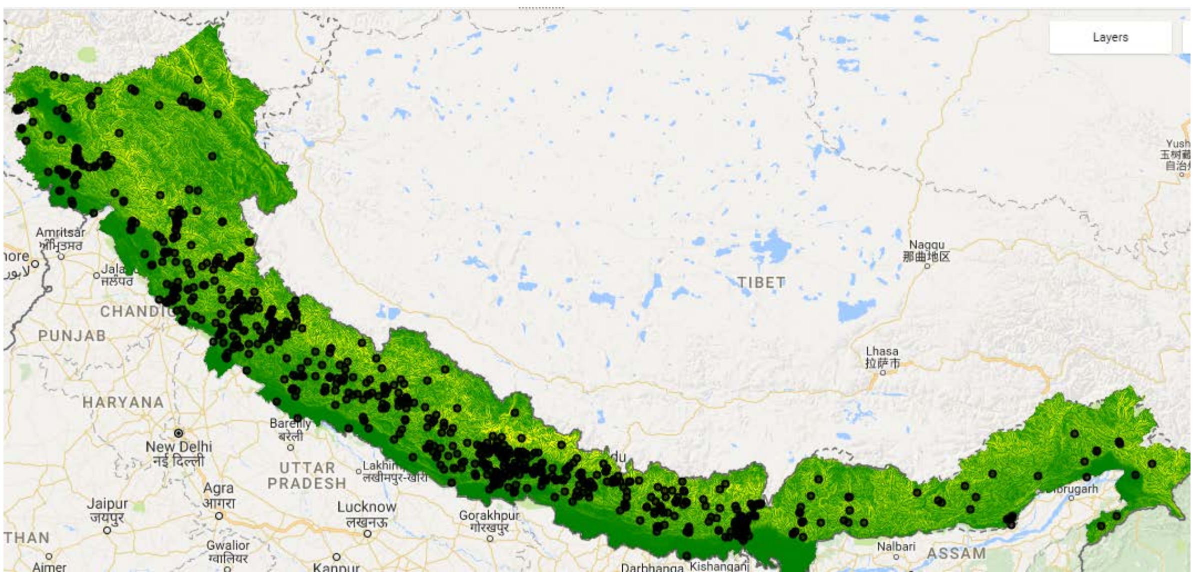

Figure 5. Landslide incidents in the Himalaya Region (2007-2017)

We have also collated a local newspaper archive for the region collectively spanning from 2007 to current and intend to parse them to construct a supplementary measure of hazards. Newspapers included in the archive include:

Nepal:
- **English**: Kathmandu Post, Himalayan Times, Republica, The Himalayan Times, The Rising Nepal
- **Nepali**: Kantipur, Gorkhapatra, Nagarik, Annapurna Post

Bhutan:
- **English**: Kuensel, The Bhutan Reporter

India:
- **English**: Hindustan Times
- **Nepali**: Himalaya Darpan

Preliminary analysis suggests strongly cyclical patterns in rain related stressors (Figure 6).

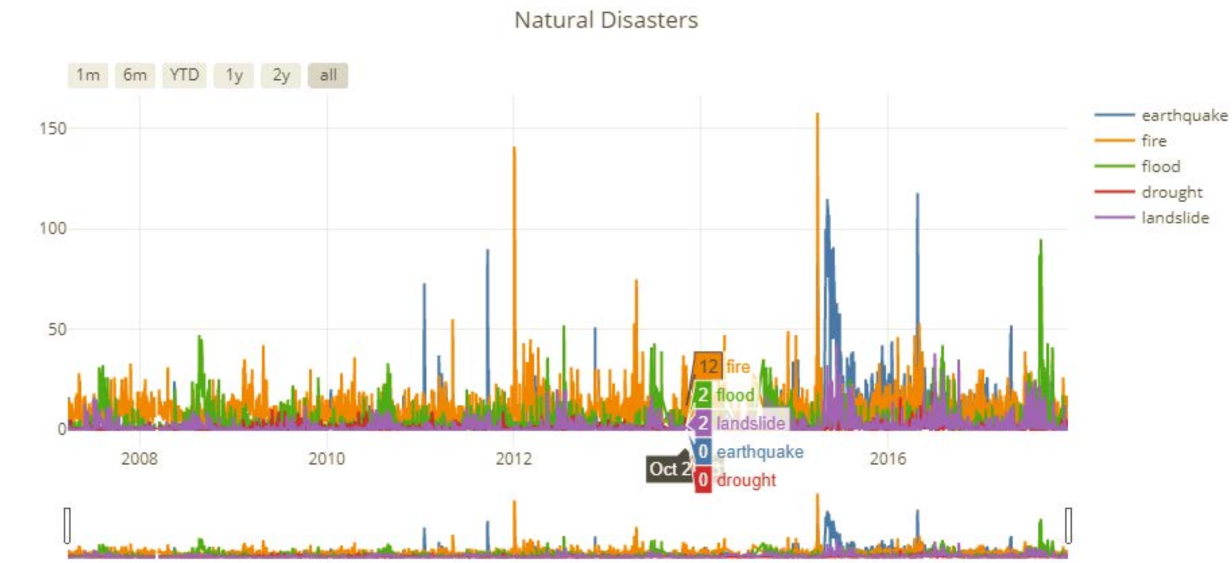

Figure 6. The temporal frequency of mention of hazards in across Nepal based on archival newspaper records from the Kathmandu Post which were scraped for the key words indicated in legend above.

Fieldwork in the HKH region in the summer of 2018 will gather stream gauge data from hydrological stations in India, Nepal, and Bhutan as input to an inundation/flooding model developed by Huang et al. (2014). Summer fieldwork will also be conducted in India to examine female headed household vulnerability to flooding in the region.

2.3. Gathering and analyzing socio-economic data for the region to better understand the sensitivity of the socio-economic system to different stressors

We have collected socio-economic data for all three countries—India, Nepal, and Bhutan—in the study region (Figure 7).

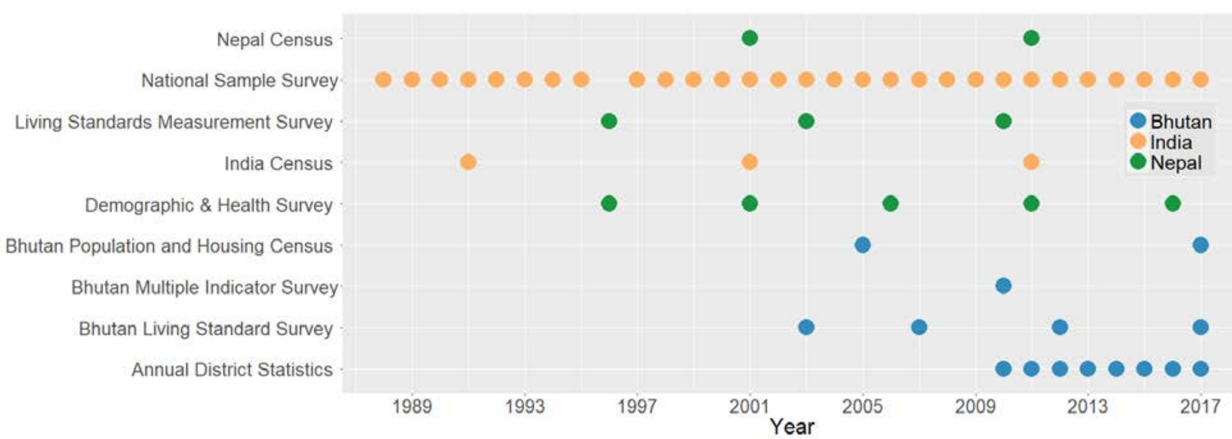

Figure 7. Temporal Resolution of socio-economic data for the region.

Preliminary analysis examines the spatial distribution of earthquake damages and whether they coincide with underlying socio-economic measures (Figure 8) to examine what drives variation in damage conditional on equivalent levels of exposure.

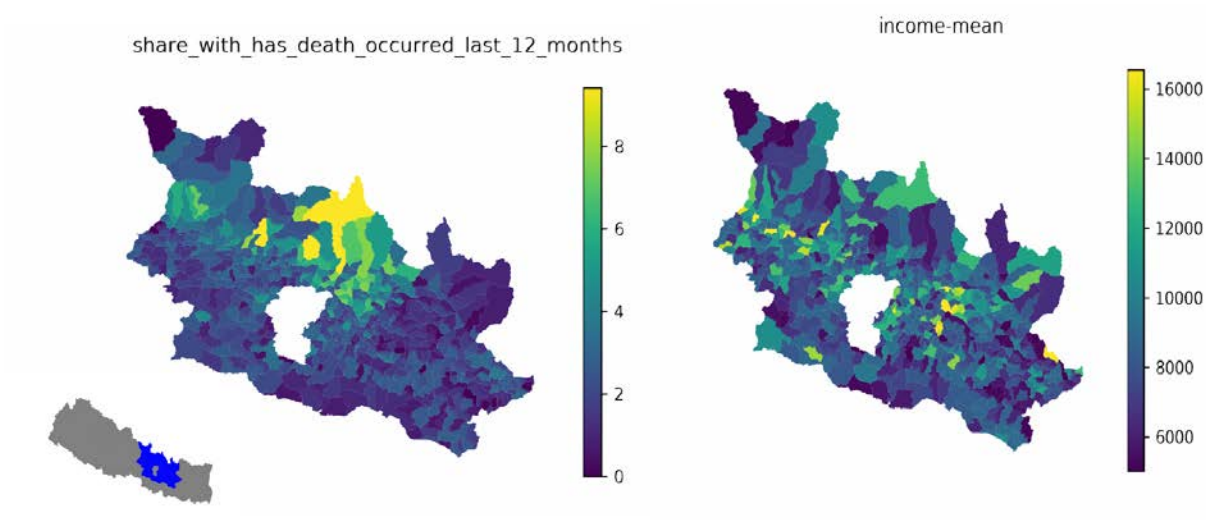

Figure 8. Examples of socio-economic data plots for Nepal: (left) distribution of casualties per household by village and (right) average income per household by village which will be used to determine drivers of variation in earthquake damages across Nepal.

We have also conducted a preliminary econometric analysis on the spatial variation in effects of hazard exposure on mortality, education attainment, and health behaviors and the extent to which disaster relief mitigated these effects. Preliminary results show a negative effect of aid received on number of deaths (Table 2)

Table 2. Summary for 2SLS estimation procedure and instrument for aid received using a village-level measure of what share of the households are 'upper caste' (which affect the receipt of aid in a plausibly exogenous way given the political economy of the setting).

IV-2SLS Estimation Summary

Dep. Variable:	post_eq_effects	F-statistic:	774.33
Estimator:	IV-2SLS	P-value (F-stat)	0.0000
No. Observations:	1036340	Distribution:	chi2(2)
Cov. Estimator:	robust		

Parameter Estimates

	Parameter	Std. Err.	T-stat	P-value	Lower CI	Upper CI
Intercept	0.0952	0.0033	29.047	0.0000	0.0888	0.1016
size_household	0.0022	9.404e-05	23.776	0.0000	0.0021	0.0024
aid	-0.0880	0.0049	-17.852	0.0000	-0.0977	-0.0783

Endogenous: aid, Instruments: bcn_share , Robust Covariance (Heteroskedastic)

3. Summary

Work on the first three research areas has made significant progress over the first year of the project and we are on schedule to complete these components of the project:

1. Determining how and where are urban settlements changing
2. Creating a database archive and mapping the frequency, magnitude, and duration of the four dominant natural hazards— earthquake, fire, flood, and landslides—to better understand they vary over time and space in the region
3. Gathering socio-economic data for the region to better understand the sensitivity of the socio-economic system to different stressors

In the next period, we will continue to advance these areas and begin focus on the remaining two research areas:

4. Determining where urban settlements most vulnerable and to what stressors are they most vulnerable.
5. Explaining differences in the vulnerability of urban settlements across the HKH region.

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