Climate Change Vulnerability Index Mapping of Nepal using NASA EOS Data

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Abstract

The main objective of this study was to develop past and present vulnerability index using climate and socioeconomic data at district level in Nepal based on IPCC 2007 framework of vulnerability. Vulnerability is expressed as a function of the exposure, sensitivity and adaptive capacity of a region to climate change effects, especially natural disasters. However, this index incorporated not only the frequency of hazard events but also the gradual changes in mean temperature and precipitation. Social vulnerability scores were mapped at district level using ArcMap 10. The assessment was carried out from 1975 to 2012 at a decadal scale. NASA climate and land cover datasets were leveraged to advance the climate change portion of the vulnerability assessment. Specifically, changes in temperature were measured using NASA MERRA data and precipitation using TRMM 3B43 monthly datasets and gauge data from Willmott and Matsuura respectively. Place based vulnerability was derived using multi criteria analysis in Arc Map 10. The resultant climate change and geographic vulnerability index were combined in ArcMap to derive the overall vulnerability index.

Monitoring potential climate change using NASA satellite data and ESRI ArcGIS software could save innumerable in situ man hours and expedite the environmental monitoring required for natural hazard early warning systems. Mapping vulnerability indices helps to identify socially and biophysically vulnerable areas and hence guide efforts towards planning climate change adaptation strategies.

This assessment shall be presented to Nepalese partner organizations and the Government of Nepal, National Planning Commission, to provide supplemental tactics to respond and adapt to potential impacts of climate change.

Keywords: Climate change, vulnerability, hazard, Nepal, NASA, TRMM, MERRA, ArcMap 10

About the Author

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Introduction

Climate change is defined as a significant departure in either the mean state of climate (temperature or precipitation) or in its extreme variability, persisting for an extended period of time (IPCC 2007). In Nepal, the average temperature increase since 1977 has been 0.06°C per year and more erratic rainfall patterns have been observed with irregular monsoons, frequent floods, and drought events. The rate of warming is much greater in the Himalayas than the global average (Shrestha et al. 1999). This is adversely affecting the social system through higher health risks, decreased crop yields, and the loss of income sources for those people who directly depend upon natural resources for their livelihood. Identification of vulnerable areas due to climate change is mostly based on empirical understanding of the area and in situ observations. These observations are often limited by the inaccessibility to mountainous terrain and a lack of a road system in good condition.

The main objective of this study was to develop past and present vulnerability index using climate and socioeconomic data at district level in Nepal based on IPCC 2007 framework of vulnerability, which is defined as a function of the exposure, sensitivity and adaptive capacity. The climate change vulnerability indices were mapped by combining social, biophysical and ground based datasets in ArcMap 10. This index was further combined with place-based vulnerability or geographical vulnerability to obtain the overall vulnerability index for 1975-2012.

Study Area and Data Sources

Nepal, a landlocked country in Southern Asia lies in the Hindu-Kush-Himalayas (HKH) region, between latitudes 26° and 31°N and longitudes 80° and 88°E, and covers an area of 1,47,181 square kilometers. The country has a wide range of topography and climatic regions and is divided into five physiographic regions- the High Mountains, Hill, Middle Mountain, Siwalik and Terai regions and has 75 districts. Most of the settlements are located in the middle Mountain and Terai regions. Vulnerability assessment is performed at district level.

Table 1: Details of data sources used

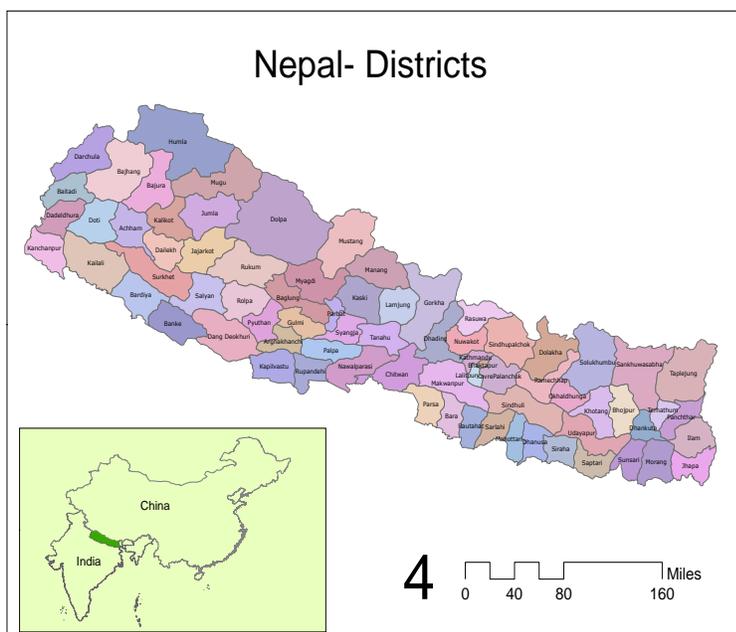| Data	Date	Source
Socio-economic data	**Census 1980-2011**	**Central Bureau of Statistics, Nepal**
Climate data	1971-2012	• Department of Hydrology and Meteorology (in situ) • GLDAS NOAH Model • The Modern-Era Retrospective analysis for Research and Applications (MERRA) • Tropical Rainfall Measuring Mission (TRMM)
Disaster data	1975-2012	DesInventar- Inventory system of the effects of disasters (In situ)
Land cover	2009	United States Geological Survey (USGS)
Digital Elevation Model		DIVA-GIS SRTM data

Figure 1: Map of study area

Methodology

I.   Data Acquisition

Climate data

Air temperature was measured using MERRA (MATMNXSLV/tavgM_2d_slv_Nx) single-level data at 0.5*0.67 degree spatial resolution and Global Land Data Assimilation System (GLDAS) Noah Land Surface Model- L4 product at 0.25*0.25 degree spatial resolution. Temperature data prior to 2000 was acquired from Willmott and Matsuura gridded precipitation data 0.5*0.5 degree spatial resolution.

The monthly accumulated rainfall data for years 2000-2011 were acquired from Tropical Rainfall Measuring Mission (TRMM) satellite 3B43 level 3 products with 0.25* 0.25 spatial resolutions. Precipitation data prior to 2000 was measured using Willmott and Matsuura gridded precipitation data with 0.5*0.5 degree spatial resolution. In addition, MERRA MATMNXLND/tavgM_2d_lnd_Nx data product was also acquired to analyze the precipitation changes. Altogether there are 282 meteorological stations in Nepal, the climate data were obtained for selected meteorological stations.

Climate related hazard

Climatic hazards, mainly floods, drought, cold wave, heat wave, landslide, GLOF flood were acquired for years 1975 to 2011 from Desinventar that provides date of occurrence of these events along with the number of deaths caused by each event.

Socioeconomic data

Socioeconomic data were acquired for years 1961, 1971, 1981, 1991, 2001 and 2011 from Central Bureau of Statistics and ICIMOD. Most of variables analyzed to measure sensitivity and adaptive capacity were based on empirical understanding of the study area. Different variables were chosen to under sensitivity, adaptive capacity such as education, access to information resources denoted adaptive capacity.

Table 2: Variable that measured exposure, sensitivity and adaptive capacity

Exposure	Sensitivity	Adaptive Capacity
Temperature change	Age group > 65	High school education
Precipitation change	Age group < 5	Housing types
Climate hazards	Population density	Households with radio
	Population without safe drinking water	
	Occupation - agriculture, forestry, fishery	
	Urban / rural population	
	Female headed household	

II. Data Processing

Climate, hazard and social data

The processing of climate data was performed using ArcGIS 10 and IDLE python 2.6.5. GLDAS, TRMM and MERRA dataset were downloaded in NetCDF format. The NetCDF files were converted into raster, clipped to Nepal extent using Python script. Mean daily temperature data from Department of Hydrology and Meteorology were averaged to compute yearly averages for minimum temperature, maximum temperature and rainfall for each station. Kriging was performed in ArcMap 10 using station data to derive temperature and precipitation maps. Zonal statistics was performed to derive the mean temperature and precipitation values for each district. Hazard frequencies were calculated for 1980s (1975-1984), 1990s (1985-1994), 2000s (1995- 2004) and 2010s (2005-2011) at district level. Total frequency was normalized to compare changes in hazard frequency across the decades. Similarly, the socioeconomic variables measured in population and households were normalized by changing them into respective percentage values. Social vulnerability was measured in 1981, 1991, 2001 and 2011.

III. Measuring vulnerability components

Exposure
Exposure was measured for each district in terms of deviation (Z score) of temperature and precipitation from mean values over a decade. The hazard events were added to the exposure from mean variation in temperature and precipitation. The overall exposure scaled in the range 0-1 presented both the mean variation from climate and climate variability.

Sensitivity and Adaptive capacity
Principal Component Analysis (PCA) was performed using IBM SPSS Statistics 20 to obtain the principal components for socioeconomic variables from 1981-2011. Each principal component score was weighted by its percentage variance such that components with higher variance contribute more towards overall social vulnerability. These principal components were summed up to construct the overall social vulnerability. Social vulnerability scores were mapped at district level to provide visual representation of social vulnerability using ArcMap 10.

Climate Change Vulnerability
A vulnerability index was created from the following Equation 1. This formula indicates the additive effect of exposure and sensitivity and subtractive effects of adaptive capacity.

Climate change vulnerability= (Sensitivity – Adaptive capacity) + Exposure....Equation 1
= Social Vulnerability + Biophysical Vulnerability

Geographical vulnerability or Place-based hazard
Agricultural practices in steep slopes (higher than 20 degrees) destabilizes slope and contribute towards slope failure (Dai 2002). Areas with slopes higher than 20 degree were identified from slope map derived from the DEM and land cover map in 2009 was used to identify the agricultural areas. The percentage of geographically hazardous areas prone to slope failure were compared to total area of each district to compute the geographic vulnerability index using ArcGIS 10.

Results and Discussions

Social vulnerability
High social vulnerability score indicates high sensitivity and low adaptive capacity of the populations. Socially vulnerability districts were clustered in the Far-western development region and some districts in southern belt. The districts with major urban centers such as Kathmandu, Bhaktapur, Lalitpur and Kaski had low social vulnerability.

Climate change vulnerability
The resultant climate change vulnerability index map of Nepal (Figure 2) integrated anomalies in decadal temperature and precipitation, frequency of climate related hazards, and social vulnerability. Red color indicates higher vulnerability to climate related stimuli whereas green color represents low vulnerability to climate change.
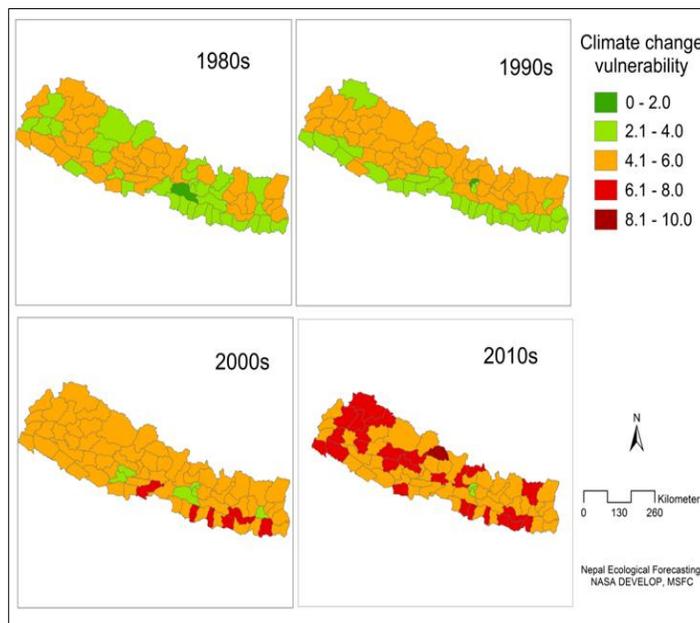

Figure 2: Climate change vulnerability in 1980s, 1990s, 2000s and 2010s

Higher vulnerability was observed in recent decades - 2000s and 2010s compared to 1980s and 1990s. In 2010s, high vulnerability observed in the Far-western development region was mainly due to socially vulnerable populations with limited access to resources, and hence low adaptive capacity to cope with climate related stimuli. Climate vulnerability index maps prepared (Figure 3) show increased climate vulnerability in Far-western development region of the country. These indices were developed based on change in climate, social as well as place-based vulnerability.
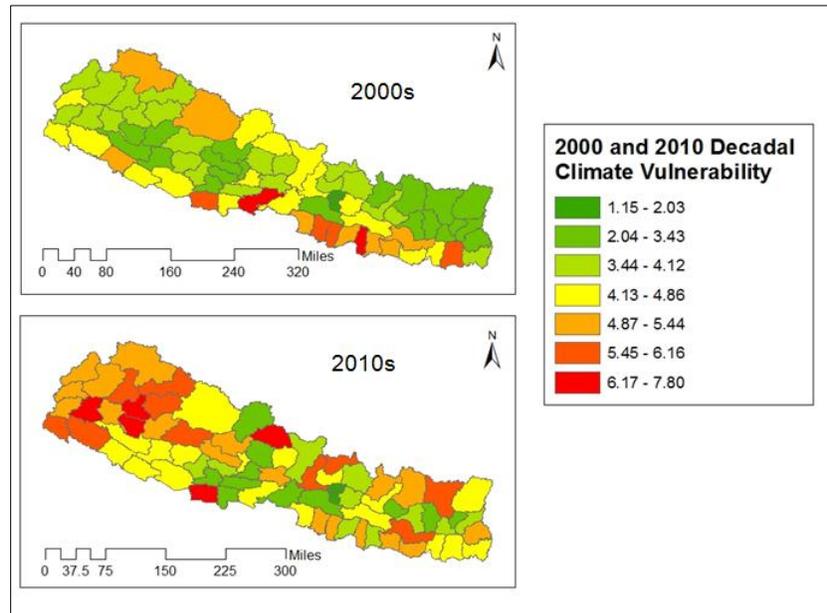
Figure 3: Overall Climate Vulnerability index in 2000s and 2009.

Conclusion:

Satellite-based remote sensing data is crucial to studying vulnerability to climate change. When combined with socioeconomic variables and exposure to extreme climatic events, NASA MERRA and TRMM provide data for understanding shifts in temperature and precipitation. As this study shows, Nepal districts that depend on natural resources, such as agriculture and forestry, become more vulnerable as their climate changes. In addition to agricultural and forestry importance, the study develops a table of variables important to understanding the overall vulnerability of districts in Nepal. The research conducted in this report provides an assessment of vulnerability for 1975 to 2012. This is important as it has quantified vulnerability posed by climate change derived from the combination of climate and social data. Moreover, it has elucidated competence of ArcGIS software facilitating not only analytical capabilities but also powerful image processing capabilities using Python script. The resultant maps could guide policy makers to identify, prioritize and to allocate resources to develop a robust integrated approach to increase resilience to climate risk at national and local level.

Acknowledgement

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