Rapid, cost-effective and high resolution assessment of climate-related vulnerability of rural communities of Sikkim Himalaya, India

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With impacts of climate change becoming increasingly visible locally, identification of areas vulnerable to climate change risks is emerging as an urgent policy need. The present study responds to this requirement by identifying the most vulnerable villages using a rapid, cost-effective and high-resolution methodology. We provide a preliminary, village-level, climate-related vulnerability assessment of the rural communities in Sikkim, India. We found that climate change impacts have resulted in a reduction in the temporal spread of rainfall and an increase in the intensity with a marked decline in winter rain. We show that the subtropical villages (less than 1000 m), especially in the drought-prone zones are more vulnerable due to an increased outbreak of pests, diseases and weeds. Spring water sources are drying up and preservation of seeds during the warm winter is becoming risky. A high variation was found in the sensitivity and adaptive capacity due to the diverse developmental profile of the villages. Hence while climate change adaptation-related developmental interventions need to have a diverse sectoral profile, they must geographically target areas with specific interventions. We expect that this study will provide a scientific basis for designing climate change adaptation policy and programmes.

Keywords: Adaptive capacity, climate change, rural communities, vulnerability assessment.

SIKKIM is the least populous and the second smallest state in India. Despite its small area, it is geographically diverse due to its location in the Himalayas, with a high variation in elevation ranging from 300 to 8598 m. Mt. Khangchendzonga, the world's third highest peak, is the guardian deity of the state. It is not only the highest but also the steepest landscape in the country, since the width of the Himalayas across its entire length is narrowest here[1]. It is a part of the Eastern Himalayas global biodiversity hotspot with 47% forest cover[2,3]. In terms of country-level vulnerability to climate change, India ranks high globally. Within India, Sikkim shows high resilience compared to other states[4]. The relative climate change vulnerability rank of Sikkim amongst the mountain ecosystems in the Eastern Himalayas was found to be 51 out of 89 (ref. 5).

The two basic responses to the threats posed by climate change are mitigation and adaptation. While mitigation has been the main focus of the climate change debate, now adaptation strategies are also getting the desired attention. Adaptation to climate change is necessary, in addition to mitigation, to avoid unacceptable impacts of anthropogenic climate change[6]. First-generation vulnerability assessments focused on climate change-related drivers (temperature, rainfall, submergence, etc.) and of late second-generation assessments are being explored, which adopt a multidisciplinary approach where non-climatic drivers (economic, education, infrastructure, etc.) are also taken into consideration[7]. Like in other developing countries, there is a lack of spatially disaggregated meteorological records. Long-term, reliable data are available only for one station – Gangtok. Climate change-related studies based on the analysis of data for this station month-wise, season-wise and annually from 1957 to 2005 indicate a trend towards warmer nights and cooler days, with increased rainfall, except in winter. The maximum temperature in Gangtok has been rising at the rate of 0.2°C per decade and the annual rainfall is increasing at the rate of nearly 50 mm per decade[8–10]. Comparison of long-term meteorological data available for Gangtok station (1957–2005) with the trend over the last few years (2006–2009), shows an acceleration of these patterns, with winters becoming increasingly warmer and drier now (Table 1). With the impacts of climate

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change becoming more visible, especially over the last few years and with increased media coverage, there is a pressure on governments now to act fast and invest in this sector. The National Action Plan on Climate Change which incorporates the country's vision on climate change was prepared in 2008 (ref. 11). The above factors have created a need for reliable and high-resolution vulnerability assessment reports, which can act as decision support systems for developmental planning.

Sikkim is administratively divided into four districts, namely North, East, South and West. Climate change-related vulnerability studies taken up in the state at the district level have found the South and West districts to be the most vulnerable[10,12]. In spite of being a small state, there is a high variation in exposure (temperature and rainfall), sensitivity (water, livelihoods and health) and adaptive capacity (poverty, literacy, environment and connectivity) indicators over short distances. So far only macro-studies had been conducted, and there is absence of studies at the village level. For the first time a micro-scale study was taken up to address the issue of high variability typical of mountain areas.

The purpose of this study was to undertake a comparative preliminary assessment of the climate-related vulnerability of the rural communities at the village level. The focus of the study is the identification of the most vulnerable villages and perception of the villagers on the nature of climate change, its impacts and current coping mechanisms. The results of this analysis are intended to provide to the government, voluntary sector and international donors a basis for improved developmental planning and policy, whereby the results are used to devise strategies that support in managing vulnerability and to raise awareness on rural livelihood issues to a broader audience.

Methodology

The Intergovernmental Panel on Climate Change[6] defines climate-related vulnerability as a function of climate-change exposure, sensitivity and adaptive capacity. Exposure is defined by the magnitude, character and rate of climate change in a given geographical area. Sensitivity to climate change is the degree to which a community is adversely or beneficially affected by climate-related stimuli. The adaptive capacity of a community is its ability to adjust to climate change and to moderate or cope with the impacts. In some cases high levels of exposure are observed, but they might get negated by high adaptive capacity thus resulting in lower vulnerability values. Owing to their comparatively lower adaptive capacity, developing countries are considered to be inherently more vulnerable to climate change. Indicators for exposure, sensitivity and adaptive capacity were derived from disaggregated attribute datasets. We used this conceptual framework to undertake a preliminary assessment of the current vulnerability of all the villages in Sikkim. This study is preliminary in the sense that a rapid approach was used, and is dependent on available data from public sources.

Table 1. Percentage variation of monthly rainfall and maximum and minimum temperature averaged for the years 2006–2009, in comparison with long period average (LPA) for the period 1957–2005 (source: K. Seetharaman, pers. commun.)

Month	Rainfall (%)	Maximum temperature (°C)	Minimum temperature (°C)
January	–73	–0.1	2.1
February	–19	0.3	2.0
March	–25	–0.3	1.5
April	7	–0.6	1.4
May	–26	0.1	1.4
June	–8	–0.4	0.9
July	–10	–0.2	1.4
August	0	–0.3	1.0
September	2	–0.2	1.0
October	–40	–0.3	1.5
November	–24	–1.0	1.6
December	–39	–0.7	2.1

There are a total of 163 Gram Panchayats (or villages) in the state, having an average population of 3000 and an extent of 10 km^2. The current study builds largely on secondary information in the form of reliable government-sourced datasets and primary information collected from village consultations. A total of 10 indicators available in a disaggregated manner at the village level were used to measure vulnerability. Ground truthing in the form of participatory approaches was also integrated. The whole study was completed in six months from April to October 2010, incurring a field expenditure of less than Rs 5 lakhs.

Data sources

Table 2 shows the 10 indicators used and their source, grouped into sectors, and into exposure, sensitivity and adaptive capacity components.

Exposure indicators: Long-term, reliable meteorological data are available only for Gangtok station and were sourced from the India Meteorological Department, Gangtok Office. Hence the disaggregated annual mean temperature data were obtained from the website www.worldclim.org. However, the annual mean rainfall pattern indicated in the website was not found to be accurate and consequently this was sourced from the rainfall distribution map of the state[13].

Sensitivity indicators: Sensitivity component includes three sectors: water resources, livelihoods and human health. For each of these sectors, 1–2 indicators were selected to represent aspects of the sector that was quantitatively analysed. The percentage of rainfed farming was used as a proxy indicator of water resources availability. To represent the sensitivity of the livelihoods sector two

Table 2. Indicators used and their source, grouped into sectors, and exposure, sensitivity and adaptive capacity components

Component	Sector	Proxy indicators	Source
Exposure	Temperature	Annual mean temperature	worldclim.org
	Rainfall	Mean annual rainfall	NBSSLUP 2000[13]
Sensitivity	Water resources	Percentage of rainfed farming	Census 2001[15]
	Livelihoods	Percentage of farming population	Census 2001[15]
		Elevation	SRTM DEM[14]
	Human health	Family size	DESME 2005[16]
Adaptive capacity	Economic capacity	Poverty rate	DESME 2005[16]
	Human capacity	Percentage of class-ten pass population	DESME 2005[16]
	Environmental capacity	Population density	DESME 2005[16]
	Physical connectivity	Rural connectivity	Census 2001[15]

indicators were selected, namely elevation and percentage of population mainly dependent on farming. Elevation was chosen since the crops in the subtropical belt (less than 1000 m) have been impacted the most by pests, diseases and weeds. Elevation was obtained from the Shuttle Radar Topographic Mission (SRTM). The SRTM 90 m DEM file (srtm_54_07.zip) was downloaded from the CGIAR-CSI GeoPortal[14]. This file in GeoTIFF format was processed in Erdas Imagine software (version 8.5) to subset the study area from this image and exported to grid format. The percentage of population mainly dependent on farming was obtained from the Census of India[15].

Adaptive capacity indicators: The socio-economic conditions having a bearing on the adaptive capacity component include economic capacity, human capacity, environmental capacity and physical connectivity. Whereas poverty rate was used as a measure of economic capacity, the percentage of population that has passed class-ten was used to represent human capacity. Population density was used as a proxy indicator of environmental capacity, and the type of rural connectivity (paved road, mud road and footpath) was used to represent physical connectivity of the village. These socio-economic data at village level were sourced from the Census of India[15] and State Socio-Economic Household Census[16].

Limitations: There are several limitations of this preliminary framework wherein the choice and representativeness of the indicators may not be adequate. Also, many of the indicators like poverty, literacy, road access, etc. are not strictly independent. Although there will always be a certain degree of arbitrariness in any set of indicators, what has to be ensured is that the dataset must be as meaningful as possible. Further research is needed to strengthen the exposure index by incorporating high-intensity rainfall events, landslides, etc. and also by using the weather data from recently installed automatic weather stations. The sample size of the villages where participatory rural appraisal (PRA) was conducted needs to be further enlarged, especially by including a few villages from the North district to make the sample representative. Predictions of future vulnerability through climate-change prediction models can also be attempted.

Ground truthing: PRA was conducted with support from German Technical Cooperation in five villages covering all the eco-regions in three of the four districts. Four tools, namely resource-based seasonal dependency matrix, seasonal activity calendar, weather event chart and hazard ranking using spider web were used. These PRAs took place in July–August 2010 and were attended by a group size of around 35, with representation of all the stakeholders.

Data analysis

We constructed an index of climate change vulnerability at the village level using the following steps. There are three components, namely exposure, adaptive capacity and sensitivity which are used to calculate the vulnerability. Then to make the indicators of a component comparable, we normalized them using the formula

$$I_n = (I - I_{min})/(I_{max} - I_{min}),$$

where I_n is the standardized value of the indictor and I is the unstandardized value. I_{max} is the maximum value of the indicator and I_{min} is the minimum value of the indicator. Then we used the simple average of the standardized indicators to calculate the value of each of the components. Since we did not have knowledge of the degree of importance of each hazard in assessing the vulnerability, we assumed equal weights for all.

$$C = \text{Average}(I_n).$$

Table 3. Community observations on climate change and associated impacts

Climate events	Community observations on climate change	Associated impacts
Snowfall	Reduced snowfall since the last four years in the temperate-belt villages; less frost as well.	Warm, dry winter and less frost.
Rainfall	Rainfall months have decreased, but the intensity has increased. The spread of rainfall had declined from nine months in a year to 5–7 months, with the subtropical zone being adversely impacted. There is heavy downpour during monsoons compared to constant low-intensity rainfall in the past. The winter rainfall has decreased significantly over the last five years, specially in the lower belt.	Frequent landslides, unreliable connectivity, floods, and longer dry period in winter.
Hail storm	Hailstorms have become unpredictable and the size of the hail has also increased.	Severe damage to tender maize, potato and orange crop.
Cold temperature	Winters have become warmer and duration has reduced from six months to 3–4 months, with the sub-tropical zone being adversely impacted.	Increased population of insects and vector-borne diseases.
High temperature	The high temperature has increased from five months to 6–8 months with the subtropical zone being adversely impacted. Autumn heat is also being experienced now.	Villagers have started using refrigerators and fans. Decrease of agricultural yield with increase in the outbreak of pests, diseases and weeds resulting in decrease in yield of crops like ginger, fruits and tomatoes. Farmers in the middle belt have started growing these crops.
Dry season	Hardly any rainfall for six continuous months from October to March.	Frequent and ascending forest fires, drying of spring water sources, decline in the production of winter crops and vegetables

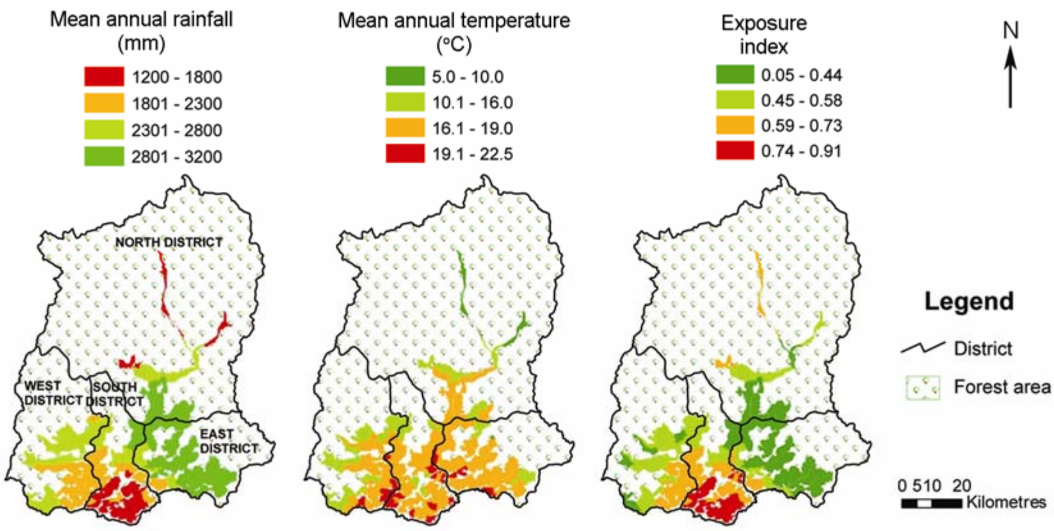

Figure 1. Map of exposure component along with indicators of mean annual rainfall and annual mean temperature of the rural communities of Sikkim, India.

Following this, the climate-related vulnerability (*V*) was calculated as

$$V = (\text{exposure} - \text{adaptive capacity}) \times \text{sensitivity}.$$

This value was standardized again to obtain the vulnerability index (VI) so that the scale used was 0–1, indicating the lowest vulnerability level (0) to the highest vulnerability level (1). To identify the vulnerable areas, we ranked the regions according to the index and divided the list into four equal parts or quintiles with classification as least vulnerable, mildly vulnerable, moderately vulnerable or highly vulnerable.

Data integration

The developmental units in the state comprise 163 Gram Panchayat Units (GPU), 24 developmental blocks and four districts. A village was defined as a GPU, and its

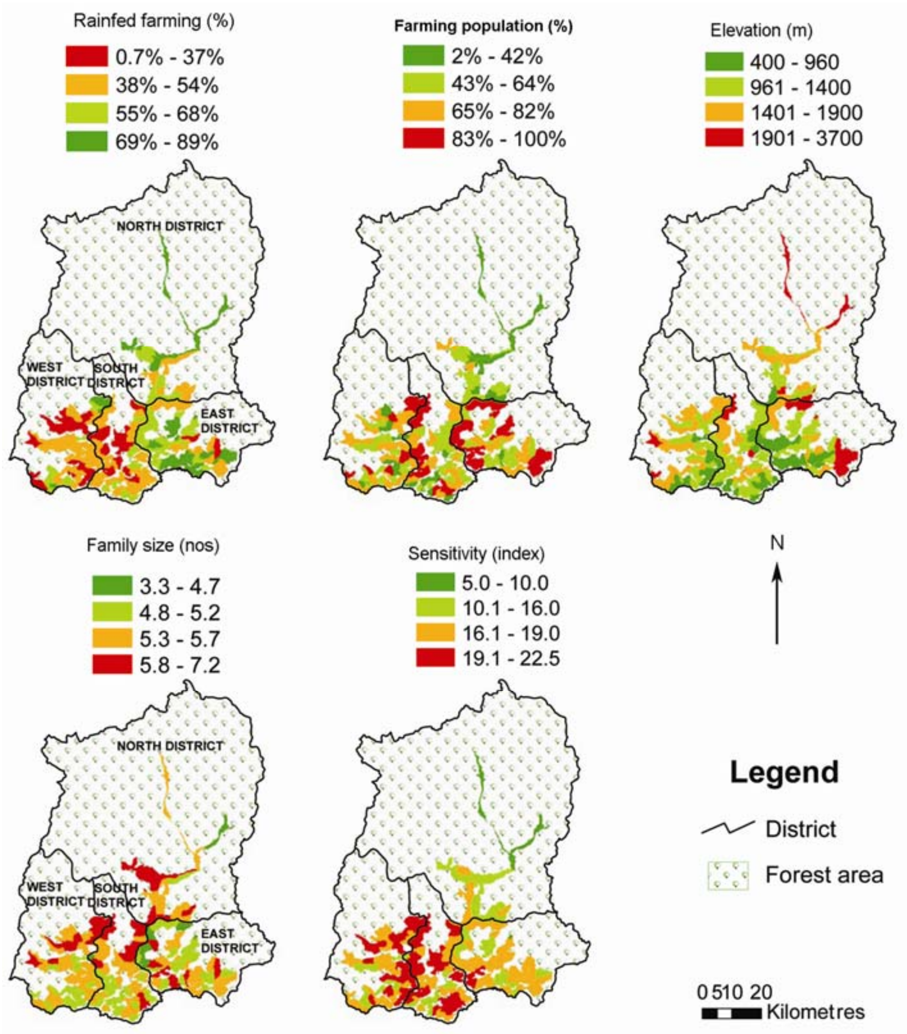

Figure 2. Map of the sensitivity component of the rural communities of Sikkim along with the participating sector values.

administrative boundaries were marked on the Survey of India 1 : 25,000 scale topographical sheets. The boundaries for all the GPUs were then digitized and the village maps prepared. The census data were integrated on a Geographic Information System (GIS) platform. ArcGIS software (version 9) was used for integration of the various layers on the GIS platform.

Results

Both temperature and rainfall showed large variations over short distances. Whereas the annual mean temperature varied from 5°C to 22.5°C, the annual mean rainfall varied from 1200 to 3200 mm (Figure 1). Exposure index was found to spatially vary from 0.05 to 0.91 with the mean being 0.53 ± 0.16. The south-central part of the state which has the lowest altitude and is also drought-prone as it falls in the rain-shadow region of the Darjeeling Himalaya was found to have the highest exposure (Figure 1). The observations of the local community regarding the pattern of climate change and the associated impacts (Table 3) are corroborated by the scientific studies (Table 1).

The sensitivity indicator varied from 0.23 to 0.72, with the mean being 0.59 ± 0.08 (Figure 2). In the subtropical zone (less than 1000 m), the production of important cash crops like ginger, orange and fruits has declined due to prolonged droughts and outbreak of pests, diseases and weeds. Plants such as maize, broom grass and turmeric were found to be the most resilient. This zone was earlier a productive area with multiple cropping; now due to less winter rain, only single cropping during the monsoon is possible. Storage and preservation of seeds is also becoming increasingly difficult due to pest, disease and dry winter. Communities in the middle and upper hills were found to be less vulnerable, and warmer winters provided new opportunities for vegetables such as tomato, chilli, carrot, cucumber, passion fruit, beetroot, etc., coupled with higher production and early ripening as well. Adaptive capacity varied from 0.24 to 0.89, with the

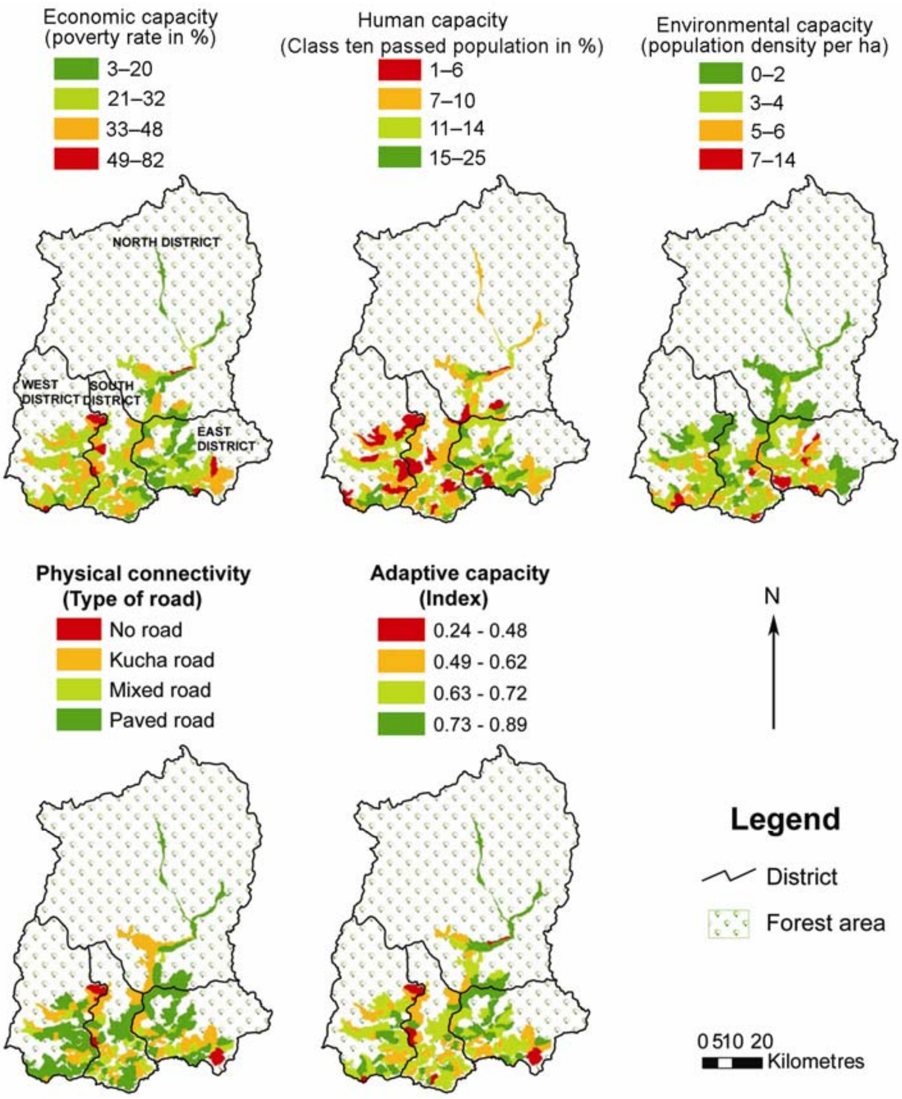

Figure 3. Map of the adaptive capacity of the rural communities of Sikkim and the participating sector values.

mean being 0.66 ± 0.1 (Figure 3). Remote villages lacking physical connectivity also showed high illiteracy and poverty, resulting in weak adaptive capacity. Villages adjacent to urban centres with good connectivity and diverse opportunities displayed high adaptive capacity.

The climate-related vulnerability index of the 163 Gram Panchayats had a mean of 0.43 ± 0.22. We identified the most vulnerable areas, which are concentrated in the subtropical zone of the South and West districts (Figure 4). These areas include the blocks of Melli, Jorethang, Sikkip, Namchi, Namthang, Soreng and Kaluk. In general, these results agree with the commonly held perceptions, since these villages face the highest exposure to climate change which coupled with high sensitivity and low adaptive capacity results in high vulnerability. The South district was found to be the most vulnerable, followed by the West district. The East and North districts were found to be relatively resilient to climate-related changes. However, areas like Karzi-Mangnam and Sakyong-Pentong village which were not highly exposed were found to be highly vulnerable due to the high sensitivity and low adaptive capacity.

The rural communities have already started coping with the impacts of climate change using indigenous methods. The national flagship programme, Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) has become an important source of climate-proof cash income in the rural areas. Rural folk have started supplementing farming livelihoods with non-farm activities like MGNREGA, tourism, trade, non-farm labour and in extreme cases, even migration. Ginger seed is now being protected from dry winter by storing it underground. Seeds of pulses, beans and soyabean are preserved by mixing with kerosene, ash, camphor, etc. The seed bank has also been expanded to account for replanting when young crops get damaged by hail. Fruit

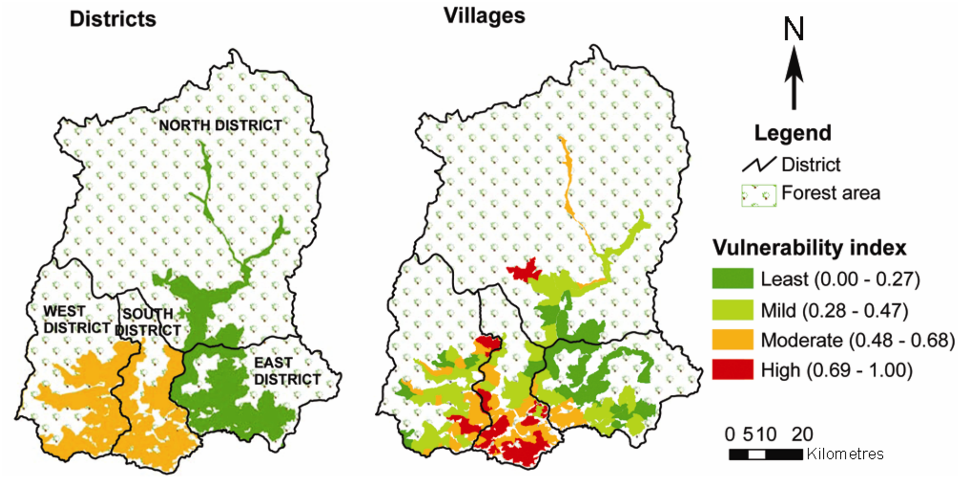

Figure 4. Map of climate-related vulnerability of the rural communities of Sikkim.

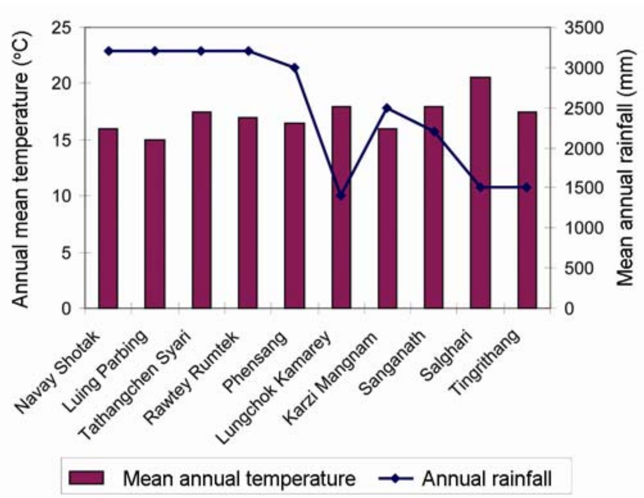

Figure 5. Exposure indicators of mean annual temperature and mean annual rainfall of the five least and most vulnerable villages of Sikkim.

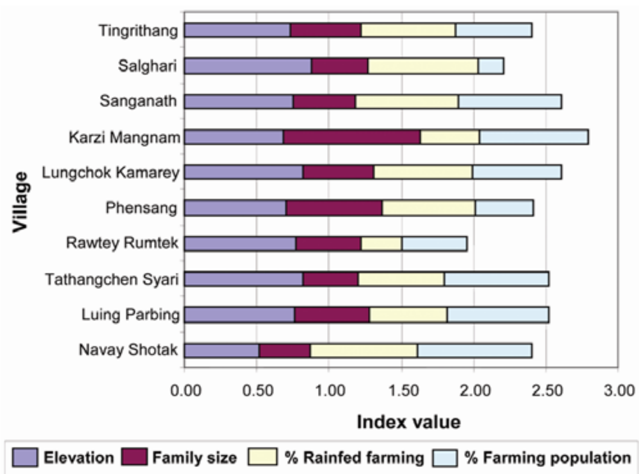

Figure 6. Sensitivity of the five least and most vulnerable villages of Sikkim and the participating sector values.

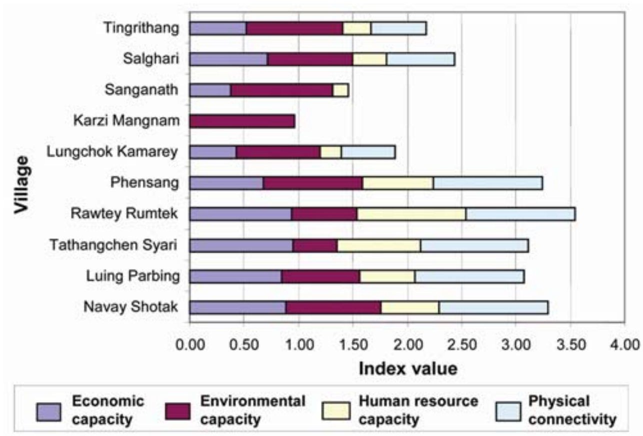

Figure 7. Adaptive capacity of the five least and most vulnerable villages of Sikkim and the participating sector values.

trees are protected from increased incidences of insect borers by applying kerosene, petrol and diesel in the holes. Springs are drying up, especially during the dry winter months, and the local communities are coping by improving the water storage infrastructure, storing water overnight in tanks and containers, and also pumping water from downstream. Crop residue is being stored for use as winter fodder for livestock.

Discussion

Recent impacts of climate change indicate a warmer and dry winter, which has resulted in a decline in the production of winter crops in the lower belt. Due to increased run-off and dry winters, springs have started drying up and their lean season discharge is reducing drastically. Annual mean rainfall showed high variation due to the geography, with the rainshadow areas in the subtropical zone of South and West districts receiving only half the

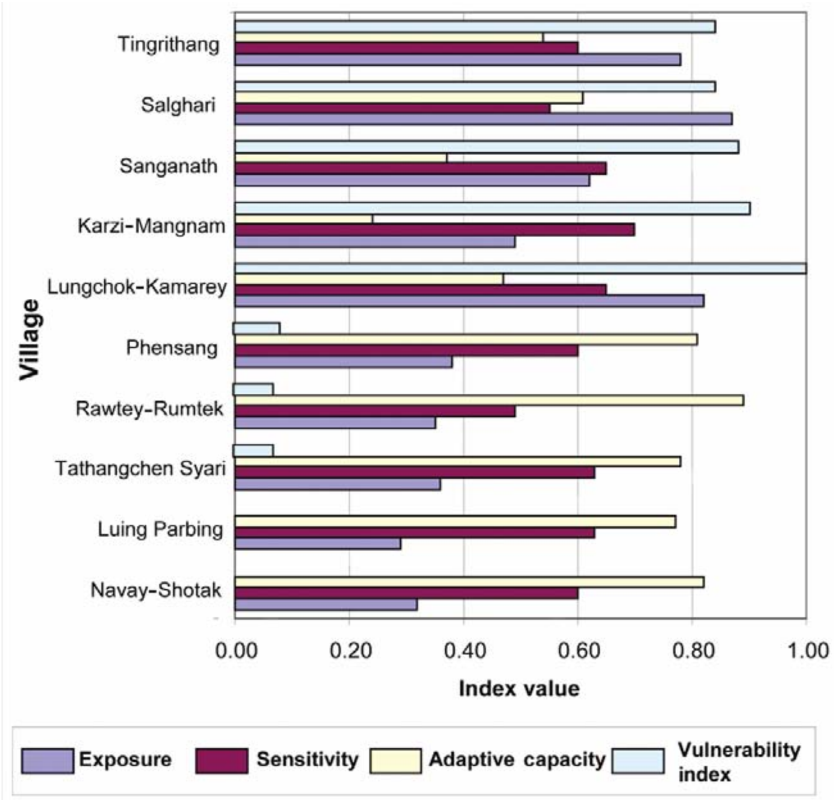

Figure 8. An overview of the range of vulnerability indicators for the five least and most vulnerable villages of Sikkim.

rainfall compared to the East district. Figure 5 shows the exposure indicators for the five most and least vulnerable villages. Most of the vulnerable villages (other than Karzi-Mangnam) lie in the drought-prone, subtropical zone of the South and West districts.

Also, Karzi-Mangnam village was found to be most sensitive due to large family size (of seven) and the total dependence (100%) on farming (Figure 6). Comparatively, Rawatey-Rumtek village was found to be the least sensitive owing to the smaller family size (of five), coupled with diversified livelihood opportunities and better irrigation facilities. Consequently, the percentage of rainfed farming and population dependent on farming (61%) was much less here. In terms of a comparison of the adaptive capacity, it was found that Karzi-Mangnam village had favourable environmental capacity which was offset by a high poverty rate (82%), low education levels (1% have passed class ten) and poor road connectivity resulting in the weakest adaptive capacity (Figure 7). On the other extreme, Rawatey-Rumtek village had a low poverty rate (8%), high education level (25% have passed class ten) and is well connected resulting in a high adaptive capacity.

In spite of having moderate exposure, due to high sensitivity and low adaptive capacity, Karzi-Mangnam village showed high vulnerability. Also, Lungchok-Kamarey village had the highest vulnerability owing to high exposure, high sensitivity and low adaptive capacity. Similarly, Navay-Shotak village had the least vulnerability owing to low exposure, low sensitivity and high adaptive capacity (Figure 8). The variation in vulnerability was stark, since the communities that practised the most climate-sensitive livelihoods had least adaptive capacity and also faced high exposure. Communities practising sensitive livelihoods of rainfed farming were found to have the least adaptive capacity (poverty, education, infrastructure, etc.) and also faced high exposure of climate-related change (drought and pests).

To counter the climate-change impacts, diverse development interventions are needed. For example, while in Karzi-Mangnam village interventions are needed in the sectors of education, health (family planning), income and roads, in others like Sanganath the priority sectors are education and roads. Significant variation in vulnerability was found within a district. Vulnerable villages like Sakyong-Pentong and Lachen (in the North district) and Central-Pendam, West-Pendam and Singbel (in the East district) were found to occur in less vulnerable districts. Also, less vulnerable villages like Okhrey-Ribdi and Yuksam (in the West district) and Lingmo-Kolthang and Paiyong (in the South district) were found to occur in vulnerable districts. This high intra-district variation in vulnerability calls for high-resolution vulnerability-assessment studies to ensure that errors of inclusion and exclusion are minimized and climate change adaptation funds are efficiently targeted especially in mountain areas.

Conclusion

To conclude, with effects of climate change increasingly impacting local livelihoods, climate change adaptation with geographical and sectoral targeting is emerging as an urgent policy requirement. The present study demonstrates a rapid, cost-effective and high-resolution climate-related vulnerability assessment of the rural communities of Sikkim, India. Maps were also prepared to show the climate change-related vulnerability of rural communities in Sikkim. While it is difficult to reduce the exposure which is an external driver, the sensitivity and adaptive capacity which are local drivers, can be addressed with local interventions. A high variation was found in the sensitivity and adaptive capacity due to the diverse developmental profile of the villages. Hence to counter this, the climate change adaptation strategy needs to be fine-scale and multi-sectoral, to encompass the diverse sectors of education, health, environment, roads, irrigation, agriculture, water, poverty alleviation, skill development, non-farm employment, etc. It is expected that the outputs of this analysis will be used by policy makers and donor agencies for better designing and targeting of the climate change adaptation policy and programmes.

1. Schaller, G. B., *Mountain Monarchs: Wild Goat and Sheep of the Himalaya*, University of Chicago Press, Chicago, IL, 1977.
2. Mittermeier, R. A. *et al.*, *Earth's Biologically Richest and Most Endangered Terrestrial Ecoregions*, Conservation International, Arlington, VA, 2004.
3. FSI, State of forest report, Forest Survey of India, 2007.
4. Malone, E. L. and Brenkert, A. L., Modeling vulnerability and resilience to climate change: a case study of India and Indian states. *Climate Change*, 2005, **72**, 57–102.
5. Tse-ring, K., Sharma, E., Chettri, N. and Shrestha, A., Climate change vulnerability of mountain ecosystems in the Eastern Himalayas; Climate change impact an vulnerability in the Eastern Himalayas – synthesis report. ICIMOD, Kathmandu 2010.
6. Intergovernmental Panel on Climate Change, *Climate Change 2007: Climate Change Impacts, Adaptation, and Vulnerability*, Cambridge University Press, Cambridge, 2007.
7. Füssel, H. and Klein, J. T., Climate change vulnerability assessments: an evolution of conceptual thinking. *Climate Change*, 2006, **75**, 301–329.
8. Seetharaman, K., Climate change scenario over Gangtok. Letters to the editor. Meteorological center, Gangtok, Indian Meteorological Department, India. *Mausam*, 2008, **59**(3), 361–366.
9. Ravindranath, N. H., Joshi, N. V., Sukumar, R. and Saxena, A., Impact of climate change on forests in India. *Curr. Sci.*, 2006, **90**(3), 354–361.
10. IISc, Climate related vulnerability and adaptation for North East India. Indian Institute of Science, Bangalore, 2010.
11. Anon., National Action Plan on Climate Change. Prime Minister's Council on Climate Change, GOI, 2008, p. 49.
12. WWF-India, An ecosystem's approach to climate change vulnerability Assessment in Sikkim and western Arunachal Pradesh. WWF–India, 2010, p. 72.
13. NBSSLUP, Sikkim soils. Prepared and published by National Bureau of Soil Survey and Land Use Planning (ICAR), Regional Centre, Kolkata, in cooperation with Department of Agriculture, Department of Forest, Government of Sikkim, 2010.
14. Jarvis, A., Reuter, H. I., Nelson, A. and Guevara, E., Hole-filled SRTM for the globe, version 3, 2006; http://srtm.csi.cgiar.org
15. Census of India, Provisional population totals: Paper 1 of 2001. Gangtok, 2001.
16. DESME, State Socio-Economic Household Census, Directorate of Economics, Statistics, Monitoring and Evaluation, Government of Sikkim, Gangtok, 2006.

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