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Social-Ecological Vulnerability to Climate Change in the Nepali Himalaya

Abstract

The climate sensitive social-ecological systems of the Nepali Himalaya are increasingly exposed to the impacts of rapid climate change. As a result, the changing climate is negatively impacting upon livelihoods of the region. Effective adaptation responses could reduce the negative impacts of change and assessments of vulnerability of local social-ecosystems are helping to initiate that process. However, insufficient research has assessed climate change-induced vulnerability of Nepali Himalayan social-ecosystems at different scales. This study measures vulnerability of social-ecosystems at the household level and within three village clusters of the Kaligandaki Basin in the Central Himalaya, Nepal. The clusters represent different ecological zones: Meghauli in the hot and wet tropical Tarai; Lumle in the cool, wet temperate Middle-Mountains; and Upper-Mustang in the cold and dry Trans-Himalaya. Data on the exposure, sensitivity and adaptive capacity of the social-ecosystems were collected through face-to-face interviews with 360 households. Exposure, sensitivity and adaptive capacity sub-indices were calculated and integrated to develop the vulnerability indices. The social-ecosystems reveal significant levels of exposure to climate change and are sensitive to change and extreme weather events, but limited capacities to adapt across all spatial scales result in very high social-ecological vulnerability. Yet, there is variation in the levels of vulnerability across the households, primarily because of different non-climatic factors such as the livelihood assets that a household commands. Given that many Nepali households have very limited adaptive capacities, the country requires an adaptation policy to address the needs of the most vulnerable households through a 'poor people first' approach, before adaptation planning and investment is extended gradually to reduce the vulnerability of social-ecosystems across the country.

Key Words: *Social-ecology, climate change, vulnerability, Kaligandaki Basin, Himalaya, Nepal*

Highlights:

- The social-ecosystems of the Nepali Himalaya are exposed to rapid climate change
- The ability of socio-ecosystems to respond to social and physical stressors are limited
- The social-ecological systems of the basin are vulnerable
- Climate change is one of many contributing factors to social-ecological vulnerability
- Household vulnerability assessments provide the opportunity for just adaptation policy

1. Introduction

Variability in climate is a natural phenomenon. There have been periods of both heating and cooling of the Earth in its history (Folland et al., 2001; Salinger, 2005). However, the change observed in the 20th and 21st centuries is anomalous to the past millennium (IPCC, 2007; Mann, Bradley, & Hughes, 1999). The recent pace of global warming is around 0.065^{O}C per decade on average, or 0.85^{o}C in total in-between 1880 - 2012 (IPCC, 2013). Future projections for warming in the 21st century are notably higher, although the estimated rates vary across models: 1.8 to 6.4^{o}C (IPCC, 2007); 3 to 10^{o}C (Stern, 2006); or 0.3^{o}C to 4.8^{o}C (IPCC, 2013). Together with warming, extreme weather events such as drought, extreme rainfall and storms have also increased and have changed in their timing and characteristics (Berrang-Ford, Ford, & Paterson, 2011; McEvoy, Matczak, Banaszak, & Chorynski, 2010). Spatial patterns of warming, changes in precipitation and distribution of extreme events, while highly variable (Caesar et al., 2011), are already affecting human populations and their associated ecologies globally.

Studies have shown that warming in the Himalaya[1] is rapid and exceeds the global average. The rates of warming are variable across the mountainous region: 0.06^{o}C yr^{-1} on average for the Himalaya (Shrestha, Gautam, & Bawa, 2012[2]) and Nepal (Shrestha, Wake, Mayewski, & Dibb, 1999[3]) to 0.27^{o}C yr^{-1} at Lamgtang region, Nepal (Chaulagain, 2006[4]); and continued warming of between 3.0°C to 6.3°C by 2090 is projected for Nepal and the Himalaya (NCVST, 2009). Depending on the location, some areas of Nepal are experiencing increased average precipitation and others decreasing (Pandey, 2014; Shrestha, Wake, Dibb, and Mayewski, 2000). For example, Shrestha et al. (2012) and Ma, Zhang, Yang, and Farhan (2015) report increased rainfall in the Himalayan region, while Duncan, Biggs, Dash, and Atkinson (2013) found decreased rainfall extremes and variability in Nepal. The contrasting findings from different studies possibly reflect the complex physiography of the Himalaya and associated local climatic effects, suggesting in turn that global and regional climate models may still be insufficient to accurately assess or project the dynamism of the Himalayan climate (Gillies, Wang, Sun, & Chung, 2013; Karmacharya, Levine, Jones, Moufouma-Okia, & New, 2015). Nevertheless, community perception research also indicates

[1] The Himalaya is a mountain system of Central and South Asia, extending from Pamir-Knot in the north-west over 1500 miles towards the east to the border of Asham. This system generally includes major four different physiographic features, namely the Outer Himalaya (the Southern *Churiya* range), the Lesser Himalaya (the Middle-Mountains or *Mahabharat Lekh*), the Greater Himalaya (Northern snowcapped mountains), and the Trans-Himalaya- (Northern frontier of the Himalaya (Burathokey, 1968).
[2] Between 1982-2006
[3] Between 1971-1994
[4] Between 1971-2000

that the Himalayan social-ecosystem is exposed to a high levels of climate change and variability, and is experiencing numerous impacts as a result of those changes (Alamgir, Pretzsch, & Turton, 2014; Bhatta & Aggarwal, 2015; Chaudhary et al., 2011; Macchi, Manandhar-Gurung, & Hoermann, 2014).

The implications of climate change for social-ecosystems are severe, unlimited, broad and complex. The implications cannot be judged precisely because of the potential non-linearity and spatial variability of change, uncertainties in impacts and differences in adaptation responses (Beck 2009; Patt, Klein, & de la Vega-Leinert, 2005; Tamerius, Wise, Uejio, McCoy, & Comrie, 2007). That said, the ecological, social, cultural and economic systems of different parts of the globe are already being affected by climate change. The life supporting environmental resources of rural populations in developing countries are at great risk because of both direct and indirect adverse food production and health impacts (McMichael & Lindgren, 2011; WHO, 2005); forced migration or displacement (Bardsley & Hugo, 2010; IFRC, 2012; Massey, Axinn, & Ghimire, 2010); conflict over local resource and security threats (Barnett & Adger, 2007; Bhattacharyya & Werz, 2012); and increasing livelihood and social-ecological vulnerability (Aryal, Cockfield, & Maraseni, 2014; Hahn, Riederer, & Foster, 2009;). Again, the implications vary between and across regions, but recent studies are indicating severe impacts in the Nepali Himalaya.

Just a few of the important early impacts of rapid climate change in the Himalaya are: reductions in crop yield, increased crop pests and diseases, and farm weeds due to increased drought and reduced water availability (Ghimire, Shivakoti, & Perret, 2010; Palazzoli, Maskey, Uhlenbrook, Nana, & Bocchiola, 2015); increased scarcity of water (McDowell, Ford, Lehner, Berrang-Ford, & Sherpa, 2012); increased climatic hazards and health problems leading to morbidity and mortality of people and livestock (Ebi, Woodruff, von Hildebrand, & Corvalan, 2007; Macchi et al., 2014); and increasing problems of resource degradation, food scarcity and the provision of basic services (Gentle, Thwaites, Race, & Alexander, 2014; Paudel, Tamang, & Shrestha, 2014). These impacts are collectively acting to undermine the livelihoods and associated social-ecosystems of the Nepali Himalaya. The diversity of Himalayan socio-ecosystems, along with the spatial variability in the pace of climate change and associated impacts, generates the need for location-specific studies to understand and compare social-ecological vulnerability to climate change.

The assessment of vulnerability is a key initial step to comprehensively identify adaptation requirements (Ford & Smit, 2003). Nepal designed and implemented a National Adaptation

Plan of Actions (NAPA) for climate change in 2009 (GoN/MoE, 2010). However, the achievements have not been effective or adequate. A critical assessment of the NAPA showed that there were many limitations in policy process and in implementation, including a lack of prioritisation of effort. The NAPA was not prepared as an integrated plan of action but as a sectoral plan that conceptualised climate change problems as if they were independent of other, broader development and sustainability concerns (Kumar n.d.). In fact, Sharma and Sharma (n.d.) identify the lack of any comprehensive analysis of the real situation in the 'situation analysis' section of the NAPA, such that social-economic injustice, implications of the decade long armed conflict and associated political transition are largely ignored in adaptation policy. The NAPA was prepared with a lack of adequate information and without sufficient representation of local researchers from relevant fields. Instead, administrative staff from the Ministry of Environment (MoE) prepared the document with the assistance of foreign experts hired by donor agencies to ensure that the country qualified for international climate change adaptation support. Fisher and Slaney (2013) have found it difficult to monitor and evaluate progress made by the Nepali NAPA, particularly due to limited local capacity to monitor actions, and the associated lack of reliable data. In such a policy context, this study aims to provide a model for knowledge generation to inform targeted and effective adaptation policy, as well as generating a guide for result-focussed monitoring, so that the failed episode of NAPA will not be repeated.

This paper assesses the vulnerabilities of social-ecosystems within individual households in three village clusters within the Kaligandaki Basin in the Nepali Himalaya, and provides examples of opportunities to apply research outcomes for effective planning. The importance of vulnerability assessments, such as those undertaken here, for resource poor countries like Nepal are that they help to define people and places of high vulnerability, such that state mechanisms can allocate resources in a just manner, by prioritising assistance for the most vulnerable households and communities.

This paper is structured into five sections. The introduction has provided background knowledge on climate change and the associated implications for Nepal, and has set the research objectives. Although the concepts social-ecology and vulnerability are not new, they are used variably in the literature, so the second section clarifies their use in this paper. The third section illustrates the comprehensive vulnerability assessment methodology, while section four provides results, explains findings and develops links with existing scholarship. Finally, the concluding remarks return to the goal of informing improved adaptation policy.

2. Conceptualizing Social-Ecology and Vulnerability

2.1 Social-Ecology

Social-ecology is a whole-of-ecosystem approach to viewing human society and the biophysical system as a complex, integrated system (Berkes & Folke, 1998). Social-ecology advocates for the transformation of mainstream anti-ecological economic development and consumption practices, socio-political and economic institutions, and technologies, and emphasizes the need to re-unite the fragmented system to establish a reconstructive, ecological, communitarian and ethical society (Adger, 2006; Beck, 2009; Bookchin, 1995). It will only be through such a transition that nature has the ability to sustain life through self-regulating and self-organizing systems, and that complex risks to society, such as climate change, will be managed effectively.

The social-ecological research approach is directly relevant for climate change vulnerability analyses that aim to help identify adaptation needs for sustainability. Social processes and institutions play important roles in maintaining the sustainability of socio-systems. However, the capacity of purely anthropogenic systems to adequately understand or accommodate environmental variability and change (Osbahr, Twyman, Adger, & Thomas, 2008), and the limited transformative capacities of communities to cope with those changes, especially in developing countries, are leading many social-ecosystems towards crisis (Bardsley, 2015). In contrast, the social-ecosystem approach to analysis accommodates collective interactions among the many human and ecological sub-systems, which as a whole, tend towards vulnerable or sustainable systems. One of the most important sub-systems in the context of this paper is the livelihood system of the studied households, and much of the analysis investigates complex changes to the vulnerabilities of those systems. In rural Nepal, households incorporate many socio-cultural, political, techno-economic and physical elements into their livelihood systems, and exploit assets such as human, social, natural, financial, and physical capitals to generate responses to shocks and risks. Climate change affects these elements differently between households because of the variable exposure to change and their differing access to and control over the different capitals. Therefore, each household has a unique micro social-ecosystem, and can form the smallest unit of a broader community or clustered social-ecological analysis. This study defines household as social-ecosystems at the micro level, assesses their vulnerabilities, and used collective indices to provide policy recommendations to achieve sustainability through adaptation to climate change.

2.2 Vulnerability

Vulnerability in relation to climate change is a function of the sensitivity of a system to climate change, the exposure of the system to climatic variability and change, and the adaptive capacity of the system (McCarthy, Canziani, Leary, Dokken, & White, 2001). Numerous factors associated with physical, social, economic, and political environments have made Himalayan social-ecosystems sensitive to climate change impacts, while the system is exposed to a rapid climate change. The concept of vulnerability is applied in various fields of studies such as natural hazards (Hewitt, 1983), food security (Dreze & Sen, 1990; Sen, 1981), and environmental change (Cutter, 1996; Kasperson, Kasperson, & Turner, 1995). As a result, there are many definitions of vulnerability and only limited consensus on the meaning of the concept. Newell et al. (2005) consider vulnerability as a 'conceptual cluster', including exposure of individuals or groups to livelihood stresses from socio-economic, political, and/or environmental change, and with insecure or inadequate structures and processes to overcome or adapt to stress (Blaikie, Cannon, Davis, & Winser, 1994; Chambers,1989).

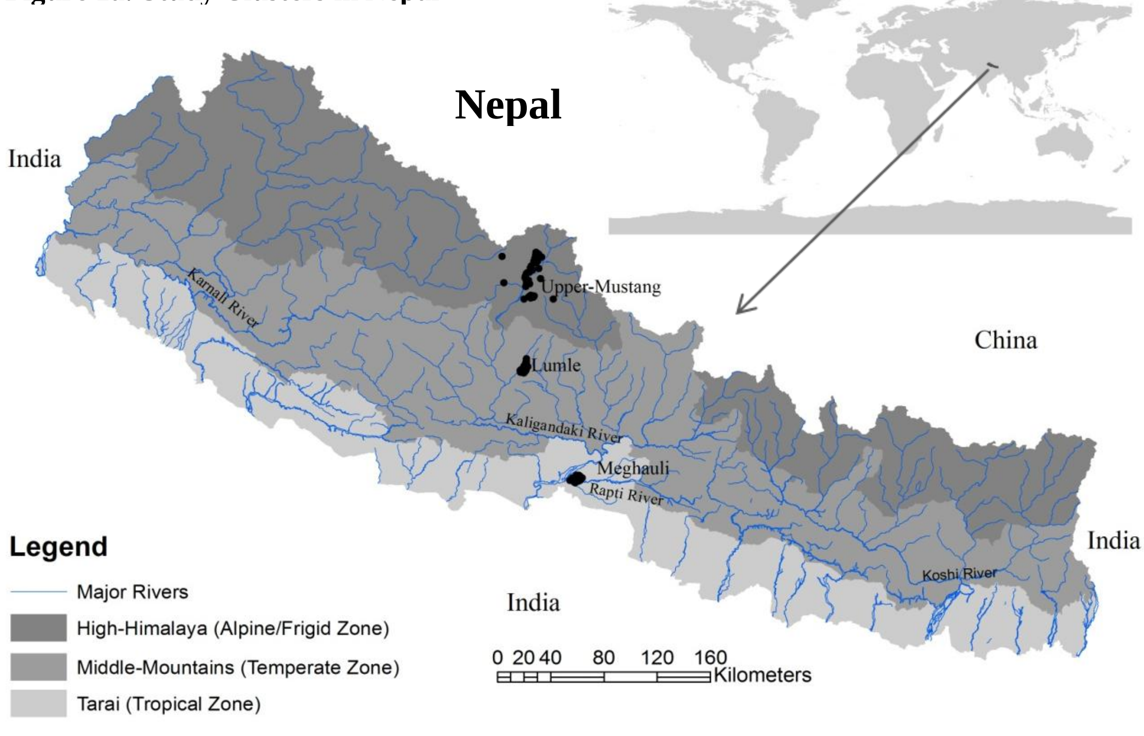
In the climate change context, the concept has come to be understood as the state of susceptibility to harm from exposure to stresses associated with environmental and social change in the context of inadequate adaptation capacities (Brooks, 2003; Cutter, 1996; McCarthy et al., 2001). Vulnerability in this paper, therefore, refers to the state of social-ecosystems in the Kaligandaki basin resulting from exposure and sensitivity to climate change; the socio-economic, ecological and political problems exacerbated by climate change; and, the inadequate adaptive capacity of those systems to accommodate impacts of change. In other words, socio-ecological vulnerability is derived from the exposure of households to livelihood stresses caused by both climatic and non-climatic factors, and their inadequate capacity to cope with or recover from the impacts or maintain household and community well-being (Adger, 1999; Kelly & Adger, 2000). When a social-ecosystem cannot cope with or recover from the impacts of a hazard or issue, the probability of systems becoming vulnerable increases (Carpenter, Walker, Anderies, Abel, 2001; Folke, Carpenter, Elmqvist, & Gunderson, 2002; Holling, 1995). Importantly however for the Nepali context, vulnerability to environmental change does not exist in isolation from the wider socio-political and economic environment (Adger, 2006; Martens, McEvoy, & Chang, 2009). Therefore, climate change vulnerability is an outcome of both external dimensions like shocks and perturbations to which a system is exposed, and internal dimensions like the inability to respond to and recover from external stressors (Gallopin, 2006). The assessment of vulnerability is complex and different methods exist for its calculations, which is why the particular method developed for this research is detailed below.

3. Methods and Materials

3.1 Study Area

The extreme topography of Nepal has generated numerous ecological zones, often summarised in three bands: the tropical southern plain - the Tarai; the temperate Middle-Mountains, and the polar High Himalaya to the north, and each is associated with an extremely complex drainage pattern. The Koshi, the Gandaki (also called Kaligandaki in the Mountains and Narayani in the Tarai), the Karnali and the Mahakali are the major river basins. This study was conducted in three small spatial clusters, with one located in each of the three major ecological zones in the Kaligandaki Basin – Meghauli in the Tarai, Lumle in the Middle Mountains, and Upper-Mustang in the Trans-Himalaya. Although these clusters are used to represent the different zones in this study, the communities each have unique and specific climatic conditions, vegetation types, and topographies, as well as socio-cultural and economic practices (Figure 1a).

Figure 1a: Study Clusters in Nepal



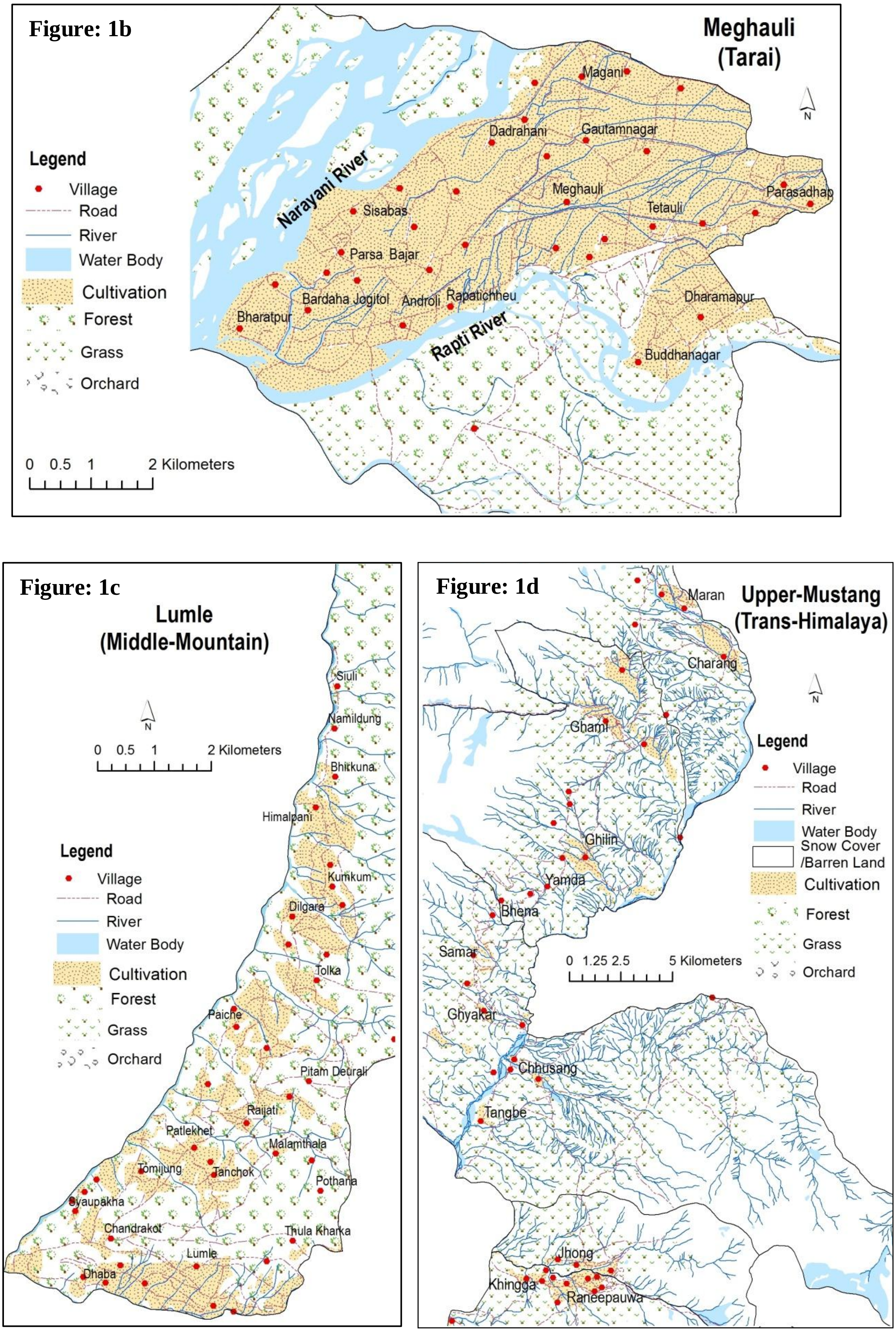


Figure 1: Map of Study Area – a. Nepal in the World Map and the locations of Study Clusters in Nepal, b. Map of the Meghauli Cluster, c. Map of the Lumle Cluster, and d. Map of the Upper-Mustang Cluster.

The environmental characteristics of each cluster are the major reason why each is vulnerable to particular hazards. The Meghauli cluster (Figure 1b) lies within the hot and wet tropical zone, in the relatively flat land of the Tarai (below 300masl). The cluster is bordered by the Narayani River in the South-West and by the Rapti River in the South-East. These rivers are the major drivers of flood risk, regularly affecting the almost 15000 people within the cluster and their livelihood resources every monsoon season. The cluster is rich in farmland, however, as it is located in the buffer-zone of the Chitwan National Park, agro-livestock suffer from wildlife encroachment and access to forest and grazing resources are constrained. The Lumle cluster (Figure 1c) is located in the cool, wet temperate zone (between 1200–1800masl) and consists largely of terraced mountain slopes. A large portion of the land is covered by forest so agricultural land is very limited, and access to forest resources are again restricted because the cluster is within the Annapurna Conservation Area. The cluster experiences the highest rainfall regime of Nepal, receiving an annual average rainfall of over 5400mm, which in turn is a major cause of severe landslides and floods, generating risks for the over 4200 people in the cluster. The Upper-Mustang cluster (Figure 1d) on the other hand is located in the cold, dry Trans-Himalaya (between 3000-4000masl). The cluster is located in the rain shadow of the greater Himalaya and is the area with the least rainfall in Nepal (annual average rainfall of about 260mm). The topography is extreme, with high, rugged and highly erosive mountains, and contains alpine shrubs and pastures. It is within such environmental contexts of the three ecological zones that this study analyses local socio-ecological conditions to estimate the differing vulnerabilities of households and village clusters in relation to the changing climate.

3.2 Sampling of Households and Data Collection Methods

A total of 360 households were sampled from a total of 4849 households in the three clusters, using proportional-stratified sampling. The sample sizes were 153 households in the Meghauli cluster, 141 in the Lumle cluster and 66 in the Upper-Mustang cluster. Households for face-to-face interviews were randomly selected from the list of households provided by the respective village councils. The informants were the head of households, and in each cluster nearly 30% of respondents were female.

To assess social-ecological vulnerability, a broad approach of interaction and feedbacks among socio-economic and ecological variables were considered. Socio-economic variables were collected under five sets of livelihood capitals namely: human, social, natural, financial and physical; while climate change and associated impacts as well as adaptation responses of the households were collected under system analysis framework (Driver→Pressure→Stage of Change→Impacts→Response or the DPSIR chain). In addition, questions on factors limiting adaptation, and the overall outcome of social-ecological interactions in relation to household food (in)security were also asked to generate the rich dataset required for a comprehensive vulnerability assessment. Initially, the variables were grouped into their various sub-components and components to calculate exposure, sensitivity and adaptive capacity sub-indices, and the social-ecological vulnerabilities of the study households were obtained. To generate those indices, the exposure component consists of 23 variables; sensitivity contains 36 variables; and adaptive capacity incorporates 59 variables (Table 1). These key variables were determined after a pilot study conducted in August and September, 2012.

Table 1: Vulnerability Components and associated Variables applied by the Study

Components	**Variables used to generate component**
Exposure: (A total of 23 variables under 5 sub-components)	Perception of climate change (a total of 14 questions related to weather variability and change: warming, rainfall, flood, droughts, hailstone, violent wind), Experienced adaptation constraints (9 questions related to factors limiting households adoption of adaptation strategies)
Sensitivity: (A total of 36 variables under 12 sub-components)	Sex of Household Head, Dependency ratio, Climate sensitive occupations, Population having health problems, Severity of health problems, Fallow farmland, Non-irrigated farmland, Current share of agriculture in livelihoods, Household debt, Perceived economic status, Monthly Household Food Insecurity Access Scale (HFIAS), and Experienced biophysical impacts of climate change (7 questions)
Adaptive Capacity (Actual adaptation in practice): (A total of 59 variables under 13 sub-components: 5 livelihood capitals, eight adaptation strategies)	Level of skills and education, Kinship and Neighbourhood supports, Land entitlement and ownership, Size of farmland, Size of *Khet* land (level terraces), Cropping intensity, Irrigated farm land, Livestock, Annual food sufficiency (household production), Annual household budget sufficiency, Household possessions (house, vehicles, equipment, valuables/convertibles), Share of non-agricultural sector resources in household livelihoods, Level of adoption of adaptation strategies (24 questions)
Social-Ecological Vulnerability Index	(Exposure Index – Adaptive Capacity Index) * Sensitivity Index

The questionnaire schedule had both open and closed questions on the socio-economic status and livelihood systems of households, perceptions of climate change and associated impacts, and adaptation responses adopted by households. Socio-economic information was collected quantitatively, while the perceptions were collected using a modified Likert Scale. A bipolar Likert Scale was transformed into unipolar, in which respondents scaled their responses from 1 (least) to 5 (most) perceived changes, impacts or adaptation responses. The fieldwork was conducted during April through September 2013 by the first author and four accompanying postgraduate students. On average, interviews lasted for one and a half hours. There were some rejections to participate in the research process, particularly in the Upper-Mustang cluster, hence the smaller sample size of 66 households from the initially designed size of 90. There were very few questions rejected or not applicable to particular households, but if there were, they were treated as the lowest value or '0' when values were standardized and transformed into indices.

3.3 Method of Analysis

The assessment of vulnerability in the context of climate change has numerous challenges because of the complex interrelationships between physical and non-physical determinants of vulnerability. Luers, Lobell, Sklar, Addams, & Matson (2003) stated that vulnerability is not a directly observable phenomenon but can be identified through a systematic analysis of a complex system. Many scholars have provided index based approaches of vulnerability assessment (Adger, 2006; Hahn et al., 2009; Mohan & Sinha, 2010; Sullivan, 2011). These scholars apply a set of variables to measure the sensitivity threshold, exposure and adaptive capacity, and use that data to develop sub-indices at first, which are used to calculate composite vulnerability indices. Berkes and Folke (1998) and Turner et al. (2003) recommend the 'social-ecosystem' be used as the unit of analysis to understand the state of a complex system comprehensively. As this paper defines the household as the micro-level unit of the social-ecosystem, the vulnerability assessment approach used by scholars cited above was modified and applied here to evaluate social-ecological vulnerability at household level, and then results were synthesised to generate cluster vulnerability indices.

The adopted method of analysis uses a holistic approach to assess vulnerability. The approach explicitly considered relevant social drivers together with biophysical and climatic drivers. This form of vulnerability assessment fits within a 'second generation of vulnerability assessment' (Füssel & Klein, 2006) or a cross-scale integrated vulnerability assessment (Füssel, 2007). To obtain social-ecological vulnerability values, a minimum-maximum method was adopted to standardize variables for comparison (Box 1, Equation 1). The applied method generates index-based values to enable further mathematical calculations, which otherwise would not be possible if the variables were of different forms and units. The method has been adopted to create the Human Development Index (HDI) since the 1990s, and has also been used to assess vulnerability in relation to environmental change (Adger, 2006; Aryal et al., 2014; Füssel & Klein, 2006; Hahn et al., 2009; Luers et al., 2003; Mohan & Sinha, 2010).

After standardization of variables, a series of calculations were performed to generate household sub-indices and composite level cluster indices. Weighted means of the various sub-components and components were obtained as sub-indices such as the exposure index (EI); sensitivity index (SI); and adaptive capacity index (ACI) for households (Box 1, Equation 2). Thereafter the social-ecological vulnerability index was calculated using the IPCC Vulnerability Framework: Social-Ecological Vulnerability Index (SVI) = (EI-ACI)* SI (Hahn et al., 2009). While Equation 2 presents the formula for Exposure measurements, the Sensitivity Index (SI) and the Adaptive Capacity Index (ACI) calculated in the same way using their respective components. The values of EI, SI and ACI indices range between '0' (least) to '1' (most). Based on the exposure, sensitivity and adaptive capacity indices, the Social-Ecological Vulnerability Index (SVI) for particular household was calculated using the formula i.e. SVI = (EI-ACI)*SI. The SVI value ranges between '-1' (least) to '1' (most). After all indices were calculated, the households were further categorised into four groups having either very high, high, medium or low levels of exposure, sensitivity, adaptive capacity and vulnerability.

Box 1: Equations used to calculate indices

Equations: 1

$$\text{Index } e_{v1}h_1 = \frac{e_{v1}h_1 - e_{v1}h_n Min}{e_{v1}h_n Max - e_{v1}h_n Min}$$

Here, Index $e_{v1}h_1$ refers to the indexed value of 'variable #1' belonging to the 'Exposure Component' (e.g. perceived warming) by 'household #1' of a cluster; $e_{v1}h_1$ is the actual value of the variable for that household; $e_{v1}h_n Max$ is the maximum value among the surveyed households of the cluster and $e_{v1}h_n Min$ is the minimum value among the surveyed households of the same cluster. Using this method, the values of all the applicable variables were standardized. Afterwards, the weighted means of components (e.g. exposure, sensitivity and adaptive capacities) were calculated as sub-indices.

Equations: 2

$$\text{Exposure Index (EI)} = \frac{\sum_{i=1}^{n=14+9} \text{Index } e_{v1}h_1}{\sum_{i=1}^{14+9} wm}$$

Here, wm refers to weighted mean of the variables related to exposure components. The weighted mean refers to the number of variables in the sub-components and components, at different stage of calculations.

There is no uniformity in the categorization of thresholds in the literature. For example, Hahn et al. (2009) and Aryal et al. (2014) do not use any categories in their analysis, while Mohan and Sinha (2011) use different threshold values for different components. Therefore, this paper adopted the HDI thresholds (which are applied to categorise countries from 'very high' to 'very low' levels of human development) as an appropriate guide to classify households.

The same HDI range was adopted to classify households based on 'adaptive capacity[5]' while a reversed scale is used to categories households in reference to exposure and sensitivity[6], considering the opposite association of these components to adaptive capacity. In addition, as vulnerability is considered as an opposite concept to development, the reverse threshold of the HDI is used to categorise households in reference to the SVI[7]. The range of the HDI (0 to 1) is transformed into '1' to '-1' to classify households since vulnerability is measured using a '-1' to '1' scale. This categorization is newly developed for this research and while it has been tested successfully, as can be seen below, it remains a proposal for scholarly and policy discourse.

4. Results and Discussions

4.1 Exposure of Social-Ecosystems to Climate Change

The exposure of a social-ecosystem to climate change is defined by the nature and degree (magnitude and duration) to which the system is exposed to significant climatic variations (McCarthy, et al. 2001; Füssel & Klein, 2006). In the context of this research, the exposure is a property of the community relative to climatic conditions, magnitude, frequency, spatial dispersion; duration, speed of onset, and temporal spacing of climate change risks (Ford & Smit, 2003), and these variables were measured using peoples' perceptions of climatic and other environmental change. The perception-based measure makes it difficult to compare result between communities because perceptions vary with changes in local circumstances. Therefore the comparisons between clusters made here are indicative measures, while judgements between households within a cluster reflect real situations.

This study found very high levels of exposure of households to climate change, yet the level of exposure varies among the households within and across the three ecological zones (Figure 2). Almost 4 out of 5 households in both Meghauli and Lumle were found to have a 'very high level' of exposure, with just under half of the households in Upper-Mustang classified in that way. 36.4% of households in Upper-Mustang, 15.7% in Meghauli and 14.9% in Lumle have a 'high level' of exposure to climate change (Figure 3). The exposure indices show Lumle in the mid-hills as the cluster having the highest level of exposure, yet since the mean index values are fairly comparable between clusters (Figure 8), it is possible to argue that all are highly exposed to climate change and associated impacts.

[5] Very high (>=0.8), High (>=0.7 and <0.8), Medium (>=550) and (<0.7), and Low (<0.550)
[6] Very high (>=0.450), High (>=0.3 and <0.450), Medium (>=0.2) and (<0.3), and Low (<0.2)
[7] Very high (>=0.3), High (>=0 and <0.3), Medium (>=-0.3) and (<0), and Low (<-0.3)

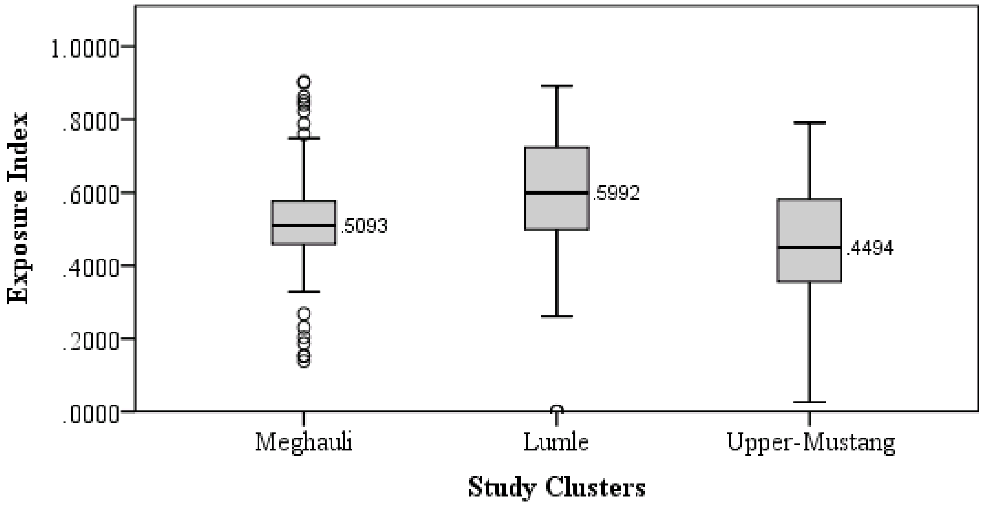


Figure 2: Exposure of Households to Climate Change in Meghauli, Lumle and Upper-Mustang, Nepal

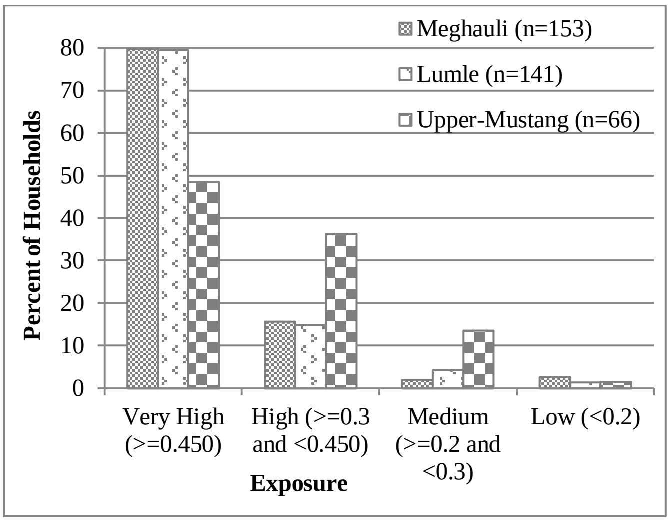


Figure 3: Proportions of Households by degree of Exposure in Meghauli, Lumle and Upper-Mustang, Nepal

Location-specific circumstances resulted in variable levels of exposure to climate change between clusters. Meghauli is located in the tropical and Lumle in temperate climatic zones. These locations experience higher levels of changes in local climatic conditions than the Trans-Himalaya (Pandey, 2014). Significant climate change has already led to major, negative impacts for agro-livestock livelihoods in Meghauli and Lumle. On the other hand, being located in a cool, dry climatic region, Upper-Mustang, although experienced notable changes in local climate like warming and increased rainfall, has led to some positive impacts for local livelihoods, so perhaps people perceived a lower level of exposure to climate change. In addition, the people of the Upper-Mustang have to some extent, accepted the remoteness and climatic harshness of the area as a part of their life, so they have fewer complaints. In contrast, households in Lumle and Meghauli have many expectations of their environments, which are now not being met, and that might be reflected in their perceptions of change. Across the whole basin, most households' social-ecosystems are exposed to higher climatic stimuli that are having negative implications for their systems.

4.2 Sensitivity of the Social-Ecosystem to Climate Change

The analysis found all of the cluster social-ecosystems to be highly sensitive to climate change and associated impacts. The sensitivity indices of households however, are variable within and between clusters (Figure 4). Out of the total, one-third of households in Lumle fall into the category of 'very high level of sensitivity'. Corresponding proportions of households in Upper-Mustang are almost one quarter, while a little over one-tenth of households are sensitive to the same level in Meghauli (Figure 5). The proportions of households that are classified as 'high level of sensitivity' are a little over two-thirds in Meghauli, over a half in Lumle and over one-third in Upper-Mustang. The calculated sensitivity indices imply that Lumle is the most sensitive cluster to climate change, followed by Meghauli and Upper-Mustang, with the mean sensitivity index highest in Lumle (0.429), followed by Meghauli (0.366) and Upper-Mustang (0.352), as shown in Figure 8.

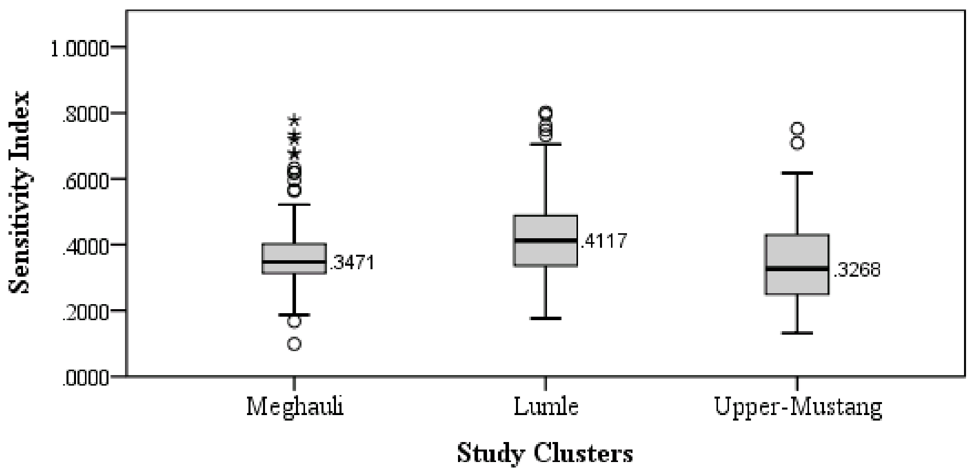


Figure 4: Sensitivity of Households to Climate Change in Meghauli, Lumle and Upper-Mustang, Nepal

Many interacting socio-ecological elements of a system determine its sensitivity (Turner et al., 2003). Societies highly dependent on exploiting natural resources such as land, forests, water or pastures for their livelihoods are generally more sensitive to climatic variability and change. In the study area, almost all households have some land, and although the majority of holdings are small in size, most are used for agriculture. In addition, a little over 87% of households keep livestock and/or poultry and over 50% of households collect various forest products to support their livelihoods. In this context, the agro-based livelihood systems of the studied households are sensitive to climatic variability and change. In the wider Nepali context, over 70% of households' livelihoods are dependent on natural resources (CBS, 2013), so the findings would infer that sensitivity to climate change is widespread across rural Nepal.

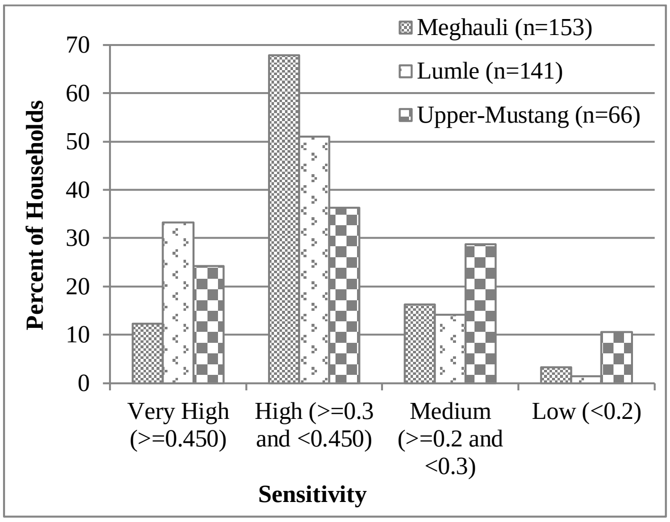


Figure 5: Proportions of Households by degree of Sensitivity in Meghauli, Lumle and Upper-Mustang, Nepal

Sensitivity to climate change generally decreases with advances in development (Mendelsohn, Dinar, & Sanghi, 2001). Some households have higher degrees of income diversification, better education, strong social networks, and relatively strong livelihood capitals that help to reduce their levels of sensitivity to climate change. Better agricultural productivity with year-round growing seasons and adoption of irrigation in Meghauli lessen sensitivity in that cluster in comparison to the other areas. On the other hand, low population density and relatively high levels of engagement in alternative economic activities such as livestock, horticulture, hospitality, trekking tourism and businesses operated in cities like Pokhara and Kathmandu in Upper-Mustang, together with some positive impacts of climate change on Trans-Himalayan agriculture, might have contributed to the relatively lower level of perceived sensitivity in Upper Mustang. In the third cluster of Lumle, the absence or limited adoption of alternative livelihood options, farmland abandonment due to lack of irrigation, and significant negative impacts linked to climate change such as increased invasive species, farm weeds, crop-livestock diseases, damage caused by drought, landslides, and hailstorms suggest very high levels of sensitivity. Nevertheless, based on the sensitivity index values, it can be seen that all of the studied clusters are sensitive to climate change.

4.3 Adaptive Capacity of the Social-Ecosystem to Climate Change

Adaptive capacity is the ability or potential of a system to respond to climate variability and change, and plan for, adapt to and recover from the exposure (Adger et al. 2007; Ebi, Kovats, & Menne, 2006). Better adaptive capacity reflects a communities' ability to reduce harmful outcomes of climate change (Brooks & Adger, 2005). The analysis of adaptive capacity in this paper, however, demonstrates very poor levels of adaptive capacity of the studied households in the three clusters (Figure 6), with 99.3% of households in Lumle, 97% in Upper-Mustang and 96.1% in Meghauli all falling into the single group having 'low adaptive capacity' (Figure 7). Lumle has the lowest level of adaptive capacity, followed by Upper-Mustang and Meghauli, although all of the clusters have fairly comparable mean adaptive capacity index (Figure 8).

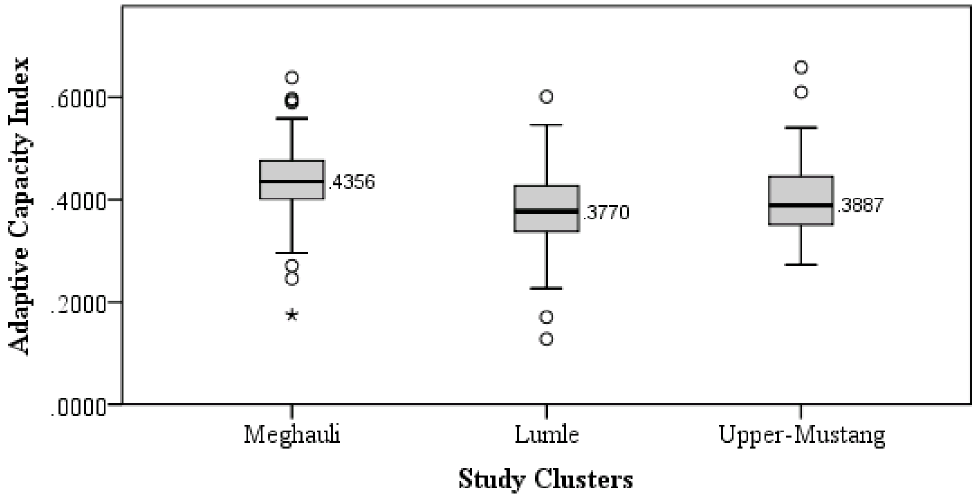


Figure 6: Adaptive Capacity of Households to Climate Change in Meghauli, Lumle and Upper-Mustang, Nepal

Multiple factors, including limited available resources and ongoing development constraints have led to poor adaptive capacities for most households. Yet, the measurement of adaptive capacity is complex and challenging because of the multiple links with exogenous and endogenous systemic factors, and uncertain adaptation outcomes, maladaptation or 'double exposure' of the adaptation process (Barnett & O'Neill, 2010; Wiseman & Bardsley, 2013). There are also assumptions made in the analysis. For example, it is assumed that rural under-development constrains local adaptive capacities, when perhaps diverse, traditional rural livelihood systems may be more resilient to change than some modern agro-ecosystems.

Nevertheless, the analysis suggests low adaptive capacities within each of the cluster social-ecosystems of the Kaligandaki Basin.

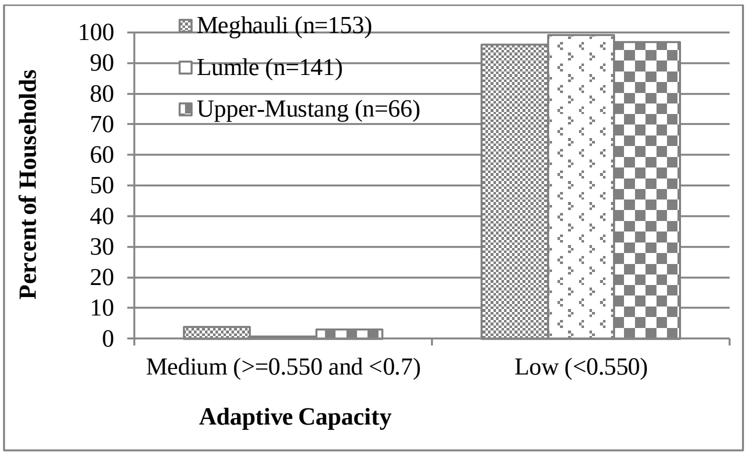


Figure 7: Proportions of Households by degree of Adaptive Capacity in Meghauli, Lumle and Upper-Mustang, Nepal

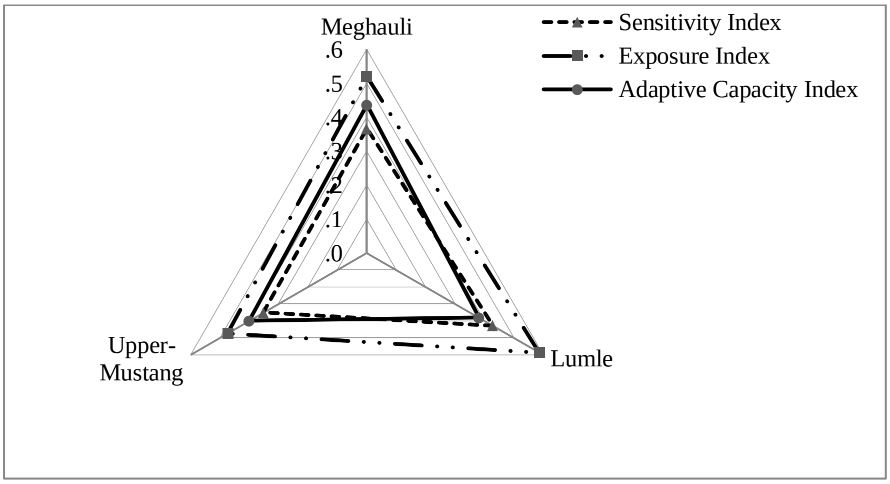


Figure 8: Mean of Sensitivity, Exposure and Adaptive Capacity Indices in Meghauli, Lumle and Upper-Mustang, Nepal

Poverty, the lack of climate change adaptive crop varieties or irrigation, as well as lack of reliable weather forecasting and other external support, which the households reported as adaptation barriers, constrain households' abilities to modify their social-ecosystems to respond to climate change impacts. There are ongoing, tumbling implications of these inabilities to adapt, because climate change is further reducing local socio-ecological systems' life-supporting capacities by altering the quality and functioning of those systems. People reported agricultural productivity is increasingly hindered by both increased drought and flooding, and the greater prevalence of crop diseases, pests and weeds linked to climatic factors. Rapid climate change and associated impacts only act to further exacerbate prevailing problems and reduce households' adaptive capacities to adapt to their local environments further. Nepal is still one of the poorest countries in the world even after many years of planning reforms, and much of that poverty is concentrated in rural areas. Even though democracy has been introduced, people have not been able to elect local governments and ongoing armed conflict adds to the political-economic stressors which act to generate poor local adaptive capacities in the region.

4.4 Social-Ecological Vulnerability to Climate Change

This study found that despite being highly exposed and sensitive to climate change, actual adaptation efforts made by the studied households and their communities remain very poor in quality or limited in scope. It is particularly because household command over adaptive resources is so weak that people cannot adequately manage the impacts of climate change. Figure 9 shows variability in vulnerability levels across the household clusters, but there are high levels across all social-ecosystems in the Kaligandaki basin. The mean of the SVI, as shown in the Figure 10, indicates that the Lumle cluster has the highest level of vulnerability (0.1), while Meghauli and Upper-Mustang have similar SVI levels (0.04). The majority of the studied households in all three clusters fall into a single group i.e. 'highly vulnerable' (Figure 11). Out of the total, 84.4% of households in Lumle, 75.2% in Meghauli and 63.6% in Upper-Mustang are highly vulnerable and their SVI range between >=0 and <=0.3. Of the total, 25.8%, 20.3% and 11.3% households of Upper-Mustang, Meghauli and Lumle respectively, fall into a 'moderately vulnerable' category with the SVI in-between -0.3 and 0. Only a small number of households i.e. 10.6% of Upper-Mustang, 3.9% of Meghauli and 3.5% of Lumle are found to have a 'low level of vulnerability'. The index values suggest Lumle contains a higher density of households who are highly vulnerable to climate change. Nevertheless, the results suggest that a dominant proportion of households across the entire basin are 'highly vulnerable'.

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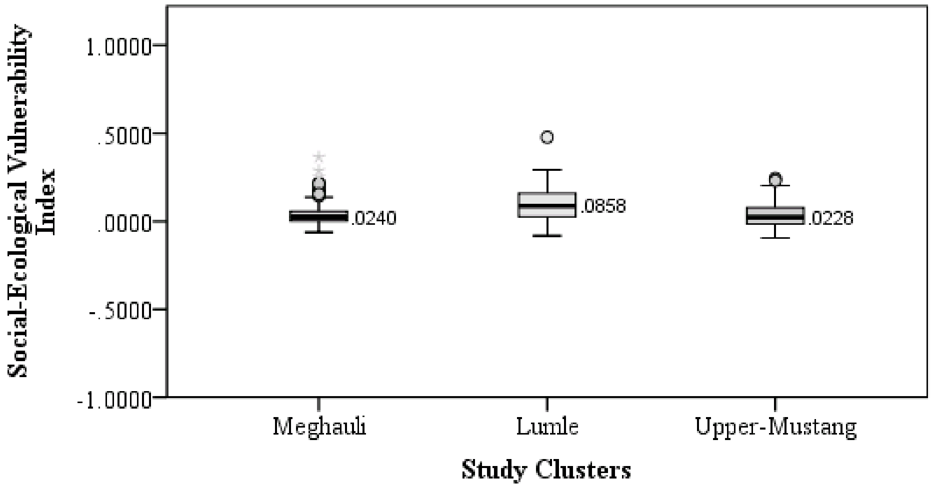

Figure 9: Social-ecological Vulnerability of Households to Climate Change in Meghauli, Lumle and Upper-Mustang, Nepal

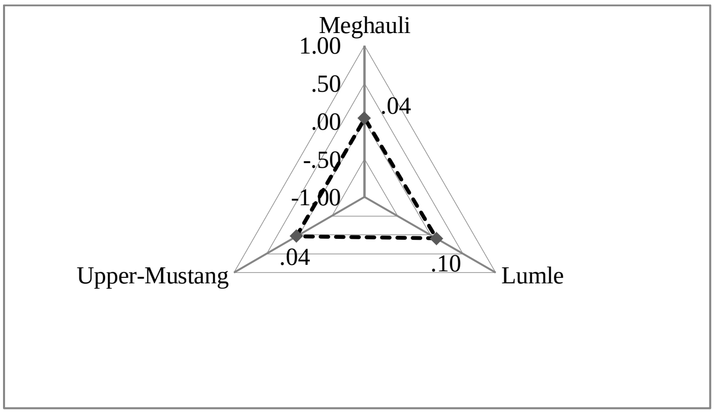

Figure 10: The Mean Social-Ecological Vulnerability Index in Meghauli, Lumle and Upper-Mustang, Nepal

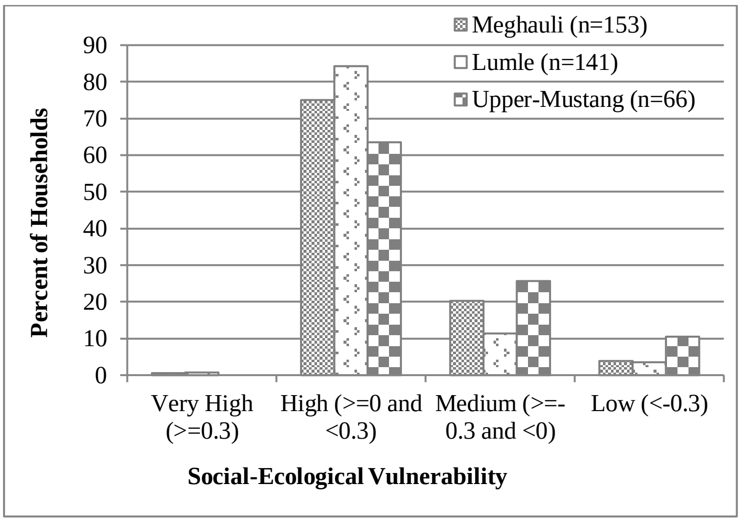

Figure 11: Proportions of Households by degrees of Social-Ecological Vulnerability in Meghauli, Lumle and Upper-Mustang, Nepal

In Nepal, much vulnerability is indicative of persistent constraints on adaptation to local environments irrespective of climate change. Climate change is affecting the individual components of local socio-ecological systems, as well as the ways those components interact. Interrelations between social-ecological factors can either amplify or reduce vulnerability, depending upon the nature of the interactions or the responses of households to environmental change. For example, in the Meghauli cluster people stated that light rain in the monsoon used to continue for 15 to 20 days at a time, but these days almost the same amount of rainfall falls in episodes of only 2-3 days, bringing devastating floods. Such events have displaced hundreds of households from the cluster at different times. Communities constructed flood control dikes along the riverbanks that have partially reduced flood impacts in recent years, but settlements and farmland are still regularly inundated. Flooding severely affects crops and livestock, human health and security systems, and the state of natural resources; or in other words, the socio-ecosystem is being transformed. People are responding by giving less priority to agro-livestock activities and preferencing activities that provide direct access to cash income. Labour migration out of the village is common, with over one-third households of the Meghauli cluster having at least one household-member participating in the international labour market at the time of the survey. Yet, income has not been spent extensively on developing local assets or adaptation technologies. Together these interacting social-ecological phenomena jeopardise the local agricultural system, the major source of livelihoods, which in turn suggests that household will experience increasing vulnerability in the future. Socio-ecological vulnerability is the outcome of complex changes interacting with multiple factors and sub-factors of socio-cultural, political, techno-economic and physical systems in Nepal, and that finding is consistent with existing scholarship (Adger, 2006; Bailey, 2010; Hahn et al., 2009). As vulnerability is a very complex phenomenon, linked to context-specific interactions/feedback mechanisms, index-based vulnerability assessments, such as those undertaken here, are increasingly required.

Many studies have been conducted in Nepal and around the Himalaya in relation to the changing climate, associated impacts, and adaptation responses of the communities. Most of these studies show rapid climate change (NRC, 2012; Shrestha et al., 2012; Turner & Annamalai, 2012) and severe impacts on the social-ecosystems of the region, which people have also made efforts to adapt to (Bhatta, van Oort, Stork, & Baral, 2015; Macchi et al., 2014). However, index-based assessments of vulnerability have not been used extensively to guide adaptation policy. Aryal et al. (2014) found sensitivity index values ranging between 0.26 to 0.43, exposure index values of 0.21 to 0.32, and adaptive capacity index values 0.39

to 0.48 in the transhumant communities of the Nepali Himalaya, in a study that measured vulnerability on a '0' to '1' scale. The vulnerability indices for the Kaligandaki basin clusters are higher than those found by Hahn et al. (2009) in Mozambique, while dominant districts of the Ganga Basin in India are classified as having 'high or very high levels' of vulnerability (Mohan & Sinha, 2010). Although studies have adopted different methodologies to calculate vulnerability indices, which makes it difficult to compare their findings directly to the current research, results from other developing rural communities seem to parallel the Nepali situation. The important emerging consensus is that poor, resource-dependent rural communities in developing countries exposed to climate change are generally highly vulnerable to that change.

The vulnerability assessment in the Kaligandaki Basin considered spatial clusters as the major unit of analysis and by combining disciplinary approaches such as biophysical and livelihood system analyses, valuable insights have been generated for guiding decision-making. In particular, the SVI analysis identifies clusters that are most in need of external support. However, in developing countries like Nepal, where vulnerabilities vary dramatically across households, communities and regions due to existing inequalities in access to and control over productive resources, analyses at the individual household level are equally important to guide adaptation policy to benefit those people in greatest need. Given the ever widening gaps in the economy, political empowerment and human development in Nepal (DFID/WB, 2006; Gurung, 2006) despite the 'positive discrimination' policies since the 1990s, greater targeting of development support based on specific information regarding the vulnerability of households and communities is now required. In another example, the ineffectiveness of post-disaster relief work after the major earthquake of 25 May 2015, which has been broadly acknowledged in the mass media, could in part be attributed to a lack of good information about the overall situation of affected households. In these broader development and disaster relief contexts, the SVI approach outlined here could provide resource poor countries like Nepal with an entry point for equitable adaptation policy to address the issues of the most vulnerable first, and move forward with caring support structures (Chambers, 1983).

5. Conclusions

The vulnerability analysis conducted in the Kaligandaki basin illustrates that vulnerability is not merely the product of physical exposure to climatic change and hazards, but also the political, economic and social contexts of households. This study generated composite vulnerability indices by analysing numerous elements of the endogenous and exogenous drivers of socio-ecological systems and the results suggest a high level of vulnerability of such systems in the Nepali Himalaya. The study results provide an opportunity to identify adaptation requirements and design and prioritise appropriate adaptation policies specific to households, communities, or clusters according to spatial units, or with alternative socio-economic clustering, according to social strata. Such a priority-focussed adaptation policy would help a country to improve the equity and social justice of their climate change responses. In fact, it is possible to conclude that such detailed vulnerability assessments, generated by reviewing and compiling location-specific knowledge on climate change impacts and adaptation practices of communities is required to design effective policy to address the needs of inherently complicated, unclear and uncertain social-ecological problems.

The development of holistic indices that integrate variables of livelihood capital, perceptions of climate change, and adaptation methods is the key value of this research. With such an approach, strong summaries of people's concerns and responses can be translated into a format that can inform policy directly. Despite the power of the method, a number of problems remain with the vulnerability assessment approach. Local people noted that the weather patterns they experience, and rainfall and hailstorm events in particular, are highly localised, and as a result, climatic impacts vary within small spatial units. Given that local climatic and non-climatic factors such as altitude, wind systems, slope and aspect, and vegetation cover all influence climate change impacts, it would be more effective if meteorological and other biophysical data could have been integrated into the vulnerability analysis. However, except for Lumle, the studied clusters do not contain their own meteorological stations. Similarly, the results could be validated by cross-verifying perception-based data on climate change and adaptive capacities with independent biophysical and socio-economic data to strengthen the arguments presented. In addition, there might be variations in the degrees of influence of global and national political ecologies and economic policies across the studied households. Yet, this study has excluded such variation in exogenous factors and to some extent assumed that entire clusters would be affected uniformly, because the variable implications of political-economic situations are unlikely to be adequately traced through the survey of perceptions at the household level. Further research is necessary to assess and verify cross-scale integrated vulnerability (Füssel, 2007) by incorporating exogenous global and national factors into the vulnerability assessment approach. Unless research can recognize and incorporate such complex influences over the vulnerabilities of people and their communities, the knowledge generated will not fully represent the true situations of socio-ecological systems to guide responses to climate change risk.

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