Climate Change Modeling For Local Adaptation In The Hindu Kush-Himalayan Region

Chapter 7 Floods, Landslides, and Adapting to Climate Change in Nepal: What Role for Climate Change Models?

Karen Sudmeier-Rieux, Jean-Christophe Gaillard, Sundar Sharma, Jérôme Dubois, Michel Jaboyedoff

CHAPTER 7

FLOODS, LANDSLIDES, AND ADAPTING TO CLIMATE CHANGE IN NEPAL: WHAT ROLE FOR CLIMATE CHANGE MODELS?

Karen Sudmeier-Rieux, Jean-Christophe Gaillard, Sundar Sharma, Jérôme Dubois and Michel Jaboyedoff

ABSTRACT

Climate change data and predictions for the Himalayas are very sparse and uncertain, characterized by a ''Himalayan data gap'' and difficulties in predicting changes due to topographic complexity. A few reliable studies and climate change models for Nepal predict considerable changes: shorter monsoon seasons, more intensive rainfall patterns, higher temperatures, and drought. These predictions are confirmed by farmers who claim that temperatures have been increasing for the past decade and wonder why the rains have ''gone mad.'' The number of hazard events, notably droughts, floods, and landslides are increasing and now account for approximately 100 deaths in Nepal annually. Other effects are drinking water shortages and shifting agricultural patterns, with many communities struggling to meet basic food security before climatic conditions started changing.

Climate Change Modeling for Local Adaptation in the Hindu Kush-Himalayan Region
Community, Environment and Disaster Risk Management, Volume 11, 119–140

ISSN: 2040-7262/doi:10.1108/S2040-7262(2012)0000011013

The aim of this paper is to examine existing gaps between current climate models and the realities of local development planning through a case study on flood risk and drinking water management for the Municipality of Dharan in Eastern Nepal. This example highlights current challenges facing local-level governments, namely, flood and landslide mitigation, providing basic amenities – especially an urgent lack of drinking water during the dry season – poor local planning capacities, and limited resources. In this context, the challenge for Nepal will be to simultaneously address increasing risks caused by hazard events alongside the omnipresent food security and drinking water issues in both urban and rural areas. Local planning is needed that integrates rural development and disaster risk reduction (DRR) with knowledge about climate change considerations. The paper concludes with a critical analysis of climate change modeling and the gap between scientific data and low-tech and low capacities of local planners to access or implement adequate adaptation measures. Recommendations include the need to bridge gaps between scientific models, the local political reality and local information needs.

Keywords: Nepal; flooding; landslides; local capacity building; downscaling climate modeling

INTRODUCTION

Climate change data and predictions for the Himalayas are very sparse and uncertain, characterized by a ''Himalayan data gap'' and difficulties in predicting changes due to topographic complexity (NVSCT, 2009). A few reliable studies and climate change models for Nepal predict considerable changes: shorter monsoon seasons, more intense rainfall and shifting precipitation patterns, higher temperatures, and drought. According to Khan (2005) during the period 1971–2005, the mean average temperature has increased by 1.7°C. The rate of temperature increase is less at lower altitudes than at higher altitudes, higher in the central high mountains (±0.04 to 0.07°C) and somewhat decreasing or stable in isolated patches in the far eastern mountains (–0.02 to 0.00°C), with a slight increase in monsoon rainfall (Khan, 2005). Future climate change predictions in Nepal will follow a similar pattern of temperature increase as the past 40 years, affecting monsoon intensity and occurrence, annual distribution of precipitation, and the rate of snow and ice melt in the high mountains (Box 1).

Box 1. Climate Change Predictions for Nepal
(Based on Khan, 2005; NVSCT, 2009; Tse-Ring et al., 2010)

- Average annual temperature increased by 0.01°C in the foothills, 0.02°C in the middle mountains, and 0.04°C in the higher Himalayas, or 1.4–1.7°C increase for the country predicted by the 2030s.
- This temperature increase is much higher than the mean global rate of predicted increase.
- Wetter monsoonal periods and drier winters.
- Less monsoonal rain across the high mountains and more monsoonal rain along the southern hills.
- Rapid decrease of snow cover and glacier retreat.

Since 80% of Nepal's rainfall occurs during the monsoon period (June–September) – varying from 150 mm to over 5000 mm per annum – more intense monsoon rainfall periods are likely to lead to landslides and floods, especially in fragile environments such as those which prevail in mountains (Baidya, Shrestha, & Sheikh, 2008; Khan, 2005; Li & Zeng, 2003; Shrestha & Devkota, 2010). To better appraise the potential impact of changing climatic patterns climate scientists often rely upon models with a range of sophistication and scales, including both Global Climate Models (GCMs) and Regional Climate Models (RCMs). These models are geared toward making projections about future climatic conditions with more certainty as well as reducing as much as possible uncertainties inherent to events that would exceed the extent of past and present experiences. They are ultimately intended as the scientific underpinnings for policy and international donor decisions regarding how to best plan ahead to improve development prospects (i.e., food security issues related to warmer climates) and reduce negative impacts (i.e., increasing numbers of hazard events related to more extreme weather events).

However, resorting to such models in addressing hazards such as landslides and floods reaffirms a research and policy paradigm where prime attention is given to natural processes to the detriment of threatened and affected people and communities (Gaillard et al., 2010). Yet decades of research and often failed policies and practice in the field known as disaster risk reduction (DRR) have shown that putting too much emphasis on hazards leads to poor results because it overlooks the root causes of people's vulnerability, which is largely hazard-independent (Wisner, Blaikie, Cannon, & Davis, 2004).

In parallel, as Nepal's current development model is based on infrastructure development, not capacity building and planning, too much emphasis is put on construction without adequate planning, which is currently creating a new set of problems. Roadside landslides are increasing, dykes are being erected along certain river segments, attracting more people to settle in dangerous places along roads in floodplains (Oven, Petley, Rigg, Dunn, & Rosser, 2008; Petley et al., 2007).

Another frequent critique addressed to models in the context of DRR is that they most often fail to mirror the complexity and diversity of local issues (Hewitt, 1983). Indeed, most climate models that are presently developed to appraise future climate change tend to focus on regional and continental scales while communities who are facing climate variation on a daily basis are rather concerned by processes and events at a very local scale (Gaillard et al., 2010). As mentioned above, in spite of predicted increases in flooding and landslides, marginalized populations in Nepal continue to live and settle near rivers, roads and steep slopes, not because they are unaware of the physical danger but because of the economic opportunities such places bring. Thus, although huge financial and human investments are poured into the development of climate change models there is little evidence regarding their actual use for those whose life and livelihoods are at stake.

This chapter explores the gap between models and local realities in the context of Nepal, where mountains and hills are considered highly sensitive environments in the face of climate change. A handful of studies have already focused on modeling climate change and assessing its potential impact for floods and landslides in the country. To counterbalance the uncertainty of climate modeling, several initiatives have been undertaken to report climate changes based on practical experiences and observations by local people (NVSCT, 2009). The general finding from the field consultations was that "temperatures have increased, precipitation has grown more variable and that it is increasingly hard to predict climate patterns" (NVSCT, 2009, p. 43). Other major changes are: increases in flood and drought conditions; changes in seasonality resulting in changed behavior of crops and livestock; increase in invasive species; and historical traditional knowledge no longer serving as a reliable guide for crop planning (NVSCT, 2009; Tse-ring, Sharma, Chettri, & Shrestha, 2010).

Concerned by these changes, the Nepalese government is taking climate change very seriously with the recent establishment of a national climate change policy to promote and implement climate change adaptation (CCA) programs, engagement in the National Adaptation Plan for Action (NAPA), and the Pilot Program for Climate Resilience (PPRC) processes (Ayers, Kaur, & Anderson, 2011; CIF, 2011; GoN, 2011; Nepal NAPA, 2010). In parallel, a Nepal Climate Change Knowledge Management Center has been established by the Nepal Academy of Science and Technology to foster the production and diffusion of scientific knowledge (NAST, 2010).

The present study particularly draws upon the example of the Municipality of Dharan and aims at (1) assessing and explaining gaps between scientific models and local realities, and (2) identifying ways forward in bridging the gap between science, policy, and practice for landslide and flood risk reduction. We observe that here climate models are practically out of reach for local decision makers as results are difficult to translate into local reality and into real action on the ground. The case study thus highlights how local capacities to address risk reduction through land-use planning, watershed management, zoning, and providing safer places for marginalized populations are the immediate goals for reducing the negative impacts of climate change.

CLIMATE MODELS FOR UNDERSTANDING CLIMATE CHANGE IN NEPAL

Nepal is a disaster hotspot and one of the world's most sensitive countries to the effects of climate change due to its social vulnerability, governance issues, topography, and heavy monsoon rains (IFRC, 2011; MoHA, 2009). Climate change models for Nepal predict shorter monsoon seasons (typically June, July, August), more intensive rainfall patterns, higher temperatures and drought (Baidya et al., 2008; Khan, 2005; Li & Zeng, 2003; Shrestha & Devkota, 2010). These predictions are confirmed by farmers who observe that over the past decade summers have become hotter and the rains are more unpredictable and seem to have ''gone mad'' (NCVST, 2009). The number of hazard events impacting society, notably droughts, floods, and landslides has increased especially over the past decade, for which reliable statistics are available and now account for approximately 100 deaths annually, with direct economic losses estimated at US$ 480,000 in 2009 (DWIDP, 2009; MoHA, 2009). According to the NCVST (2009) report, ''under median climate change projections, the flood impact on each household will double and the number of households affected directly will increase by 40%'' (p. 70). The human impact of these disasters and other climate-related changes are difficult to estimate and predict as they include drinking water shortages, shifting agricultural patterns, food insecurity, reduced hydropower production, and increased health problems. However, NCVST (2009) based on a climate change model (The Rohini River Model) for the entire Nepali plains region (Terai) has predicted that costs related to more frequent five-year flood damage will amount to 63,027 NPR per household, or the equivalent of three-months' income (NCVST, 2009). Expected biophysical changes include biodiversity changes, increasing biomass in wetlands, more extreme weather events, reduced snowfall in frequency and amount at higher elevations, contracting ice fields, and upward shift of the tree-line (Jianchu, Shrestha, Vaidya, Eriksson, & Hewitt, 2007; Jing & Leduc, 2010; WECS, 2011).

To better understand the information available on climate change for Nepal, the most common models are briefly described, followed by a brief overview of the policy framework in Nepal to address climate change and its impacts on the country.

Climate Change Modeling Relevant to Nepal

Based on projections from 22 different GCMs operated by various universities and research centers from around the world, the Intergovernmental Panel on Climate Change (IPCC) projects an overall change in annual precipitation ranging from -15% to $+20\%$ for South Asia by 2099 (Christensen et al., 2007). This prediction is for a large geographic area, timescale, and too broad to be of use for Nepal, whose climate is complicated by the South Asian monsoon and the complex topography of the Himalayas, both of which are not captured well by GCMs (Lamadrid & MacClune, 2010; NCVST, 2009). In order for climate change predictions to be useful, they need to be downscaled to the regional and local level. The two main downscaling techniques are *dynamic downscaling* (i.e., the method used by RCMs HadRM2 and PRECIS – Providing Regional Climates for Impacts Studies, Hadley Centre) or *statistical downscaling methods* (i.e., as used by the Canadian third generation coupled climate model (CGCM3), or the Indian Institute of Tropical Meteorology (IITM) regional climate scenarios) (Khan, 2005; Lamadrid & MacClune, 2010; Tse-ring et al., 2010).

Three challenges make climate change predictions for Nepal difficult: (1) the lack of continuous and reliable local precipitation data with which global models can be correlated to verify the reliability of predictions; (2) the extra complications for predicting trends because of the extreme topography of the Himalayan range; and (3) changing relationships between the monsoon rainfall and ENSO (El Niño Southern Oscillation)

(Opitz-Stapleton & Gangopadhyay, 2009). Often, there are enormous contradictions between the models in the pattern of changes, therefore, the average of several GCM's is combined to improve predictions (called an "ensemble"). In addition, according to the NCVST (2009) report, most GCMs for the South Asia region are based on data for all-India monsoon rainfall, so it cannot be assumed that the Nepal summer monsoon rainfall shares the same characteristics. This scalar mismatch thus skews most predictions for Nepal.

To bring the assessment of potential climate change down to an even more local level, RCMs have been developed.

The most commonly used RCMs in the Himalayan region today are (Lamadrid & MacClune, 2010):

1. PRECIS (next generation of HadRM2)
2. RegCM3 (ICTP, Italy)
3. HadRM2 (being replaced by PRECIS)
4. WRF (emerging use; formerly MM5)
5. REMO (emerging use)

In addition, several hydrological models have been developed: WatBal, Hydrocomp Forecast and Analysis Modeling (HFAM), and Block-wise use of TOPMODEL (BTOPAC) (Opitz-Stapleton & Gangopadhyay, 2009). The WatBal model (Water Balance Hydrological Model) is used by several ministries in Nepal to assess impacts of climate change on water resources for river basins (WECS, 2011). It estimates five parameters: direct runoff, surface runoff, subsurface runoff, maximum catchment water holding capacity, and base flow (Yates, 1994). To be accurate, the model requires hydrological data on rainfall, temperature, relative humidity, etc. HFAM (Marino, Lisa, & Crawford, 1997) divides a watershed into hydrologically homogeneous land segments to simulate hydrological processes using local data applicable for snow accumulation, snowmelt, evapotranspiration, interception, surface flow, subsurface flow, interflow, and deep groundwater flows (Khan, 2005). Finally, the BTOPMC based on the hydrological model TOPMODEL (Beven & Kirkby, 1979) has been tested and validated for various small and large watersheds in South and Southeast Asia. For Nepal, all three models show inconclusive results, as they depend on reliable hydrological data (Khan, 2005). Therefore, accurate predictions of climate change at river basin or watersheds levels in Nepal using any of these models are even more questionable (Opitz-Stapleton & Gangopadhyay, 2009).

In sum, current climate change predictions for Nepal provide general trends and quite wide ranges of possible scenarios including both drought and more weather-induced disasters, consistent with observable data by government agencies as well as local populations. However, existing climate change models have limited use at the local level, as they do not provide specific guidance for action to be undertaken to actually face climate change. As the Nepal Climate Vulnerability Study Team concludes, "[at] this stage, there are insufficient RCM outputs to make definitive statements of the range of possible future changes at fine resolution across Nepal" (NCVST, 2009, p. 46).

In addition, the policy framework for addressing climate change in Nepal is only being established now. Although Nepal became party to the National Adaptation Programme for Action (NAPA) in 1994, its climate change policy was established only just in 2011. It is one of seven countries to have been awarded funds (US$ 110 million) by the Pilot Programme for Climate Resilience (PPCR), established by several international development banks "to build climate resilience of watersheds in mountain regions, build resilience to climate-related hazards, and build climate-resilient communities through private sector participation" (CIF, 2011). But the effect of this program is yet to be evaluated. In terms of capacity building, several institutions and think tanks are directly addressing the issue of climate change in Nepal, notably the Nepal Climate Change Knowledge Management Centre (NCCKMC) and International Centre for Integrated Mountain Development (ICIMOD), which publishes extensively on the topic of climate change. Yet, in spite of these recent advances toward addressing climate change impacts in Nepal, the financial, institutional, and human capacities are lacking for real implementation of CCA policies, not to mention the capacity to integrate climate change models at the local governmental level. In order to illustrate this gap between local capacities and climate change models, the following case study is presented on issues facing Dharan Municipality in Eastern Nepal.

CASE STUDY: FLOOD RISK IN DHARAN, EASTERN NEPAL

This case study was developed as part of a larger comparative study from 2009 to 2011 of several communities affected by landslides and flooding in central and Eastern Nepal to better understand issues of vulnerability and resilience. The research methodology combined "bottom-up" qualitative and quantitative participatory social science approaches with "top-down" quantitative geological assessments, remote sensing, flood modeling, and a geographic information system (GIS) database. To better understand the hazards and risk due to flooding and landslides, a household survey ($n = 59$) was carried out combined with a detailed geographical assessment of landslides on its western flank, and flood hazard modeling of the main rivers passing through the city.

Geographical Context

Dharan is a town of 100,000 people located in an alluvial fan below the Siwalik foothills at 400–500 m above sea level (Fig. 1). The climate is tropical, with temperatures ranging from 32 to 10°C and average annual rainfall of 2,600 mm (Dharan Municipality, 2011). Dharan evolved over the centuries as one of the major trading cites between the mountains of Nepal and the Gangetic Plain of India. It has prospered thanks to the British "Gurkha Recruitment Center" established in 1953, which helped many Nepalese gain employment and settle here to retire with generous pensions from the British army (Dharan Municipality, 2011). The city is very multiethnic. Dominant ethnic groups include Rai and Limbu, but there are significant minorities of Dalit, Tamang, Gurung, Karki, Shrestha, and Brahmin groups also present.

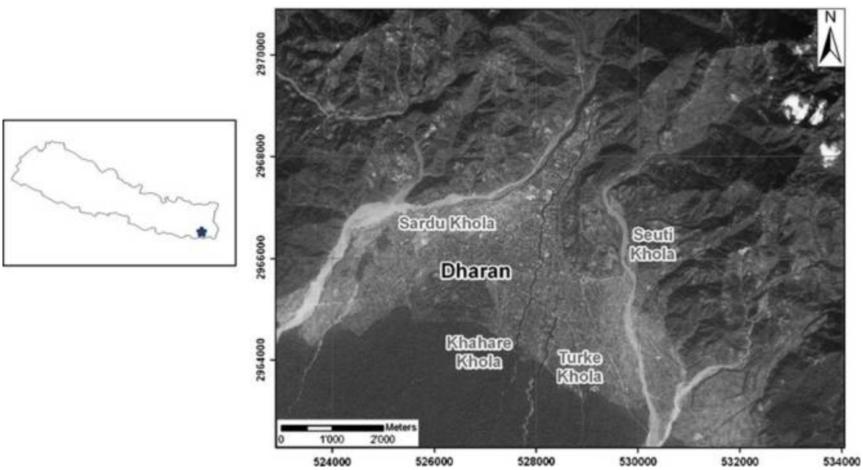

Fig. 1. Situation Map, Dharan Municipality and Main Rivers (*khola*) (Dubois, 2010).

Dharan is flanked by two larger rivers – the Sardu Khola to the west and Seuti Khola to the east – and is bisected by several smaller rivers crossing the city – the Khahare Khola and Turke Khola. All of the streams are subject to inundations and flash flooding. In spite of being surrounded by rivers, many neighborhoods face severe drinking water shortages during the dry season. Some residents acknowledged they have to travel 10 km to find drinking water and there are often fights at the communal water pump during the dry season. The city was severely damaged by the 1988 earthquake (6.8 in Richter scale), which killed 138 people and injured 2,117, with damage to 2,500 buildings (NSET, 2011). Earthquakes continue to pose a high risk and are the highest priority for risk reduction but flooding remains the most frequent and problematic hazard. Landslides are a problem on slopes along the west side of Dharan, mainly affecting terraces along the slopes where people are not allowed to live. A large earthquake could trigger a major landslide, creating an artificial dam, seriously threatening the population living along Sardu Khola (Dubois, 2010).

In recognizing the role of forest degradation and slope instability, nine community forests were established around Dharan. Strict rules for grazing, gathering fodder, and firewood were established with various levels of community participation and success. Water is however the city's biggest

Fig. 2. Destroyed School Building After a September 2009 Flash Flood, Khahare Khola. *Photo*: Dubois (2009).

concern, with not enough during the dry season and too much during the monsoon season. Urban runoff, encroachment of settlements on riverbanks and in river channels themselves, poorly maintained canalizations, upstream deforestation, and increasingly intense monsoon rains have together led to severe flash flood incidents (Fig. 2).

Social Context

Housing conditions for the river communities, which have settled along the city's channels and rivers are very poor. A majority or 76% of households in the river communities surveyed were in-migrants from either the vicinity of the Koshi River or the Middle Hills region. They have settled along the rivers, sometimes in the riverbed itself and elsewhere, drawn by better economic opportunities but also due to landslides and flooding along the nearby Koshi River and in the Middle Hills (Fig. 3).

Most river communities live in one-story makeshift huts constructed out of bamboo, iron sheets, or other light materials and many people live off of gathering stones from the rivers and breaking them into gravel manually. The community living by Khahare Khola and Seuti Khola are very poor day laborers, having migrated here from other places in the Middle Hills or Koshi River region, either attracted to the city for economic reasons or pushed out by food insecurity, health problems, landslides, or flooding. There is a very big difference between these poor landless communities and wealthy retired British army recruits living in immaculate three-story houses sometimes only one kilometer away (Fig. 4).

Risk Perceptions, Vulnerability, and Coping Strategies

Risk perception among river communities is very high. All respondents of the study were very worried about the flash flooding and considered the probability of repeated flooding very high. As most exposed households have to rebuild their houses almost once a year because of flooding, household maintenance can be very costly. Some gabion walls have been built to protect river communities from flooding but these are not entirely effective, as all respondents claimed that they were flooded several times every year. Other coping strategies for river community households include rebuilding, cleaning, and trying to keep any valuable household items dry during frequent flooding. In spite of the flood threat, main priorities were

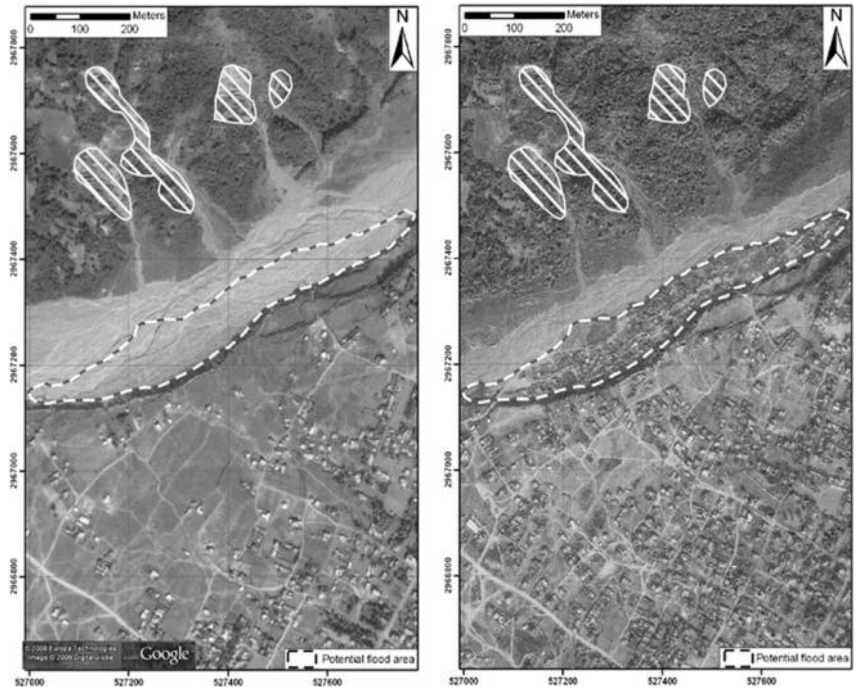

Fig. 3. Left: Google Earth Image from 2004 of Sardu Khola. Recent Landslides are Observable on the River's Right Bank. Right: The Same Riverbank in 2009, with New Unplanned Settlement in the Riverbed. Vegetation Cover has Increased on the Former Landslides due to the Establishment of Community Forests. Based on 2009 Ikonos 2 Satellite Image (Dubois, 2010).

Fig. 4. Left: House for Family of Three along the Seuti Khola River; Right: Characteristic House of Retired British Army Recruits. *Photos*: Sudmeier-Rieux (2009).

actually development related: mainly education, employment, road development, followed lastly by flood mitigation. In spite of perceptions of high flood risk and the costs incurred by flooding, residents continue to live here and improve their houses after every flood, reflecting the marginalized status of these communities, where basic needs and everyday economic risks take priority over seemingly less important physical risks such as flooding. This finding is consistent with other similar studies of marginalized people living in dangerous places (Gaillard & Cadag, 2009; Nathan, 2008).

Flood Risk Model (FLOW-R)

The FLOW-R flood risk model was run for this study based on a digital elevation model (DEM) calculated from 20 m contour lines of the topographic map field studies, satellite images – a Google map from November 2004, and an Orthophoto Ikonos 2, pan-sharpened image from December 2009, purchased for this study – and rainfall data acquired from the Nepal Ministry of hydrology for Dharan. The FLOW-R software (Horton, Jaboyedoff, & Bardou, 2008) was originally designed to model debris flows, but it can also be used to model floods (Jaboyedoff et al., 2010). It detects potential hazard sources and calculates the fluid propagation of debris flows, floods, or avalanches. Here, the detection of the sources was conducted manually by adding the potential overflow identified during the field study to the river bed. The model uses two algorithms to calculate the propagation from the given sources on a DEM, which is a grid showing elevation changes. The first one calculates the flow direction probability dependent on the slope. The second one defines the length of propagation using the potential energy (Dubois, 2010). The main outcome of the model is a susceptibility map (Fig. 5), which illustrates potential flooding indicated for a 10-year return rainfall event, in the range of 250–300 mm. Such modeling is important at least in theory since extreme flooding events are expected to increase in frequency and intensity due to climate change (IPCC, 2012).

With reliable climate change predictions at a local scale, it would be possible to produce several scenarios of flooding that can be useful for local flood planning, as well as developing risk maps. Such maps take into consideration population vulnerability and exposure as well. Results from our study and modeling simulation were used to prepare a study of Sardu Khola watershed to improve management of the water supply for the city of Dharan (IUCN-Nepal, 2011). However, according to Suraj Shrestha, head

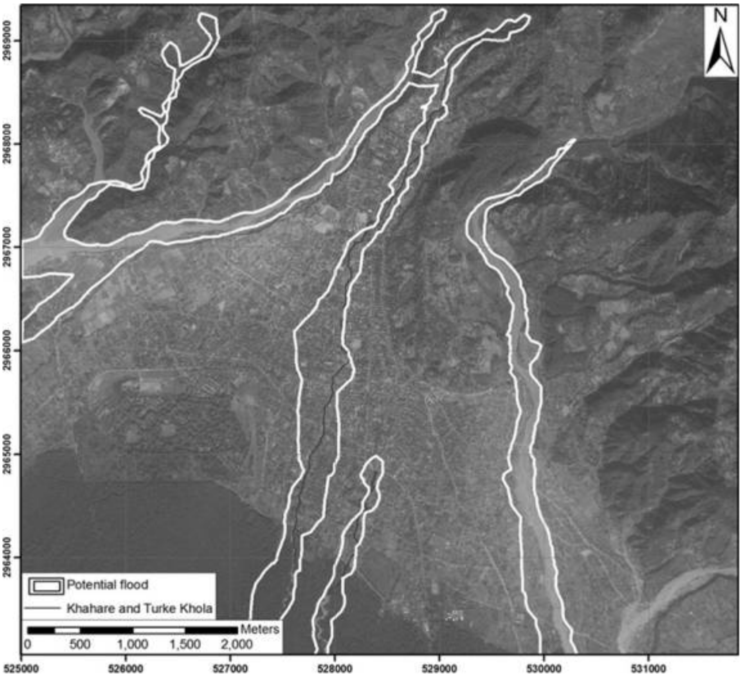

Fig. 5. FLOW-R (Horton et al., 2008) was Used to Model Water Propagation in the Case of Overflow of Dharan's Watercourses (Dubois, 2010).

engineer at Dharan Municipality none of our research findings have been implemented to reduce flood risk due to lack of capacity at the municipality (personal communication). The main problems are: (1) structural problems – in other words the need to physically reduce runoff and improve urban infrastructure; (2) the increased number of people living in hazardous areas, and the associated need to physically relocate these river communities; and (3) lack of capacity at the municipal level to undertake the above actions.

This situation highlights a very common problem in Nepal: municipalities and local government are overwhelmed with basic every day issues of water supply, sanitation, and basic maintenance, without being able to properly address any other issues, such as flooding, landslides, earthquakes, or other physical safety issues. Low budgets, low salaries, and a ''brain drain'' of educated professionals migrating out of the municipality are hampering local development. Thus for climate change, which is still considered a problem of the future, the problem is not access to information about flooding, but rather lack of capacity and budgets to address the most urgent municipal needs of today.

Considering the situation on the ground, several questions face both climate scientists and policy makers: how to design and communicate more locally relevant data to support local decision-making, considering local needs and capacities. If it is not currently possible for climate scientists to design more accurate locally relevant data, then it may be necessary to seek less sophisticated methods by ensuring more accurate rainfall data readings and providing locally specific hydrological models and risk maps. For policy makers, the issue is how to enhance local capacities to deal with a number of acute issues including reducing the occurrence of epidemics through access to clean drinking water and improved sanitation, keeping people out of harm's way through land-use planning and reducing the occurrence of flooding and landslides through improved disaster planning and prevention.

GAPS BETWEEN CLIMATE CHANGE IMPACT MODELS AND LOCAL NEEDS

The above case study of risks from extreme flooding in Dharan illustrates the main challenge for CCA and DRR: most Nepalese face urgent basic everyday risks above disaster risk. These other risks include poor access to drinking water, poor sanitation, epidemics (i.e., cholera, diarrhea), and food insecurity, which all need to be addressed before or in parallel to addressing future threats relating to floods or climate change. In spite of greater decentralization and increased budgets at the local level, local capacities remain low and basic current needs are still not being met. Planning ahead for climate change is a far second priority and especially if there is very little reliable and locally specific data. The issue with climate change models for Nepal can be summed up by two main gaps: a *knowledge gap* due to lack of appropriate data and information relevant at the local scale; and a *capacity gap* between scientific and technical knowledge and the ability to appropriate the scientific results and technical practices and take action. The reason for these gaps is principally due to poor governance and local capacity. To address each gap, several recommendations are proposed as discussed below.

Bridging the Knowledge Gap: Make Technical Knowledge Work for People by Improving the Relevance of Climate Change Impact Models at a Local Scale

This gap relates to institutions on the information-providing side. As noted above in the section on climate change models, modeling at the regional scale still has a wide margin of error, even more so when brought down to the national and subnational scales. Greater efforts are needed on behalf of information providers to provide data that are as useful as possible at the local level that translates how the climate change model data will affect local conditions, and concrete implications for local planning. Therefore, making climate change models relevant at the local scale will require a lot more sophisticated modeling and especially dynamic downscaling. In parallel, what is needed is more accurate rainfall data to allow for better estimates of current as well as future rainfall trends. For example, in Dharan, it was clear that the main challenge for the municipality is providing clean and regularly available drinking water, proper sanitation and basic services such as garbage collection and education. On-site visits with municipal technical staff to areas frequently affected by flash flooding demonstrated that although they were highly aware of the flooding problem, their capacities to address this problem were limited and earthquake risk was higher on the list of priorities. Therefore, long-term planning to anticipate climate change-induced flood risk, even if adequate local data were available, was not the first priority.

Where no accurate data on trends in climatic conditions exist, it is also possible to complement with qualitative local knowledge on local environmental conditions (NVSCT, 2009). Local people are on the "front-line" of climate change impacts and due to low government capacity, they bear the prime burden and responsibility to deal with hazard events, drought, changing crop patterns, and health problems due to changing climate conditions. As climate change predictions are uncertain at the local level and basic hydrological data are often lacking, local observations of environmental and climate changes can be used to cross-validate climate change models, as demonstrated by the NCVST (2009) consultations with stakeholders.

Bridging the Capacity Gap: Addressing Poor Governance and Local Capacity

This gap relates to institutions on the receiving end of climate change impact models. Many models using complex, inaccessible technology (e.g., remote sensing and Geographic Information System (GIS) for hazard monitoring, early warning, and response) are not widely applicable due to low technological capability and the costs involved. At the local level (village and district), local planners may be aware of climate change impact models but their usefulness is limited as basic tools such as GIS, good topographic maps, and baseline data on local rainfall are lacking. At the regional scale, the issue is not availability of climate change data for planning but the capacity of local government to enforce land-use planning and identify flood and landslide mitigation as priorities among other competing needs. In Dharan, the municipal staff was acquainted with GIS but had old versions of the software, low-performing computers, and virtually no data useful for a GIS database. Climate change data needs to be coupled with the appropriate local technology and human capacity in order to be of use.

This recommendation also emphasizes much more dedicated collaboration between the government of Nepal with Nepal-based and international research organizations to enhance local capacity building of local government, including providing basic tools such as topographic maps, GIS capabilities, remote sensing and satellite images, and the ability to perform basic modeling of flooding as described in the above case study. The Nepal Climate Change Knowledge Center (NCCKC) is also a good initiative for establishing dialogs between communities and local government and there is certainly the potential to do more for local capacity building.

Since the new national government was installed in 2008, budgets and development planning have been significantly decentralized. Five-year development plans have been replaced by annual plans, and so local politics rather than real development needs or considerations for climate change adaptation are driving local development planning and priorities. Development is currently influenced by infrastructure development and road building in rural areas, which does not include proper drainage and stabilization measures. Budgets for local land-use planning are usually quite limited and do not prevent people from settling in dangerous places such as floodplains. Therefore, poor governance and limited budgets are main obstacles to effective planning, with or without good climate change impact modeling.

However, there are a few, albeit not enough, success stories of DRR and CCA at the local level that are based on participatory/community-based approaches and local knowledge. Two examples of community-based approaches include the Dahachowk Sabo Model Work for landslide reduction using the "Participatory water-induced disaster mitigation approach" (DWIDP, 2004) or the Sundar Community Forest Model Work for reducing fires using "Community-based Fire Management" (GFMC, 2007, 2008).

Community-based approaches to DRR and CCA can be very successful if based on local knowledge and enhanced by climate change knowledge if available and understandable at the local level.

CONCLUSIONS

The current development model in Nepal is based on infrastructure development, not capacity building. Without capacity building of local government, climate change models will remain inaccessible. Local development plans can only be sustainable if made with a longer timeframe in mind that includes climate knowledge for CCA disaster risk management. International aid agencies can assist by supporting initiatives that strengthen integrated and participatory approaches to DRR, CCA, and rural development.

DRR and CCA are a challenge for Nepal due to minimum budgetary provision by the government, low local government capacities, and not enough emphasis on community involvement in programming planning, implementation, and benefit sharing. In spite of several positive developments at the national and local level for improving DRR and CCA, including the NAPA and PPRC processes, Nepal Climate Change Policy Act, the creation of the NCCKC, and the wealth of resources at ICIMOD, these policies and institutions have not sufficed for catalyzing real action. Yet the potential is great for bridging the huge gap between the high-tech wealth of information housed at NCCKC and ICIMOD and the very low-tech capabilities of most local government agencies in Nepal.

In addition, almost all national institutions (e.g., Ministry of Home Affairs, Ministry of Environment, Ministry of Forest and Soil Conservation, Department of Water-Induced Disaster Prevention, Department of Soil Conservation and Watershed Management), and many international institutions (e.g., ICIMOD, SAARC, UNISDR-Regional South Asia Wildland Fire Network) have clear mandates to address climate change (ICIMOD, 2011; SAARC, 2011). Yet, collective and collaborative actions for CCA and DRR are lacking. In summary, the answer lies not in the tool (i.e., climate change scenarios and impact models) but how the tool is used. This requires good governance, resources, political willingness, and community participation, not just better data.

The main challenge is how to achieve both locally accurate climate change scenarios and impact models, as well as the capacity to utilize these tools in order to reduce the gap between science and practice. Another question is whether existing climate models will be used effectively for decision-making about CCA (e.g., through the PPRC) and DRR. Or stated differently, how can climate change scenarios and impact models be better adapted to meet current and future decision-making to reduce economic and health impacts? Considering the stakes and uncertainty surrounding climate change predictions for Nepal, it will be wise to design models that meet local decision-making needs and capacities, such as more locally appropriate hydrological models for establishing local hazard predictions (e.g., flooding, landslides, GLOFs) that can be more effectively and readily utilized for local decisions to reduce the impacts of climate change. Certainly investing in more accurate RCMs will be useful in the long run for reducing the impact of climate change. In the meantime, the immediate need is for locally useable data, such as that produced for Dharan Municipality, and investment in local capacities to deal with acute current risks – often of greater concern than climate disaster risks – that will only become aggravated by climate change.

ACKNOWLEDGMENTS

The first author would like to express sincere gratitude for the Swiss National Science Foundation grant (#26083591) for the period 2009–2011, which provided funding for the research on Dharan Municipality, among other study sites. Many thanks also go to Mr. Gopi Krishna Basyal (NSET, Nepal) for his collaboration and feedback on this chapter.

REFERENCES

Ayers, J., Kaur, N., & Anderson, S. (2011). Negotiating climate resilience in Nepal. *IDS Bulletin*, *42*(3), 70–79.

Baidya, S. K., Shrestha, M. L., & Sheikh, M. M. (2008). Trends in daily climatic extremes of temperature and precipitation in Nepal. *Journal of Hydrology and Meterology*, *5*(8). Society of Hydrology and Meterology, Kathmandu, Nepal.

Beven, K. J., & Kirkby, M. J. (1979). A physically based variable contributing area model of basin hydrology. *Hydrologic Science Bulletin*, *24*(1), 43–69.

Christensen, J. H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, R., … Whetton, P. (2007). Regional climate projections. In *climate change, 2007: The physical science basis*. Contribution of Working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 847–940), Cambridge University Press, Cambridge, UK.

CIF (Climate Investment Fund). (2011). Retrieved from http://www.climateinvestmentfunds.org/cif/ppcr. Accessed on July 1, 2011.

Dharan Municipality. (2011). Retrieved from http://www.dharan.gov.np/english/default.asp. Accessed on July 1, 2011.

Dubois, J. (2010). *Flood study in Dharan, Sunsari District, Nepal*. Unpublished report. University of Lausanne, Institute of Geomatics and Analysis of Risk, Lausanne (33pp.).

DWIDP. (2004, August). *A final report on Dahachowk Sabo model work*. Department of Water Induced Disaster Prevention/Disaster Mitigation Support Programme Project (DMSP/JICA), Pulchowk, Lalitpur, Nepal.

DWIDP. (2009). *Disaster review 2009* (24 pp.). Kathmandu: DWIDP.

Gaillard, J. C., & Cadag, J. R. (2009). From marginality to further marginalization: Experiences from the victims of the July 2000 Payatas trashslide in the Philippines. *Jàmbá: Journal of Disaster Risk Studies*, *2*(3), 195–213.

Gaillard, J. C., Wisner, B., Benouar, D., Cannon, T., Créton-Cazanave, L., Dekens, J., … Vallette, C. (2010). Alternatives pour une réduction durable des risques de catastrophe. *Human Geography*, *3*(1), 66–88.

GFMC (Global Fire Monitoring Center). (2007). *Community-based fire management (CBFiM) training – An approach towards participatory planning*. Global fire Monitoring Center (GFMC)/Foreign Office, Federal Republic of Germany, Office for Humanitarian Assistance, Freiburg, Germany.

GFMC (Global Fire Monitoring Center). (2008). *Community forest fire management plan of Sundar Community Forest, Sundar Community Forest User's Group/District Forest Office*. Makawanpur/Global fire Monitoring Center (GFMC)/Foreign Office, Federal Republic of Germany, Office for Humanitarian Assistance, Chaukitole, Hetauda, Makawanpur, Nepal.

GoN (Government of Nepal). (2011). *Climate change policy 2067 (2011, Nepali)*. Government of Nepal, Ministry of Environment, Climate Change and Development Portal. Retrieved from http://www.climatenepal.org.np/main/?p=research&sp=onlinelibrary&opt=detail&id=469. Accessed on July 1, 2011.

Hewitt, K. (1983). The idea of calamity in a technocratic age. In: K. Hewitt (Ed.), *Interpretation of calamities* (pp. 3–32). The Risks and Hazards Series. Boston MA: Allen and Unwin.

Horton, P., Jaboyedoff, M., & Bardou, E. (2008). Debris flow susceptibility mapping at a regional scale. *4th Canadian conference on geohazards*, Université de Laval, Canada.

ICIMOD. (2011). *Web portal of the International Centre for Integrated Mountain Development (ICIMOD)*. Retrieved from http://www.icimod.org. Accessed on May 28, 2011.

IFRC (International Federation of Red Cross and Red Crescent Society). (2011). *Analysis of legislation related to disaster risk reduction in Nepal* (68pp.). Geneva: IFRC.

IPCC (2012). *Summary for policy makers. Managing extreme events and disasters to advance climate change adaptation*. A special report of working groups I and II of the Intergovernmental Panel on Climate Change (pp. 1–19). Cambridge University Press, Cambridge, UK.

IUCN. (2011). Integrated watershed conservation and management plan: Sardu Watershed, Dharan, Sunsari, Nepal (p. 158). Kathmandu: International Union for Conservation of Nature.

Jaboyedoff, M., Michoud, C., Mazotti, B., Choffet, M., Dubois, J., Breguet, A., …, Pedrazzini, A. (2010). *Cartes indicatives des dangers des communes de Bagnes et Vollège*. Unpublished report. University of Lausanne, Institute of Geomatics and Analysis of Risk, Lausanne (35pp.).

Jianchu, X., Shrestha, A., Vaidya, R., Eriksson, M., & Hewitt, K. (2007). *The melting Himalayas regional challenges and local impacts of climate change on mountain ecosystems and livelihoods* (23 pp.). Kathmandu: ICIMOD.

Jing, F., & Leduc, B. (2010). *Potential threats from climate change to human wellbeing in the Eastern Himalayan Region China – Climate change impact and vulnerability in the Eastern Himalayas*. Technical report 6. ICIMOD, Kathmandu (23 pp.).

Khan, A. (2005). *Enhancement of national capacities in the application of simulation models for the assessment of climate change and its impacts on water resources and food and agricultural production*. Final report for APN CAPaBLE Project: 2005-CRP1CMY-Khan. GCISC, Islamabad (97 pp.).

Lamadrid, A. J., & MacClune, K. L. (2010). *Climate and hydrological modeling in the Hindu-Kush Himalaya Region*. Oslo: CICERO, ISET.

Li, J., & Zeng, Q. (2003). A new monsoon index and the geographical distribution of the global monsoons. *Advances in Atmospheric Science*, *20*, 299–302.

Marino, L., Lisa, A., & Crawford, N. H. (1997). *On-line help: HFAM*. Menlo Park, CA: Hydrocomp.

MoHA (Ministry of Home Affairs). (2009). *Nepal disaster report 2009, the hazardscape and vulnerability*. Kathmandu: Ministry of Home Affairs, Government of Nepal (185 pp.).

NAST (Nepal Academy of Science and Technology). (2010). *Nepal climate change knowledge management center*. Lalitpur: Nepal Academy of Science and Technology.

Nathan, F. (2008). Risk perception risk management and vulnerability to landslides in the hill slopes in the city of La Paz, Bolivia. A preliminary statement. *Disasters*, *32*(3), 337–357.

NCVST (Nepal Climate Vulnerability Study Team). (2009). *Vulnerability through the eyes of vulnerable: Climate change induced uncertainties and Nepal's development predicaments*. Institute for Social and Environmental Transition-Nepal (ISET-N), Kathmandu and Institute for Social and Environmental Transition, ISET, Boulder, CO.

Nepal NAPA (National Adaptation Programme of Action). (2010). *Climate induced disaster thematic working group report, for national adaptation programs of action*. Retrieved from http://www.napanepal.gov.np. Accessed on June 15, 2011.

NSET (National Society for Earthquake Technology, Nepal). (2011). Retrieved from http://www.nset.org.np/nset/php/EAP_Dharan_.php. Accessed on July 1, 2011.

Opitz-Stapleton, S., & Gangopadhyay, S. (2009). Downscaling climate information in data limited contexts: Potential changes in the Rohini Basin, Nepal and India. In M. Moench, E. Fajber, A. Dixit, E. Caspari & A. Pokharel (Eds.), *Catalyzing climate and disaster resilience, processes for identifying tangible and economically robust strategies* (p. 328). Kathmandu: Institute for Social and Environmental Transition.

Oven, K., Petley, D. N, Rigg, J., Dunn, C., & Rosser, N. (2008). Landslides, livelihoods and risk: Vulnerability and decision-making in Central Nepal. In N. Casagli, R. Fanti, & V. Fanti (Eds.), *Proceedings of first world landslide forum*. Tokyo, Japan (pp. 236–240).

Petley, D., Hearn, G. J., Hart, A., Rosser, N., Dunning, S., Oven, K., & Mitchell, W. (2007). Trends in landslide occurrence in Nepal. *Nat Hazards*, *43*, 23–44.

SAARC. (2011). *Web portal of the South Asian Association of Regional Cooperation on Hazards and Disasters*. Retrieved from http://www.SAARC-Disaster/SAARCFire report.mht

Shrestha, A. B., & Devkota, L. P. (2010). *Climate change in the Eastern Himalayas: Observed trends and model projections*. Climate change impact and vulnerability in the Eastern Himalayas – Technical Report 1. ICIMOD, Kathmandu (15 pp.).

Tse-ring, K., Sharma, E., Chettri, N., & Shrestha, A. (2010). *Climate change vulnerability of mountain ecosystems in the Eastern Himalayas* (116 pp.). Kathmandu: ICIMOD.

U.S. Geological Survey. (2006). *HYDRO1k elevation derivative database*. Retrieved from http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30/hydro

Water and Energy Commission Secretariat (WECS). (2011). *Water resources of Nepal in the context of climate change Singha Durbar*. Kathmandu: WECS.

Wisner, B., Blaikie, P., Cannon, T., & Davis, I. (2004). *At risk, natural hazards, people's vulnerability and disasters* (2nd ed.). London/New York: Routledge.

Yates, D. (1994). *WatBal: An integrated water balance model for climate impact assessment of river runoff*. IIASA (International Institute for Applied Systems Analysis), WP-94-64, Laxenburg, Austria.