HI-AWARE Working Paper 9

HI-AWARE
Himalayan Adaptation, Water and Resilience Research

CARIAA
Collaborative Adaptation Research Initiative in Africa and Asia

The Gandaki Basin

Maintaining Livelihoods in the Face of Landslides, Floods, and Drought

Consortium members

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About HI-AWARE Working Papers

This series is based on the work of the Himalayan Adaptation, Water and Resilience (HI-AWARE) consortium under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) with financial support from the UK Government's Department for International Development and the International Development Research Centre, Ottawa, Canada. CARIAA aims to build the resilience of vulnerable populations and their livelihoods in three climate change hot spots in Africa and Asia. The programme supports collaborative research to inform adaptation policy and practice.

HI-AWARE aims to enhance the adaptive capacities and climate resilience of the poor and vulnerable women, men, and children living in the mountains and flood plains of the Indus, Ganges, and Brahmaputra river basins. It seeks to do this through the development of robust evidence to inform people-centred and gender-inclusive climate change adaptation policies and practices for improving livelihoods.

The HI-AWARE consortium is led by the International Centre for Integrated Mountain Development (ICIMOD). The other consortium members are the Bangladesh Centre for Advanced Studies (BCAS), The Energy and Resources Institute (TERI), the Climate Change, Alternative Energy, and Water Resources Institute of the Pakistan Agricultural Research Council (CAEWRI-PARC) and Alterra-Wageningen University and Research Centre (Alterra-WUR). For more details see www.hi-aware.org.

Titles in this series are intended to share initial findings and lessons from research studies commissioned by HI-AWARE. Papers are intended to foster exchange and dialogue within science and policy circles concerned with climate change adaptation in vulnerability hotspots. As an interim output of the HI-AWARE consortium, they have only undergone an internal review process.

Feedback is welcomed as a means to strengthen these works: some may later be revised for peer-reviewed publication.

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The Gandaki Basin
Maintaining Livelihoods in the Face of Landslides, Floods, and Drought

Contributors

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Contents

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Acronyms and Abbreviations

GLOF	glacial lake outburst flood
LAPA	Local Adaptation Plan of Action
LPG	liquefied petroleum gas
masl	metres above sea level
NAPA	National Adaptation Plan of Action
VDC	village development committee
WWF	World Wildlife Fund

Introduction

The Gandaki river basin is a transboundary basin lying north-south in the central Himalayan region. It extends from China in the north, through Nepal, to India in the south and is bounded by the Karnali basin to the west and the Koshi basin to the east (Figure 1). The basin has a total drainage area of 46,300 km^2 – 72% in Nepal, 18% in India, and 10% in China – and includes part of Xiagaze prefecture in Tibet Autonomous Region in China, 19 districts in Nepal (12 entirely and 7 partially within the basin), and 9 districts in India. The Gandaki river is known as the Narayani in the plains of Nepal and as the Gandak in India, where it joins the Ganges (Ganga) at Hajipur near Patna. It has seven major tributaries (the Kali Gandaki, Seti Gandaki, Madi, Marsyangdi, Daraudi, Budhi Gandaki, and Trishuli), of which all except the Daraudi and Madi have catchment areas with glaciers (Bajracharya and Shrestha 2011). There are 1,710 glaciers in the upstream catchments (as of 2005), with an area of 2,285 km^2 and estimated ice reserves of 194 km^3 (Bajracharya and Shrestha 2011: 56). Many smaller rivers and rivulets also drain into the Gandaki including, for example, the east Rapti river, which joins the river at Chitwan.

The basin has a wide variation in elevation and topography and marked variations in climate and vegetation. The opportunities and challenges for, and livelihood strategies and adaptive capacity of, the people who live in the basin are correspondingly diverse. Overall the poverty levels are fairly high and socio-economic indicators low, and the basin population is vulnerable to a range of natural hazards. Avalanches, landslides, glacial lake outburst floods (GLOFs) and other floods triggered by heavy rainfall, and drought are the major climatic issues in the upstream area; landslides and drying up of springs in the midstream area; and riverine floods in the plains.

This report presents the results of a situational analysis of the Gandaki basin carried out under the Himalayan Adaptation, Water and Resilience (HI-AWARE) research initiative. The initiative focuses on the likely impact of climate change in glacier-fed river basins originating in the Hindu Kush Himalayan (HKH) region with the aim of informing policy and practice to enhance the climate resilience and adaptive capacity of the poor and vulnerable communities living in the basins. The study used published data and field research to provide a qualitative and quantitative baseline for assessment of vulnerability drivers and adaptive responses.

Figure 1: **Gandaki basin with districts and main tributaries**

Source: Map - Gauri S Dangol; inputs by Santosh Nepal and Pranita Udas

Methodology

The research methodology included an analysis of climate change trends and vulnerability; an in-depth review of primary and secondary literature on climate change impacts in the upper, middle and lower sections of the basin; and field visits to the upper and midstream parts of the basin in Nepal and one site each in the floodplains of Nepal and India.

For the analysis, the catchment was divided on the basis of district boundaries into upstream (includes three districts of Nepal and the area within China), midstream (includes 14 districts of Nepal), and downstream (includes 2 districts of Nepal and 9 districts in Bihar, India) as shown in Figure 1. These regions correspond approximately to the High Mountains, Middle Mountains (hills), and Siwaliks and Terai physiographic zones (see next section). Gorkha and Makwanpur districts fall into multiple geographic areas but were classified as midstream in line with the greatest part of their area.

The first part of the study comprised an analysis of climate trends using a combination of published data and primary data from hydro-meteorological stations located in the Trishuli corridor, together with an analysis of trends in disasters from data provided by the Ministry of Home Affairs.

The second part consisted of a review of the literature on climate change and adaptation focusing on Rasuwa, Manang, and Mustang districts upstream; Nuwakot, Dhading, and Makwanpur districts midstream; and Chitwan and Nawalparasi districts downstream in Nepal; together with a socio-economic analysis for the Nepal area of the basin.

The third part involved field visits to selected villages in Rasuwa (upstream), Nuwakot (midstream), and Chitwan (downstream) in Nepal and West Champaran district of Bihar in India (downstream). The villages were selected based on issues around climate change, variability, and adaptation. The selected villages were Bhorle, Daibung, and LaharePauwa VDCs in Rasuwa; Bagaicha, Belkot, Bidur, Charghare, Chaughada Kadga Bhanjyang, Kalyanpur, Madanpur, Malakot, and Ratmate VDCs/municipalities in Nuwakot; Ayodhyapuri, Gunjanagar, Madi, Mangalpur, Meghauli, VDCs/municipalities in Chitwan in Nepal; and in West Champaran district in India, Bhagwanpur, Charki Bishambharpur, and Gurdiya in Nautan block; Bhikna Thori, Rajoutiya, and Raupaliya in Gaunaha block (outside but close to the Gandaki basin); Mangalpur Rakhahi in Jogapatti/Bairia block; and Badki Rakhahi in Thakraha block. The field visits were carried out between February and October 2015 (Rasuwa – three days in September/ October; Nuwakot – three days in February, three days in March; Chitwan three days in March, three days in April; West Champaran five days in February, five days in March). Information was collected through direct observation, interviews, and focus group discussions guided by a checklist.

Major Basin Characteristics

Physiographic zones

The basin is classified into five zones based on physiography (elevation and topography): from north to south the Trans-Himalaya (Tibetan Tethys Himalaya), Higher Himalaya, Lesser Himalaya (middle hills), Siwaliks, and Terai (Figure 2b), which differ in climate and vegetation. The upstream essentially includes the high mountains of the Trans-Himalaya and Higher Himalaya with an elevation above 3,000 masl, and is characterized by an abrupt rise of topography, extremely rugged terrain, steep slopes, and deeply cut valleys. The land cover varies from glaciers, snow, and bare soil and rock at the highest elevations, through shrubs and grass and coniferous forest at the lower elevations. The midstream basically comprises the lesser Himalayan (middle mountains/ mid hills) zone to the north of the Siwalik range with an elevation range from 1,000 to 3,000 masl. This region is characterized by hills with large areas of dense broad-leaved and mixed forest and extensive agriculture, often on terraced slopes. The downstream area is mostly below 1,000 masl, and includes the Siwalik hills, and the extensive plains areas of the Terai and beyond, at elevations down to 44 masl. The Siwalik zone has dry and unconsolidated soil materials which are highly prone to erosion and landslides, while the Terai area is characterized by vast flood plains with deciduous forest and agriculture and subject in many places to annual inundation.

Hydrology

The climate is dominated by the Indian summer monsoon system; about 80% of the precipitation falls between June and September (Panthi et al. 2015). During this season, heavy rainfall commonly leads to water-related disasters such as landslides in the hills, flash floods in the Siwaliks, and riverine floods in the plains. The spatial distribution of precipitation varies across the zones creating microclimates that affect annual water availability. In the hills, springs are a major source of water and depend on annual rainfall to recharge the aquifers that feed them.

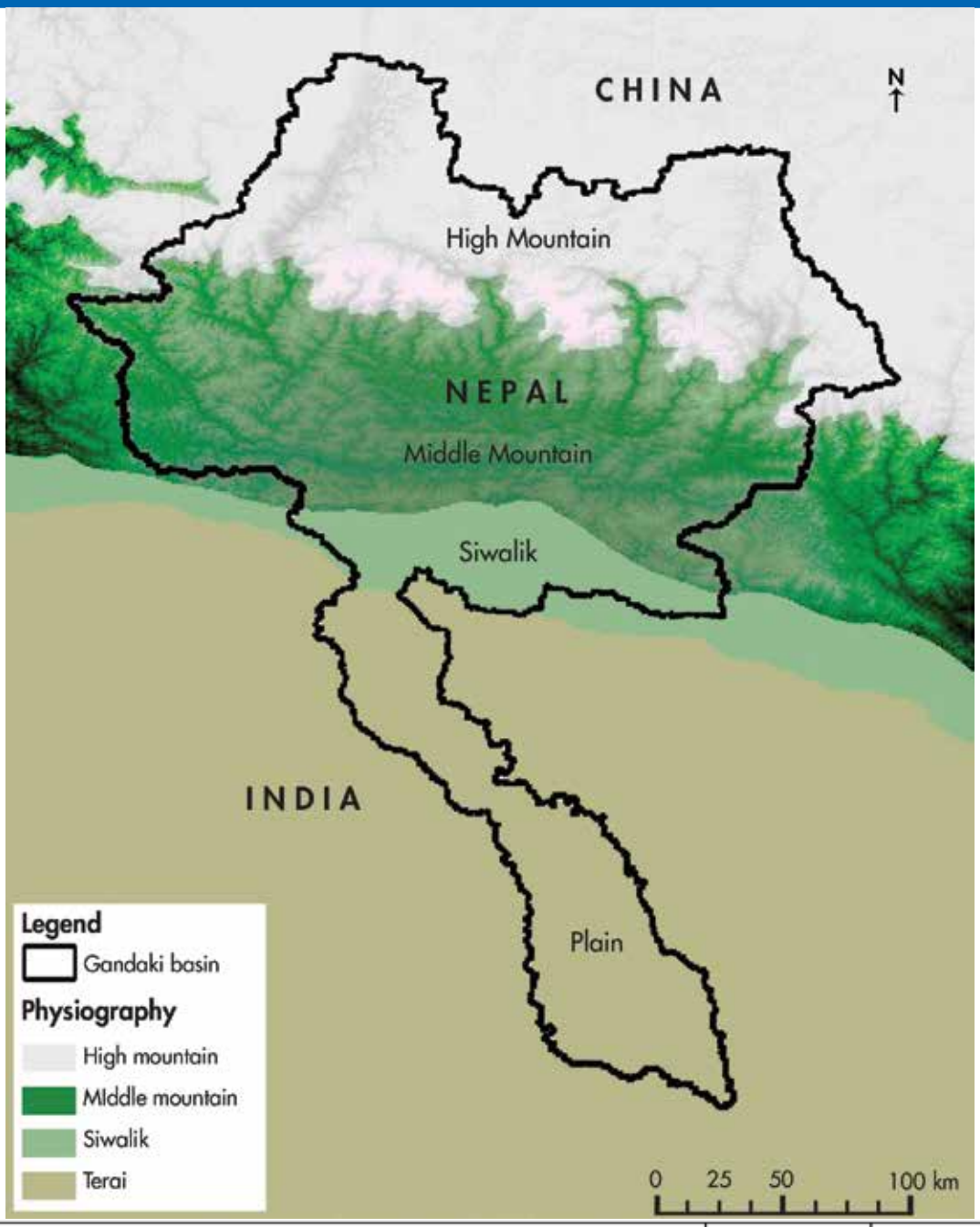
The river discharge varies throughout the year influenced by both snow melt and precipitation. The hydrograph of the Devghat stations in Chitwan district (below the confluence of the Kali Gandaki and Trishuli rivers) showed a seasonal variation in average monthly discharge in the period 1963–2010 ranging from 277 m^3/sec in March to 4,634 m^3/sec in August (Figure 3). The maximum daily discharge recorded was 14,100 m^3/sec on 05 August 1974. The daily values show a rise in discharge from the month of May contributed by snow and glacier melt, followed by a further increase resulting from rainfall run-off from June onwards. Manandhar et al. (2012) observed a (statistically insignificant) increasing trend in the pre-monsoon and post-monsoon discharges and decreasing trend in annual minimum discharge at Kotagaon station over the period 1964–2006.

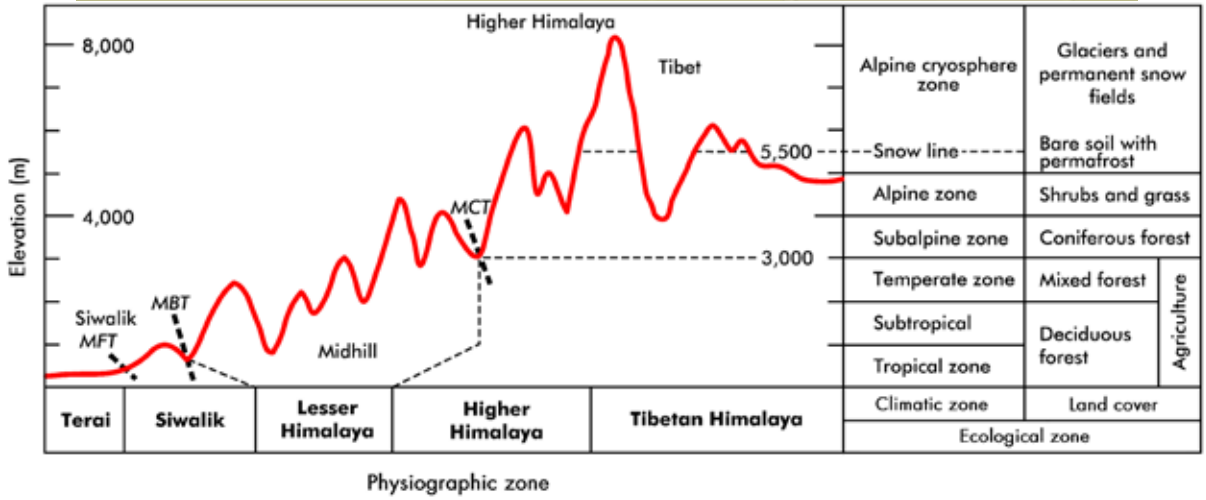
Socio-economic parameters

The total population in all the districts that lie partly or wholly in the basin is about 40 million (8 million in China, 5 million in Nepal, and 27 million in India, as of 2011). The population within the basin itself is somewhat lower. It includes people from many different ethnic groups, with Tibeto-Burman groups (mainly Tamang, Gurung, and Rai) predominant upstream and Indo-Aryan groups downstream. The southern plains are home to indigenous communities like Tharus as well as migrants from many different caste groups.

A socio-economic analysis was carried out for the Nepal part of the basin based on official statistics. The analysis used district level data with districts grouped into upstream, midstream, and downstream – approximately corresponding to mountains, hills, and plains – as described above and shown in Figure 1. Some selected major socio-economic parameters are shown in Table 1.

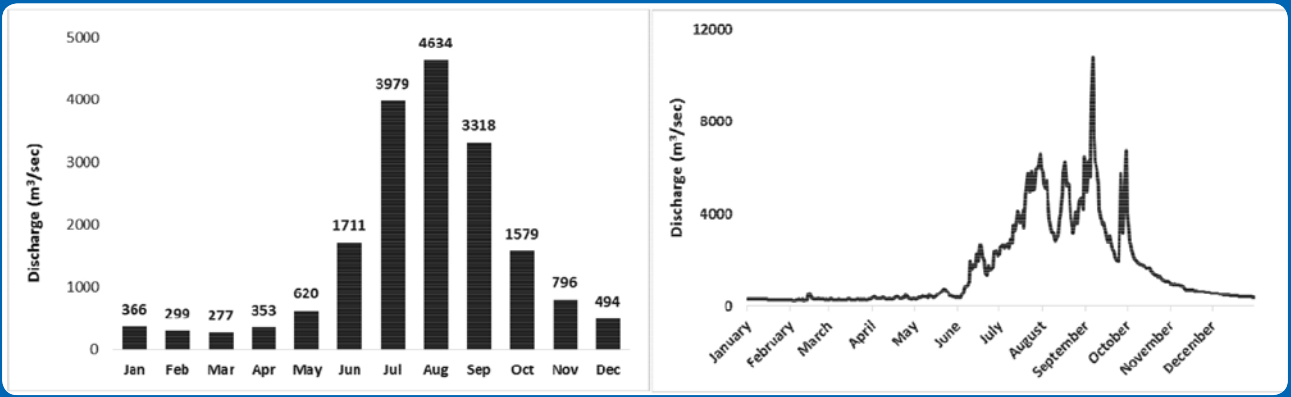
Figure 2: **Physiographic zones in the Gandaki basin**





Source: Modified after Nepal et al. 2017. (Note: MFT = main frontal thrust; MBT = main boundary thrust; MCT = main central thrust

Figure 3: **Monthly average discharge 1963–2010 (left) and daily discharge 2010 (right) at Devghat hydrological station on the Narayani**



Source: DHM, Nepal

Table 1: **Selected socio-economic indicators in the Nepal part of the Gandaki basin**

	Mountains (upstream)	Hills (midstream)	Terai (downstream)	Total
Area (km²)	7,363	21,013	4,400	32,776
Population				
Male	32,229	1,757,681	582,762	2,372,672
Female	31,061	2,087,469	640,730	2,759,260
Total	**63,290**	**3,845,150**	**1,223,492**	**5,131,932**
Population density (people/km²)	9	183	278	157
Literacy rate (%)				
Male	73	80	82	78
Female	56	64	67	62
Total	**65**	**72**	**74**	**70**
Economically active (%)				
Male	75	60	64	67
Female	69	59	53	60
Total	**72**	**60**	**58**	**63**
Under-five mortality (%)				
Male	29	33	40	34
Female	24	32	45	34
Total	**27**	**33**	**43**	**34**

Source: CBS 2012

The topographical differences have led to different population densities: low in the upstream and gradually increasing downstream with the highest density in the plains. There is a marked sex bias in the population with more females than males everywhere except the mountains. CBS (2012) also showed an increase in female-headed households from 15% in 2001 to 26% in 2011, with the absence of males mainly attributed to labour-related migration, which more than doubled between 2001 and 2011.

In Nepal, the incidence of poverty is higher in the mountains than in the hills and plains: 42% compared to 24% (CBS 2012). There is a higher incidence of poverty in Bihar in the Indian floodplains (33% in 2011) compared to the floodplains in Nepal, attributed among others to historical inequities such as feudal land management (Sengupta 1982). Across the basin, women have lower levels of literacy and except in the hills are less likely to be economically active, indicating a lower status and cultural barriers to women working outside the home (Table 1). The mortality rate for children below five years is high, and higher in the plains than in the mountains.

The basin is particularly vulnerable to water-induced hazards during the monsoon season. Of the 2,719 fatalities that resulted from floods and landslides in Nepal between 2000 and 2014, 939 (35%) occurred in the Gandaki basin, which has only 22% of Nepal's land area. Events tend to be more common in the mid hills, especially the districts of Parbat, Syangja, Gorkha, Dhading, and Nuwakot – Dhading had the highest incidence of floods and landslides with 123 events over the 15-year period. However, more families are affected downstream, with Nawalparasi having the highest number of affected families (8,187 out of 22,637) (Ministry of Home Affairs disaster database, accessed 2015). Such natural disasters are critical drivers of vulnerability for people in the basin. Although the most common disasters are floods and landslides, the greatest economic loss in the basin is from forest fires which are triggered by wind in the dry season.

Key Climate Trends

The climate of the basin varies considerably from the river source to the point where it meets the Ganges. The upstream areas have a mainly temperate or subalpine climate; the mid-stream areas a subtropical to temperate climate, and the downstream areas a more tropical climate (Fig.2). It is important to study the climate trends at different locations, as the changes will affect local adaptation patterns. Baidya et al. (2008) investigated daily temperature data from 1971 to 2006 from eight stations, and rainfall data from 1961 to 2006 from 26 stations covering the climate zones of Nepal. Three of the temperature stations and five of the rainfall stations were located in the Gandaki basin. Analysis of the daily data using climate indices indicated an increasing trend in the number of warm days and decreasing trend in the number of cool days, which was more marked at higher altitudes. Bajracharya et. al. (2011) analysed temperature and precipitation data from five stations in the Gandaki basin using simple linear regression and found warming at higher rates at the higher elevation stations, which is consistent with the findings of Shrestha et al. (1999), Chaulagain (2006), and Baidya et al. (2008). Analysis of the temperature data from the stations at Nuwakot (mid hills) and Rampur (plains) showed a generally increasing trend in minimum temperature, and a similar but less marked increase in maximum temperature, between 1980 and 2010.

Precipitation trends were analysed using daily rainfall data for thirty years from 1980 to 2010 from stations at Dhunche and Timure (upstream), Nuwakot and Dhading (midstream), and Rampur (downstream), with regression analysis of both annual rainfall and monsoon rainfall. No significant trends were found across the basin overall, which is in line with observations by others (Shrestha et al. 2000; Gurung and Bhattarai 2009). There was some variation within the basin: there was a small (non-significant) decreasing trend in both annual and monsoon rainfall at the midstream stations and a slightly increasing trend in the downstream plains area. There was a marked variation in annual rainfall between years especially at the two upstream stations: the maximum annual rainfall recorded at Dhunche was 3,399 mm in 1988 and the minimum 1338 mm in 1990; while at Timure the maximum was 2,457 mm in 1992 and the minimum 313 mm in 1983. This erratic rainfall pattern is likely to have an impact on river discharge and other water systems as well as on the incidence of floods.

A trend analysis over 63 years from 1951 to 2013 indicated that the onset, withdrawal, and duration of the summer monsoon has changed, with onset and withdrawal both delayed and the duration increased (Gautam and Regmi 2013).

Climate Change Risks, Vulnerabilities, and Impacts in Different Sectors

The increasing temperature and shifting rainfall patterns are already affecting, or are expected to affect, the livelihoods of the people in the basin. In Nepal, the Ministry of Environment listed the sectors most sensitive to climate change in the National Adaptation Programme of Action (NAPA) document as agriculture, forestry, water, energy, health, infrastructure, tourism, industry, livelihoods, and the economy, mainly as a result of the low level of development of protection mechanisms (MOE 2010). The main climate change risks, vulnerabilities, and impacts were analysed using information from the literature study together with observations made and information gathered during the field visits.

Water

An in-depth analysis of water resources in Nepal identified two potentially critical impacts of climate change that have implications for water supplies for drinking, irrigation, hydropower, and other livelihood related activities: variability and change in river flow, especially reduced dry season flow, and a potential increase in the number of GLOFs (Agrawala et al. 2003). Floods occur naturally and the annual variation is high so that changes are difficult to identify, while a reduction in water supplies can be the result both of changing precipitation patterns and of human activity. However, there is some indication that heavy rainfall events have increased (accompanied by a decrease in rainy days) and this is clearly likely to affect both flooding and water availability. The major water-related concerns in the different parts of the basin are changes in snowfall in the upstream areas, water-induced landslides, drying up of springs, and drought in the midstream areas, and floods in the plains.

Water availability

The water available in the basin depends on both annual rainfall and snow and glacier melt, and changes in these are likely to affect supplies. Untimely and erratic rains resulting in floods and droughts, together with human related interventions like river diversion schemes, have led to increased problems for water supply systems, including damage to headworks and drying of spring sources. Most non-functioning water supply schemes are faced with problems at the headworks due to seasonal variance in the flow of the river.

The effects of climate change on water sources has been observed upstream in Rasuwa, where most piped water is sourced from springs which are drying up, posing a threat to local communities. A study conducted by Youth Network for Social and Environmental Development (YONSED) in Laharepauwa, Ramche, and Bhorle VDCs in Rasuwa, identified 29, 30, and 55 springs, respectively, that had dried up, as well as some springs that had emerged after the earthquake in 2015 (YONSED 2015). Landslides had also washed away spring sources and affected water availability. Loss or partial drying up of springs increases the burden on women as they need to walk longer distances to collect drinking water, especially during the peak dry months.

In Nuwakot (midstream), most villages use untreated spring water for drinking, which is generally seen as good quality and reliable, but the fieldwork revealed that some sources are no longer used for drinking as the water was thought to cause discomfort and possibly sickness. Elsewhere villagers had no quality concerns, but some communities, for example those in Malakot and Suryamati, depend on river water (from both the main river and its tributaries) for drinking during the latter part of the dry season as the springs dry up and the public system is

unusable. The reduction in rainfall is increasing the dependence on river water, while at the same time reducing the volume of surface water, which leads to deteriorating water quality and has health implications. In the monsoon season, landslides, mudslides, and prolonged periods of rainfall affect settlements, destroy crops, and disrupt both water sources and spring conveyance systems. Intense rainfall may spell disaster for people if the pipe network conveying water from the springs is disrupted.

The source of water for agriculture in the midstream area varied from spring water conveyed by pipe systems to irrigate small plots (in Belkotgadi, Belkot, and Madanpur VDCs) to river water channelled directly to the fields (in Chaughada, Suryamati, and Kalyanpur VDCs). Some small scale storage systems in the form of ponds and tanks were observed in VDCs like Belkot. However, poor operation and maintenance of irrigation systems has been noted as a limiting factor in cultivating two or three crops per year. Although water access in the mid-stream is high due to the increased use of motor pumps and tube wells, the water availability for irrigation is perceived to have decreased. Reduced rainfall in the dry season months is reducing the amount of water available for irrigation, with a marked effect on those who continue to depend on rainfall and surface sources as they are unable to afford motorized pumps. Close to the river, many farmers have started pumping river water for irrigation, but the river flow in the dry season has reduced substantially, which exacerbates the impact of low water availability on agriculture.

Impacts of landslides and floods

The impact of landslides and floods varies across the basin. Upstream, Fort (2015) suggested that heavy snowfall and rapid melting have resulted in an increase in the occurrence of flash floods in the Kali Gandaki region in Mustang. In the midstream, the major concern is the impact of water-induced landslides. The hilly part of Makwanpur district ranks among the highest in landslide vulnerability and is low in drought vulnerability.

Downstream, the major concern is with floods. People from Gunjanagar and Mangalpur reported that silt accumulation from flash floods had raised the riverbed, and that the courses of the Narayani and Rapti rivers had shifted. The entire Madi area has been affected by the problem of siltation, and frequent changes in the course of the smaller streams and rivers now cause floods in areas where they never occurred before. Flash floods have affected many communities in Chitwan by washing away arable land and creating a subsequent water crisis. Especially in Meghauli, people reported having lost large expanses of arable land and agricultural crops to flash floods, mostly in the monsoon season.

In West Champaran in India, intense rain in the upstream can result in inundation of the downstream villages close to the river for up to four months of the year. The problems vary depending on whether a village is located inside the embankment towards the river or outside the embankment in the protected area. Inside the embankment, villages face the constant threat of flood; during floods, they move onto the embankment to stay protected, but lack of clean drinking water and sanitation facilities make them vulnerable to waterborne diseases and skin infections. Beyond the embankment, the land is mostly protected from floods but faces problems of reduced fertility as it no longer receives an annual input from silt and is also prone to waterlogging when monsoon rainfall water becomes trapped. In Gurdiya village, inside the embankment, floodwater submerges land for most households for four to five months of the year and only one crop can be grown, in winter. One respondent had had a portion of his land acquired by the government to build an embankment as flood protection, and reported that the structure had helped somewhat as the water was impounded. With a large family to feed and a small piece of land, life is a struggle, and remittances from family members who have migrated for work is critical for many households to survive during times of distress. Mangalpur Rakhahi village also bears the brunt of the Gandaki floods every year because of its location within the embankment. Discussions with local communities revealed that the irrigation canal project (Trihut Nahar Yojana) in Bairia block, which is currently under maintenance, will mainly benefit the wealthy landlords; poorer farmers are unlikely to receive even a small amount of water when it is operational. Rakhahi village is located close to the canal project but most of the inhabitants are landless farmers. Those owning only a small piece of land find their lands submerged under two metres of floodwater for four or more months of the year; at this time, they have to move with their meagre belongings to higher ground, often by paying exorbitant fares to boatmen. There is little government intervention during or after the floods (apart from radio updates on the flood and helping to move people to designated safe grounds), and local communities are trying to find their own means

of adaptation by storing food and organizing the move to safer ground when the water levels start rising. Access to fresh water is extremely limited and consumption from polluted sources often leads to health problems.

Rajoutiya village lies close to the Nepal-India border just outside the Gandaki basin but still in West Champaran, where the irrigation canals bring water into India from the Gandaki. The village is extremely vulnerable to floods. Here, the local river (the Burhi Gandaki which flows into the Ganges) has eroded fertile fields and converted them into sand dunes, leaving the households landless with no government compensation. No lives have been lost, but there has been physical damage to both agricultural land and private property. The water channels are very unstable, with the river taking a new course every monsoon.

Agriculture

The agricultural sector is particularly vulnerable to climate change, especially increased variability in temperature, changes and unpredictability in precipitation affecting water availability, and the increased frequency and intensity of extreme weather events, including excessive rainfall followed by waterlogging and drought (Fellmann 2012; IPCC 2007).

The upstream population in the Gandaki basin mostly rely on rainfed farming. Around 80% of the agricultural land in Rasuwa is rainfed; only 21% of the 5,031 ha available in the district is irrigated. Thus farming in the upstream areas is particularly vulnerable to water stress and uncertainty resulting from climate change (DDC 2006). Focus group discussions with farmers in Laharepauwa VDC revealed the impact of the late monsoon and other climate-related changes on the farming pattern. The traditional mixed crop barley/potato system relies on winter rains and moisture retention through snowfall to grow barley (or another cereal) in winter. In Daibung and Laharepauwa, the reduction in winter rain and snow has led to a shift away from the traditional cereal-based cropping to cash-generating vegetable and organic farming in polytunnels. This adaptation can have advantages in increasing cash income, but is only viable for farmers who have access to a water source for irrigation and to a market, and even then not at the higher elevations. Maize has remained an important crop for farmers in Rasuwa who have shown keen interest in cultivation during the summer (May) due to its greater tolerance to a variable climate. Farmers reported that high temperatures were leading to early maturity of maize which could be harvested within two months and have demanded subsidies for chemical fertilizer for the crop, indicating their interest in increasing productivity (Nepalnews 2010).

A study by Manandhar et al. (2011) in Mustang, also upstream, noted changes in the pattern of farming of buckwheat, both sweet and bitter, due to delayed frost. Sweet and bitter buckwheat take 70 to 90 days to mature and are sensitive to frost during the harvest season (September/October), especially sweet buckwheat. Previously it wasn't possible to grow bitter buckwheat in lower Mustang because the harvesting season in September coincided with the start of the frost period. But frost has now reportedly been delayed by a month to the second week of October and farmers can grow both bitter and sweet buckwheat, without the pressure to harvest sweet buckwheat early. Farmers can also grow maize in the upper regions of lower Mustang as the higher temperatures favour growth, whereas previously it could only be grown at lower elevations (Manandhar et al 2011; 345-346). With the general warming trend, crop diversification has become an important feature of agriculture in Mustang, with vegetables such as cucumber, beans, tomato, pumpkin, and chilli now grown in the upper regions (Malla 2008), both in the open and in greenhouses. Vegetable beds are sometimes replacing apple orchards. However, vegetable farming relies on access to water for irrigation and water stress remains a problem. In Kunjo, Lower Mustang, an increase in the number of rainy and foggy days has led to a decline in apple production as the humid conditions make the apple crop more prone to pests, forcing farmers to use chemicals or revert to cereal farming. However, cereal crops may also be affected in the long run and the use of chemicals may be unsustainable (Manandhar et al 2011: 345-346).

In the midstream, water for irrigation is an increasing concern amongst the farming community, because of the variability of rainfall. Previously, farmers harvested two cereal crops annually in locations above 1,000 masl, paddy in the monsoon season and maize or wheat in winter. Now, the reduction in winter rain can make it difficult to grow

a winter crop. In Nuwakot, an estimated 47% of agricultural land is irrigated, but only 20% receives sufficient water to grow two crops per year (CBS 2012). Climate variability has affected many irrigation systems due to damage at the headworks following excessive precipitation or landslides. More important, inequitable upstream-downstream water allocation between farmers within irrigation systems was noted during the field visits, with upstream users withdrawing water at the expense of downstream users who cannot irrigate crops during the dry months. Some VDCs such as Chaughada had water user associations, but the downstream users complained of the ineffectual allocation system based on power and political relationships of upstream users. Drought resistant crops such as lentils, sesame, maize, potatoes, peanut, mustard, and drought resistant rice are cultivated in rainfed areas and staple crops such as rice, wheat, maize, potato, and a variety of vegetables in irrigated areas. The vast majority of farmers use hybrid rather than locally-sourced seeds and apply fertilizers and pesticides throughout the cultivation season. Rising temperatures are likely to result in increased breeding of micro-biological pests which feed on crops and reduce production, and will also lead to stress on crops and ultimately crop failure, particularly of non-drought resistant varieties.

Downstream communities engaged in agricultural activities are more vulnerable to the impact of flash floods and other water-induced disasters, with the settlements in Meghauli and Madi along the river banks more affected than those in Mangalpur and Gunjanagar. The areas close to the river are affected by inundation of fields and massive silt deposition during floods which reduces the productivity of the land. Siltation forces households to either leave the land fallow for a long period or to use increased amounts of chemical fertilisers to maintain agricultural productivity. Lack of proper irrigation facilities also adversely affects agriculture. The Kumal people who settled near the banks of the Narayani and Rapti rivers in Meghauli have lost an enormous area of land as a result of floods. The river was reported to have changed its course immensely over the last fifty years, washing away agricultural lands which had now turned into riverbeds, and causing landowning farmers to become landless and vulnerable to extreme poverty. In the Madi area, people noted that some decades ago it was possible to cultivate wheat near the river, but this became impossible because of the deteriorating quality of the produce, for example reddening of paddy plants due to high iron. The shifts in the monsoon pattern, with a late onset as well as late start to winter, was mentioned by women as a problem for paddy cultivation. Lack of rainfall during the growing season had made it mandatory to irrigate the land for paddy, making cultivation expensive, especially for those who had to take loans for this purpose. Many farmers had ceased to cultivate paddy altogether. The effects of the changing climate on crops had only been noticed over the past two to four years, as farmers had not perceived any drastic changes in the temperature and rainfall patterns. The main changes observed were decreased agricultural productivity and shifts in farming seasons, particularly for paddy, which had increased the economic vulnerability of the less wealthy farmers.

In the downstream floodplain areas in the south of Makwanpur in Nepal and in West Champaran in India, the most common change in climate perceived by the local communities was an increase in sporadic heavy rainfall events. The changes in cultivation of cash crops (in Makhwanpur) also provided an indication of significant change in rainfall patterns. In the floodplains of West Champaran in Bihar, communities living near the river or inside the embankments are unable to carry out any agricultural activities for 3–4 months a year, as their fields are either eroded by the river or completely inundated. Even where the floodwaters recede fast, the land can't be used to cultivate vegetables as the flood deposits leave more sand in the soil, which only supports cultivation of wheat. In Rakhahi village, households with a small parcel of land in safer locations had been pursuing sharecropping, but they face problems in irrigating their fields as most have to hire diesel pumps to access water and the pumping costs about USD 4 (INR 260) per hour. For landless households, the main source of income during the floods is wage labour in fields that are not inundated. Sometimes, farmers take loans to buy land, paying 10% interest per month, but very few manage to buy land on higher ground where they can continue their agricultural activities. Farmers whose lands are submerged have started cultivating sugarcane as a cash crop, which is sown when the floods come. Sugarcane needs a lot of water, and utilises the floodwater as it grows. As the floodwater gradually recedes, the crop matures, taking a total of 9-10 months with the harvest in March. Some of the landless households in Mangalpur made chattais (straw mats) from the narkatiya grass that grows in the floodwater as a source of income, for example the Mukhiya family from the Bin caste who walked 18 kilometres to the nearest market in Bettiya to sell their chattais, thereby earning USD 74 (INR 5000) per month for 4–5 months.

Conflicts around water sharing from the rivers with farmers across the border is common during the dry season, when the farmers grow paddy. In the area around Bhikna Thori, which is just outside the Gandaki basin but receives irrigation water from the Gandaki by canal, there are more farmers on the Indian side and the amount of water diverted towards India through the two canals is greater than the amount delivered by the one canal in Nepal. The allocation process was traditionally decided by communities on both sides based on agricultural requirements. Now the water diversion towards India is often disrupted, while farmers in India block the market access to Nepalis, forcing them to release more water. The Indians claim that they have traditional and documented rights over the water that have existed for almost a century, but the Nepalis claim that their water rights are legitimate because the river flows through their land. This conflict is leading to greater vulnerability for farmers who do not receive water from the river during the sowing season.

Energy

The main sources of energy for cooking are fuelwood, liquefied petroleum gas (LPG), and cow dung, and for lighting, electricity. In the upstream areas, 80% of households use fuelwood for cooking (CBS 2012). Electricity is mainly used for lighting. The upper Gandaki has considerable potential for hydropower development with nine mega and several micro projects mentioned by the communities during the field visit. Overall 76% of households in the midstream areas have access to electricity, rising to an estimated 83% in Nuwakot (midstream), higher than in other parts of Nepal (CBS 2012). Those without electricity use solar power, kerosene, or biogas for lighting. The main source of fuel for cooking is fuelwood (an estimated 90% of households), while a few use LPG (CBS 2012).

The downstream villages of Mangalpur, Gunjanagar, and Meghauli in Nepal have limited access to electricity; Ayodhyapuri is mostly dependent upon solar power as not all parts of the VDC have been electrified. However, even where electricity is theoretically available, it is unreliable: Meghauli and Ayodhyapuri were experiencing 18 hours of power cuts a day at the time of the field visits. Most of these settlements depend on fuelwood for cooking as the electricity transmission lines mostly go towards the city of Bharatpur, and what power is available is used to operate irrigation pumps and electrical appliances. The situation was even worse in the floodplain areas of West Champaran. Villages such as Bhagwanpur and Rakhahi are not connected to the electricity grid at all. In Rakhahi, some households had installed solar panels (at a cost of around USD 110) to help them recharge their mobile phones and provide energy for lighting.

Climate change has serious implications for hydropower. The hydropower projects in the upper Gandaki basin face challenges as a result of the changes in rainfall and temperature and fluctuation in runoff and discharge, which affects power generation. Inconsistent energy production has been reported from the Trishuli and Chilime hydropower projects due to variations in the water supply (Bajracharya et al. 2011). The factors affecting the availability of water, and thus power generation, include retreating glaciers, expansion of glacial lakes, and changes in the seasonality and intensity of rainfall. The managers and operators at the Trishuli run-of-the river hydropower station, a 15 MW station located near Bidur, noted that reduced river inflow during the summer months of April and May was limiting electricity generation to below optimal capacity. The projected reductions in rainfall during the pre-monsoon summer months as a result of climate change will exacerbate the problem of limited electricity generation further. Climate change also has implications for other sources of fuel. For example, a rise in temperature in the summer may lead to an increased incidence of forest fires which could affect the availability of fuelwood, which many households depend on to meet their energy needs, and forage.

In the upstream areas, several maintenance and management issues will need to be addressed to avoid future crises in energy supply. In the midstream, socio-economic factors play an important role in the use of different energy sources. For example, collection of fuelwood to meet household energy needs is the responsibility of women, who often go deep into the community forests for collection to avoid being caught when collection is restricted. Downstream in Nepal, LPG is available from nearby towns, but lower income groups are affected by crisis-driven price rises and general price fluctuation. Solar energy is subsidised by the government, but awareness amongst communities, and thus use, is limited.

Health

Health risks are likely to increase with climate change, both as a result of increased water-related hazards and reduced productivity of crops. A study by Ebi et al. (2007:269) identified climate-related health determinants and outcomes in the mountains and plains of Nepal. They included heat waves, flash floods, and GLOFs, together with reduced water quality and water scarcity, leading to an increased incidence of water-borne diseases and vector-borne diseases like malaria, Japanese encephalitis, and kalazar. The field studies suggested that common diseases like diarrhoea could be affected by climate change if it leads to more drinking water sources becoming contaminated during the monsoon season and increased lack of water during the dry months.

The respondents in upstream Rasuwa reported the emergence of new health problems including high blood pressure and diabetes, which they attributed to the consumption of food with prolonged application of chemical fertilizers and pesticides and other environmental changes. CBS (2012) lists 50 health institutions in the three upstream districts of Rasuwa, Manang, and Mustang that can take care of basic health-related problems, a ratio of 1 per 3,537 inhabitants. There were hospitals and health posts in all three villages visited in Rasuwa, but people prefer to go to hospitals in Trishuli and Nuwakot. According to a health worker in Daibung, there has been a marked improvement in the status of women and child health in Rasuwa as a result of the work of a range of organizations, including SUAAHARA (USAID) and Parivartan Nepal in the water, sanitation, and health (WASH) sector.

In midstream Nuwakot, the availability of health institutions and access to health facilities depends largely upon the geographical location of communities, their socio-economic status, and transportation facilities, including the condition of roads. Landslides regularly wash away or block roads in remote areas during the monsoon, limiting access to health care facilities. There were no particular health issues that could be directly attributed to climate change, although there seems to be a general feeling that some health problems are increasing with the rising temperature. However, contamination of water sources during floods or even the scarcity of water in the dry season (January to May) may increase the vulnerability of communities and exposure to vector-borne diseases.

In the downstream areas, the increase in temperature is thought to be responsible for a resurgence in cases of malaria, which had been virtually eradicated. People in Meghauli and Ayodhyapuri in Chitwan faced many health hazards related to floods, with nausea, vomiting, and diarrhoea common during and after the monsoon floods. No other particular health risks from hazards were observed. Although some older people believed that there were new diseases, others considered that there were simply more doctors now who diagnosed health problems more efficiently. Women, especially, claimed that the health problems had always existed, but getting a doctor's opinion and diagnosis for a problem was a more recent phenomenon. The lowest portion of the basin in India is affected by devastating floods every year; lack of sanitation facilities forces people into open defecation which leads to water contamination and contributes to the outbreak of cholera and other water and vector borne diseases. People in the study villages in West Champaran district were affected by skin diseases; their scarred legs and feet indicated the adverse impacts on health of poor water quality and hygiene. The women in the villages identified an urgent need for sanitation and toilets, as they are the most vulnerable during the floods. While men are busy protecting their homes from the floods, the women take care of the children, thus it is difficult for any of them to access health services located far away. The essential medicines for diarrhoea and fever are supplied from local health centres, which is easier.

Land use and urban development

In 2006, the Government of Nepal declared Rasuwa (upstream) and parts of the basin in Nuwakot (midstream) as areas for raising trout (Shrestha and Pant 2012). In 2007, there were five farmers involved in trout farming in Rasuwa, but the rising temperature has affected these cold water fish which are showing increased rates of mortality (Malla 2008). Temperature increases and the consequent emergence of vector-borne diseases of humans and livestock, is likely to lead to a relocation of activities to higher physiographic zones. Some land at higher elevation that cannot support particular crops or certain non-farm activities at present may become more useful in the near future.

The population in Nuwakot (midstream) increased from 1981 to 2001 and then decreased slightly to 2011 as a result of migration to local areas like Battar bazar, Trishuli bazar, and Kathmandu, as well as abroad (census data). The high rate of migration is due in part to the increased problems in agriculture resulting from the decline in water availability and insufficient production. When rain is sufficient, farmers stay home; when the winter rains fail and/or springs dry up then they migrate for labour. The impact is noticeable in areas like Bidur municipality, the district headquarters of Nuwakot, where the population has increased as a result of in-migration of subsistence farmers in search of better facilities and economic opportunities. The major challenges in the urban sector include the poor design and construction of buildings, non-compliance with building codes, increasing unplanned squatting on public and private land, and unmanaged land use practices making land unsafe during extreme events. Growing urbanization has led to an increased demand for sand. Sand mining continues unabated along the river leading to an increase in landslides, floods, riverbank collapse, and riverbed subsidence. Further, loss of forest in the Chure region has increased runoff and reduced infiltration for groundwater recharge, as well as contributing to severe river bank erosion.

Downstream, the increase in flooding is also resulting in an increase in displaced population as homes are inundated. The floods in 2011 displaced almost 400 people in Mangalpur in Chitwan (ICIMOD 2011). The people were housed temporarily in nearby urban areas in schools and other public buildings. Such situations can place a tremendous pressure on a town's basic services. In Makhwanpur, tourism has been affected by the changing climate and increased incidence of landslides and floods. In West Champaran, settlements have been washed away during floods and by bank erosion. The communities felt the need for building of flood-safe houses and structures such as 'thokar', a barrier constructed on the edge of river to divert the flow from the Gandak.

Factors Co-determining Impacts and Vulnerability

There are a number of co-factors that aggravate communities' vulnerability and the impact of climate change in the Gandaki basin. Levels of poverty are high, estimated at 25% on average across Nepal (CBS 2012). Those in the basin living below the poverty line are likely to have a lower adaptive capacity and to be more vulnerable to the impacts of climate change. Socio-economic status, which includes the means of income generation, personal savings, caste, and social standing, also affects vulnerability. Upstream there is some indication that the decline in cereal production due to pest attacks is leading to food grain shortages, which has affected agricultural income. At the same time, farmers in lower Mustang can now grow buckwheat due to the warmer conditions as well as a wide variety of vegetables, which was not possible earlier.

Upstream, the mountain areas are fragile, and heavy rainfall during the monsoon triggers landslides that obstruct and wash away roads, cultivated land, and houses. The landslides limit access to road transport and represent a major impediment for farmers. Agricultural output that is ready to be transported to the market is stalled when landslides cause road blocks. This greatly reduces the ability of farmers in remoter areas to sell higher-value crops and produce at local markets, thus relegating them to subsistence farming of staple crops. However, the respondents did note that the frequency of landslides in 2014/15 had been much lower as there was less rainfall during the monsoon. Farmers also face other problems. UNDP (2015) reported that several farmers in Langtang VDC in Rasuwa had stopped practising agriculture and opted for professions like portering due to the problems caused by wild boar moving up to their farmlands.

Political influence and policies also affect the extent of vulnerability. For example, Malakot VDC in Nuwakot (midstream) benefited from the construction of a bridge over the river as it is the home of the National Finance Minister, and this improved farmers' access to markets and children's access to school, where previously they had to wade through the water. On the other hand, the poor state of roads in the villages studied in Nuwakot, except in Bidur municipality, affects the transportation of agricultural outputs to nearby markets, and thus farmers' income. The lack of provision of basic services by the local government also contributes to local vulnerability, particularly in remote areas. For example, in some places government constructed drinking water systems have ceased to function, and local residents have had to improvise and use systems to convey spring water for drinking and other domestic needs. As in some other parts of the basin, Nuwakot is characterized by male outmigration. The women left behind are often vulnerable and unable to negotiate for water rights and access to facilities unless they are from a higher caste group. Women's wages for agricultural employment are also 50% lower than men's, which affects household income.

Downstream in the Siwaliks, communities are vulnerable to flash floods and landslides that affect their fields and forests, and thus availability of fuelwood. Electricity is very limited and people depend on the community forests for fuel, but access to the forests is very limited and people are exposed to risks of wildlife attack. Villages close to Chitwan National Park are prone to attacks by tigers, elephants, and wild boar, which destroy crops, kill livestock, and threaten people's lives. In Chitwan, wild animals regularly come out of the forests and destroy crops and threaten lives in areas such as Gunjanagar and Madi VDCs that are close to national parks. Rhinoceros were reported to be creating havoc, destroying traditional and cash crops and vegetables, and with a particular preference for radish which they reportedly dug out from the ground. Despite farmers' training programmes on alternative agricultural and farming practices, wild animals continued to create havoc, eating and destroying agricultural crops and increasing people's vulnerability both through loss of income and lack of personal safety.

In the lowest part of the basin in West Champaran district, the major problem is bank erosion during floods. Crossing the river to get to a safer location is essential, but also extremely risky due to the strong currents. Few

boats are available and the charges are exorbitant so that whatever people earn during the year is lost during the floods. With lack of proper homes, land, and sources of income, landless people work in fields belonging to others for very low wages, often exploited by rich landlords (zamindars). Men and women receive different wages for the same work: women are paid a daily wage of INR 40 (USD 0.60) and men INR 100 (USD 1.50) both lower than the official minimum wage of INR 178 (USD 2.60). In Rakhahi, villagers working in family groups received bundles of wheat as wages for crops harvested, which they sell to buy necessities. At these rates, wages can be insufficient to support large families and households often resort to taking loans, especially during floods, at interest rates of 10% per month, leading to further vulnerability.

Local Adaptation Practices and Responses

In all parts of the Gandaki basin, agriculture is one of the most sensitive and hardest hit sectors when it comes to changes in climatic variables. While higher temperatures are affecting crops in the upstream areas, heavy rainfall and floods are causing havoc downstream. Water availability is also limited by the drying up of springs and contamination during the monsoon season. In Bhorle (upstream), the community pooled funds to buy the land housing springs and install a piped drinking water supply system in the village from this source as a way of securing village access to water that is becoming scarce, especially during the dry season.

The major problem faced by farmers in the upstream areas is the decline in crop yields. The adaptation strategies include changing from traditional local crop breeds to high yielding hybrid varieties, and shifting from cereal crops to vegetable crops such as tomato, cauliflower, cabbage, ginger, radish, potato, and green vegetables. Commercial herb farming is also emerging in the villages in Rasuwa. Broom grass is being grown on open barren land to prevent soil erosion and provide a source of fodder for livestock, thus contributing to household income. In Daibung and Laharepauwa VDCs, farmers have adopted integrated pest management (IPM) practices to counter pest attacks on crops. Plastic-roofed sheds are used to grow organic vegetables; a slurry made from buffalo dung and urine mixed with titepati, neem, and sisnu leaves is sprayed on the crops as an organic pesticide. In upstream Mustang, houses used to have mud roofs which resisted snow. However, these are no longer suitable as snow is increasingly being replaced by rain, and farmers have adapted by shifting to tin roofs. Other adaption approaches include turning to tourism as an alternative source of income and developing tourism villages.

In Nuwakot in the midstream area, landslides affect pipes supplying spring water and women walk to other locations or the river to fetch water, or collectively engage in repairing the systems. In order to cope with the lack of irrigation water, farmers are trying to grow less water intensive crops, negotiating with upstream users to increase their allocation of water within their water user associations (if present), and reducing canal leakages and plot drainage. Adaptions also include using pumps to draw groundwater for irrigation and constructing temporary storage sources, as in Belkot VDC where small scale water storage ponds have been constructed to irrigate potato fields. This type of small scale localised water storage, which captures rainfall and runoff during periods of relative water excess, is a good adaptation response for rainfed agriculture in the dry season. When all efforts prove insufficient, farmers revert to growing two crops per year and do not cultivate during the dry season. Another problem in the midstream area is the high river flow during floods in the Tadi Khola river, which erodes the banks and destroys crops. The local government in Chaughada VDC has responded by providing funds for the purchase of metal cage wire to construct gabion boxes for rocks which will be used to construct an embankment and provide a reliable structure to reduce river bank erosion.

Tourism, and especially ecotourism, can provide a viable alternative to agriculture for farmers in many parts of the basin. However, it has not provided as many jobs for local people as hoped, as resorts tend to be built by people living from outside, who do not hire locals to work except as porters. Ecotourism is expected to gain momentum downstream as Madi in Chitwan has been declared a municipality and is promoting homestay businesses.

Outmigration both within and outside the country is also becoming a common means of adapting to the changing climate in all areas as agriculture becomes less profitable and alternative employment opportunities scarce. The most popular destinations for migrants are nearby towns and the gulf countries. However, most workers must take loans at high interest rates to cover the costs of recruitment, and until these are paid off, the families see little benefit and the financial burden makes them more vulnerable. For example, manpower companies recruiting people from Meghauli to go to the Middle East charge a fee of up to USD 550 (NPR 60,000) per person, and

workers may be unable to repay the loans they take out even after six months or more of work. Once the loans are paid off, the earnings can be quite good for meeting family expenses, but some workers find themselves trapped in very poor conditions with low wages forcing them to return, still in debt. Migration has also led to a reduction in the agricultural work force in the villages which is a challenge for the families left behind. Overall, migration has helped many families to adapt, with many able to move to safer locations away from landslide and flood prone zones, notwithstanding the difficulties some face and the disruption to family life.

In Chitwan downstream, local people have adapted to the problems posed by extreme rainfall events by raising the height of tube wells and toilets to maintain safe water and sanitation facilities. There is also an increasing realization of the need to adopt simple livelihood options, such as fishery, banana cultivation, cash crop plantation, animal husbandry, apiculture, raising poultry, and even silk farming to earn a living. The Kumals in Meghauli have moved from chicken to pigeon rearing, which requires less effort and fulfils a demand for birds for religious sacrifice, while villagers in Mangalpur are engaged in well-organized poultry farming practised in groups of two to four individual investors, with market linkages and sufficient entrepreneurial amenities. One farmer in Meghauli had started a banana plantation on a 22 ha (32 bigha) plot of rented land, and had trained a former wage labourer in ploughing and other farming techniques who was now cultivating a part of the plantation for himself. Even allowing for the costs of rent and irrigation, the returns were good, with each sapling producing up to 500 bananas on average per year for up to 10 years. However, strict vigilance was needed to protect the crops from damage by wild animals as they could easily destroy large areas. In Ayodhyapuri, which is prone to floods, a group of three partners had started a fish farming business with loans from the agricultural bank. The 11 hectares of fish ponds produced 1–1.2 tonnes of fish per year. Farmed fish offer a reliable source of income as they are not affected by animal attacks. These two cases indicate clever alternative livelihood options which help villagers to adapt to the adverse effects of biophysical hazards such as wild animal incursions, while also demonstrating that water sources can be used in innovative ways to sustain livelihood practices. Most villages in Ayodhyapuri have no access to electricity and solar panels have become popular although they are not subsidized. Solar power is generally used for lighting and to run one household appliance, mostly a television. In general, people were able to relate to the benefits of using solar energy. Solar energy was less important at the three other study sites in Chitwan as they had at least some electricity.

In the lower floodplains in West Champaran, villagers move to higher ground and safer houses to protect themselves during floods. In some villages, ECOSAN toilets have been built which have helped to provide basic sanitation facilities during the floods. As mentioned previously, crops that exploit the floods like sugarcane and narkatiya grass are also used to provide income. However, in most cases migration offers the only way to adapt to unemployment and achieve a degree of food security in the flood season. Initially, families migrate to safer grounds to protect themselves, and later family members migrate further afield for employment. All households in Rakhahi village are affected by floods annually and younger household members generally migrate to the cities for work. Men travel to Indian states like Uttar Pradesh, Punjab, Gujarat, and even Kerala. The wages in Punjab are good and remittances are sufficient to meet the food needs of the family. Although for some households, migration is seasonal, for some the only choice is long-term migration. In Punjab, for example, the infrastructure is better and wages are higher, attracting more labourers to migrate for longer periods of time.

Policies and Institutions Responding to Climate Change

India signed the United Nations Framework Convention on Climate Change in 1992 and Nepal in 1994. Nepal prepared a National Adaptation Plan of Action (NAPA) in joint agreement between the Ministry of Environment, Science and Technology (now Ministry of Environment) and United Nations Development Programme (UNDP) in 2010. The Nepal NAPA is the main policy document designed to address climate change issues for adaptation. It reviews activities for climate change adaptation; the processes to be followed in identifying priorities, modalities, and guidance for the design and implementation of identified adaptation measures; and challenges and barriers to implementing these measures. The NAPA envisages involvement of both state and non-state actors and experts in adaptation planning at district level, together with some non-government organizations (NGOs) for programme implementation. The public sector is expected to play the role of facilitator, ensuring a stake, resolving policy issues, and streamlining and scaling up the outcomes (Pant and Gautam 2012). The primary objective has been to aid adaptation needs by prioritizing sectors, undertaking activities that respond urgently to people's needs, and building resilience for those most affected by climate change. The adaptation needs include those needs for which further delay would mean increasing vulnerability and related costs. For building resilience, the NAPA is gathering information from vulnerable communities as well as relevant national level sources that provide data on climate variables and possible climate stresses (UNFCCC 2007). The six thematic areas identified in the NAPA are water resources and energy, agriculture and food security, forest and biodiversity, public health, urban settlements and infrastructure, and climate induced disaster risk reduction. In addition, there are three cross-cutting themes of livelihood and governance, social inclusion, and gender.

A Local Adaptation Plan of Action (LAPA) framework to implement the NAPA at local level and involve stakeholders and local communities has been endorsed and adopted by the Government of Nepal. The LAPA aims at inclusive adaptation planning, taking into account local knowledge of adaptation to climate change and associated risks combined with scientific and technical knowledge of current and future climate change impacts. LAPAs have been prepared for Timure, Daibung, and Langtang in Rasuwa. The reports produced on these three VDCs identify the specific impacts of climate change that the Upper Gandaki basin is likely to face.

One important institutional response that is currently promoted in the region for addressing the uncertain climate situation is the promotion of insurance services for agriculture and livestock. The Board of Insurance of the Nepal Government has made it mandatory for all non-life private insurance companies to include agricultural insurance (Khanal 2015). The Alliance Insurance Company in Mustang, Sidhhartha Insurance Company in Manang, and Shikar Insurance Company in Rasuwa will soon provide such services. Similar schemes are also being developed in the midstream and downstream areas. For example, in Chitwan there is a crop insurance scheme, for bananas and other crops. The Netherlands development agency SNV is involved in studying whether crop-based or climate-based insurance will more effective for ensuring farmers' livelihoods

There are a number of specific activities in the upstream area. The Government of Nepal and the Asian Development Bank (ADB) are together supporting irrigation techniques in the upper basin. The District Agriculture Development Office (DADO) in Rasuwa and other organizations have provided funds to encourage farmers to pursue commercial livestock rearing of goats, cows, poultry, and pigs, as well as beekeeping and others, and launched the 'Goath Sudar Karyakram' to help farmers rearing commercial livestock. Responses to climate change are being supported by the United Nations Development Programme and several other international organizations, including Care Nepal and the World Wildlife Fund (WWF), which have implemented the Strengthened Actions for Governance in Utilization of Natural Resources (SAGUN) programme in Rasuwa district (Care Nepal 2009:40-41) SAGUN aims to raise awareness about climate change; undertake capacity building strategies and programmes to

counter the impact of climate change; implement afforestation programmes; and support governance, biodiversity conservation, and livelihood enhancement of communities. Several mother's groups and eco clubs have been established in Rasuwa which focus on raising awareness about climate change issues and linking these issues with biodiversity conservation; in Ramche, the programme has supported infrastructure development such as roads and schools. The SAGUN programme helps to enhance the knowledge, skills, and capacity of poor households, thereby contributing to building community resilience through improving livelihood assets and health conditions. In other activities, the Development Project Service Centre (DEPROSC) and Parivartan Nepal have been involved in projects to manage drinking water and sanitation.

In Nuwakot in the midstream, WWF has provided both technical and financial support to install biogas plants in villages to promote renewable energy use, and the Irrigation Department is helping to build canals for irrigation. District development councils are allocating funds for disaster risk reduction and undertaking programmes with VDCs. The VDCs have provided compensation to relatives of victims who have lost their lives due to floods, and are protecting slopes to reduce landslides. Various organizations, including the Red Cross Society, have been involved in providing critical health and educational facilities and support to communities during floods.

Downstream in Chitwan, the district government has been working on issues linked to the provision of irrigation and drinking water, flood control and erosion, construction of river bank protection structures, and water-induced disaster mitigation, and has allocated resources and implemented development plans focused on these areas. The formal institutions at local level, such as VDCs, Seti Ban communities, health posts, and community forest user groups are responsible for local development planning, resource allocation, and implementation, while also engaging in river basin conservation, ecosystem conservation, and water-related issues. Information gathered during the field interviews indicated that although USD 45,000 (NPR 4,800,000) had been allocated for development in the VDC budget in the Narayani area, no resources had been allocated for infrastructure building or flood management. However, the local government provides compensation to the relatives of victims of floods and wild animal attacks. The institutions have also provided 72 basic medicines free of charge to the local communities. In Meghauli, the government is planning to install drinking water pipelines, while the forest department will be involved in controlling the use of forest products, working in tandem with the buffer zone management committees (BZMCs). BZMCs have provided USD 450 (NPR 50,000) as compensation to the victims of wild animal attacks. In Gunjanagar, funds have been allocated to the VDCs for disaster risk reduction and USD 21,000 (NPR 2,255,993) was reportedly allotted towards helping the flood affected population in the village. The Government of Nepal is also providing subsidies for small home solar systems, institutional solar photovoltaic systems, photovoltaic pumping systems, solar cookers, and solar dryers, as this seems to provide a sustainable and reliable energy source. However, at present, subsidies are only available in those villages connected to the electricity grid. International organizations like the Red Cross provide food and blankets to people who have been affected by floods and other water-induced disasters.

Unfortunately, there are few programmes to support the poor landless communities in the lower floodplains in West Champaran district in India. The government has played a role in providing information about the status of floodwaters through early warning systems on the radio. They have also allocated areas of higher ground where people living inside the embankments can move to when floodwaters rise. The local government departments are engaged in protection of the river embankment and identification of volunteers in each village who can support in relief and rehabilitation work during the floods. But there has been very little effort towards land allocation for the landless communities, who are the most vulnerable during the floods and desperately lack sources of income to support their families. As per a new policy, 0.02 ha (5 decimals) per family have been allocated as building land to the landless, and the government is trying to find ways and means to help the landless communities as per the government policies.

There is an urgent need to provide energy sources for the communities in the floodplain areas, as they are not linked to the power grid and only a very few can afford to install solar panels. The lack of support in the far downstream of the basin contrasts starkly with the support extended to communities in the upper reaches. The office of the District Magistrate in West Champaran prepares a disaster risk reduction document every year, but little can be seen on the ground that benefits communities in concrete terms apart from the improved communication

systems. Private people provide boats, but charge exorbitant amounts and even extend loans at high interest rates to cover these during the crisis period. There are no transport systems to the local markets, villagers must walk 18 kilometres to sell their products in order to buy grain for the family.

Women have made an urgent request for toilet facilities during floods, but only ECOSAN toilets were visible during the visit to Rupauliya. These toilets can separate urine and night soil; urine is used as a biopesticide while night soil becomes manure in 3–4 months. A family of five can produce up to USD 37 (INR 2,500) worth of organic manure every 3–4 months. A local grassroots organization – Megh Pyne Abhiyan (MPA) – is committed to making behavioural changes amongst the rural communities to effectively revive, innovate, and institutionalise water and sanitation management practices, and mainstream issues concerning floods, through collective accountability and action. The organization is part of a functional network of grassroots organizations organized as an MPA network in north Bihar, together with Gramyasheel, Kosi Seva Sadan, Samta, Ghoghardiha Prakhand Swarajya Vikas Sangh, and Water Action, and is working in five flood-prone districts – Supaul, Saharsa, Khagaria, Madhubani, and West Champaran.

Conclusion

The Gandaki basin is very large, extending across three countries and affected by multiple and complex issues of climate change, upstream-downstream conflicts, and technological interventions, which affect people's lives across the basin in different ways. Several villages in each section of the basin were visited in order to collect people's perceptions of the changing climate and its effects on critical sectors such as water, agriculture, energy, health, and habitat, as well as information about the ways in which communities are adapting and the role of different institutions. The study also used secondary literature to collate information about the scenario in the basin, substantiated with field observations and interactions.

Climate analysis shows that the upper part of the basin is being affected by higher temperatures. These increase the rate of glacier melting and affect the spring sources, from which local communities obtain drinking water, as well as river discharge, which has shown major fluctuations between 2001 and 2011. Low rainfall during winter is also causing a severe crisis, which is expected to worsen over time. The region is also threatened by GLOFs, which can cause devastating floods downstream. The changing climate has been a boon as well as bane, depending on the location of communities vis-a-vis water availability and the prevailing climatic conditions. Warmer weather in Mustang has favoured the cultivation of bitter and sweet buckwheat and a wide variety of vegetables, but apple production has reduced considerably due to pest attacks and lack of sufficient cold periods in winter. Maize is emerging as an important crop for farmers upstream in Rasuwa, who have shown a keen interest in cultivating the crop and demanded subsidies for chemical fertilizer to increase the productivity. However, water for irrigation is an increasing concern amongst the farming community because of the variability of rainfall and reduction in water available from the river. The reduced water levels also affect hydropower generation, and communities continue to depend on fuelwood from the forests for lighting, heating, and cooking, which affects forest cover. The emergence of new health problems like raised blood pressure and diabetes in this section of the basin are believed to be an outcome of the consumption of food grown with prolonged application of chemical fertilizers and pesticides, as well as other environmental changes. Access to health care is limited because of the remoteness, and landslides during the monsoons make it even more difficult to access services. The lack of access increases the vulnerability of sick people and women and children. Landslides blocking roads also affect the marketing of vegetables and other agricultural produce in nearby towns.

The midstream part of the basin experiences flash floods and landslides during the monsoon, with increased runoff during extreme events, which is accompanied by reduced infiltration and groundwater recharge. Water for irrigation is a growing concern and most households are shifting to using pumps to extract groundwater, as surface flows are extremely limited. In Nuwakot, poor operation and maintenance of irrigation systems has been noted as a limiting factor in being able to cultivate multiple crops in a year. Moreover, landslides, mudslides, and prolonged periods of rainfall during the summer affect settlements, destroy crops, and disrupt water sources and spring water conveyance systems, as well as disrupting basic infrastructure like electricity lines and roads, trails, and the general means of transport. The hill area of Makwanpur district is one of the areas most affected by landslides in the country.

Downstream in Chitwan, arable lands are washed away during floods reducing livelihood opportunities; the tourism industry also has limited options for most local people. Electricity is the main source of energy, but solar panels installed by some households help in running basic home appliances. Few households know about government subsidies for solar power, and fuelwood continues to be an important source of energy; women often risk their lives to collect fuelwood illegally from the community forests. This region bears the brunt of wild animal attacks, which destroy crops and challenge the ability of farmers to profit from their hard work. There are few alternative livelihood options, which has encouraged large-scale migration to Gulf countries for work. Health hazards in the region are mostly associated with floods: especially nausea, vomiting, and diarrhoea resulting from contamination of water. In Meghauli and Ayodhyapuri, higher temperatures have resulted in an increased incidence of malaria, but there are medical facilities within an accessible distance in Nuwakot. Bidur is an important town but faces

challenges including poor design and construction of buildings, non-compliance to building codes, increasing unplanned squatting on public and private lands, and unmanaged land use practices, which makes areas unsafe during extreme events. Sand mining activities along the river to meet construction demands continue unabated and increase the vulnerability of communities to landslides, floods, riverbank collapse, and riverbed subsidence.

The lowest part of the basin in India is extremely vulnerable to floods; subsistence farmers become more vulnerable to losing their source of income when floodwaters submerge the lands they cultivate. Floods also cause bank erosion, which in Rakhahi village results in loss of cultivable land and increased landlessness almost every year. Communities are displaced from their original homes by the floods and have to move to safer locations, often having to pay high fares to the boatmen, which leaves them with no savings to survive for the remainder of the year. Migration, generally to Punjab and Kerala, where wages are higher, becomes the only option for landless farmers. In the river basin, day labourers are exploited by rich landlords and often paid considerably less than the official minimum wage. Some people take loans to purchase a new piece of land in safer locations for agriculture, but require irrigation support. Vegetables cannot be grown within the embankment as the flood deposits are sandy and only support wheat cultivation. The Bin communities make mats from the narkatiya grass which grows in the floodwaters to sell in the nearby market of Bettiya and supplement household income. Some households have taken advantage of the floods by sowing sugarcane when the rains begin and harvesting the crop as the water recedes. The health of communities is affected by the lack of sanitation facilities and resultant contamination of water during floods, which results in an increased incidence of water borne and skin diseases. The region has received little support from the government in terms of land distribution to the landless farmers.

The Government of Nepal has adopted a Local Adaptation Plan of Action (LAPA) in order to implement the National Adaptation Plan of Action (NAPA) at the local level and involve stakeholders and local communities. The LAPA aims at inclusive adaptation planning, taking into account local knowledge of adaptation to climate change and associated risks, combined with scientific and technical knowledge of current and future climate change impacts. The activities of several institutions such as CARE Nepal, WWF, and the Nepal Red Cross have helped local communities in the upstream area of the Gandaki basin adapt to climate change, both directly and indirectly. In the midstream area, useful initiatives supporting adaptation include river conservation, health initiatives, protection of forests, provisioning of energy alternatives and building awareness of solar power, and providing irrigation facilities. In contrast, initiatives in the far downstream part of the basin have been extremely limited, although the grassroots organization Megh Pyne Abhiyan has been working hard with other local organizations to provide support to people in the flood affected districts of north Bihar.

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