HI-AWARE Working Paper 8

The Upper Ganga Basin

Will Drying Springs and Rising Floods Affect Agriculture?

Consortium members

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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Contributors

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Introduction

The Ganga (Ganges) is a transboundary river with headwaters in the Hindu Kush Himalayan region (Figure 1). It begins at the confluence of the Bhagirathi and Alaknanda at Devaprayag in the Tehri Garhwal district of Uttarakhand in India and flows for almost 2,500 kilometres through India and Bangladesh before emptying into the Bay of Bengal (NIH/GOI 2015). The Alaknanda itself has five confluences before joining the Bhagirathi, the last of which is the confluence with the Mandakini at Rudraprayag. The river has many major tributaries, with the Tons (Tamsa), Gandaki, Yamuna, and Koshi among the most important. The Ganga river emerges from the mountains at Rishikesh and enters the plains at Haridwar, also in Uttarakhand. The upper Ganga basin is considered to be the part to just below the Kanpur barrage in Uttar Pradesh as shown in Figure 1.

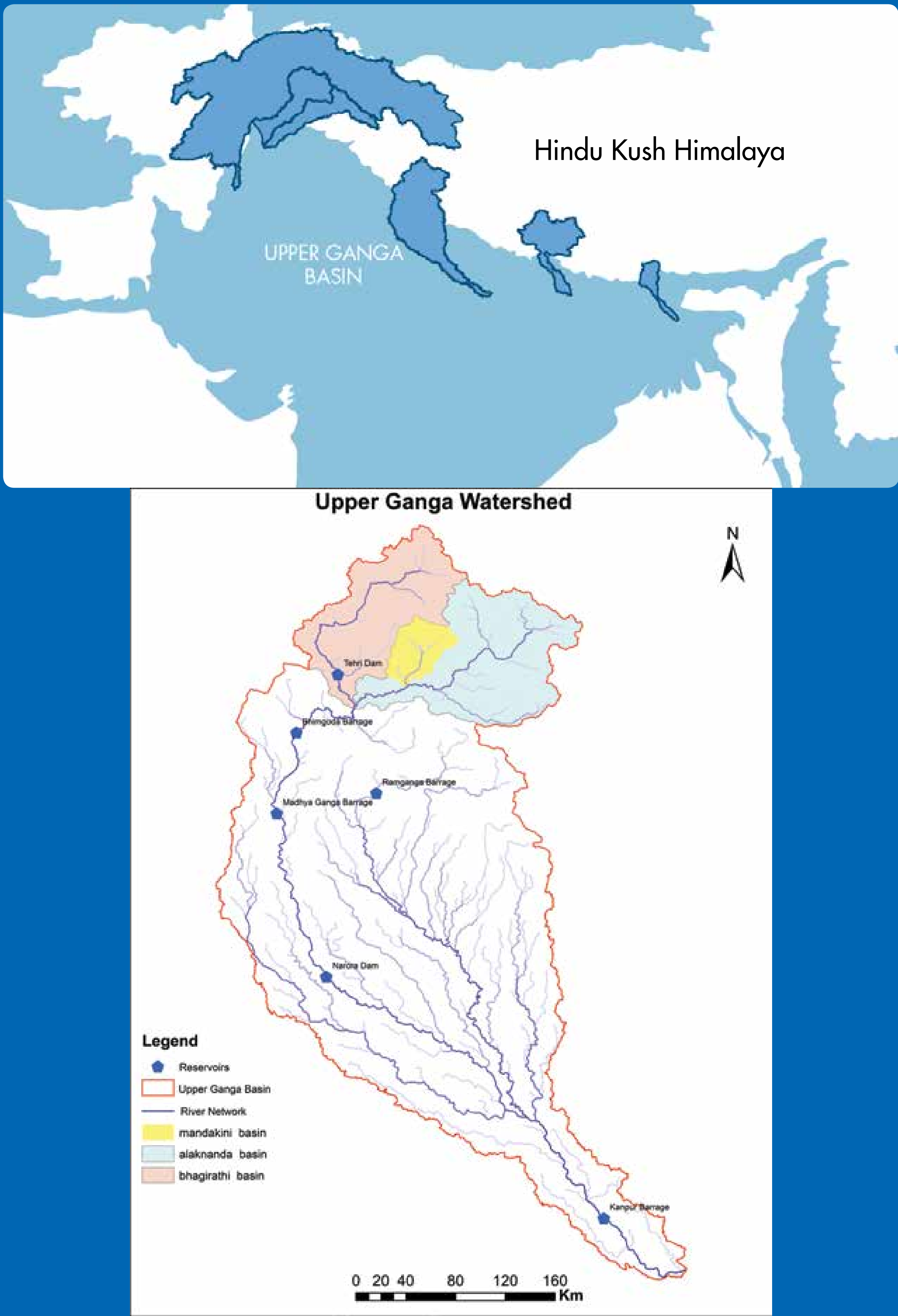
The upper Ganga basin has a wide variation in elevation and climate. The elevation ranges from about 7,500 masl in the high mountains to around 100 masl in the lower part (Bharati and Jayakody 2010). The average annual rainfall ranges from about 550 to 2,500 mm with the southwest monsoon as the major contributor.

This report presents the results of a situational analysis conducted in the upper part of the upper Ganga basin, i.e. the part of the basin lying in the Himalayan mountains and the adjacent hills and plains in Uttarakhand. The aim was to identify and document the conditions in the upper, middle, and lower regions of in this area and highlight some critical sectors and how they are affected by the changing climate. The study also investigated the non-climate stressors that play an additional role in increasing the vulnerability of communities. The objectives of the study were as follows:

- to identify areas and sectors which are prone to climate change risks in the high, mid, and low elevation sites of the upper Ganga basin;
- to identify and understand community perceptions of climate change and the impact of these changes on people's lives and livelihoods;
- to identify and document existing adaptation practices for coping with the identified climate change impacts; and
- to assess the responses of the state and civil society in addressing issues related to climate change.

Following these objectives, the study aims to provide an analysis of the existing situation to serve as an input for an in-depth study on devising coping strategies relevant to hazards and risks arising from climate change.

Figure 1: **The upper Ganga river basin: a) location with India; b) details showing the boundary of Uttarakhand and major barrages**



Methodology

A three-step approach was used for the situational analysis. First, a systematic review was carried out using keywords, keeping in mind the climate and hydrological context. The review helped to determine the main issues related to environmental risks, socioeconomic vulnerability, and adaptive capacity relevant to the study area. These issues were further validated by conducting fieldwork in selected villages across the basin and undertaking key informant interviews with experts who had an understanding of the context and the study area and with local communities, while keeping gender disaggregation in mind.

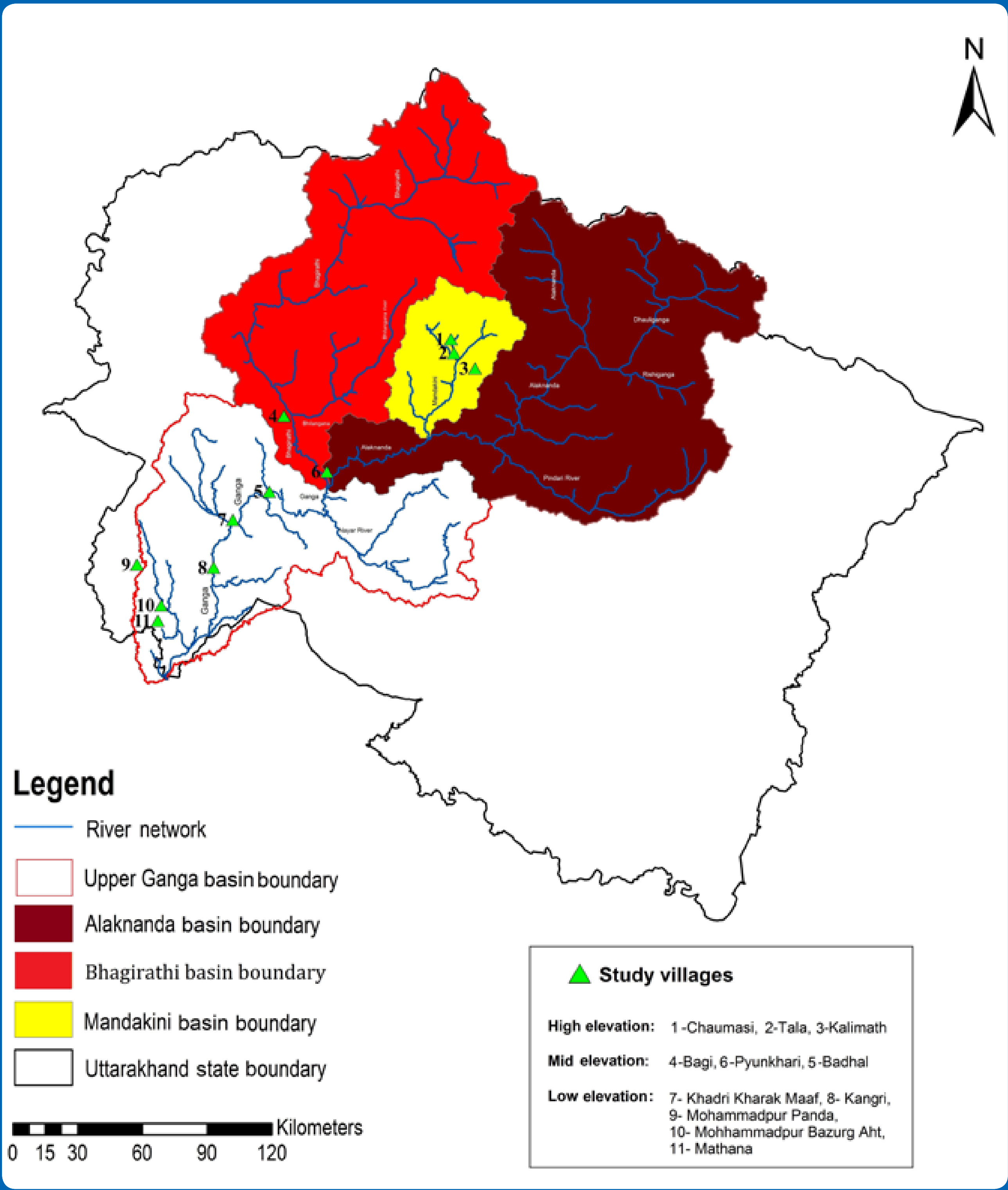
For the analysis, the study area was broadly divided into three areas: the higher elevations above 1,500 masl, the mid hill areas between 400 and1,500 masl, and the low hills and plains below 400 masl. Villages were selected within each of these areas to represent the overall situation and also the specific issues identified in the preliminary review. The location of individual villages is shown in Figure 2; the selection is described below.

The selected higher elevation villages were Chaumasi, Tala, and Kalimath, located in Rudraprayag district. Rudraprayag has a low density road network compared to the state average. Agriculture is largely rainfed and the district has a low net sown area, attributed to the harsh terrain and poor irrigation facilities. The district lies within Seismic Activity Zone V (GoU nd) and this coupled with high intensity rainfall makes it vulnerable to landslides which have degraded the landscape and caused extensive damage to the forests. The selected villages are all likely to be affected by changes in climate. Chaumasi has a local pastoral community that migrates to the alpine meadows in the high hills for summer grazing; Tala village is heavily dependent on forests for both non timber forest products (NTFPs) and firewood; and Kalimath was adversely affected by the floods in 2013.

The selected mid-hills villages were Bagi, Pyunkhari, and Badal in Tehri Garhwal district. Bagi has suffered the impacts of cloudbursts and other hazards in the recent past. Pyunkhari is located about seven kilometres uphill from Devaprayag, the confluence point of the Alaknanda and Bhagirathi and the start of the Ganga. The villages situated around the confluence point are all experiencing seasonal scarcity and water shortages leading to distress migration, and Pyunkhari has been facing extreme water shortages, with government supplied water provided only once in three days and the natural springs slowly drying up. Badal further downstream is located very close to the Ganga and is popular for adventure sports tourism.

The selected lower elevation and plains villages were Khadri Kharak Maaf in Dehradun, and Kangri, Mohammadpur Panda, Mohammadpur Bazurg Aht, and Mathana in Haridwar district. While the plains have always been a hotspot for floods, climate change and other social drivers have worsened the situation.

Figure 2: **Study area and village sites in the upper Ganga basin**



Major Basin Characteristics

Hydrology

The upper Ganga basin is largely fed by rainfall, although glacier and snow melt also play a significant role in basin runoff. The average monthly flow starts to peak in June and remains high to September, with the maximum flow during August, corresponding to the months when the south-west monsoon is most active (GOI 2009).

Socioeconomic parameters

The upper part of the basin covers the greater part of Uttarakhand, which is a relatively new state carved out of Uttar Pradesh in 2000. About 60% of the land cover is agriculture (main crops wheat, maize, rice, sugarcane, millet, and potato); 20% is forest, mostly in the upper mountains; and approximately 2% is permanent snow and ice (Shukla et. al 2014).

Uttarakhand is a predominantly agrarian state; average landholdings are small, with about 50% less than 0.5 ha, and around 70% less than 1 ha, reflecting the predominant practice of subsistence agriculture (Bhatt 2006). The overall socioeconomic condition in the higher elevation district of Rudraprayag is low, with 37% of the population below the poverty line, and road connectivity is poor.

Tehri Garhwal in the mid-hills is one of the largest districts of the state with a population of 618,931 (6.1% of the state total) and a growth rate of 2.4% over the decade from 2001 to 2011 (GOI 2011a). The headquarters are at New Tehri, but only 13% of the population is urban. Agriculture and related activities are the mainstay of the economy; among 'main workers' (those who have worked for more than half of the year), 63% are cultivators, 0.8% agricultural labourers, and 36% non-agricultural workers (WSMD 2009). The district has a high proportion of marginal workers – 32% compared to the state average of 26% (WSMD 2009). Other sources of livelihood include household industry, casual employment, and tourism-related activities such as shopkeeping, running eateries, and providing accommodation. More than 45% of the population lives below the poverty line – only two other districts in the state, Chamoli and Uttarkashi, have such a high proportion. The state average is around 30 to 40% (WSMD 2009).

Haridwar district in the plains is agriculturally rich with high agricultural productivity due to its location in the fertile Terai region. Both Haridwar and Dehradun have well-established road networks and thus good accessibility. Dehradun is the administrative centre of the State of Uttarakhand, and Dehradun city is the state capital. The district experienced a population growth of 32% between 2001 and 2011 and has a population density of about 801 inhabitants per km2. Both Dehradun and Haridwar have a high degree of urbanization, 37% in Haridwar and 56% in Dehradun – almost double the state average (GOI 2011a; Planning Commission 2009). Dehradun and Haridwar are among the four districts in the state with a concentration of industry, the others being Nainital and Udham Singh Nagar. The literacy rate is high, 84% in Dehradun – the highest in the state – and 73% in Haridwar. At the time of the 2002 census on poverty, 32% of the population of Dehradun was below the poverty line and 18% in Haridwar – the lowest percentage in the state (WSMD 2009).

Key Climate Trends

The Ganga basin is predominantly characterized by tropical and sub-tropical temperature zones. The average annual rainfall varies from 39 to 200 cm, with an average of 110 cm. Eighty per cent of the rainfall occurs during the monsoon months, i.e. between June and October, which largely governs the hydrological cycle of the basin.

PRECIS simulations indicate that the Himalayan region is likely to be experiencing a net increase in temperature in the 2030s ranging from 1.7–2.2°C compared to the 1970s (GOI 2010). Contrary to the rise in annual mean temperatures, winter temperatures are projected to fall by as much as 2.6°C in the months of October, November, and December with respect to the 1970s. The EU High Noon study projected that the Ganga basin would warm at a rate faster than the global mean, based on regional climate models (Moors 2012). The study also suggested that the mountainous regions would face more pronounced warming. A continuous decreasing trend in maximum temperature and increasing trend in minimum temperature has been observed at lower elevations in Pantnagar (in Udham Singh Nagar district), which is taken as representative for the plains of Uttarakhand (GoU 2012). The Uttarakhand State Action Plan on Climate Change (SAPCC) (GoU 2012) also highlighted the reduction in bright sunshine hours due to increasing cloud cover, which can adversely impact crops. Mishra et al. (2013) studied the temperature data for 102 years from 1901 to 2002 in the Upper Ganga Canal Command region, and found an increasing trend in temperature for Haridwar city.

The increasing temperature is likely to have a direct impact on evaporation rates in the region, which has been established in a study carried out specifically for the Upper Ganga Canal (Mishra et al. 2013). On average, every square km of the Ganga basin receives a million cubic metres (MCM) of water as rainfall annually; of this, 30% is lost as evaporation, 20% seeps below the surface, and 50% is surface runoff (GOI 2009). A study conducted by the International Water Management Institute (IWMI) has suggested that precipitation, evapotranspiration, and runoff will increase by approximately 10% in the basin. The projected precipitation indicated a net increase of 60–206 mm in the higher elevation areas by the 2030s with respect to the simulated rainfall of the 1970s. Rainfall is projected to increase in all seasons in the Indian Himalayan region, with a maximum increase in the monsoon months (GOI 2010). The increase in precipitation is also expected to lead to an increase in the sediment load of up to 25%, which could prove detrimental for existing water resources projects, apart from the inevitable damage to the environment. The rainfall records (2000–2002) for Uttarakhand suggest that the peak of the annual hyetograph has shifted from July to August, and in the last two decades there have been incidences when the peak has been in September. The shifting of the rainfall peak indicates that the rainfall pattern in Uttarakhand is gradually changing due to climate change (GoU 2014a). There has also been an increase in heavy rainfall events. The state witnessed heavy rainfall of over 24 hours on 15th and 16th of June 2013, with 325 mm recorded at the Chorabari Glacier camp located at 3,820 masl (Climate Himalaya 2013).

Climate Change Risks, Vulnerabilities and Impacts

Water

The main sources of water for the higher elevation settlements are springs and rivulets, whereas in the mid-hills, water for domestic use is mostly supplied to villages through a piped system. At lower elevations, drinking water of acceptable quality is provided through pipes and/or hand pumps, while the main source of water for irrigation is groundwater as agricultural activities are pursued on a much larger scale than at higher elevations. At higher elevations, agriculture is mostly rainfed.

In recent times, water availability has become an issue in the higher elevation areas of the basin as the springs and rivulets supplying the population have started drying up. Since river water cannot be easily accessed, fluctuations in spring flow pose a major problem. Some 45% of natural springs have dried up completely and 21% have become seasonal with most active springs now heavily rainfall dependent. Stream discharge declined by 11% between 1981 and 2011 (Tiwari and Joshi 2012). Studies also indicate that a majority of the Himalayan glaciers are retreating (CWC 2008), which is expected to affect river base flows with an initial spike followed by a downward trend. The villagers in Kalimath noted that the number of springs had reduced over the recent years, but considered that it had not had any adverse impact. However, if the trend continues, areas once water rich (for household purposes) could become water scarce, thereby exacerbating the vulnerability of those living in the area. People living in Chaumasi and Kalimath observed that the water from the springs during the rainy season was muddy and sediment laden, but they were forced to consume it because there was no alternative.

In Pyunkhari in the mid-hills, water is pumped from the Alaknanda river through the Bhagwan Pumping Scheme (gravity-based) into a common overhead tank from where it is collected, mostly by women. In times of scarcity, women also use hand pumps situated along the road away from the main settlement to pump groundwater. Badal also has a water pipeline that empties into a tank at the top of the hill where the village is located, but the villagers don't know the source of the water. Nearly 200 villages are covered under this scheme, but the supply is erratic with supplies coming once in 2–3 days. The communities face severe scarcity, especially during the summer months. The system can only provide 50 litres of water per household per day against an average demand of 200 litres per day. Women often have to walk long distances to fetch water from natural springs and streams which become active during the monsoons, but this water has large quantities of sediment; the quality concerns have not been addressed under any government schemes. The recent degradation of oak forests due either to deforestation or floods and landslides has contributed to the decrease in groundwater recharge which is leading to lower base flows in the springs. A contingency plan for drought-affected rural areas in the district has been made with deployment of tankers to 115 villages (GoU 2014b). The perception of communities that the springs in the region are drying up has been validated in a study conducted by Kelkar et al. (2008) in a different watershed of the upper Ganga basin. Further, a study by Sati (2005) cites that springs had ceased to yield any water or do so only during the rainy season in over half of Uttarakhand's villages.

Agriculturally, the mid-hills are characterised by minimal irrigation, with water mostly sourced from canals and guls (man-made diversion channels to take water from the main river along natural terrain, mainly used for irrigation at higher altitudes) (GOI 2011b). Studies carried out at lower elevations indicate that the high levels of water extraction from the river and its tributaries affects surface water availability and is leading to increasing dependence on groundwater in the basin (Wong et.al. 2007; Mohan and Sinha 2011). Overall, the irrigation facilities provided to the mid-hill areas in Tehri Garhwal district are limited compared to other districts. The net irrigated area is low and most agriculture in the study villages was rainfed. The availability of water for domestic and agricultural purposes is becoming a concern in the mid-hills, and stakeholder groups in the area have reported an increasing problem of water depletion. Discharge from the gravity sources reduces considerably in summer, and since most of the rural schemes are gravity based, the village communities face an acute shortage of drinking water leading to a majority of the population depending on the government to supply potable water for domestic purposes. The decrease in water availability adds to the burden of women. At the same time, extreme precipitation events trigger landslides in this terrain that often damage pipelines leaving the local community in a village with virtually no water for days to weeks. The key reasons identified for water scarcity were drying up of natural springs and streams (fall in the number of active springs and more marked seasonality of those left), frequent damage to the pipelines due to extreme precipitation events and landslides, erratic/scanty rainfall causing seasonal scarcity, decreased winter rains, topography, deforestation, and the rise in population. Stakeholders also cited differences in the priority accorded to different villages and among different groups in the same village as reasons for the lack of water. With increased variability in rainfall being witnessed in the Himalayas, the issue of water availability for irrigation and domestic purposes is expected to be further exacerbated (Vandana and Bhatt 2009).

The plains of the upper Ganga basin are fertile and highly productive and agriculture is a key source of livelihoods. Most of the agricultural systems are heavily dependent on groundwater or canal water. Studies carried out in and around the study area have indicated overexploitation of the water resources for agricultural purposes (Singhal et al. 2010). The majority of the population depends on groundwater for irrigation and a decrease in water availability would increase their vulnerability, as cultivation of water-intensive crops such as sugarcane, rice, and wheat is prominent. Climate change characterized by an erratic rainfall regime is likely to affect groundwater recharge with implications for agriculture and irrigation in the plains areas of the basin. The ongoing loss of forests in the region as a whole, and the plains in particular, is likely to further increase the severity of floods and aggravate their effect on the population leading to greater vulnerability (Mohan and Sinha 2011; GOU nd). Soil erosion due to loss of forests has reduced the water-carrying capacity of the rivers resulting in riverbeds being engulfed, which also contributes to floods in the plains. Other social and economic drivers further exacerbate this process. Floods caused by climate and non-climate stressors, are likely to pose a risk for communities living close to the rivers, whether the Ganga or its tributaries, into the future. Four out of the five villages studied in the plains of Uttarakhand had faced frequent floods in the last 3-4 years, with Mathana and Mohammadpur Bazurg Aht particularly susceptible (NIDM nd), and this had had a serious impact on other sectors like agriculture, health, and energy.

Agriculture

Uttarakhand is strongly affected by climate change, which is having an impact on a range of livelihoods. The impact on agriculture affects the food security of the hill communities, which rely heavily on agriculture and animal husbandry; 70% of the hill population depends on the production of cereal crops for their subsistence (GOI 2011a). The state has a net irrigated area of 336,000 ha (in 2010/11), mostly in the plains, but 70% of landholdings, covering 27% of the cultivated area, are less than 1 ha. The productivity of the plains districts is high compared to that at higher elevations, where landholdings are small and often scattered due to division within families over generations (GoU 2012).

The higher altitude locations are known for horticultural crops such as fruit, vegetables, off-season vegetables, floricultural crops, and aromatic and medicinal plants, but rising temperatures are affecting their growth and productivity. There are some benefits: potato and wheat can now be cultivated at higher elevations than before due to the rise in temperature. However, there has been a considerable drop in the productivity of key horticultural crops like peaches, apricots, plums, and apples as the required chilling isn't obtained due to the decrease in snowfall, as noted by a scientist at Uttarakhand University of Forestry and Horticulture. The flowering season for these plants has also advanced due to the rise in temperature, which is not desirable. Incidences of hailstorm damage have increased raising quality issues, and apple orchards in the high hills also face the threat of frequent landslides, especially from July to September, the peak season for the apple market. A decline in the productivity of horticultural crops due to monkey invasion (an example of human-wildlife conflict) has also been noted. The lack of well-established markets remains a recurring problem for farmers. All of these factors are leading to a shift from horticulture to vegetables and no new orchards are being planted in the region.

The subsistence form of agriculture which is practised in the villages alongside horticulture also faces threats from climatic and non-climatic stressors (such as monkey attacks). About 90% of agriculture in the Himalayas is rainfed, and agriculture in the western ranges (Vedwan and Rhoades 2001) is expected to be severely affected by more frequent and intense droughts (Singh et al. 2010). At the same time, floods remain a major cause of concern; in Kalimath village huge tracts of farmland are washed away during floods every year. The locals also stated that rhododendron has shown a decrease in productivity over time, and the size of Malta orange has decreased. Similar concerns were raised in Chaumasi and Tala. Tala is one of the cluster of villages that depend heavily on forests for their livelihood. The reduction in forest cover is expected to have a negative impact on these communities by taking away their livelihood source. The Chaaniwala community (pastoralists) at higher elevation expressed concern about pastoralism being affected by the higher temperatures. Better quality alpine meadows are now only available in the upper reaches above the existing grazing zones. Broad-leaved tree species, a highly nutritious source of fodder, are also gradually disappearing from the forests in the Tehri-Garhwal region as a result of the lack of moisture, which is accentuated by frequent forest fires which prevent germination (BBA 2011).

Intensive cultivation is not feasible in the mid-hills due to the harsh terrain and limited area under irrigation – only 7.4% of the cultivated land, the lowest level in the state – which reduces agriculture to subsistence level. The major crops grown are wheat, ginger, and onion in the winter (rabi) season, and paddy, mandua, maize, rajma, soybean, potato, and turmeric in the monsoon (kharif) season. Ginger and soybean are the only crops that are marketed. Unlike other areas of the mid-hills, feminization of agriculture is not common in any of the surveyed villages in the mid-elevation areas and agricultural operations are largely undertaken by men. There is a widely practised crop diversification system in the midhill areas called baranaja in which more than 12 varieties of crops are cultivated together (Sati 2012), but this was not prevalent in the study villages. Seasonal vegetables are grown through canal irrigation but there is virtually no development of groundwater for irrigational use (GOI 2011b). Several studies conducted in the region support the view of the different stakeholders that the low agricultural productivity is due to the small size and scattered landholdings, difficult terrain, unfavourable climatic conditions for some crops, inadequate availability of improved inputs and technology, and lack of credit and marketing facilities (Dewan and Bahadur 2005). A study by Beej Bachao Andolan – Save Seed Campaign (BBA 2011) documenting farmers' perceptions in Tehri Garhwal noted that erratic, unpredictable, and insufficient timely rainfall has led to a drastic reduction in the cultivation of rice and other crops such as wheat, cauliflower, and potatoes. The uncertainty in precipitation due to climate change, coupled with the relatively low productivity of staple crops, may discourage investment in the agricultural sector in the mid-hills (Hosterman et al. 2012). Communities in the mid-hills that are traditionally dependent on forest products as a source of income are also hard-hit by intense rainfall events and frequent floods and landslides, which cause destruction to the vegetation cover. Moreover, urban growth resulted in the loss of 6% of natural forests between 1981 and 2011.

Agriculture in the plains areas of the basin faces a different set of problems. These areas are likely to face threats from increasing heat stress. Wassmann et al. (2009) notes that in parts of Asia current temperatures are already approaching critical levels and are affecting the growth of rice through complex interactions. A large reduction in wheat yields is projected over the Indo-Gangetic plains by the 2050s due to climate shifts (Ortiz et al. 2008). There is evidence of increased warming, which may lead to a shortening in the maturity period of winter crops and increased pest infestation. In recent decades, peak rainfall has been observed in August/September instead of July/August resulting in damage to kharif (rainy season) crops. Winter precipitation in January/February instead of December/January has resulted in delayed sowing of winter crops and a decline in barley and wheat yields (GoU 2014a). In the plains, agriculture is largely dependent on groundwater irrigation, which is leading to over-exploitation and depletion of groundwater resources. Field observations in the five low elevation villages confirmed that most irrigation was carried out using bore wells. Mishra et al. (2013) reported a fall in productivity of rice and wheat in the upper Ganga basin. However, discussions and observations in most of the villages studied did not indicate any fall in the productivity of the major crops grown, including wheat and rice, although in Khadri Kharak Maaf and Mohammadpur Panda, there have been changes in the type of crops grown. In Mathana, farmers grow wheat and sugarcane in place of rice, the predominant crop 30 years ago. In Kangri, a shift took place from bajra and maize to wheat and rice after electricity became available, which led to an increase in private bore wells. Subsistence farmers and smallholder livelihood groups in the area experience a number of stresses and are more vulnerable and risk prone (Morton 2007). Risks include droughts and floods, crop and animal disease, and market shocks, which may be felt by individual households or entire communities. Smallholder agriculture is also prone to 'the centrality of the social', which means that the grounding in social relations within households (particularly gender relations) and between households affects production decisions, knowledge of the market, and so on (Morton 2007). This was seen in Mathana, where landholdings are much smaller than in the other villages, which makes the communities more vulnerable to climatic and non-climatic stresses.

Energy

It is predicted that extreme events like cloudbursts, landslides, and floods will pose a serious threat to energy infrastructure in the region. The base flows of many Himalayan rivers are likely to increase in the short term as the Himalayan glaciers retreat, but this increase won't necessarily be beneficial to existing hydropower projects since the variability in flows associated with deglaciation is not optimal for hydropower (Blackshear et al. 2011). Hydropower generation may be reduced and plans for increasing the number of micro and mini and run-of-the-river projects shelved (Rao et al. nd). The Uttarakhand State Action Plan on Climate Change also states that a reduction in snow cover in the upper reaches of the Himalayan glacial systems, the point of origin for several perennial rivers such as the Ganga, Yamuna, and Kali, will eventually result in decreased discharge and hence impact generation capacity. Damage due to floods and landslides also poses a threat to energy infrastructure assets such as transmission lines (GoU 2014a; University of Cambridge and World Energy Council 2014).

Field discussions also showed the impact of floods on hydropower facilities. Damage to hydropower projects had been experienced in the areas around the villages visited in Rudraprayag following heavy rainfall and an outburst due to a glacial fall near the Chorabari glacier in mid-June 2013. Two days of heavy rainfall led to widespread flooding in the river Mandakini and damage to many hydropower projects as observed while travelling to the villages. A project with the Uttarakhand Jal Vidyut Nigam Limited (UJVN Ltd) was damaged beyond repair. Another funded by the Asian Development Bank at Kaliganga was left in a similar state. The floods also caused extensive damage to power lines rendering a few thousand people without power for over a week.

Villagers in both the high elevation and mid-hills areas (especially in Badal village) also pointed out that the floods in 2013 had caused extensive damage to the forests, affecting the availability of fuelwood. There is a high dependency on forests for fuel as LPG is often either not available or not affordable (a cylinder refill costs around INR 400 or USD 6) and there is a lack of non-conventional cooking technology schemes, which increases the energy insecurity of communities.

In the mid-hills, fuelwood, kerosene, electricity, LPG, and non-conventional energies like solar and wind are important sources of energy, but the difficult terrain and inaccessibility of remote areas means LPG can be difficult or impossible to obtain and fuelwood from the forests is used for cooking, lighting, and heating. Adventure tourism is also impacting forest cover in the mid-hills. Areas stretching from Rishikesh to Shivpuri have become quite popular among tourists for such activities. Although a lucrative livelihood option, Farooquee et al. (2008) noted that "the sporadic increase of commercial camping and white water rafting has already had a severe impact on the forests of the narrow Ganga valley between Devaprayag and Rishikesh".

Communities from the lower elevation villages of Kangri and Khadri Khadak Maaf also reported a decrease in forest cover. Women spend several hours a day collecting fuelwood and fodder from the forest as they have to walk long distances across difficult terrain. This results in loss of time for other activities which might be beneficial or provide a source of income.

The Temperature-Humidity Index (THI) is used as a weather safety index to monitor and reduce heat-stress related losses. The THI is projected to increase by 2030 compared to the baseline scenario reaching values of >80 from March to September, with a maximum in April to July, in many parts of the Himalayan region. This will lead to high temperature stress in all places in the basin (GOI 2010). It will also pose a risk to the energy sector as it will lead to increased energy consumption, especially in cities, of which there are a number in the plains of the upper Ganges basin, thereby increasing the supply-demand deficit (GoU 2012). There was a 20% energy deficit in Uttarakhand in 2011/12 (GoU 2014a) which can only rise as the Temperature-Humidity Index increases.

Health

Climate change will have serious ramifications for the health sector. Disasters will continue to be a major concern for public health and the increase in mean annual temperature is likely to result in an increase in the occurrence of vector-borne diseases (Githeko et al. 2000).

The impact of climate change has been felt across the region in the emergence of new health issues. The Government of India (GOI 2010) noted the effects of a changing climate on the range and activity of various infective vectors and parasites – leading to changes in the geographic range and an increase in incidence of vector-borne diseases such as malaria, dengue fever, and several types of encephalitis. The intensity and frequency of extreme weather events such as droughts, floods, extreme precipitation, and others are projected to exacerbate the adverse health effects (IPCC 2014). These health risks will be inequitably distributed and will disproportionately affect the marginalized and the poorest of the poor (McMichael et al. 2007; Strazdins et al. 2011) A study by Moors et al. (2013) established a strong relationship between climate change and the incidence rate of diarrhoea. Climate change would affect four diarrhoea relevant climate factors, with an expected 13% increase in cases on average over the Ganga basin.

An important issue faced by local people after the floods in 2013 was the large-scale contamination of water sources. The Integrated Disease Surveillance Programme (NRHM 2013) confirmed that there had been an outbreak of acute diarrhoeal disease in the flood affected districts of Rudraprayag, and diarrhoea and other waterborne diseases are generally on the rise due to contamination of water sources during floods. Grazing of cattle near water points also results in faecal contamination. The increase in the Temperature-Humidity Index will also affect the health of humans and animals, values above >80 severely affect the health and productivity of livestock. Villagers in Badal and Pyunkhari reported an increase in the incidence of malaria, diarrhoea, fever, and other water-related diseases, and the lack of proper health care services in these villages will only exacerbate such health risks. There are no health centres in the village and people have to travel long distances to the nearest towns to access medical facilities.

Land use and urban development

Urbanization in Uttarakhand has been unplanned and rapid and is increasing. Rural settlements are being converted to small towns, and small towns into large cities. Tourism is one of the fastest growing sectors and is emerging as an important driving force for urban growth in the high elevations and mid-hills. The high hills are a hub of religious tourism and are centres for pilgrims. These areas are major pilgrimage destinations during the 'yatra' (pilgrimage) season, and the influx of tourists poses tremendous pressure on the available resources. The local population is extremely vulnerable to such changes, which can only be exacerbated by climate change (GoU 2014a). The urban population has grown fast, particularly since 1971 (Tiwari and Joshi 2011). The growth from 1971 to 1981 and 1981 to 1991 was much higher than the average for India as a whole (GOI 2001) and has continued with a further increase in the proportion of urban population from 26% in 2001 to 31% in 2011. The number of urban centres is increasing, while the small towns in the mid-hills located along roads, mostly in the valleys, are growing fast as people from villages in remote areas migrate in search of employment. Urbanization is leading to an increase in the problems of sanitation, slums, congestion, and degradation of land, as the capacity to provide basic amenities is limited.

It is important to investigate the changing land use in the basin as it has considerable implications for both people and the ecology. Tsarouchi et al. (2014) concluded that most of the land-use change in the basin is characterized by conversion from forest and barren land to agricultural areas; between 1984 and 2010, agricultural areas increased more than 150% and forest areas decreased by 28%. Sen et al. (2002) analysed land use/cover changes and their ecological and socioeconomic implications from 1963 to1993 in Pranmati watershed in Chamoli district in the higher elevation area of the upper Ganga basin adjacent to Rudraprayag district. Agricultural land use increased by 30%, while the forest area decreased by 5%. About 60% of the agricultural expansion occurred in community forests, compared to 35% in protected forests and 5% in reserve forests. The mean annual fodder yield from cropland declined by 44%, while manure input, soil loss, and run-off increased by 46, 90, and 51%, respectively. The changes in agricultural land use were such that the mean manure input at the watershed scale increased by 50%, and fodder output from crops decreased by 40%, indicating the increasing pressure on forests. Such land use changes have important implications for the livelihood of communities that are mostly dependent on traditional crop and livestock mixed farming (Tiwari 1996).

Hill agriculture is also prone to impacts from the landslides that are frequent in the higher elevation areas. Each year, 550 m3 of debris per km of road is produced by landslides and rock falls (with 5–10 landslides per km), with 2,410 m3 of sediment sliding down the mountain slopes and disrupting vegetation, choking mountain streams, and contributing to floods in the plains (Valdiya 1985; Dewan 1988). In Kalimath village, floods were observed to wash away farmlands and forests.

Land use in the rural areas of the plains of the basin has also seen major changes since 1971. Ahluwalia (2014) noted that in Haridwar district between 1971 and 2001, the area under forest registered a small decline (from 7.0% to 6.8%) and the area of cultivated land a more marked decline (from 65% to 56%), while the area under cultivable wasteland had increased (from 3% to 8%) as had the area not available for cultivation (from 25% to 29%). The Forest Survey of India reports for 2005 and 2009 show a reduction in forest area in Haridwar district, mainly in open forest, from 274 to 238 km2 (FSI 2005; FSI 2009). The loss of forest cover in Haridwar was attributed to the resettlement of Gujjars and people ousted from the Tehri dam area, as well as rotational felling of eucalyptus trees around Shyampur and Chiriapur. In Khadri Kharak Maaf and Kangri, local villagers confirmed that forest cover had decreased. In Kangri, the change in land use was attributed to locals selling their land to outsiders for housing and other uses due to the lack of opportunities to earn money within the village. In these villages, the absolute percentage of agricultural land has decreased, unlike the situation further downstream in Mohammadpur Panda, Mohammadpur Bazurg Aht, and Mathana, which still have comparatively large tracts of farmland.

Factors Co-determining Impacts and Vulnerability

A number of factors co-determine climate change impacts and the subsequent vulnerability of sectors such as agriculture, water, energy, health, and urban habitat. Processes like population growth, urbanization, tourism, and increasing pressure on existing infrastructure may compound or exacerbate the impacts of climate change and increase the vulnerability of environmental systems and socioeconomic structures.

In the upper Ganga basin, climate change impacts together with other non-climate stressors are leading to severe environmental impacts, which is further increasing the vulnerability of the population. Subsistence farmers and smallholder livelihood groups are more vulnerable to risks as they have fewer options (Morton 2007), especially where landholdings are particularly small as observed in Mathana. Frequent floods and landslides have led to loss of farmland and forest, which is affecting livelihoods and the availability of fuelwood, as well as causing problems related to sedimentation. Agricultural expansion has further affected forests, exacerbating the problem of obtaining sufficient fodder and fuelwood. Commercial development in the hills to cater to tourism is also leading to clearance of forest cover on marginal land, which in turn contributes to increased runoff and risk of landslides, with resultant devastation and loss of life and property. The changes in forests also play a role in the changes in water supply. For example, an interviewee from Kalimath explained the importance of oak forests in the regeneration of natural water sources. The deep roots of the oak help spring regeneration, but pine is now replacing oak at an increasing rate, and this affects the natural flow of water. The changing climatic conditions are leading to an increase in pest attacks on agricultural crops, and the impact is compounded by the increased attacks on standing crops by wildlife from nearby forests, which also increase as the area of forest is reduced.

Across the hills, the weak economic base, lack of means to irrigate land, and lack of alternative livelihood options have resulted in seasonal, and sometimes permanent, migration to nearby urban centres. The extreme precipitation events have often damaged cropland making agriculture the least preferred option for livelihoods. Migration not only poses a pressure on local infrastructure, it changes the land use in the surrounding area leading to loss of forests and reduced infiltration, which in turn increases the occurrence of floods and landslides. The high rate of outmigration in search of better livelihoods was apparent in Badal village, which people left for employment in tourism related trades, and in Pyunkhari, which they left to work as wage labourers. The sizeable outmigration of men, has left many female-headed households with women as major contributors to the household economy. However, there are no self-help groups for women in any of the villages studied, and no alternative employment available locally. The decreasing forest cover and the disappearance of springs have further added to the drudgery of women with regard to water and fuelwood collection.

Overall, the huge risk of floods to life and property adds to the vulnerability of communities, especially older people and women, while the extreme precipitation events, which are thought to be associated with climate change, also directly affect the options for alternative livelihoods. In Badal, the 2013 floods affected adventure tourism, especially rafting. But it is difficult for these communities to diversify into other livelihood options as huge amounts of investment have been made into rafting. At higher elevations, in Kedarnath, the 2013 disaster has had a marked impact on pilgrimage tourism, a major source of livelihoods. Approximately 80% of all tourists visit Kedarnath during the summer months of April to June in the yatra season, and it is common for people to earn enough from religious tourism in the six-month season to last for the whole year. However, the tourist influx has considerably reduced since 2013 and communities are very vulnerable as they unable to diversify into other livelihood options. The floods have also left many families with no breadwinners, especially those from the higher caste who served at the Kedarnath shrine who lost their lives, leaving women and children with no source of support.

Landslides not only affect agricultural land, they also have an impact on marketing of produce when access roads are blocked, as well as on the procurement of goods and services. The latter can be important even in villages like Kalimath and Chaumasi, both of which depend on subsistence agriculture with little produced for sale; Kalimath benefits from better market access for procurement of goods.

Social factors also play a role in determining the extent of vulnerability to climatic factors. In Khadri Karak Maaf, the Buksa community depend on farming and work mostly as farm labourers. They are an indigenous social group and reside in the low lying areas of the village close to the rivers Song and Ganga, where they are vulnerable to floods, while the more advantaged communities live in the higher parts where they are less exposed to floods.

The lack of health facilities and administrative capacity makes people more vulnerable to health impacts during floods, such as increased incidence of diarrhoea and malaria. Some areas in Kangri and Mathana are completely cut off during floods, with lack of access to health facilities leading to an increase in fatalities. The larger number of cases of malaria, diarrhoea, fever, and other water-related diseases in Mohammadpur Bazurg Aht and Mathana is at least in part due to the lack of proper healthcare facilities.

The region is prone to earthquakes, and these too can compound the impacts of climate change, for example by making the land less stable and increasing the vulnerability to landslides, as well as impacting on water courses and further reducing water availability.

Local Adaptation Practices and Responses

The Uttarakhand Himalayas are among the most fragile ecosystems in the world. The region is characterized by an underdeveloped economy, remoteness, and very unstable and delicate landscape. The people living in the upper Ganga basin are extremely vulnerable to floods, drought, and other climate and non-climatic stresses which affect their lives in a variety of ways, and it is essential for them to find ways to adapt to the changes taking place.

Farmers are having to adapt to issues related to agriculture such as loss of land due to floods and changed productivity due to shifting seasons and higher winter temperatures, which affect the growth of traditional crops. At higher elevations, the traditional crops are being replaced with cash crops that could not be grown previously due to the low temperature. Low chilling varieties of apple are also being recommended as a means of adapting to the changing climate, but these are still in the experimental stage. In the mid-hills (Pyunkhri and Bagi) cultivation of potato (*Solanum tuberosum* L.) as a cash crop has completely replaced the traditional cultivation of buckwheat (*Fagopyrum esculentum* L., *Fagopyrum tataricum* (L.) Gaertner), hogmillet (*Panicum miliaceum* L.), and foxtail millet (*Setaria italica* (L.) Beauv.), which have been abandoned due to unfavourable conditions, as have other traditional horticultural crops. In Badal, farmers have developed a clever system to protect crops against the increasing animal attacks. They set up strings with empty cans and rocks suspended on them that run from their homes through the fields. During animal attacks, they pull on the strings and the noise scares the animals away.

One of the major adaptation approaches in the study villages in the mid-hills is migration for labour to supplement household income. Tehri Garhwal, together with Pauri and Almora, has been known for out migration since the 1870s (Singh 1990). Local labour migration is usually seasonal. In Badal, which lies along the route to Shivpuri, there has been a gradual shift from traditional means of livelihood such as agriculture to adventure tourism. Most people from the village work as wage labourers or support staff for rafting activities and beach camp establishments. In Pyunkhari, every household had at least one family member who had migrated to a nearby town or city in search of employment, and many work for wage labour in nearby villages.

Farmers in the lower part of the basin increasingly use groundwater for irrigation to compensate for the reduction in surface water. However, this is leading to a drop in the groundwater table. Access to electricity in some areas has led to new bore wells being dug to grow crops like paddy. In some places there has been a loss in productivity of pulses and vegetables and the cropping pattern has changed from wheat, rice, vegetables, and pulses to mostly wheat and rice, as observed in Khadri Khadak Maaf.

Communities in the plains areas living close to the river are adapting to the increased incidence of floods by moving their houses to locations away from the river, but this choice is only available to people who own land in suitable locations. In Khadri Kharak Maaf, many people are selling their land and shifting to business such as setting up shops, leasing out land for business, or real estate. But this possibility is not available to the Boksa community who reside at lower elevations near the river banks; although this land is rich in sediments, it is difficult to sell due to the proximity to the river and vulnerability to flooding. These people are choosing to work as wage labourers in infrastructural activities in place of farming. In Mathana, lack of road connectivity limits the access to markets, but lack of alternative opportunities in the non-farm sector has limited peoples' ability to diversify away from agriculture in response to the vagaries of the climate. In contrast, many people in Mohammadpur Panda and Kangri have moved away from agriculture to other livelihood options such as government jobs and small businesses. These villages highlight the variation in people's capacity to adapt to climatic and non-climatic stresses.

Policies and Institutions

There are a number of organizations involved in addressing issues related to climate change and its impact on communities in the upper Ganga basin. Krishi Vigyan Kendra (KVK, a front-line agricultural extension centre financed by the Indian Council of Agricultural Research), is one of the most important organizations helping farmers (GoU 2014a; GOI 2015). Most agriculture in the region is rainfed, and farmers need new varieties of seeds that are more resistant to climate extremes. The KVKs provide information about newer varieties of crops as well as better techniques for water management. Among others, the KVKs have been conducting on-farm testing to identify the best agricultural technologies under various farming systems, which would also be location-specific; have organized needs-based training for farmers to update their knowledge and skills in modern agricultural technologies; and produce quality seed.

The private sector has also been working with the government to help improve the adaptive capacity of people in the basin. For example, Reuters Market Light (ICIMOD 2014) has been successfully implemented in over seventeen states in India, and has been implemented as a public private partnership in Uttarakhand since 2012 (Garhwal Post 2012). The service uses mobile technology to provide subscribers with information about the spot prices for crops across markets, a local weather forecast, and information about government schemes and sources of finance and various other tips to farmers to ensure crop productivity remains high. These services help farmers to take informed decisions about their produce, and make them less vulnerable to the ploys of middlemen. The local weather forecast helps farmers prepare for extreme rainfall and heat events well in advance and take necessary action to reduce crop damage, as well as determine the best time for sowing and harvesting. The government weather-based crop insurance scheme (GOI 2013), initially piloted in 2003 in a few states, has now been extended to Uttarakhand. In contrast to a yield guarantee insurance, this type of insurance takes into account weather parameters that determine crop productivity, and with erratic events seeing a rise, this would help address the risks in the farming sector.

The Integrated Watershed Management Programme (IWMP) from the Department of Land Resources aims to restore the ecological balance in micro-watersheds by harnessing, conserving, and developing degraded natural resources. These schemes are intended to prevent soil erosion, regenerate natural vegetation, enable rainwater harvesting, and recharge the groundwater table. The Uttarakhand Decentralized Watershed Development Project (GRAMYA Phase I), a sub-project under IWMP which ran from 2005 to 2011, helped develop about 300,000 ha of watersheds in the mid elevations of the Himalayas (700–2,000 masl) (Chauhan 2010). The scheme not only guaranteed employment but had the added benefit of improving essential services such as roads, buildings, bunds, and check dams. The majority of the work was linked to water, soil, and land. Other government programmes such as Indira Awas Yojana (IAY) and the National Rural Livelihoods Mission (NRLM) that are directed towards the poor, who are particularly vulnerable to climate change (Welt-sichten 2008), can also be used to support adaptation. IAY provides financial assistance to rural households to construct their own houses, which can help protect beneficiaries from weather extremes and floods. The Mahila Kisan Sashaktikaran Pariyojana (MKSP) programme is a sub-component of NRLM focused on regeneration and sustainable harvesting of non-timber forest product species. It also promotes organic and low-chemical agriculture and increased soil health and fertility to sustain agriculture-based livelihoods. These programmes add to the adaptive capacity of communities and will play a crucial role in both developmental and adaptation policies.

The Uttarakhand University of Forestry and Horticulture (Ranichowri Campus) has noted a recent shift in government policies, which are now largely focusing on the production of nuts rather than horticulture based crops, which are becoming increasingly difficult to grow due to the non-conducive climatic conditions. Nuts are resilient to erratic climate parameters and occupy a wider ecological niche, thus they are a good cash crop for adaptation.

Conclusion

The upper part of the upper Ganga basin occupies a large part of Uttarakhand state in India and is not only characterized by a fragile mountain terrain, but also by weak socioeconomic conditions. The uppermost area is generally very cold, with snow cover during most of the year except in summer, when it receives a large number of tourists on pilgrimage. The central part has sprung up as an area for adventure tourism along with religious interests. The entire area is extremely vulnerable to floods, drought, and heat stress. Floods are the most frequent hazards and affect agricultural land, forests, and hydropower installations; during the 2013 Kedarnath floods, the Chorabali project was completely destroyed. Floods have several causes, including heavy precipitation events and the breaking off of ice sheets from glaciers leading to the outburst of glacial lakes. Landslides are also common and can be highly destructive, while cloudbursts can have serious impacts causing damage to life and property.

Local communities in the upper part are witnessing warmer weather conditions, which has affected water availability for drinking and irrigation. Water is available from springs or rivers and brought through pipelines to the settlements. Springs are the primary source in the upper part of the area. Drying of these springs is leading to an increasing burden on women, who must travel long distances to fetch water from other sources, especially during the dry season. Contamination of springs and other water sources is common during floods and other disasters and is responsible for health problems like diarrhoea, which has become very common after the floods that hit the area in 2013. Local herders have also been affected by the warmer conditions and are moving to higher elevations to access grazing lands.

In both the upper elevations and mid-hills, landslides triggered by heavy rainfall lead to the destruction of forests and heavy silting, which affects groundwater recharge and availability of fuelwood. Moreover, species like oak that help recharge groundwater are being slowly replaced by pine. Fuelwood is the only source of energy for cooking and heating in remote areas where LPG is unavailable, as well as in areas where LPG is unaffordable, and collection is becoming a burden for women who must travel long distances for the purpose.

The irrigation system in the mid-hills is limited to canals and guls on a small scale. Lack of development of efficient irrigation systems, together with limited water availability due to climate change, has resulted in low productivity of traditional crops making them less feasible for cultivation. Horticultural crops are also being damaged by the higher temperatures and pest attacks and are being replaced by vegetables. Farmers with scattered small plots become more vulnerable when their lands are washed away by floods or productivity is lowered, affecting income. When men migrate to nearby towns to find the income they need to cope, women and children become more vulnerable, as they face the brunt of disasters but have no earnings. In the mid-hill areas, farmers are also threatened by animal attacks, which destroy standing crops, although some communities have found innovative ways of coping with the problem.

In the plains areas, better access to electricity has encouraged farmers to dig new bore wells and cultivate paddy, although the water table is declining due to over exploitation. The climate projections suggest that the plains are also likely to be affected by increased heat stress, which could further affect people's livelihoods.

Livelihoods generated by tourism have been markedly affected since the floods in 2013 as the number of pilgrims has fallen drastically, affecting a large number of households that directly depend on this sector. Those pursuing agriculture are also becoming vulnerable, not only because of climate-related stresses, but also as a result of issues related to road connectivity, markets, lack of irrigation facilities, and others. This has resulted in people moving away from agriculture to other activities like shops, real estate, or becoming labourers in nearby towns. Migration into large and small towns in Uttarakhand is increasing and is posing a tremendous pressure on the existing infrastructure and land use of the towns. In some areas, homes have been rebuilt, away from the river banks to adapt to the floods, but adaptive capacities vary considerably, according to the physical, social, and economic conditions.

There are a number of ongoing or planned government policies and interventions by private organizations to help communities in the basin to adapt better and build their resilience to climate change. The Krishi Vigyan Kendra (KVK) (GoU 2014a) is helping farmers to adopt new varieties of seeds and new techniques for water management. while the public private partnership initiative Reuters Market Light (RML) is using mobile technology to inform subscribers about market prices for crops, local weather, and schemes and sources of finance for farming activities. A weather-based crop insurance scheme has been introduced (GOI 2013), and an integrated watershed management programme (IWMP) by the Department of Land Resources has helped protect and regenerate watersheds in the mid elevation areas while providing local employment and improving essential services. Government programmes geared towards the poor like Indira Awas Yojana (IAY) and the National Rural Livelihoods Mission (NRLM) can also be used to support adaptation programmes, and several other local organizations are involved in developing livelihood options with a special emphasis on women.

This situational analysis identified marked effects of climate change in the upper elevation areas, which have affected the local economy. The floods of 2013, which had a major impact, indicate the possibility that the region may be prone to more such extreme events in future. The loss of lives and livelihoods in this one event has already highlighted the vulnerability of the local communities, who depend largely on tourism for income, as tourists have now been dissuaded from visiting the region. Although some local level systems that support adaptation by agriculturists have been implemented by the government, there is still an urgent need to develop alternative livelihoods. More climate proofing is necessary in every sector, otherwise the area will be become extremely impoverished and may witness large-scale outmigration.

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