Vulnerability and adaptation to climate variability and water stress in Uttarakhand State, India

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Abstract
This paper presents a participatory approach to investigate vulnerability and adaptive capacity to climate variability and water stress in the Lakhwar watershed in Uttarakhand State, India. Highly water stressed microwatersheds were identified by modelling surface runoff, soil moisture development, lateral runoff, and groundwater recharge. The modelling results were shared with communities in two villages, and timeline exercises were carried out to allow them to trace past developments that have impacted their lives and livelihoods, and stimulate discussion about future changes and possible adaptation interventions.

1. Introduction

The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) points out that freshwater availability in Asia is projected to decrease due to climate change. By the middle of the 21st century, annual average river runoff and water availability are projected to decrease by 10–30% relative to 1900–70 over some dry regions at mid-latitudes and in the dry tropics. Further, reduced water availability is projected for regions supplied by melt water from glaciers and snow (IPCC, 2007).

India receives an average annual precipitation of about 4000 billion cubic metres (BCM). Of this, utilizable surface water and groundwater resources are estimated to be only 690 and 432 BCM, respectively (CWC, 2005). As a result of wide fluctuations in the availability of water, spatially and temporally, water shortage is virtually an annual feature in several parts of the country. Moreover, acceleration in the rate of consumption due to an increasing population and changing lifestyles is a cause for concern for effective sustainable management and utilization of this resource. Per capita annual water availability in India has steadily declined from 1820 m$^3$ in 2001 to 1703.6 m$^3$ in 2005, coming close to the water stress threshold of 1700 m$^3$ (CWC, 2005). Agriculture accounts for more than 80% of water withdrawals in the country, using both surface and groundwater resources. Water demand for irrigation is projected to rise from 541 BCM in 2000 to 910 BCM in 2025, and to 1072 BCM in 2050 (CWC, 2005).

Specifically for the Lakhwar sub-basin, part of the Upper Yamuna sub-basin in Uttarakhand state, Narula and Bhadwal (2003) found that about 1500 km$^2$ of the 4000 km$^2$ sub-basin receives an annual runoff of less than 1250 mm, and as a result is highly sensitive to increased water stress due to climate change. The study projected a decrease of 20–30% in total flows due to climate change alone by 2041–60 relative to 1961–90, with monsoon rainfall likely to become less intense and more sporadic. The potential impacts of such changes could include the following:

- Reduced groundwater availability—Under the changed climate scenario, since the total water availability will go down by about 30% relative to the reference period of 1961–90, the groundwater recharge will also be reduced, translating into a fall in groundwater tables. This will also lead to an increase in the extraction costs because higher capacity equipment has to be installed to maintain yields.
- Reduced surface water availability—Decrease in total runoff levels would reduce the availability of drinking water for humans and livestock. This would specifically have seasonal patterns worth studying. In conjunction with reduced groundwater availability, this could lead to increased conflicts over water, and would certainly increase the burden of water collection on women.
Dehradun is the state capital of the north Indian state of Uttarakhand (earlier called Uttaranchal). Located at an altitude of 640 m above sea level, the district is spread over 3088 km², nestled among mountain ranges. About 51% of the district is covered by forests (FSI, 2008) with the mountain slopes dominated by sal (Shorea robusta). Agriculture is practiced in the valley, along with agroforestry, orchard cultivation, and tea gardening.

Dehradun district has two sub-divisions—Dehradun and Chakrata. The lower part of Chakrata is called Jaunsar and the upper part (at higher elevation) is called Bawar. This is difficult terrain, poorly connected by transportation facilities, and generally neglected when Uttarakhand was part of the large Uttar Pradesh state. The inhabitants of Jaunsar claim descent from the Pandavas of the Mahabharata, and traditionallly practiced polyandry.3

Cultivation takes place mainly in narrow patches of terraced fields cut into the hill slopes. About half of all landholdings are less than 0.5 ha in size, and 70% are less than a hectare. Tenant farming and sharecropping are not common. As pointed out by Sati (2005), geography and culture (i.e. the way of life in the hills) have created a relatively equitable, if impoverished, land distribution in Uttarakhand.

The total water requirement for Uttarakhand state (including human consumption, animal consumption, agriculture, and industry) is estimated as only 3% of the annual precipitation received. However, rainfall is available for only 100 days, and flows out swiftly from the steep slopes constituting the major part of the state. The cultivable command area (excluding forestland, populated land, and non-irrigable land) of the state is 1.14 million ha, of which 0.55 million ha remains unirrigated and lies primarily in the hilly areas of the state. In the hill districts, the irrigated area is merely 14%, compared with 46% in the foothills and plains (Government of Uttaranchal, 2004). The State's draft water policy (Government of Uttaranchal, 2004, p. 1) notes that “It is a paradox that the local people of the state and their lands are facing shortage of water for domestic consumptive uses in the remaining period of the year.”

Uttarakhand (and its neighbouring state Himachal Pradesh) have had a tradition of water harvesting (Table 1). Water for household use was obtained from springs, mountain streams, or man-made rainwater harvesting structures. Open ponds and tanks provided water for animals, irrigation, and washing. For human consumption, water was tapped from underground seepages (in baoris/naulas) or springs (dharas). Terraced fields were irrigated by diverting water (using bundlers and branches) from nearby mountain streams through small gravity flow channels known as guhls. Typically a farmer floods his field and then removes a stone plug at the outside edge of the field so that water can flow to the next terrace below. Some channels also provide hydropower for gharats (water mills). All these structures were usually common property resources, which were largely owned, used, and maintained by local communities. However, an increasing number of guhls have been taken over by state government agencies, and fallen into disrepair due to lack of a sense of ownership (PSI, 2003). At the national level, there has been a significant shift in thinking with water being increasingly viewed as a commodity, rather than a natural resource. This is reflected in the National

In light of the predicted impacts of climate change outlined above, this study aims to assess the vulnerability and adaptive capacity of households engaged in agriculture in Lakhwar sub-basin to climate variability and water stress. Recognizing that vulnerability needs to be understood at the local level, and that households engaged in agriculture employ a variety of measures in response to changing stresses and incentives, the study complements watershed modelling with a participatory approach to gain insights through mutual learning and exchange with the affected communities. It attempts to address the following specific research questions:

1. What is the capacity of households in the study region to cope with current climatic variability and water stress?
2. Are their responses only temporary coping measures, or would these responses help households adapt in the long run?
3. What are the possible scenarios of interventions (at different levels—policy, institutional, technological, community, individual) that can help build adaptive capacity?

2 North India has two agricultural seasons. Rabi is the winter season and the rabi crop is harvested in April. Kharif coincides with the monsoon or the rainy season. Wheat is an important rabi crop while paddy is an important kharif crop.

3 Polyandry is the practice of having more than one husband at one time. Majumdar (1962) termed the practice, observed in this region, of fraternal polyandry with multiple wives as “polygynandry.”
Water Policy (2002), which formalizes the concept of the rights of water users, and allows trading in entitlements.

The mid-Himalayan ranges are dry, with small streams fed by winter snow. Agriculture in Jaunsar-Bawar is characterized by natural irrigation i.e. no lift irrigation, tubewells/borewells, but only guhls. Sati (2005) cites a 1996 study which found that in about half of Uttarakhand’s villages, springs had either ceased to yield water, or did so only during the rainy season, calling this the "too little—too much syndrome". There has been a decrease in spring discharge ranging from 25% to 75%, and this has resulted in a considerable decrease in water flow; estimated to be around 30–40% in the last decade or two.

Against this background, the draft water policy for the state notes that production of food grains has increased from around 0.5 million tonnes in the 1950s to about 1.79 million tonnes in 1999/2000, but stipulates that this will have to be raised to around 2.5 million tonnes by the year 2025.

3. Framework

This study adopts a place-specific approach to understand vulnerability and adaptive capacity through mutual learning and exchange with the affected communities. While choosing a specific watershed as the case study area, the stresses acting on the exposure unit were studied as part of a larger context, with external forces acting as both constraints to, and opportunities for, coping responses.

The working definition of vulnerability adopted for this study is that defined by Turner et al. (2003, p. 8074) as "the degree to
which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress”. Various factors shape the differences in vulnerability of individuals or groups: entitlements, personal heterogeneity, variations in social obligations, environmental location, livelihood diversification strategies, support networks, empowerment or power relations, access to knowledge, information, and technology (Noronha, 2003). A combination of factors may increase vulnerability or enhance resilience to stresses (i.e. the capacity to cope or respond to stress in different ways). Within the context of climate studies, the most vulnerable are considered to be those who are most exposed to perturbations, who possess a limited capacity for adaptation, and who are least resilient to recovery (Bohle et al., 1994).

4. Methods

Schröter et al. (2005) propose a set of five criteria for global change vulnerability assessments to inform adaptation decision making by stakeholders: they should have a knowledge base from various disciplines and stakeholder participation, be place based, consider multiple interacting stresses, examine differential adaptive capacity, and be prospective as well as historical. On the basis of these criteria, they suggest eight methodological steps. Fig. 2 outlines the various steps taken and methods used in this study correspond to the Schröter et al. (2005) framework.

The study combined watershed modelling with a participatory approach to investigate vulnerability and adaptive capacity to climate variability and water stress in the Lakhwar watershed. Water balance modelling for Lakhwar watershed was carried out using SWAT (Neitsch et al., 2002) and MODFLOW (McDonald and Harbaugh, 1988) models. Areas that would be most affected due to changes in flows and water stresses were identified, and two villages were selected for community-level interactions. This paper does not go into the details of the watershed modelling component, which is summarized below, but focuses more on the participatory assessment.

4.1. Water balance modelling for Lakhwar watershed

Two widely used models viz. SWAT and MODFLOW were used to evaluate water resources for the Lakhwar watershed. While SWAT models the land and water phase of the hydrological cycle that includes surface runoff, soil moisture development and lateral runoff, and groundwater recharge or baseflows, MODFLOW models the groundwater movement.

The input database for the model analysis was built from climatic, pedological, geological, topographical, hydrological, and demographic data listed in Table 2. The modelling, analysis and cartographic representation were carried out in the Arc/Info and ARCVIEW geographic information system (GIS). The model results were validated by comparing the calculated runoff values with actual flows for the sub-basins measured at runoff gauges maintained by the Central Water Commission, Ministry of Water Resources, Government of India.

The hydrological model results for the Lakhwar watershed show that the average daily surface runoff (water yield) is very high. The peak flows are in the range of 600 to >1000 cubic metres per second (cumecs). The average daily flows are in the range of 80–120 cumecs. Surface runoff was found to be the most important component of the overall water balance for this watershed (Table 3). This implies that useful interventions for this watershed could include:

- capturing surface runoff through catchment level rainwater harvesting and local check dams,
- enhancing gravity schemes for water supply to villages, and
desilting and management of local ponds at the village level.

4.2. Site selection

Based on the water balance modelling, the five microwatersheds in the Lakhwar watershed were ranked in terms of relative water stress. The southernmost part of the watershed was identified as the most water stressed with total annual water availability estimated to be 995 mm, followed by the microwatershed immediately to its north where total annual water availability was estimated to be 1030 mm.

The modelling results were shared with a local NGO partner, the Society for Motivational Training and Action (SMTA), to ground-truth the analysis and to identify one village each in the two most water stressed areas. We wanted to select villages that were typical in terms of the economic importance of agriculture and the type of cultivation practiced in the region. While population density in the hills is often low, we attempted to select villages with at least 30–40 households to get a reasonable sample size. Lakhwar village, identified in the most water stressed microwatershed, is characterized by purely rainfed farming, and Chhotou village in the second most water stressed microwatershed has a mix of irrigated and rainfed farming.

4.3. Participatory methods

Participatory learning and action research has evolved as an approach that utilizes the knowledge of poor, rural, natural resource users—recognizing them as “crucial agents of change and development, and not merely targets of technological advice" (Tyler, 2006, p. 20). This “lay knowledge” as opposed to “expert knowledge” (Kasemir et al., 2003) is being increasingly considered relevant to environmental decision making. The two publications cited above demonstrate with respect to community-based natural resource management and global climate change respectively, that understanding the complexity of social and ecological systems and knowing current perceptions of problems and values is essential to effect sustained changes. Further, this approach attempts to conduct field-based social science research in a less
Kasemir et al. (2003) where climate change integrated assessment understanding, and addressing of issues by the local community. Researchers should facilitate the identification, extractive manner, i.e. instead of taking information from respondents, researchers should facilitate the identification, understanding, and addressing of issues by the local community.

The authors drew inspiration from the methods described in Kasemir et al. (2003) where climate change integrated assessment.

Table 2

<table>
<thead>
<tr>
<th>Subject area</th>
<th>Data basis</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic data</td>
<td>Boundaries of the river basin, administrative boundaries,</td>
<td>Survey of India (SoI), Central Pollution</td>
</tr>
<tr>
<td></td>
<td>flowing waters</td>
<td>Control Board</td>
</tr>
<tr>
<td>Climatic data</td>
<td>Daily precipitation, daily temperatures (mean, minimum</td>
<td>Indian Meteorological Department</td>
</tr>
<tr>
<td></td>
<td>and maximum), mean annual precipitation in the hydrological</td>
<td></td>
</tr>
<tr>
<td></td>
<td>winter months, mean annual precipitation in the hydrological</td>
<td></td>
</tr>
<tr>
<td></td>
<td>summer months, mean annual temperature (mean, minimum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and maximum), mean annual potential evaporation</td>
<td></td>
</tr>
<tr>
<td>Soil-physical data</td>
<td>Soil characteristics (% silt, sand and clay), effective</td>
<td>National Bureau of Soil Survey and Land</td>
</tr>
<tr>
<td></td>
<td>root penetration density, useful field capacity, capillary</td>
<td>Use Planning</td>
</tr>
<tr>
<td></td>
<td>elevation, influence on groundwater or perched aquifer</td>
<td></td>
</tr>
<tr>
<td>Land use data</td>
<td>Ground cover</td>
<td>SoI, Satellite imageries, State Agricultural</td>
</tr>
<tr>
<td>Hydrogeological data</td>
<td>Groundwater-bearing lithologic units</td>
<td>Board Geological Survey of India (GSI)</td>
</tr>
<tr>
<td>Topographical data</td>
<td>Mean slope; mean slope exposure</td>
<td>Sol</td>
</tr>
<tr>
<td>Gauge data</td>
<td>Mean flows and mean minimum flows (monthly, annual for</td>
<td>Central Water Commission, Ministry of Water</td>
</tr>
<tr>
<td></td>
<td>30 years)</td>
<td>Resources, Government of India</td>
</tr>
</tbody>
</table>

Fig. 2. Outline of study methodology.

Evans et al. (2006) also describe how natural resource dependent communities can discuss today’s concerns as a starting point for arriving at a vision for the future. “The way that the public understands and defines the issues then becomes a complementary input to the scientific assessment and ultimately the policy making process” (Kasemir et al., 2003, p. 7).

Group discussions were held in each village during May–July 2005 to elicit community perceptions about climatic changes and learn about factors impacting agricultural livelihoods over time. Stratified random sampling was undertaken (details in Section 5.1) and semi-structured interviews were conducted with different types of households to elicit information on their agricultural practices and non-agricultural responses in the face of water scarcity. Key person interviews were carried out with village elders and leaders. Time budgeting exercises were carried out with women. The community in each of the two villages was brought together for group discussions and timeline exercises, separately with men and women. Water availability maps developed in the watershed modelling exercise were shared with the community to stimulate brainstorming on a possible pool of options that would enhance the adaptive capacity of vulnerable households in the long run. A timeline was developed by the community of key developments in the village, including the changing water stress situation, extending into future scenarios for water stress and possible interventions.

5. A tale of two villages: preliminary observations from case studies

Amartya Sen’s entitlements and capabilities approach gives emphasis to differential access, or “entitlement” to resources, as a determinant of household/individual vulnerability (Sen, 1981, 1999). To explore factors influencing vulnerability of agricultural
households over time, and coping measures employed by different types of households, case studies were carried out in Lakhwar and Chhotau villages. This section reports insights gained through group discussions and individual interviews in the two villages.

5.1. Lakhwar and Chhotau: socio-economic profiles

Lakhwar is part of a dense cluster of villages comprising Lakhwar, Dhanpau, Bispnau, Mistau, Jakhnau, and Sawda, about 60 km from Dehradun. The total cultivated and uncultivated area of Lakhwar village specifically is 72 ha. The patwari (local revenue official) had a record of 47 households (5 with medium land-holdings, 15 with small landholdings, and 27 with marginal landholdings), of which we surveyed 30 (5 with medium landholdings, 9 with small landholdings, and 16 with marginal landholdings). Many of the farmers lost irrigated fields during the construction of the Lakhwar dam, and received compensation from the government.

Chhotau village is about 100 km from Dehradun and 10 km from Chakrata town, and is at a height of about 1500 m above mean sea level. The total number of households is 38, of which we interviewed 32. Chhotau can be accessed only by a 1.5 km steep downhill walk. It lacks basic amenities such as electricity, drinking water, toilets, health centre, road connectivity, telephones, and education beyond the primary school level. Houses are made of mud, stone, and wood, and indoor air quality is poor due to the use of traditional cookstoves. Only one house in the village has a toilet. The nearest primary health care centre is in Dehradun. After the fifth grade, students have to walk 6–7 km to the school in Puroli or Chakrata and the nearest hospital is in Dehradun. For many years there has been no snowfall in December. There don't find snow even on Deoban (at a higher elevation). As mentioned before, these communities have traditionally relied on the timely onset of the monsoon (Table 4).

Respondents noted a decrease in scattered light rainfall useful for percolation, and an increase in intense rainfall which destroys crops and runs off. Some of the indicators mentioned by Lakhwar community members were:

- Earlier one could not see the stars throughout the month of shrawana (July/August).
- A few days ago temperature reached 38 C which was unthinkable earlier. Fans were never needed till 2–3 years ago.
- Mosquitoes have become a problem in the last 10 years, although this is not just because of temperature rise but also due to poor drainage and sanitation.
- It used to rain a lot when I came to the village as a young bride. These days the sunshine has more heat.
- Around 1984, rainfall would come in the second week of May, but now it tends to be delayed by a month.
- Maize should have been planted by the beginning of June but the rains have been coming late every year.
- We remember lush yields when we would get tired harvesting the crop. Now it does not rain on time—what will grow in the fields?
- Groundwater has been declining. There is acute lack of water in streams in the lean season.

In Chhotau the more obvious indicator was the decline in snowfall:

- When we were children the December snow would stay on the roofs till March, forming layers of frost and ice.
- During the annual fair in April in Chakrata Bazaar, the army would have to push the snow to the sides of the road. Now you don't find snow even on Deoban (at a higher elevation).
- For many years there has been no snowfall in December. There is late snow in January–February when temperatures are already rising—it melts away and does not feed into the streams.
- As children, as soon as we saw rain, we would bring down the livestock from the hilly slopes, to save them from being drowned. Now the streams are all dry.
- 35–40 years ago it used to snow for stretches of 2–4 days when livestock were kept in the house and men would stay indoors and play cards. The snow was like manure—knee deep snow that covered the ground and retained soil moisture underneath.
- It should rain in vaisakha–jyaishtha (i.e. April/May) but the rains are delayed by 2 months. This year the gagli and ginger

### Table 3

<table>
<thead>
<tr>
<th>Period of simulation</th>
<th>5 years</th>
<th>As % of precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average precipitation (mm)</td>
<td>1848</td>
<td></td>
</tr>
<tr>
<td>Actual evapotranspiration loss (mm)</td>
<td>663</td>
<td>36%</td>
</tr>
<tr>
<td>Recharge (mm)</td>
<td>144</td>
<td>8%</td>
</tr>
<tr>
<td>Surface runoff (mm)</td>
<td>1041</td>
<td>56%</td>
</tr>
</tbody>
</table>


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4 Work on Lakhwar dam on the Yamuna river started in 1976, but was halted due to the high cost of production.

5 A cooperative society is a collectively owned enterprise, for instance farmers organizing themselves to market their produce collectively. Agricultural credit cooperatives have existed in India for more than a hundred years. Successful examples in sugar production in Maharashtra state and dairy marketing in Gujarat state have shown how cooperatives can be vehicles of self-empowerment and rural development.
heavily on rainfall, and hence the challenges they face are two-

The traditional cropping pattern in the region was called "barahnaj", literally "twelve seeds" that were grown together to protect common lands. Without collective ownership, there is no incentive to manage resources collectively. People remember collecting wood from thick forests as a young boy in the 1960s. Now there are eucalyptus plantations that soak up water excessively. Deforestation in Uttarakhand has its roots in the expansion of the British empire in India—the growing demand for sleepers by the railways, timber and fuel for new emerging cantonments and hill stations—and reached a peak during the Second World War (Dangwal, 2005). The traditional forests in the hills were replaced by commercial monoculture plantations of pine trees for railway sleepers and turpentine, which had a negative impact on the soil texture (Furtado, pers comm). However, at present the tendency is to cut trees indiscriminately for timber and firewood, and to start forest fires to encourage regrowth for cattle fodder. There are no joint forest management programmes or awareness initiatives in this region. Without collective ownership, there is no incentive to protect common lands.

5.3. Changes in cropping patterns and agricultural practices

Onset of rainfall has become erratic (%) 32 69
Onset of rainfall has become late (%) 65 25
Rainfall has declined over the last 10–15 years (%) 90 87.5

There was concern that rainfall is lost to surface runoff, streams and springs are drying up, and soil moisture has declined.

Many people linked these climatic changes to deforestation and forest fires. A farmer remembered collecting wood from thick forests as a young boy in the 1960s. Now there are eucalyptus plantations that soak up water excessively. Deforestation in Uttarakhand has its roots in the expansion of the British empire in India—the growing demand for sleepers by the railways, timber and fuel for new emerging cantonments and hill stations—and reached a peak during the Second World War (Dangwal, 2005). The traditional forests in the hills were replaced by commercial monoculture plantations of pine trees for railway sleepers and turpentine, which had a negative impact on the soil texture (Furtado, pers comm). However, at present the tendency is to cut trees indiscriminately for timber and firewood, and to start forest fires to encourage regrowth for cattle fodder. There are no joint forest management programmes or awareness initiatives in this region. Without collective ownership, there is no incentive to protect common lands.

5.4. Women’s role in agriculture

Women bear the major burden of performing agricultural operations and gathering supplies for household needs. Time accounting exercises showed that they spend 14 h a day working in the fields, and gathering fodder and firewood, preparing manure, collecting drinking water, rope-making, hay-making, etc.

fold. On the one hand there are climatic and ecological stresses, while on the other, newly emerging economic and societal structures—and these two kinds of stresses must be studied in conjunction to get the true picture of vulnerability (O’Brien and Leichenko, 2004).

1. Economic pressures: The fragmentation of land holdings in the hills prevents economies of scale and creates challenges for irrigation and pest management. With poor road connectivity and frequent landslides during the rains, the lack of transportation, storage, and marketing facilities is obviously a prohibitive barrier. Farmers do not consider it worthwhile to transport their small quantities of produce to distant markets where the price may be higher. As more and more land is brought under vegetable cultivation, oversupply combined with the absence of cold storage facilities and the high price of seeds means that farmers become price takers. A Lakhwar village elder remembered that in the 1960s, Lakhwar had a self-sufficient agriculture-based economy, with only one person in the village working in the service sector. But now aspirations for city living standards and the lack of other economic opportunities in the villages have meant that the younger generation no longer considers agriculture as a viable livelihood.

2. Climatic and ecological stresses: Although Chhotau has some irrigated fields,7 the river dries up in the summer. Crops like potatoes, peas, gogli, and ginger have all been damaged in the last 5–10 years due to late rains. The availability of fodder goes down in the summer, livestock ownership is also reduced, and with it milk production and manure availability declines. It is no longer possible to cultivate millets like mundhwa and todiya, and pulses like urad that grew on residual soil moisture after the maize crop had been harvested.8 The winter rains are also delayed, and the wheat crop has been very poor for the last 10–15 years. About 15–20% of the agricultural land is left barren.

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<ref>Table 4</ref>

<table>
<thead>
<tr>
<th>% of respondents</th>
<th>Lakhwar</th>
<th>Chhotau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall has declined over the last 10–15 years (%)</td>
<td>90</td>
<td>87.5</td>
</tr>
<tr>
<td>Onset of rainfall has become late (%)</td>
<td>65</td>
<td>25</td>
</tr>
<tr>
<td>Onset of rainfall has become erratic (%)</td>
<td>32</td>
<td>69</td>
</tr>
</tbody>
</table>

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6 Mandua (finger millets), ramdana/chua (amaranthus), rajma (common kidney beans), ogal (buckwheat), urad (green gram), moong (black gram), naurangi (mix of pulses), gahath (horsegram), bhat (soybean), lobiya (French beans), kheera (cucumber), bhang (cannabis) and other crops.

7 About 10–15% of the cultivated land is river irrigated, while fields on higher slopes are rainfed.

8 Chopra and Pasi (2002) have highlighted the impact of this trend on protein intake and food security.
Agrawal (2002) points out that men tend to perform agricultural operations where they have a dominant role involving animals or tools, whereas women's jobs depend on manual labour, and hence have a lower status. Often women are the only family members remaining in the village to tend to the fields while the men look for city jobs. The result is an acute shortage of manpower, and rising cost of agricultural labour. Several girls are enrolled in city schools and colleges but go to the city only to appear for examinations, while working on the fields the rest of the year. But there is also some awareness of the successful examples of nearby villages: in Dhanpau village, women made and sold organic manure, while in Luhan village, farmers formed a cooperative society and were able to command good prices for chillies and gagli.

5.5. Coping measures

Households engaged in agriculture can employ a range of strategies in responding to water scarcity (Narain, 2003):

- by improving their access to available water (e.g. makeshift storages, digging deeper tubewells, exchanging irrigation timeshares, buying groundwater, and engaging in water theft),
- by reducing their demand for water (e.g. switching to less water intensive crops, adopting more efficient irrigation practices, and altering dates for agricultural operations),
- by coping with the adverse impacts of periodic drought (e.g. credit, sale of valuables and livestock, use of stored seeds and foodgrains) and
- by diversifying their sources of livelihood (e.g. alternative employment opportunities, migration).

Fig. 4 shows coping options employed in Lakhwar village. Many households report that in poor rainfall years they shift to less water-intensive crops or look for other sources of employment. Other options include obtaining loans or selling assets during low income periods. However, closer analysis reveals that it is the higher-caste Rajput families who report that they take loans, in addition to “other” options such as “son sends cash”, “help from brother”, or “buying food from market”. The lower caste farmers have no option but to find other labour related jobs. The average annual income reported by Harijan households was about USD 1621 with agricultural income supplemented by income from service, pension, and money sent by family members.

In Chhotau the picture is more “equitable, if impoverished” with Joshi (Brahmin) families reporting an average annual income of USD 408 and Harijan families reporting USD 380. When the river starts drying up in the summer, farmers take turns to flood their fields and stay up all night till the fields slowly fill up. People keep fewer livestock, and the quantity of milk is reduced.

Traditional money lenders charge interest of 5 Rupees per month per 100 Rupees, i.e. 60% per annum. Commercial banks charge 10–12 or 18% but there is cumbersome paperwork involved and distrust due to poor understanding of terms and conditions. Reciprocal exchange of cash, produce, and most importantly, labour is a common coping strategy in the hills, particularly in the face of manpower shortages (Agrawal, 2002).

5.6. Scenarios and interventions

In group discussions carried out separately with men and women in the two villages, the results of the watersheds modelling exercise were shared through a series of coloured charts (Fig. 5). The participants expressed keen interest in the exercise and related it to the water stress they were currently facing. They were requested to recall and prepare a timeline of key developments that have taken place in the village over the last fifty years, and have impacted their lives and livelihoods (Fig. 6). They were asked to reflect on the watershed modelling results and brainstorm about future scenarios. This helped stimulate discussion about possible adaptation interventions, which are summarized in Table 5.

6. Discussion

The survey in Lakhwar and Chhotau villages revealed that current coping capacity of people in the region to climate variability and water stress is quite low. Households are considerably dependent on low-value rainfed agriculture. Institutional capacity is also poor, particularly in terms of connectivity and the availability of formal credit, which constrains their ability to use their agricultural skills and assets more effectively. They also have limited human resources in terms of formal education or vocational skills, which limits their options in seeking off-farm employment opportunities.

The types of responses to poor rainfall reported by households are only temporary coping measures, some of which, like selling assets or taking loans from traditional moneylenders, may actually increase their vulnerability over time by worsening impoverishment or indebtedness. As they move towards non-agricultural jobs in the city, they appear to be making a more lasting adaptation to climate stresses, but in so doing many are becoming more vulnerable due to dislocation and disruption of their familiar way of life.

In general, the richer and more detailed scenario discussions in Lakhwar reflect the higher education levels and relatively more comfortable economic status of this community. Both villages, however, were similar in their belief that agriculture in its present form is simply not a viable livelihood for future generations. There was concern about unemployment (“crime will rise and we will get the same atmosphere as in the plains”), and the discussions focused less on interventions related to water resources and more on alternative livelihood opportunities. There was a sense that one cannot go back to the old way of life due to changing economic structures, tastes, and aspirations.

Many of the desired interventions are highly ambitious and require not just technical inputs but demand surveys and a reliable raw material sourcing and marketing chain. However, water harvesting interventions are clearly feasible, and are being promoted by the Government of Uttarakhand, albeit in a top-down manner without always understanding the ground situation. One of the success stories reported by the Watershed
Management Directorate of Uttarakhand is water harvesting in village Kui in Nir microwatershed. The village, with 31 households, had only a pipeline with scanty and irregular flow, 1 km below the habitation. Twenty-eight roof harvesting tanks were constructed, with the villagers being responsible for the purchase of collection pipes. There was a positive impact on agriculture, hygiene, and women’s daily burden. While earlier the villagers grew few vegetables (potato, garlic, coriander) in the rainy season in their homestead to meet their household needs, they could now grow onion, green pea, and carrot, and increase the production of potato, garlic, and coriander, making a profit of Rs 587–1030 per household. Hygiene too improved with availability of water allowing regular bathing, washing of clothes and of animals. Time spent by women on collecting water also reduced considerably (Watershed Management Directorate Uttarakhand, 2004).

7. Conclusions

The study was formulated as a pilot case for the application of a participatory approach, whereby insights can be gained into vulnerability and adaptive capacity through mutual learning and exchange with the affected communities. The interactions with communities acutely highlighted the mismatch between top-down policy recommendations and ground-level needs and aspirations. It is difficult to reconcile a situation where there is severe lack of water and near abandonment of farming as a livelihood, with the National Water Policy (2002) which lays emphasis on the sale of water, and the right of the government or gram sabhas to sell excess water.

The sharing of modelling results with the community, however, can benefit through the presentation of more dynamic information. The replication and refinement of the study methodology can help
develop a programme of participatory research on adaptation responses to water stress that are evolved by the affected communities themselves. Such a programme can help policymakers more effectively target resources to minimize the adverse effects of current and future water scarcity.

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