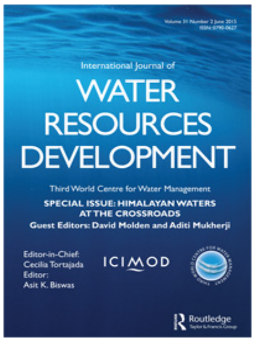

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Farmers' responses to climate change impact on water availability: insights from the Indrawati Basin in Nepal

Neera Shrestha Pradhan[a]*, Suman Sijapati[b] and Sagar Ratna Bajracharya[a]

[a]*International Centre for Integrated Mountain Development, Kathmandu, Nepal*
[b]*INPIM, Kathmandu, Nepal*

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There is a need to assess the potential impacts of climate change on agriculture in order to plan appropriate adaptation measures. Farmers are already adapting to these changes to a certain degree. This article presents a case study of rainfed and farmer-managed irrigated agriculture in the Indrawati Basin, Nepal. It describes farmers' perceptions of climate change, an analysis of historical water availability, and future projections of temperature and precipitation. Adaptation strategies already being used by farmers are identified and new ones are recommended based on primary information collected from farmers and an in-depth analysis of the climate data.

Keywords: Indrawati Basin; Nepal; climate change; farmers' perception; water availability; adaptation; projections

Introduction

There is a consensus that climate change will bring about long-term adverse impacts not only on water resources (IPCC, 2007) but also on agriculture (Nelson et al., 2009), ecosystems (Littell, McKenzie, Kerns, Cushman, & Shaw, 2011), and human and environmental health (Patz, Campbell-Lendrum, Holloway, & Foley, 2005; Malik, Awan, & Khan, 2012). The effect on water availability is likely to be profound and will affect agricultural production (IPCC, 2007; Parry, Rosenzweig, Iglesias, Livermore, & Fischer, 2004). South Asia (Nelson et al., 2009) and the entire Hindu Kush Himalayan region (Lutz, Immerzeel, Shrestha, & Bierkens, 2014) are expected to be hit particularly hard.

With high rural poverty and rapid climate change, the Himalayan nation of Nepal is a hot spot of climate change impact. Agriculture is the economic sector most sensitive to climate change, as changes in temperature, precipitation, wind speed and atmospheric condition can have significant impacts on crop productivity (Rakshit, Ewbank, & Bhandari, 2014; Meza & Silva, 2009) and are likely to shape the future of food security (Lobell & Gourdji, 2012). Given the significance of changes in water for agriculture, farmers have developed adaptation and coping strategies as a general survival strategy (Pradhan, Khadgi, Schipper, Kaur, & Geoghegan, 2012; Reid & Schipper, 2014). Responses include changes in cropping patterns, such as alternative crop rotation; selection or genetic development of new crop varieties; increasing efficiency in agricultural water use; altering the timing or location of cropping activities and calendar; changes in crop management (use of inputs, alternative tillage systems, proper irrigation and drainage); changes in agricultural policy; and capacity building (Salinger, Sivakumar, & Motha, 2005; IPCC, 2007).

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*Corresponding author. Email: Neera.Pradhan@icimod.org

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Adaptation strategies have a wide range of possible forms (managerial, financial, technical), scales (local, regional, global), and participants (farmers, industries, governments) and need to be carefully tailored to meet the needs of specific locations and situations (Smit & Skinner, 2002). Given the wide range of farmers' responses to change, it is important to evaluate the effectiveness of different adaptation strategies based on farm type, location, climate stimuli, and economic, political and institutional conditions (Smit & Skinner, 2002; Ficklin, Luo, Luedeling, & Zhang, 2009). In addition, the coping capacity of the rural poor is low, especially in marginal areas, and there is a need to mainstream good practices for climate change adaptation into sustainable development planning. (Sivakumar & Stefanski, 2011). This article is intended to contribute to the growing body of knowledge on such practices and to help fill the knowledge gap by assessing the impact of climate change on water resources and community-managed irrigation systems in the Indrawati River basin in Nepal and identifying feasible adaptation measures to enhance farmers' coping strategies.

Methods

Study area

Indrawati is one of the seven sub-basins of the Koshi Basin in the central region of Nepal. Geographically, it extends from 27°37′11″ to 28°10′12″N latitude and 85°45′21″E to 85°26′36″E longitude and covers 1239 km^2 of catchment area. The river originates in the high Himalayas and flows south across Nepal for 59 km before meeting the Sun Koshi River at Dolalghat (Figure 1). The basin falls in the alpine and subtropical climatic zones; 44% of the total area is covered by natural forest, 33% by agricultural land, and 12% by ice and snow (Mishra, 2001).

The average annual rainfall in the basin ranges from 3874 mm at higher elevations (Sarmathang) to 1128 mm at the lowest elevation (Dolalghat), with high spatial and temporal variation (Mishra, 2001). About 93% of the precipitation falls between mid-May and mid-October. The average annual potential evapotranspiration is about 954 mm (WECS/IWMI, 2001). The relative humidity varies from 60% in the dry season to 90% in the rainy season, with an average of 75%. The water flow in the river has significant seasonal variation, with 90% of the total occurring from June to October (Mishra, 2001). There is marked variation in crops and cropping patterns within the basin, with rice, maize and vegetables in the lower elevation zones and potato, millet and beans in the higher elevation zones. The basin is of significant national importance in view of its high potential for irrigated agriculture, cultivation of high-value crops, livestock production, possibility of providing water to the capital city of Kathmandu, potential for hydroelectric power development, and ecotourism.

Considering the diverse topography and climate of the basin, for this study, the entire basin is divided into five zones (Figure 1). Zone 1 is most suitable for agriculture, primarily because of higher temperature, less elevation change, and fertile soils (in the flood-plain of the river). Land availability is limited but used for agriculture and settlements (33.6 households/km^2). Zone 2 and 3 has more land availability than zone 1 but less intensity of agriculture and more settlements (42.8 and 49 households/km^2 respectively). Zones 4 and 5 are less suitable for agriculture and have fewer settlements (21.7 and 3.4 households/km^2, respectively).

For this study, 10 representative villages were selected (2 from each zone), with average family size of 5.7 members (50.5% men and 49.5% women). The majority of the inhabitants of the study area reported that agriculture has been their sole occupation, which makes them

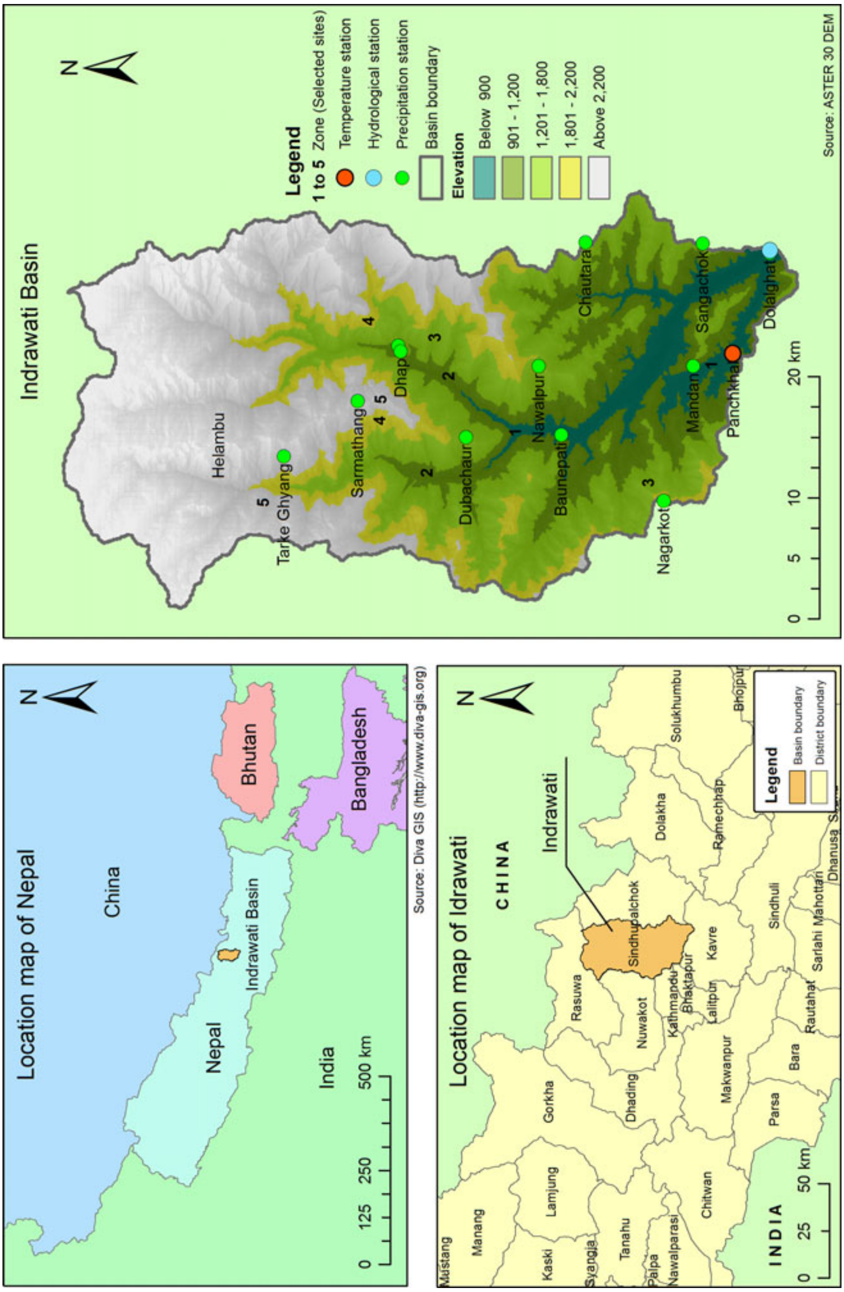

Figure 1. Location, elevation, and zones of the Indrawati Basin, Nepal. *Note*. The international boundary is from the Diva GIS data-set (http://www.diva-gis.org/Data).

highly dependent on agriculture for income generation. The average annual household income (in cash) of farmers in the study area is about USD 1000 (max. USD 6000, min. 100). Eleven per cent of the total population of the study area (15% of men and 7% of women) migrate for work and send back remittances. The average landholding among respondents is 4528 m^2, the most prevalent land types being gently sloping, terraced, flat and steep. In terms of education, 37% of the total population reported no education, 37% basic education (below secondary level), and 26% some secondary education.

Methodological framework

The study was conducted using a methodological framework including geophysical and social science perspectives (Figure 2).

Hydrological modelling

The study included hydrological modelling and analysis using the Soil and Water Assessment Tool (SWAT) and analysis of climate data using a statistical downscaling model (SDSM) to compare present and future water and climate scenarios.

SWAT (Arnold, Srinivasan, Muttiah, & Williams, 1998, Neitsch, Arnold, Kiniry, Williams, & King, 2002) is a distributed-parameter and continuous-time simulation model. The SWAT model predicts the hydrological response of ungauged catchments to natural inputs and human interventions, assessing water quality and water and sediment yields. The model, physically based using readily available inputs, is computationally efficient and capable of simulating long periods to compute the effects of management

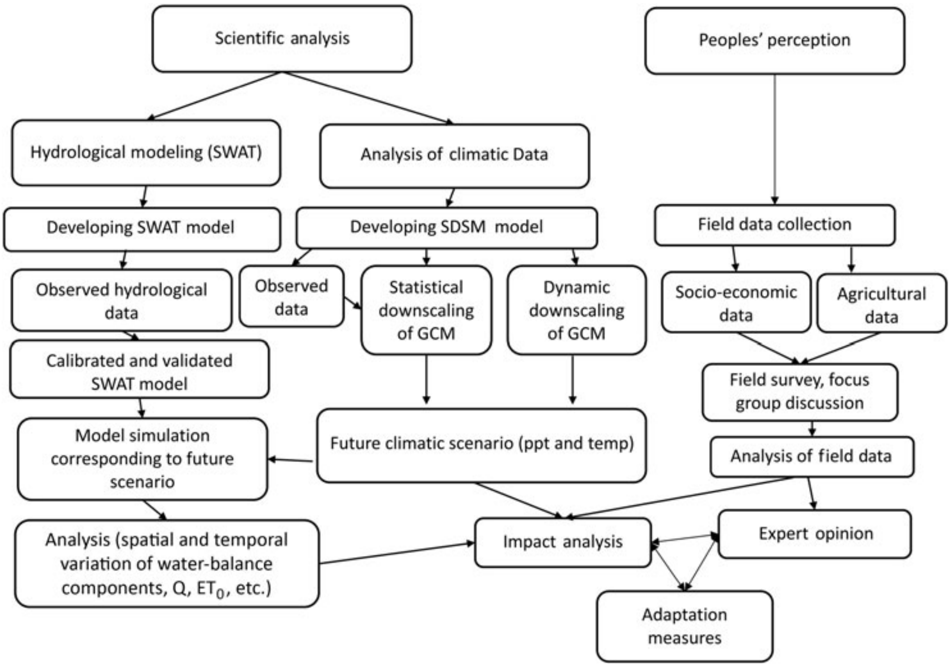

Figure 2. Methodological framework. *Note*. SWAT = Soil and Water Assessment Tool. SDSM = statistical downscaling model. GCM = general circulation model.

changes. The major advantage of the SWAT model is that unlike the other conventional conceptual simulation models it does not require much calibration and therefore can be used on ungauged watersheds.

The SWAT model in this study included data from a digital elevation model from the Shuttle Radar Topography Mission website (http://srtm.csi.cgiar.org) with a specific spatial resolution of 90 m by 90 m; data from the Soil and Terrain database (SOTER) based on ISRIC World Soil Information (http://www.isric.org); a global land cover map, used to represent the existing land cover system of the basin (http://www.waterbase.org); and daily meteorological data (precipitation, temperature, relative humidity and others) from the Department of Hydrology and Meteorology of Nepal (http://www.dhm.gov.np). The SWAT model used available data with 1981–2000 as the baseline period and was calibrated against the observed discharge using daily and monthly data. The results from the model were used to assess both the hydrological water balance and the projected impact of climate change on water availability.

Climate data were extracted for one grid point (27.5°N, 86.25°E; spatial resolution 2.5° × 3.75°) at a daily time scale. Future data from a selected emission scenario (HadCM3 A2) were generated using a statistical downscaling model (SDSM 4.2) to produce high-resolution monthly climate information from coarse-resolution general circulation model (GCM) simulations. Data from 11 meteorological stations were collected and processed to generate future scenarios of precipitation. The developed model was used to obtain projections of maximum and minimum temperatures and precipitation from simulations of HadCM3. The analysis was performed on a monthly basis, and all evaluations were carried out on a seasonal basis. The climate scenarios were then generated in terms of multi-decades, i.e. 2020s (2010–2030), 2055s (2046–2065), and 2090s (2080 to 2099).

Social survey

The social research included farmer interviews conducted using a semi-structured questionnaire focusing on climate parameters, prevailing agricultural practices, perception of change in climate parameters, and responses to climate change. The data were analyzed by the study team members and verified by relevant experts working in similar fields, and the results were used to develop recommendations for possible responses to likely future change in the Indrawati Basin.

The Indrawati Basin varies significantly in terms of topography. Starting from an elevation of about 616 m above mean sea level at Dolalghat (the pour point of the basin), it goes as high as 6359 m. The climate, natural vegetation, agricultural systems and land cover vary with elevation. Following the procedure of stratified random sampling, five zones (Figure 1) were divided considering that the effect of climate change and the consequent required adaptation measures would be different in different agro-climatic zones. Further, socio-economic, agricultural and farmers' perception data were collected using a survey questionnaire at 10 sample villages selected to represent the different zones (2 villages per zone). A total of 166 respondent households (80% male, 20% female respondents) were selected using random sampling (Table 1).

Farmers were asked about their perceptions of changes in water availability, agricultural patterns, and rainfall and temperature patterns in the last 10 years (2002–2012), as well as their opinions on future climate change, its likely impact on their lives and livelihoods, and existing and potential adaptation measures. The data were analyzed using standard statistical analysis. The results were used to identify existing and future adaptation measures.

Table 1. Sample selection in the Indrawati Basin (site locations are shown in Figure 1).

Zone	Elevation (m asl)	zone	Village	Total households (Source: Survey Department, 2005)	Sample households
1	<900	1	Kunta Besi	60	34
			Melamchi Bazar	72	
2	900–1200	2	Tipeni	23	34
			Kiul	17	
3	1200–1800	3	Thangpal Dhap	27	34
			Nangle	42	
4	1800–2200	4	Thangpal kot	25	32
			Timbu	26	
5	>2200	5	Melamchigau	57	32
			Shermathang	41	
			Total	390	**166**

Results and discussion

Historic temperature change

Almost all the respondents (97%) believed that the average temperature in the Indrawati Basin had changed compared to the previous decade (Table 2). Nearly half (46%) thought that temperatures were slightly higher, with 31% saying that the hot seasons had become hotter, and more than a third (37%) thought that frost was less common; but 19% thought that the cold seasons had become colder. All those who reported no change in temperature were from zone 1 (elevation less than 900 m; see Table 1).

For this study, daily temperature and precipitation data were used to compute climate change indices using specially designed software, RClimDex (1.0), which is a freely available tool designed to provide a user-friendly interface to compute indices of climate extremes (http://www.climdex.org/indices.html) and runs in the R programming environment (http://www.r-project.org/). RClimDex performs in R Console and also includes a data quality control procedure before computing the indices. It computes 27 core indices recommended by the Commission for Climatology, the World Climate Research programme’s Climate Variability and Predictability component project, and the Expert Team on Climate Change Detection Monitoring and Indices. Of the 27 climate indices, 11 are precipitation indices and 16 are temperature indices. However, only the relevant parameters were selected for this study.

Analysis of climatic data from the Nagarkot meteorological station (SI1043) from 1975 to 2010 showed that daily maximum temperature increased by 0.01 °C/y, and daily minimum temperature by 0.05 °C/y. Increases were also observed in the annual count of days when daily maximum temperature was greater than 25 °C (+0.26 days/y), warm days

Table 2. Respondents’ reports of temperature changes ($n = 166$).

	Yes (%)	No (%)
Change in average temperature compared to last decade	97	3
Temperature slightly higher	46	54
Hot seasons hotter	31	69
Cold seasons colder	19	81
Frost less common	37	63

(+0.36 days/y), warm nights (+0.5 days/y), cool nights (+0.12 days/y), and the average duration of warm spells (+0.02 days/y).

Warming is more noticeable in the daily minimum temperature trend than in the daily maximum temperature trend. However, there was no change in the monthly mean difference between maximum and minimum temperature. Therefore, although people have noticed a change in average temperature compared with the last decade, they have adapted to this change in that period of time. There was no change in the number of cool days per year. The results indicate that the hot seasons are becoming hotter but there is no change in the cold seasons, which is consistent with the farmers' perceptions (Table 2).

Projected temperature change

Figure 3 shows the baseline (1990) and projected maximum and minimum temperatures for 2020, 2055 and 2090 for the Indrawati Basin (average of the two available stations). The model simulation indicates a rise in daily mean maximum and minimum temperatures in the region by 2090, with a more pronounced increase in the minimum than in the

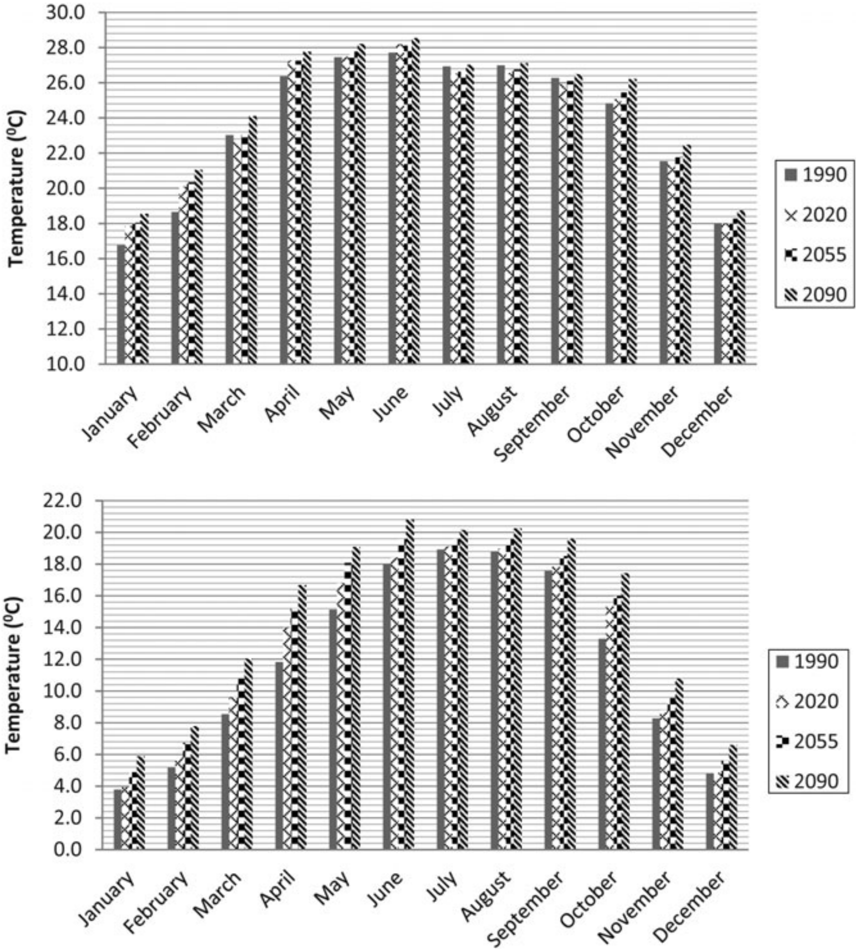

Figure 3. Mean daily maximum (a) and minimum (b) temperatures in the Indrawati Basin, projected from the downscaled climate change scenario.

maximum. These results are in agreement with previous studies for the Indus using the PRECIS model over three time slices – near future (2011–2040), mid-century (2041–2070), and distant future (2071–2098) (Rajbhandari, Shrestha, Kulkarni, Patwardhan, & Bajracharya, 2014).

The changes in projected temperature indicate that in the future, winter and spring crops might be adversely affected by higher temperatures. The impact will be more pronounced at lower elevations, where the prevailing temperature is already high. The increase in temperature will have a marked negative impact on those crops which are already being grown close to their temperature tolerance threshold (Sivakumar & Stefanski, 2011).

Historic precipitation change

Precipitation change appeared to be a greater cause of concern among our respondents than temperature change. Three-quarters (74%) of all respondents reported experiencing changes in the amount of annual precipitation, and 72% of these reported a declining trend. Almost all (99%) respondents noted changes in the precipitation pattern, including a decrease in the number of snowfall days (reported by 36%) and a decrease in precipitation intensity (reported by 38%). In addition, 27% believed that rainfall had become more erratic in general, and 53% noted a delay in the arrival of the rains; 28% believed that hailstorms had become less frequent.

Analysis of the rainfall data from Nagarkot meteorological station (SI1043) from 1975 to 2010 showed fluctuations but no significant long-term trend in total annual rainfall (Figure 4). However, there were some long-term trends in the pattern of the rainfall. The total annual precipitation on wet days increased by 3.33 mm/y, the monthly maximum 1-day precipitation by 0.36 mm/y, and the number of consecutive dry days by 0.85 days/y. The number of days with precipitation over 50 mm decreased by 0.02 days/y, whereas the number of days with precipitation over 100 mm increased by 0.02 days/y. The change towards fewer but wetter wet days indicates a tendency towards more erratic patterns of rainfall and an increase in extreme events. The results are not consistent with

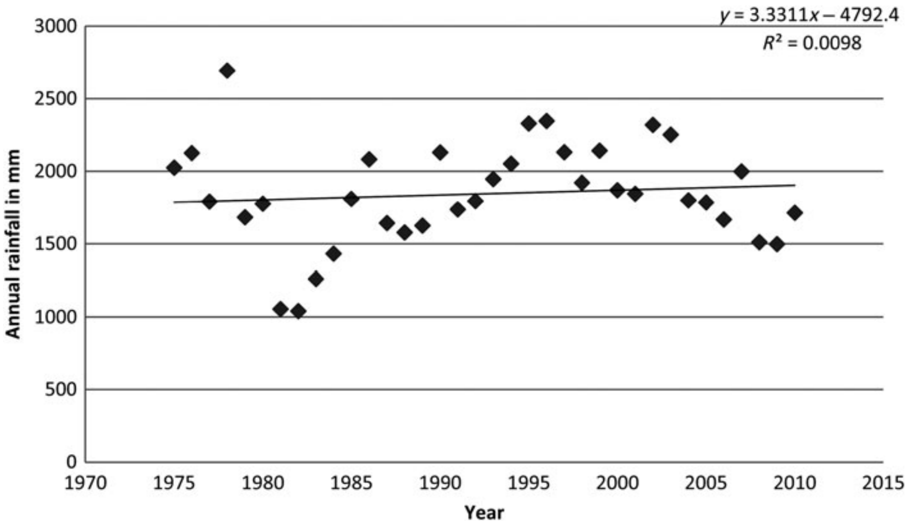

Figure 4. Average annual rainfall at the Nagarkot (SI1043) station.

Table 3. Projected variation of rainfall (as a percentage of the 1990 baseline) in the Indrawati Basin (HadCM3 A2 scenario).

Season	Late winter		Spring			Summer			Autumn		Early winter		
Month	1	2	3	4	5	6	7	8	9	10	11	12	Annual
2020s	0.8	− 28.3	60.0	27.4	11.9	7.8	− 11.2	− 3.4	− 11.3	9.9	72.0	73.1	− 0.9
2055s	− 20.1	− 23.5	47.3	17.5	8.0	16.4	− 20.9	− 4.8	− 13.3	− 5.4	111.0	65.3	− 1.4
2090s	− 6.8	− 43.4	38.3	7.2	4.1	23.4	− 38.9	− 6.8	− 11.1	− 9.0	120.7	102.2	− 3.0

farmers' perceptions that overall rainfall has decreased, but they are consistent with their observations of more erratic rainfall.

Projected precipitation change

Table 3 summarizes the variation of the projections for precipitation in the Indrawati Basin from the baseline. The projections show a gradual slight decrease in annual average rainfall, by 0.9% of baseline in the 2020s, 1.4% in the 2055s and 3.0% in the 2080s. There is a clear increase in rainfall during the early winter months (120% of baseline for November and 102% for December by the 2080s), and a small increase in spring and early summer, but a decrease in late winter, mid-to-late summer, and autumn. These results indicate that farmers will need to adapt to changing rainfall patterns.

The results from the individual meteorological stations show a high spatial variation across the basin in both the magnitude and direction of projected precipitation change, with a decrease in average annual rainfall in the vicinity of 6 of the 11 stations, which was more pronounced at low elevation (Zones 1–3; see Table 1). The results also suggest the possibility of precipitation being more concentrated, with fewer rainy days, which could make the basin more prone to flash floods and landslides. The trends were not significant.

Trends in water availability

Streamflow was assessed to provide an estimate of water availability in the basin. Due to the lack of long-term observations of discharge in the study area, it was not possible to analyze the trend in streamflow accurately. The simulated values from the calibrated and validated SWAT model were used to evaluate the trends in streamflow and thus water availability in the basin for 1980–2008. The influence of land cover changes during the simulation period was not taken into account in estimating the water availability. The trend in streamflow was evaluated for the entire Indrawati Basin at the exit point in Dolalghat; the results are shown in Figure 5.

No significant trend was seen in annual water availability between 1980 and 2008. There was no significant overall trend in average annual precipitation, although this does not exclude the possibility of changes in precipitation pattern such as changes in the number of dry days, wet days, frequency, or intensity. The contribution of snowmelt to stream flow is not significant. In addition to annual values, an attempt was made to analyze the trend in water availability on a seasonal basis in winter (December–February), spring (March–May), summer (June–August) and autumn (September–November). Overall, no trend was observed during the simulation period in any of the seasons.

Farmers in the study area had a general perception that there had been a decrease in water availability for irrigation and agriculture over the last decade, with 84% of respondents experiencing a decline in water supply in the past 5 to 10 years (Figure 6).

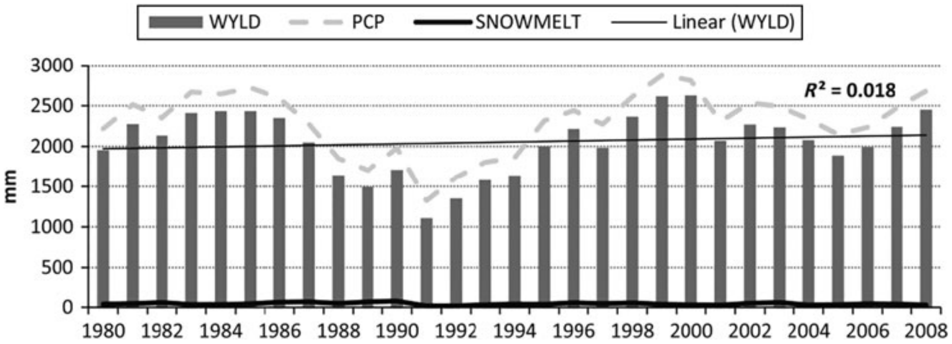

Figure 5. Annual trend in water availability at Dolalghat in the Indrawati Basin. *Note*. WYLD = water yield of the whole Indrawati Basin. PCP = precipitation.

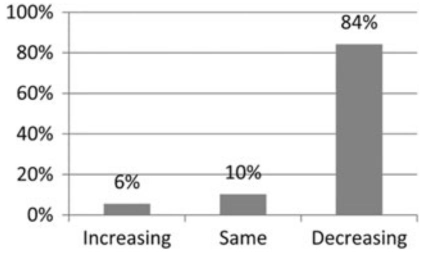

Figure 6. Perceptions of water availability in the Indrawati Basin.

Almost a quarter of respondents (23%) said that water sufficiency was less than 60% of the agricultural requirement. This might be due in part to changes in cropping patterns in the area, with farmers now cultivating three crops per year, rather than two, over the past 10 years (2002–2012). Another factor is likely to be the change in diet; the development of local markets has encouraged farmers to cultivate paddy, which has a high water requirement. The perceived inadequacy in water supply is also likely to be due in part to the low efficiency of the irrigation systems, which are not properly maintained. Managing an efficient irrigation system is likely to be one of the most effective adaptation measures for addressing the competing demands for water from different sectors. Another plausible reason for water scarcity perception is changes in local water regimes – such as localized springs – which may or may not have direct hydrological links with river flows. In the mid-hills (i.e., the terrain between 700 and 2000 metres above sea level), most of the people depend on springs for their water needs, including irrigation. There is anecdotal evidence from all over Nepal that such springs are either drying up or yielding less water than before, though there are almost no systematic studies to confirm such perceptions. Farmers variously attribute the failure of springs to road construction, changes in land use and land cover (such as the planting of single-species forests, like pine), earthquakes and forest fires.

Changes in cropping patterns and crop productivity

Climate change and other drivers of change affecting water availability are expected to have a significant effect on crop production. The productivity of most crops has either remained constant or gradually increased over the past 10 years (2002–z2012), with the exception of wheat and to a lesser extent spring maize, which show a small decline

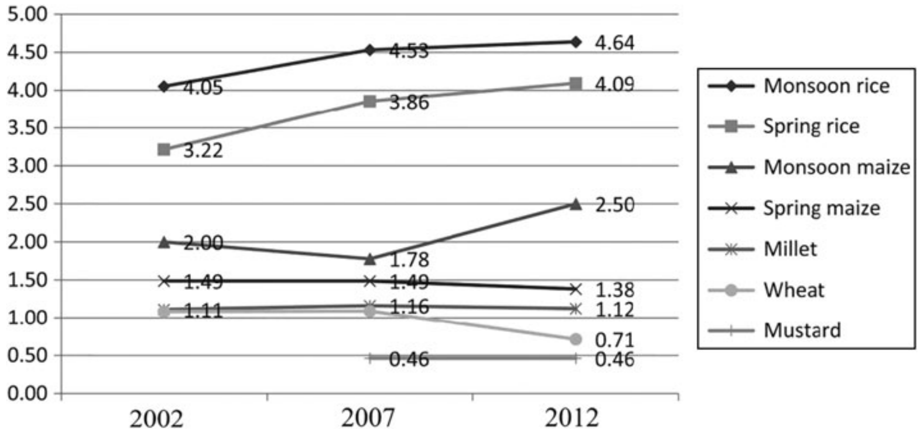

Figure 7. Productivity of crops between 2002 and 2012 in the Indrawati Basin (1 muri/ropani = 0.98 t/ha). (No early data are available for mustard seed as it is a recent crop.)

(Figure 7). Sivakumar and Stefanski (2011) calculated that a 0.5 °C rise in winter temperature could reduce wheat yield by 0.45 t/ha in India because wheat is already being grown close to its temperature tolerance threshold. They noted that a temperature rise of more than 2.5 °C could lead to a significant decrease in yields of non-irrigated wheat and rice, and that this could lead to a loss in farm-level net revenue of 9–25%. Crop yield projection results obtained using the HadCM2 climate model have shown that crop yields could increase by up to 20% in South-East Asia, but in contrast could decrease by up to 30% in South Asia even if the direct positive physiological effects of CO_2 are taken into account (Cruz et al., 2007).

According to the field survey, most farmers have retained the same overall cropping patterns in recent years but they have changed some of the crops that they cultivate, abandoning some and introducing others (Figure 8). The crops that they have most commonly stopped growing are pulses, especially grey pulses (*gahat*), black gram (*mas*),

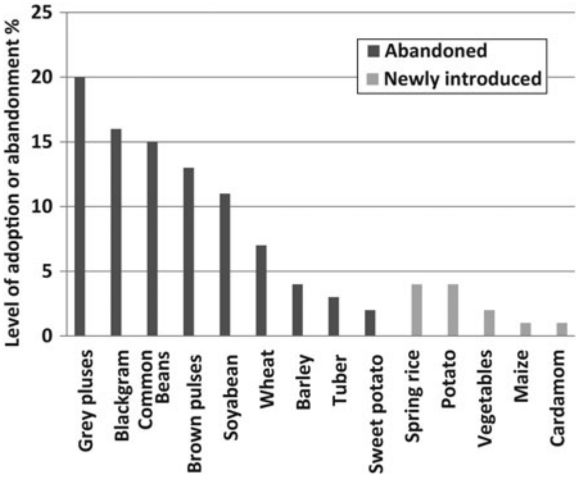

Figure 8. Abandoned and newly introduced crops in the Indrawati Basin.

common beans (*bodi*), brown pulses (*mashyang*), and soya beans (*bhatmas*). Some cereals, like barley (*phaper*) and in a very few cases millet (*kodo*), have also been abandoned, as have some root crops like tuber (*pidalu*) and sweet potato (*shakkarkhanda*). Farmers have continued growing millet to make alcohol for local consumption. Relatively few new crops have been introduced in place of the abandoned ones, and thus the cropping system has become less diverse. Newly introduced crops include cereals like spring rice and maize, and vegetables like onion, garlic and cucumber. Some new cash crops like cardamom are also being tested, but they have yet to be adopted on a large scale.

The changes in crops were reported to have occurred in and around 2004. The main reasons given for the changes were crop-specific diseases, lack of water for irrigation, low production, lack of benefit, and unfavourable climatic conditions, especially for pulses. Crop choices had also changed in response to the increased access to markets, which encourages the production of lucrative crops like vegetables. The change in people's diets and development of local markets, which ensure the availability of inorganic fertilizers and the development of irrigation infrastructure, also encourage farmers to cultivate rice, which has a high water requirement. This demonstrates that different factors are at play in influencing farmers' cropping decisions, and that adaptation to changed climatic conditions is not always the only or even the main factor influencing such decisions.

Farmers' responses to climate change

With dramatic increase in use of inorganic fertilizer in recent years, coupled with easy availability of insecticides and pesticides, there is already some evidence of adverse impact on soil quality in the lower elevations of the Indrawati Basin. While in general farmers are aware of the link between soil quality deterioration and use of chemical fertilizers, they are constrained by the lack of organic fertilizers and continue to depend on chemical ones to maintain crop yields. The decline in livestock rearing has led to lower availability of organic manure. However, smallholder farmers, who cannot afford to buy pesticides and chemical fertilizers, continue to rely on compost-based fertilizers and biopesticides produced locally using animal dung and weeds.

Some of the farmers have abandoned crops like pulses, traditional cereal crops, tuber and sweet potato and introduced new crops like spring rice, maize, onion, garlic, cucumber, and cardamom. However, millet is grown for distilling local alcohol. Even though farmers have started using chemical fertilizers and pesticides, they have yet to adopt high-yielding varieties of seeds because they believe local seeds to be better adapted to their agro-climatic conditions. Other agronomic practices that have found acceptance are mulching, minimum tillage and similar practices for *in situ* moisture conservation using locally available materials like rice straw and crop residues. Some farmers have also started harvesting rainwater by collecting it in farm ponds for supplementary use in irrigation. Many have started adjusting sowing and harvesting times to better cope with perceived changes in rainfall pattern.

In addition, this study identified a number of other promising adaptation strategies, such as the following.

- Cultivating more than one crop at a time (multi-cropping) is a promising adaptation strategy for small-scale farmers. While more labour-intensive than single-cropping, multi-cropping has advantages because it is more resistant to pest attacks, allows for a diversified diet and reduces the risk of crop failure.

- While the majority of the farmers in the study area practise traditional methods of constructing terraces for soil and water conservation, there are some areas where slopes are being cultivated without terraces. In those areas, it is imperative to convince farmers to adopt terrace cultivation because it helps store water in the fields and hinders erosion of topsoil.
- Few communities still practise traditional methods of conserving rainwater. There is a need to support farmers to restore these practices by construction of rainwater control and management structures and rainwater storage for supplementary irrigation (in farm ponds, sand/subsurface dams, earth dams, tanks, and others) for coping with the high seasonal variation in rainfall patterns.
- Weather forecasts are disseminated by the Department of Hydrology and Meteorology in Nepal. Weather updates are also normally available on the Internet (in English). But the low literacy rate and limited access to the Internet mean that weather information seldom reaches the farmers. There is a need to establish a weather information system specially designed for the farming community in remote rural areas so that the farmers can make rapid decisions about sowing, irrigation and other farm practices. Such information could be broadcast through community radio programmes or disseminated through mobile phones.

Conclusion and recommendation

This article provides a number of insights on potential impacts of climate change on water availability and farmers' adaptation strategies in the Indrawati Basin in Nepal. By doing so, it enhances the knowledge base for decision makers in agriculture and water management. In summary, the following conclusions and recommendations emanate from this study.

First, the SWAT model projects a slight increase in temperatures (both minimum and maximum), with significant seasonal variation, by 2090, with warmer winters and springs. This is likely to have an adverse impact on crops. There was no consistent trend in average annual precipitation, although this does not exclude the possibility of changes in the pattern of precipitation such as number of dry or wet days, or frequency or intensity of precipitation. The contribution of snowmelt to streamflow will not change significantly. However, in these regions, there is a considerable dependence on local springs, yet very little is known about the hydrogeology or current status of use and abuse of these springs, making this an important study area for the future.

Second, farmers' observations suggest that water availability for irrigation and agriculture has decreased over the last two decades or so, but it seems likely that this is related more to changes in farming practices, as well as low efficiency of irrigation infrastructure, than to actual decrease in water availability. Whether the changes are induced by climate or not, farmers have been adapting to them in myriad ways. These autonomous adaptation measures need to be encouraged by providing accurate climate information. Capacity building is also needed to prepare flexible and planned adaptation measures to enhance farmers' resilience.

Third, this article shows that the people are responding to the changes in their own ways at the household level, focusing on individual benefits. Whether it is the use of fertilizers or composting, abandoning certain crops or introducing new ones, using traditional ways of water harvesting or modern techniques, these depend on farmers' past experience, perception and judgement. Individuals' judgements about the climate are based on what they have perceived recently and how they interpret the climate information presented to them. Considering that the worst impact of climate change could take place many years from now, it is important to consider long-term socio-economic transition; moving away from primary sectors like agriculture is what will ultimately help farmers cope best with climate change.

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