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Hydro-climatic trends and people's perceptions: case of Kali Gandaki River Basin, Nepal

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ABSTRACT: Water resources, especially snow-fed rivers, are vulnerable to climate change. Water resources management requires analysis of both hydro-climatic trends and people's perception of climate change. We used available data to assess hydro-climatic trends, and household surveys to assess perceptions of climate change and its effects, in the snow-fed Kali Gandaki River Basin (KGRB) in western Nepal. The methodology consisted of: (1) definition and calculation of climate variability indices, (2) assessment of people's perception of climate change, (3) analysis of river flow variability and (4) discussion and summary of the spatial variation in climatic trends, peoples' perceptions, and the effects of climate change. The results showed a greater warming trend at higher altitude, while precipitation indices showed variable trends. Increasing temperature at high altitudes has affected pre-monsoon, post-monsoon and minimum discharges in the Kali Gandaki River. Household surveys in the Mustang district indicate that people's perception of climate change is consistent with climate data. They are concerned about the prevailing effects on water resources, ecological systems, agriculture and livelihoods. This will facilitate water resources planning and management in the basin.

KEY WORDS: Climate change · Hydro-climatic trends · Perception · Snow-fed river · Kali Gandaki River Basin

1. INTRODUCTION

Increased warming is projected to accelerate widespread mass losses from glaciers and reductions in snow cover throughout the 21st century, reducing water availability and hydropower potential, and affecting the seasonality of flows in regions supplied by meltwater from major mountain ranges, where more than one sixth of the world's population currently live (IPCC 2007). Increased climatic variability is posing major problems for water resource managers (Werritty 2002, Bajracharya et al. 2011). study of changes in climate indices (daily temperature and precipitation) can aid in understanding protracted hydrologic variability, especially in snow-fed river basins. However, in planning adaptation measures, the perception of people directly affected is equally important (Deressa et al. 2009)for decisions on adaptation measures. Knowledge of these perceptions can give important insights into local concerns and help to generate relevant solutions (Byg & Salick 2009). Combining analysis of local perceptions with local hydro-meteorological data occupies its own niche in the study of climate change.

Hydro-climatic trends at different locations in Nepal have been demonstrated by several studies. The analysis of 1978–2007 temperature and precipitation data at Lumle station in Kaski district of the Kali Gandaki River Basin (KGRB) showed a temperature increase of 0.9°C over this 30 yr period and a substantial decrease in rainfall, which also showed large inter-annual variability (Bhusal 2009). Trend analysis

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of maximum, minimum and mean temperatures at 7 meteorological stations in and around the KGRB for about 30 yr starting in the 1970s found a temporal variation, with positive trends for 6 stations and a negative trend for 1 station (Shrestha 2005). Dhungel (2009) pointed out that apart from changes in the mean state of climate; changes in frequency and intensity of extreme climate events have profound impacts on nature and society. Rising temperature directly affects water resources and hydropower; glacier retreat caused by rising temperature in turn causes greater variability in stream flow and can trigger glacial lake outburst floods that pose significant risk to hydropower facilities, other infrastructure, and human settlements (Bajracharya et al. 2011). Vaidya (2009) also warned about possible impacts of climate change on hydropower potential in the Bagmati and the Koshi river basins in Nepal. Although climate change is a global phenomenon, its effect on the local hydrology is considerable. WECS (2011) stated that the contribution of runoff from snow melt to flow in snow-fed rivers is increasing, whereas for non snow-fed rivers, dry season flows are decreasing and wet season flows are increasing. Trend analysis of seasonal flows and extreme events in a study of the Bagmati River in central Nepal showed that monsoon seasonal floods are decreasing while other seasonal flows are constant. It further showed temporal shifts in hydrography, thereby affecting water availability (Sharma & Shakya 2006). Bhusal (2010) also found an increasing trend in consecutive dry days (CDD) in the Bagmati river basin and predicted intense drought events in the future. Furthermore, hydro-climatic trend assessment of a non snow-fed watershed in Nepal, the Jhikhu Khola Watershed, showed that annual average, maximum and minimum flows are increasing. This increase in stream flow coincides with a trend of increasing rainfall in the yearly monsoon (June to September) and pre-monsoon (March to May) periods. However, no consistent trend was observed in the temperature change for the whole watershed (Gautam et al. 2010). The aforesaid studies confirm climatic changes in various regions of Nepal, including the KGRB, and warn of additional uncertainties in future hydro-climatic trends.

Baidya et al. (2008) and The Small Earth Nepal (2008) calculated climatic indices at national and district scale, using a core set of 27 indices developed by the Expert Team on Climate Change Detection and Indices (ETCDDI) (Zhang & Yang 2004). These indices describe climate extremes in terms of characteristics such as frequency, amplitude and persistence that are widely used for climate analysis in different regions of the world (e.g. Zhang et al. 2005, Alexander et al. 2006, Li et al. 2010). Both the above mentioned studies indicated a generally increasing trend in temperature extremes and increased spatial variation in precipitation extremes in the studied districts and in Nepal as a whole. However, calculation and analysis of the indices at the level of local river basins is still lacking. The magnitude of climate change and its effects varies over spatial and temporal scales (Bhusal 2010). Moreover, water resources in the rivers of Nepal are already vulnerable to climate change due to lack of proper management (Sharma & Shakya 2006, Pandey et al. 2009, 2010). Therefore, understanding hydro-climatic trends and their effects on water resources at the local level is very necessary for water resources planning and management; and knowledge at the scale of local river basins will be particularly useful.

This study aimed to provide insights into observed trends and people's perception of hydro-climatic variability in the snow-fed river basin KGRB in Nepal (Fig. 1). The study contributes to the knowledge base on climate variability and change in Nepal and provides inputs for water resources planning and management. Although extreme climatic events cannot be predicted with certainty, a proper assessment of existing hydro-climatic trends and people's perception of them would provide important knowledge for planning appropriate adaptation measures to deal with possible adverse effects.

2. MATERIALS AND METHODS

2.1. Study area

The Kali Gandaki River originates from the southern edge of the Tibetan Plateau in western Nepal. The KGRB encompasses nearly 11 770 km^2, extending from 188 to 8147 m above mean sea level (m asl). An estimated 23.4 % of the total basin area is covered by barren land, 23.6 % by cultivated land, 51.3 % by other vegetation types, 0.4 % by water bodies, and 1.3 % by glaciers (USGS 2011). The basin has a diverse climate, ranging from arid tundra at the highest altitudes, through alpine, cold temperate, warm temperate and subtropical with decreasing altitude, with a monsoon climate in the lowest areas. Therefore, there is great variation in temperature and precipitation patterns within the basin (Table 1). Annual precipitation in 2000 ranged from 275 to 6238 mm, at Lomanthang and Lumle stations, in the northern and southern parts of the basin, respectively (Lumle is the

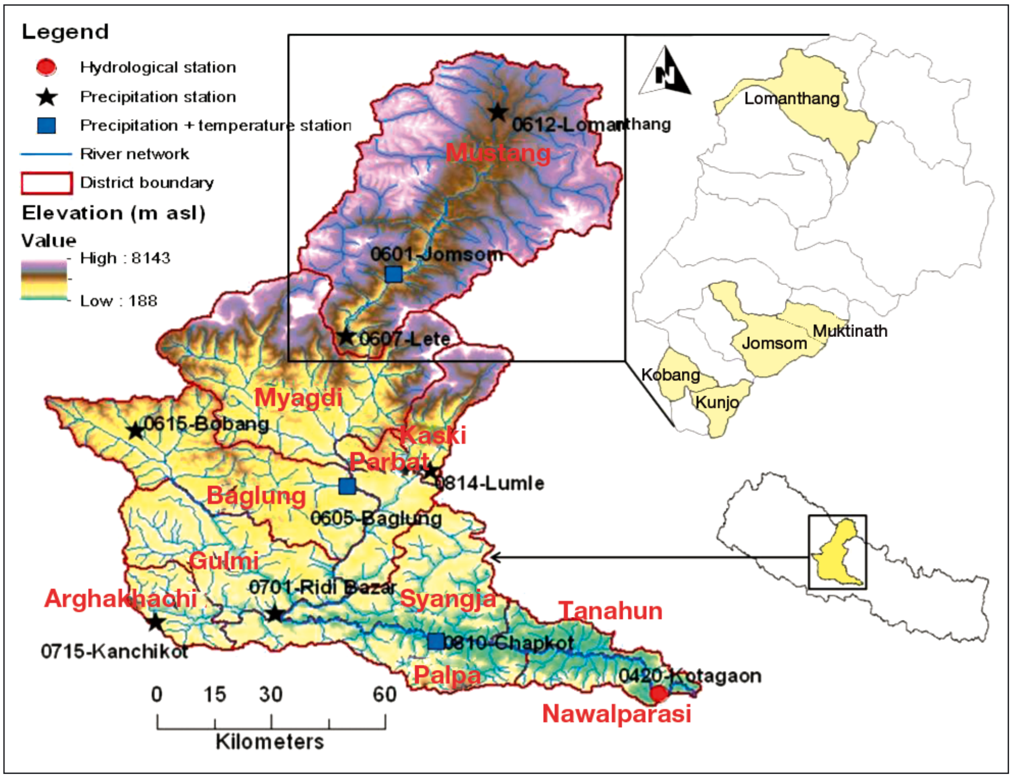


Fig. 1. Kali Gandaki River Basin (KGRB), Nepal, drainage network and basin boundary (NGIIP 2010), digital elevation map (Jarvis et al. 2008), and location of precipitation and temperature stations (DHM 2010). asl: above sea level

wettest region of Nepal) (DHM 2010). Given the large contribution of snow melt to the Kali Gandaki River, even small changes in rainfall and temperature could have tremendous impacts on water availability, and thus on the hydrology of the KGRB.

The cascading effects of rising temperature and loss of ice and snow are witnessed throughout the Himalayan regions (Xu et al. 2009, Eriksson et al. 2011). Studies by Shrestha et al. (1999), Baidya et al. (2008) and Macchi (2010) have demonstrated that temperature is increasing more rapidly in the mountain region than in lower areas of Nepal. Mountain regions are the most fragile environments on Earth, places where even a small change in temperature can turn ice and snow into water, with marked effects on water availability, biodiversity and agriculture (Tse-ring et al. 2010). There is already evidence of climate change and its effects in the upland/mountain district of Mustang in the KGRB (Manandhar et al. 2011). Therefore, Mustang district (area 3573 km^2) was selected for a case study of people's perception of hydro-climatic variability and its effects in the KGRB. The district is located in the rain shadow of the world's 7th and 10th highest mountains (Dhaulagiri, 8168 m asl; Annapurna, 8137 m asl) and receives on a average <200 mm annual rainfall, with relatively higher rainfall in the southern part of the district. It is a deeply incised valley of the Kali Gandaki River with an arid valley bottom and characteristic diurnal wind system.

Table 1. Meteorological and hydrological stations in the Kali Gandaki River Basin, Nepal. Data period: 1981–2007 (except Kotagaou: 1964–2006). Annual rainfall and annual average temperature are values for 2007 (DHM 2010)

Stn	Data	Latitude (°N)	Longitude (°E)	Elevation (m)	Annual rainfall (mm)	Annual mean temp.(°C)
1 Jomsom	Temp. & precip.	28.78	83.71	2744	312	12
2 Lete	Precip.	28.63	83.60	2384	1424	
3 Bobang	Precip.	28.40	83.10	2273	1923	
4 Kanchikot	Precip.	27.93	83.15	1760	2040	
5 Baglung	Temp. & precip.	28.26	83.60	984	2477	21
6 Chapkot	Temp. & precip.	27.88	83.81	460	2076	23
7 Ridibazar	Precip.	27.95	83.43	442	1451	
8 Kotagaon	Discharge	27.75	84.34	198		

2.2. Methodology

The methodology consisted of 4 main steps: (1) definition and calculation of climate variability indices, (2) assessment of people's perception of climate change, (3) analysis of river flow variability and (4) discussion and summary of spatial variation climatic trends, peoples' perceptions, and the effects of climate change. The method is summarized in Fig. 2.

2.3. Data and analysis

2.3.1. Precipitation and temperature data

There are 39 rain and 11 temperature gauging stations administered by Department of Hydrology and Meteorology (DHM) within the study area (i.e. KGRB). Stations with short length of data (less than 20 yr), data interruptions for 4 or more years, and the high Himalayan area for which rain gauge data is unavailable, were excluded from this study. Problems with data quality, which are common in Nepal, meant that data from only 14 rain and 5 temperature gauging stations were available for analysis. Nevertheless, an attempt was made to choose a network of stations that were representative of the study basin. The study presented here provides the most comprehensive analysis that is possible, given the data availability and quality.

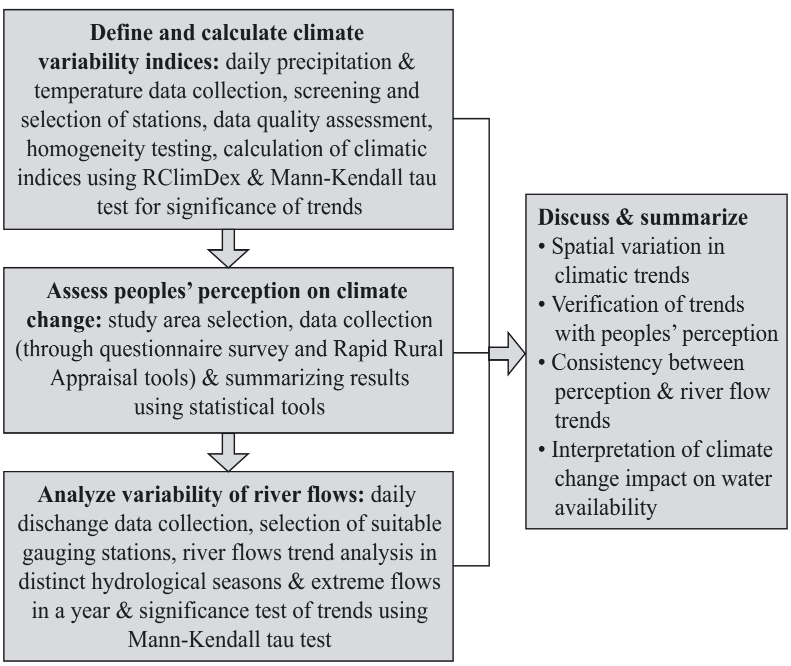


Fig. 2. Methodology used in the study of hydro-climatic trends and people's perceptions of climate change in the Kali Gandaki River Basin, Nepal

2.3.2. Data quality assessment and homogeneity testing

The data quality was assessed using a computer program, RClimDex 1.0. The program detects some common errors and outliers, where outliers are the values outside a user-defined threshold determined by the mean plus/minus a number of standard deviations (Rusticucci & Renom 2008, Li et al. 2010). In this case outliers (25° and 0°C as upper and lower thresholds of daily maximum temperature, 20° and 0°C as upper and lower thresholds of daily minimum temperature, and 25 mm as the threshold of daily precipitation) were determined from precipitation and temperature data, which were checked manually by comparing data series within the year and between different years. Additionally, inhomogeneities in the daily time series of precipitation and temperature were tested using the 2-phase regression-based homogeneity testing program RHtestV2, which consists of series of R functions to detect and adjust multiple change-points (shifts in the mean) in a series. Historic metadata is essential to evaluate the breaks detected as well as for future attempts to correct series from these breaks, but it was unavailable for the stations studied. Stations with inhomogeneous data were excluded. The remaining 7 rain and 3 temperature gauging stations (Fig. 1, Table 1) were considered for computation of the precipitation and temperature indices.

2.3.3. Defining and computing the indices

The ETCCDI core set of 27 indices derived from daily precipitation and temperature data describes characteristics of extremes, including frequency, amplitude and persistence. Of these, 19 relevant indices were selected for use in this study. Many of the ETCCDI indices are based on percentiles with thresholds set to assess moderate extremes that typically occur a few times every year rather than high impact, once in a decade weather events. The reason for choosing mostly percentile thresholds rather than fixed thresholds is that the number of days exceeding the percentile thresholds is more evenly distributed in space and meaningful in every region (WMO 2009). The indices

Table 2. Definition of the temperature and precipitation indices used in this study (after Zhang & Yang 2004, Alexander et al. 2006, Kioutsioukis et al. 2009). Precipitation indices are shown in **bold**. TX: daily maximum temperature; TN: daily minimum temperature

Category	ID	Indicator name	Definition	Unit
Indices based on station-related thresholds	TN10p	Cold nights	Percentage of days when TN < 10th percentile	d
	TN90p	Warm nights	Percentage of days when TN > 90th percentile	d
	TX10p	Cold days	Percentage of days when TX < 10th percentile	d
	TX90p	Warm days	Percentage of days when TX > 90th percentile	d
	R95p	**Very wet days**	**Annual total precipitation when daily precipitation amount > 95th percentile**	**mm**
	R99p	**Extremely wet days**	**Annual total precipitation when daily precipitation amount > 99th percentile**	**mm**
Indices based on fixed thresholds	SU25	Summer days	Annual count when TX > 25°C	d
	TR20	Tropical nights	Annual count when TN > 20°C	d
	FD0	Frost days	Annual count when TN < 0°C	d
	R10mm	**Number of heavy precipitation days**	**Annual count of days when precipitation ≥10 mm**	**d**
	CDD	**Consecutive dry days**	**Maximum number of consecutive days with daily precipitation amount <1 mm**	**d**
	CWD	**Consecutive wet days**	**Maximum number of consecutive days with daily precipitation amount ≥1 mm**	**d**
	SDII	**Simple daily intensity index**	**Annual total precipitation divided by the number of wet days (defined as precipitation ≥1.0 mm) in the year**	
Non-threshold indices	TXx	Maximum daily maximum temperature	Monthly maximum value of TX	°C
	TNx	Maximum daily minimum temperature	Monthly maximum value of TN	°C
	TXn	Minimum daily maximum temperature	Monthly minimum value of TX	°C
	TNn	Minimum daily minimum temperature	Monthly minimum value of TN	°C
	RX1day	**Maximum 1-day precipitation amount**	**Monthly maximum 1 d precipitation**	**mm**
	PRCPTOT	**Annual total wet-day precipitation**	**Annual total precipitation in wet days (daily precipitation amount ≥1 mm)**	**mm**

are grouped into 3 categories and their abbreviations and definitions are given in Table 2.

For this study, the indices were calculated on an annual basis using RClimDex (1.0). Annual values were calculated if <15 d were missing in a year. The change in a variable over a given period of time was described as the slope of a linear trend. Trends are the simplest component of climate change and provide information on the first-order changes over the time domain considered (WMO 2009). The statistical significance of the trend (of the indices) in each station was tested through a nonparametric Mann-Kendall tau test.

2.3.4. People's perception of climate change

To gain an understanding people's perception of the climate change and its effect on water resources, household surveys were conducted in the Mustang district, located in the mountainous region of the KGRB (Fig. 1). Structured questionnaires (Table 3) were used to gather detailed information on people's perception of climate change and its impact on water resources. Both open- and close-ended questions were included in the questionnaire. Because of the low and scattered population in the Mustang district, households were selected through a simple random sampling technique. The sample included 5 % of the households in the district (155 out of 3089) along a transect from lower to higher elevation. The sampled households were located in areas administered by the Kunjo, Kobang, Jomsom, Muktinath and Lomanthang Village Development Committees (VDCs) (Fig. 1). VDCs are the fourth level units (of altogether 6 units) in the administrative hierarchy in Nepal. Among the 5 areas, Kunjo in the south receives more rain than the others in the central and northern area of Mustang (NTNC 2008).

Focal group discussions (involving the elderly and community leaders), key informant interviews (with the village headperson and teachers), and individual discussions (with elderly people) were conducted to retrieve information on their perception of climatic trends and their effect on water resources. However, in most cases, it was not easy to get answers from old people due to their faded memories of past climatic events. They were able to recall climatic events of the past in most cases only with reference to important political or other events that had occurred at the same time. Triangulation (Holmelin 2010), i.e. combination and cross-checking of various methods of data

Table 3. Key aspects of the questionnaires used during household survey of people's perception of climate change in in the Kali Gandaki River Basin, Nepal

Broad questions
- What does the climate mean to you?
- Have you experienced or ever heard of climate change (climate change belief and awareness)?
- How is the climate change in its present form affecting ecosystems, water availability, agriculture and livelihoods, in your experience?

Specific questions

Temperature change:
- Has it become hotter or colder during any season compared to past years (when you were a child, young and at present)?
- Does this change from year to year or do you feel that it has changed on the whole since then or is it just different during some years?

Change in precipitation amount and intensity:
- Has it become more rainy compared to past years?
- Does this change from year to year or do you feel that it has changed on the whole since then or is it just different during some years?

Change in precipitation timing:
- Do the rains still come when you expect them to come?
- If no, what changes have you noticed?
- How do these things affect water resources?

Snowfall incidences:
- Does the snow still fall (depth of snow) as it used to be in past years?
- If no, what are its effects?

production, was adopted to ensure the reliability of the information gathered by field survey.

Household survey data were processed using statistical tools available in Microsoft Excel 2007. In addition to simple descriptive statistics such as summation and frequency, contingency tables and χ^2 tests were also performed to investigate the relation between people's perception and climatic parameters. Comparisons between people's perception, temperature and precipitation trends, and variability of river flow were also done.

2.3.5. Hydrological data

There are 5 hydrological stations administered by the DHM within the KGRB. However, due to the unavailability of long-term data from 4 of these stations, the only option was to choose Kotagaon station, in the downstream area of the KGRB, for further processing (Fig. 1, Table 1). Lack of distributed hydrological data in the basin is a major limitation in analyzing variability of river flows at different locations in this study. After checking the data from Kotagaon station, gaps were filled using simple linear temporal interpolation techniques for temperature and discharge data, and spatial interpolation techniques for precipitation data. Trends of river flow in various hydrological seasons (pre-monsoon: March to May; monsoon: June to September, and post-monsoon: October to February) and extreme flows in a year were calculated and plotted using Microsoft Excel 2007. The observed trends were further statistically tested through a nonparametric Mann-Kendall tau test.

3. RESULTS AND DISCUSSION

3.1. Temperature indices

Between 1981 and 2007, at higher altitude (Jomsom station), temperature indices showed statistically significant upward trends, whereas at the 2 other temperature stations (Chapkot and Baglung) the changes were not significant (Table 4). The number of summer days (SU25) increased over the study period at Baglung, while the number of tropical nights (TR20) decreased at Chapkot and Baglung. Ice days (ID0; days with max. temperature < 0°C) were not recorded at any of the stations, and this index was not considered further in the analysis. Frost days (FD0) significantly decreased at Jomsom while they were absent at the other 2 stations. Monthly maximum and minimum values of daily minimum temperatures (TNx and TNn, respectively) decreased at Jomsom. The monthly maximum value of daily maximum temperature (TXx) decreased at Chapkot but increased at the other 2 stations, whereas monthly minimum values of daily maximum temperature (TXn) decreased at all 3 stations. The percentage of warm days (TX90p) increased at Baglung and Chapkot but significantly decreased at Jomsom. In addition, the percentage of cold nights (TN10p) significantly decreased and warm nights (TN90p) occurred more frequently at Jomsom (Fig. 3a,b). There was considerable warming at Jomsom, and this accelerates melting of the glaciers (there are 399 glaciers over 563 km^2, with 51.6 km^3 of ice; ICIMOD 2010); this contributes up to 50% of the average annual flow in the rivers.

3.2. Precipitation indices

The northernmost part of the basin (especially Jomsom station) has little precipitation, even in winter when it is under the influence of the western dis-

Table 4. Trends in temperature indices at the study stations in the Kali Gandaki River Basin, Nepal. A negative sign denotes a decreasing trend and the trend values represent a slope of the linear trend. Mann-Kendall test results (p-values) are shown in parentheses, with significant ($p < 0.05$) values in **bold**; na: not applicable. See Fig. 2 for explanations of temperature indices

	Indices based on fixed thresholds			
	SU25	TR20	FD0	
Chapkot	−0.040 (1.000)	**−0.733 (0.047)**	na	
Baglung	0.473 (0.242)	−0.063 (0.833)	na	
Jomsom	−0.072 (0.611)	na	−2.113 **(0.000)**	
	Non threshold indices			
	TXx	TXn	TNx	TNn
Chapkot	−0.045 (0.233)	0.059 (0.106)	−0.028 (0.314)	−0.024 (0.867)
Baglung	0.009 (0.477)	0.029 (0.738)	−0.013 (0.720)	0.004 (0.916)
Jomsom	0.006 (0.899)	0.022 (0.883)	0.073 **(0.001)**	0.174 **(0.000)**
	Indices based on station related thresholds			
	TX10p	TX90p	TN10p	TN90p
Chapkot	0.053 (1.000)	0.062 (0.707)	0.301 (0.453)	−0.161 (0.196)
Baglung	−0.141 (0.316)	0.171 (0.392)	−0.001 (0.113)	−0.182 (0.243)
Jomsom	+0.204 **(0.027)**	−0.080 **(0.027)**	−0.635 **(0.000)**	0.508 **(0.00)**

turbances; while in summer this area is under the influence of a strong rain shadow. In contrast, other parts of the basin (at Bobang, Kanchikot, Baglung, Chapkot, Lete and Ridibazar stations considered in this study) have high precipitation in summer, under the influence of the SE monsoon. Unlike temperature indices, most precipitation indices exhibited a roughly equal proportion of increasing and decreasing trends. Moreover, only a small fraction of the station trends were statistically significant for any indices (Table 5). The maximum number of consecutive dry days (CDD), showed an increasing trend at all stations, with a significant rise at Bobang (Fig. 3c). This is in accordance with the decreasing trend shown by monsoon rainfall record over the 27 yr study period (Table 6). This is associated with an increase in the longest dry spell (dry season length). A significant increasing trend in consecutive wet days (CWD) was found at Lete, while at other stations this index showed variable trends. The simple daily intensity index (SDII, see Fig. 2) decreased at the majority of studied stations indicating a fall in average rainfall intensity over the river basin area; at Baglung this index showed a significantly increasing trend (Fig. 3d).

The increase in precipitation intensity, however, was concentrated in days with heavy (or extreme) precipitation (R10mm), whose number increased at 4 out of 7 study stations, but decreased significantly at Ridibazar (Table 5). Regarding other indices, very wet days (R95p) and extremely wet days (R99p) decreased at most of the stations; this was highly correlated with the increasing trend in CDD. Annual total wet-day precipitation (PRCPTOT) decreased at 4 out of 7 study stations and a very significant decrease was recorded at Ridibazar (Fig. 3e). The all-Nepal record agrees well with the precipitation records from northern India, while it does not compare well with the all-India precipitation record (Shrestha et al. 2000). The decreasing total annual precipitation trend in the KGRB agrees well with the downward moving trend in northeastern India (Sen Roy & Balling 2004). Similarly, the maximum 1 d precipitation amount (RX1day) decreased at most of the stations, and significant trends were observed at Chapkot (Fig. 3f) and Kanchikot. Thus, the change in precipitation was ambiguous throughout the basin, with an increase in some places and decrease in others.

Further analysis of intra-annual rainfall variation showed an increasing trend in pre-monsoon (March to May) precipitation, but in contrast a decreasing trend in monsoon (June to September), post-monsoon (October to November) and winter precipitation (December to February) at most of the stations. The Indian monsoon has often been used as a proxy for the Asian monsoon as a whole. The decreasing trend in monsoon rainfall in the KGRB found in this study is consistent with the decreasing frequency and magnitude of monsoon rainfall in India studied over the period 1910–2000 by Pal & Tabbaa (2010). As in other river basins of Nepal, where intra-annual variation in precipitation is the primary driver that impacts river flow even though they are fed by melt and groundwater (Hannah et al. 2004), the observed intra-annual variation in rainfall may influence the river flow in the Kali Gandaki River and its tributaries.

3.3. People's perception of climate change

People's perception of climate change in Mustang corresponded well with the computed temperature and precipitation trends. χ^2 analysis showed statistically significant result for all tests made between people's perception and the climate parameters at 5% level of significance (Table 7). It confirmed that most of the interviewed locals have perceived climate change and are aware about its effects on

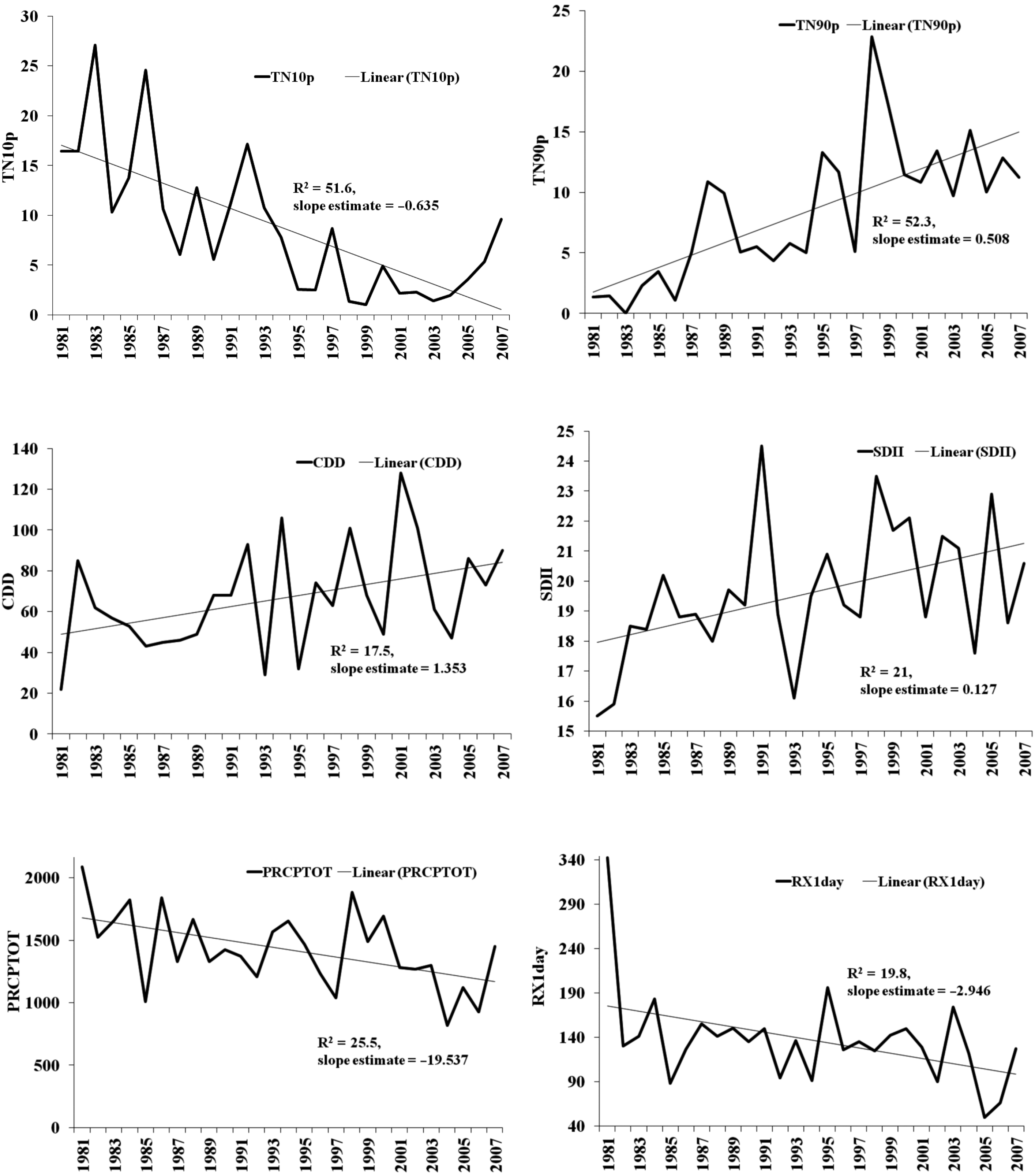


Fig. 3. Significant trends in climate indices recorded at weather stations in the Kali Gandaki River Basin, Nepal, between 1981 and 2007: (a) TN10p, Jomsom; (b) TN90p, Jonsom; (c) CDD, Bobang; (d) SDII, Baglung; (e) PRCPTOT, Ridibazar; (f) RX1day, Chapkot. See Table 2 for explanations of climate index abbreviations and Fig. 1 for locations of weather stations

Table 5. Trends in precipitation indices at the study stations in Kali Gandaki River Basin, Nepal, listed in order of increasing elevation. A negative sign denotes a decreasing trend. Mann-Kendall test results (p-values) are shown in parentheses, with significant ($p < 0.05$) values in **bold**; na: not applicable. See Fig. 2 for explanations of precipitation indices

	Fixed thresholds				Station related thresholds		Non−threshold	
	CDD	CWD	SDII	R10mm	R95p	R99p	PRCPTOT	RX1day
Ridibazar	1.146 (0.099)	0.012 (0.704)	−0.128 **(0.021)**	−0.558 **(0.007)**	−5.332 (0.453)	−3.245 (0.668)	−19.537 **(0.015)**	−0.409 (0.573)
Chapkot	0.648 (0.477)	0.089 (0.467)	−0.204 (0.113)	0.119 (0.142)	−5.275 (0.573)	−4.312 (0.105)	−6.391 (0.802)	−2.946 **(0.035)**
Baglung	0.452 (0.754)	0.010 (0.752)	0.127 **(0.020)**	0.349 (0.160)	5.473 (0.260)	6.845 (0.220)	8.718 (0.327)	0.687 (0.692)
Kanchikot	1.563 (0.087)	−0.105 (0.426)	−0.084 (0.087)	−0.106 (0.585)	−14.781 **(0.052)**	−8.068 (0.104)	−18.701 (0.073)	−3.386 **(0.035)**
Bobang	1.353 **(0.038)**	−0.183 (0.754)	−0.084 (0.369)	−0.170 (0.490)	−11.368 (0.099)	−4.894 (0.259)	−13.519 (0.182)	−0.291 (0.754)
Lete	0.170 (0.916)	0.311 **(0.025)**	−0.063 **(0.036)**	0.019 (0.600)	0.524 (0.917)	1.438 (0.472)	5.833 (0.182)	0.536 (0.359)
Jomsom	0.454 (0.251)	−0.035 (0.567)	0.038 (0.490)	0.018 (0.719)	−0.697 (0.769)	−0.910 (0.147)	0.112 (0.723)	−0.407 (0.631)

Table 6. Trends in seasonal precipitation variation at the study stations in Kali Gandaki River Basin, Nepal, listed in order of increasing elevation. A negative sign denotes a decreasing trend; '0' denotes no trend. Mann-Kendall test results (p-values) are shown in parentheses, with significant ($p < 0.05$) values in **bold**

	Pre−monsoon	Monsoon	Post−monsoon	Winter
Ridibazar	0.164 (0.900)	−1.533 (0.317)	−0.314 (0.602)	−0.100 (0.851)
Chapkot	−0.157 (0.738)	−2.011 (0.337)	−0.260 (0.786)	−1.050 (0.133)
Baglung	0 (1.000)	0.270 (0.287)	0.233 (0.646)	−0.580 (0.504)
Kanchikot	−0.500 (0.983)	−4.794 (0.079)	−0.940 (0.175)	−0.513 (0.491)
Bobang)	0.160 (0.950)	**−2.175 (0.007)**	0.526 (0.818)	−0.650 (0.337)
Lete	0.500 (0.616)	0.200 (0.573)	−0.107 (0.884)	0 (1.000)
Jomsom	−0.114 (0.759)	1.050 (0.079)	0 (0.883)	0.104 (0.676)

Table 7. χ^2 test for people's perceptions of climate change and climatic parameters in Mustang

Perceived climate change	p
Temperature	0.006
Precipitation intensity	0.037
Precipitation timing	0.011
Snowfall	0.019

ecological systems, farming, livelihoods and water availability in their locality (Table 8). However, perceived climate change differed significantly even within a small geographic area (Table 8), reflecting the enormous altitudinal gradient and varied eco-climatological conditions within the study area.

Lower areas of Mustang receive more rain than the central and northern areas, with Kunjo VDC receiving the highest rainfall among the 7 areas studied. This is why people's perception of the intensity of precipitation in lower areas was very different from that of people in the other areas. The increasing trend of CWD at Lete (Table 5), neighbor VDC of Kunjo (see Fig. 1), agrees with local people's experience of increasing rainfall in lower Mustang. Continuous heavy rain from 6 to 7 July 2007 destroyed buckwheat plantations and an irrigation canal in Wards 6 and 9 of Kunjo VDC, af-

Table 8. People's perception of climate change in the Kali Gandaki River Basin, Nepal, based on a field survey of 155 households, conducted in 5 Village Development Committees (VDCs) in Mustang District in 2010. Values show the number of households that gave the response shown (I: increase; NC: no change; D: decrease). Locations of surveyed VDCs are shown in Fig. 1, and details of survey questions in Table 3. VDCs are listed in increasing order of elevation above sea level (Kunjo: 2539 m; Kobang: 2561 m; Jomsom: 2795 m; Muktinath: 3025 m; Lomanthang: 3686 m).

VDC	No. of households	Temperature		Precipitation					Snowfall		Effect of climate change						
				Amount			Timing				Water avail.			Ecosystem		Agriculture	
		I	NC	I	D	NC	On time	Erratic	D	NC	I	D	NC	I	NC	I	NC
Kunjo	30	26	4	24	2	4	3	27	28	2	20	6	4	28	2	29	1
Kobang	30	25	5	22	3	5	4	26	25	5	12	9	9	26	4	29	1
Jomsom	35	30	5	2	28	5	4	31	32	3	6	25	4	30	5	31	4
Muktinath	30	25	5	4	21	5	3	27	28	2	1	26	3	28	2	28	2
Lomanthang	30	24	6	4	22	4	5	25	29	1	1	24	5	24	6	25	5
Total	155	130	25	56	76	23	19	136	142	13	40	90	25	136	19	142	13
(%)	(100)	(84)	(16)	(36)	(49)	(15)	(12)	(88)	(92)	(8)	(26)	(58)	(16)	(88)	(12)	(91)	(9)

fecting more than 12 households, as reported by the District Agriculture Development Office (DADO), Mustang. Most people interviewed in Jomsom VDC commented on the increasing intensity of rainfall, which they described as the occurrence of short but intense downpours in recent years, leading to leaks in mud rooftops, and interviewees throughout the district reported increasingly erratic rainfall within and between seasons. Locals of Thini village in Jomsom VDC believed that rain used to follow immediately after local women performed religious rituals in the monastery, but stated that now they were no longer able to influence the weather this way. A notable result was the decrease in the volume of snowfall and snow cover in the nearby mountains reported by 92% of interviewees in Mustang. Snow accumulation in the high Himalayas is highly correlated with summer monsoon precipitation in northeastern India (Duan et al. 2006). Sen Roy & Balling (2004) discuss the decreasing trend of rainfall in northeastern India, which might be linked to decreasing snowfall in the mountainous district Mustang.

More than 90% of locals interviewed reported effects of climate change on agriculture and livelihoods, in response to questions about unexpected climatic events and losses incurred in crops and livestock productivity. Locals agreed that decreasing snowfall has led to moisture constraints which have severely affected the germination of barley seeds in the field and regeneration of grasses in pasturelands, leading to late and poor harvests of barley, and low productivity of livestock. Moreover, more than two-thirds of the locals interviewed in the extremely dry Lomanthang VDC noted that the decreasing snowfall and erratic rainfall have caused the drying-up of streams and water channels in nearby areas, thereby limiting water availability for irrigation and household use. Older people interviewed had stronger perceptions of water shortage, and reported greater changes in local water resources than younger generations, indicating decreasing water availability over the years.

In addition, local people perceived major changes in both summer and winter temperatures. They are experiencing warmer winter days than in the past years, which is in line with increasing TXx, TXn, TNx and TNn at Jomsom station (see Table 4). More than 85% of the people interviewed opined that temperature change has brought about changes in the ecosystem (Table 8). They observed that there were no mosquitoes in the past but that increasing temperature has been favorable for mosquitoes and other insects. Moreover, they also noticed a shift in the tree line. Apple production has declined in the lower areas of Mustang and expanded into higher altitudes. The increasing temperature has gradually created more favorable conditions for the diversification of agriculture, but on the other hand has also led to an increase in pests. It has also led to melting of snow: locals observed less snow in the mountains and higher water levels in the Kali Gandaki River in recent years—see Section 3.4 below. They were concerned about the decreasing snow and water availability in the mountains and in their locality. The extent to which farmers' perceptions of the effects of temperature change on snow melt and river water levels corresponded to actual changes taking place could not be further verified due to the absence of a river gauging station in the upper region of the KGRB. Overall, however, evidence from local people interviewed and the analysis of hydro-climatic trends provide inputs for the formulation of plans and climate change adaptation strategies to enhance efficient water resources management.

3.4. Variability of river flow

Hydrological seasons in Nepal comprise (1) a dry pre-monsoon season (March to May) with hot, dry weather and scattered rainfall; (2) a rainy monsoon season (June to September) when most of the annual rainfall occurs; and (3) a post-monsoon season (October to February) with very little or almost no rainfall (Fig. 4). Long-term study of hydrological variability over the entire water year provides information on temporal river flow regime characteristics that can be analyzed from both hydrological and socioeconomic perspectives (Chalise 2002, Hannah et al. 2004). The trend of river flow in the 3 hydrological seasons and extreme flows in a year (maximum and minimum discharges) were studied using data from Kotagaon station for the period 1964 to 2006. The flow in the river is unregulated. Although an increasing trend was observed in the dry pre-monsoon and post-monsoon discharges, and a decreasing trend in the annual minimum discharge, all changes were statistically insignificant (Mann-Kendall test). However, the magnitude of changes can be expected to increase in the near future. There will be much less rain in dry pre-monsoon and post-monsoon seasons, compared to the monsoon season and, in these seasons, snow melt and/or sub-surface inflow will provide most of the river flow. Thus the increasing trend in dry pre-monsoon and post-monsoon discharges (Fig. 5a,b) indicates melting of snow and increasing water level in

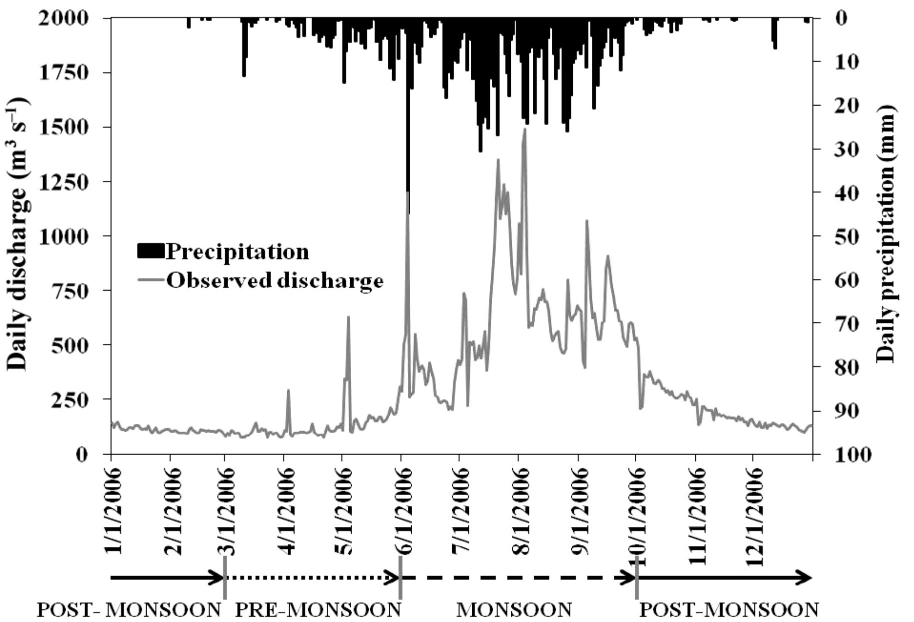
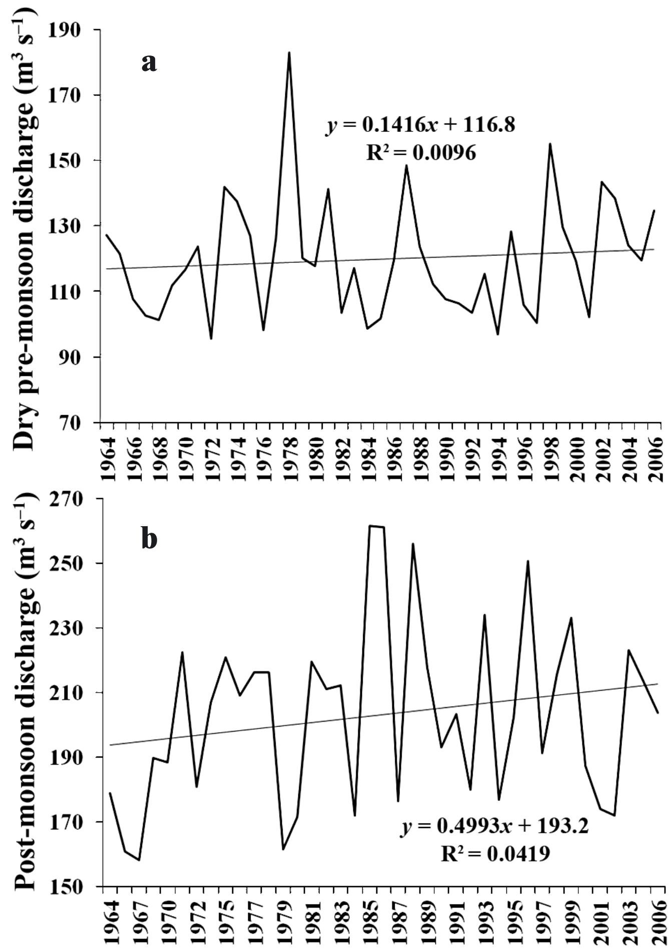


Fig. 4. Pattern of precipitation and river flow in the Kali Gandaki River Basin in 2006. Dates given as mo/d/yr

the rivers due to rising temperature in the high mountains.

The annual minimum discharge at Kotagaon showed a decreasing trend (Fig. 5c) A possible reason could be a decrease in total annual rainfall in the sub-basins contributing to the river flow downstream, as indicated by the results of precipitation indices calculated in Table 5. CDD increased at all stations while wet days (R95p and R99p) and PRCPTOT decreased at the majority of the stations, which would reduce discharges into the river.

The aforementioned results support people's perception of rising water levels in the main rivers, but drying-up of small streams and channels, in post- and pre-monsoon seasons. The melting of ice increases the pre- and post-monsoon discharge in rivers and can be expected to enhance the water availability for some years, but the situation will eventually be reversed with declining snow depth. Likewise, the decreasing rainfall will reduce water availability in rain-fed streams and channels, and discharge into the rivers, which will affect the reliability of local water resources. The people in mountainous districts of the KGRB are therefore rightly concerned about the increasing impacts of climate change. Knowledge of flow regimes provided by this study will permit water resources to be used more effectively for different purposes during the various hydrological seasons of the year.



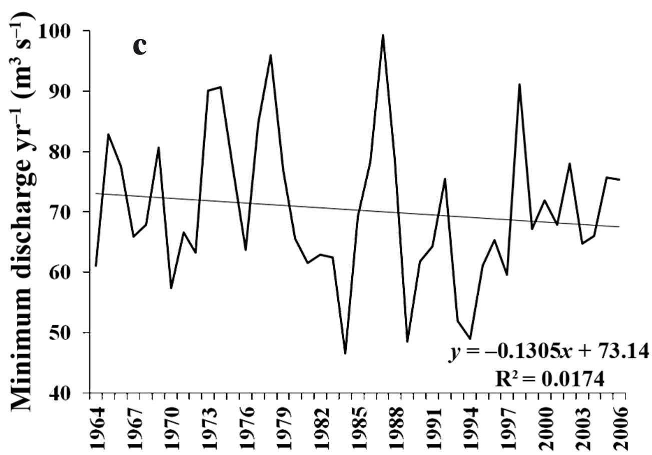


Fig. 5. Trends in seasonal (a) dry pre-monsoon (b) post-monsoon and (c) yearly discharges in the Kali Gandaki River at Kotagaon between 1964 and 2006

4. CONCLUSIONS

Climate variability indices revealed warming trends at Jomsom station in the mountain region of Nepal, while no consistent changes were observed in precipitation indices at other stations. The precipitation indices SDII, R95p, R99p, PRCPTOT and RX1day decreased, while CDD and R10mm increased at many stations. Increasing temperature accelerates snow melt, which is an important source of water during the pre-monsoon and post- monsoon seasons. These trends account for increasing trends in annual dry pre-monsoon and post-monsoon discharge recorded at Kotagaon. Climate change and increasing climatic variability will trigger the problems associated with both too much and too little water. Local people in Mustang, a mountainous district of the KGRB, have perceived these changes and are concerned about the increasing effects of climate change on ecological systems, farming, livelihoods and water availability in their locality. Analysis of trends in hydro-climatic variables together with people's perceptions of climate effects can facilitate implementation of water resources management plans and strategies.

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