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Climate change in Nepal: a comprehensive analysis of instrumental data and people's perceptions

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Abstract
Despite broad scientific consensus on climate change, public views may not always correspond with scientific findings. Understanding public perceptions of climate change is thus crucial to both identifying problems and delivering solutions. Investigations of climate change that integrate instrumental records and people's perceptions in the Himalayas are scarce and fragmentary compared to other regions of the world. We analyzed nationally representative data ($n = 5060$) of local peoples' perception of climate change in Nepal, and assessed annual and seasonal trends of temperature and precipitation, onsets of seasons, and trends of climate extremes, based on gridded climate datasets. We firstly used quantitative and spatial techniques to compare local perceptions and the instrumentally observed trends of climate variables. We then examined the possible association of demographic variables, place attachment, regional differences, and prior understanding of climate change with the accuracy of people's perceptions. Instrumental evidence showed consistent warming, increasing hot days and nights, and increasing annual precipitation, wet spells, heavy precipitation and decreasing dry spells in Nepal. Our results indicate that locals accurately perceived the shifts in temperature but their perceptions of precipitation change did not converge with the instrumental records. We suggest that, in future as exposure to changes in weather, particularly extreme events, continues, people may become more likely to detect change which corresponds with observed trends. With some new methodological insights gained through integrating community perceptions with observed climate data, the results of this study provides valuable information to support policies to reduce climate-related risk and enhance climate change adaptation.

1 Introduction

Global climate change is one of the greatest challenges to humanity and ecosystems (Pachauri et al. 2014). Despite the broad scientific consensus on climate change, public views about this major environmental change are not unequivocal and, at times, do not converge with the scientific evidence (Weber 2010). Community support for climate change policy is greatly

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influenced by people's beliefs, attitudes, and risk perceptions (Howe et al. 2015). People's perceptions of climate change often reflect their concerns over the specific impacts of climate change on their daily life (Ayal and Leal Filho 2017). The public perception of climate change is thus an essential element of understanding climate change adaptation problems and delivering potential solutions (Weber 2010). Combining scientific observations with public perceptions would help deepen the knowledge base and, hence, help reduce uncertainty in adaptation planning (Marin 2010). In many parts of the world where instrumental records of climate are limited, local perceptions provide a strong basis to ascertain change in climate variables (Alexander et al. 2011). However, both instrumental observations of climate and periodic surveys of public perception of climate change tend to be largely confined to developed countries, with little evidence coming from the developing world (Roco et al. 2015).

Compared to other regions of the world, there have been few comprehensive studies of climate change and its impacts in the Himalayan region, including Nepal (Pandit et al. 2014; Shrestha et al. 2012). Only recently have attempts been made to analyze the extent and severity of climate change in Nepal based on historical records of temperature and precipitation (Duncan et al. 2013). Other studies have examined trends in temperature and precipitation extremes (Karki et al. 2017; Shrestha et al. 2017) and documented local perceptions of climate change (Chaudhary et al. 2011; Chaudhary and Bawa 2011; Macchi et al. 2015; Mishra et al. 2015; Uprety et al. 2017). Results from these studies show that climate change, exemplified by changes in the incidence of heavy rainfall and drought, has already affected hydrology, biodiversity, ecosystems, agricultural production, and human health, and has exacerbated disaster risks in this region (Duncan et al. 2013; Shrestha and Bawa 2014; Dhimal et al. 2015; Bhattacharjee et al. 2017). While there is an emerging body of evidence of climate change impact, a consolidated and comprehensive picture of climate change in Nepal is still lacking.

Our review of existing research shows that there are several limitations in studies of climate change in Nepal. Firstly, analysis of trends in temperature and precipitation in Nepal is limited by data availability and quality; there is a limited number of weather stations, most of which are poorly maintained (Shrestha and Aryal 2011; Bhattacharjee et al. 2017; Karki et al. 2017) and most studies have used only relatively short-term (less than three decades) climate records (e.g., Shrestha and Aryal 2011; Duncan et al. 2013; Karki et al. 2017). Secondly, studies documenting public perceptions that may complement the limited climate records have been conducted in highly localized places and small villages with limited sample sizes (e.g., 205 households by Chaudhary and Bawa 2011). Thirdly, the majority of the studies have focused just on either analyzing scientific data or documenting public perceptions. Finally, even when some studies have attempted to compare instrumental data with local perceptions (Chaudhary and Bawa 2011), these have been made at different spatial resolutions and scales, hence lack congruence. Such studies have also failed to examine the effect of multiple covariables (demographic, place attachment, regional difference and prior understanding of climate change) on the accuracy of people's perceptions of climate change.

Against this backdrop of less than robust climate change research in Nepal, this study conducted an integrated analysis of instrumental climate records and a large-scale comprehensive study of people's perceptions of climate change. We conducted a long-term (1979–2016) analysis of annual and seasonal trends of temperature and precipitation, onsets of the seasons, and patterns of selected extreme indices of temperature and precipitation, based on high-resolution gridded temperature and precipitation datasets. We accessed data from the most comprehensive nationally representative survey ($n = 5060$) of local peoples' perception of climate change ever conducted in the country. We then compared the locals' perceptions with the observed trends of climate using quantitative and spatial techniques, with a view to examining the possible effect of demographic variables, place attachment (year of living in the locality), regional differences (geography), and prior understanding of climate change on the accuracy of locals' perceptions. This paper thus not only presents the findings from a large-sample size study of people's perceptions and analysis of instrumental observations but also offers a correlational analysis of the two sets of findings (scientific and local perception), thus producing a comprehensive analysis of climate change in Nepal.

2 Materials and methods

2.1 Survey data

Survey data used in this study were from the National Climate Change Impact Survey (NCCIS) conducted during July to December 2016 by Nepal Government's Central Bureau of Statistics (CBS) (CBS 2017). The survey is the most comprehensive and representative ever conducted in Nepal to understand people's perceptions of climate change and its impacts on social, economic, and environmental aspects of their life. To make this survey nationally representative, Nepal was divided into 16 strata, covering four climatic zones (tropical, sub-tropical, temperate, and sub-alpine), five development regions (Eastern, Central, Western, Mid-western, and Far-western), and the Kathmandu valley (the capital). Altogether, 253 primary sampling units (PSUs) were identified, and 20 households per PSU were randomly selected for questionnaire survey. Respondents aged at least 45 years who had resided in the locality for the past 25 years were eligible to participate in the face-to-face interviews (for details of the sampling methods and survey questions, see CBS 2017).

Survey responses related to nine questions covering public perceptions of climate change, changes in precipitation and temperature pattern, onset of summer and winter seasons, the beginning of monsoon and winter rainfall, and the frequency of extreme events (changes in drought, heavy rainfall, heat wave, and cold wave) were selected. Frequencies and percentages of responses were pooled at the national level.

2.2 Climate data

We extracted data for Nepal from gridded global datasets of temperature (Smith and Reynolds 2005) and precipitation (Xie et al. 2010), produced by the National Oceanic and Atmospheric Administration's (NOAA's) Climate Prediction Center (CPC). Daily maximum and minimum temperature data and daily precipitation data over the period 1979–2016 were downloaded from the CPC, National Centers for Environmental Prediction (NCEP), NOAA. These datasets have been produced by combining observations from stations, satellite measurements, and interpolation techniques and are available at $0.5° \times 0.5°$ spatial resolution.

2.3 Data analysis

We created annual anomalies of temperature and precipitation from 1979 to 2016, using the reference period 1981–2010, which is the most recent baseline recommended by the World Meteorological Organization. Selected summary statistics and climate indices based on the CCl/CLIVAR (Climate and Ocean: Variability, Predictability and

Change)/JCOMM Expert Team (ET) on Climate Change Detection and Indices (ETCCDI) definitions were computed from the subset datasets. Percentile-based extreme indices of temperature and precipitation were calculated using climdex.pcic R-package (Bronaugh 2015) that uses bootstrapping techniques outlined by Zhang et al. (2005) as per ETCCDI definitions. To align with the survey questions, trends of four temperature extremes, the frequencies of hot days (TX90p), hot nights (TN90p), cold days (TX10p), and cold nights (TN10p), were calculated. Similarly, trends of four precipitation extremes, the maximum length of the dry spell (CDD), the maximum length of the wet spell (CWD), the number of heavy rainfall days (R10mm), and the number of very heavy rainfall days (R20mm), were calculated. Survey questions were dealt with documenting changes over the last 25 years; therefore, we limited our analysis of climate extremes to the last 30 years (1987–2016) to match the period mentioned in survey questions, while fulfilling the minimum required period of 30 years of climate data to study climate change as recommended and adopted by the IPCC (IPCC 2001). We also compared monthly average mean temperature and total precipitation between two periods (from 1979 to 1998 and from 1999 to 2016) by dividing the whole period (38 years of available data) into two equal halves. We calculated grid-wise trends of the annual and seasonal temperature and precipitation, using a non-parametric Mann–Kendall test using Kendall R-package (McLeod 2015). We used Sen's slope estimator based on Kendall's τ (Sen 1968) to determine a magnitude of trends using ZYP R-package (Bronaugh and Werner 2015).

2.3.1 Spatial analysis

We spatially mapped perceptions of respondents based on their locations and overlaid them onto the maps showing trends of actual changes in annual and seasonal temperature and precipitation as well as the patterns of related extreme indices using ArcGIS 10.2. To compare local perceptions of climate change with the observed climatic trends, respondents were geolocated using the geographic coordinates gathered during the survey. We used the names of the villages and their geographic coordinates for missing cases. We created maps to compare people's perceptions with scientifically analyzed climate trends and constructed cross-tabulations of individual perceptions by trends of the observed climate indicators related to the perceptions. Altogether, we compared local perceptions of eight climatic indicators with 12 different trends of average, seasonal, and extreme climate indices calculated from actual climate data. To investigate the effects of demographic factors on the accuracy of public perceptions, we created perception accuracy score. If a respondent's perception to the related climate index parameter agreed with the actual trend, we considered it a "match" and scored 1; otherwise, we considered it a "mismatch" and scored 0. We summed up the scores of agreed perceptions of all climate indices to produce a total score. As there were 12 different comparisons, the total scores of agreed perceptions ranged from 0 (low accuracy) to 12 (high accuracy). We regressed this perception accuracy score as dependent varible against demographic variables, place attachment, climatic zone, and previous understanding of climate change as independent variables using generalized regression models.

Demographic variables included in the study are gender, age, caste/ethnicity, education, occupation, and household income. Other independent variables used are living in the locality, climatic zone, and the previous understanding of climate change.

3 Results

3.1 Demographic characteristics of the respondents

The 5060 respondents are diverse in terms of gender, age, social composition (caste/ethnicity), education, occupation, income, and their geographic locations (Table 1). Two thirds of the respondents were male. The majority of the respondents (41.2%) were between 45 and 54 years, followed by respondents aged between 55 and 64 years (30.1%). Only a small proportion (8.1%) of the respondents were older than 75 years. *Janajati* (38.5%) and *Brahmin/Chhetri* (33.7%) were the major ethnic composition. Significant proportion of the respondents were illiterate (43%), and only 4% have completed bachelor or higher degree. More than half of the respondents (55%) were farmers by profession, followed by the people involved in

Table 1 Socio-demographic characteristics of the respondents

Socio-demographic variables	Number	Percentage
Sex		
Male	3396	67.1
Female	1664	32.9
Age (years)		
45–54	2083	41.2
55–64	1522	30.1
65–74	1043	20.6
> 75	412	8.1
Caste/ethnicity		
Brahmin/Chhetri	1705	33.7
Madhesi	522	10.3
Dalit	599	11.8
Janajati	1947	38.5
Muslim	126	2.5
Others	161	3.2
Climate zone		
Tropical	2705	53.5
Sub-tropical	2038	40.3
Temperate	297	5.9
Sub-alpine	20	0.4
Education		
Illiterate	2199	43
Below secondary	1977	39
Secondary	704	14
Bachelor or higher	180	4
Occupation		
Agriculture	2797	55
Jobs	649	13
Other non-agricultural business	608	12
Household chores	298	6
Not working (unemployed/retired/unable to work)	708	14
Year of living in the locality		
25–34	1058	21
35–44	553	11
45–54	1545	31
55–64	1039	21
> 65	865	17
Average household annual income (USD) (SD)	2570	4350
Average family size (SD)	4.9	2.5

various jobs and non-agricultural business. The average annual household income reported by the respondents was USD 2570 ± 4350, and family size was 4.9 ± 2.5 members.

3.2 Local perceptions of climate change

The respondents had a broad understanding of, and diverse views on, climate change (Table 2). Almost all the respondents (95%) agreed that climate has changed over the last 25 years. However, only half of them (51%) heard about "*Jalabayu Pariwartan*"- Nepali translation of "climate change." Other respondents heard about climate change from radio, television, newspaper, and discussion with neighbors, relatives, and family members. The majority of participants perceived that summer temperature had increased

Table 2 People's perception of changes in key climatic variables and extremes

Survey questions and responses	Number	Percentage
Have you heard the term climate change?		
Yes	2490	49
No	2570	51
Do you think climate in this place is different than it was 25 years before?		
Yes	4823	95
No	237	5
How has the summer temperature changed compared to 25 years before?		
Increased	4560	90
Decreased	109	2
No change	391	8
How has the winter temperature changed compared to 25 years before?		
Increased	1333	26
Decreased	2827	56
No change	900	18
How has the rainfall in monsoon changed compared to 25 years before?		
Increased	219	4
Decreased	4573	90
No change	268	5
How has the winter rainfall changed compared to 25 years before?		
Increased	35	1
Decreased	4565	90
No change	460	9
How have you experienced the changes in heat waves in this area over the past 25 years?		
Increased	402	73.8
Decreased	143	26.2
How have you ever experienced the changes in cold waves in this area over the past 25 years?		
Increased	723	42.4
Decreased	981	57.6
How have you experienced the changes in drought in this area over the past 25 years?		
Increased	4508	99.4
Decreased	25	0.6
How have you experienced the changes in flood in this area over the past 25 years?		
Increased	1030	62.5
Decreased	617	37.5
How have you experienced the changes in heavy rainfall events in this area over the past 25 years?		
Increased	341	30.6
Decreased	773	69.4
How have you experienced the changes in sporadic rain in this area over the past 25 years?		
Increased	1959	92.7
Decreased	154	7.3

while more than half (56%) of the participants believed that winter temperature had decreased, in contrast to the 26% of respondents who perceived an increase in winter temperature over the last 25 years.

In a common perception of shifts in seasonal changes, about 47–59% of respondents perceived that the start of the summer season had shifted a month earlier now, as underpinned by the temperature change (Fig. 1a). There had been no change in timing of onset of winter as perceived by the majority of the respondents (Fig. 1b). While respondents perceived no change in the timing of the onset of winter, a clear shift in the responses was observed in timings of onset of winter and monsoonal rainfall. A majority of the respondents (66–68%) felt that timing of the start of the monsoon rainfall had delayed by a month now than 25 years ago. According to them, the start of monsoon season was *Jesth* (the Nepalese month that falls between May 15–June 14) before, and it is now in *Ashar* (the Nepalese month that falls between June 15–July 15) (Fig. 1c). A similar shift by a month in the onset of winter rainfall was mentioned. A majority of the respondents (41–43%) believed that winter rainfall started in *Poush* (the Nepalese month that falls between December 16 and January 14) before, and it is now in *Magh* (the Nepalese month that falls between January 15 and February 14) (Fig. 1d).

A majority of the respondents mentioned that heat waves have increased (74%) while cold waves have decreased (58%), although the number of respondents who believed in the decrease in the cold wave was also high (42%). Almost all the respondents (99.4%) thought that drought has increased. Contrasting views on heavy precipitation and flood events were observed although both are correlated; a high percentage of the respondents (62%) perceived that floods have increased, whereas the majority (70%) perceived a decline in the occurrence

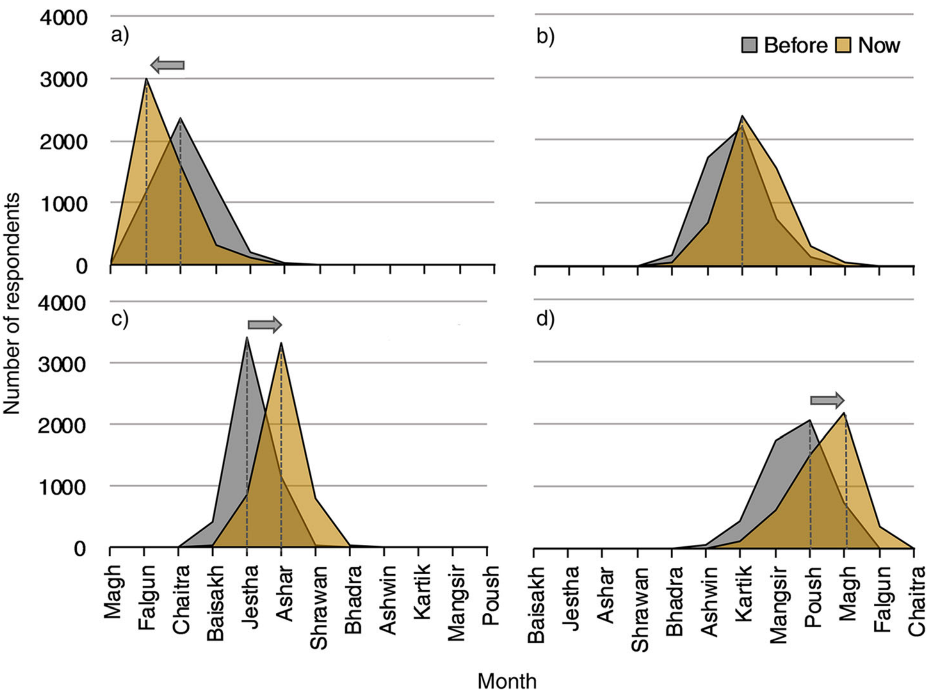

Fig. 1 People's perceptions of changes in the timing of the start of the season between 25 years before and now. **a** Summer season. **b** Winter season. **c** Summer rainfall. **d** Winter rainfall

of heavy rainfall. More than 90% of the respondents perceived that sporadic rainfall has increased.

3.3 Change in temperature and precipitation patterns

Significant changes in temperature and precipitation patterns across the country was observed for the period 1979–2016 with a large spatial variation. Mean annual temperature of Nepal has increased by 0.03 °C/year ($p \leq 0.001$), with an increase in maximum temperature by 0.02 °C/year ($p = 0.009$) and minimum temperature by 0.04 °C/year ($p \leq 0.001$). The rate of increase was more pronounced after 2005, making 2016 the hottest year (Fig. 2a). Spatially, mean annual temperature in a majority of grids (58 out of 82) showed a significant increase while a single grid showed decrease; the increase in mean temperature ranged from 0.01 to 0.09 °C/year (Fig. 2b). Mean summer and winter temperature has increased by 0.02 and 0.04 °C/year, respectively, during the last 38 years. Summer temperature was significantly increased in 49 grids and decreased in 1 grid, and the rate of increase ranged from 0.01 to 0.07 °C/year (Fig. 2c). Likewise, winter temperature has increased in 46 grids and decreased in 1 grid, and the rate of increase ranged from 0.03 to 0.11 °C/year (Fig. 2d).

Annual precipitation in Nepal has increased with a rate of 8.7 mm/year ($p = 0.03$) with a major increase in monsoon season by 7.67 mm/year ($p = 0.02$) from 1979 to 2016. The increase in annual precipitation was more pronounced in recent years particularly after early 2000, while a continuous decrease was observed before 2000 (Fig. 3a). Although trend in winter precipitation was decreasing, it was not significant. There was a large spatial variation in annual and seasonal trends of precipitation in Nepal. A majority of grids (64 out of 82) showed an increase ($p \leq 0.10$) in annual precipitation (Fig. 3b) and 58 grids showed an increase ($p \leq 0.10$) in monsoon precipitation across Nepal during the period of the last 38 years (Fig. 3c). However, none of the grids showed significant trends in winter precipitation (Fig. 3d).

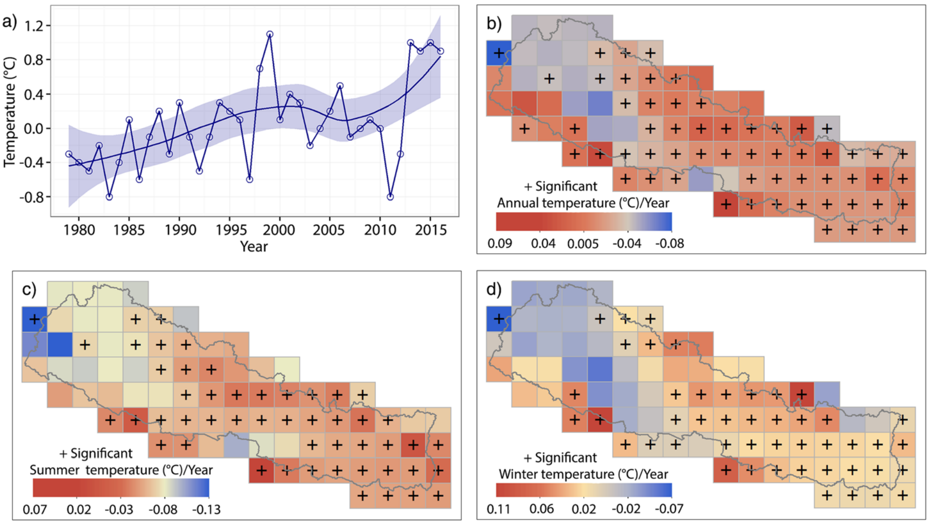

Fig. 2 Temporal and spatial trends of temperature (1979–2016). **a** Time series of the country averaged temperature anomaly. **b** Spatial trend of changes in annual temperature. **c** Spatial trend of changes in summer temperature. **d** Spatial trend of changes in winter temperature

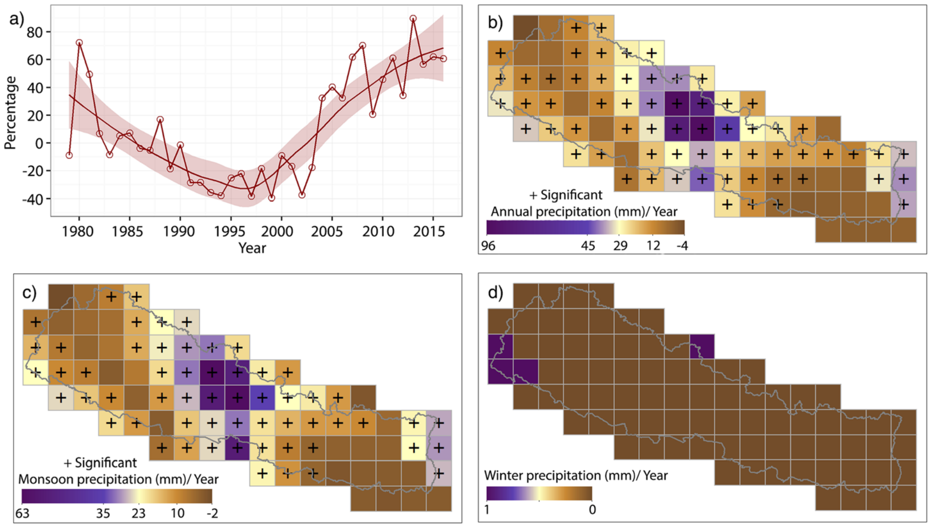

Fig. 3 Temporal and spatial trends of precipitation (1979–2016). **a** Time series of the country averaged precipitation anomaly. **b** Spatial trend of changes in annual precipitation. **c** Spatial trend of changes in monsoon precipitation. **d** Spatial trend of changes in winter precipitation

3.4 Changes in temperature and precipitation extremes

Overall, we observed increasing trends of hot days/nights and decreasing trends of cold days/nights as well as a decreasing trend of the dry spell and increasing trends of the wet spell and heavy precipitation (Table 3). A frequency of hot days (TX90p) increased in 22 grids while decreased significantly in four grids. A frequency of hot nights (TN90p) also showed a significant increase in the majority of grids (R Core Team 2017) and decreased in a single grid. A number of cold days (TX10p) decreased significantly in 27 out of 82 grids and increased in one grid. Likewise, a number of cold nights (TN10p) decreased significantly in 49 grids and increased in one grid. The dry spell (CDD) has significantly decreased in 25 grids while the number of the wet spell (CWD) significantly increased in 55 grids. The annual count of heavy precipitation days (R10mm) and very heavy precipitation days (R20mm)

Table 3 Grid wise trends of key climatic indices for the 82 grids representing the whole country

Climate indexes	Significantly decrease	Decrease	No change	Increase	Significantly increase
Annual precipitation		1		17	64
Monsoon precipitation	1			23	58
Winter precipitation		31		51	
Mean annual temperature	1	1		22	58
Mean summer temperature	1	7		25	49
Mean winter temperature	1	10		25	46
Hot days (TX90p)	4	17		39	22
Hot nights (TN90p)	1	10		41	30
Cold days (TX10p)	26	46		9	1
Cold nights (TN10p)	49	16		16	1
Dry spell (CDD)	25	54		3	
Wet spell (CWD)		1	4	22	55

significantly increased in 58 and 48 grids, respectively. The number of very heavy precipitation days decreased in a single grid.

3.5 Comparison between perceptions and observed climatic trends

An agreement between local perceptions and trends of observed climate data is higher in the case of temperature- than precipitation-related indices (Table 4), indicating that local people can perceive temperature-related indices more accurately than the precipitation-related indices. Local perceptions of change in summer temperature highly corresponded with the actual change in summer temperature resulting in 87% match ($\chi^2 = 4.14$ and $p = 0.042$) (Fig. 4a). The congruence between perceptions and winter temperature was low (Fig. 4b).

Contrastingly, a high level of divergence was observed between local perceptions of seasonal precipitation and actual trends of seasonal precipitation (Fig. 4c, d). About 96% of the local perceptions of monsoon rainfall did not match with the observed trends of monsoon rainfall. Although a majority of respondents perceived that the rainfall season has shifted by a month, our analysis of monthly rainfall data of two different periods provided no evidence to support the perception (Fig. 5b). However, an early start of summer season could be explained by a consistent increase in monthly average temperature (Fig. 5a).

Perceptions of increased heatwave matched with an increased frequency of hot nights by 74% ($\chi^2 = 1.76$, $p = 0.278$) (Fig. 6b). Similar agreement (60%) was observed between perceptions of decreased frequency of the cold wave and actual trends of the frequency of cold days ($\chi^2 = 42.8$, $p = 0.000$) (Fig. 6c). A higher percentage of respondents perceived an increased drought in many localities while actual drought spells in those areas were decreasing and wet spells were increasing. The perception of increased drought did not match with the actual trends of dry spells by 96% ($\chi^2 = 0.92$, $p = 0.338$) (Fig. 6e, f). Similar mismatch was observed between perceptions of heavy precipitation and actual trends of rainfall extremes (heavy precipitation) by 69%.

3.6 Factors affecting accuracy of the perceptions

We also examined if an accuracy of climate change perceptions was associated with demographic factors, place attachment, regional differences, and prior understanding about climate change using a generalized linear model (Table 5). Our model showed that a positive association between gender (female) and accuracy of perceptions. Likewise, people living in a same locality for a longer period can predict actual climate more accurately; the greater the number of years respondents are living in the localities, more accurately they can predict the changes. Respondents in two occupations, living in the comparatively milder region were found having a lower predictive accuracy of climate change. Prior understanding of climate change, age, household income, and education were not associated with the accuracy of local perceptions of climate change.

4 Discussion

This study has presented an integrated body of evidence, incorporating the most recent climate data not covered by the previous national-level studies (Shrestha et al. 1999; Duncan et al. 2013). Our results confirm a consistent trend of warming in Nepal and but a lower rate of

Table 4 Cross-tabulation showing agreements and disagreements between the actual trends (columns) and people's perceptions (rows) for various climatic indices

Summer temperature				
		Actual trend		
		Increase	Decrease	Total
Perceptions	Increased	4393	167	4560
		94%	4%	98%
	Decreased	109	0	109
		2%	0%	2%
Winter temperature				
		Actual trend		
		Increase	Decrease	Total
Perceptions	Increased	1125	208	1333
		27%	5%	32%
	Decreased	2409	418	2827
		58%	10%	68%
Monsoon rainfall				
		Actual trend		
		Increase	Decrease	Total
Perceptions	Increased	219		219
		5%		5%
	Decreased	4573		4573
		95%		95%
Winter rainfall				
		Actual trend		
		No change	Increase	Decrease
Perceptions	Increased	6	13	16
		0%	0%	0%
	Decreased	798	2034	1733
		16%	40%	34%
	No change	116	113	231
		2%	2%	5%
Hot days				
		Actual trend		
		Increase	Decrease	Total
Perceptions	Increased	315	87	402
		58%	16%	74%
	Decreased	131	12	143
		24%	2%	26%
Hot nights				
		Actual trend		
		Increase	Decrease	Total
Perceptions	Increased	400	2	402
		73%	0%	74%
	Decreased	141	2	143
		26%	0%	26%
Cold days				
		Actual trend		
		Increase	Decrease	Total
Perceptions	Increased	55	668	723
		3%	39%	42%
	Decreased	13	968	981
		1%	57%	58%
Cold nights				
		Actual trend		
		Increase	Decrease	Total
Perceptions	Increased	134	589	723
		8%	35%	42%

Table 4 (continued)

	Decreased	113	868	981
		7%	51%	58%
Maximum length of dry spell (CDD)				
		Actual trend		
		Increase	Decrease	Total
	Increased	160	4348	4508
Perceptions				
		4%	96%	99%
	Decreased	0	25	25
		0%	1%	1%
Maximum length of wet spell (CWD)				
		Actual trend		
		No change	Increase	Total
	Increased	359	4149	4508
Perceptions				
		7%	92%	99%
	Decreased	1	24	25
		0%	1%	1%
Number of heavy precipitation days (R10)				
		Actual trend		
		Increase	Decrease	Total
	Increased	341	0	341
Perceptions				
		31%	0%	31%
	Decreased	773	0	773
		69%	0%	69%
Number of heavy precipitation days (R20)				
		Actual trend		
		No change	Increase	Total
	Increased	70	271	341
Perceptions				
		6%	24%	31%
	Decreased	212	561	773
		19%	50%	69%

warming than was reported by Shrestha et al. (1999). The difference could be attributed to different datasets used in the two studies and differential number of stations and pixels in data capture. The findings of an increase in annual and monsoonal precipitation in Nepal corroborate the findings of increasing trends of annual and monsoonal precipitation (Duncan et al. 2013; Shrestha et al. 2017). Monsoonal precipitation contributes ~80% to the annual precipitation (Karki et al. 2017), and hence, the increase in annual precipitation is the result of increased monsoonal precipitation.

4.1 Local perceptions of climate change

Our findings of increasing wet spell and decreasing dry spell are consistent with Sheikh et al. (2015) and Shrestha et al. (2017) but partially inconsistent with Karki et al. (2017). The partial inconsistency may have been caused by the difference in the periods of analysis between two studies. Karki et al. (2017) reported mixed trends of significant increase and decrease in dry spells although the number of stations with a significant increase of dry spells is slightly higher than that of the significant decrease. Nevertheless, increase in heavy and very heavy precipitation might be concerning to the flood and landslide-prone countries like Nepal. Changes in

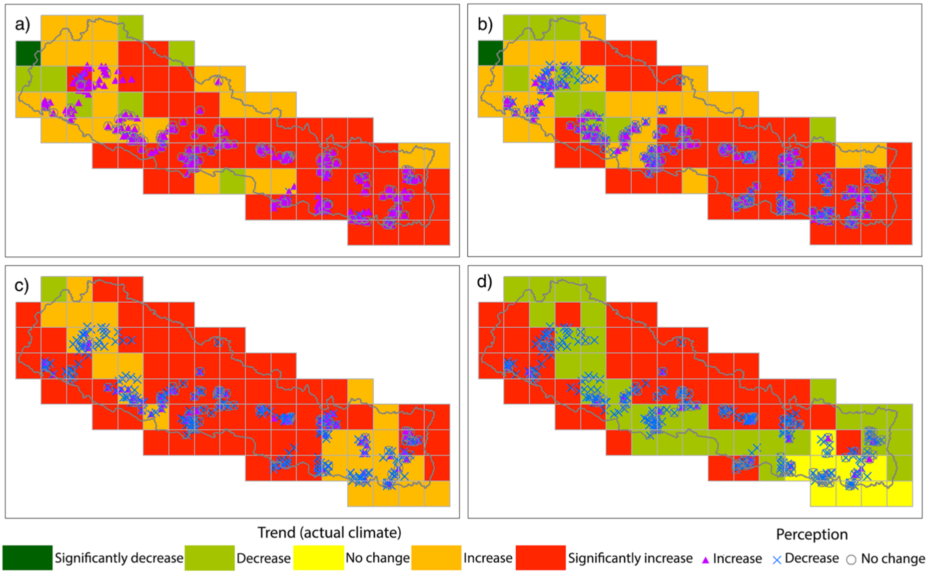

Fig. 4 **a** Spatial comparison between people's perception of change in summer temperature and summer temperature trend. **b** Spatial comparison between people's perception of change in winter temperature and winter temperature trend. **c** People's perception of change in monsoon rainfall and monsoon rainfall trend. **d** People's perception of change in winter rainfall and winter rainfall trend

the frequency of extreme temperature especially hot extremes have become more common and cold extremes have become less frequent in South Asia including Nepal (Sheikh et al. 2015; Shrestha et al. 2017), and our analysis substantiates the similar trend. Despite overall warming, observed decrease of hot days and nights and increase of cold days and nights in some pixels may be the results of fog episodes in winter that have become more frequent over the past decade, which reduced maximum temperature considerably making a smaller difference between maximum and minimum temperatures (Baidya et al. 2008; Shrestha et al. 2017).

We observed a higher degree of congruence between the perceptions of temperature change (summer warming, heat wave, and cold wave) and the observed changes in temperature parameters while a greater divergence was observed between the perceptions of precipitation change (average and seasonal precipitation, droughts, and heavy rain) and the observed changes in precipitation parameters. A high level of disaccord was observed between the perceptions of drought and actual dry and wet spells. The perceptions of increased floods and

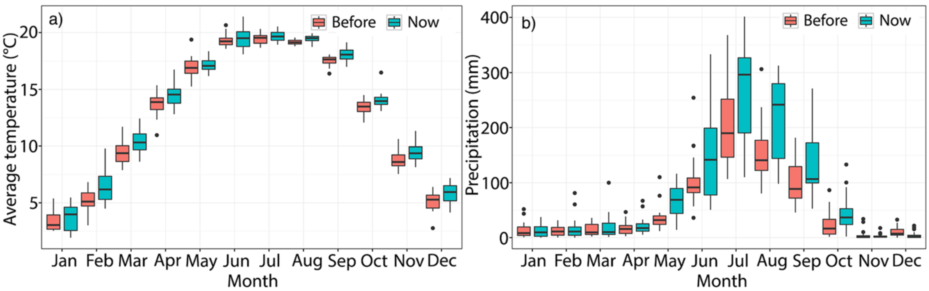

Fig. 5 Comparison of the changes in **a** average monthly temperature and **b** average monthly precipitation between two periods (1979–1998 as before and 1999–2016 as now)

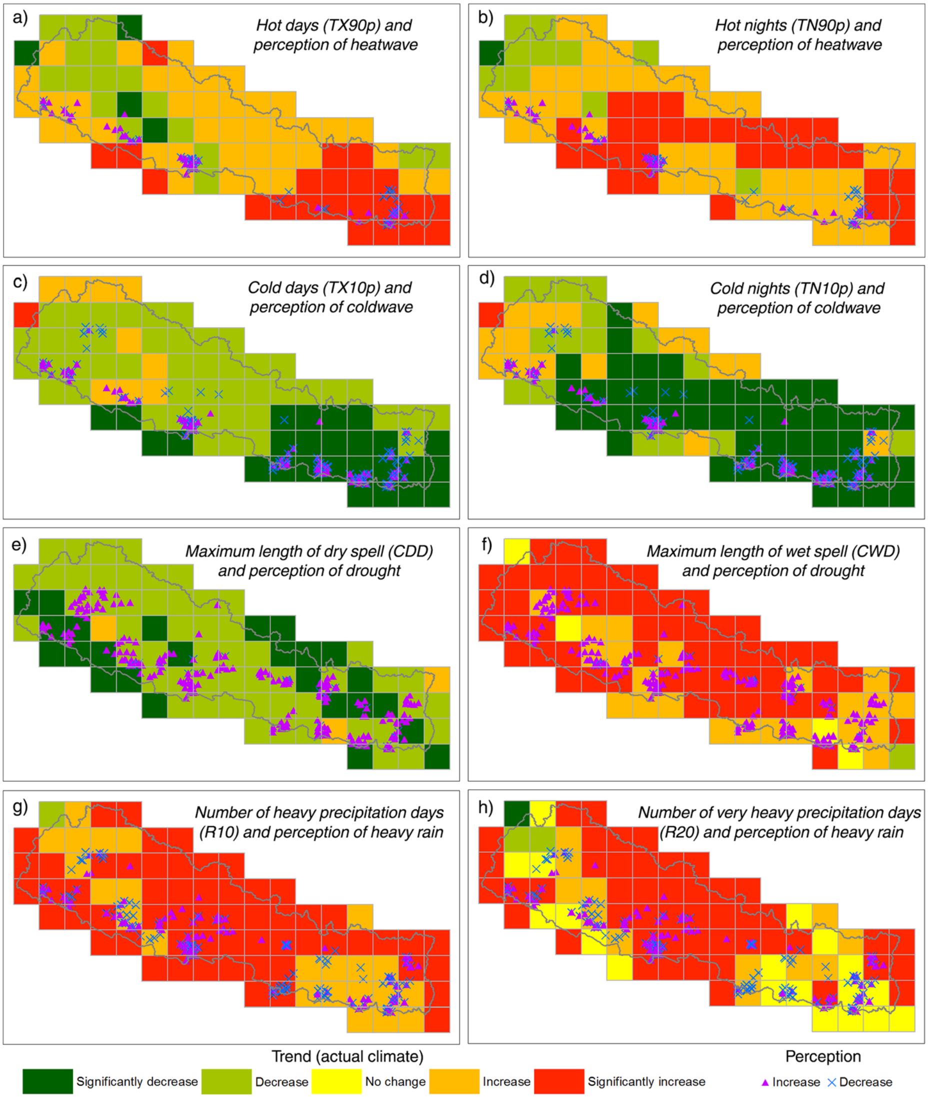

Fig. 6 **a** Spatial comparison between people's perception of the change in heatwave and trends of hot days. **b** Spatial comparison between people's perception of the change in heatwave and trends of hot nights. **c** Spatial comparison between people's perception of the change in cold wave and trends of cold days. **d** Spatial comparison between people's perception of the change in cold wave and trends of cold nights. **e** Spatial comparison between people's perception of drought and trends of the length of CCD. **f** Spatial comparison between people's perception of drought and trends of the length of CWD. **g** Spatial comparison between people's perception of heavy rain and trends of the number of R10. **h** Spatial comparison between people's perception of heavy rain and trends of the number of R20

decreased heavy rainfall were conflicting as well. Negative events have a greater impact on the human psychological state than positive ones (Baumeister et al. 2001). Therefore, negative bias might cause locals to remember negative events like floods better than positive events. The individual's perception of precipitation change was not always coupled with the observed changes in precipitation as evident from very local, regional (West et al. 2008; Kosmowski

Table 5 Generalized linear model predicating accuracy of peoples' perceptions of climate change

Dependent variable	Regression coefficients (standard error)
(Intercept)	2.3770 (0.0760)***
Demographics	
Gender[a] (female)	0.1904 (0.0472)***
Age[b] (55–64)	0.0039 (0.0610)
Age (65–74)	− 0.0430 (0.0674)
Age (> 75)	− 0.1094 (0.0914)
Caste/ethnicity[c] (Madhesi)	− 0.0592 (0.0691)
Caste/ethnicity (Dalit)	0.0623 (0.0642)
Caste/ethnicity (Janajati)	− 0.0448 (0.0433)
Caste/ethnicity (Muslim)	− 0.3243 (0.1222)**
Caste/ethnicity (Others)	− 0.1231 (0.1069)
Education[d] (below secondary)	0.0403 (0.0444)
Education (secondary)	0.0262 (0.0662)
Education (bachelor or higher)	− 0.1910 (0.1105)
Occupation[e] (jobs)	− 0.1372 (0.0587)*
Occupation (other non-agri-business)	−0.1477 (0.0608)*
Occupation (household chores)	− 0.1268 (0.0822)
Occupation (unemployed)	− 0.0781 (0.0595)
Household income	0.0000 (0.0000)
Location attachment	
Living in the locality[f] (Sherwood and Fu 2014; Shrestha and Aryal 2011; Shrestha et al. 2017; Shrestha et al. 1999; Shrestha and Bawa 2014; Simelton et al. 2013; Slegers 2008; Smith and Reynolds 2005; Sundblad et al. 2007; Weber 2010)	0.1297 (0.0700)
Living in the locality (45–54)	0.1378 (0.0547)*
Living in the locality (55–64)	0.1941 (0.0731)**
Living in the locality (> 65)	0.2195 (0.0834)**
Climate change knowledge	
Heard climate change[g] (no)	− 0.0660 (0.0403)
Geography	
Climatic zone[h] (sub-tropical)	− 0.4235 (0.0407)***
Climatic zone (temperate)	− 0.3900 (0.0807)***
Climatic zone (sub-alpine)	− 0.3683 (0.2893)

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

[a] Reference category is "male"

[b] Reference category is "45–54"

[c] Reference category is "Brahmin/Chhetri"

[d] Reference category is "illiterate"

[e] Rreference category is "farming"

[f] Reference category is "25–34"

[g] Reference category is "yes"

[h] Reference category is "tropical"

et al. 2016), and global (Savo et al. 2016) studies. Several factors such as potential mismatch in spatial and temporal scales of comparisons and biases on human perceptions could contribute to these divergences (Savo et al. 2016). Furthermore, rainfall pattern might be harder to perceive if a persistent high variability occurs and rainfall changes can be easily confused with changes in farming system sensitivity (Simelton et al. 2013). An observed high spatial and temporal variability of rainfall (co-occurrence of increasing and decreasing trends of precipitation) in the Himalayan region including in Nepal (Duncan et al. 2013; Shrestha et al. 2017) may have limited local's ability to perceive the trend correctly. In this survey, more than 90% of the respondents viewed that sporadic rainfall has increased, indicating the rainfall variability.

Our findings are consistent with the previous studies showing that local perceptions correspond with the observed changes in average and seasonal temperature but not with precipitation parameters (West et al. 2008; Marin 2010; Osbahr et al. 2011; Savo et al. 2016). The highest inconsistency occurred between perceptions of droughts and trends of dry spells (CDD) and wet spells (CWD). CDD is mostly related to a large-scale weather systems rather than localized systems (Casanueva Vicente et al. 2014) while individual's perception is highly localized. Given the varied topography and geography of Nepal, there is a tremendous variation in the amount and pattern of precipitation within a span of a few kilometers. Perceiving drought by individuals is always challenging because it is a slow-onset hazard with a long-time horizon, broad spatial extent, and subjected to diverse sets of conceptual and operational definitions (Howe et al. 2015). The meaning of drought for farmers is broader than a simple lack of rain (Slegers 2008). Several factors other than the amount of precipitation contributes to drought (Sherwood and Fu 2014); therefore, CCD and CWD can only indirectly characterize drought. Perceptions of drought may be the impact of higher temperature, higher evapotranspiration, and greater water stress (Osbahr et al. 2011). Premature cessation of rainfall, a mismatch between the timing of rainfall and farmer's expectation, and variance in the amount of rainfall and farmer's need may lead agrarian communities to perceive "drought." Normally in agrarian society, if big rains are expected to fall during the time of sowing crops or other agricultural activities that require rain, or if there is a change in the timing or frequency and timing does not meet their expectation, farmers refer to the period as "dry spell," even if it has received some modest rainfall (West et al. 2008). On the contrary, persistent availability of water to irrigate crops leads farmers to perceive wet season or notice an increase in annual precipitation, despite the observed stable condition in rainfall (Niles and Mueller 2016). Agricultural outcomes are also used as proxies when quantifying rainfall by many natural resource-dependent communities (Marin 2010). People may refer "drought" year if agriculture production declines. It is difficult to differentiate yield impacts of weather from the effects of other confounding factors even if the farming is highly sensitive to changes in rainfall (Mulenga et al. 2017). Therefore, local perception of drought may not correspond with the drought indices.

4.2 Factors affecting accuracy of the perceptions

Previous studies report that gender, age, and caste/ethnicity affect the level of understanding and perception of reality and the urgency of climate change (Wolf and Moser 2011; Macchi et al. 2015). Gender is a widely demonstrated demographic factor related to risk judgments, including the risks of climate change (Sundblad et al. 2007). American women were found to have greater knowledge of climate change than men (McCright 2010). Our results of the higher predictive accuracy of the perceptions of climate change of female are paralleled with the perspective that women are more concerned about environmental issues that are relevant to the families and communities (Liu et al. 2014; Habtemariam et al. 2016). Furthermore, in the agrarian societies like Nepal, women are highly engaged with the environment, which may contribute to better understanding of environmental phenomena such as climate change.

Unlike other groups, farmers engage intensively with the environment and thus have a better understanding of the environment, enabling them to detect changes in the climate more accurately (Roco et al., 2015). However, we did not find any linkages between farming and the perceptual accuracy of climate change. Although previous studies found the role of age in predicting climate change, and that older age groups were more likely to perceive actual temperature trends (Habtemariam et al. 2016), we did not find any correlation between age and predictive accuracy. It might be because our sample populations were all mature and experienced (older than 45 years old), and there might not be much difference in perceptions between people of similar age group. In Nepal, mountain communities are considered the most vulnerable to climate change (Macchi et al., 2015) and the magnitude of warming is also higher in the mountain region (Shrestha and Aryal 2011). The negative correlation between the climate zone (sub-tropical and temperate) indicates that people living in the milder climate as in sub-tropical and temperate zones of Nepal might have lower predictive accuracy. The temperature ranges in sub-alpine and tropical regions are narrower than those of sub-tropical and temperate regions, and hence, any deviation is likely to have an effect that is significant. Therefore, people living in the milder climatic zones may have less experience of climate extremes causing a lower accuracy in perceptions. Household incomes, prior understanding of climate change, and education were not found to be related to the predictive accuracy of perceptions of climate change. Nevertheless, income and education play crucial role in adaptive capacity; the poorest households are more likely exposed to impacts associated with climate change (Macchi et al., 2015).

5 Conclusion

We provide a comprehensive assessment of climate change in Nepal through an integrated analysis of people's perceptions and actual climate data, with largest ever survey of local perceptions and the first ever attempt to collate instrumental records starting from 1979. The survey data included 5060 responses across the country, while the climate data covered a long-term (1979–2016) analysis of annual and seasonal trends of temperature and precipitation, onsets of the seasons, and trends of the selected extreme indices of temperature and precipitation.

This study presents an important contribution to the climate change literature. First, we observed the consistent trend of warming, increasing hot days and nights, increasing annual precipitation and wet spells, heavier precipitation, and decreasing dry spells in Nepal. Second, we have also advanced a methodological approach for integrating people's experiential knowledge with systematically observed climate data. Third, this study has established associations (or lack of associations) between various respondent attributes and their ability to make accurate judgment about various climatic phenomena, by showing that local perceptions of climate change does not always correspond with instrumental records of climate change. It appears that locals cannot accurately predict the onset, duration, amount, and extreme patterns of rainfall due to several factors such as biases and invalid heuristics. The difference in understanding of some precipitation indices between locals and scientists may lead to different and contrasting conclusions about the phenomenon of climate change. Furthermore, detecting changes in precipitation patterns amidst precipitation variability is challenging for local people. Co-occurrence of the perceptions of precipitation (almost equal number of people saying both increase and decrease) and the mismatch with the observed trends show that local people as individual agents lack sufficient cognitive skills to perceive rainfall patterns.

Our findings have at least three important implications. First, local perception alone does not always provide a good basis for adaptation planning, although it is important to consider people's perception in adaptation policy. Understanding of public perceptions is useful but using the results of public perception alone to devise adaptation policy and program is not sufficient. Other studies have shown that perceptions—whether accurate or not—are correlated with climate change belief and future climate concerns and risk (Niles and Mueller 2016). Therefore, we recommend caution while using the results of the local perceptions of climate change in policy and program. The public perceptions of climate change are changing over time, and the predictive accuracy of public perception could improve through having meaningful climate communication between the public and scientists. For example, as majority of people do not have a capacity to perceive precipitation accurately, increased awareness and capacity building at the local level might help to better adapt to climate change. Moreover, as locals continue to be exposed to changes (extreme weather, frequency, and intensity) in climate, they are likely to detect change more accurately. Therefore, a constant re-evaluation of the local perceptions of climate change is necessary in future.

Second, advancing the blended approach—combining perceptions and instrumental records—is important in developing a robust climate science. More research is needed to fully understand the effects of demographic, ideological, conceptual, and other variables on the accuracy of climate change perceptions. Better framing of the questions that address the discrepancies between local understanding of drought and scientific analysis of drought may result in better coherence between the local perception of rainfall and observed data. Such a blended method can provide a basis for not only checking the limitations of the single method but also providing additional insights into the analysis and thus deepening the quality of evidence. Finally, a data scarce region like the Himalaya would benefit from periodic and coordinated large-scale survey of local perceptions as well as the continuous update of observed records of climate change.

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