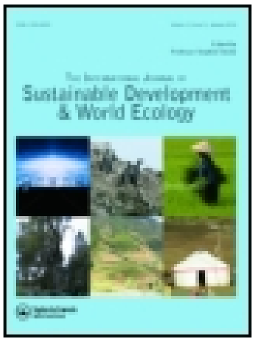

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Historical evidence of climatic variability and changes, and its effect on high-altitude regions: insights from Rara and Langtang, Nepal

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ABSTRACT
Climatic variability and its effects have been experienced in the high-altitude regions of Nepal for some considerable time. Most of the studies on local people's perception available so far in Nepal on climate include with respect to weather changes, and almost none have been verified with satellite imagery. This study thus attempts to combine meteorological and satellite imagery for comparing local people's perception so that a more robust validation can be established. Both qualitative (transect walk, key informant interview, focus group discussion and institutional visit) and quantitative (meteorological and satellite image) data and techniques were employed. Local people from Rara and Langtang in Nepal shared their observations and perceptions on the changing climate for the last three decades and the effects on them and their local microclimate. Apart from temperature, rainfall and snowfall anomalies, locals observed changes in the water sources and increasing drought along with alteration in the phenology of tree and agricultural crops as well as vegetation range migration. Satellite image analysis also confirms a change in snow cover as notified by the local people. This study shows that local people's knowledge could be considered as a complement to the observed scientific evidences of climate change science and their perceptions can be used reliably where scientific data are lacking. Finally, perceived climatic risks, current gaps and future opportunities are discussed and some recommendations are suggested.

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Climate variability and changes; perception; high-altitude region; Nepal

1. Introduction

The evidence of climatic variability and its effects in Nepal has been reported by many studies and some have expressed serious concern on its negative effects on ecosystem and biodiversity. Chaudhary and Aryal (2009) documented perceptions of local people on climatic variability and its effects on ecosystems and its biota in eastern Nepal while Chapagain et al. (2009) also portrayed similar interesting stories from a wide arrays of people living in lowland, hill and high-altitude regions of Nepal. They both mentioned different perceived experiences of local people, especially on changes in weather and climatic pattern over the last few decades and how different plant and animal species respond to the new temperature and rainfall regime. Bhusal (2009) reported corresponding effects on ecosystem function and biological systems such as prolonged drought, shifting of plants, changes in flowering and fruiting time of forest and horticultural crops, arrival of new invasive species and altered crop ripening and harvesting time. Local people of the Kanchenjunga region of eastern Nepal documented similar diverse observation on changes in their local ecosystems and biodiversity (Chaudhary et al. 2011).

Himalayan regions are among the most vulnerable regions in the world (Shrestha et al. 2012), and the real concern is that large portions of landmass of Nepal fall into this region. A recent study (Salick et al. 2014) of alpine regions on the 1500 km stretches of Eastern Himalaya that contains portions of China's Tibetan plateau, Bhutan and Nepal revealed an increase in average annual temperature by 1.5°C and total annual rainfall by an average of 360 mm over the last 60 years (1950–2010), both indicating and validating the effect of global climate change in this region. In Nepal, past studies have shown that climate change is real in most of the high-altitude regions, and local people have perceived those changes. Some of these include increases in annual temperature (Macchi et al. 2011; Manandhar et al. 2011; Gentle & Maraseni 2012; Aryal et al. 2014a; KC and Parajuli 2015), annual rainfall (Macchi et al. 2011; KC and Parajuli 2015), erratic rain fall (Gentle & Maraseni 2012; McDowel et al. 2013; Konchar et al. 2015), delay in monsoon (Macchi et al. 2011), decreased winter rainfall (Aryal et al. 2014b) and rapid snowmelt (Manandhar et al. 2011; McDowel et al. 2013; Aryal et al. 2014a, 2014b; KC and Parajuli 2015; Konchar et al. 2015). Such observations of increased temperature,

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erratic and less rainfall and delayed monsoon were also revealed for the hills of Nepal (Piya et al. 2012) and Terai lowland (Devkota et al. 2011; Ireland 2012). These evidences clearly show that the high-altitude and other low-lying regions of Nepal have experienced climatic variability. Similar changes of climatic pattern on temperature, rainfall and snowfall have also been perceived by the people living in other neighboring high-altitude regions of South Asia, such as eastern Himalaya (Sharma et al. 2009); Bhutan (RSPN 2012); Bangladesh (Huda 2013); Himachal state of India (Basannagari and Kala 2013; Kaul & Thornton 2014); Uttaranchal state of India (Kumar et al. 2008); northeast Sikkim Himalaya (Mishra et al. 2014); northern highland of Pakistan (Joshi et al. 2013; Gioli et al. 2014; Maryam et al. 2014); also in northwest Yunnan region (Haynes & Yang 2013) and Tibet region (Li et al. 2013) of China.

Bickerstaff (2004) defined perception as subjective evaluation that evolves from experiences and personality disposition that affects one's individual behavior and attitude while Wakefield et al. (2001) narrated that individual's everyday experience and exposure to media and other outside sources helps in forming and reinforcing perception. Consideration of perception is an important prerequisite for developing any kind of climate strategies for the field-level programs such as adaptation and mitigation. This is because if a person perceives the ongoing variability in climate and also recognizes its likely effects, then implementation of climate effect offset strategies will become easier. As Vedwan and Rhoades (2001) stated, study of people's perceptions on climate and the environment is a must in order to understand how they might respond to climate change. Similarly, Leiserowitz (2007) documented a global perception on climate change and stated that public risk perception of climate change influences the way they respond against it and is an important indicator to change the behavior that collectively could have enormous effect on our climate. In many instances, people's perceptions have been found consistent with climatic data generated by meteorological stations (Gbetibouo 2009; Wiid & Ziervogel 2012; Haynes & Yang 2013; Teye et al. 2015). Therefore, such observations and perceived thought of local people on climate change recorded at a local level could offer valuable place specific and culturally contextualized information, which in most cases we are unable to derive from global and regional assessment models (Konchar et al. 2015) and is especially important for a data-deficient developing country such as Nepal.

The recent technological development of both meteorological records and geospatial techniques such as remote sensing is helpful in studying and validating climate change phenomena. Meteorological station records temporal data on different climatic parameters of the locality and could be readily used for understanding climatic phenomena and validation of human natural observations. Satellite remote sensing techniques have now become a requisite for ecological applications and measuring environmental changes (Kerr & Ostrovsky 2003). It is now a pioneer in climate change studies, mainly due to its unparalleled global and fine-scale spatial coverage, characterized by independent source of observation (Yang et al. 2013). The snow cover changes could be some of the potential effects of warming temperature in the high-altitude regions, and satellite remote sensing is an appropriate tool for analyzing such trends.

We do not have to wait for scientific outcomes in hand for implementing remedial measures. This especially holds true for a country like Nepal, where scientific research lags far behind compared to other developed countries and also has acute data deficiency. Available literature on people's observations and perceptions in Nepal is in most cases in agreement with meteorological observations, meaning that it could be used as baseline information to reach conclusions and then design or formulate suitable strategies for adaptation and mitigation of extreme climatic effects on the ecosystems. For example, some recent government efforts on adaptation directed toward responding to climate change under climate change policy (2011) include the formulation and piloting of Nepal national adaptation program of action and local adaptation plan of action, both of which could benefit greatly if they consider integrating local's climatic observations and perceptions. In the context of Nepal, most of the studies available so far on climate perception include perception with respect to weather changes, and almost none have been verified with satellite imagery. This study, on the other hand, attempts to combine both meteorological and satellite imagery for comparison with perception data so that a more robust validation can be established. The objectives of this study are thus (i) to document and discuss the effects of climate variability and change on the high-altitude ecosystems of Nepal through a perception-based analysis, and (ii) to validate whether anomalies in climatic variables, mainly temperature, rainfall and snow cover, conform to the local perception.

2. Methodology

2.1. Study area

Two geographic locations, Rara and Langtang regions of western and central Nepal, respectively, representing high-altitude ecosystems, were selected for this study (Figure 1). The main purpose of selecting two study sites was to look at the nature and extent of climatic effect on local landscape including ecosystem

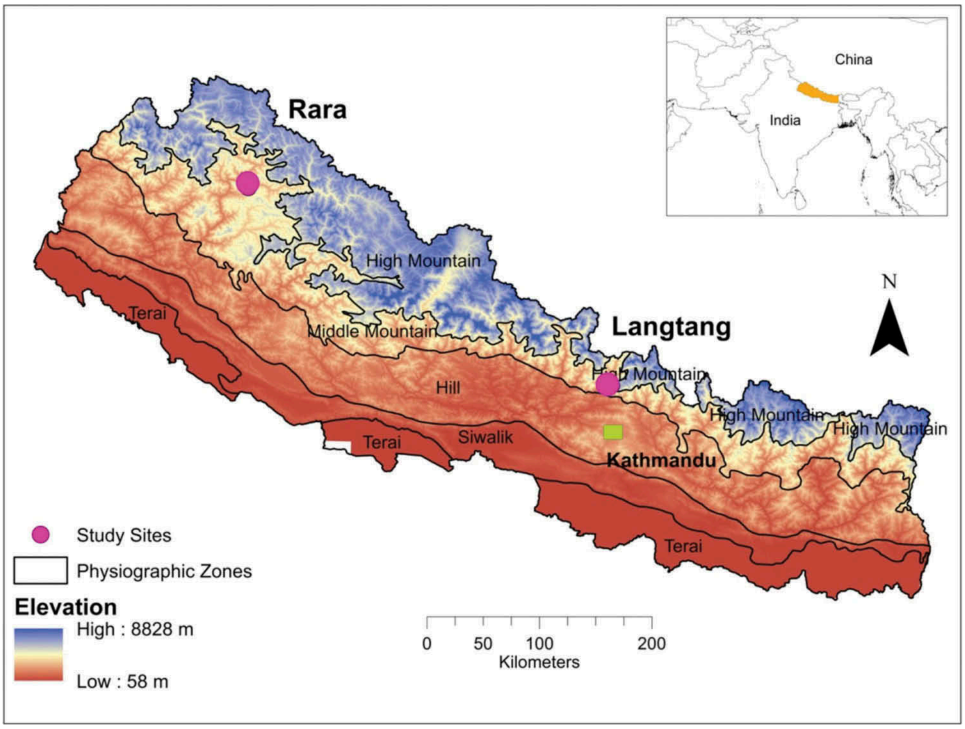

Figure 1. Study area showing high-altitude Rara and Langtang regions.

and biodiversity as well as document how people living in similar altitudinal range but spatially different locations observe and perceive the same environmental phenomena. As Crona et al. (2013) stated, most of the perception-based climate change studies are specific place based, and therefore comparative studies across sites could explain how people with different socioecological context understand and interpret climate change and its risks.

Rara is located between 29°26′ to 29°34′N and 82° 00′ to 82°10′E within the administrative unit of Mugu and Jumla districts. The area is also under jurisdiction of Rara National Park, which was established in 1976. Rara region comprises 11 forest types consisting upper subtropical to alpine zones. The climate belongs to dry winter and wet monsoonal summer. The winter is quite severe, starting from October, with snow falling during December to April, temperature falling below 0°C. There are 67 settlements in the buffer zone, located inside and at the periphery of the park boundary, with estimated 2548 households. The major ethnic groups include Chhetri and Thakuri. Agriculture is the major occupation of most of the inhabitants, while tourism activity is very low as compared to other high-altitude regions (MFSC 2014).

Similarly, Langtang is located between 28°00′ to 28°20′N and 85°15′ to 86°00′E within the administrative unit of Rasuwa, Nuwakot and Sindhupalchok districts, under jurisdiction of Langtang National Park, established in 1976. Langtang region comprises 18 forest types consisting of montane tropical to alpine zones. The seasonal rainfall pattern is dominated by the southerly monsoon that occurs between June and September. Similarly, temperature in the region reaches its maximum during July–August and falls to a minimum during December–January, with minimum average temperatures below 0° from November to April. There are more than 110 small and large settlements in the buffer zone, located inside and at the periphery of the park boundary, with an estimated 16,000 households, mainly belonging to local Sherpa and Tamang of Buddhist community. The major occupation of the local people is tourism activity as this region attracts good number of national and international visitors each year due to its beautiful Himalayan landscape and the location of the Gosainkunda Lake, a place of significant religious value (MFSC 2012).

2.2. Study approach

Both qualitative and quantitative data were used in this study. Qualitative data included observation and perception of local people on changing climatic variables and its effects, while quantitative data included satellite imagery and ground-based meteorological information of temperature and rainfall.

2.2.1. Field observation

This includes various participatory rural appraisal and rapid rural appraisal techniques such as transect walk, key informant interviews (KIIs), focus group discussions (FGDs) and institutional visits carried out in November 2015, in both Rara and Langtang regions. We carried out two FGDs in Rara [each in Pina and Karkibada Village Development Committees (VDCs)] and one in Langtang (Syapru VDC). Similarly, four

Table 1. Sampled VDCs and settlements for KII and FGD in the study sites.

Study sites	Districts	VDCs	Settlements	Elevation range (m)
Rara	Mugu	Karkibada, Rara, Pina	Talcha Airport, Talcha Gimu khola, Jhyari, Rara, Murma	2900–3200
Langtang	Rasuwa	Syapru	Chandanbari, Cholangpati, Lauribina, Thulo Syapru	3000–3600

and five KIIs per settlement were conducted in Rara and Langtang, respectively. Field observations on the effects of climate change on both study area were carried out simultaneously during transect walks and while doing KIIs and FGDs. The respondents for the KIIs were selected purposively after consultation with the department staff and executive members of the buffer zone of both national parks. In order to get historical information, two criteria were set: a respondent should be at least 35 years old and he/she should have been residing in the area for at least 30 years. The sampled VDCs and settlements for this study, all of which lie within buffer zone, are given in Table 1.

Each FGD consisted of 8–10 participants. The main purpose of the FGD was to get additional information that was not captured during KII and to verify prior information from the people. A semistructured questionnaire was designed, pretested in the field and finalized. The questionnaire mainly seeks information on key indicators of climatic variability and change that people have readily observed in their daily life, such as summer and winter temperature, rainfall season, duration and intensity, snowfall season and intensity, drought, tree and crop phenology, and invasive species. Furthermore, our study also focused on understanding how people of the two geographical locations observed and perceived the changes in snow cover and upward shifting of vegetation tree line over the last 30 years. Different trend criteria were set to extract information on climatic parameters (Table 2). During FGDs, discussions were undertaken to extract additional information on similar climatic indicators and audio recorded in order to use for data analysis. We portrayed qualitative information obtained through KIIs and FGDs in the form of narrative experiences and observations, bearing witness to the changing climate and increasing climatic variability in both the study sites.

2.2.2. Meteorological data analysis

Ground station-based two major climatic variables, temperature and rainfall of both the study sites for 25 years, were collected from the Department of Hydrology and Meteorology, Nepal, and analyzed. The trends were used to validate the climatic opinion made by respondents. For temperature and rainfall historical data, we used data recorded at meteorological station located near the study sites (Rara: index no. 0307, elevation 3048 m; Dhunche: index no. 1055, elevation 1982 m; Kyanzin: elevation 3920 m). These meteorological data were analyzed and graphically presented using Microsoft Excel package.

2.2.3. Satellite image analysis

Freely available Landsat images of four different time periods covering 38 years for both study sites (Table 3) were downloaded from the United States Geological Survey Earth Explorer web portal. ERDAS Imagine 2015 software was used to preprocess and then classify the acquired images. The MSS image was resampled to 30 m pixel size to make it comparable with the other higher-resolution images. Geometric correction was carried out for all the images. Dark object subtraction and top of atmosphere were done as part of image preprocessing. Classification in our case mainly focused on snow and no snow detection as our objective was to extract the extent of snow cover change in the study region. Unsupervised classification was employed for the classification of four different time period images, which uses automated computer-based ISO data algorithm to locate snow features from a heterogeneous sample and classify them to the closest snow cluster. Unsupervised change detection technique is the most basic form of direct multidata classification based on a single analysis of combined data sets of two or more dates (Singh 1989). We used a cluster of 50 spectral classes and

Table 2. Criteria for extracting information on climate change observation of local people.

Trend criteria	Climatic parameters
Increasing, decreasing or no change in the last 30, 20 and 10 years	Rainfall pattern, snowfall pattern, summer temperature (hotness), winter temperature (coldness), traditional water source and drought
Number of days it rains during mid-June to mid-September (90 days in total) prior to 20 years and since 7 years back	Rainfall days
Depth of snow on villages if snow falls for 24 h for 20 years ago and since the last 7 years	Snowfall thickness
Start month and end month of snowfall for 20 years ago and since the last 7 years	Snowfall season
Start week/month and end week/month of flowering or harvesting time of vegetation for 20 years ago and since the last 7 years	*R. arboreum* and other agricultural crops

Table 3. Snow cover change in Rara and Langtang regions over the period of 38 years.

Year/month	Snow cover area (ha)	Change in snow cover area (ha)
Rara		
1977 March	2083	1977 to 1994 = −331
1994 March	1752	1994 to 2003 = −395
2003 March	1357	2003 to 2014 = + 24
2014 March	1381	
Langtang		
1977 March	53,830	1977 to 1988 = + 24,131
1988 April	77,961	1988 to 2002 = −3925
2002 March	74,036	2002 to 2014 = −9622
2014 March	64,414	

20 iterations, as Mukherjee and Mukherjee (2009) reported that for unsupervised classification error propagation could be well reduced by increasing the number of such spectral classes. As this study lacks in situ ground truth measurements, freely available high-resolution Google Map was used for verification of snow data wherever possible, as suggested by Jensen (2005). Finally, change detection maps were prepared using ArcGIS software (version 10.2, ESRI Inc., Redlands, CA, USA). As per WMO (2011), 30 years of satellite time-series data could provide a base to detect reliable trends of climatic variables, and many of the essential climate variables of the earth's atmospheric and terrestrial domain could substantially benefit from satellite observation.

3. Results

3.1. Local's observation and perception of changing climate

3.1.1. Rainy days and rainfall pattern

In Rara, respondents mentioned that 20 years ago there used to be an average 63 rainfall days during mid-June to mid-September, while it is only around 13 days over the same period during the last seven years. The average net change in rainfall day was found to be 49 days. The majority, that is, 70% of the respondents in Rara, indicated that the number of rainy days during the rainy season (mid-June to mid-September) has decreased continuously in the last 30 years. One respondent narrated on the past rainfall that 'during rainy season many insects used to emerge on the farm land and village roads, however the extent of such insects has decreased drastically in recent times due to less rainfall'. Another voiced, 'Three water mills used to operate whole year in Nijar River, an outlet of Rara Lake, but now they hardly run four months during the rainy season'. Similarly, in the Langtang region, there used to be around 65 rainfall days during the same monsoon season, which has now reduced to around 22 days. The average net change in rainfall day was 43 days, which is lower compared to Rara. Around 75% of the respondents observed continuous decline of rainy days compared to the past 20 years.

All respondents at both sites fully agreed with the statement that rainfall pattern has been unpredictable in recent years compared to the past. For example, a respondent in Langtang lamented, 'We had never seen such an unpredictable nature of rainfall timing and intensity in the past. The past rainfall used to be very normal, timely and useful for agricultural crops but now-a-days, it is unusual and more intense that rather damages agricultural crops and terraces'. Similarly, a majority of the respondents at both sites, apart from confirming a shift in the months of rainy season these years, agreed that rainfall pattern and intensity has been abnormal and very difficult for them to predict, affecting their traditional annual crop calendar.

3.1.2. Snowfall thickness, pattern and season

Snowfall was found to be higher in Rara compared to Langtang. There used to be an average of 5 feet of snow in Rara 20 years ago if snowfall continued for 24 h (almost 55% agreed) compared to the recent years of 2 feet snow (almost 75% perceived), with the net change of 3 feet. People perceived snowfall benefits agriculture. A local told, 'The year that brings more snow in mid January to mid March is a lucky year for us as more snow means more moisture in the soil, which will in turn help in more production of barley (*Hordeum vulgare*) and wheat (*Triticum aestivum*), the main staple food for us'. However, he further recalls that there has been no snowfall in his village since 2005. Another respondent said, 'Some 15 to 20 years ago, snowfall was in sufficient quantity so that agricultural pests were in control (because of chilling effect insects die), giving rise to agricultural production, but in recent years there is more occurrence of pest attacks because of less snowfall'. Some villagers cited decreased movement of snow leopard (*Uncia uncia*) as an indicator of less snowfall. In Langtang, it used to be 4 feet of snow in the past if snowfall continued for 24 h (45% agreed), which in recent years has decreased to around 1.5 feet, with net changes of 2.5 feet. This was clearly reflected during the FGD, 'We all were born and brought up in the lap of Langtang Mountain, that always used to be covered by thick snow all the year round up to its base. Now you see it as a mass of bare black rock with thin snow cover most of the time'. Snowfall pattern has also changed in the Langtang region in recent times as some respondents recounted, 'Earlier in the winter season, snowfall started from the hilltop Gosainkunda (4400 m) and slowly came down up to Syaprubesi (2000 m), but now the snow hardly even touch Cholangpati (3300 m)'.

Similarly, in Rara, a mixed observation was noted on changes in the snowfall season. Earlier, mid-November to mid-April had the most snowfall, which nowadays extends from mid-September to mid-May, but with reduced snow quantity. A comparable finding to Rara was observed in the Langtang region. Earlier, mid-November to mid-April had most of the snowfall; however, nowadays it starts from mid-October up to mid-May. Some respondents did not observe any changes in snowfall season.

3.1.3. Summer temperature

In Rara, 70% of the respondents indicated that summer temperature (hotness) has been increasing continuously for the last 30 years in the region. 'We never observed apple growing 20 years ago but now it is in everybody's homestead due to increase in temperature', said one respondent. Another echoed, 'I knew local birds such as *Chancher, Phangras, Danphe (Lophophorus impejanus)* and *Kalo Kalij (Catreus wallichii)* used to migrate down to the lower elevation such as Lamachaur (300 m) from Rara (3000 m) during snowfall season of mid December to mid February, however since the last 7–8 years, they are not migrating as we have now more warming weather compared to the past'. In Langtang, 75% of the respondents observed the continuous increment in temperature in the last 30 years. Retreating glaciers in the Langtang region were presented as evidence of recent warming of the Himalaya. A local trekking guide said, 'I work as a trekking guide and travelled to many mountain ranges in the Langtang. I have seen glaciers of Ganesh and Lantang Mountain retreating very fast since the last 10–12 years'. 'Banmara (*Ageratum adenophora*), an invasive shrub grown normally on low land, having with hot climatic conditions, such as Bharku, Kalikasthan and Trishuli are now invading Langtang region since 7–8 years back', agreed by respondents in FGD.

3.1.4. Winter temperature

Fifty percent of the respondents in Rara believed that winter temperature has decreased compared to the last 30 years. On the contrary, one-fourth were of the view that winter temperature has instead increased in these years while 15% said that it has indeed started increasing only from the last 20 years. Ten percent did not think there is an alteration in the trend of winter temperature. In Langtang, only 30% of the respondents agreed on the statement of decreasing winter temperature compared to that of Rara. 'Earlier, in the winter season, river water got converted and remained as ice, blocking us for swimming, but these days no such incident is seen though it is cold', informed the locals. Forty percent believed that winter temperature is continuously increasing while 25% expressed not observing any such changes. People narrated that the more the snowfall, the less the coldness and vice versa, 'In the past, there used to be sufficient snow during the winter season, making it less cold, however due to less snow in recent times, winter is getting cold'. This indicates no clear pattern of coldness as we see in rainfall.

3.1.5. Traditional water sources

Seventy percent of the respondents in Rara noted traditional water sources, main sources of drinking water available from ground recharge, in the villages have decreased continuously due to anomalies in rainfall pattern and intensity. As they said, 'We had one big natural water sources just ten minutes away from the village but it dried some years ago. Now we have managed piped water from another water source which is around 5 km away'. Interestingly, in Langtang, a similar proportion of respondents felt the declining state of such water sources. One local shared, 'The disappearance of nearby water sources has forced us to use snow over the roof for water harvesting for drinking and other household chores'.

3.1.6. Drought

Drought is also considered as an indicator of rainfall amount. The majority (70%) of the respondents in Rara noted increased drought in the last 30 years while 15% of them have seen drought as a major stress only for the last 10 years. An elder local shopkeeper narrated, 'Drought has been so extreme and common these days, the effect of which has been on the potato (*Solanum tuberosum*) production, the main staple of this cold region due to less rainfall'. Similarly, a majority (65%) of respondents in Langtang also agreed that drought has been continuously increasing since the last 30 years. A respondent voiced that 'in the last 7–8 years, we received very less rainfall, and as a result, crops like potato and maize (*Zea mays*) dry in the field. Apart from decreased production of major staple crops such as potato, wheat, beans (*P vulgaris*), maize, finger millet (*Eleusine coracana*) and barley, we have also noticed the increase of insect pest in farm land because of this drought'.

3.1.7. Species migration and phenological changes

Respondents in both the study sites informed of the migration of plants and animals from their original habitat. In Rara, 20% of the respondents noted range shift by plant species in their locality. For instance, one respondent from Rara said, '*Abies spectabilis, Juniperus indica* and *Betula utilis* has migrated upwards in many hilltops in Rara region but I am not sure when it started'. Villagers also cited some new plant and bird species that were not around in the past. 'We are seeing two plants, locally called *Tilkhulo* and *Badigola* as well as a bird locally called *Nyauli* only from the last 8–10 years back', a local teacher revealed. A change in the phenology of a migratory bird was explained as, 'common coot (*Fulica atra*) a migratory bird, used to visit the lake in mid-August to mid-September but since the last 7–8 years they are

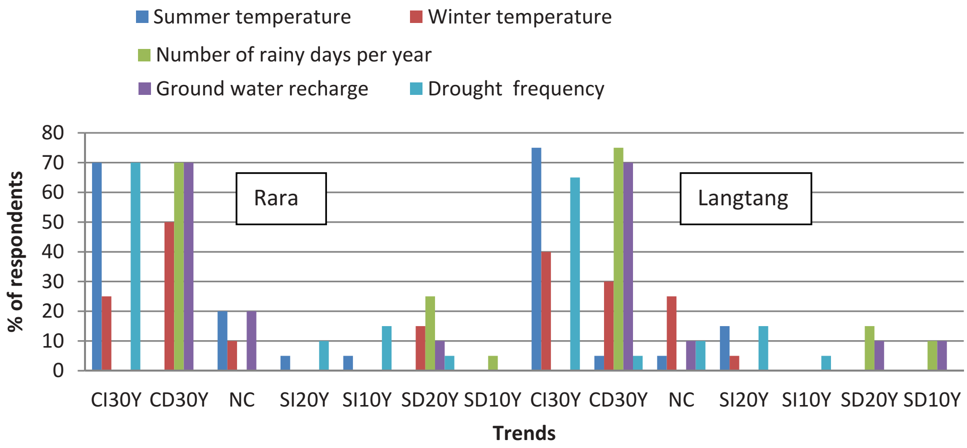

Figure 2. Diverse local perception on climatic parameters in Rara (*n* = 20) and Langtang (*n* = 20) regions. Notes: CI30Y: continuous increasing since the last 30 years; CD30Y: continuous decreasing since the last 30 years; NC: no change seen since the last 30 years; SI20Y: started increasing since only 20 years back; SI10Y: started increasing since only 10 years back; SD20Y: started decreasing since only 20 years back; SD10Y: started decreasing only since 10 years back.

coming mid September to mid November, nearly with a one month delay'. Another such change was narrated by a woman who runs a local lodge near Talcha airport,

> 25 years back in Gamgadi (a Bensi, a village located in lower elevation landscape), some agricultural crops such as *Kaun, Mas* (black gram), finger millet, and *Bhatmas* (soybean) and local rice varieties such as *Papare Dhan and Khetali Dhan* used to ripen in mid October to mid November, which at that time was not possible in Tobla settlement of Pina VDC (a Lekh, a village located in higher elevation landscape) located 300 m above from Gamgadi. Surprisingly all of those crops can grow in Pina VDC these days. I am not sure if it is due to increased temperature that we are feeling from the last 10 years or other unknown factors.

Similar stories surfaced in the Langtang region where around 70% of the respondents noted they saw upward march of plant species. 'Upward shifting of *A. spectabilis* and *Berberies* sp., is taking place slowly in the pasture land of Polangpati, Dikling and Sungati', said a local hotel owner. More respondents validated this notion by saying 'upward march of *A. spectabilis* is a common phenomenon we have seen in the Lauribina, Langtang, Timure, Yarsa and Nagthali area in the last 25 years'. Others also confirmed, 'We are very sure that *A. spectabilis* and some *Rhododendron* sp., found in the upper belt and locally called *Chimal*, are shifting upward from their normal habitat range in the Lauribina area'. Another respondent narrated, 'I have only seen *Alnus nepalensis* tree in Dhunche, a Bensi earlier but since 10–12 years, this species started growing in our Lekh. Similarly, decline and other morphological changes in apple have also been observed. The places such as Bravel, Chandanbari and Thulosyapru used to produce tasty apple. However, in the last 10 years, the apple production in these areas has sharply declined along with the changes in taste and size, because of unwanted warming weather' (Figure 2).

3.1.8. Phenological changes of *Rhododendron arboreum* and other agricultural crops

Mixed observations were reported by the local people regarding the phenological changes in *R. arboreum*, locally called *Rato Gurans*, which is a very common plant species in both areas that people could remember its changes over time. In Rara, half of the respondents recalled a shift of flowering time of the Gurans by 2 weeks in recent times compared to 20 years back, but a few respondents (10%) also mentioned a delay of flowering by 3 weeks. Nearly 65% of the respondents in Langtang were able to notice the phenological changes in *R. arboreum*. All the shifting had occurred between 4 months from mid-January to mid-May. A majority (30%) viewed that the flowering had advanced by 3 weeks in recent times compared to 20 years ago while only 10% said it had been delayed by 6 weeks, double compared to Rara.

Apart from *R. arboreum*, some respondents in Rara mentioned a change in harvest time of local staple crops. For instance, harvesting of finger millet has been advanced by 2 months from mid-October/November to mid-August/September; barley advanced by 1 month, from mid-August/September to mid-July/August; potato advanced by 2 months, from the start of November to the start of September; and buck wheat (*Fagopyrum esculentum*) by 1 month, from mid-September to mid-August. However, the respondents of the Langtang region could not recall such changes in harvesting time of agricultural crops as the region has less agricultural practice compared to Rara and most of the people practice pastoral grazing system.

4. Climatic variability trends

The historical trends of climatic variables, that is, maximum, minimum and average temperature as well as annual rainfall pattern of both study sites, are shown in Figure 3.

The annual average and minimum temperature at Rara has been increasing at a rate of 0.023 and 0.0897°C, respectively, while the annual maximum temperature has been decreasing at a rate of 0.0437°C per year. The annual average, minimum and maximum temperature at Dhunche has been decreasing at a rate of 0.0125, 0.0021 and 0.003°C per year, respectively. The annual average, minimum and maximum temperature at Kyanzin has been increasing at a rate of 0.0657, 0.1057 and 0.0259°C per year, respectively. The average annual rainfall in Rara has been decreasing at a rate of 0.704 mm per year. The average annual rainfall in Dhunche and Kyanzin has been increasing at a rate of 3.955 and 6.2548 mm per year.

4.1. *Satellite image analysis for snow cover change*

Satellite image analysis showed an overall decreasing trend of snow cover in both study sites over the period of 38 years (Table 3 and Figure 4). In the Rara region, snow cover area decreased by 16% in 1994 from the base period of 1977, by 23% in 2003 from 1994 while slightly increased by 2% in 2014 from 2003. Similarly in the Langtang region, snow cover area had increased by 45% in 1988 from the base period of 1977, then decreased by 5% in 2002 from 1988 and again decreased by 13% in 2014 from 2002.

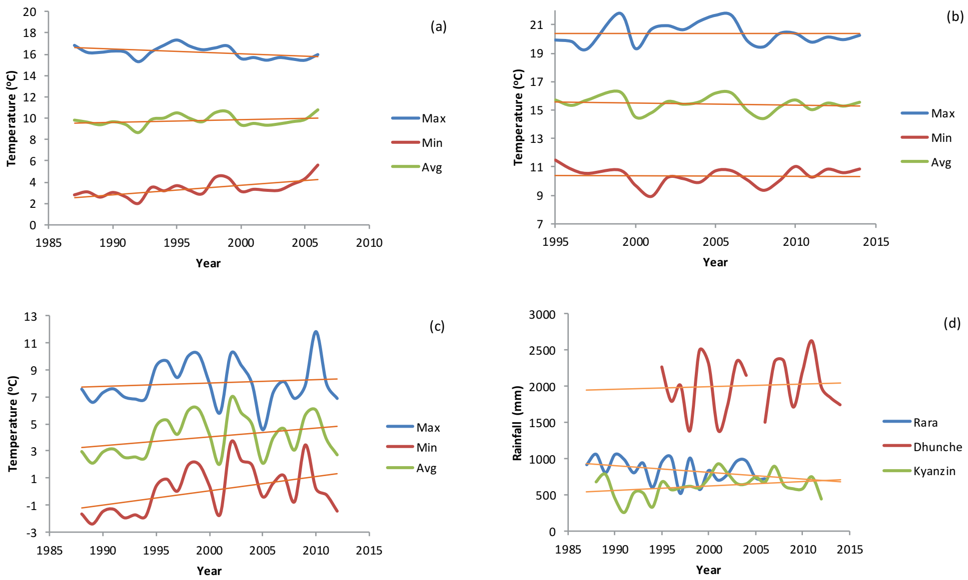

Figure 3. Maximum, average and minimum temperature of (a) Rara, (b) Dhunche and (c) Kyanzin; annual rainfall of Rara, Dhunche and Kyanzin (d).

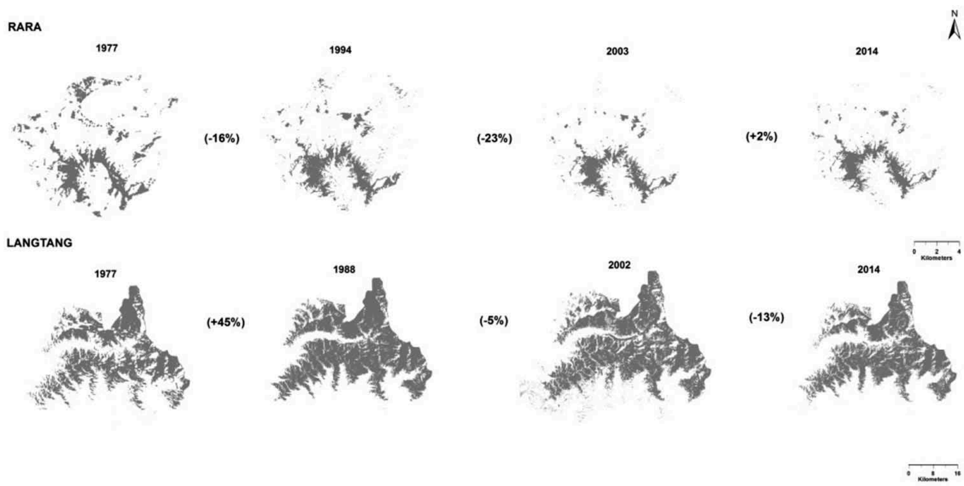

Figure 4. Snow cover change in Rara and Langtang regions from 1977 to 2014.

The variation observed in the snow cover area between the two study sites is due to the differences in the spatial extent and altitudinal location.

5. Discussion

An analysis of 25 years of climatological data shows variable trends for annual average rainfall for both study sites (Figure 3(d)). In Rara, it has been decreasing. Local people in the Rara region also noted decreasing rainfall trend in the last 30 years. In contrast, the rainfall amount in the Langtang region shows an increasing trend. Ichiyanagi et al. (2007) found an inverse relationship between annual rainfall and elevation only in western Nepal, where rainfall amount decreased with increasing elevation above 2000 m. Therefore, the decreasing and increasing rainfall trend of the Rara and Langtang regions is somehow explained by this finding. Similar to Langtang, the increasing trend of rainfall was also documented for the Manaslu region (KC and Parajuli 2015), lower Mustang (Manandhar et al. 2011) and South Asia (Shiekh et al. 2015). Sigdel and Ma (2015) have predicted a likely increase in rainfall up to 14% in the arid region of Nepal by 2050. However, the rainfall trend was against local people's perception that they had felt decreasing trend of rainfall.

Similarly, all the respondents in both the sites confirmed shifting in the months of rainy season in the last few years, and all also agreed that rainfall has become erratic (Figure 3(d)) and very difficult for them to predict its timing now, which normally used to be mid-June to mid-September. This observation is in line with other studies undertaken in similar altitudinal regions within the country: Kanchanjunga (Chaudhary et al. 2011), Khumbu (McDowell et al. 2013) and Namche region (Smadja et al. 2015) of eastern Nepal; and Mustang region (Manandhar et al. 2011) and Manang region (Konchar et al. 2015) of central Nepal.

Local people perceived a decrease in the thickness and intensity of snowfall in both sites and increased melting process compared in recent years. This is obvious as some studies (Chaulagain 2009; Shrestha & Aryal 2011) already reported low snowfall and rapid meltdown processes all over Nepal. Konchar et al. (2015) reported less amount and irregular timing of snowfall in the Manang region of central Nepal. Because of this, local people mentioned that permanent snow line and snow cover thickness was reduced on the nearby mountain peaks such as Chanyanath, Rinimokshya and Chuchemara in Rara, and Langtang and Ganesh in Langtang. This is also verified from the satellite image analysis (Table 3 and Figure 4), which shows a decreasing trend of snow cover in both sites over the period of more than three decades. Chaudhary et al. (2011) reported that the mountain range in the Kanchenjunga of eastern Nepal bears less permanent snow line compared to the past. Similar remarks were revealed by the people in the Manaslu region (KC and Parajuli 2015) of central Nepal, Namche region (Smadja et al. 2015) and Khumbu region (McDowell et al. 2013) of eastern Nepal. Furthermore, Shrestha and Joshi (2009) and Gurung et al. (2011) also found decreasing trend of snow cover in the Himalayan region over the last few decades.

The maximum temperature pattern in both the study sites shows mix trends. The annual maximum temperature in Rara (Figure 3(a)) has been decreasing. However, this finding contradicts with the local people's perception and the trends found in Jumla (Gentle & Maraseni 2012). The annual maximum temperature at Dhunche (Figure 3(b)) has also been decreasing and was opposite to what the locals revealed. However, at a higher altitude of Kyanzin, the graph shows increasing trend (Figure 3(c)), conforming our findings of the observation by the majority of local people as well as those reported in other studies (Manandhar et al. 2011; KC and Parajuli 2015; Konchar et al. 2015).

The minimum temperature pattern in both the study sites (Figure 3) also shows mixed trends. The annual minimum temperature in Rara (Figure 3(a)) has been increasing. This increase of minimum temperature has also been reported in the Jumla region of western Nepal (Gentle & Maraseni 2012), in very close proximity to Rara. Weather data analysis supports local perception. However, minimum temperature at Dhunche (Figure 3(b)) shows decreasing trend and is comparable to the findings of KC and Parajuli (2015). Local people also mentioned that coldness in the region has increased. In contrast, the minimum average temperature at Kyanzin (Figure 3(c)) has been increasing, which is also felt by the local respondents and inline with Smadja et al. (2015). Micro-topographic element, consisting of differential elevation, aspect and slope controls solar radiation into an area and could be one of the reasons for such locational variation in temperature trend found in the study sites.

The overall average annual temperature shows differing trends (Figure 3) in both the study areas. Annual temperature has been increasing at a rate of 0.023°C in Rara as was perceived by the locals. On the other hand, it has been decreasing at a rate of 0.0125°C per year in Dhunche and against the information provided by the local people while increasing at Kyanzin of Langtang with a rate of 0.0657°C per year, equal to the current national increment average of 0.06°C per year, and also conforming to the finding of KC and Parajuli (2015) in the Manaslu region in Gorkha as well as observation of the locals. Karmacharya et al. (2007) and Cruz et al. (2007)

predicted the likely increase of warming in Nepal for all the seasons by mid-twenty-first century, with northern highland regions warmer than the lower regions, corroborating with the current increasing trend seen in Rara and Kyanzin of Langtang. Reduction of snow and glaciers in high-altitude regions has also been attributed to high rate of warming in such areas (Meehl 1994; Yamada et al. 1992 as cited in Shrestha et al. 1999). This could be a possible reason that the locals in both our study sites felt a warming trend in recent years as they witness less snow and glaciers (Table 3 and Figure 4).

At both study sites, a majority of the respondents noted decreasing number of traditional water sources (both drinking and irrigation) in their villages. Temperature and rainfall patterns could be decisive factors for the change. Drying up of natural water sources due to increased temperature and decreased rainfall has been observed by the people of eastern Nepal (Chaudhary & Bawa 2011). A majority of the respondents agreed that they had witnessed increasing drought frequency in their region since the last few decades. The infestation of new agricultural crop pest in the Langtang region was also reported: this could be the effect of less rainfall and increased frequency of drought. Chaudhary et al. (2011) in Kanchenjunga and Manandhar et al. (2011) in the Mustang region also mentioned a similar frequency of drought and pest infestation. Both the decreased water source and increased drought in Rara and Kyanzin of Langtang are explained by Figure 3. Temperature has been increasing and rainfall decreasing in Rara while temperature has been increasing at a higher rate with rainfall increasing but at a slower rate in Kyanzin.

Shifting from the original habitat range of some biota was observed by the locals in both the study sites. For instance, *A. spectabilis, B. utilis, J. indica* in Rara while *A. spectabilis, A. nepalensis, J. indica, Rhododendron* sp. and *Berberis concinna* in the Langtang region were reported to march further toward higher altitudes from its usual range. We also noticed an upward range shift by *J. indica* above Lauribinayak area during the field visit (Figure 5). The shifting of range by *A. spectabilis* and *B. utilis* has also been reported (Aryal et al. 2014a) in the upper Mustang region of central Nepal, while *A. nepalensis* (Chaudahry et al. 2011) in the Kanchenjunga Himalaya region of eastern Nepal.

Variable perceptions of the locals on phenological changes in *R. arboreum* and other agricultural crops are understandable. Differential topographic elements such as elevation, aspect and slopes at both sites cause microclimatic variation that controls the amount of solar radiation, moisture content and wind velocity, which affects overall plant physiological and morphological growth (Moeslund et al. 2013). Even across the same landscape, Liancourt et al. (2013) reported that climatic change is not always able to produce consistent consequences for the same species because of the biotic and abiotic sources of variation in plant growth and development. Thus, local people saw different phenological development of the *R. arboreum* and agricultural crops within a region characterized by such topography.

Variation in meteorological data and perception of the locals may differ, especially in the high-altitude region, where one settlement differs with other settlements in proximity due to steep terrain. As local climate is determined by elevation, exposure and aspect, the variation in perception of locals on the change as well as impact could be expected (Byg & Salick 2009). For instance, Kansakar et al. (2004) reported that the summer monsoon pattern of Nepal decreases in length and time from east to west, and the existing topographic barrier and mountainous relief plays a significant role in yielding localized rainfall pattern. Crona et al. (2013) found similar contrasting observations and perception in Fiji and Ecuador within the same locality and suggested that such variations are common in countries where there is no mechanism to serve homogenized information and knowledge on climate change. Most of the respondents easily memorize changes in temperature, rainfall and snowfall as they directly affect their agricultural activities and hence relatively accessible and

Figure 5. Tree line shift by *J. indica* above Lauribinayak area, Langtang (photo taken: November 2015).

easily observed phenomena. However, some of them do not notice upward shifting of vegetation line because those boundaries are normally in the hill top pasture, far away from their settlements and do not have a direct link with their agricultural occupation. As Weber (2010) suggested, climate change is sometimes difficult to detect accurately solely based on personal experience, and sometimes the laypeople wrongly characterize some events to climate change and are unable to reveal real changes in climate. This study discovered homogenous observations and perceptions within and between settlements in both sites, as opposed to the findings of Teye et al. (2015), Weber (2010) and Kofinas (2002), even though they varied in spatial, altitudinal, cultural and occupation variables.

Every respondent at both the study sites knew the term climate change, not by its scientific definition, rather by changes they had seen and experienced in the variability of their microclimate, such as warming and coldness, sudden and erratic rainfall pattern, changes in rainfall season, snowfall amount and timing, and drought frequency. This was noted during individual KIIs and further confirmed in FGDs. This is a very important prerequisite for the government and other concerned organizations before formulating and implementing any climate-related adaptation and mitigation program at the field level. Until and unless people are at least aware about climatic change and its possible effects, that is, perceived climate change risk on their ecosystem and society, the strategy and program on adaptation and mitigation will not bear a fruitful outcome. Vedwan and Rhoades (2001) argue that the risk perception ultimately decides how an individual responds to the climate variability and changes. Some of the climatic risks that laypeople in our study areas have foreseen include untimely and shortage of rainfall for agricultural crops, drying up of natural water sources and consequent drought in the farmland, which overall leads to food shortage and insecurity in the long run. Similarly, invasion by Banmara to the farmland and forest floor, especially in the Langtang region, is another concern. People have realized its destructive capacity to the soil and planted crops in their farmland through overconsuming essential minerals and suppressive capacity to biodiversity, mainly the indigenous medicinal and other natural regenerated tree saplings in the surrounding forest. Even though people in Rara and Langtang knew about climate change, they were totally unaware of its causes, supporting the argument of Ahsan and Brandt (2015), Bangura et al. (2013), and Adelekan and Gbadegesin (2005), who put forth that people in most developing countries lack knowledge on the rationale behind climatic variability phenomena as compared to developed countries. Interestingly, people in both regions were found to be quite curious to get well acquainted on the underlying causes of such changes and the way to tackle it. Overall, this suggests that locals in our study sites were well informed about climate variability and changes they have encountered since the last 2–3 decades.

6. Study limitations, research gaps and future opportunity

Despite a one-time visit and consultation with local people, this paper finds interesting relationships between local perception, climatological data and image analysis. A future study with the incorporation of household-level sample in addition to KIIs and FGDs could generate further interesting outcome. A 20–30-year recall period among rural people in this type of perception-based study is really challenging and could lead to misinformation. However, we validated such misinformation through FGDs in both the study sites. Few meteorological stations and a lack of long-term weather data of the selected regions were the other constraints. Otherwise, comparison of climatic trends could have been greatly improved. Similarly, the use of unsupervised classification and the rugged terrain of the study sites could have either under- or overestimated the final results to a small extent, though due attention has been paid in preprocessing and avoiding using images with high cloud and shadow. However, one needs to be cautious doing the interpretation of snow cover result.

Gagne et al. (2014) argued that specific place-based research is fundamental to debate an ongoing environmental phenomenon such as global climate change. The major advantage of involving and listening to the observations and perceptions of the local people, as per Byg and Salick (2009), is the generation of information on local climate, which in most cases is not addressed by the current global climate change model. Therefore, climatic observation and perception, like we found in this study, could complement such global scientific models, on the one hand, while supporting the formulation of immediate adaptation plans and strategies in developing countries to offset adverse effects.

7. Conclusion and recommendations

Local people are the first ones to feel and observe the changes in their local microclimate. Environmental effects of global warming are already being felt in various high-altitude regions of Nepal and are further endorsed by this study, where people's observations of climatic variability and changes in snow cover as well as ecosystem function such as phenology are mostly analogous with locally observed meteorological data, image analysis, as well as with other studies conducted in a similar environment. People at both the study sites expressed a similar nature of climatic observation and perception, and its effects on flora, fauna and agricultural production. Hence, this led us to believe that there is an ongoing climatic variability and changes in both the Rara and Langtang regions and therefore warrants immediate action to offset the resultant effects. We should accept people's perceptions and rely on their information in the absence of scientific data from this region of Nepal. This study was able to contribute to the growing local and regional evidence of variability and changes to climate systems of high-altitude regions of Nepal and documents how the people residing in such mountain localities observe and perceive the risks associated with such changes in their local environment. As discussed earlier, the realization of such risks by the climatic sufferers is essential to formulate national-level policies and response strategies, and this study has succeeded in demonstrating such risk perceptions in Rara and Langtang, which could be an opportunity for policy and strategy makers to capitalize.

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References

Adelekan IO, Gbadegesin AS. 2005. Analysis of the public perception of climate change issues in an indigenous African city. Int J Environ Stud. 62:115–124.

Ahsan D, Brandt US. 2015. Climate change and coastal aquaculture farmers' risk perceptions: experiences from Bangladesh and Denmark. J Environ Plann Man. 58:1649–1665.

Aryal A, Brunton D, Raubenheimer D. 2014a. Impact of climate change on human wildlife ecosystem interactions in the Trans-Himalaya region of Nepal. Theor Appl Climatol. 115:517–529.

Aryal S, Maraseni TN, Cockfield G. 2014b. Climate change and indigenous people: perceptions of transhumant herders and implications to the transhumance system in the Himalayas. J Geol Geosci. 3:162.

Bangura KS, Lynch K, Binns JA. 2013. Coping with the impacts of weather changes in rural Sierra Leone. Int J Sust Dev World. 20:20–31.

Basannagari B, Kala CP. 2013. Climate change and apple farming in Indian Himalayas: a study of local perceptions and responses. PLoS ONE. 8:e77976.

Bhusal YR. 2009. Local peoples' perceptions on climate change, its impacts and adaptation measures in mid-mountain region of Nepal: a case study from Kaski District. Kirtipur (Nepal): Tribhuwan University; p. 31.

Bickerstaff K. 2004. Risk perception research: socio-cultural perspectives on the public experience of air pollution. Environ Int. 30:827–840.

Byg A, Salick J. 2009. Local perspectives on a global phenomenon-climate change in Eastern Tibetan villages. Global Environ Chang. 19:156–166.

Chapagain BK, Subedi R, Poudel NS. 2009. Exploring local knowledge of climate change: some reflections. J For Livelihood. 8:108–112.

Chaudhary P, Aryal KP. 2009. Global warming in Nepal: challenges and policy imperatives. Journal of Forest and Livelihood. 8:4–13.

Chaudhary P, Bawa KS. 2011. Local perceptions of climate change validated by scientific evidence in the Himalayas. Biol Lett. 4. doi:10.1098/rsbl.2011.0269

Chaudhary P, Rai S, Wangdi S, Mao A, Rehman N, Chettri S, Bawa KS. 2011. Conistency of local perceptions of climate change in the Kangchenjunga Himalaya landscape. Curr Sci India. 101:504–513.

Chaulagain NP. 2009. Climate change impacts on water resources of Nepal with reference to the glaciers in the Langtang Himalayas. J Hydrol Meteorol. 6:58–65.

Crona B, Wutich A, Brewis A, Gartin M. 2013. Perceptions of climate change: linking local and global perceptions through a cultural knowledge approach. Clim Change. 119:519–531.

Cruz RV, Harasawa H, Lal M, Wu S, Anokhin Y, Punsalmaa B, Honda Y, Jafari M, Li C, Ninh NH. 2007. Asia. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, editors. Climate change 2007: impacts, adaptation and vulnerability. Cambridge: Cambridge University Press; p. 469–506. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change.

Devkota RP, Bajracharya B, Maraseni TN, Cockfield G, Upadhyay BP. 2011. The perception of Nepal's Tharu community in regard to climate change and its impact on their livelihoods. Int J Environ Stud. 68:937–946.

Gagne K, Rasmussen MB, Orlove B. 2014. Glaciers and society: attributions, perceptions, and valuations. WIREs Clim Change. 5:793–808.

Gbetibouo GA 2009. Understanding farmer's perceptions and adaptions to climate change and variability: the case of the Limpoo Basin, South Africa. IFPRI Discussion Paper No. 00849; p. 52.

Gentle P, Maraseni TN. 2012. Climate change, poverty and livelihoods: adaptation practices by rural mountain communities in Nepal. Environ Sci Policy. 21:24–34.

Gioli G, Khan T, Scheffran J. 2014. Climatic and environmental change in the Karakoram: making sense of community perceptions and adaptation strategies. Reg Environ Change. 14:1151–1162.

Gurung DR, Giriraj A, Aung KS, Shrestha B, Kulkarni AV. 2011. Snowcover mapping and monitoring in the Hindu Kush-Himalayas. Kathmandu, Nepal: Int Centre Integr Mt Dev.

Haynes MA, Yang Y. 2013. Adapting to changes: transition in traditional rangeland management of Tibetan yak herders in Northwest Yunnan. Env Dev Sust. 15:1065–1077.
Huda MN. 2013. Understanding indigenous people's perception on climate change and climatic hazards: a case study of Chakma indigenous communities in Rangamati Sadar Upazila of Rangamati District, Bangladesh. Nat Hazards. 65:2147–2159.
Ichiyanagi K, Yamanaka MD, Muraji Y, Vaidya BK. 2007. Precipitation in Nepal between 1987 and 1996. Int J Climatol. 27:1753–1762.
Ireland P. 2012. Nepalgunj, the centre of the world: local perception of environmental change and the roles of climate change adaptation actors. Local Enviro Int J Justice Sustain. 17:187–201.
Jensen JR. 2005. Introductory digital image processing: a remote sensing perspective. 3rd ed. Upper Saddle River, NJ: Pearson Prentice Hall.
Joshi S, Jasra WA, Ismail M, Shrestha RM, Yi SL, Wu N. 2013. Herder's perceptions of and responses to climate change in Northern Pakistan. Environ Manage. 52:639–648.
Kansakar SR, Hannah DM, Gerrard J, Rees G. 2004. Spatial pattern in the precipitation regime of Nepal. Int J Climatol. 24:1645–1659.
Karmacharya J, Shrestha A, Rajbhandari R, Shrestha ML 2007. Climate change scenarios for Nepal based on Regional Climate Model RegCM3. APN CAPaBLE project report. Global Change Impact Studies Center, Pakistan Meteorological Department and Department of Hydrology and Meteorology, Kathmandu, Nepal; p. 35.
Kaul V, Thornton TF. 2014. Resilience and adaptation to extremes in a changing Himalayan environment. Reg Environ Change. 14:683–698.
KC A, Parajuli RBT. 2015. Climate change and its impact on tourism in the Manaslu Conservation Area, Nepal. Tourism Plann Dev. 12:225–237.
Kerr JT, Ostrovsky M. 2003. From space to species: ecological applications for remote sensing. Trends Ecol Evol. 18:299–305.
Kofinas G. 2002. Community contributions to ecological monitoring: knowledge co production in the US-Canada Arctic Borderlands. In: Krupnik I, Jolly D, editors. The earth is faster now: indigenous observations of Arctic environmental change. Fairbanks, AL: Arctic Research Consortium of the United States; p. 54–91.
Konchar KM, Staver B, Salick J, Chapagain A, Joshi L, Karki S, Lo S, Paudel A, Subedi P, Ghimire SK. 2015. Adapting in the shadow of Annapurna: a climate tipping point. J Ethnobiol. 35:449–471.
Kumar K, Joshi S, Joshi V. 2008. Climate variability, vulnerability, and coping mechanism in Alkananda catchment, Central Himalaya, India. Ambio. 37:286–291.
Leiserowitz A 2007. International public opinion, perception and understanding of global climate change. Occasional Paper, Human Development Report Office, UNDP; p. 40.
Li C, Tang Y, Luo H, Di B, Zhang L. 2013. Local farmer's perceptions of climate change and local adaptive strategies: a case study from the middle Yarlung Zangbo River Valley, Tibet, China. Environ Manage. 52:894–906.
Liancourt P, Spence LA, Song DS, Lkhagva A, Sharkhuu A, Boldgiv B, Helliker BR, Petraitis PS, Casper BB. 2013. Plant response to climate change varies with topography, interactions with neighbors, and ecotype. Ecology. 94:444–453.
Macchi M, Gurung AM, Hoermann B, Choudhary D. 2011. Climate variability and change in the Himalayas: Community perceptions and responses. Kathmandu, Nepal: ICIMOD; p. 78.
Manandhar S, Vogt DS, Perret SR, Kazama F. 2011. Adapting cropping systems to climate change in Nepal: a cross regional study of farmer's perception and practice. Reg Environ Change. 11:335–348.
Maryam A, Khan S, Khan K, Khan MA, Rabbi F, Ali S. 2014. The perception of local community about the effects of climate change in upper Swat, Khyber Pakhtunkhwa, Pakistan. J Earth Sci Clim Change. 5:4.
McDowel G, Ford JD, Lehner B, Berrang-Ford L, Sherpa A. 2013. Climate related hydrological change and human vulnerability in remote mountain regions: a case study from Khumbu, Nepal. Reg Environ Change. 13:299–310.
Meehl GA. 1994. Influence of the land surface in the Asian summer monsoon: external conditions versus internal feedbacks. J Climate. 7:1033–1049.
MFSC. 2012. Management Plan: Langtang National Park and Buffer Zone, 2012-2017. Babarmahal, Kathmandu: Ministry of Forest and Soil Conservation, Government of Nepal; p. 132.
MFSC. 2014. Management Plan: Rara National Park and Buffer Zone, 2015-2019. Babarmahal, Kathmandu: Ministry of Forest and Soil Conservation, Government of Nepal; p. 74.
Mishra M, Barik B, Singh A, Timsina K, Bhutia KDO, Balasuddareshwaran A. 2014. Vulnerability and adaptive capacity of rural household to changing climate in Sikkim Himalaya. Asian J Res Soc Sci Humanities. 4:257–271.
Moeslund JE, Arge L, Bocher PK, Dalgaard T, Svenning JC. 2013. Topography as a driver of local terrestrial vascular plant diversity pattern. Nord J Bot. 31:129–144.
Mukherjee S, Mukherjee P. 2009. Assessment and comparison of classification techniques for forest inventory estimation: a case study using IRS-ID imagery. Int J Geoinformatics. 5:63–73.
Piya L, Maharjan KL, Joshi NP. 2012. Perceptions and realities of climate change among the Chepang communities in rural mid hills of Nepal. J Contemp India Stud Space Soc Hiroshima Univ. 2:35–50.
RSPN. 2012. Assessment of climate change vulnerabilities in Kangpara Gewog, Trashigang. Thimpu, Bhutan: Royal Society of Protection of Nature; p. 62.
Salick J, Ghimire SK, Fang Z, Dema S, Konchar KM. 2014. Himalayan alpine vegetation, climate change and mitigation. J Ethnobiol. 34:276–293.
Sharma E, Chettri N, Tsering K, Shrestha AB, Fang J, Mool P, Eriksson M. 2009. Climate change impacts and vulnerability in the Eastern Himalayas. Kathmandu, Nepal: ICIMOD; p. 32.
Sheikh MM, Manzoor N, Ashraf J, Adnan M, Collins D, Hameed S, Manton MJ, Ahmed AU, Baidya SK, Borgaonkar HP, et al. 2015. Trends in extreme daily rainfall and temperature indices over South Asia. Int J Climatol. 35:1625–1637.
Shrestha AB, Aryal R. 2011. Climate change in Nepal and its impact on Himalayan glaciers. Reg Environ Change. 11:65–77.
Shrestha AB, Joshi SP. 2009. Snow cover and glacier change study in Nepalese Himalaya using remote sensing and geographic information system. J Hydrol Meterol. 6:26–36.
Shrestha AB, Wake CP, Mayewski PA, Dibb JE. 1999. Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal for the period 1971-94. J Clim. 12:2775–2786.

Shrestha UB, Gautam S, Bawa KS. 2012. Widespread climate change in the Himalayas and associated changes in local ecosystems. PLoS ONE. 7:e36741.
Sigdel M, Ma Y. 2015. Evaluation of future precipitation scenario using statistical downscaling model over humid, sub humid, and arid region of Nepal: a case study. Theor Appl Climatol. 123:453–460.
Singh A. 1989. Digital change detection techniques using remotely sensed data. Int J Remote Sens. 10:989–1003.
Smadja J, Aubriot O, Puschiasis O, Duplan T, Grimaldi J, Hugonnet M, Buchheit P. 2015. Climate change and water resources in the Himalayas: field study in four geographic units of the Koshi Basin, Nepal. J Alpine Res. 103–2.
Teye JK, Yaro JA, Bawakyillenuo S. 2015. Local farmers' experiences and perceptions of climate change in the Northern Savannah zone of Ghana. Int J Clim Change Str. 7:327–347.
Vedwan N, Rhoades RE. 2001. Climate change in the Western Himalayas of India: a study of local perception and response. Clim Res. 19:109–117.
Wakefield SEL, Elliott SJ, Cole DC, Eyles JD. 2001. Environmental risk and (re)action: air quality, health, and civic involvement in an urban industrial neighborhood. Health Place. 7:163–177.
Weber EU. 2010. What shapes perceptions of climate change? WIREs Clim Change. 1:332–342.
Wiid N, Ziervogel G. 2012. Adapting to climate change in South Africa: commercial farmers' perception of and response to changing climate. South African Geographical Journal. 94:152–173.
WMO. 2011. Systematic observation requirements for satellite-based data products for climate: 2011 update. Global Climate Observing System GCOS-154; p. 126.
Yamada T, Shiraiwa T, Iida H, Kadota T, Watanabe T, Rana B, Ageta Y, Fushimi H. 1992. Fluctuations of the glaciers from the 1970s to 1989 in the Khumbu, Shorong and Langtang regions, Nepal Himalayas. Bull Glacier Res. 10:11–19.
Yang J, Gong P, Fu R, Zhang M, Chen J, Liang S, Xu B, Shi J, Dickinson R. 2013. The role of satellite remote sensing in climate change studies. Nat Clim Change. 3:1001-1001.