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Climate Change Perceptions, Data, and Adaptation in the Garhwal Himalayas of India

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Abstract

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Keywords

Kedarnath Wildlife Sanctuary, India, Himalayas, climate change, local perceptions, adaptation

Disciplines

Environmental Education | Environmental Sciences | Environmental Studies

Climate change perceptions, data, and adaptation in the Garhwal Himalayas of India

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Abstract
Himalayan communities that primarily depend on rain-fed agriculture are disproportionately vulnerable to the effects of climate change. To initiate appropriate adaptation strategies, communities must have sufficient resources and accurately perceive the changes that are occurring. In this study, we compare local perceptions of climate change from a household survey (n=251) to climate data obtained from the Global Land Data Assimilation System (GLDAS 2.1) and MODIS Terra Snow Cover data product datasets. The study is situated in and around the Kedarnath Wildlife Sanctuary, which is located within the Garhwal Himalayas in the Indian state of Uttarakhand. We found that a large majority of respondents perceive that rainfall is increasing and that snowfall is decreasing, while a smaller majority perceives an increase in summer temperatures and no change in winter temperatures. Agreeing with the perceptions of the majority, the climate data show an increase in summer temperature and winter rainfall. However, the climate data also show an increase in winter temperature, and no monotonic change in snowfall, findings which are contrary to the perception of the majority. Consistent with previous studies, respondents are more perceptive to increasing temperatures in the hot season than the cold season. Furthermore, respondents are highly perceptive to increasing rainfall, potentially due to the importance of rain to livelihood, the visual salience of rain, and the recent major flooding events in the region. Climate data do not show a decrease in snowfall but do indicate that snowfall has shifted later at higher elevations. Household perceptions of climate change were not associated with adaptation; while many households perceived change, very few reported that they were taking action or planning to adapt. To encourage adaptation, communities would benefit from locally appropriate climate and weather data products, and active collaboration on best practices with researchers, NGOs, and extension services.

Keywords
Kedarnath Wildlife Sanctuary, India, Himalayas, climate change, local perceptions, adaptation

1. Introduction

In the past 50-60 years, the Himalayas have experienced a rising number of extreme heat events, a decrease in the number of extreme cold events, and locally variable snowfall trends (Bolch et al., 2019; Krishnan et al., 2019). The warming trends in the Himalayas are higher than the global average (Xu & Grumbine, 2014), resulting in melting glaciers, changing vegetation distribution, altered crop phenology, and new pests and weeds (Chaudhary et al., 2011; Sharma & Shrestha, 2016). Glacial retreat threatens to reduce stream flow and fresh water availability for drinking and crop irrigation, and lead to stress on groundwater resources (Mall et al., 2006; Negi et al., 2012).

Communities that primarily depend on agriculture and subsistence farming are disproportionately vulnerable to the effects of climate change (IPCC 2018). Yet in such communities in the Himalayas, adaptation responses to climate change are incremental, insufficient, and poorly integrated with wider efforts (Mishra et al., 2019). A major reason for the inadequate response to climate change is a lack of resources -- lower caste families, women, and other marginalized groups have particular difficulty adapting to climate change (Macchi et al., 2015; Stock et al., 2017). In addition, adaptation to climate change is influenced by perceptions of risk and by personal experiences (Ricke & Caldeira, 2014). Without accurate perceptions, the communities may not initiate appropriate adaptation strategies (Amadou et al., 2015; Piya et al., 2012). Several studies in the Himalayas have found that the majority of people hold perceptions of climate change that are in agreement with the instrumental record (i.e. warmer temperatures, precipitation variability, and drying of water resources) (Abid et al., 2015; Chaudhary et al., 2011; Sharma & Shrestha, 2016; Uprety et al., 2017). However, other studies have shown that perceptions are highly variable. For example, one study found that the perception of Nepalese farmers matches the observed trends for maximum temperature, but not for minimum temperature or rainfall (Budhathoki & Zander, 2019). Another study found that perceptions of temperature and winter precipitation varied by study area across Nepal and India, while perceptions of annual precipitation, monsoon onset, and crops/pests were widely consistent (Macchi et al., 2015). A study of communities in Nepal found that while many correctly perceive climate change, a large minority of people do not correctly perceive changes (Piya et al., 2012).

The present study compares perceptions of climate change from 16 Himalayan villages to climate data from NASA data sets. The key research goals are to (1) determine whether local perceptions of climate change are in agreement with climate data, and (2) identify the probable reasons for the agreement/lack of agreement and implications for adaptation to climate change. The study is situated in the Kedarnath Wildlife Sanctuary (KWS) Landscape, located in the Indian state of Uttarakhand. A better understanding of perceptions of climate change would allow decision-makers to formulate adaptation measures and policy that address the impacts of greatest concern to communities (Reyes-García et al., 2015; Simelton et al., 2013), to identify linkages between environmental change and livelihoods that may not be self-evident (Byg & Salick, 2009; Reyes-García et al., 2015; Savo et al., 2016), and to help explain why people undertake adaptation strategies or not (Singh et al. 2018).

2. Methods

2.1. Study Area

The study area for this research comprised 16 villages located within the two central valleys of the KWS landscape, Madhmaheshwar Valley and Kalimath Valley (Figure 1).

Established in 1972, the Kedarnath Wildlife Sanctuary is among the largest protected areas in Uttarakhand (975 km^2), and ranges in elevation from 1,100m to 7,068m. This large elevational gradient results in high variability in climate and floral assemblages. It is approximately 48% forested, including oak-dominated forests (*Quercus* sp.) in the temperate region (1500-2900m) and Pine-dominated forests (*Pinus roxburghii*) in the subtropical regions (<1500m) (Prabhakar et al., 2001). The KWS attracts thousands of tourists and religious pilgrims who come to visit numerous holy sites (Manral, 2018).

Figure 1: Study Area: The Kedarnath Wildlife Sanctuary (KWS) Landscape in Uttarakhand, India.

We surveyed residents from 251 households within 16 villages located in this geographic area. The locations of study households ranged from 1,068 to 2,969 meters in elevation, representing a climatic gradient of sub-tropical to temperate. Of the 16 villages, 5 are located within the wildlife sanctuary and 11 are located outside the sanctuary boundaries (Table 1). As in most parts of the Western and Central Himalaya, residents depend on cultivation of small agricultural terraces, as well as forest resources for fuelwood and fodder (Malik et al., 2014; Manral et al., 2017). Dominant crops include paddy, wheat, kidney beans, and traditional grains. A small number of households seasonally migrate with their livestock to temporary summer settlements at higher elevations with better fodder availability.

Table 1: Study area villages

2.2.Survey Data on Climate Perceptions

Fieldwork for this study took place from May-July 2015. To evaluate local perceptions of changing climate, a household-level survey was conducted in 16 villages within the KWS landscape (Table 1). Within each village, a two-person team systematically visited every fifth home, administering the survey to a total of 251 households across the 16 villages (approximately 20% of households). At each home, a detailed questionnaire-based interview was conducted with a single adult member of the household. In households with more than one adult member, a single adult was invited to participate – adults of different genders and generations were chosen to ensure the representativeness of the sample. Informed consent was obtained prior to each interview; participation was voluntary and unpaid. The questionnaires were administered in Hindi or Garhwali depending on the respondent's preferred language. The responses were then translated to English and entered into a spreadsheet for coding and analysis.

The questionnaire dealt with four categories: climate trends, changes to agro-ecological systems, changes in resource availability in local forests, and wildlife sighting and conflict. Only the first of these categories is analyzed in this study. A separate study analyzed a broader set of questions from same questionnaire and found few differences between the responses of subgroups (i.e. categories of gender, education, or wealth) *(citation redacted).* Thus, in this study we focus primarily on aggregate results and do not stratify by subgroup.

The present study analyzes results from a subsection of the questionnaire dealing with respondent perceptions of climate trends. Key questions followed the format: "Have you noticed changes in any of the following environmental conditions over past 15-20 years?" The respondents were asked whether they perceived an increase, decrease, or no change (or "don't know") for environmental conditions including temperature, rainfall, and snowfall. Respondents were given an opportunity to explain their answers ("Explain your concerns about environmental changes in this area") and to provide additional, free-form narrative data. These explanations are selectively quoted in the discussion. Finally, respondents were asked whether they are "taking or planning actions in response to environmental change" (i.e. adapting or planning to adapt). They were given an opportunity to describe their adaptations or explain why they had no plan for adaptation. Using chi square tests, we evaluated whether those who perceive environmental change are more likely to report adaptation.

2.3.Climate Data

We used climate data from the Global Land Data Assimilation System version 2.1 (GLDAS-2.1) and the MODIS Terra Snow Cover data product. The primary data source was GLDAS-2.1, which uses satellite and ground observation to generate rasters representing daily climate conditions and contains a variety of bands that align with the climate variables measured in the survey (Table 2). GLDAS-2.1 has a spatial resolution of 0.25 arc degrees, which corresponds to approximately 28 km x 24 km at the latitude of the study area. The grid cell covering the study area (Figure 1) has an average elevation of 2,997 meters, which is higher than the elevation of the households (1,068 to 2,969 m). An additional dataset was the MODIS Terra Snow Cover Daily Global 500m product (MOD10A1). The snow cover data uses the Normalized Difference Snow Index (NDSI) and other tests for the presence of snow. NDSI shows the spatial extent of snow cover rather than snow depth or rate of snowfall. The MODIS data product is more spatially detailed than GLDAS-2.1 and was used to evaluate spatial variation in snowfall within the KWS landscape. We used data from the beginning of the datasets (1/1/2000 for GLDAS-2.1, 2/24/2000 for MODIS) through 6/30/2015 (the last full month of the household survey). Annual summaries of the climate variables in Table 2 were calculated for the following seasons:

- Winter (November-February)
- Summer (April-June)
- Monsoon (July-September)
- Annual (full calendar year)

Table 2: Selected survey questionnaire items and associated climate data sources.

For each climate variable, we used a non-parametric linear regression to evaluate trends in mean and standard deviation over time. Specifically, we used the Mann-Kendall (M-K) test to test for monotonic trends (i.e. consistent upward or downward trends that may or may not be linear). The M-K test is suitable for annual data where there is no seasonal trend present, and requires that the original data or any power transformation of the data be distributed similarly over time (Helsel & Hirsch, 2002). Therefore, unlike OLS regression M-K tests may be used in many cases where the variance of the original data changes over time. We also use the non-parametric Theil-Sen linear regression to quantify the slope of the trend. The Theil-Sen method calculates the slope of every data pair and uses the median slope to characterize the trend (Sen, 1968). Theil-Sen is robust to outliers and noise, which makes it particularly appropriate to identifying trends in climate and weather data (Fernandes & Leblanc, 2005). In addition, for each MODIS pixel in the study area, we found the simple linear trend between NDSI and time. We then created scatterplots between elevation and slope (i.e. rate of change in NDSI) for each month for the 2001-2015 period. Google Earth Engine was used for image processing of MODIS data products (Gorelick et al., 2017).

While there is no weather station data available for the entire span of the study period, monthly data is available for 2008-2010 from the weather station at Tungnath. Located 8 km east of the study area, the Tungnath weather station is located at treeline at an elevation of 3360 meters – higher than the elevation of households (1,068 to 2,969 m) and also higher than the average elevation within the GLDAS-2.1 grid cell (2,997m). We found that the GLDAS-2.1 data are significantly correlated to monthly data from the Tungnath weather station (Table 2). Temperature and rainfall had the highest correlation, while monthly snowfall rate and snow cover were moderately correlated.

The methods we have used to analyze climate trends have general applicability; the datasets (i.e GLDAS 2.1 and Modis Snow Cover data sets) and statistical methods (i.e. Mann-Kendall Trend and Sen's Slope Estimate) have not been used in previous studies of climate perception, and could potentially be applied to other places with no long-term weather stations.

2.4.Comparison of Questionnaire Items to Climate Data

To evaluate whether there was general agreement between perceptions and associated climate data (Table 2), we first defined "agreement" as cases when the modal perception for an environmental change (increase, decrease, or no change) is consistent with the direction of the Sen slope. For the changes for which there is agreement, we then compared the level of consensus about environmental change (% of respondents who give the modal response) and the statistical confidence (p value of the M-K test). Because perceptions may be influenced by recent trends, we also calculated the percentile of climate data from recent years (i.e., 2013-2015) within the time series. Finally, we evaluated how change in snow cover relates to elevation, and assessed how spatial and temporal patterns of snow cover may relate to perceptions of annual snowfall.

An important caveat is that we are comparing data collected at two different scales: local household perceptions and regional climate data. Since local climate is strongly correlated with regional climate, it is common practice to assess potential local impacts of climate change using regional climate data (Maraun and Widmann, 2015). However, it is important to recognize that complex terrain (e.g. the rain shadow of mountain ranges) can complicate the relationship (Maraun and Widmann, 2015). We found that we found that temperature and rainfall at the Tungnath Weather Station are strongly correlated to GLDAS-2.1 temperature and rainfall. Snowfall at the weather station location had a lower correlation, but we were able to supplement with a more detailed dataset, the MODIS Terra Snow Cover data product. Furthermore, it is important to note that household perceptions of climate change are shaped by both regional and local factors. This is evident from qualitative responses noted later in the paper, i.e. respondents mentioned regional flooding events and snow in the mountains at higher elevations than where they live.

3. Results

3.1. Perceptions of climate change

The greatest consensus among respondents relates to precipitation: 82% of respondents perceive that rainfall is increasing and 79% perceive that snowfall is decreasing (Figure 2). In terms of temperature, results are split with 53% perceiving an increase in summer temperature but only 34% perceiving an increase in average winter temperatures. The majority of respondents

(51%) perceive no change in winter temperatures, and a large minority (43%) perceived no change in summer temperatures.

Figure 2: Respondent perceptions of environmental change

3.2.Climate Data

Temperature increased monotonically during all seasons (Figure 3), with a steeper increase in temperature during the summer (0.26 degrees Celsius [ºC] annually) and monsoon season (0.27 ºC annually) than the winter season (0.20 ºC annually) (Table 3). In addition, the standard deviation of temperature in the summer and monsoon seasons increased monotonically, which suggests that temperature became increasingly variable over time.

Rainfall mean and standard deviation increased monotonically only during winter (Figure 3), but not during other seasons. Winter snowfall rate and snow cover did not change monotonically in terms of either mean or standard deviation. This suggests that winter rainfall has increased, but winter snowfall has not changed monotonically over time.

Table 3: Mann-Kendall (M-K) Trend and Sen's Slope Estimate for mean and standard deviation of climate variables 2000-2015.

Figure 3: Change in (a) temperature, (b) winter rainfall rate, (c) winter snowfall rate.

Over time, we found a complex non-linear relationship between elevation and the slope of change in snow cover 2001-2015 (Figure 4a and 4b). At elevations below treeline (approximately 3,500m), there is no trend in average snow cover over the time period. At elevations between 3,500-5,000m, however, there is a negative slope for snow cover in early winter (Figure 4b) and a positive slope for snow cover in late winter (Figure 4c). The results indicate that while the annual snow cover has not changed monotonically, the seasonality of snow cover has shifted at higher elevations during the time period studied.

Figure 4: Elevation versus slope of NDSI for the early and late winter season. (Positive slope indicates an increase in snow, while a negative slope indicates a decrease).

3.3. Agreement between local perceptions and climate data

There is agreement between perceptions and climate data for average summer temperature and rainfall. In both cases, more than 50% of respondents perceive an increase, there is a positive Sen slope, and the M-K test is significant at the $p<.05$ level (Table 4). For winter temperature and snowfall, there is no clear agreement. While there is evidence of a monotonic increase in winter temperatures (positive Sen slope and significant M-K test), 51% of respondents perceived 'no change'. A significant minority (34%) did perceive an increase in winter temperatures. While there is no evidence of a monotonic change in snowfall (M-K test not significant), 79% of respondents perceive a decrease. There is, however, a decrease in snowfall at higher elevations in the early winter period (Figure 4a, b).

Table 4: Agreement of perceptions and climate data

Interestingly there is little relationship between the level of consensus about environmental change (% of respondents who give the modal response) and the statistical confidence (p value of the M-K test) (Table 4). For example, a large number of respondents (82%) perceive that rainfall is increasing, but statistically the confidence is moderate that rainfall is increasing ($p <0.05$ but not $p<.01$). In contrast, a smaller number of respondents (34%)

believe that winter temperature is increasing, but statistically the confidence is high that winter temperature is increasing ($p< 0.01$). The averages of the three years leading up to the survey (2013-2015) were characterized by above average temperatures, above average rainfall rate, and close to average snowfall rate (Table 5).

Table 5: Percentile of recent years within time series.

3.4.Climate Perceptions and Adaptation

Of the 251 households in the survey, only 35 (14%) reported that they are adapting (i.e. "taking or planning actions in response to environmental change"). Chi square tests suggested that perceptions of environmental change were for the most part not associated with adaptation. Adaptation households did not differ significantly from no-adaptation households in terms of perceptions of summer temperature (χ=1.72, p=0.19), winter temperature (χ=0.684, p=0.408), or winter snowfall (χ=0.03, p=0.862). However, 60% of respondents in adaptation households perceived an increase in rainfall versus 87% for no-adaptation households [$F(1,249)=14.982$, $p=0.000$]. Overall, these results underscore that in terms of perceptions of temperature and snowfall, the households that report adaptation are similar to those who report no adaptation. In the discussion section (4.4) we evaluate the reasons behind this finding.

Households reported adaptations such as planting vegetation (e.g. fruit and fodder trees) to stabilize landslide areas, switching from traditional staple grains to crops typically grown in warmer climates (e.g. mustard, lentils, or alternate grains), and increasing insecticide use to combat the increase in agricultural pests. In open-ended comments, some respondents provided explanations for why they were not adapting, including a lack of money, a lack of knowledge, and a general sense that the environmental changes they face are beyond their control.

4. Discussion

In the following section, we interpret the agreement between survey data and climate observations, compare the results to other similar studies, and suggest implications for adaptation.

4.1.Temperature

The GLDAS-2.1 dataset shows that temperatures increased in all seasons, and the increase was particularly steep during the summer and the monsoon season. Temperature also became more variable in summer and the monsoon season. These results are consistent with studies elsewhere in the Himalayas. For example, across the Himalayas the warming trend has been ~0.06ºC/year since circa 1980 (Negi et al., 2012; Shrestha et al. 2012). Higher rates of change were observed in winter months (Chaudhary et al., 2011) and at higher elevations (Negi et al., 2012).

Worldwide, perceptions of temperature increase typically correspond to observed temperature increase from climate records (Howe et al., 2012). While some Himalayan studies have found that residents perceive temperature increases in both summer and winter (Chaudhary et al., 2011, Sharma and Shrestha 2016), we found that the majority of people perceive increasing temperatures only in summer. This finding is similar to those reported by Piya et al. (2012) in Nepal, in which the majority also perceived increasing summer temperatures yet disagreed about the direction of winter temperatures. It may be that respondents are more likely to perceive warming when the ambient temperature is already high. A survey of 91,073 people across 89 countries found that whether the survey was conducted during the warm or cool season had an influence on perceptions of warming; during the warm season respondents were 11-19% more likely to perceive that average temperatures had increased (Howe et al., 2012).

4.2.Rainfall

The GLDAS-2.1 dataset shows that rainfall increased and became more variable in the winter. Outside of winter, there was no significant change in rainfall. Previous studies have found that in India rainfall mean has not changed since the 1950s, but the frequency and magnitude of extreme events has increased (Goswami et al., 2006). At the local level, some regions in India are experiencing an increase in rainfall and others a decline (Mall et al., 2006). While we found no monotonic change in monsoon rainfall, it is possible that there are local variations that we could not detect at the resolution of the GLDAS 2.1 data; a previous study found that in Uttarakhand, monsoon rains declined at high altitudes and increased in low altitudes from ca. 1960s-2000s (Singh & Mal, 2014).

Consistent with the GLDAS-2.1 data, the majority of respondents perceive rainfall to be increasing. Other studies also found that local populations were able to perceive changes to the amount, frequency, and intensity of rainfall (Amadou et al., 2015; Chaudhary et al., 2011; Sharma & Shrestha, 2016), and that farmers are more likely to perceive changes than non-farmers (Piya et al., 2012). This may be attributed in part to the visual salience (ease of observation) of rainfall (Vedwan & Rhoades, 2001) and to the utilitarian importance of rain. Farmers are highly dependent on rainfall for their crops and consequently they may be more aware of changes to rainfall (Amadou et al., 2015; Meze-Hausken, 2004). In the study area, rainfall early in the growing seasons (i.e. June- July and November-February) is particularly important for a successful harvest. Only one of the 16 villages in the study area has an irrigation system; the remainder employs entirely rain-fed agriculture.

Recent rain events may influence perceptions of long-term change. A study in Tibet found that locally reported perceptions are more in line with short-term, rather than long-term, trends possibly due to the direct impact on current livelihoods from recent events (Piya et al., 2012). This may also be true for the present study; extreme flooding rather than long-term trends may shape respondents' perception of rainfall. Two years before the survey for the present study, severe flash floods and debris flows in KWS landscape led to more than 4,000 deaths, many including many tourists and pilgrims (Chevuturi & Dimri, 2016; Kala, 2014). In qualitative comments, a number of respondents cited "irregular rains" and "increased landslides" as specific concerns (e.g. "due to fast rain fertile soil is running away and soil is no more fertile.") While we found an increase in rain in the winter, there is no significant monotonic trend in rainfall in the summer or the monsoon season (Table 3).

4.3. Snowfall

Neither the GLDAS-2.1 dataset snowfall rate (2000-2015) nor the MODIS Terra Snow Cover data product (2001-2015) shows a monotonic trend. However, the MODIS data set does suggest that the seasonality of snow cover has shifted at higher elevations, with less snow cover in early season (i.e. November-December) and more snow late season (i.e. January through early summer). Studies elsewhere in the Himalayas have also found snow cover trends that are elevation-dependent. For example, the length of the snow-covered season in Tibet has decreased at lower elevations and increased at higher elevations (Gao et al., 2012). In locations where snowfall has remained high, an increase in precipitation has likely compensated for increase in air temperature (Gao et al., 2012). In contrast, in the upper Indus basin, there has been a decrease in snow cover in winter at higher elevations, but the change was not significant at lower elevations (Immerzeel et al., 2009).

In the present study, the majority of respondents believe that snowfall has decreased over the last 15-20 years. The result is consistent with what has been found worldwide; communities across a range of biomes have reported a reduction in snowfall and snowpack in mountains (Savo et al., 2016). Similarly, glacial retreat and a decline in snowfall have been reported by communities in the Himalayas and Tibet (Byg and Salick 2009; Chaudhary et al. 2011). Local farmers are highly perceptive of snowfall changes because of the high visual salience of snow (Vedwan & Rhoades, 2001) as well as the impacts that diminished snowfall has on crop production (Byg & Salick, 2009; Vedwan & Rhoades, 2001). Although we did not ask respondents to comment on the timing of snowfall, participants in other similar studies have perceived rain and snowfall to be shifting to a later timing (Chaudhary et al., 2011; Byg & Salick, 2009; Piya et al., 2012; Vedwan, 2006).

There are a number of possible reasons why residents in our study area would perceive a decline in snowfall even though the datasets do not show a monotonic change. One possibility is that they are responding to changes other than "snowfall intensity" or "snow cover". For example, respondents may be responding to changes in snow depth, the moisture content of snow, the volume of snowmelt, or the magnitude of individual snow events. These other characteristics of snow are not directly contained in the GLDAS 2.1 or MODIS snow cover datasets.

A second possibility is that residents are sensitive to changes in snowfall at particular times of the year. One study suggested that apple growers in the Himalayas are more perceptive of snow early in the winter season, because early season snow promotes the required "chilling period" for apple trees (Vedwan, 2006). Similarly, in the KWS landscape, residents expressed the belief that snowfall in early winter can kills pests and result in good harvest, while snowfall in late winter may damage flowering plants. Therefore, it is possible that residents are more perceptive of changes in snow at certain times of year. Third, as with perceptions of rain, it is possible that residents are responding to recent weather: snowfall in the year prior to the survey was significantly lower than average (Table 5). Fourth, it is possible that snowfall has lower visual salience for residents of the study area; most snowfall in the region occurs at elevations much higher than where people live. Finally, it is possible that residents perceived other climate-related changes and presume that snow must be decreasing. As one respondent said, "When we were young then there was lot of snowfall, but today if it rains heavily than there are landslides. Earlier it was not like this." Similarly, numerous respondents perceive that the increase in pests is associated with a decrease in snow: for example, "Earlier there was a lot of snowfall that used to kill rodents, but now due to less snowfall they are increased" and "Earlier insects used to die due to frost and snowfall, but now climate is changing and insects are not dying". Our analysis suggests, however, that although rain is increasing in the winter, there is no corresponding decrease in winter snowfall over the time period studied.

4.4. Implications for adaptation to climate change

Previous studies have suggested that people are not motivated to adapt to climate change without accurate risk perception and personal experience (Tripathi & Mishra, 2017) as well as scientific awareness (Rudiak-Gould, 2014). Furthermore, poor and marginalized groups have difficulty adapting to climate change (Macchi et al., 2015; Stock et al., 2017).

While accurate perceptions of climate change may be necessary for successful adaptation, they were not sufficient to prompt adaptation in this case. We found that the majority of respondents accurately perceived increasing summer temperatures and annual rainfall, yet very few engaged in adaptation or planned to do so in the future. Indeed, very few households of any income level or socioeconomic group are taking action or planning to adapt. The small number of households that are adapting report actions that are limited in scope (e.g. planting warmer-weather crops, applying insecticide, planting vegetation to stabilize soil). In open-ended comments, respondents mentioned many barriers to adaptation, i.e. cost, a lack of knowledge, and a sense that there is nothing they can do.

While perceptions of climate can shape peoples' behavior (i.e. whether or not to adapt), factors in the "operational environment" such as institutions, information, resources, and technology also play an essential role in shaping risk perceptions and behavior (Singh et al 2018). In the KWS landscape, respondents have access to few resources and many do not believe that organizations (particularly the Forest Department, Central Government, or NGOs) are helpful. Thus, many respondents believe that they do not have the capacity to make meaningful adaptations, a collective belief that may shape the behavior and willingness of members of the community to adapt.

To encourage adaptation in the communities of the KWS landscape, we believe that new programs must be developed by local governments and organizations. The programs should acknowledge the perceptions of climate change, address misconceptions, and provide adaptation knowledge, resources, and opportunities for community involvement. Toward these ends, we propose the following actions for regional researchers, relevant NGOs, extension services, and local governmental bodies: (1) expand the weather station network and make the data publicly available; (2) actively involve communities in identifying and disseminating locally appropriate climate data products; and (3) collaborate with communities to create a better operational environment for adaptation.

First, we propose expanding and maintaining the weather station network, particularly in the hills and mountains. The Himalayas and Tibetan Plateau tend to be data poor and are sparsely covered by weather stations (Piya et al., 2012). In Uttarakhand, automatic weather stations exist but some are poorly maintained, and the data are typically not publicly available (SANDRP, 2013). The weather stations that do exist do not capture the significant altitudinal and topographical variation (Macchi et al., 2015). In this study, we used the GLDAS-2.1 dataset because it is the only consistently collected publicly available climate data for the entire span of the study. Unfortunately, GLDAS-2.1 is coarse, not 'real time,' and requires technical expertise to access. A wider network of monitoring stations would also help communities manage risk and water supply (Gao et al., 2019).

Secondly, we propose actively involve communities in identifying and disseminating locally appropriate climate data products. Making choices about how best adapt to climate change requires access to reliable and timely information and is a precursor to community self-empowerment (Ogra & Badola, 2015). Scientific knowledge must be presented in locally appropriate ways that take into account social structure, community complexities, and local needs (Muccione et al., 2016). While classic meteorological variables (e.g. air temperature, humidity, air pressure, precipitation, and wind) should be reported (Gao et al., 2019), so too should data summaries that directly relate to local livelihoods. Since the seasonality of climate change is important to residents, climate summaries should include the timing and intensity of change in addition to current weather and annual averages.

Finally, researchers, local governments, NGOs, and extension services should collaborate more with communities to build a better operational environment for adaptation. Extension service agents can play an important role as information disseminators between government support programs and beneficiaries (Abid et al., 2015). The Forest Department authorities in the KWS and the NGO sector are well-positioned to assist local communities to adapt to climate change. It is important that the staff members of these institutions are trained in basic meteorology and climate science (Piya et al., 2012), as well as recognize how climate change differentially impacts livelihood vulnerability (Shukla et al., 2016; Ogra & Badola, 2015). By disseminating knowledge and building a community around climate change adaptation, local governmental organizations and NGOs can create viable pathways for a wider range of effective adaptation strategies.

5. Conclusion

Changes in temperature and precipitation have direct impacts on agricultural productivity, leading to reduced water availability for irrigation, lower soil fertility, declines in crop yields, shifting of crop cycles, and invasion of new weeds and pest species (Negi et al., 2012; Tripathi & Mishra, 2017). In the KWS landscape, we found evidence that temperature is increasing across all seasons, that rainfall is increasing in the winter, and that there is no monotonic change in winter snowfall or summer/monsoon rain. The majority of respondents perceived an increase in summer temperature and an increase in rainfall, but contrary to the climate data, perceived no change in winter temperature and perceived a decrease in snowfall. One finding differs from other related studies: respondents perceive a decrease in snowfall decrease, while snowfall has primarily shifted later in the season but has not decreased overall during the period of the study.

There are several reasons why perceptions do not consistently match climate data. Rain and snow have greater visual salience (more easily observable) than temperature (Vedwan & Rhoades, 2001). This may explain why respondents are in greater agreement about trends in precipitation than trends in temperature even though the statistical evidence for temperature is stronger. Furthermore, perceptions of climate change are influenced by short-term local weather patterns, which are variable and may not reflect long-term trends (Howe et al., 2012; Shao, 2015; Piya et al., 2012; Lehner & Stocker, 2015). The 2013 floods in Uttarakhand may have influenced respondent perceptions of "total rainfall" even though there is no long-term monotonic trend in rainfall in the summer or monsoon seasons. Finally, perceptions can be affected by climate factors that we did not measure. For example, while there is no evidence of a change in total snowfall, residents may perceive that snow is melting more quickly and presume that increased winter rain necessarily leads to decreased winter snowfall.

In this study, the perceptions of climate change were not clearly connected to adaptation; very few households have plans for adaptation regardless of their climate perceptions or socioeconomic factors. To encourage a wider range of effective adaptation measures, communities in the KWS landscape and other similar regions in the Himalayas would benefit from improved weather and climate monitoring, locally appropriate data products, and active collaboration on adaptation strategies with researchers, NGOs, local government, and extension services.

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Table 1: Study area villages.

Village Name	Number of Households Surveyed	Minimum Elevation (m)	Maximum Elevation (m)	Proximity to KWS
Bedula	20	1271	1665	Outside
Bhatwari	7	1283	1392	Outside
Buruwa	16	1346	1622	Outside
Chaumansi	10	1926	2354	Inside
Chilond	10	1878	2117	Inside
Gadgu	18	1550	1755	Inside
Gaundar	10	1700	2969	Inside
Jal Malla	15	1463	2043	Outside
Kalimath	16	1221	1335	Outside
Kaviltha	8	1404	1524	Outside
Khonu	8	1608	1700	Outside
Kotma	20	1438	2021	Outside
Mansoona	22	1307	2687	Outside
Ransi	24	1251	2649	Inside
Raulaink	29	1290	1752	Outside
Sansari	18	1068	1305	Outside

Table 2: Survey questions and associated climate data sources.

Survey question: "Have you noticed changes in any of the following environmental conditions over past 15-20 years?"	**GLDAS-2.1 Data (2000-2015)**	**Tungnath Weather Station Data (2008-2010)**	**Pearson's R Correlation of monthly GLDAS 2.1 and Tungnath Weather Station Data (2008-2010)**
Temperature (Winter and Summer)	Average surface skin temperature, ºK	Temperature, ºK	.95 **
Total Rainfall	Rain precipitation rate, $kg/m^2/s$	Rainfall (cm)	.85 **
Total Snowfall	Snow precipitation rate, $kg/m^2/s$	Snowfall (cm)	.67 **
	Snow Cover (NDSI)		.64 **

* significant at p<.05 level

** significant at p<.01 level

Table 3: Mann-Kendall (M-K) Trend and Sen's Slope Estimate for mean and standard deviation of GLDAS-2.1 climate variables 2000-2015.

Climate Variable (Mean)	**Mann-Kendall Trend**	**Sig**	**Sen's Slope Estimate**	**RMSE Residuals**
Annual temperature (C)	3.65	***	0.22	0.66
Winter temperature (C)	2.47	*	0.20	0.70
Summer temperature (C)	2.93	**	0.26	1.01
Monsoon temperature (C)	3.76	***	0.27	0.48
Annual Rain precipitation rate (kg/m2/s * million)	2.12	*	0.06	3.45
Winter Rain precipitation rate (kg/m2/s * million)	3.07	**	0.69	0.46
Summer Rain precipitation rate (kg/m2/s * million)	-0.23		-0.30	11.90
Monsoon Rain precipitation rate (kg/m2/s * million)	1.19		0.96	13.13
Winter Snowfall rate (kg/m2/s * million)	0.11		0.02	1.08
Winter Snow Cover (NDSI)	0.00		0.02	3.28
Climate Variable (Standard Deviation)	**Mann-Kendall Trend**	**Sig**	**Sen's Slope Estimate**	**RMSE Residuals**
Annual temperature (C)	3.02	**	0.10	0.42
Winter temperature (C)	1.64		0.09	0.54
Summer temperature (C)	2.03	*	0.14	0.70
Monsoon temperature (C)	1.98	*	0.09	0.63
Annual Rain precipitation rate (kg/m2/s * million)	2.12	*	0.57	3.45
Winter Rain precipitation rate (kg/m2/s * million)	3.18	**	2.84	20.12
Summer Rain precipitation rate (kg/m2/s * million)	-0.14		-0.89	48.78
Monsoon Rain precipitation rate (kg/m2/s * million)	1.19		2.14	32.37
Winter Snowfall rate (kg/m2/s * million)	1.39		1.52	15.67
Winter Snow Cover (NDSI)	0.11		0.02	3.28

* significant at p<.05 level

** significant at p<.01 level

Table 4: Agreement of perceptions and climate data

Survey Variable	**Modal perception of change (15-20 years leading up to 2015)**	**Monotonic change in climate data (2000-2015)**	**Agreement**
Summer Temperature	Increase (53%)	Increase **	Yes
Winter Temperature	No Change (51%)	Increase **	No
Total Rainfall	Increase (82%)	Increase *	Yes
Total Snowfall	Decrease (79%)	No Change	No

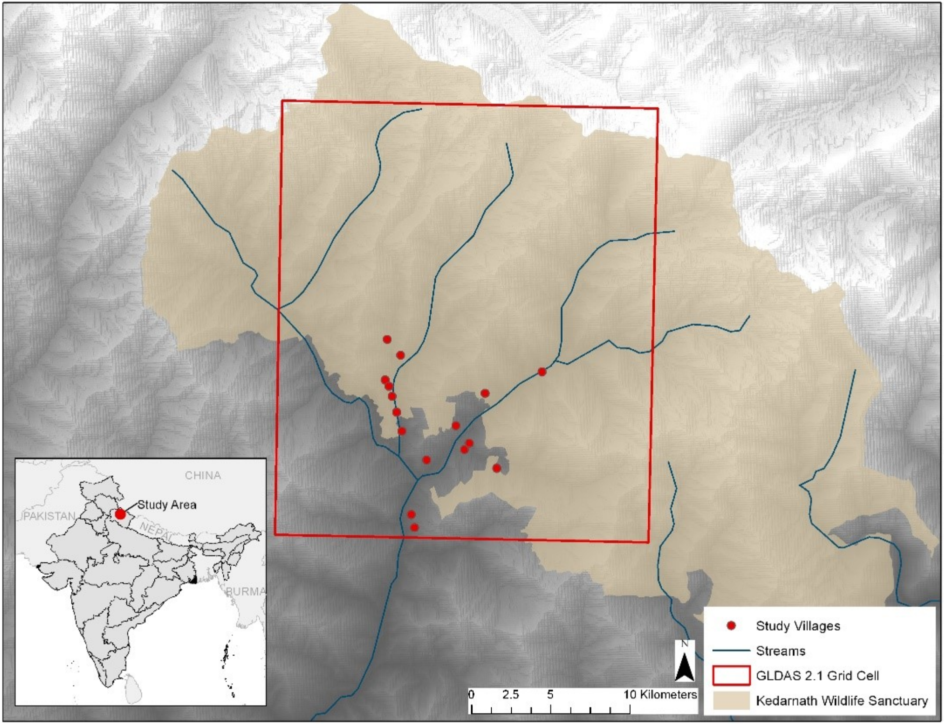
* significant at p<.05 level

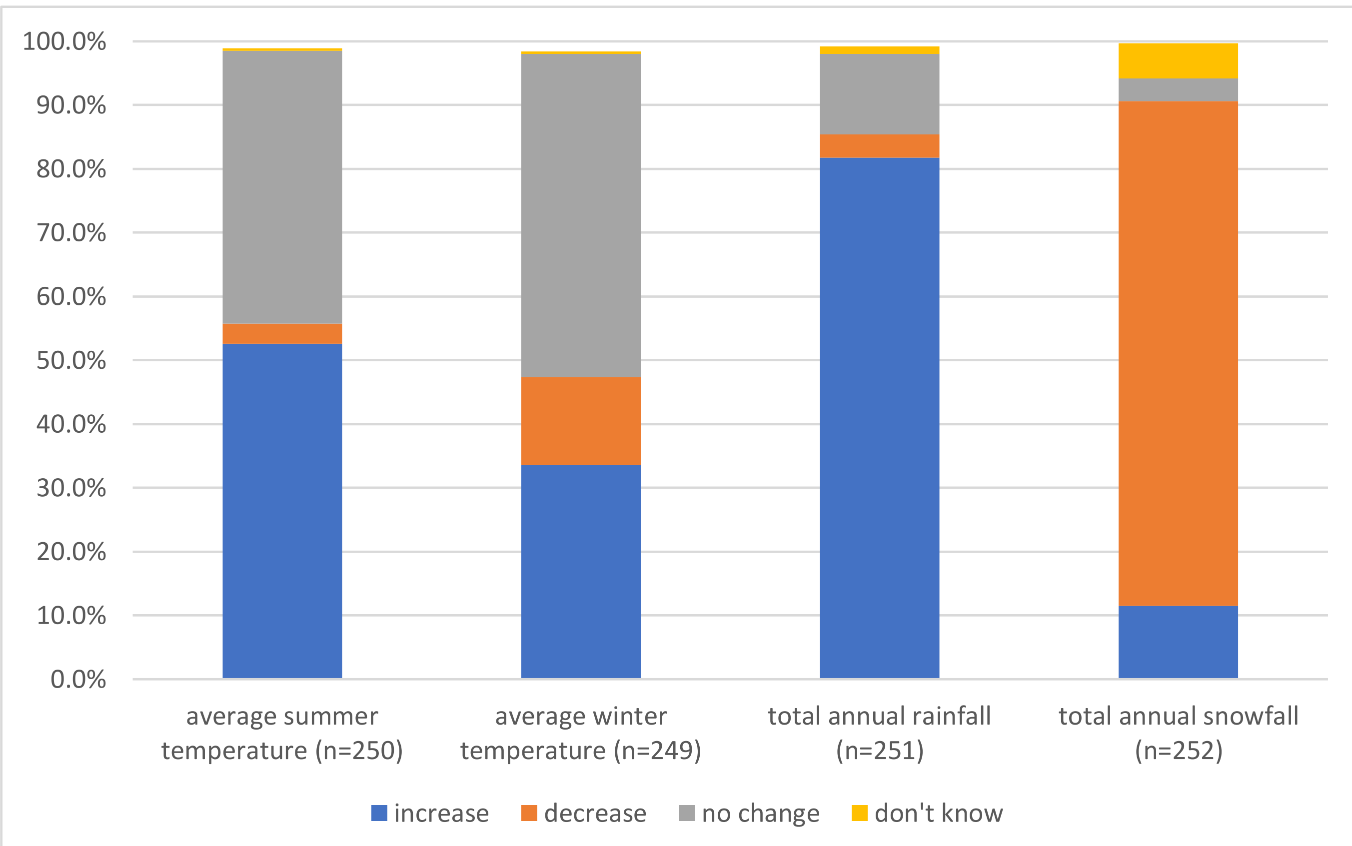
** significant at p<.01 level

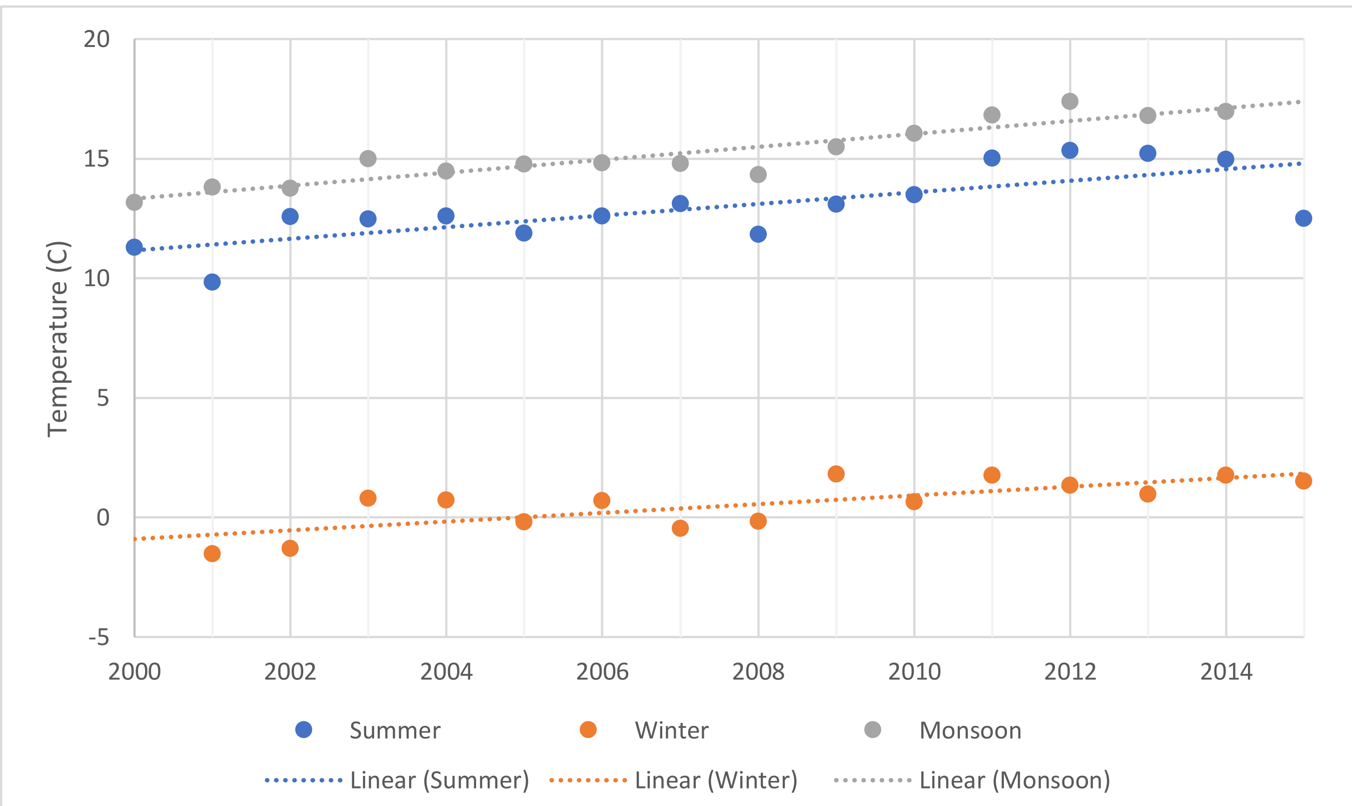
Table 5: Percentile of recent years within time series.

Climate Variable	2013	2014	2015	Average
Annual Temperature	100%	93%	*	97%
Winter Temperature	64%	85%	75%	75%
Summer Temperature	93%	80%	33%	69%
Monsoon Temperature	100%	77%	*	88%
Annual Rainfall Rate	100%	60%	*	80%
Winter Rainfall Rate	57%	100%	92%	83%
Summer Rainfall Rate	100%	27%	73%	67%
Monsoon Rainfall Rate	36%	50%	*	43%
Winter Snowfall Rate	73%	33%	60%	56%
Winter Snow Cover	54%	85%	*	69%

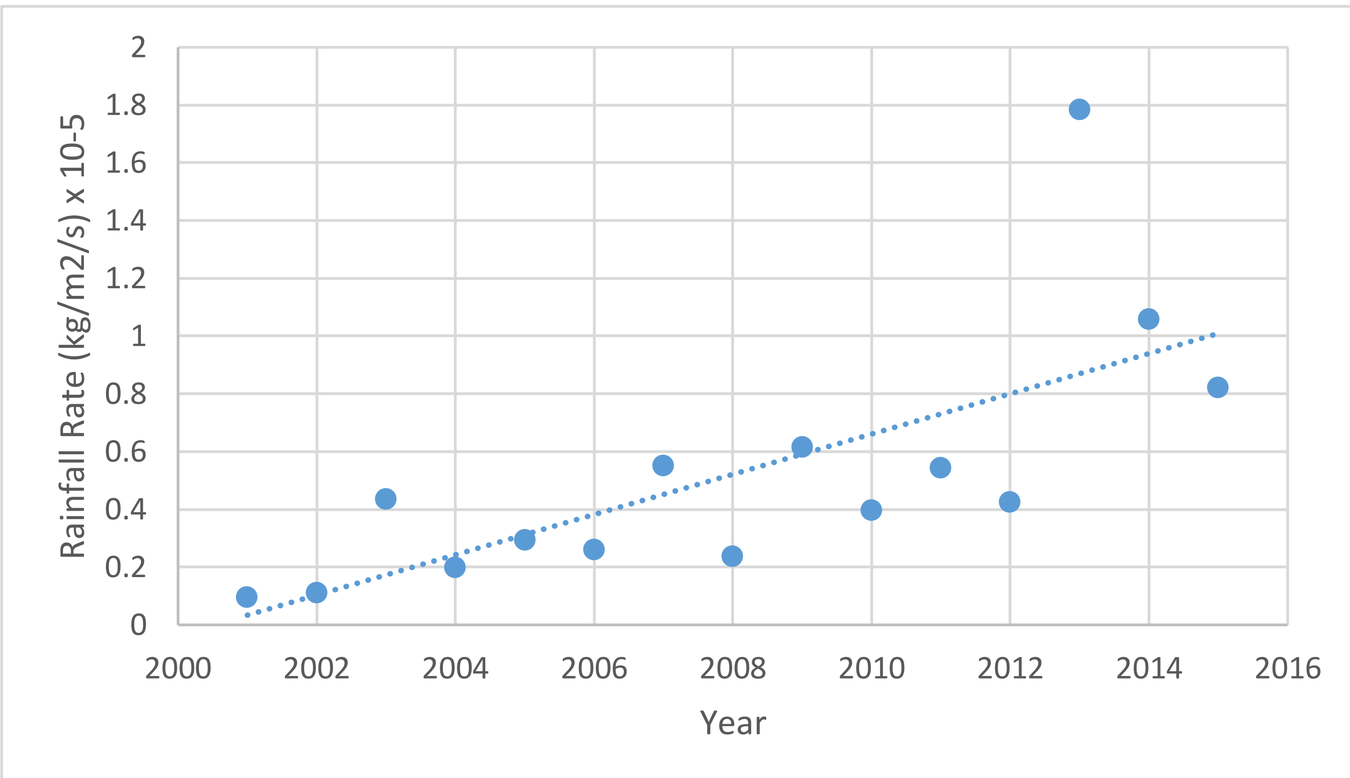
* Excluded (post-survey)


CHINA
Study Area
PAKISTAN
NEPAL
BURMA
Study Villages
Streams
GLDAS 2.1 Grid Cell
Kedarnath Wildlife Sanctuary
N
0 2.5 5 10 Kilometers

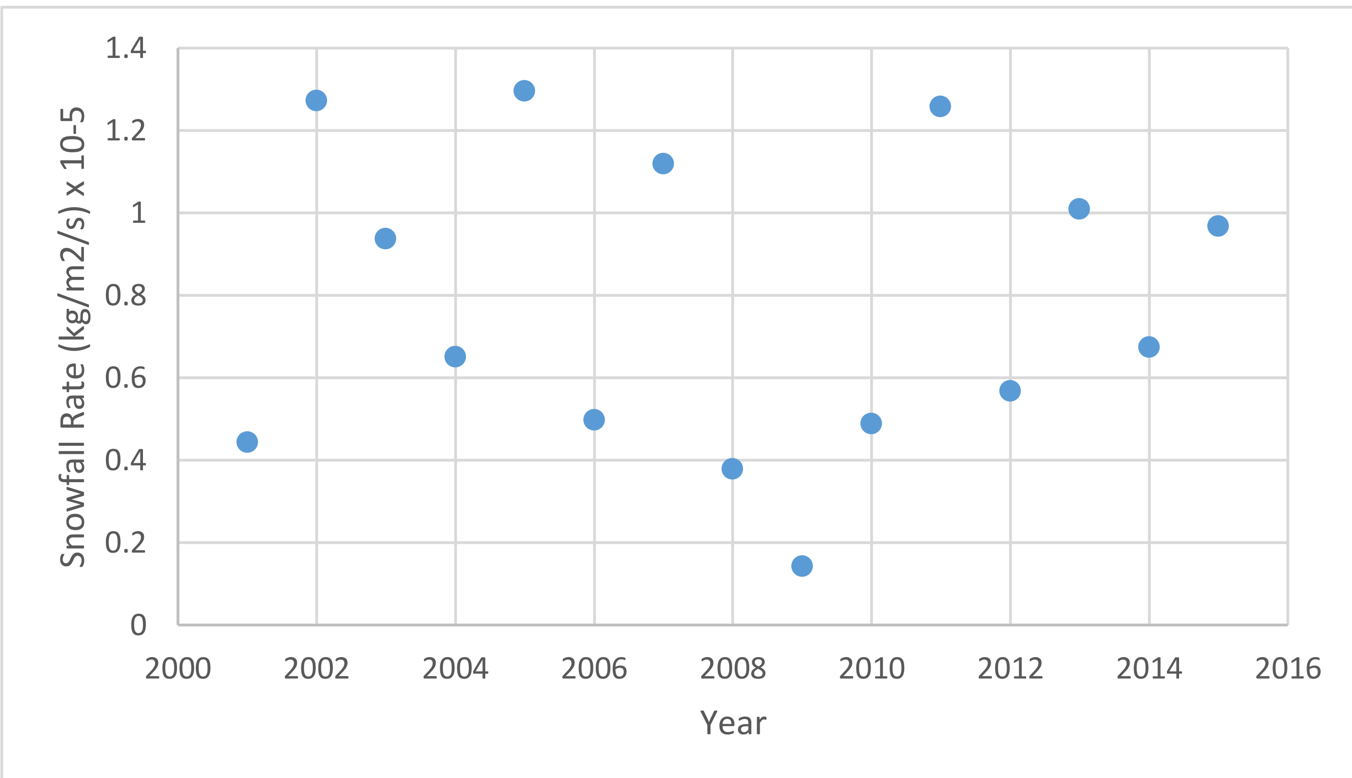

100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
average summer temperature (n=250)
average winter temperature (n=249)
total annual rainfall (n=251)
total annual snowfall (n=252)
increase
decrease
no change
don't know

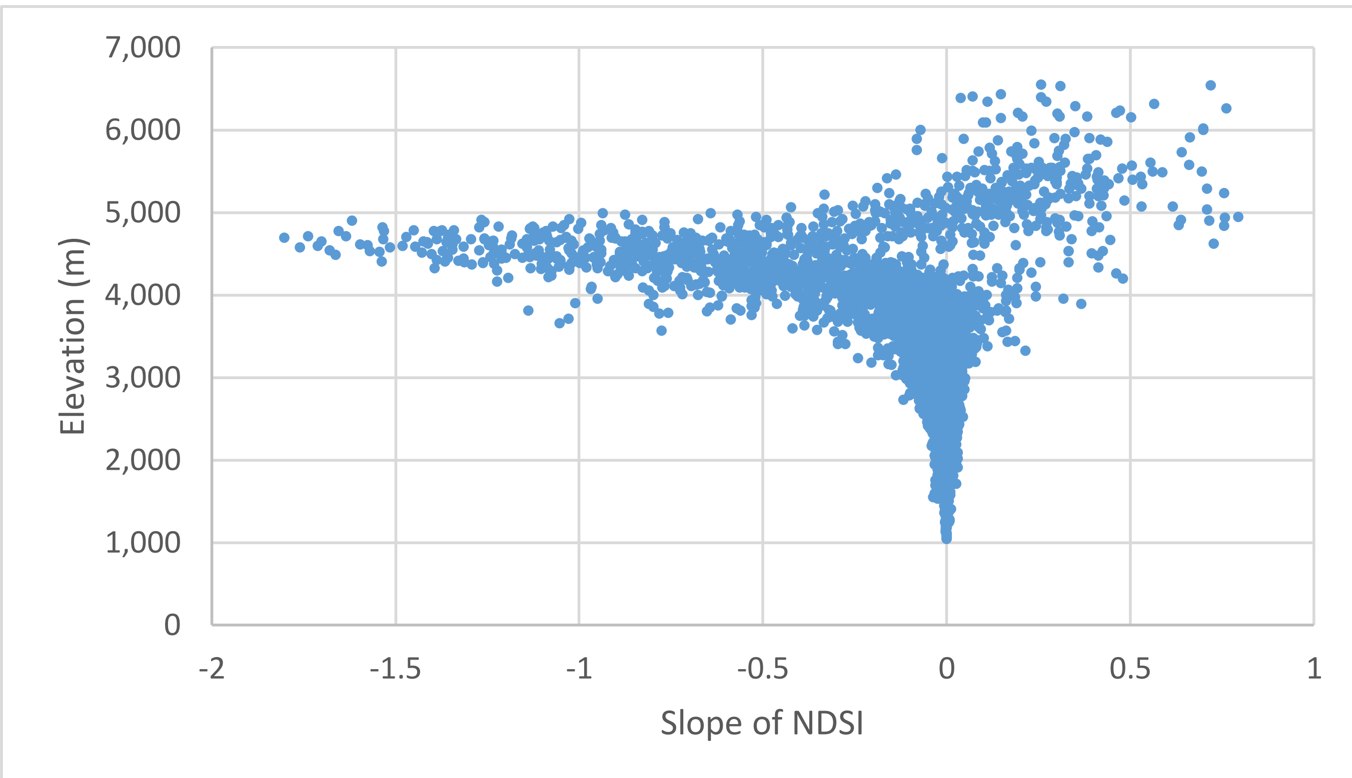


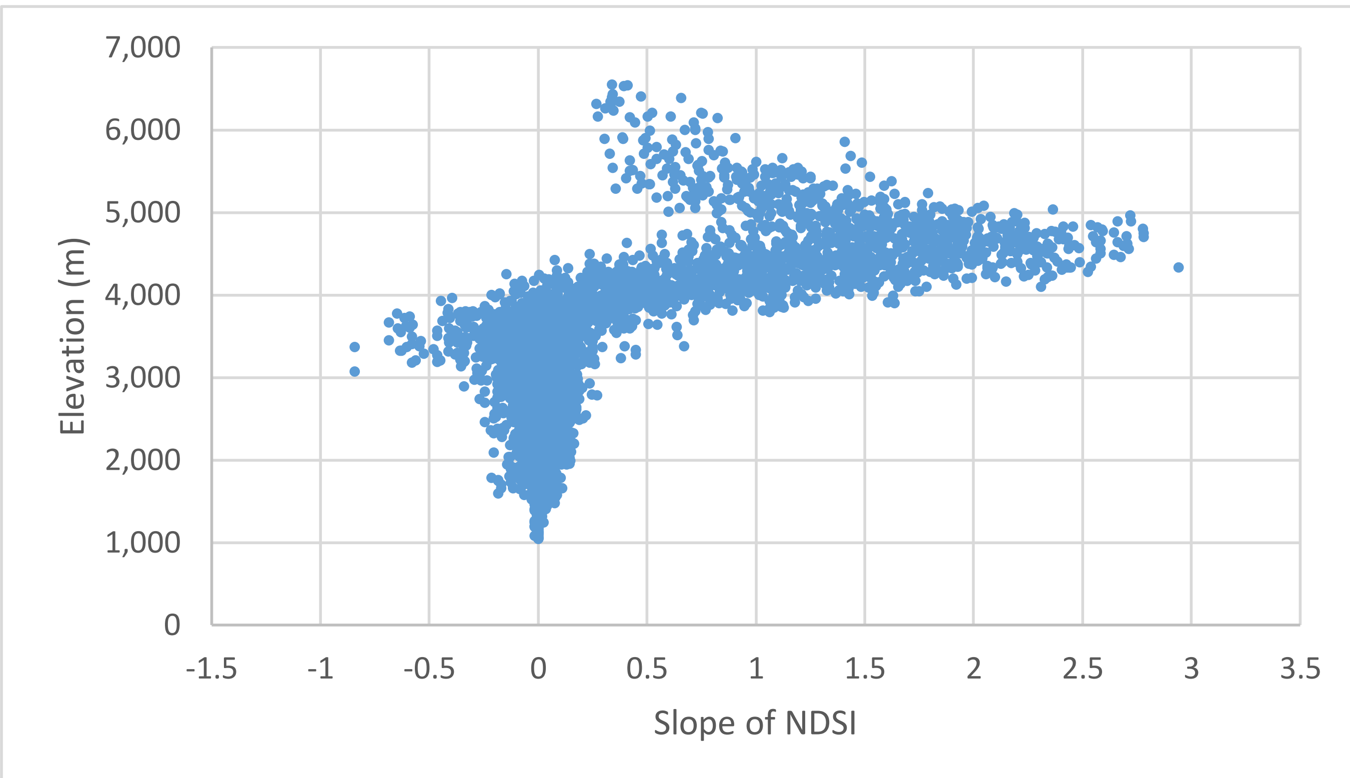
20
15
10
5
0
-5
Temperature (C)
2000
2002
2004
2006
2008
2010
2012
2014
Summer
Winter
Monsoon
Linear (Summer)
Linear (Winter)
Linear (Monsoon)



Rainfall Rate (kg/m2/s) x 10-5
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year


Snowfall Rate (kg/m2/s) x 10-5
0
0.2
0.4
0.6
0.8
1
1.2
1.4
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year


7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Elevation (m)
-2
-1.5
-1
-0.5
0
0.5
1
Slope of NDSI


7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Elevation (m)
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
Slope of NDSI