Applied Ecology and Environmental Sciences, 2019, Vol. 7, No. 6, 206-215
Available online at http://pubs.sciepub.com/aees/7/6/1
Published by Science and Education Publishing
DOI:10.12691/aees-7-6-1

Assessment of Climate Change and People's Perception on Climate Change and its Impacts in Solu Khola Catchment of the Mt. Everest Region of Eastern Nepal

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Received September 18, 2019; Revised October 24, 2019; Accepted November 17, 2019

Abstract Climate change is a real occurring phenomenon worldwide which has first order impacts on water resources because of its direct connectedness with the components of hydrological cycle. This study attempts to assess the extent of climate change impacts at catchment scale which lies at the southern slope of Himalayas i.e. Mt. Everest Region primarily through the vision and experiences of local people residing in that area for years and directly witnessing the changes. Impact assessment was performed through analysis of meteorological data and assessment of people’s perception on changes. People’s perception was studied through generalized questionnaire survey of 90 households and key informants interview. The study was carried out in May 2013. The results depicted rise in temperature in the study area in the recent years in comparison to the past years, with highest temperature increase in winter season. Precipitation showed increasing trend. Winter precipitation had the declining trend but total annual precipitation showed increasing trend. In contrast, total number of rainy days was decreasing. Most of the households in the catchment area were dependent upon spring sources of water, which was mostly affected by the consequences of climate change in terms of decrease in quantity of supply, early drying up as well as late emergence. Other perceived impacts were increased intensity of natural hazards (agreed by 83% of the respondents), decreased intensity, frequency and duration of snowfall (perceived by 87% in Salleri), decrease in flow of Solu Khola (perceived by 49% of the respondents) etc. Apart from all these, the impacts were non uniform in distribution. The VDCs lying in the downstream stretch of Solu Khola were much affected than those in the upstream section. The results from this research can be used to raise awareness on extent of climatic changes in the area as well as support for local decision making.

Keywords: *climate change, Mt. Everest, Solu Khola, precipitation, people's perception*

Cite This Article: Kabita Poudyal, Binod Dawadi, and Lochan P. Devkota, “Assessment of Climate Change and People's Perception on Climate Change and its Impactsin Solu Khola Catchment of the Mt. Everest Region of Eastern Nepal.” *Applied Ecology and Environmental Sciences*, vol. 7, no. 6 (2019): 206-215. doi: 10.12691/aees-7-6-1.

1. Introduction

Climate change in Intergovernmental Panel on Climate Change (IPCC) usage refers to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and persists for an extended period, typically decades or longer. Globally, the linear warming over the period of 1880-2012 was 0.85°C and 1983-2012 was the warmest 30 years' period of the last 1400 years in the Northern Hemisphere [1]. Glaciers continue to shrink almost worldwide due to climate change, affecting runoff and water resources downstream. It is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together [1].

The mean temperature in Nepal has increased at a rate of 0.04°C per year during the years 1975 to 2005 [2]. Glacial fragmentation, the higher retreat of small glaciers and climate change are influencing the sustainability of Himalayan glaciers [3]. Most intensive shrinkage in glacial status is observed in the Himalayas characterized by the greatest reduction in glacial length, area and the most negative mass balance [4].

Community perceptions, views, and opinions regarding climate change is important in designing mitigation policies, adaptation strategies [5] as well as ensuring acceptance based on the perception of associated risks [6]. Even though many studies on climate change have been carried out in the southern slope of the Central Himalaya [7-17], few studies have been done about the climate change impacts and people’s perception [18]. Moreover, studies on recent climate trends from the Himalayan range are still limited [19]. In particular, such studies are lacking around the area in the highest peak of the earth i.e. Mount Everest Region. Very often, the experiences and observations of the communities living in remote rural areas can be the source of information for the scientific communities [20]. The Solukhumbu district, where this study has been carried out, has high vulnerability ranking (0.725) to climate change [21].

The current study analyzes the overall trend of meteorological variables (temperature, precipitation) in the study area and assesses the perceived impacts of climate change experienced by local people in the study area mainly focusing on water resources. There are few documented studies regarding the perception of climate change on a local scale [5]. Though this research is not completely new, the perception of the people towards climate change in this region is largely unexplored. The objective of the study is to assess the perceived level of impacts with the eyes of local data sources witnessing the change for years around the highest peak of the earth.

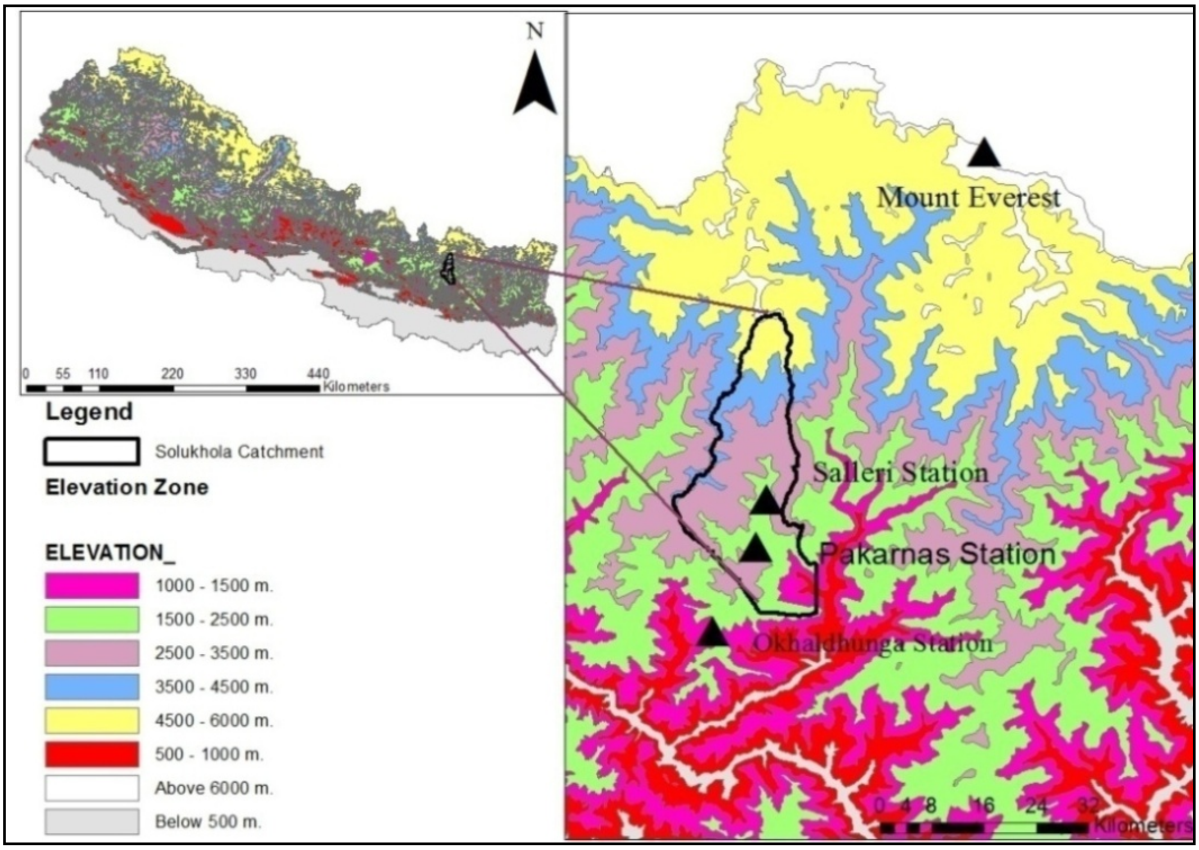

Figure 1. Location Map of Study Area

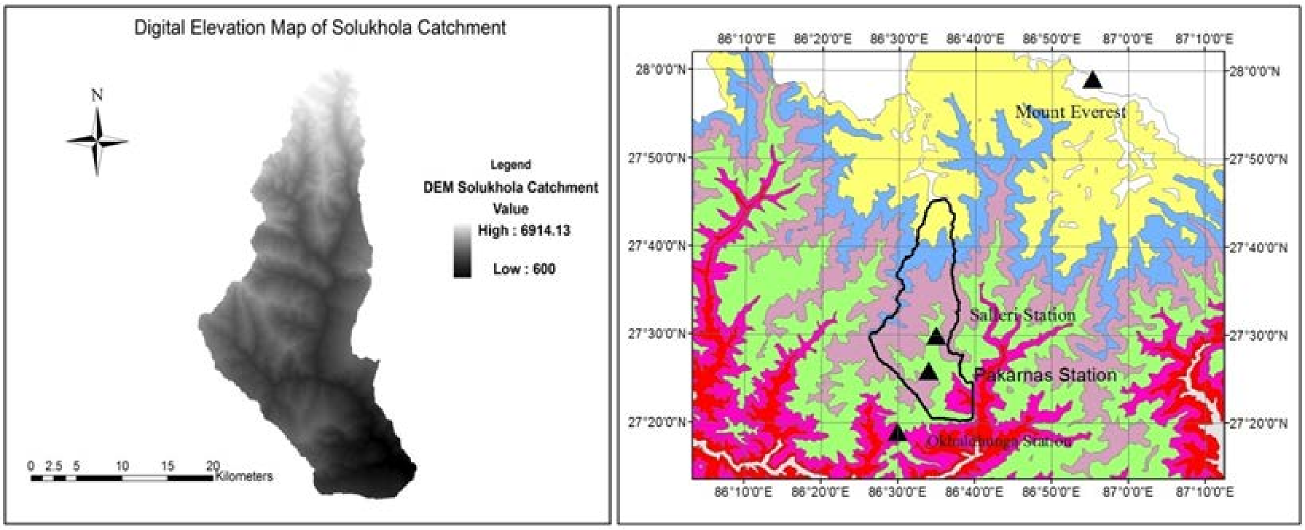

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Figure 2. A) Digital Elevation Map and B) Latitudinal and longitudinal map of Study Area

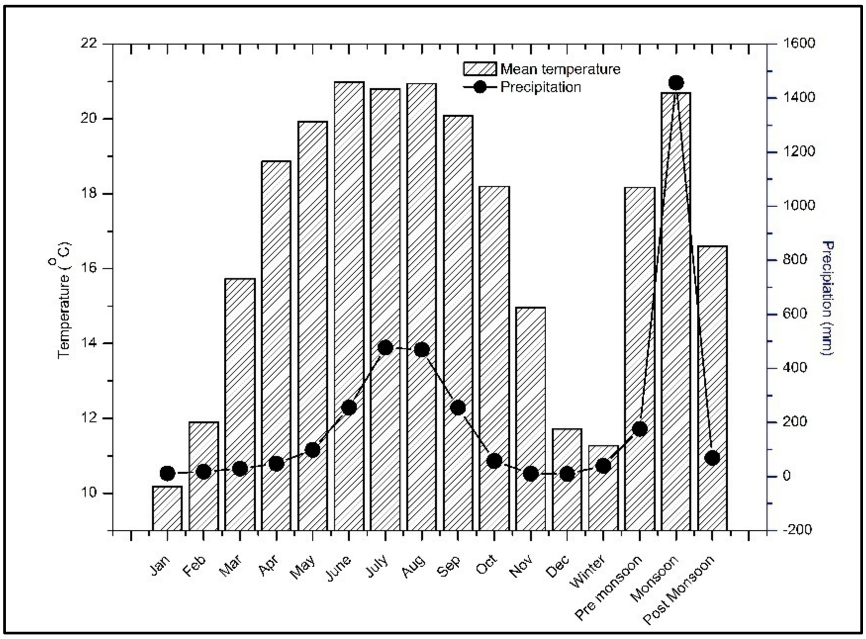

Figure 3. Climatology of the study area showing monthly temperature and precipitation

2. Materials and Methods

2.1. Study Area

The study has been conducted in Solu Khola catchment (bounded by 27°20’16.302”N to 27°45’22.861”N latitude and 86°26’18.16”E to 86°40’47.447”E longitude) of Dudhkoshi Basin. The study area is located in the Mount Everest Region in the southern slope of Nepal's Himalayan region in Solukhumbu district (Figure 1). The Solu Khola system is one of the main tributaries of the Dudhkoshi River which originates from Solukhumbu district. Basa Khola and Beni Khola flowing from north to south intersect each other at Beni, after which it is called Solu Khola and it intercepts Dudhkoshi river on the southern border of the district at Tuintar. The climatology of the study region showed distinct seasonal variation (Figure 2). Monsoon season (June, July, August, September) is the season with the highest temperature and precipitation where as winter season (December, January, and February) has the lowest temperature and precipitation. Based on the long-term average (1975-2011), the highest temperature occurs in the month of June (20.98°C) and the lowest temperature in the month of January (10.17°C). Similarly, 38 years averaged monthly precipitation shows that the highest rainfall occur in July (477mm) and lowest occur in December (9.7mm).

The total area of this catchment from the hydrological point of its origin is 520.3 km^2 whereas the lower catchment has area of 311.4 km^2 where the perception-based study was focused, due to larger inhabitation of people in the lower stretch. The highest and lowest points in the catchment are 6914 m asl and 600 m asl respectively.

2.2. Datasets

The primary data was collected through simple random sampling without replacement technique based on principle of hypothesis testing where the maximum number of sizes was covered. A total of 90 samples was taken for the household survey for 6 Village Development Committee (VDCs) namely: Salleri, Garma, Tingla, Salyan, Necha Batase and Necha Betghari VDCs.

The detail sampling procedure is as follows;

$$n = \frac{pqz_{\alpha}^{2}}{d^{2}} = \frac{0.5\times0.5\times1.64\times1.64}{0.0863\times0.0863} = 90$$

Where;

n = Size of sample

p = q = 0.5, the maximum number of size to be obtained, where there are not be any prior information about population is known and

$z_{\alpha} = 1.64$, desired degree of precision at 95% confidence interval for one tail test.

d = considerable level of margin of error to measure true population parameters.

Meteorological data from 1975-2015 for this study was collected from the Department of Hydrology and Meteorology, Government of Nepal. The nearest station i.e. Okhaldhunga station was used as source of temperature and Salleri and Pakarnas stations for precipitation. The details of station are provided in the table below (Table 1):

We applied established methods and techniques [23] for equality control and identify outliers of the temperature and precipitation data series for all stations and years.

Table 1. Location and coordinates of the stations

Station no.	Station name	Latitude (°N)	Longitude (°E)	Elevation (masl)	Temperature (°C)			Rainfall (mm)
					Tmax	Tmin	Tavg	
1206	Okhaldhunga	27°19'	86°30'	1720	21.27	12.78	17.03	-
1219	Salleri	27°30'	86°35'	2378	-	-	-	1698.23
1203	Pakarnas	27°26'	86°34'	1982	-	-	-	1810.9

Climatic trend analysis was performed from data available from stations situated within the catchment or adjacent to the Solu Khola catchment boundary. Temporal data comprising daily temperature and daily precipitation were collected. First, the data was carefully examined and the outliers were removed. Then, it was used to calculate yearly and seasonal average for trend analysis.

2.3. Methodology

Meteorological data were analyzed both through the linear trend test and Mann-Kendall test. Mann-Kendall test, a nonparametric statistical trend test is widely used for the analysis of the trend in climatologic time series. The Mann–Kendall (MK) test [24,25] is a rank-based nonparametric trend test that can handle non-normality and has high asymptotic efficiency [26]. The null hypothesis H0for this test is that there is no trend in the series whereas the alternative hypothesis is that there is a trend in the series. In comparison with other nonparametric procedures, the power of the Mann–Kendal test is robust and similar to the extent of giving indistinguishable results in practice [27]. The test is based on the calculation of Kendall's tau which is a measure of association between two samples, which is itself based on the ranks within the samples. Mann-Kendall test was used because of its advantage, applicability, and relevancy to our dataset. Software used for performing the Mann-Kendall statistical test was Addinsoft’s XLSTAT 2013. The null hypothesis was tested at 95% confidence level for both temperature and precipitation data including both annual and seasonal data of temperature and precipitation.

People's perception was analyzed in terms of the percentage of the respondents witnessing the change and has been presented in graphical form. Data were analyzed using both Statistical Package for Social Sciences (SPSS) and Microsoft Excel. The household survey and key informants interview are considered to be an effective tool for climate change impact studies and for developing adaptation strategies. The future impact can also be stimulated through the people’s perception and their coping capacity [28].

3. Results

Temperature trend, precipitation trend and the perception of the local people in terms of changes in the sectors directly and indirectly related to water were analyzed.

3.1. Trend in Meteorological Variables

The linear trend line showed that the mean temperature was increasing at the rate of 0.048°C per year and the increase was statistically significant. The linear trend is shown in Figure 4 and Mann-Kendall test result is shown in Table 2.

Seasonal mean temperature trend was also analyzed for four seasons - pre-monsoon (March to May), monsoon (June to September), post-monsoon (October and November) and winter (December to February). The linear and Mann-Kendall trend of seasonal temperature is shown in Figure 5 and Table 2 respectively.

In case of precipitation, analysis of total annual precipitation showed that there was slightly increasing trend in the total amount of annual precipitation in the study area as represented by average of nearby precipitation stations (4.75 mm per year), but the trend was not significant. The linear trend result is presented in Figure 6 whereas Mann-Kendall trend results in shown in Table 2.

Analysis of pre-monsoon precipitation depicted slightly increasing trend. Precipitation in monsoon showed slight increasing trend and the precipitation in winter showed slightly decreasing trend. Again, analysis of number of rainy days was done. Rainfall greater than 1mm in a day was considered a rainy day and extracted from daily rainfall data available from nearest precipitation stations. The analysis of number of rainy days showed the decreasing trend (Figure 7 and Table 2).

Mann-Kendall statistical trend test

The analysis of statistical significance of trends in meteorological variables (37 years of time series) showed that the trends in all the parameters of temperature except minimum temperature were statistically significant. In contrast, most of the series in precipitation (both annual and seasonal) were statistically insignificant. Mann-Kendall test and linear trend showed the similar results. Mann-Kendall trend test results are shown in Table 2.

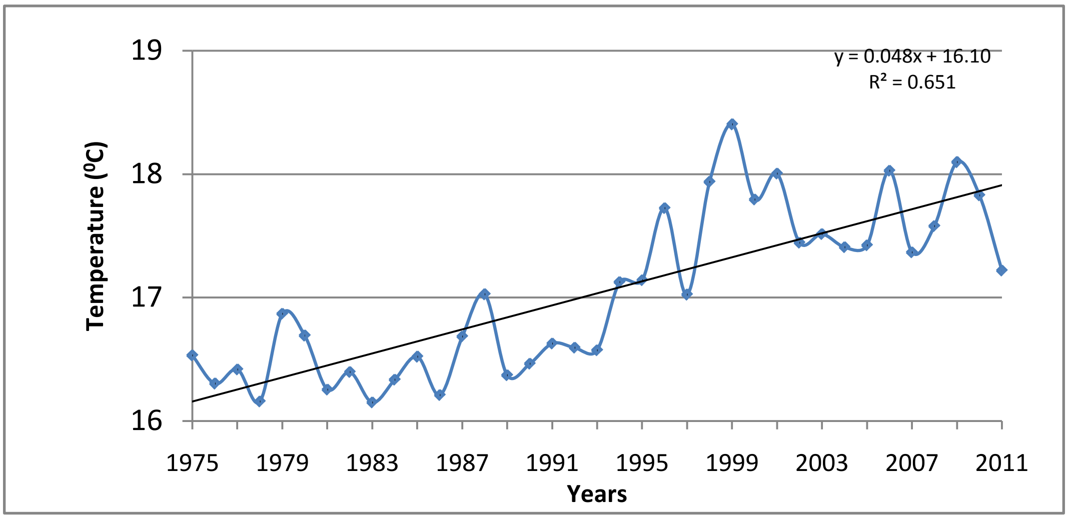

Figure 4. Mean temperature trend

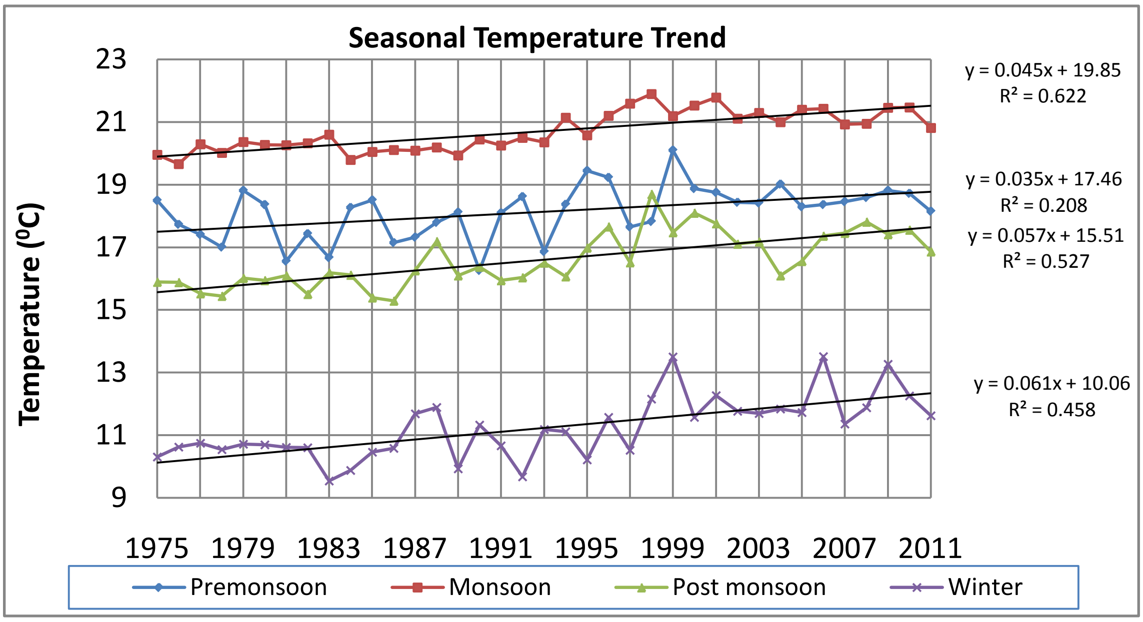

Figure 5. Seasonal temperature trend

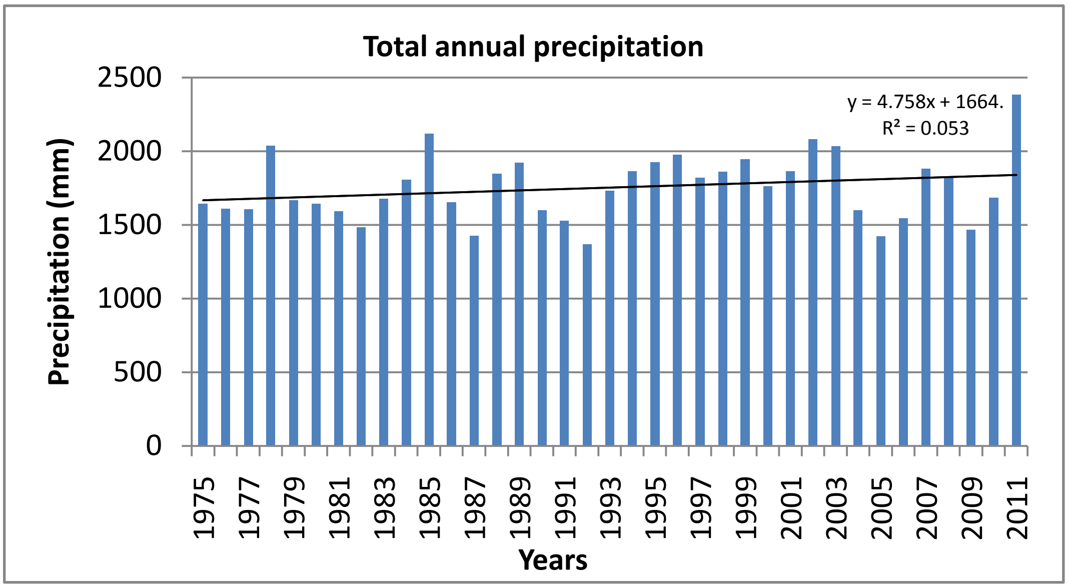

Figure 6. Trend of total annual rainfall depicted by Nearest Stations

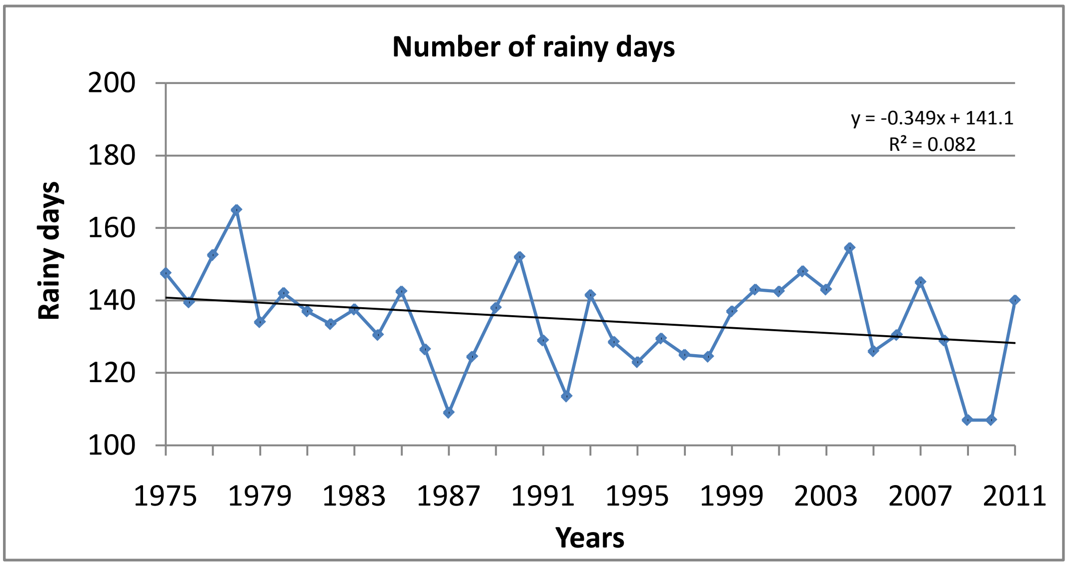

Figure 7. Trend of number of rainy days depicted by Nearest Stations

Table 2. Results of Mann-Kendall statistical trend test

SN	Station	Parameters	Linear trend line slope	Mann-Kendall test statistics				Response	Remarks
				Sen's slope	Kendall's tau	p-value	Alpha		
1	Okhaldhunga	Maximum temperature	0.099	0.1	0.616	<0.0001	0.05	Increased	Significant
2		Minimum temperature	0.000	0.003	0.098	0.403	0.05	Increased	Insignificant
3		Mean temperature	0.048	0.047	0.583	<0.0001	0.05	Increased	Significant
4		Pre-monsoon	0.035	0.033	0.306	0.007	0.05	Increased	Significant
5		Monsoon	0.045	0.043	0.550	<0.0001	0.05	Increased	Significant
6		Post-monsoon	0.057	0.053	0.559	<0.0001	0.05	Increased	Significant
7		Winter	0.061	0.051	0.461	<0.0001	0.05	Increased	Significant
8	Salleri	Total annual precipitation	5.421	5.071	0.165	0.155	0.05	Increased	Insignificant
9		Pre-monsoon	2.407	2.467	0.321	0.005	0.05	Increased	Significant
10		Monsoon	2.226	2.038	0.051	0.668	0.05	Increased	Insignificant
11		Post-monsoon	1.006	0.422	0.075	0.524	0.05	Increased	Insignificant
12		Winter	-0.357	-0.296	-0.108	0.353	0.05	Decreased	Insignificant
13		Number of rainy days	-0.177	-0.167	-0.074	0.530	0.05	Decreased	Insignificant
14	Pakarnas	Total annual precipitation	4.094	4.214	0.093	0.428	0.05	Increased	Insignificant
15		Pre-monsoon	0.818	0.83	0.099	0.398	0.05	Increased	Insignificant
16		Monsoon	3.741	2.798	0.087	0.459	0.05	Increased	Insignificant
17		Post-monsoon	-0.164	-0.164	-0.027	0.825	0.05	Decreased	Insignificant
18		Winter	-0.309	-0.463	-0.122	0.295	0.05	Decreased	Insignificant
19		Number of rainy days	-0.520	-0.551	-0.255	0.028	0.05	Decreased	Significant

3.2. People's Perception on Climate Change Impacts on Water Resources

A total of 90 samples were taken for household survey from Salleri, Garma, Tingla, Salyan, Necha Batase and Necha Betghari Village Development Committees (VDCs) completely lying in lower Solu Khola catchment. Both structured and unstructured questions were applied. Majority of respondents belonged to age group 45-65, had agriculture as their major occupation and were illiterate. The details of participants are presented in Table 3.

Among the total of 90 households surveyed, majority were female respondents (53%), illiterate (69%), and dependent on agriculture (76%).

3.3. Perception of Impact on Source of Water

As shared by the respondents, many small spring sources had dried out completely. Non-perennial sources had shifted later in time of emergence and had shown tendency to go dry earlier. 65% of the respondents witnessed the incidence of springs being dried out and 48% of them responded to significant numbers of springs that are in the phase of drying out. The incidence of the drying of sources was more prominent in lower areas of the catchment in VDCs like Salyan, Necha Batase and Necha Betghari (experienced by 84%, 92% and 77% respectively). The result is shown in Figure 8.

Table 3. Distribution of respondents in terms of gender, age group, education and occupation

Gender		Age group				Education level		Occupation			
Male	Female	<25	25-45	45-65	>65	illiterate	literate	Agriculture	Business	Service	Student
42	48	4	33	39	14	62	28	68	4	13	5

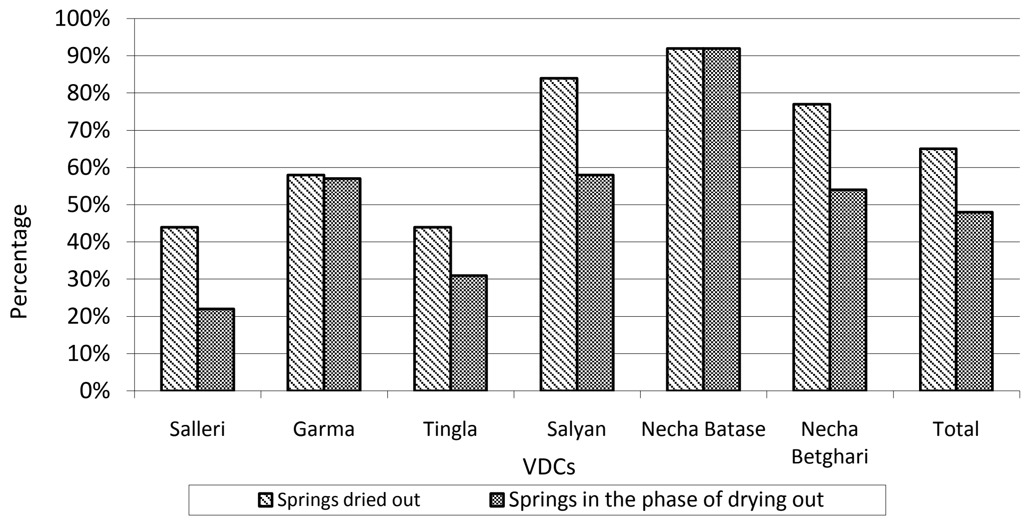

Figure 8. People's perception on changes in sources of water

3.4. Perception on Change in Snowfall Intensity, Frequency and Duration

Majority of the respondents in each VDCs (where there is snowfall or had been snowfall) said that snowfall frequency, intensity and duration had decreased. In Salleri and Garma VDCs, 87% and 72% of the respondents respectively said that amount of snowfall had decreased along with the decrease in snow retention time.

3.5. Perception on Change in Flow of Solu Khola

In response to the change in flow (discharge) of Solu Khola, 49% experienced decrease in flow while 13% did not experience any sort of change in terms of flow in the river. 4% of the respondents said that the flow had increased while 33% others were unknown about the change in flow to the river.

3.6. Perception on Change in Intensity, Frequency and Duration of Hazards

Most common types of natural hazard in the study area were landslides, windstorms, hailstones, irregularities of precipitation etc. Change in hazards' intensity, frequency and duration was mainly accessed for hydro-meteorological hazards or extreme weather events such as flash floods, drought, extreme temperature, forest fires, storms (thunderstorms, lightening), intense snowfall, mass movements etc. For the duration of natural hazards, standard classification tool was not employed, rather the perception was accessed in terms of whether the duration of occurrence of hazards (when they occurred) had increased or decreased in comparison to the previous years. 83% of the total respondents agreed that the intensity, duration and frequency of such natural hazards had increased in the recent years in comparison to the past. The result is shown in Figure 10.

3.7. Perception of People to Climate Change

Of the total household respondents surveyed, 51% of them had not even heard about the term climate change but they seemed to have experienced its effects. 27% of the respondents, including most of the educated respondents had both heard and experienced climate change while another 10% had heard it but not experienced its effects. Climate change was perceived mainly in terms of rise in mean temperature in all seasons.

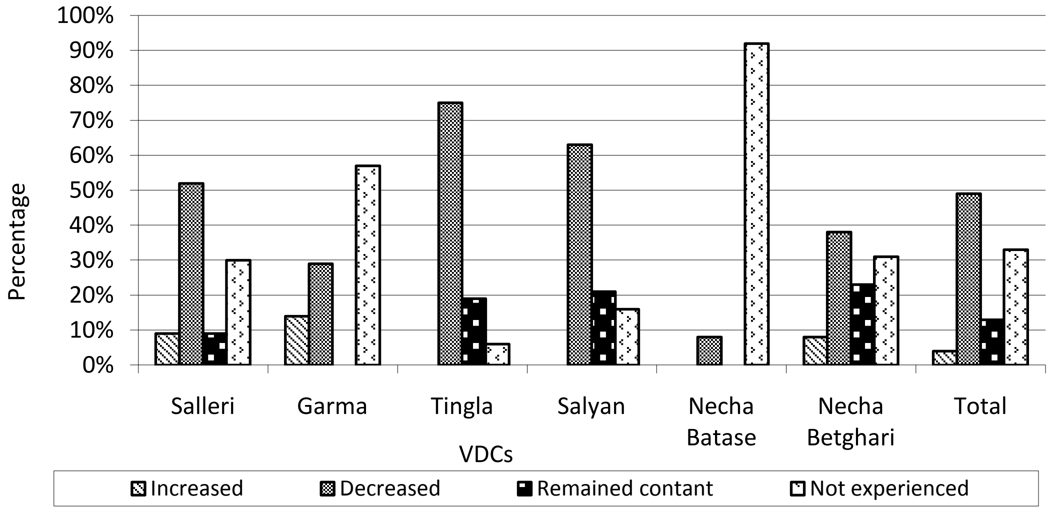

Figure 9. People's Perception on Change in flow of Solu Khola

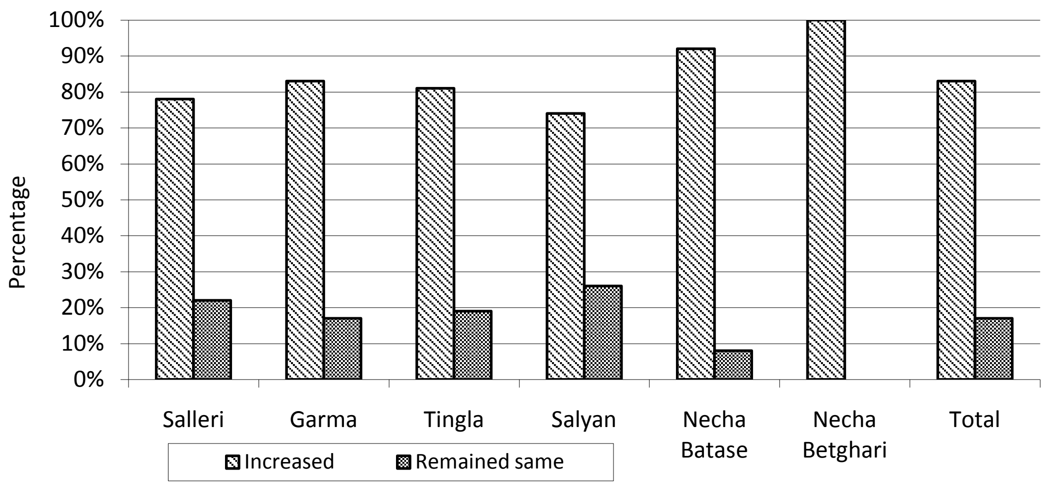

Figure 10. People's perception on change in intensity, frequency and duration of hazards

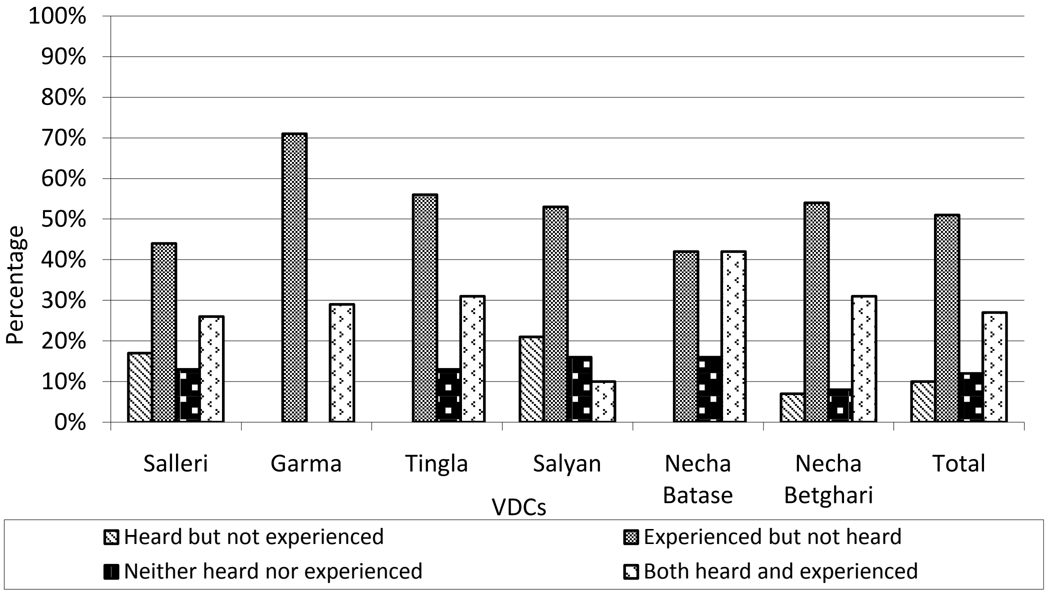

Figure 11. Perception on climate change

4. Discussion

Analysis of temperature data (1975-2011) revealed that maximum temperature and mean temperature were increasing at the rate of 0.09°C and 0.048°C per year respectively. The result is in consistence with findings by Reference [7] which showed a temperature increase of 0.06°C to 0.12°C per year in most of the Middle-mountain and Himalayan regions. Reference [29] also showed the increasing annual temperature trend by 0.055°C per year and >0.035°C per year for Middle-mountain and Himalayan regions respectively. Reference [23] observed that the magnitude of warming was higher for maximum temperatures on the basis of data from 13 mountain stations of three decades (1980-2009). Reference [18] illustrated that the average temperature increase (from 1973 to 2008) was at the rate of 0.043°C which is in consistence with people's perception in which an increase of both summer and winter temperature (agreed by 63.7% and 52.7% of people) has been witnessed. Climatic trend analysis of Nepal (1971-2014) showed that all Nepal annual temperature trend was positive (0.056°C per year) and significant [30]. Another study in the southern slope of the Everest Region between 1971 and 2009 showed the annual mean temperature in the study area was 20°C and rising at rate of 0.025°C per year, and the temperature increase was highly influenced by the maximum temperature in this region [16].

Seasonal mean temperature analysis showed that winter temperature had increased. This has some of the positive effects like moderation of winter temperature but in the long term can create natural imbalance and severely impact the water sector with increased intensity of drought and impacts on winter crops. Similarly, pre-monsoon and monsoon mean temperature showed an increasing trend at the rate of 0.035°C and 0.045°C per year respectively. The findings are consistent with seasonal and annual temperature trend results of Reference [7] where winter season showed the greatest and the pre-monsoon season showed the lowest rate of increase for mean annual temperature over the period 1997-1994. As per the climatic trend analysis of Nepal majority of the districts (90%) and all five physiographic regions show a significant positive trend for maximum temperature [30]. Study in the same basin (Koshi basin) in the southern slope of Himalayas showed an increased in temperature especially in winter and springs [19] and an increase in precipitation [31].

The current study shows that the total annual precipitation is increasing slightly. The year 1992 was noticeably the drier year which coincides with the elongated El Niño of 1992–1993 and the Mount Pinatubo eruption suggesting that Pinatubo aerosol played a major role in the drought of that particular year in Nepal [32]. Other studies also have concluded that the southern part of Mount Everest showed an abrupt decrease of rainfall occurred in early 1990s [19,33]. A similar study revealed that the annual precipitation was 1729.01 mm and the precipitation showed an increasing trend of 4.27 mm per year, but this was not statistically significant [16].

Pre-monsoon and monsoon precipitation was increasing. In contrast, winter precipitation was decreasing slightly. The seasonal precipitation trend depicted by this study is also in good agreement with the findings of the study on climate change in the Himalayas that average annual precipitation has increased by 163 mm (6.52 mm per year) during the 25 year period (1982-2006). This increase has largely resulted from an increase of 187 mm (7.48 mm per year) during the summer months (June, July and August), balanced by a decrease of 17 mm (20.68 mm per year) in winter (December, January, and February) [15]. Supporting the results of this study, an increasing pattern of rainfall from south to north was observed throughout all season in Koshi basin [32]. The number of rainy days was decreasing. Even if the number of rainy days was decreasing, the total annual precipitation was increasing. Studies have indicated that on a general level, the summer monsoon (June to August) will become more intense, but also more variable, meaning more frequent heavy precipitation events, even as the number of rainy days decreases [34]. The variability and intensity of precipitation, apart from total precipitation, will affect the stability of the landscape surface [35]. Reference [36] found that the precipitation trend was increasing in the Koshi basin (eastern Nepal), based on data from 1947 to 1993 and the results of the current study are consistent with this study. As per climatic trend analysis of Nepal, in terms of precipitation, only pre-monsoon precipitation show a negative trend in high Himalayan region. Coherent but insignificant patterns could be associated with short term variability in atmospheric phenomena. However, a number of rainy days have an increasing trend in the northwestern district[30].

According to people's perception too, it can be generally ascertained that climate change had shown its effects on various dimensions directly and indirectly related to the water sector (sources of water, snowfall intensity, frequency and duration, agricultural productivity, the intensity of hazards, etc.). But the effects were quite non-uniform in the distribution along the study area. It means that Salyan and Necha Betghari VDCs were more affected by the adversaries of climate change which are the regions already bearing water stress in terms of sufficiency of water, provision of irrigation, etc. The effect was mostly experienced in terms of drying up of spring sources and a decrease in crop yield. This evidence underline the fact that these changes could be considered as a rather factual phenomenon most probably linked to the climatic changes observed at that scale. Similar results on perception were obtained by Reference [29] on climate change study from Himalaya to Terai region in which local people, based on their past experience responded that warming days, erratic precipitation patterns, ecological variability, biological change and their adverse effects on human beings had increased. More than 50% of respondents said that warming days had been increasing, precipitation patterns had become more unpredictable, seasons had been changing, frequency of drought had increased, natural water sources had been decreasing and windstorm was getting stronger. Other studies show that the frequency and magnitude of flash floods, debris flow, and landslides have increased in countries like India, Pakistan, Afghanistan and Nepal.

Similar study but in the different physiographic setting was performed in Dhare Khola watershed of Dhading district where sixty percent of sources dried in 15 to 20 years (1990-2010) and the drying of such water sources caused problems for the availability of drinking water, irrigation water and in business too [37]. Effects of climate change on crop yields, especially decreasing crop productivity have been reported by various studies such as [38,39].

5. Conclusion

This study assess climatic changes in a small catchment lying in the southern slope of the Central Himalayas, Nepal. Through the analysis of meteorological data and perception of people, this study concludes that climatic changes are occurring and have been perceived in the study area. The changes were mainly witnessed in terms of rising temperatures. The mean temperature was increasing at the rate of 0.048°C per year whilst 78% of the respondents have experienced climate change in the study area. The results of this study can be used to better understand climatic variability with the eyes of local people residing in the community for years and understand the change in climatic characteristics in the study area. Though the research is not completely new, the perception of people towards the changes in this study area is largely unexplored. The outcomes of this study can be used to raise awareness of changes in the study area as well as aid in local decision making. However, the important effects of topography, geology, and influence of regional-scale could not be studied which was the limitation of this research.

Acknowledgments

The authors would like to acknowledge Glacier Trust for providing Field Grant, which was awarded to first author. We are thankful to Mr. Robin Garton of Glacier Trust for his words of encouragement. It is also worth appreciating WWF Nepal, Mr. Rai Bahadur Rai, Mr. Bhawani Dangol and Mr. Jagadish Parajuli of WWF for their precious guidance, generous support during field works. Sincere appreciation goes to Ms. Sabina Khanal for her support during preparation of this work. The corresponding author (BD) is thankful to Kathmandu Center for Research and Education, Chinese Academy of Sciences-Tribhuvan University, (KCRE) for the support.

Conflicts of Interests

The authors declare that there is no conflict of interests regarding this paper.

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