The Geographic Base
Vol. 7: 1-14, 2020
Doi: 10.3126/tgb.v7i0.34262
Nepal Geography Student Society, CDG, TU

Observed Climate Extreme in Nepal

Ram Prasad Awasthi[*,1] and Jeffrey S. Owen[2]
[1]Ministry of Population and Environment, Government of Nepal
[2]Department of Environment Science, Hankuk University of Foreign Studies, Korea
[*]**Corresponding E-mail:** awasthiramprasad@gmail.com

Received: 27th April, 2020 **Accepted:** 12th August, 2020

Abstract

The climate induced disasters are causing more than half of the total economic and human losses annually due to natural disasters and that hampers the socioeconomic development of the country. In recent decades, these climate extreme induced disasters are increasingly becoming more pronounced and devastating, is further known to be intensified due to anthropogenic warming. In this context, this study endeavors to address the research gap on spatial and temporal variability of temperature and precipitation extremes in Nepal. Here, a total of 26 climate extreme indices of temperature (13) and precipitation (13) as recommended by the World Meteorological Organization (WMO) were calculated using RClimDex software for 90 meteorological stations. Then the statistical significance of the long-term trend of the indices was tested using the Mann-Kendall method, and true magnitude of the trend was identified utilizing Sens' slope method for each index at each station. Overall, the hot (warm days, warm nights, summer days, tropical nights, and warm spells) and cold (cold days, cold nights, cold spells) extreme indices show significant positive and negative trends respectively. However, extreme precipitation indices also show an increasing trend, but the statistical significance and spatial coherence is low. Extreme temperatures increased more in the Mountain and Himalayan regions than the other regions. Extreme wet day precipitation events are significantly increasing in far western region, adjoining areas of mid-western and western Siwalik though Mountain regions and then again in the central and eastern Mountains and Himalayan regions.

Keywords: Climate extremes, extreme precipitation indices, temperature indices, RclimDex

Introduction

Extreme events can causes huge economic and human losses and damage along with various environmental disruptions (Alexander & Tebaldi, 2012). Climate extremes are influenced by factors such as geography (elevation), physical circumstances (proximity to water bodies) and urbanization at regional and local scales (Choi et al., 2009). Human activities have played lead role in unprecedented changing of Earth's atmosphere compositions. The potentiality of those changes to influence the Earth's climate are visible to us (IPCC, 2013). Climate data clearly shows warming and its rate has significant differences among different regions in the Earth (Bhatt and Mall, 2015). It will be hard to predict the future climate change accurately for the larger spatial scales due to the anthropogenic influences such as greenhouse gas emissions or modernization of land use pattern result in changes in climate forcing (Bhatt & Mall, 2015).

Nepal is a mountainous country, with a highly variable climate within a small area due to the complex topographical characteristics in Nepal and the extreme range in elevation. Nepal also experiences complex seasonal weather patterns which are primarily affected by the South Asian Monsoon and the Himalayas (Bhatt & Nakamura, 2005). Analysis of past climate data have shown that climate in Nepal is changing. The frequencies of extreme weather events have become more unpredicted in time and place. The data also show that the warming trend is not uniform, but varies with elevation and topography. The maximum temperature in Nepal has increased at the rate of 0.04-0.06 °C per year (NAPA, 2010). The increase in surface temperature is greater in the Himalayan and mountain regions than in the low lands (Baidya, Shrestha, & Sheikh, 2008). Animal and plant habitats are shifting with respect to elevation and changes in seasonality are occurring. Rising temperatures in northern Nepal might increase the rate of glacial melt and increase the risks from GLOFs (Glacial Lake Outburst Floods). There is evidence that glaciers are melting more rapidly and the number of newly formation glacier lakes is increasing. The threats of glacier lake outburst floods and increasing frequency of snow avalanches are becoming serious challenges in Nepal (Gautam & Dulal, 2013).

Globally, around 85% of natural disasters are related to extreme meteorological events (Obasi, 1994). In Nepal, the natural disasters related to extreme meteorological events result abundance economic, human loss and damage annually. Floods, erratic rainfall, intense rainfall, landslides, prolonged droughts, thunderstorm, hail storms, heat waves and cold spells are examples of weather and climate- induced disasters (MoHA & DPNet-Nepal, 2015) with impacts on agriculture, water resources, biodiversity and ecosystems. Shifting of the onset of the monsoon season, duration and rainfall amount, increased temperatures and extreme heat waves, frequent occurrence of winter drought and abnormal cold spells, fog events, decreased snowfall events, rapid melting of glaciers, and the increasing risk of untimely floods and glacier lake outburst floods (GLOFS) are major evidence of climate change in Nepal. The social-ecological systems in Nepal are highly exposed to climate change and sensitive to extreme events, and might differ among geographical and topographical regions. For example, some studies have found that mid-mountain areas with limited adaptive capability results in high social-ecological vulnerability (Pandey & Bardsley, 2015; Piya et al., 2016).

Previous studies have shown that the frequency of high intensity precipitation events (precipitation greater than 100mm in 24 hours) is increasing (Devkota & Bhattarai, 2015). Heavy rainfall events and subsequent flooding, drought, and prolonged dry spells impact marginalized communities and physical infrastructures. The diurnal temperature differences are most pronounced during the winter season, and least during the active period of the monsoon.

Methods and Materials

The data used in this study were weather variables such as daily maximum temperature; minimum temperature and precipitation available from the Department of Hydrology and Meteorology (DHM), Government of Nepal (GoN). The disasters data were taken from Ministry of Home Affairs, GoN. The temperature and precipitation data (1970-2015) were collected from DHM, the only legal agency for collecting and monitoring weather and climate variables in Nepal in accordance with the World Meteorological Organization (WMO) standards. 90 meteorological stations were selected in order to satisfy the regional coverage for the study (WMO, 2012). The three procedures; (i) If 5 years of random or 3 years of continuous data missing were rejected, (ii) If more than 15 days of missing values within a year was rejected and (iii) If more than 3 days of missing value in a month was rejected and monthly value was not calculated were used to handle missing data for a station (Karl et.al 1995):Stations with large number of missing values as stated in above procedures were excluded from the analysis (Devkota & Bhattarai, 2015).

This study considered the analysis extreme temperature and precipitation events using 13 temperature and 13 precipitation indices out of the total 27 extreme climate indices set by the WMO Commission for Climatology and the Research Program on Climate Variability and Predictability (CCl/CLIVAR) Expert Team for Climate Change Detection Monitoring and Indices (ETCCDMI). Those indices are computed using the values of daily temperature and daily precipitation amount (Karl, Nicholls, & Ghazi, 1999). There are temperature and precipitation indices divided into different groups based on threshold or intensity, absolute, duration and percentile. Few indices are based on fixed threshold values for particular applications (Sillmann et al., 2013). These indices are classified into four groups as fixed threshold indices (frost days (FD), summer days (SU), icing days (ID), tropical nights (TR), heavy precipitation days (Rnn)), absolute indices (highest daily maximum temperature (TXx), highest daily minimum temperature (TNx), lowest daily maximum temperature (TXn): lowest daily minimum temperature (TNn): highest 1-day precipitation (Rx1day), maximum consecutive 5-day precipitation (Rx5day), percentile (cold nights (TN10p), cold days (TX10p), warm nights (TN90p)**,** warm days (TX90p), very wet days (R95pTOT)**, e**xtremely wet-day precipitation (R99pTOT) and duration indices(warm spell duration index (WSDI), cold spell duration index (CSDI), heavy precipitation days (R10mm), very heavy precipitation days (R20mm), consecutive dry days (CDD), consecutive wet days (CWD) (Manton et al., 2001). However simple precipitation intensity index (SDII), daily temperature range (DTR)**,** wet day precipitation (PRCPTOT) does not fall on any above categories and categorized as the other indices for the study. Among these indices, the absolute indices are based on the user defined daily values of maximum temperature, minimum temperature and precipitation amount can be termed as daily threshold temperature index (DTTI) and daily threshold rainfall Index (DTRI). Those DRRI and DTRI were confirmed based on historical rainfall and temperature value (Islam et al., 2008).

Results and Discussion

General trends of temperature and precipitation

The temperature and precipitation trends were analyzed for each season. The results show that the overall precipitation and temperature are decreasing (not statistically significant) and increasing (statistically significant) in Nepal. The mean temperature has increased by 0.76^{o}C during the last 45 years, which is quite higher than the global increasing rate (Alexander, 2016). Post-monsoon and winter temperatures are increasing higher in High-mountain and Himalayan regions compared to other regions and seasons**.** Overall, the temperature anomaly shows a positive trend for Nepal.

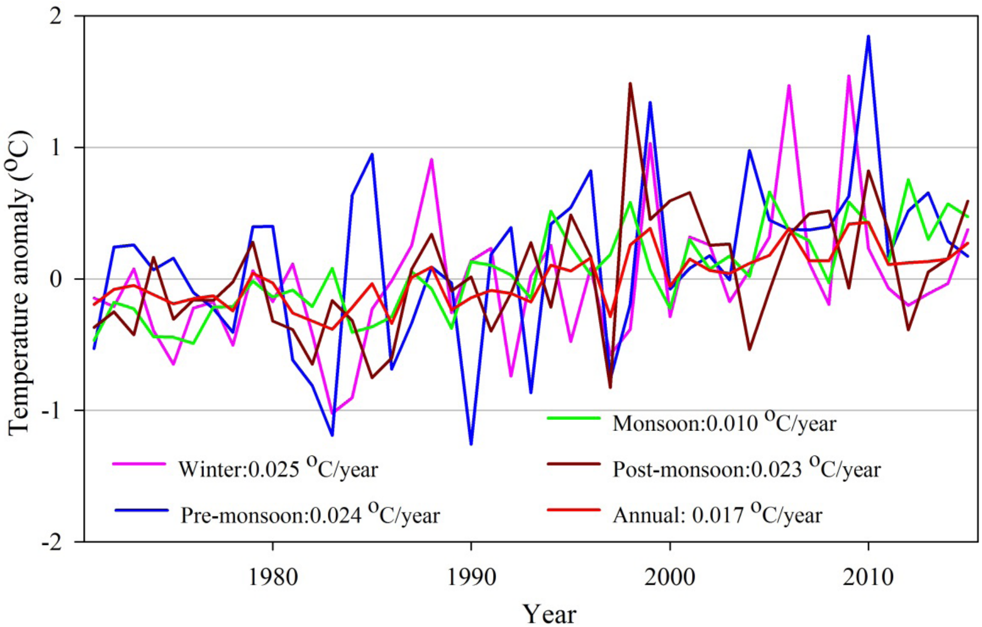

Figure 1. Temperature anomaly trend 1971-2015 for Nepal

Total precipitation has decreased in all regions and seasons expect for far western region, western parts of western region, central Tarai, high-mountain and Himalayan areas and some isolated areas of the eastern Tarai and Siwalik. Pre-monsoon precipitation shows increasing trend in the southern (low elevated) parts and decreasing trend northward (high elevated places). Monsoon precipitation is significantly increasing in far western and western regions, central and eastern Tarai, Siwalik, and Mid-mountain as well as in the central high Himalaya. Post-monsoon precipitation has a decreasing trend throughout the country, which is consistent to the finding from (Karki et al., 2017). Winter precipitation has decreasing trend in the central and eastern parts while western regions have increasing pattern.

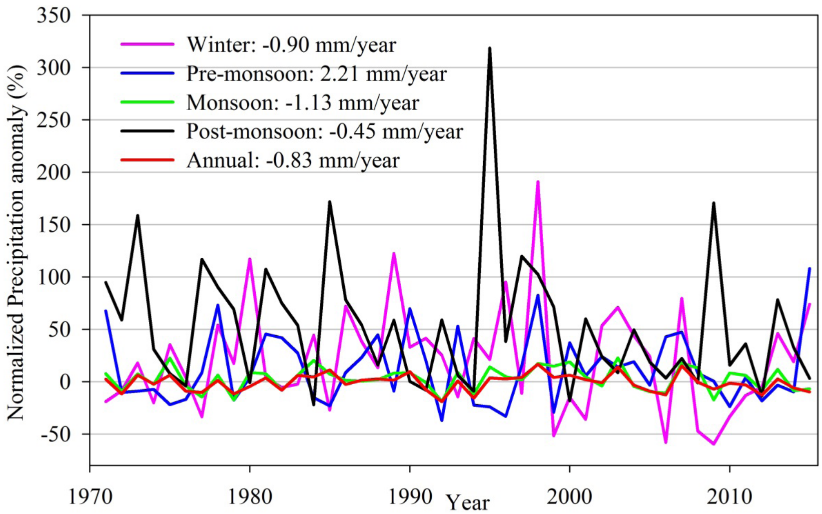

Figure 2. Precipitation anomaly trend during 1971-2015 for Nepal

Table 1. Mean temperature trend (°C/year) in physiographic regions

Seasons/ Physiographic Regions	Annual		Pre-monsoon		Monsoon		Post-monsoon	Winter	
Tarai	0.013	***	0.015	**	0.018	***	0.013**	0.001	***
Siwalik	0.025	***	0.027	***	0.027	***	0.023**	0.023	*
Mid-mountain	0.029	***	0.027	**	0.026	***	0.027***	0.034	***
High-Mountain	0.020	***	0.025	***	0.006	***	0.023 **	0.034	***
High Himalaya	0.04	*	0.04		0.00		0.03	0.04	*

Table 2. Physiographic region total precipitation trend

Seasons/ Physiographic Regions	Annual	Pre-monsoon	Monsoon	Post-monsoon	Winter
Tarai	0.458	1.331	0.385	-0.374	-0.039
Siwalik	-1.980	-0.128	-0.887	-0.491	-0.110
Mid-mountain	-1.344	0.159	-0.286*	-0.402	-0.080
High-Mountain	0.479*	0.323**	0.282*	-0.226	0.713**
High Himalaya	-0.33**	-0.92**	-0.04**	-0.45**	0.08**

*, **, *** represents significance at confidence level of 0.05, 0.1, 0.01 respectively

Extreme temperature indices

The extreme indices are varying with the altitude and topographical characteristics within the short range of distance. The annual warming trend is higher in mountain regions than the southern plain lands. But cold events are decreasing and the rate is intensifying with altitude. But the Himalayan minimum temperature and Tarai diurnal temperature are significantly decreasing. In exception to other seasons warm (cold) days are decreasing (increasing) during the monsoon season; it might be due to the occurrence of monsoonal thick clouds (Tang & Leng, 2012). Warm nights are increasing in all regions except in Mid-mountain regions. But cold days are increasing in Tarai regions during winter. Mean maximum and extreme maximum temperatures are increasing in all seasons for all regions except slight decrease in Tarai and Siwalik region due to persistent fog occurrence (Jenamani, 2007) during winter. The fog conditions favors the increase in cold waves (Dimri & Chevuturi, 2016). Maximum temperature is increasing faster in the Mountain and Himalayan regions than the lower lands, this result is consistent with (Shrestha, Wake, Mayewski, and Dibb,1 999). But the mean and extreme minimum temperature have followed slight decreasing trend for Mountain and Himalayan regions except monsoon season, which cause the increase in diurnal temperature range. The maximum temperature is increasing (0.05^{o}C/year) higher than the minimum temperature is slightly (0.003^{o}C/year) in annual basis.

The Hottest day (TXx) and night (TNn) temperature has increased in all regions during all seasons except the decrease of hottest night time temperature in high-mountain region. TXx trend is higher in the Mountain and Himalayan regions in all seasons and also greater during post-monsoon and winter season. Coldest day temperature (TXn) is slightly decreasing only in the Tarai during pre-monsoon and winter season and have significant increasing trend for remaining seasons and regions. Similarly, coldest night temperature (TNn) is decreasing only in High-mountain and Himalayan region during monsoon and post-monsoon seasons and increasing for remaining. The diurnal temperature range (DTR) has only decreasing trend for the Tarai region during pre-monsoon, post-monsoon and winter seasons. Due to large rising trend of maximum temperature and slow trend of minimum temperature DTR shows increasing trend for most of the regions and seasons.

Extreme precipitation indices

Dry spells are increasing in all the regions and more serious to mid-mountain downwards. However, the total precipitation is increasing only in the Tarai region. Wet spells are also following the same trend. Heavy and very heavy precipitation events are increasing significantly in Tarai, Siwalik and Mid-mountain regions. The 24 hours total maximum precipitation amount is increasing in Siwalik upwards during winter and pre-monsoon and is decreasing during monsoon and post-monsoon. The very heavy and extremely heavy precipitation amount are increasing downward to the Mid-mountain and upward to the Siwalik. The relation between the extreme indices and elevation is analyzed by Pearson correlation method significant at 0.05 level (Gevorgyan, 2014). There is significant proportional relationship for mean temperature, diurnal temperature range, maximum temperature, summer days and consecutive wet days with altitude. But minimum temperature has significant negative relation with altitude. Similarly, cold (warm) night and day have negative (positive) relation with altitude. This implies that higher elevation regions are warming at higher rate than the lower elevations. Heavy precipitation events are positively correlated with the elevations but the total precipitation has weakest negative relation.

Based on the temperature record from 1970-2015, the year 2010 has observed as the warmest year followed by the years 2009, 1999, 2006, 2015. The data showed that the last decades are hottest than the previous decades. The most of the years before the 1995s have experienced colder than the later time period (Table. 3).

Table 3. Country mean temperature change (^{o}C) rank

Year	2010	2009	1999	2006	2015	1998	2005	1996	2001	2014	2008	2013	2007	2012	2004	1994	2011	1988
Index	0.43	0.41	0.38	0.37	0.26	0.25	0.17	0.16	0.15	0.14	0.13	0.13	0.13	0.11	0.11	0.1	0.1	0.09
Year	2002	1995	2003	1987	1985	2000	1991	1992	1990	1993	1984	1989	1981	1997	1982	1986	1983	
Index	0.06	0.06	0.03	0.01	-0.04	-0.1	-0.1	-0.1	-0.2	-0.2	-0.2	-0.2	-0.3	-0.3	-0.3	-0.3	-0.4	

Similarly, the most of the year in the last two decades are recorded as the precipitation deficient and some years as precipitation excess year in comparison to the previous years. The year 1992, 1994, 2005, 2006, 2012 and 2015 have deficient rainfall and 1992, 1998, 1990, 2003, 2000, 2007, and 2003 have the excess rainfall. Thus, the rainfall deficient years experienced meteorological drought and excess rainfall year experienced floods, landslides and other effects in the ecosystem and society. Both the rainfall excess and deficient rainfall has various negative socio-economic and environmental impacts. Especially, the Tarai, Siwalik, Mid-mountain and Himalayan regions are most susceptible to drought. The drought happened in year 1992, 1994, 1972, 2006, 2012, 1979, and 2015 were most serous events in terms of its effect and damages to the people, livestock and crops.

Table 4. Country normalized precipitation anomaly (%) rank

Year	1998	2007	2003	1985	1990	2000	1983	1984	1997	1981	1999	1995	1988	1996	2013	2001	1987	1989
Index	16.7	15.4	13.6	11.1	9.39	6.14	5.7	4.52	4	3.97	3.94	3.4	2.75	2.65	2.46	1.91	1.82	1.62
Year	1993	2008	2002	2010	1986	2004	2011	2014	2009	1991	1982	2005	2015	2006	2012	1994	1992	
Index	0.69	-0.5	-1.3	-1.3	-3	-3.3	-3.3	-5.9	-7.3	-7.5	-7.9	-9	-9.8	-13	-13	-16	-19	

The data shows drought events are reoccurring in 2-3 years period. Most of the drought occurring in El Nino years; negative (positive) southern oscillation index have deficient (excess) rainfall events i.e. droughts are significantly related to El Nino events (Shrestha, 2000; Sigdel and Ikeda, 2011). The drought is occurring highly in western region than the eastern region (Shrestha and Kostaschuk, 2005; Wang et al., 2013).

Table 5. Country standard precipitation index rank

Year	1998	2003	2007	1990	1985	2000	1983	1995	1984	1997	1988	1999	1996	1989	2013	1981	2008	2001
Index	1.12	0.94	0.94	0.82	0.79	0.56	0.54	0.53	0.48	0.47	0.41	0.41	0.38	0.36	0.36	0.31	0.27	0.26
Year	1987	1993	2002	2010	1986	2011	2004	2014	1991	2009	1982	2005	2015	2012	2006	1994	1992	
Index	0.25	0.25	0.25	0.21	0.09	0.02	-0.04	-0.1	-0.1	-0.2	-0.2	-0.3	-0.3	-0.5	-0.5	-0.6	-0.9	

Consistent with the temperature, the heavy precipitation events, warm days and nights have gradually increased after 1985. This time also follows the decreasing trend for the cold night and days. Increase of warm events together with the consecutive dry events results the wild fire as disaster mainly during the pre-monsoon season. Nearly 78% of households are agro-base and houses made of stone and wood are more susceptible for catching fire during the dry and hot weather conditions in the months of April, May and June.

It shows that the more than 85% of disasters are related to climate extreme (heat waves, cold waves, thunderstorms, hailstorms, windstorms, snowstorms, drought, and heavy rainfall) and hydrological (floods, GLOFs, avalanches, debris flows). Other 25% related to the geophysical (earthquakes, landslides) and forest fires. The combined annual loss from the climate and hydrological disasters varies from 60% to 80% of total loss due to natural disaster. The human loss from the hydro-meteorological disaster is increasing rapidly in recent decades it has been varying between 70% to 90% during last six-year period except the year of devastating earthquake occurred in 2015. The cold wave, heat wave, windstorm, hailstorm, thunderstorm and flood are affecting life every year in Nepal.

Ever recorded extreme events

The highest rainfall of 456.8mm occurred in 2003 measured at Hetauda station, the central Tarai part of Nepal. The total frequency of occurrence of extreme heavy precipitation events of more than 150 mm amount per day during 1971-2015 is 1023. Out of those 60% and 40% had occurred after 1990s and 2000s. Similarly, the rainfall events with greater than 200 mm/day are recorded in 411 times in Nepal. Most of the extreme precipitation occurred in Tarai and Siwalik (up to the foothills of Mountains) causing devastating floods, landslide and serious environmental disruptions. Extreme rainfall events observed more in the western part of the country, be the most susceptible to extreme rainfall. The daily events greater than 400 mm were recorded in Hetauda (456.8mm in 2003.7.31 and 453.2 in 1990.8.27), Karmaiya (432mm in 2004.7.10), Rampur (405.4mm in 2006.8.31), Malepatan (445.7 mm in 2007.6.13) and Surkhet (423.1mm in 2014.8.15). However recent data at Hetauda overcomes the past records rainfall amount with new record of 516.2 on 13 August 2017 at Hetauda.

Conclusion

The study found increasing trends in warm spell duration and warm day temperature during the summer season. Summer favors heat wave conditions in the Tarai and Siwalik regions. Warm spells events are increasing in higher rate from the Tarai upward to the High-mountain regions. Cold spell is decreasing mostly in the valley area like Kathmandu and Karnali, Chisapani. In same time and increase in cold spell duration and decrease in coldest day/night temperature resulting prolonged cold waves in the Tarai and southern parts of Siwalik. Mountain regions are experiencing much colder night time temperatures. Himalayan region is getting warmer in all seasons. Cold days are increasing in the Tarai and high-Himalayan regions during winter and summer respectively. Maximum temperature and minimum temperature are decreasing in the Tarai and high-Himalaya during winter and summer. Extreme temperatures increased more in the Mountain and Himalayan regions than the other regions. While the mean maximum temperature is increasing in all regions and seasons but the mean minimum temperature has slightly decreasing trend especially in high-mountain regions. The diurnal temperature range is increasing in all regions and seasons except in Tarai regions.

The very heavy and extremely heavy precipitation amounts are increasing through Mid-mountain down to the Tarai and Siwalik upward to the high-Himalayan region respectively. Dry spells and wet spells are becoming clearest indicators for abnormal climate conditions in Nepal. High intensity precipitation is increasing in Mid-mountain, Siwalik and Tarai regions, while decreasing in high-mountain and Himalayan regions. 10mm, 50mm and 100mm rainfall days are increasing annually. 1-day and 5-day extreme precipitation amount is increasing in Tarai, mid-mountain and Himalayan regions. But the 5-day total extreme precipitation amount is increasing throughout the country.

The analysis presented here confirms that extreme temperature and precipitation amounts are breaking the historical records in recent decades. The frequency and intensity of the extreme temperature and precipitation events are increasing significantly impacting the life and nature seriously in all regions and seasons. The summer and winter season are becoming more susceptible to climate extreme and resulting disasters. Thus, the continuation of warming proofs the global warming agenda in Nepal. The increasing heavy precipitation duration, severe cold and hot in winter and summer, untimely torrential rain and persistent dry spells are the main significant observed climate extremes in Nepal. The warming and heavy precipitation magnitudes are intensifying with altitude. It's strongly concluded that warming is significantly amplifying with altitude in all regions.

In future, reanalysis of additional climate data and the use of high-resolution grid should be used to compare with the results of this study and to develop some future projections in the climate indices. The present analysis will be beneficial for planning and implementing national policies related to climate change and climate change adaptation.

References

Alexander, L., & Tebaldi, C. (2012). Chapter 10 - Climate and weather extremes: Observations, modelling, and projections BT - The future of the world's climate (Second Edition). Elsevier, Boston, 253–288. https://doi.org/https://doi.org/10.1016/B978-0-12-386917-3.00010-5

Alexander, L. V. (2016). Global observed long-term changes in temperature and precipitation extremes: A review of progress and limitations in IPCC assessments and beyond. *Weather Clim. Extrem*. 11: 4–16. https://doi.org/10.1016/J.WACE.2015.10.007

Baidya, S. K., Shrestha, M. L., Sheikh, M. M. (2008). Trends in daily climatic extremes of temperature and precipitation in Nepal. *J. Hydrol. Meteorol.* 5(1): 38–50.

Bhatt, D., Mall, R.K. (2015). Surface water resources, climate change and simulation modeling. *Aquat. Procedia* 4: 730–738. https://doi.org/10.1016/J.AQPRO.2015.02.094

Choi, G., Collins, D., Ren, G., Trewin, B., Baldi, M., Fukuda, Y., Afzaal, M., Pianmana, T., Gomboluudev, P., Huong, P.T.T., Lias, N., Kwon, W.-T., Boo, K.-O., Cha, Y.-M., Zhou, Y. (2009). Changes in means and extreme events of temperature and precipitation in the Asia-Pacific Network region, 1955-2007. *Int. J. Climatol.* 29: 1906–1925. https://doi.org/10.1002/joc.1979

Devkota, R.P., & Bhattarai, U. (2015). Assessment of climate change impact on floods from a techno social perspective. *J Flood Risk Manag*. doi:10.1111/jfr3.12192

DHM. (2015). *Study of climate and climatic variation over Nepal*, Kathmandu: Department of Hydrology and Meteorology, Government of Nepal.

Dimri, A.P., & Chevuturi, A. (2016). *Western disturbances – impacts and climate change BT - Western Disturbances - An Indian Meteorological Perspective, in: Dimri, A.P., Chevuturi, A. (Eds.)*, . Springer International Publishing.

Gautam, D. K., & Dulal, K. N. (2013). Determination of threshold Runoff for flood early warning in Nepalese rivers. *IDRiM J* 3:126–136

Gevorgyan, A. (2014). Surface and tropospheric temperature trends in Armenia. *Int. J. Climatol*. 34: 3559–3573. https://doi.org/10.1002/joc.3928

IPCC. (2013). *Climate change 2013: The physical science basis contribution of working group i to the fifth assessment report of the intergovernmental panel on climate change.* [In: Stocker T.F, Qin D, Plattner G.K, Tignor M.M, Allen S.K, Boschung J, Nauels A.

Islam M. N., Ferdousi, M. A., and Abdullah, S. M. A. (2008). *Understanding the rainfall climatology and detection of extreme weather events in SAARC region: Part I-Bangladesh*, SMRC No. 21, 01-35.

Jenamani, R.K. (2007). Alarming rise in fog and pollution causing a fall in maximum temperature over Delhi. *Curr. Sci*. 93: 314–322.

Karki, R., Hasson, U.S., Schickhoff, U., Scholten, T. & Böhner, J. (2017). Rising precipitation extremes across Nepal. *Clim.* . https://doi.org/10.3390/cli5010004

Karl, T.R., Nicholls, N. & Ghazi, A. (1999). C*LIVAR/GCOS/WMO workshop on indices and indicators for climate extremes workshop summary bt - weather and climate extremes: changes, variations and a perspective from the insurance industry,* in: Karl, T.R., Nicholls, N., Ghazi, A. (Eds.), . Springer Netherlands, Dordrecht, pp. 3–7. https://doi.org/10.1007/978-94-015-9265-9_2

Manton, M.J., Della, M., Haylock, M.R., Hennessy, K.J., Nicholls, N., Chambers, L.E., Collins, D.A., Daw, G., Finet, A., Gunawan, D., Inape, K., Isobe, H., Kestin, T.S., Lefale, P., Leyu, C.H., Lwin, T., Maitrepierre, L., Ouprasitwong, N., Page, C.M., Pahalad, J., Plummer, N., Salinger, M.J., Suppiah, R., Tran, V.L., Trewin, B., Tibig, I., Yee, D. (2001). Trends in extreme daily rainfall and temperature in Southeast Asia and the South Pacific: 1961-1998. *Int. J. Climatol*. 21: 269–284. *https://doi.org/10.1002/joc.610*

Obasi, G.O.P. (1994). WMO's role in the international decade for natural disaster reduction. *Bull. Am. Meteorol. Soc.* 75: 1655–1661. https://doi.org/10.1175/1520-0477(1994)075<1655:WRITID>2.0.CO;2

Pandey, R., & Bardsley, D.K. (2015). Social-ecological vulnerability to climate change in the Nepali Himalaya. *Appl. Geogr.* 64: 74–86. http://doi.org/10.1016/j.apgeog.2015.09.008

Peterson, T.C., Easterling, D.R., Karl, T.R., Groisman, P., Nicholls, N., Plummer, N., Torok, S., Auer, I., Boehm, R., Gullett, D., Vincent, L., Heino, R., Tuomenvirta, H., Mestre, O., Szentimrey, T., Salinger, J., Førland, E.J., Hanssen-Bauer, I., Alexandersson, H., Jones, P. & Parker, D. (1998). Homogeneity adjustments of in situ atmospheric climate data: a review. *Int. J. Climatol.* 18: 1493–1517. https://doi.org/10.1002/(SICI)1097-0088(19981115)18:13<1493::AID-OC329>3.0.CO;2-T

Piya, L., Joshi, N.P., & Maharjan, K.L. (2016). vulnerability of chepang households to climate change and extremes in the Mid-Hills of Nepal. *Climate Change* 135: 521–537. *https://doi.org/10.1007/s10584-015-1572-2*

Shrestha, A., Kostaschuk, R. (2005). El Niño/Southern Oscillation (ENSO)-related variablity in mean-monthly streamflow in Nepal. *J. Hydrol*. 308, 33–49. *https://doi.org/https://doi.org/10.1016/j.jhydrol.2004.10.020*

Shrestha, A.B., Wake, C.P., Mayewski, P.A., Dibb, J.E. (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. https://doi.org/10.1175/1520-0442(1999)012<2775:MTTITH>2.0.CO;2

Shrestha, M.L. (2000). Interannual variation of summer monsoon rainfall over Nepal and its relation to Southern Oscillation Index. *Meteorol. Atmos. Phys.* 75, 21–28. *https://doi.org/10.1007/s007030070012*

Sigdel, M., & Ikeda, M. (2011). Spatial and temporal analysis of drought in Nepal using standardized precipitation index and its relationship with climate indices. *J. Hydrol. Meteorol.* 7: 59–74. *https://doi.org/10.3126/jhm.v7i1.5617*

Sillmann, J., Kharin, V. V., Zhang, X., Zwiers, F.W. & Bronaugh, D. (2013). Climate extremes indices in the CMIP5 multimodel ensemble: Part 1. Model evaluation in the present climate. *J. Geophys. Res. Atmos.* 118: 1716–1733. *https://doi.org/10.1002/jgrd.50203*

Tang, C. Y., & Leng, C. (2012). Penalized empirical likelihood and growing dimensional general estimating equations. *Biometrika (Biometrika*). DOI: 10.2307/41720724

Vincent, L.A., Peterson, T.C., Barros, V.R., Marino, M.B., Rusticucci, M., Carrasco, G., Ramirez, E., Alves, L.M., Ambrizzi, T., Berlato, M.A., Grimm, A.M., Marengo, J.A., Molion, L., Moncunill, D.F., Rebello, E., Anunciação, Y.M.T., Quintana, J., Santos, J.L., Baez, J., Coronel, G., Garcia, J., Trebejo, I., Bidegain, M., Haylock, M.R. & Karoly, D. (2005). Observed trends in indices of daily temperature extremes in South America 1960–2000. *J. Clim.* 18: 5011–5023. *https://doi.org/10.1175/JCLI3589.1*

Wang, S.Y., Yoon, J.H., Gillies, R.R., & Cho, C. (2013). What caused the winter drought in Western Nepal during recent years? *J. Clim.* 26: 8241–8256. *https://doi.org/10.1175/JCLI-D-12-00800.1*

WMO. (2012). *National climate monitoring products.* World Meteorological Organization (WMO), Geneva.