P: ISSN No. 2231-0045 RNI No. UPBIL/2012/55438 VOL.-6, ISSUE-4, May- Supplementary Issue - 2018

E: ISSN No. 2349-9435 Periodic Research

Evaluation of Long Term Precipitation Trends in Eastern Middle Himalayas: A Study of Darjeeling-India (1901-2000)

Shafi Bhat
Senior Assistant Professor,
Deptt. of Geography and Regional Development,
University of Kashmir,
Srinagar (J&K)

Javeed Ahmad Rather
Senior Assistant Professor,
Deptt.of Geography and Regional Development,
University of Kashmir,
Srinagar (J&K)

Abstract

Climate change caused by anthropogenic activities is a burning problem faced by mankind across the globe. It has got multifaceted implications as revealed by contemporary research findings at global, regional and local levels. Studies carried out in Indian context also testify the prevalence of a strong warming trend in the mean maximum temperature and a modest increasing trend in the mean minimum temperature. The analysis of meteorological data reveals that, precipitation has remained fairly stable in the mainland India with marginally positive bias during the last hundred years. However it has also been observed, that Himalayan region has witnessed drastic decline in rainfall from 1901-2000. The present study aims to ascertain the magnitude of temporal variability in precipitation in the Darjeeling Region of West Bengal, India during the 20th century. The study reveals that Darjeeling, a high rainfall zone, with long-term average annual rainfall of 2800 mm has witnessed a drastic decline of 470 mm in average annual rainfall, which translates into a decrease of 16 % on annual basis during the study period. It has also been found that substantial decrease in precipitation is also accompanied by the abnormal increase in mean maximum temperature in Darjeeling, which has increased by 2.5^{o} C during the above mentioned period. Furthermore Mann-Kendall Test confirms the prevalence of a statistically significant decreasing trend in precipitation and a statistically significant increasing trend in mean maximum temperature with 90% confidence level. The drastic decline of rainfall and steep increase in mean maximum temperature will be having adverse ecological implications, as it will negatively impact the water resources by inducing glacial recession in the area. It has the potential to affect negatively the agriculture, ecology, livelihood patterns and pastoral communities and can also aggravate the hydro-meteorological hazard scenario in the region. The present study provides insights which can be used by policy makers, planners and environmentalists to devise effective strategies to combat the fallout of the climate change in the sensitive Middle Himalayan Region.

Keywords: Meteorological Data, Temporal Variability, Mann-Kendall Test, Warming Trend, Precipitation Regime, Glacial Recession, Hydro-Meteorological Hazards.

Introduction

Mountains are widely recognized as areas containing highly diverse and rich ecosystems, and thus, they are key components of the Biosphere. At the same time, mountains contain ecosystems that are quite sensitive and highly vulnerable to natural disasters and ecological changes, be it through the occurrence of rapid mass-movements, such as landslides, or land degradation due to anthropogenic activities, with all the attendant socio-economic implications (Messerli and Ives, 1997). The Himalayas, also regarded as the third pole, since they contain the third largest body of snow on the earth after the Antarctic and Arctic. Almost 9% of the Himalaya is occupied by glaciers, and about 30-40% additional area is covered with snow (Navdanya, 2009). They supports half of humanity by feeding the mighty rivers of Asia and are the abode of highly fragile and sensitive ecosystems which provide insights about the impact of global warming and other human-induced ecological imbalances. Various studies carried out by researchers on Himalayas from India, Bhutan, Nepal, Pakistan and China confirms the Prevalence of a warming trend in temperature.

The study carried out by Dash et al. (2007) reveals a rise of 1°C in

Mean maximum temperature from 1901-2003 over the whole northeast India. Similarly Immerzeel (2008) confirmed a basin-wide warming trend similar to global average temperature (0.6 °C/100 year) in the eastern Indian Himalayas and Tibetan Plateau using 1901-2002 gridded dataset. Shrestha et al. (1999) in a study on the Nepalese Himalaya also saw a warming trend in the last century and reported a trend varying between 0.4 and 0.9 °C in the mean annual maximum temperature across different ecological belts of Nepal. Tse-ring et al., 2010 in their study, noticed that the average temperature in the Himalayas in Bhutan region increased by 0.5 °C in the non-monsoon season from 1985-2002. In another study carried out by Xu, et al., (2008) on the Tibetan Plateau noticed that Precipitation has increased in most of the eastern and central regions but decreased in the western region during 1961-2001.

The present study aims to ascertain the temporal variability in precipitation in the Darjeeling Region of West Bengal, India during the 20th century. Darjeeling is located at 27^o 3' N & 88^o 16' E longitudes. Darjeeling is the main town of the Saddar subdivision of West Bengal and is located at an elevation of 6,700 ft (2,000 m) in the Darjeeling Himalayan hill region on the Darjeeling-Jalapahar range. The range is Y-shaped with the base resting at Katapahar and two arms diverging north of the Observatory Hill. The hills are nestled within higher peaks and the snow-clad Himalayan ranges. World's third-highest peak, Kanchenjunga, 8,598 m high, is the most prominent mountain visible (Kennedy Dane 1996). Darjeeling has a temperate climate with strong Monsoonal influence. It experiences wet summers and is categorized as Cwb as per the Koeppens climatic classification. The average mean maximum and mean minimum temperature at Darjeeling is 14.9 °C and 8.9 °C respectively. Average annual long-term precipitation at Darjeeling is 2800mm. Spring, Summer, Monsoon, Post-Monsoon and Winter are the five distinct seasons recognized in Darjeeling (Sarkar, S.1999).

Data Base and Methodology

The present study is based on the secondary sources of data pertaining to various climatic variables (precipitation and temperature) recorded by Indian Meteorological Station, Darjeeling, West Bengal, India. Furthermore, data has also been obtained from Indian Meteorological Centre Research, Pune. For the analyses of variables various parametric and non parametric tests such as Mann Kendall Test, students T-Test have been used. Some of the important statistical techniques, such as, Time Series Analysis and linear regression have also been used to draw inferences and conclusions.

Review of Literature

The Himalaya "The Mountain of snow" has also been called the third pole, since it is the third largest body of snow on our planet after the Antarctic and Arctic. Almost 9.04% of the Himalaya is covered with glaciers; with 30-40% additional area being covered with snow (Navdanya, 2009). According to the Intergovernmental Panel on Climate Change (IPCC TAR-2001), "glaciers in the Himalayas are receding faster than in any other part of the world and if the present rate continues, the likelihood of them disappearing by the year 2035 and perhaps sooner is very high; if the earth keeps getting warmer at the current rate". According to the IPCC report the total area of glaciers in the Himalaya will shrink to 38,000 square miles by 2035.The lives of billions are at stake.

With the largest snow and ice cover in the world outside the polar regions, the Himalayan region is one of the most important mountain systems in the world and is referred to as the "third pole" (Schild, 2008). Himalayas directly or indirectly affect lives and livelihood of over 300 million people (Schild, 2008). The fragile landscapes of the Himalayan region are highly susceptible to natural hazards, leading to ongoing concern about current and future climate change impacts in the region (Cruz et al., 2007). Climate change concerns in the Himalayas are multifaceted encompassing floods, droughts, landslides, human health, biodiversity, endangered species, agriculture livelihood, and food security (Barnett, Adam, and Lettenmaier, 2005).

Climate change can influence the socio-economic setting in the Himalaya in a number of ways. It can influence the economy (e.g. agriculture, livestock, forestry, tourism, fishery, etc.) as well as human health. Specific knowledge and data on human wellbeing in the Himalaya is limited, but it is clear that the effects of Climate Change will be felt by people in their livelihoods, health, and natural resource security, among other things (Sharma et al., 2009).

Some of the documented impacts on mountain agriculture that are linked with Climate Change in the Himalayan region are: (i) Reduced availability of water for irrigation; (ii) Extreme drought events and shifts in the rainfall regime resulting into failure of crop germination and fruit set; (iii) Invasion of weeds in the croplands and those are regularly weeded out by the farmers; (iv) Increased frequency of insect-pest attacks; (v) Decline in crop yield (Negi & Palni, 2010).

Temperature data in the Himalayas overwhelmingly show a warming trend, albeit at different rates in different periods depending on the regions and seasons. In a very recent regional study using Climate Research Unit's reconstructed temperature dataset, Diodato, Bellocchi, Tartari,(2011) found that in the last few decades, the Himalayan and Tibetan Plateau region have warmed at a rate higher than that in the last century. Dash et al., (2007), reported that the western Indian Himalayas saw a 0.9 °C rise over 102 years (1901-2003). They report that much of this observed trend is related to increases after 1972. Using winter (Dec-Feb) monthly temperature data from 1975-2006, Dimri and Dash (2011) also found a warming trend over the western Indian Himalayas, (1.1-2.5 °C) with the greatest observed increase in (T max). Shafi, et.al. (2015) in their study on Kashmir Valley analysed core-winter temperatures and found aggressive warming and decline in precipitation in the region which was having adverse implications on the water resources in the region

The Nepalese Himalaya also saw a warming trend in the last century. Shrestha et al., (1999) reports a trend varying between 0.4 TO 0.9 °C in the mean annual maximum temperature across different ecological belts of Nepal, with the high Trans-Himalayan region showing the highest and the Terai (lowland region) showing the lowest. Yang et.al.,(2006) discovered that the Everest (Qomolangma) region in China also exhibits warming at an average rate of 0.234°C/decade in Tav from 1971-2004. Higher warming rates of 0.28°C/decade for annual average temperature are noted in the Chinese side of Brahmaputra basin during 1961-2005 (You et al., 2007).

Bhutiyani, Kale, and Pawar, (2007) in their study over the Northwest Indian Himalayan region, found 1.6 °C warming (0.16° C /decade) in the last century. Singh et al., (2008) observed increasing trends in (Tmax) and seasonal average of daily maximum temperature for all seasons except Monsoon over the lower Indus basin in the Northwest Indian Himalaya. Bajracharya and Mool (2010) have shown that several glaciers in Dudh Koshi basin in Nepal retreated in both 1976-2000 and 2000-2007, while a few glaciers show stability. Temporal variability is observed in the Gangotri Glacier, a well-monitored Indian glacier, which showed no retreat during 2006-2010 (Kargel et al., 2011)

Results and Discussion

An in-depth analysis of meteorological data reveals that Darjeeling is greatly affected by the climatic variability during the course of 20th century. Mann Kendall Test Confirms a Statistically significant increasing trend in the mean maximum temperature with 90% confidence level. It also confirms a statistically significant declining trend in the precipitation with 90% confidence level from year 1901-2000 which is evident from (table 1.1). Linear regression as well as Students T Test also confirms the increasing trend in mean maximum temperature and declining trend in the precipitation at Darjeeling with the 90 % confidence level. However Mann Kendall Test and Students T Test indicate that no statistically significant trend prevailed in the mean minimum temperature at Darjeeling during the course of 20th century.

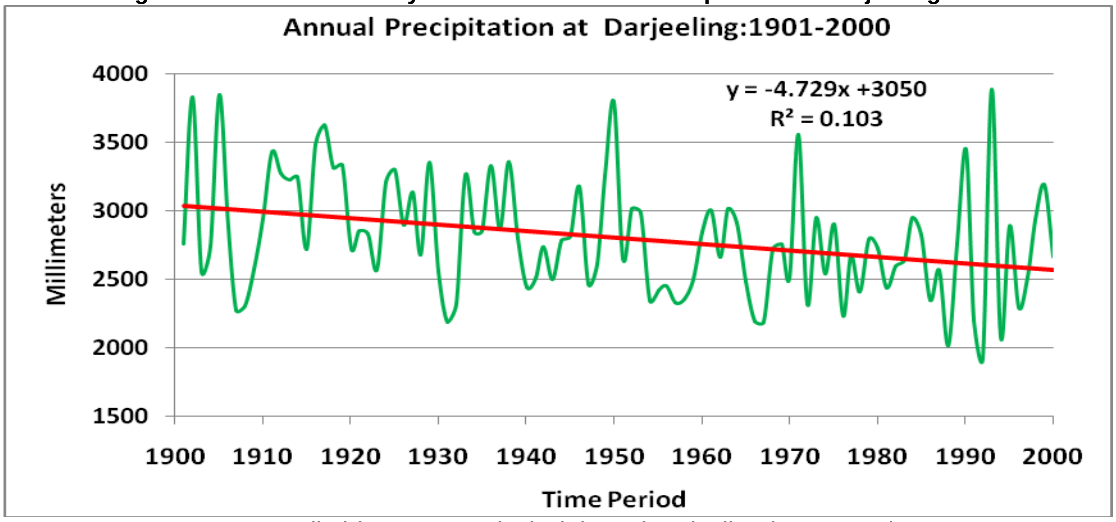
Table 1.1 Mann Kendall test Statistics of Darjeeling Station 1901-2000

VARIABLE	Test	Test statistic	a=0.1	a=0.05	a=0.01	RESULT
Mean Max. Temp.	Mann-Kendall	8.223	1.645	1.96	2.576	S (0.01)
	Linear Regression	11.334	1.663	1.987	2.633	S (0.01)
	Student's t	-7.28	1.663	1.987	2.632	S (0.01)
Mean Min. Temp.						
	Mann-Kendall	-1.03	1.645	1.96	2.576	NS
	Linear Regression	-1.797	1.663	1.987	2.633	S (0.1)
	Student's t	0.56	1.663	1.987	2.632	NS
Rainfall						
	Mann-Kendall	-3.166	1.645	1.96	2.576	S (0.01)
	Linear Regression	-3.298	1.663	1.987	2.633	S (0.01)
	Student's t	3.401	1.663	1.987	2.632	S (0.01)

Source: Compiled from meteorological data of Darjeeling (1901-2000).

Precipitation analysis reveals that rainfall has witnessed a significant declining trend in Darjeeling during the study period. There has been an alarming decline of about 470 mm in annual rainfall during the 20th century. Although Darjeeling is a high rainfall region with an average rainfall of about 2800mm, despite that it has registered a decline of about 16% in average annual precipitation (Fig:1). The average annual rainfall at Darjeeling during the first quarter was recorded at 3032 mm which declined to 2860 mm during the second quarter. The third quarter registered an average annual rainfall of about 2663mm which further decreased to 2639mm during the last quarter of the 20th century. July is the wettest month with mean rainfall of 735mm followed by August and June with 568mm and 528mm respectively. On the other hand December is the driest month with 8mm rainfall followed by January and February with 19mm and 23mm respectively.

Figure 1 Time Series Analysis of Mean Annual Precipitation at Darjeeling



Source: Compiled from meteorological data of Darjeeling (1901-2000).

The seasonal analysis of precipitation reveals that despite overall decline of annual precipitation some seasons have on the contrary registered an increasing trend in precipitation. Monsoon season is worst affected as it has registered a significant decline of 300mm during the 20th century. Time Series Analysis indicates that precipitation in Monsoon period has registered a decline of around 300 mm, which translates into a decrease of 20% during the last century. Summer precipitation has also registered a significant decline of about 130mm which translates into a decrease of 12%. Darjeeling has also witnessed reduction in the seasonal precipitation of post monsoon period in the range of 40-50mm. However on the contrary winter season has registered an increase of 10 mm in average seasonal precipitation followed by spring which has registered an increase of about 20mm during the 20th century. Year 1905 has been the wettest year in Darjeeling with an annual precipitation of 3845mm while as year 1992 is the driest year with a total rainfall of 1929mm. It is the testimony of the fact that Darjeeling has witnessed a 37% surplus to a deficit of 31% in the annual precipitation. The results of Trend Analysis of seasonal precipitation at Darjeeling are presented from figure 2 to 6.

Figure 2 Time Series Analysis of Monsoon Precipitation at Darjeeling

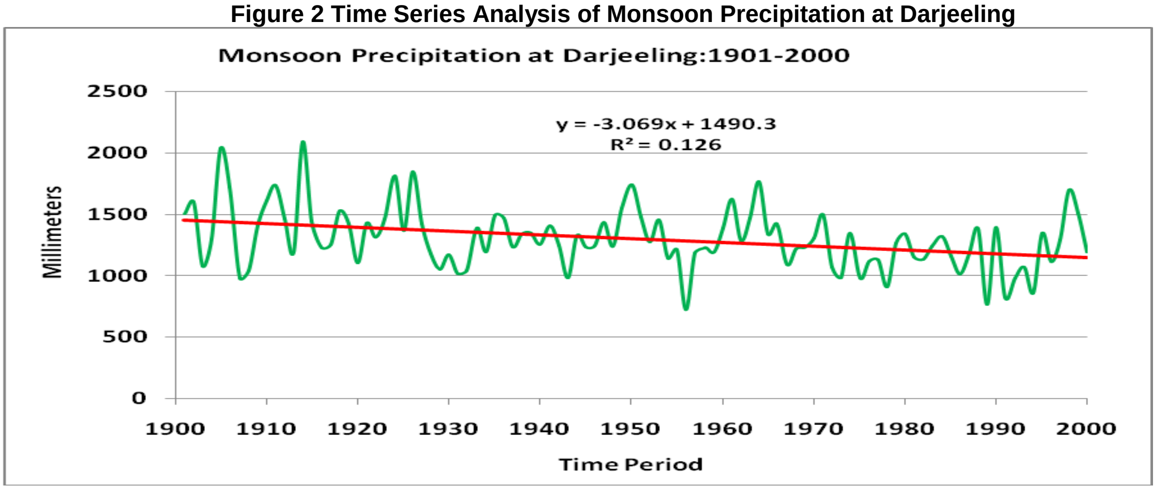


Figure 3 Time Series Analysis of Summer Precipitation at Darjeeling

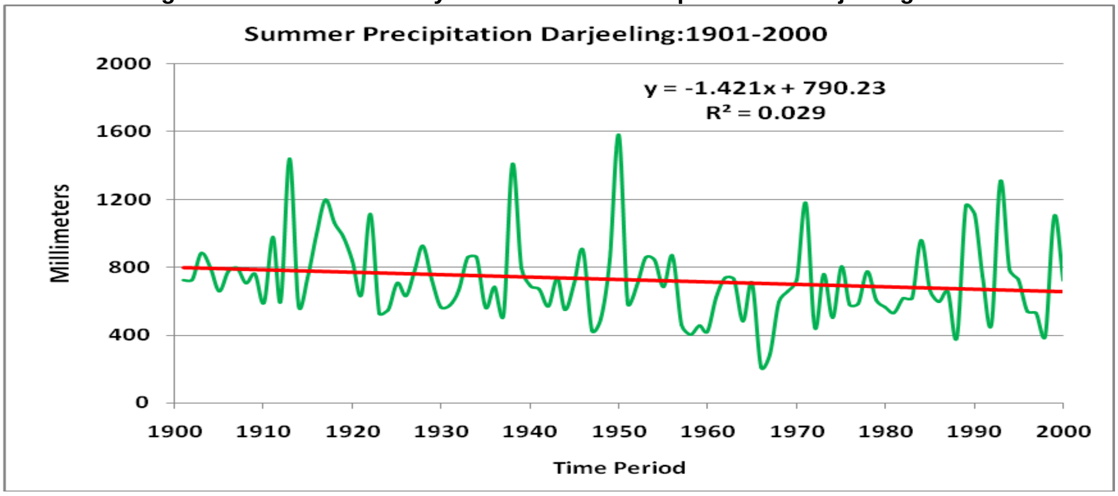


Figure 4 Time Series Analysis of Post-Monsoon Precipitation at Darjeeling

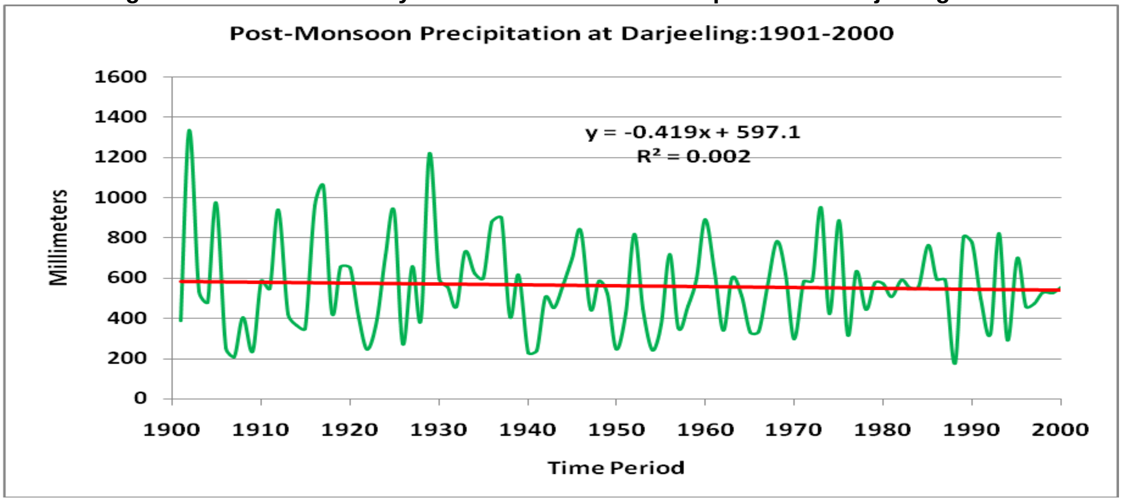


Figure 5 Time Series Analysis of Winter Precipitation at Darjeeling

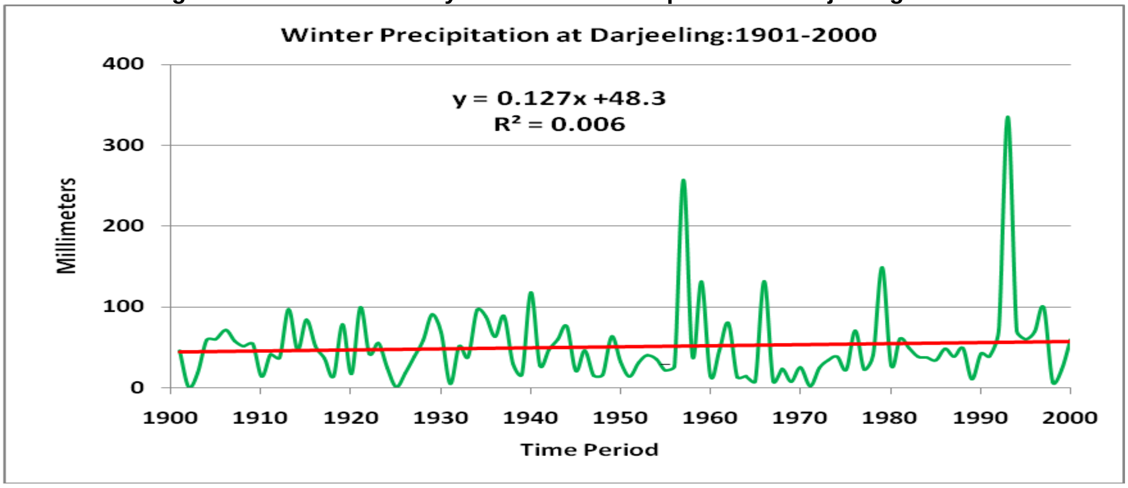
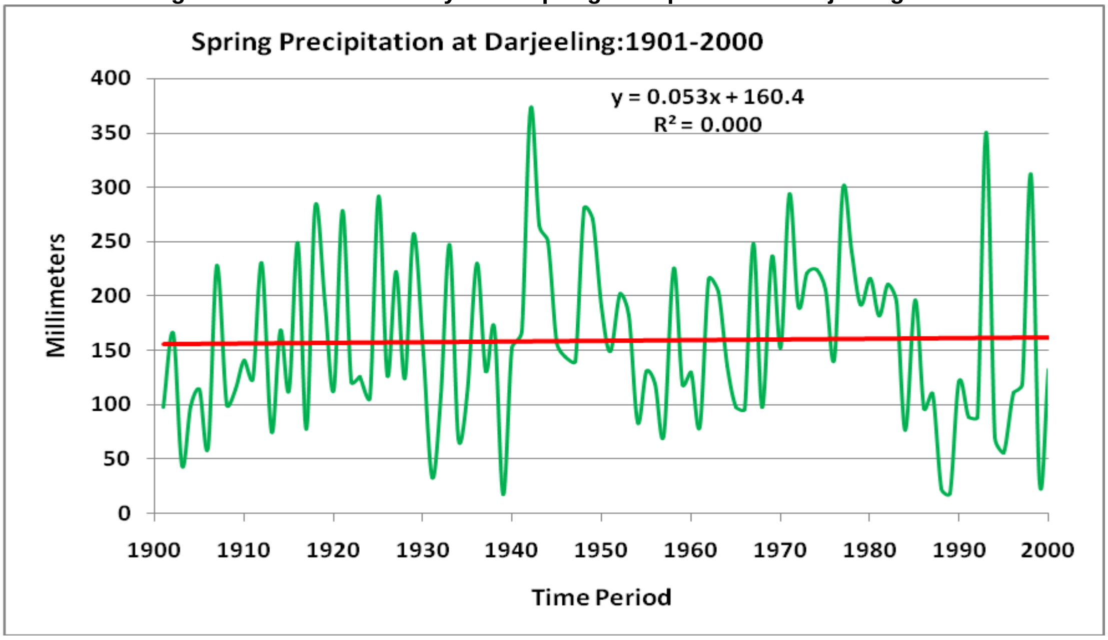


Figure 6 Time Series Analysis of Spring Precipitation at Darjeeling

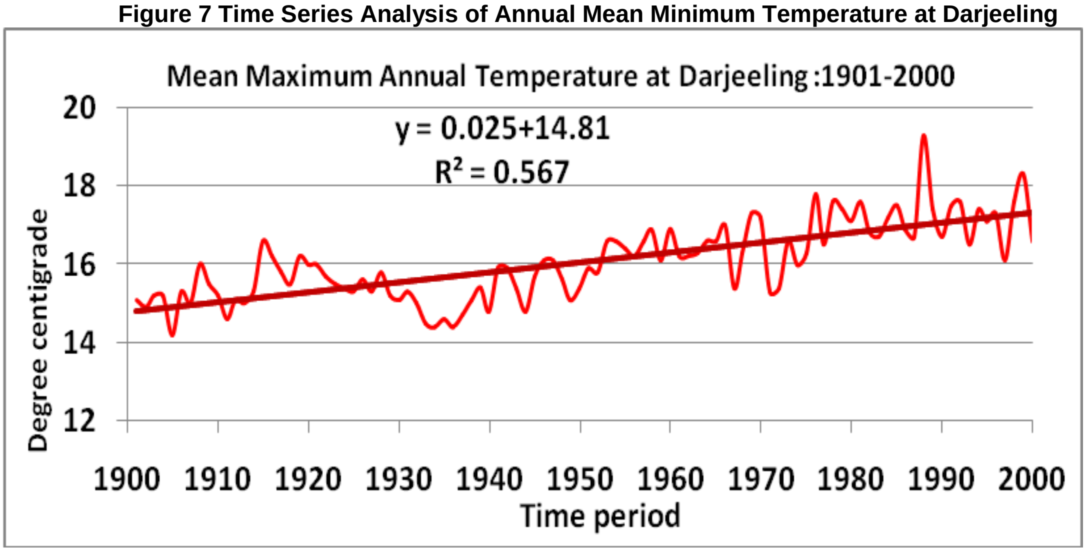


While analyzing the impact of climatic variability on the distribution of temperature across various seasons, it is evident that all the seasons at Darjeeling witnessed a warming trend of varying intensity during 20th century. The Post-Monsoon period is worst affected with an approximate increase of 4.7°C during the last century. This is followed by winter season with an increase of 3.7°C. Spring season has registered an increase of 2.1°C while as summer season has registered an increase of 1.2°C. Monsoon season is the least affected with an increase of 0.7°C.

The Time Series Analysis reveals that there is a gradual increasing trend in the mean minimum temperature at Darjeeling. However the increase in mean minimum temperature is less pronounced as compared to mean maximum temperature. Mean minimum temperature in Darjeeling presents a contrasting scenario. Some seasons have experienced an increasing trend, while as others have witnessed a decreasing trend. Winter season is worst affected and has registered an increase of 1.1°C while as spring has witnessed an increase of 0.3°C. Autumn season has experienced an increase of 0.6°C in mean minimum temperature.

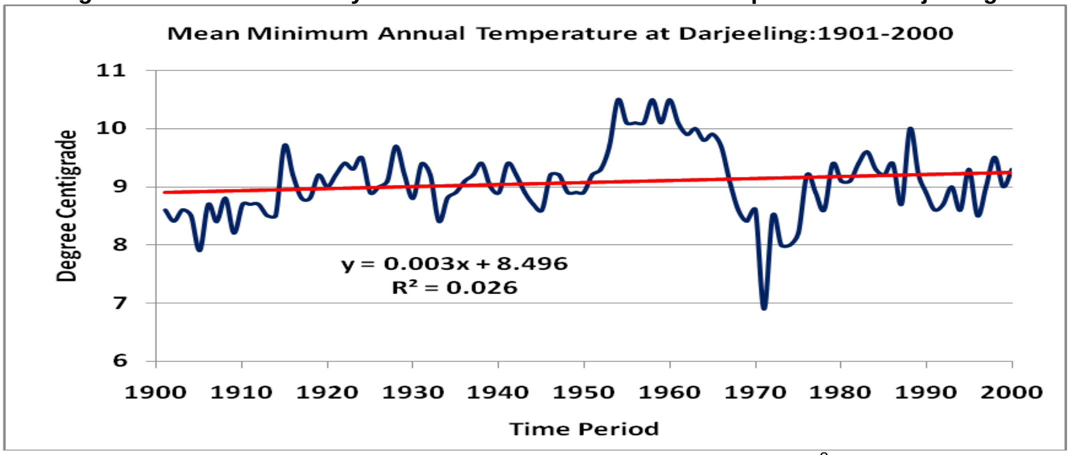
Summer season has recorded a decline of 0.3°C while as Monsoon season has witnessed a decrease of 0.5°C in the mean minimum temperature. In terms of mean minimum temperature, January is the coldest month with 1.9°C followed by February and December with a temperature of 3.1°C and 3.6°C respectively. Long term temperature trends at Darjeeling are depicted in Figure No. 7 & 8 respectively.

Figure 7 Time Series Analysis of Annual Mean Minimum Temperature at Darjeeling



.

Figure 8 Time Series Analysis of l Mean Minimum Winter temperature at Darjeeling



Quarterly analysis of data reveals that, there is a robust increasing trend in mean maximum temperature. The data reveals that the average mean maximum temperature for the first quarter of 20th century was 15.4°C which declined marginally to 15.2°C in the second quarter. However third quarter registered an abnormal increase in mean maximum temperature and it climbed to 16.3°C. This warming further intensified in the last quarter and the mean maximum temperature went up to 17.2°C. August is the hottest month with a mean maximum temperature of 19.7°C followed by July and June with 19.5°C & 19.4°C respectively.

Mean minimum temperature at Darjeeling also registered a modest increase during the 20th century. However, the trend is gradual and less robust as compared to mean maximum temperature. Overall an increase of 0.3°C in the mean minimum temperature has been registered from 1901-2000.

The analysis of extreme weather events at Darjeeling from 1890-1990 also gives a fair idea about the prevailing climatic variability in the region. Darjeeling has relatively cool temperature climate where mean maximum winter temperature of around 10.5°C, however it is evident from the table 3.2 that at times, mean maximum winter temperature has touched 19-20°C which is almost double the mean seasonal average. Mean minimum temperature in the winter has even dipped down to -7.2°C (30/1/1971) and -6.4°C on 30/2/1971. A detailed account of the extreme events in temperature and precipitation at Darjeeling from 1880 -1900 is given in (table number 1.2).

Table 1.2 Extreme events in at Darjeeling from 1880-1990

Station	Month	Highest Maximum Temperature °C			Lowest Minimum Temperature °C			24 Hour heaviest Rainfall (mm)		
		Max. Temp	Date	year	Min. Temp	Date	Year	Rainfall	Date	Year
Darjeeling	Jan	18.9	20	1952	-7.2	30	1971	134	10	1957
	Feb	18.3	28	1969	-6.9	30	1971	43	20	1940
	Mar	24	24	1976	-4.8	1	1971	73	31	1951
	Apr	26.7	13	1910	0	16	1971	135	18	1916
	May	25.7	30	1964	1.4	1	1981	240	28	1989
	Jun	27.7	23	1969	6.6	6	1970	454	12	1950
	July	28	22	1988	3.9	26	1944	216	6	1964
	Aug	28.5	21	1970	8	21	1975	237	8	1915
	Sep	27.5	3	1973	6.2	27	1972	493	25	1989
	Oct	26	3	1985	3.2	31	1972	334	20	1929
	Nov	24.5	1	1988	-4.4	26	1970	219	2	1912
	Dec	20	4	1988	-4.6	29	1970	31	19	1885

Source: IMD Pune

Mean maximum summer temperature usually revolves around 19°C in Darjeeling, but on certain occasions it has touched 28.5°C (21/8/1970) and 28°C (21/7/1998), which is almost 10°C higher than the mean seasonal temperature. It translates into an increase of 50% in the mean maximum temperature. While analyzing the extreme events in precipitation during 24 hour time-period, it becomes clear that Darjeeling has observed more than 200 mm of rainfall in 24 hours in seven months from May to November. The heaviest ever recorded 24 hours precipitation is 493mm which dates back to 25/9/1899. The second highest daily Precipitation of 454mm was recorded on 12/6/1950. It gives a fair idea about the fact that lower catchment areas in the Darjeeling region can experience flash flood any time from May to November.

The data reveals that most of the highs in mean maximum temperature were recorded during the 2nd half of 20th century between years1980-1990.

On the other hand most of the lows in mean minimum temperature were recorded from 1970-81. In terms of precipitation most of the extreme events have been recorded during the last quarter of 19th and the first quarter of 20th century.

Conclusion

Present study reveals that Eastern Middle Himalayan region is greatly influenced by climatic variability in the course of 20th century. It has experienced a drastic decline in the annual precipitation. The monsoon Season is the worst affected and has registered a decline of around 15% during the last century. It has also been observed that the impact of climate change on the distribution of precipitation varies across the seasons, which is evident by the fact that winter rainfall has marginally increased during the study period. Mean maximum temperature is showing a robust increasing trend; while as mean minimum temperature has experienced a marginal increase during the last century. The drastic decline of precipitation along with abnormal increase in temperature in the Middle Himalayan region of Darjeeling will have adverse environmental and ecological consequences. It will adversely affect the livelihood patterns, agriculture, hydrological systems, and will intensify hydro-meteorological hazard scenario in the region. Therefore proper adaptation and mitigation strategies should be taken to counter the fall out of climate change in this region.

Acknowledgment

The Present study has been conducted in Eastern Middle Himalayas in the Darjeeling region covering a study period of entire 20th century (Year 1901-2000). We are highly thankful to IMD Pune for providing the necessary data on long term basis.

References

1. *Bajracharya, S.R., and P. Mool, (2010). Glaciers, Glacial Lakes and Glacial Lake Outburst Floods in the Mount Everest Region, Nepal. Annals of GlaciologyVol: 50: pp. 81-86.*
2. *Barnett, T.P., J.C. Adam, and D.P. Lettenmaier, (2005). Potential Impacts of a Warming Climate on Water Availability in Snow-dominated Regions. Naturevol: 438: pp.303-309.*
3. *Bhutiyani, M.R., V.S. Kale, and N.J. Pawar, (2007). Long-term Trends in Maximum, Minimum and Mean Annual Air Temperatures across the Northwestern Himalaya During the Twentieth Century. Climatic Change 85: pp. 159-177.*
4. *Cruz, R.V., H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Safari,C. Li, and N. Huu Ninh, 2007. Asia. Climate Change (2007): Impacts, Adaptation and Vulnerability. In ML Parry, OF Canziani, JP Palutikof, PJ Van Der Linden, CE Hanson (Eds.) Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK. pp. 469-506.*
5. *Dash, S.K., R.K. Jenamani, S.R. Kalsi, and S.K. Panda, (2007). Some Evidence of Climate Change in Twentieth-century India. Climatic Change 85: pp. 299-321.*
6. *Dimri, A.P., and S.K. Dash, (2011). Wintertime Climatic Trends in the Western Himalayas. Climatic Change. doi:10.1007/s10584-011-0201.*
7. *Diodato, N., G. Bellocchi, and G. Tartari, (2011). How do Himalayan areas respond to global warming? International Journal of Climatology. doi: 10.1002/joc.2340.*
8. *I.P.C.C. Third assessment report (2001).*
9. *Immerzeel, W., (2008). Historical Trends and Future Predictions of Climate Variability in the Brahmaputra Basin. International Journal of Climatology vol: 28 pp. 243-254.*
10. *Immerzeel, W., L.P.H. Van Beek, and M.F.P. Bierkens, (2010). Climate Change Will Affect the Asian Water Towers. Science vol: 328: pp. 1382-1385.*
11. *Ives, J.D., 1992: Preface, The State of the World's Mountains [Stone, P. (ed.)]. Zed Books, London, UK, pp. xiii-xvi.*
12. *Kennedy, Dane (1996). Magic Mountains: Hill Stations and the British Raj. University of California Press. p. 265. ISBN 0-520-20188-4*
13. *Messerli, B. & Ives, J.D.(eds),(1997). Mountains of the world: A Global Priority. The Parthenon Publishing Group.*
14. *Sarkar, S. (1999). Landslides in Darjeeling Himalayas, India. Transactions of the Japanese Geomorphological Union vol: 20 (3). pp. 299–315.*
15. *Sarkar, S., (2011). Climate change & disease risk in the Himalayas. Himalayan Journal of Sciences vol: 6: pp. 7-8.*
16. *Schild, A. (2008). ICIMOD's Position on Climate Change and Mountain Systems. Mountain Research and Developmentvol: 28: pp. 328-331.*
17. *Shafi M., J.A. Rather, T.A. Kanth, Bhat M.S.(2015) "Core-Winter Temperature in Kashmir Valley (1950-2010) as an Indicator of Climatic Change" Asian Resonance ISSN No. 2349 - 9443 pp 151-155*
18. *Sharma, E., N. Chettri, K. Tse-ring, A. B. Shrestha, F. Jing, P. Mool & M. Eriksson. (2009). Climate ChangeImpacts and Vulnerability in the Eastern Hima-layas. International Centre for Integrated MountainDevelopment, Kathmandu.*
19. *Shrestha, A.B., C.P. Wake, P.A. Mayewski, and J.E. Dibb, (1999). Maximum Temperature Trends in the Himalaya and Its Vicinity: An Analysis Based on Temperature Records from Nepal for the Period 1971-94. Journal of Climate 12: pp. 2775-2786.*
20. *Shrestha, A.B., M. Eriksson, P. Mool, P. Ghimire, B. Mishra, and N.R. Khanal, (2010). Glacial Lake Outburst Flood Risk Assessment of Sun Koshi Basin, Nepal. Geomatics, Natural Hazards and Risk 1: pp. 157-169.*
21. *Singh, P., K.H. Umesh, and N. Kumar, (2008). Modelling and estimation of different components of streamflow for Gangotri Glacier basin, Himalayas/Modélisation et estimation des*

différentes composantes de l'écoulement fluviatile du bassin du Glacier Gangotri, Himalaya. Hydrological Sciences Journal 53: pp. 309-322.

22. *Tse-ring K, E. Sharma, N. Chettri, and A. Shrestha (Eds), (2010). Climate Change Vulnerability of Mountain Ecosystems in the Eastern Himalayas-Synthesis report. Kathmandu, ICIMOD. ISBN 978-92-9115-141-7.*
23. *www.navdanya.org/climate-change/in-the-himalayas.*
24. *Xu, J., R.E. Grumbine, A. Shrestha, M. Eriksson, X. Yang, Y. Wang, and A. Wilkes, (2009). The Melting Himalayas: Cascading Effects of Climate Change on Water, Biodiversity, and Livelihoods. Conservation Biology 23: pp. 520-530.*
25. *Yang, X., Y. Zhang, W. Zhang, Y. Yan, Z. Wang, M. Ding, and D. Chu, (2006). Climate Change in Mt. Qomolangma Region Since 1971. Journal of Geographical Sciencesvol: 16: pp. 326-336.*
26. *You, Q., S. Kang, Y. Wu, and Y. Yan, (2007). Climate change over the Yarlung Zangbo river basin during 1961–2005. Journal of Geographical Sciencesvol: 17(4): pp. 409-420.*