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Erratic Precipitation: Repercussion of Climate Change

(A Case study of Uttarakhand Mountain of Indian Himalaya)

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Abstract: Millions of farmers in mountainous region dependent on rainfed agriculture are at risk from erratic nature of rainfall. Heavy precipitation also increased in the last century even with less change in annual total rainfall *(Groisman et al., 1999)*. In Asian continent, where irrigation was greatly expanded in recent decades, rainfed agriculture is still extensive, accounting for 66 percent of the total cropped area. Over the last 50 years, there has been a slight decrease in annual precipitation over China, which is supported by a significant (5 percent confidence level) decrease in the number of rainy days (3.9 percent per decade) *(Zhai and Ren, 1999)*. There are several studies that have examined the actual variability that has happened in the rainfall in India for the past several years and the trends were varied according to the period of study and the region. Retreat of glaciers and ice sheets are considered as the powerful evidence of global climate change because it is directly linked with the rising atmospheric temperature. Gangotri Glacier has lost 0.41±0.03 km^2 from its front at the rate of approximately 0.01 km^2 per year from 1965 till 2006 *(Bhambri et al. 2012)*.The focus of the present paper is to study erratic precipitation trend and melting glaciers are the repercussions of changing climate in Uttarakhand Mountains of Indian Himalaya.

Keywords: Erratic Precipitation, Glaciers retreat, Climate Change, and Uttarakhand Mountains.

INTRODUCTION

Global land precipitation has increased by about 2 percent since the beginning of the 20th century *(Jones and Hulme, 1996; Hulme et al., 1998)*. The increase is statistically significant with spatial and temporal variation *(Karl and Knight, 1998)*. Over the 20th century, the Northern Hemispheric mid- and high latitudes, averaged precipitation increased by between 7 percent and 12 percent, respectively. Precipitation over the United States has increased by between 5percent and 10 percent since 1900, but this increase has been interrupted by multiyear anomalies such as the drought years of the 1930s and early 1950s *(Karl and Knight, 1998; Groisman et al., 1999)*. Precipitation in Canada has increased by an average of more than 10percent over the 20th century *(Mekis and Hogg, 1999)*.

There have been marked increases in precipitation in the latter part of the 20th century over northern Europe, with a general decrease southward to the Mediterranean *(New, 1998)*. Over the former USSR, precipitation has increased since 1891 by about 5 percent in the western region for both warm and cold seasons *(Bogdanova and Mestcherskaya, 1998; Groisman and Rankova, 2001)*. In eastern Russia, a negative precipitation trend was noticed since 1945 with a century long positive precipitation trend *(Gruza et al., 1999)*.

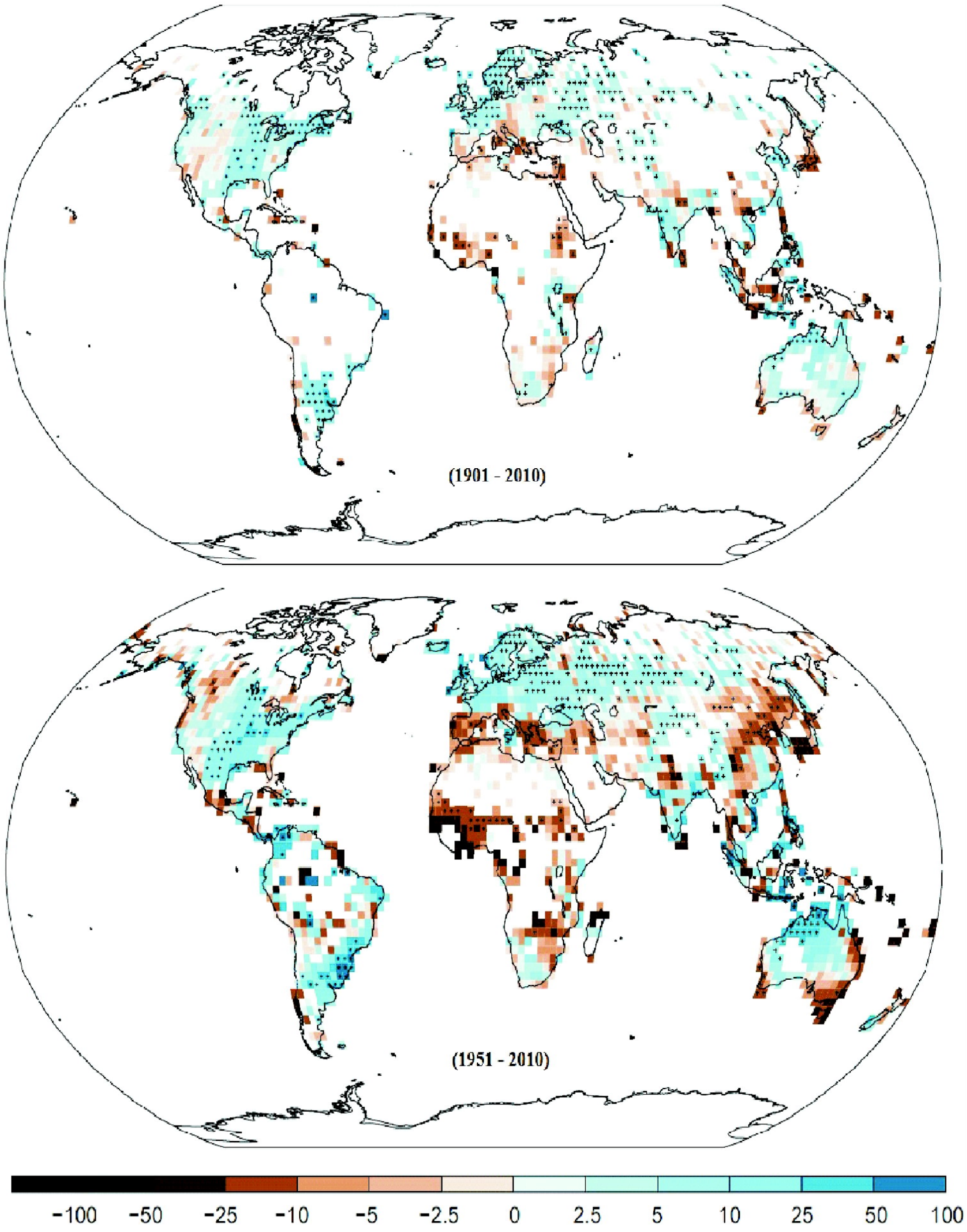

Figure 1: Maps of observed precipitation change from 1901 to 2010 and from 1951 to 2010 (in mm yearr^{-1} decade^{-1}). Trend in annual accumulation calculated where data availability permits a robust estimates i.e. only for grid boxes with greater than 70 percent complete records and more than 20 percent data availability in the first and last 10 percent of the time period, other areas are white

Source: AR 5, Climate change 2013, The Physical Science basis

An analysis of rainfall data since 1910 by *Haylock and Nicholls (2000)* reveals a large decrease in total precipitation and related rain days in south-western Australia. Annual total rainfall has increased over much of Australia with significant increases of 15 percent to 20percent in large areas. The increase in total rainfall has been accompanied by a significant 10 percent rise in the average number of rain days over Australia *(Hennessy et al., 1999)*.

From 1906 to about 1960, global monsoonal rainfall increased, then decreased through 1974 and has increased since. The trend in annual precipitation has been negative (1 to 2 percent per decade) over the southwest USA, northwest Mexico and the Baja Peninsula. Across South America, increasingly wet conditions were observed over the Amazon Basin and south- eastern South America, including Patagonia, while negative trends in annual precipitation were observed over Chile and parts of the western coast of the continent. The largest negative trends in annual precipitation were observed over western Africa and the Sahel *(IPCC, 2007)*. The increased atmospheric moisture content associated with warming might be expected to lead to increased global mean precipitation. Global annual land mean precipitation showed a small, but uncertain, upward trend over the 20th century of approximately 1.1 mm per decade. However, the record is characterized by large inter-decadal variability, and global annual land mean precipitation shows a non-significant decrease since 1950.

Analysis of long term climate data show that the most intense precipitation occurs in warm regions and studies have shown that even without any change in total precipitation, higher temperatures lead to heavy and very heavy precipitation events *(Trenberth et al., 2003)*. *Trenberth et al. (2005)* point out that since the amount of moisture in the atmosphere is likely to rise much faster as a consequence of rising temperatures than the total precipitation, this should lead to an increase in the intensity of storms, offset by decreases in duration or frequency of events. IPCC projected the increase in intensity of precipitation events, particularly in tropical and high latitude areas that experience increases in mean precipitation. Even in areas where mean precipitation decreases (most subtropical and mid-latitude regions), precipitation intensity is projected to increase but there would be longer periods between rainfall events *(see figure 1)*.

Increases in the amount of precipitation are very likely in high latitudes, while decreases are likely in most subtropical land regions, if the recent trends in observed patterns are continuing *(IPCC, 2007 & 2013)*. National Aeronautics and Space Administration's (NASA) models projected that for every 1 degree Fahrenheit of carbon dioxide induced warming, heavy rainfall will increase globally by 3.9 percent and light rain will increase globally by 1 percent. However, total global rainfall is not projected to change much because moderate rainfall will decrease globally by 1.4 percent *(Cole and Hansen, 2013)*.

Evidences from Indian Subcontinent

There are several studies that have examined the actual variability that has happened in the rainfall in India for the past several years and the trends were varied according to the period of study and the region *(Rajeevan, 2001; Goswami et al., 2006; Guhathakurta and Rajeevan, 2006; Lal et al., 2001; Krishnamurthy and Shukla, 2000; Naidu et al.1999; Kumar et al., 1992; Mooley and Parthasarathy, 1984)*. Amount of annual rainfall increased over Central India and decreased over some parts of eastern India for the period 1901–1960 *(Menon and Pandalai, 1960)*. There was an increasing trend in mean annual and south west monsoon (SWM) rainfall over the meteorological sub-divisions of Punjab, Haryana, west Rajasthan, east Rajasthan and west Madhya Pradesh during the period 1901–1982 *(Pant and Hingane, 1988)*. Half of the meteorological subdivisions witnessed an increasing trend in annual rainfall. Annual and monsoon rainfall decreased, and pre-monsoon, post monsoon and winter rainfall increased over the years for the last 135 years from1871 to 2005 *(Krishnakumar et al., 2007; Mooley and Parthasarathy, 1984)*.

Guhathakurtha and Rajeevan, (2008) and Rajeevan *et al.* (2006) analysed the rainfall of a network of 1476 rain gauge stations in India for the period 1901–2003 and showed a significant decreasing trend in the monsoon rainfall for three sub-divisions such as Jharkhand, Chhattisgarh and Kerala. Subdivisions like Gangetic West Bengal, Western Uttar Pradesh, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra, Rayal seema, coastal Andhra Pradesh and North Interior Karnataka experienced a significant increasing trend. Goswami et al. (2006) found that showed that there were significant increasing trends in extreme rain events over central India during the monsoon season, at the same time there was a significant decreasing trend.

The rainy season in Uttarakhand is characterized by the downpour of the SW monsoons between June and October. The ranges of average precipitation observed are between 972.7 mm at Joshimath to 2599.4 mm at Munsyari *(Sati and Kumar, 2013)*. The SW monsoon trimmings in late September and then begins autumn season, which is the best season for Uttarakhand. After the long rainy season, the weather ultimately clears up during autumn. In this season, weather remains favourable in most regions, except high elevations where the first snowfall generally take place in mid-October. The autumn season is virtually frost free while the days are warm and the nights are cool and pleasant.

Winter is longest season of Uttarakhand. In most parts of the hilly region, winter sets in during the end of November and continues until in the end of March with increase in the day temperature. Temperature goes lowest during winter in hills, especially in upper tracts of Uttarakhand. A thick blanket of snow covers the ground for three to four months during this season in higher reaches. Snowfall occurs usually over the elevation of 2,200 m. Frost is experienced in the valleys and terai and *bhabhar* tracts. Avalanches and snowstorms are common above the snow line in the winter season.

Precipitation Trend in the Study Area

Analysis of precipitation data in mountainous regions of Uttarakhand showed change over the region i.e., it has got significantly increased annually and seasonally during the last five to six decades. If see the pattern data of last three decades in the region it is found that total monthly and heaviest monthly precipitation of Mukhim and Mukteshwar weather station in a year are showing increasing trend, on the contrary annual trend of number of rainy days in a month of both station are predicting diminishing trend (see figure 2, 3 and 4).

Annual trend of total monthly precipitation of Mukhim ($R_{M\_TRm\_Annual}$) and Mukteshwar ($R_{R\_TRm\_Annual}$) weather station are predicting the increase of 0.66 mm year $^{-1}$ and 0.04 mm year $^{-1}$, respectively. More or less, annual trend of heaviest monthly precipitation of Mukhim ($R_{M\_HRm\_Annual}$) and Mukteshwar ($R_{R\_HRm\_Annual}$) weather station are also predicting the same trend as 0.02 mm year $^{-1}$ and 0.01 mm year $^{-1}$ of decrease, respectively. On the contrary annual trend of number of rainy days in a month of both weather stations; Mukhim ($R_{M\_NRd\_Annual}$) and Mukteshwar ($R_{R\_NRd\_Annual}$) are predicting the decrease of 0.008 days year $^{-1}$ and 0.005 days year $^{-1}$, respectively. The above interpretations reflect the changing condition of annual precipitation; i.e. total and heaviest precipitation is increasing with decline in number of rainy days.

Seasonal Trend: Winter Cropping Season

If see the precipitation trend of winter season in the region it is found that total monthly precipitation, heaviest monthly precipitation and number of rainy days of Mukhim weather station are showing diminishing trend. On the contrary total monthly precipitation and number of rainy days of Mukteshwar weather station during winter season are showing increasing while heaviest monthly precipitation is showing decrease trend. Moreover, total monthly precipitation ($R_{M\_TRm\_winter}$), heaviest monthly precipitation ($R_{M\_HRm\_winter}$) and number of rainy days ($R_{M\_NRd\_winter}$) of Mukhim weather station during winter season are predicting decline of 0.29 mm year^{-1}, 0.17 mm year^{-1}, and 0.046 days year $^{-1}$, respectively. While total monthly

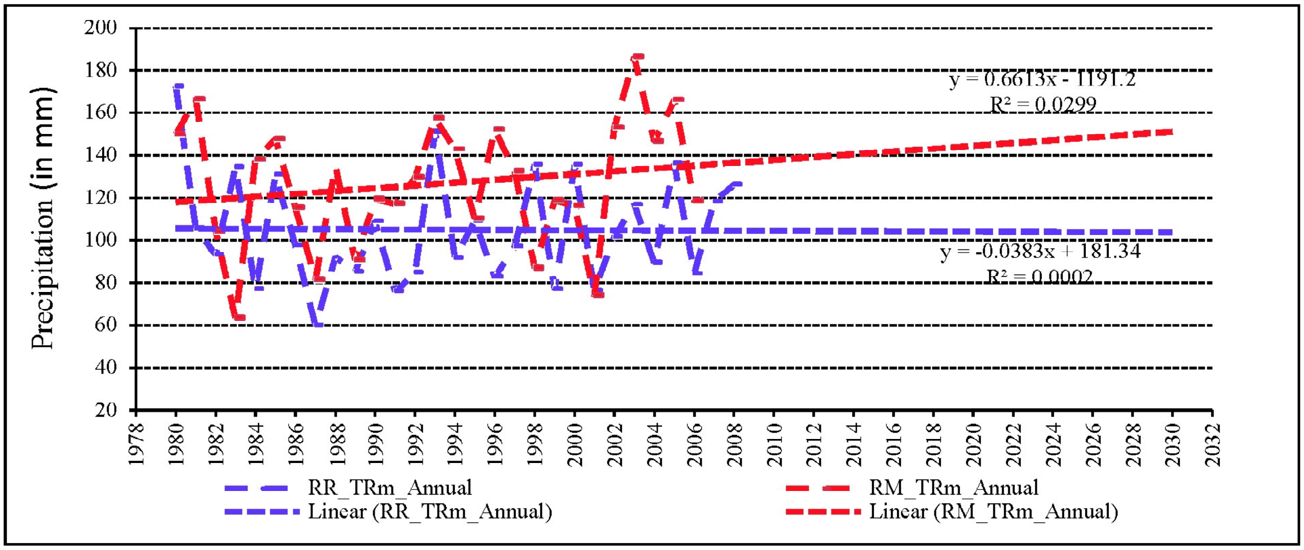

Figure 2: Annual trend of total monthly precipitation of Mukhim weather station ($R_{M\_TRm\_Annual}$), and Annual trend of total monthly precipitation of Mukteshwar weather station ($R_{R\_TRm\_Annual}$)

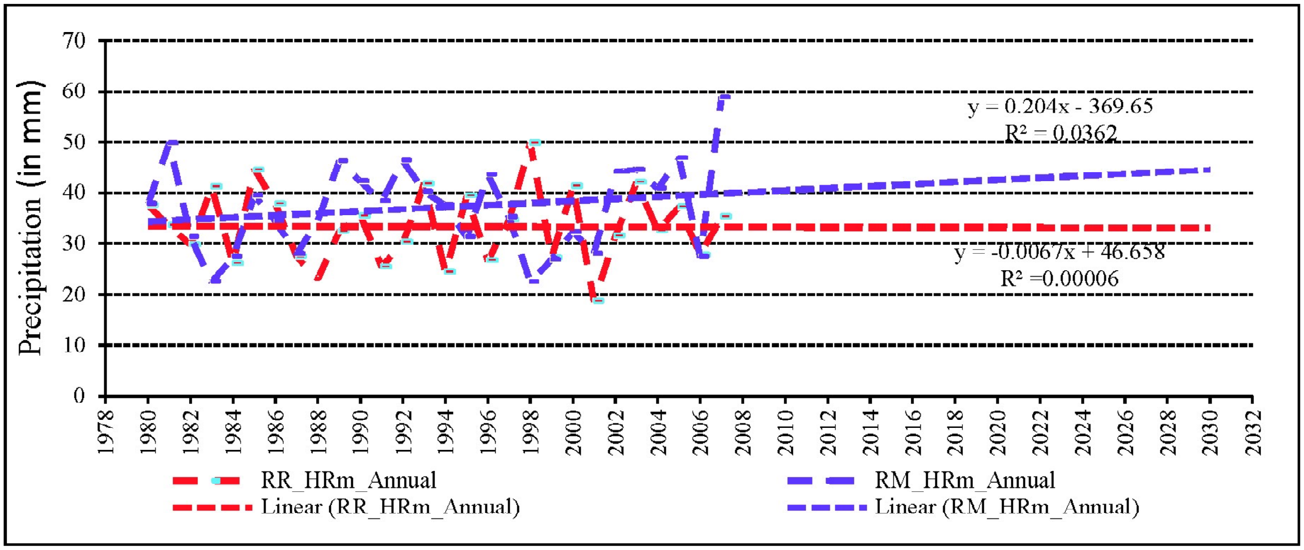

Figure 3: Annual trend of heaviest monthly precipitation of Mukhim weather station ($R_{M\_HRm\_Annual}$), and Annual trend of heaviest monthly precipitation of Mukteshwar ($R_{R\_HRm\_Annual}$)

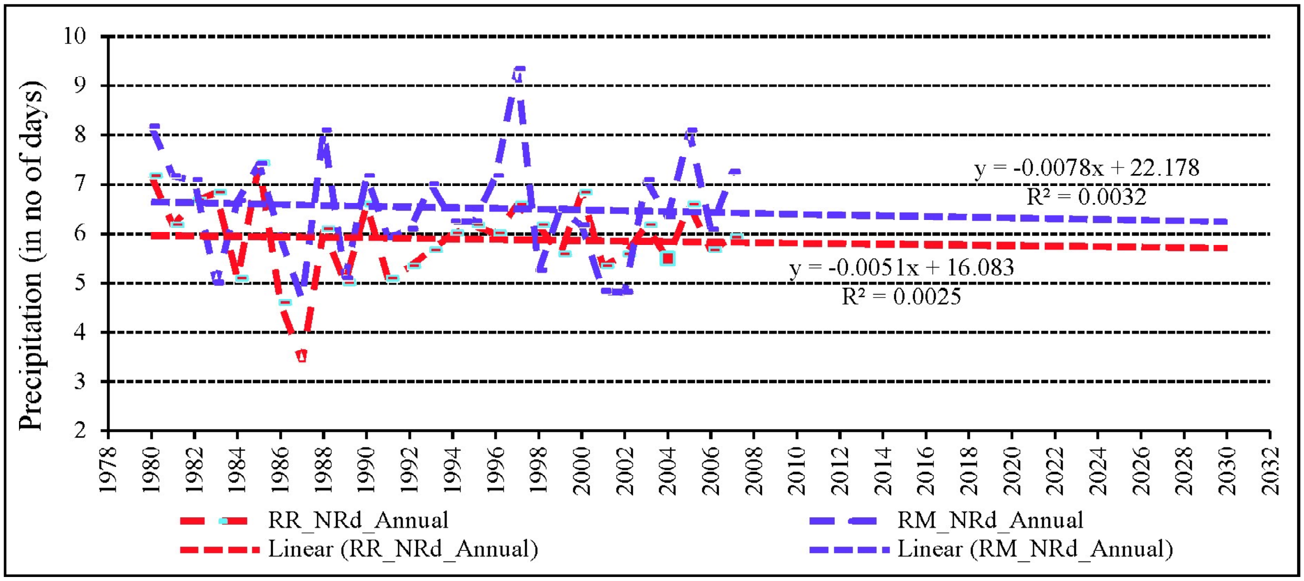

Figure 4: Annual trend of number of rainy days in a month of Mukhim weather station ($R_{M\_NRd\_Annual}$), and Annual trend of number of rainy days in a month Mukteshwar weather station ($R_{R\_NRd\_Annual}$)

precipitation ($R_{R\_TRm\_winter}$) and number of rainy days ($R_{R\_NRd\_winter}$) of Mukteshwar weather station during winter season are predicting incline of 0.07 mm year^{-1} and 0.002 days year^{-1}, respectively while heaviest monthly precipitation ($R_{R\_HRm\_winter}$) is predicting decline of 0.012 mm year^{-1}. The above interpretations reflect the different climatic condition in both weather stations, i.e. whereas, Mukhim weather station is predicting loss of rainfall while Mukteshwar is predicting slight gain of precipitation in the region during winter season (see figure 5, 6 and 7).

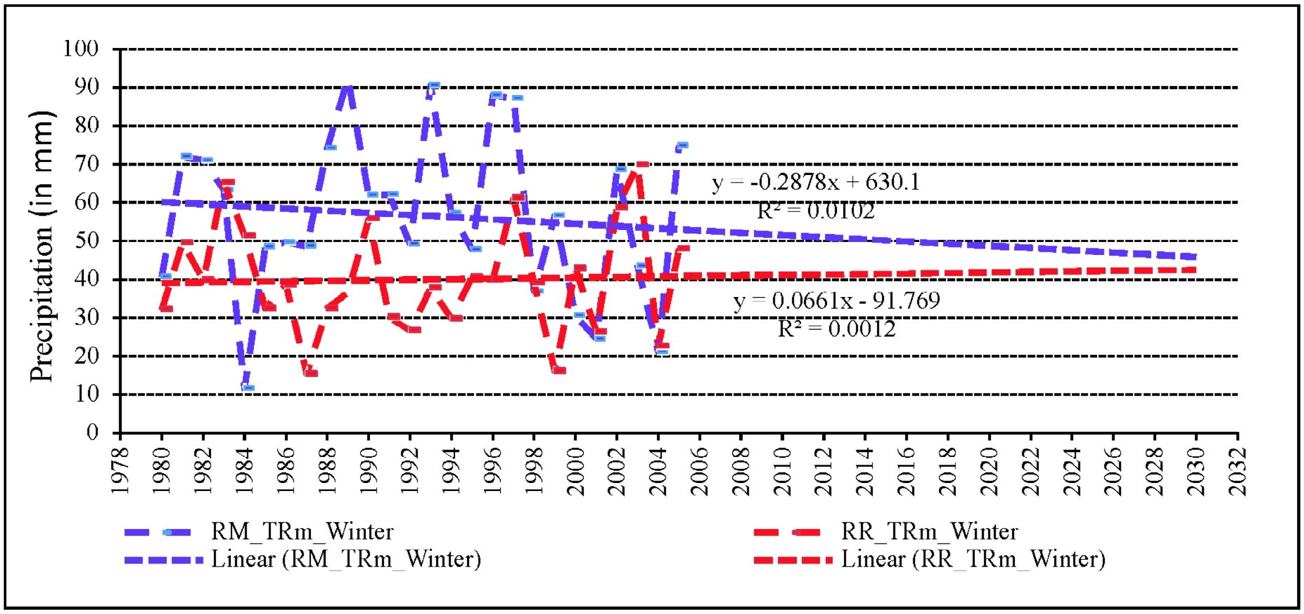

Figure 5: Trend of total monthly precipitation of Mukhim weather station during winter season ($R_{M\_TRm\_winter}$), and trend of total monthly precipitation of Mukteshwar weather station during winter season ($R_{R\_TRm\_winter}$)

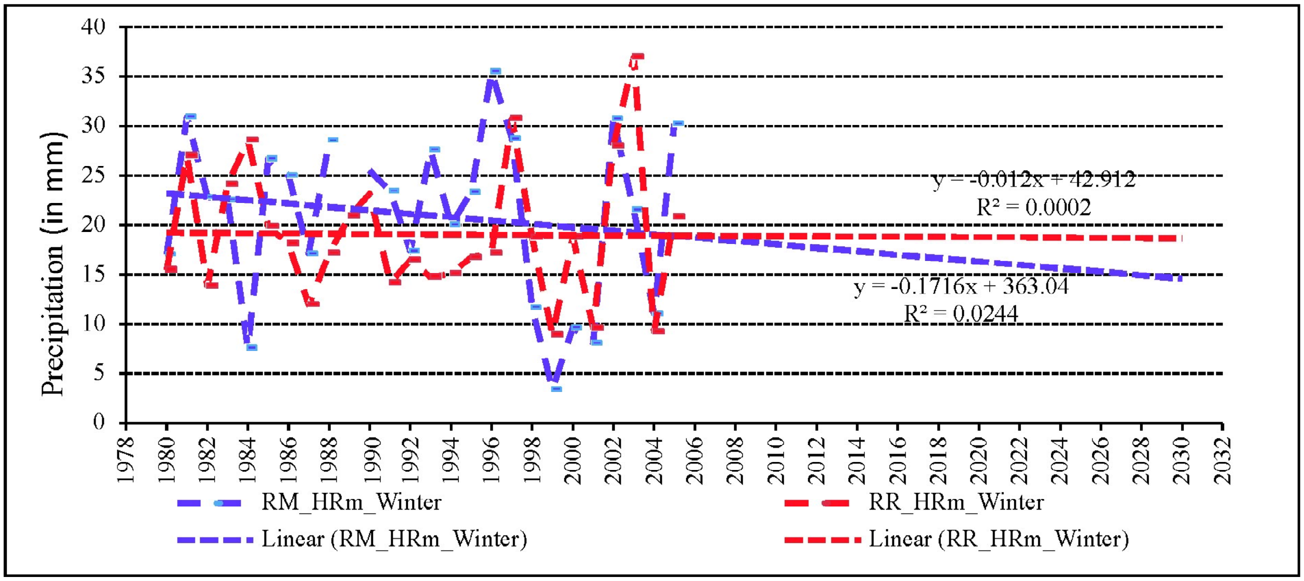

Figure 6: Trend of heaviest monthly precipitation of Mukhim weather station during winter season ($R_{M\_HRm\_winter}$), and trend of heaviest monthly precipitation of Mukteshwar during winter season ($R_{R\_HRm\_winter}$)

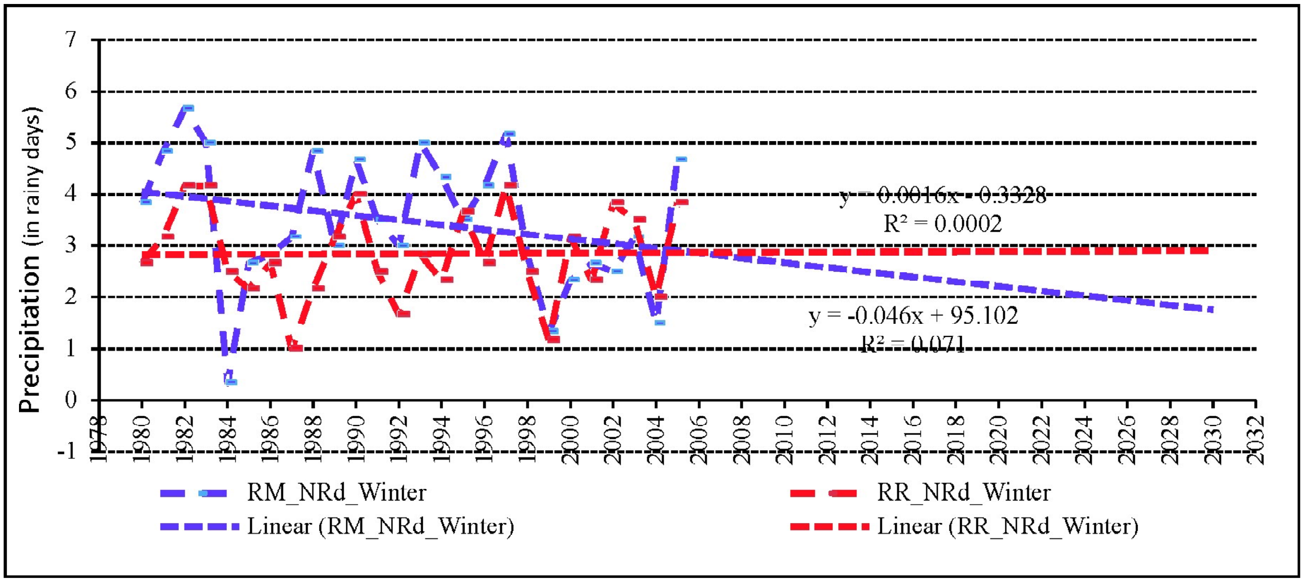

Figure 7: Trend of number of rainy days in a month of Mukhim weather station during winter season ($R_{M\_NRd\_winter}$), and trend of number of rainy days in a month Mukteshwar weather station during winter season ($R_{R\_NRd\_winter}$)

Seasonal Trend: Summer Cropping Season

If see the precipitation trend of summer season in the region it is found that total monthly precipitation, heaviest monthly precipitation and number of rainy days of Mukhim weather station are showing inclining trend. On the contrary total monthly precipitation and number of rainy days of Mukteshwar weather station are showing decreasing while heaviest monthly precipitation is showing increasing trend. Moreover, total monthly precipitation ($R_{M\_TRm\_summer}$), heaviest monthly precipitation ($R_{M\_HRm\_summer}$) and number of rainy days ($R_{M\_NRd\_summer}$) of Mukhim weather station during summer season are predicting incline of 1.99 mm year^{-1}, 0.43 mm year^{-1}, and 0.015 days year^{-1}, respectively. While total monthly precipitation ($R_{R\_TRm\_summer}$) and number of rainy days ($R_{R\_NRd\_summer}$) of Mukteshwar weather station during summer season are predicting decline of 0.50 mm year^{-1} and 0.011 days year $^{-1}$, respectively while heaviest monthly precipitation ($R_{R\_HRm\_summer}$) is predicting incline of 0.06 mm year^{-1}. The above interpretations reflect the different climatic condition in both weather stations (see figure 8, 9 and 10).

Glacier Retreat

Retreat of glaciers and ice sheets are considered as the powerful evidence of global climate change because it is directly linked with the rising atmospheric temperature. Global glaciers and ice caps excluding the large ice sheets of Greenland and Antarctica cover an area between 512 X 103 and 546 X 103 km^2 *(Raper and Braithwaite, 2005; Ohmura, 2004)*. Total volume of these glaciers and ice caps varies considerably from 51 X 103 to 133 X 103 km^3, representing sea level equivalent (SLE) of between 0.15 and 0.37 m. Including the glaciers and ice caps surrounding the Greenland Ice Sheet and West Antarctica, but excluding those on the Antarctic Peninsula and those surrounding East Antarctica, yields 0.72±0.2 m. It was reported that retreat of glacier tongues started after 1800, with substantial mean retreat rates in all regions after 1850 lasting throughout the 20th century. A slowdown was noticed during 1970 *(Oerlemans, 2005)*. Retreat rate was again started rapidly in the 1990s; the Atlantic and the SH curves reflect precipitation-driven growth and advances of glaciers in western Scandinavia and New Zealand during the late 1990s *(Chinn et al., 2005)*.

Studies on three glaciers (Helheim Glacier, Kangerdlugssuaq Glacier, and Jakobshavn Glacier) of Greenland ice sheet showed that they together represented more than 16percent of the Greenland ice

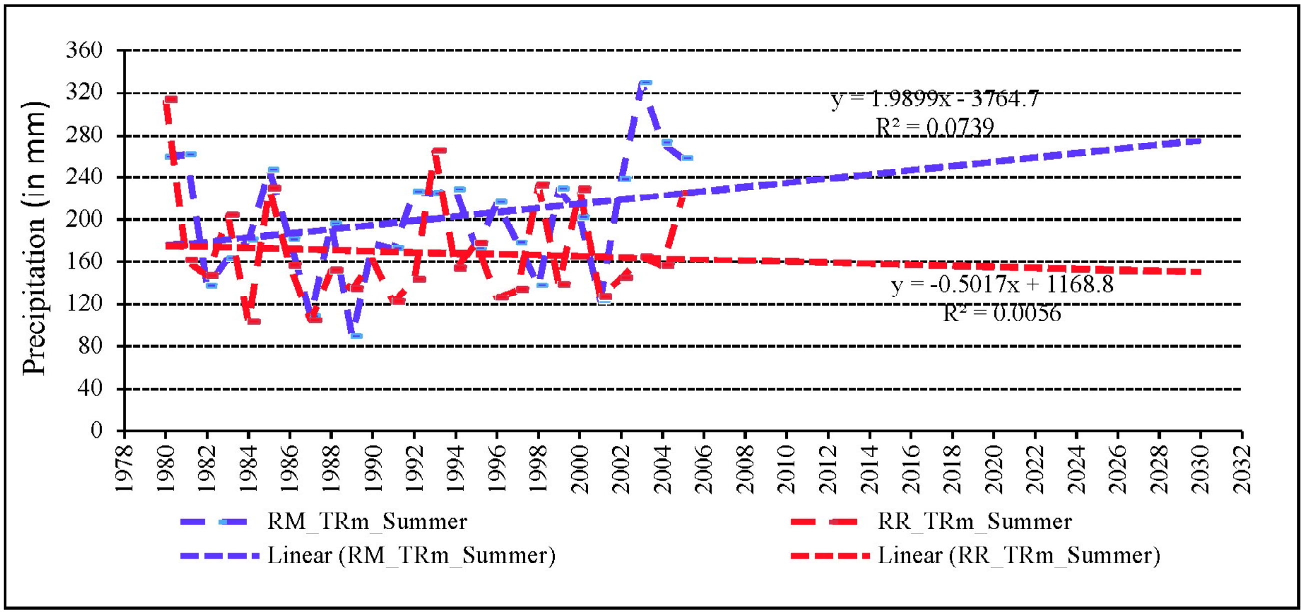

Figure 8: Trend of total monthly precipitation of Mukhim weather station during summer season ($R_{M\_TRm\_summer}$), and trend of total monthly precipitation of Mukteshwar weather station during summer season ($R_{R\_TRm\_summer}$)

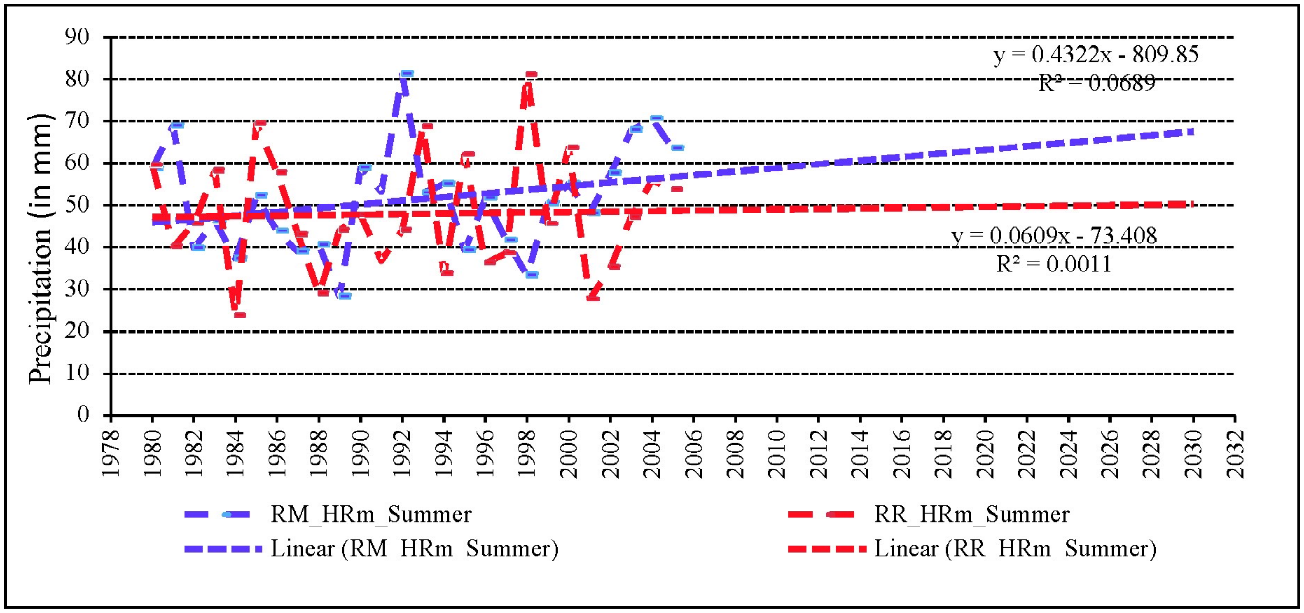

Figure 9: Trend of heaviest monthly precipitation of Mukhim weather station during summer season ($R_{M\_HRm\_summer}$), and trend of heaviest monthly precipitation of Mukteshwar during summer season ($R_{R\_HRm\_summer}$)

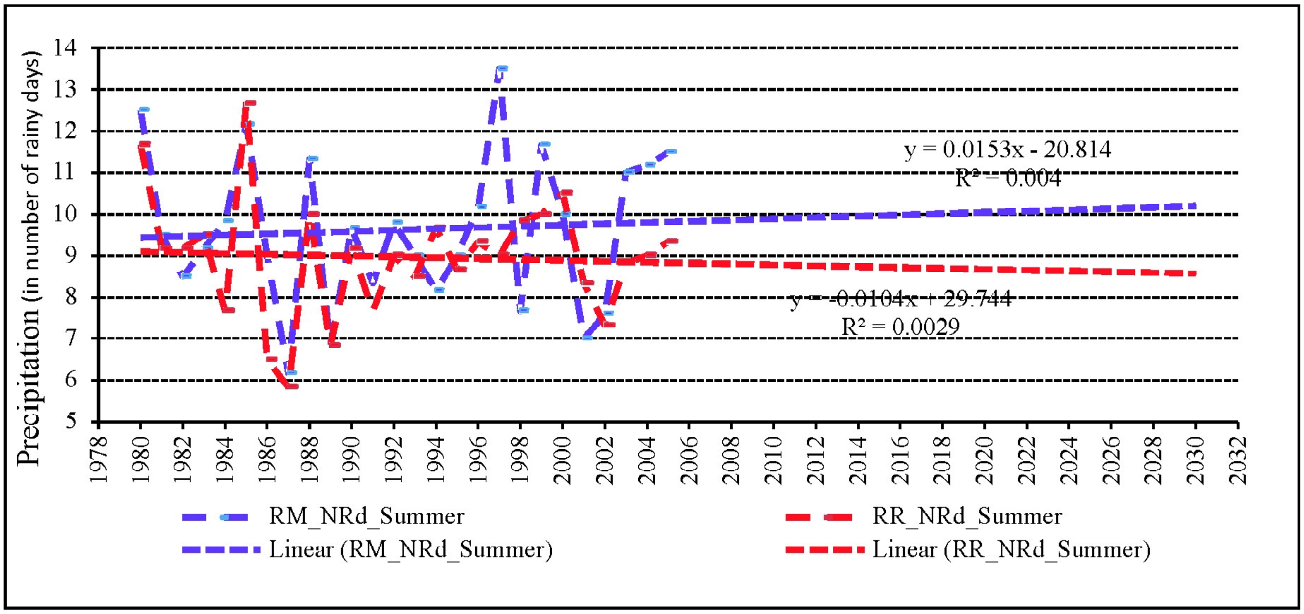

Figure 10: Trend of number of rainy days in a month of Mukhim weather station during summer season ($R_{M\_NRd\_summer}$), and trend of number of rainy days in a month Mukteshwar weather station during summer season ($R_{R\_NRd\_summer}$)

Sheet. In the case of Helheim Glacier, researchers used satellite images to determine the movement and retreat of the glacier. Satellite images and aerial photographs of Helheim Glacier from the 1950s and 1970s show that the glacier tongue had remained in the same level for decades. During 2001 the glacier began retreating rapidly, and by 2005 the glacier has been retreated a total of 7.2 km with a rate of 20 to 35 m per day during that period *(Howat et al., 2005; Howat et al., 2011).*

Using satellite radar interferometer observations of Greenland, it was detected that the acceleration of ice discharge in the west and particularly in the east doubled the ice sheet mass deficit in the last decade from 90 to 220 km^3 per year. This will certainly accelerate the increased contribution of Greenland to global sea-level rise will *(Rignot and Kanagaratnam, 2006)*. Studies on the flow of several large glaciers showed an accelerated retreat of Greenland Ice Sheet. This change, combined with increased melting, suggests that existing estimates of future sea-level rise are too low *(Dowdeswell, 2006)*. Greenland was not an exception; many of the glaciers on the earth surface were facing the threat of shrinking of its size.

During the 20th century glaciers and snow cover have experienced extensive loss in mass balance which have contributed to sea level rise. Mass loss of global glaciers and ice caps (excluding those around Greenland and Antarctic ice sheets) was estimated to be a sea level equivalent of 0.50±0.18 mm per year. Glacier fluctuations show a strong statistical correlation with air temperature at least at a large spatial scale throughout the 20th century *(Greene, 2005)*. Analyses of glacier mass balances, volume changes, length variations and homogenized temperature records for the western portion of the European Alps *(Vincent et al., 2005)* clearly indicate the role of precipitation changes in glacier variations in the 18th and 19th centuries. Nesje and Dahl (2003) reported the glacier advances in southern Norway in the early 18th century due to increased winter precipitation rather than colder temperatures. The biggest glacier mass losses reported were from Alaska with 0.11 mm per year sea level equivalent from 1960/1961 to 1989/1990 and 0.24 mm per year SLE from 1990/1991 to 2002/2003 (see figure 11).

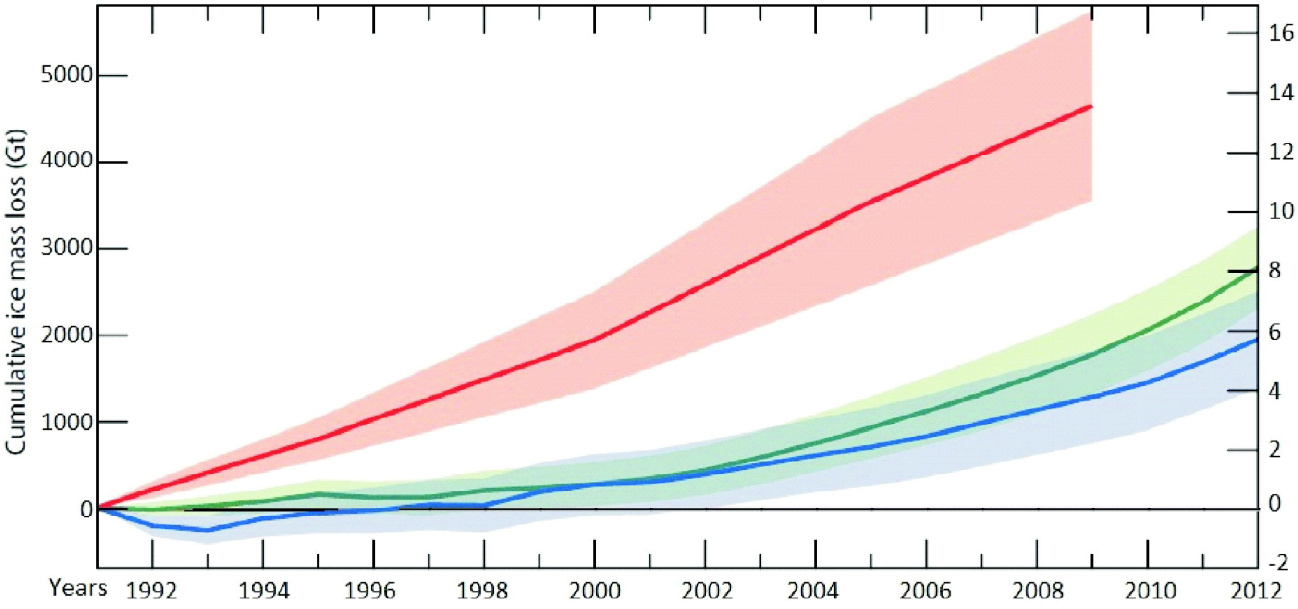

Figure 11: Cumulative ice mass loss from glaciers (red line) and ice sheets (Greenland in green line and Antarctica in blue line), in sea level equivalent, is 1.0 to 1.4 mm per year for 1993-2009 and 1.2 to 2.2 mm per year for 2005-2009

Source: IPCC AR5, Climate change 2013: The Physical Science Basis

The Gangotri glacier is a system of as many as 32 tributary glaciers ranging from 1.05 km^2 to 17.70 km^2 in area is one of the largest in the Himalayas has been constantly receding since measurements began in 1780. Bhambri et al. (2012) in his study shows that Gangotri Glacier lost 0.41±0.03 km^2 from its front at the rate of approximately 0.01 km^2 per year from 1965 till 2006. However, over the last 25 years of the 20th century the rate was increased and it has retreated more than 850 meters i.e. 34 m year^{-1} and 76 meters from 1996 till 1999 i.e. 25 m year^{-1} (see image 12).

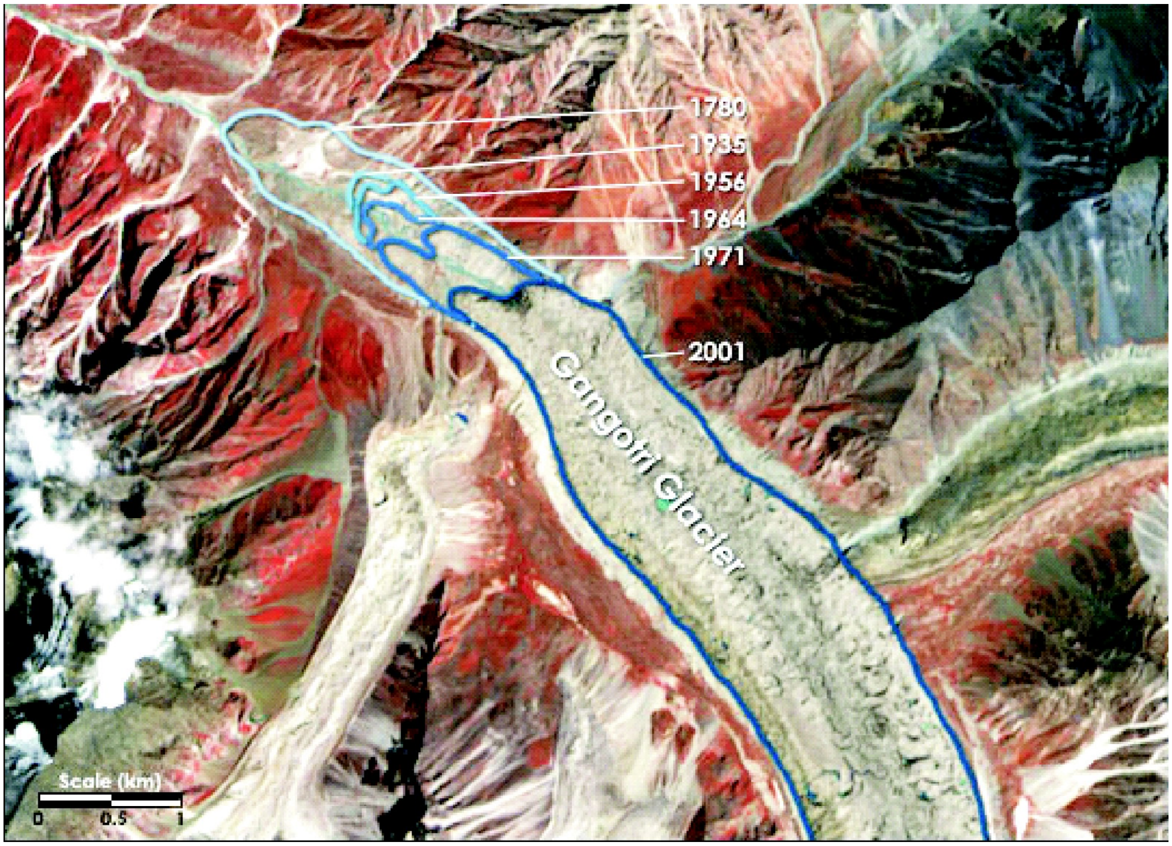

Figure 12: Retreat of Gangotri glacier since 1780. The false-color image shows the Gangotri Glacier, situated in the Uttarkashi District of Garhwal Himalaya. The blue contour lines drawn here to show the recession of the glacier's terminus over time are approximate

Source: NASA image by Jesse Allen, Earth Observatory; based on data provided by the ASTER Science team

The tiny and small glaciers are retreating relatively at a faster rate. For example, Chhanguch, a tributary glacier of the Pindari, retreated at more than 10 times higher rate (i.e. 85 m year^{-1}) during 1958 to 1966 compared to the retreat rate (i.e., 25 m year^{-1}) of its master Pindari glacier. Similarly, the rate of retreat of the two tributary glaciers, viz., the Raktvarna and Thelu is near about two times higher compared to the retreat rate (19 m year^{-1}) of their master glacier, viz., the Gangotri. Numbers of tiny and small glaciers have completely disappeared from the region, which is not documented. Signatures of development of pro-glacial lakes have started coming up in the region, which is another sharp evidence of the impact of global warming in the region *(see table 1)*.

Table 1
Rate of recession of different glaciers of Uttarakhand

Name of Glacier	*Period*	*Duration*	*Recession*	*Rate of Retreat*
Gangotri	1936–1996	61 years	1147 m	19 m year^{-1}
Pindari	1845–1906	61 years	1600 m	26.22 m year^{-1}
	1906–1958	52 years	1040 m	20.0 m year^{-1}
	1958–1966	8 years	200 m	25.0 m year^{-1}
	1885–1966	121years	2840 m	23.47 m year^{-1}
Milam	1849–1957	108 years	1350 m	12.5 m year^{-1}
Dokriani	1962–1991	29 years	480 m	16.5 m year^{-1}
	1991–2000	9 years	161.15 m	18.0 m year^{-1}
Tributary Glaciers				
Chhanguch	1958–1966	8 years	680 m	85 m year^{-1}
Thelu	1962–2004	42 years	1248 m	30.66 m year^{-1}
Raktvarna	1962–2004	42 years	1585 m	37.73 m year^{-1}

Source: SPACC, 2014

CONCLUSION

This paper deals with aftermath of climate change in the Himalaya. Accumulation of greenhouse gases in the atmosphere since the beginning of industrial revolution is largely responsible for the current warming and changes to global climate that are witnessing today. Global as well as regional evidences are showing that global climate has got changed and the mean temperature of the planet has gone up and it continues to go up at an increasing rate. Mountainous evidences of rapid climate change have now throwing drastic impact over the entire globe. Unprecedented change in climate leads to erratic rainfall in the Himalayas as well in the entire world. This can have unprecedented effects on agriculture, food supply, biodiversity and human health of outreach population of Mountains. It can be seen that global warming is the by-product of human development which has been and still largely driven by fossil energy. As negative consequences of increasing temperature, far reaching glaciers of the Himalayas are depleting readily which are penetrating the equilibrium of water balance in the region.

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