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VARIABILITY OF HIGH-INTENSITY RAINFALL EVENTS UNDER GLOBAL WARMING SCENARIO: A CASE STUDY OF RAMGAD WATERSHED, KUMAUN LESSER HIMALAYA, UTTARAKHAND

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Abstract:

Global warming has become the most apparent threat to humanity on Earth. Under the worldwide warming mechanism, a set of equations is found between thermodynamic and dynamic components that can control the changes in the intensity and frequency of rainfall events over a region. Due to global warming, scientists widely expect these trends to pursue as the earth warms; for each degree of Celsius warming, the air extent of water vapor goes up by about 7 percent. Therefore, an atmosphere with more water vapor can generate more intense rainfall events. In this paper, the study investigates the variability of high-intensity rainfall events under the global warming scenario on an annual and seasonal basis in Ramgad Watershed, Kumaun Lesser Himalaya Uttarakhand, India, over the past fifty years. The study used the ground observed climatic data of the Automated Weather Station [AWS] of the Indian Meteorological Department situated in the watershed for the last 50 years. The result shows that the annual mean temperature of Ramgad Watershed is increased at the rate of 0.18^0C during the past fifty years while the study investigates the watershed recorded a progressively increasing trend in the events of high-intensity rainfall, overall, 123 high-intensity rainfall events with an increasing rate of 0.11% in the past fifty years. Furthermore, during the monsoon month, it has been observed that a considerably large proportion of high-intensity rainfall events fall in the category of severe rainfall events. At the same time, high-intensity rainfall events have shown a declining trend in the watershed during winter, summer, and post-monsoon seasons. The Study concluded that the increasing rate of mean annual and seasonal temperature over the watershed region has progressively increased the variabilities of high-intensity rainfall events, which emerged as the significant environmental ultimatum and diminishing the sustainability of the socio-ecological system and thus increasing the vulnerability of the population to water, food, and livelihood insecurity in rainfed and densely populated Lesser Himalayan Mountains.

Key Words: Thermodynamic, Global Warming, High-Intensity Rainfall Events,

1. Introduction:

Himalaya, which is one of the most massively populated and fast-urbanizing mountains in the world (Heath et al., 2020; Tiwari et al., 2019 and 2021; Tiwari and Joshi, 2012 and 2015) is highly vulnerable to rain-induced hazards in the form of flash flood and cloud burst which generally caused by high-intensity rainfall events due to constant rise in temperature (Trenberth et al., 2003; IPCC,2012). Under global warming, the variability of rainfall is more intense and frequent for heavy rainfall but less frequent and weaker for light rain (Goswami,2006; Fujibe et al.,2005; Chou,2011). For each degree of warming, the air's capacity for atmospheric water vapor increases by about +6% to +7% per degree warming, known as Clausius-Clapeyron scaling (Allen et al.,2014). In simple terms, As the air warms, it can retain more water vapor than cooler temperatures that can subsequently fall as rain (Chou,2011, wester,2019). It is predicted that the temperature in the Indian sub-continent will rise by 3.5 and 5.5ºC by 2100, and on the Tibetan Plateau by 2.5ºC by 2050 and 5ºC by 2100 due to the relies of heat-trapping greenhouse gases into the atmosphere (ICIMOD,2009). As temperature rises, more water evaporates from the soil, plants and ocean, intensifying heavy rainfall events (Allen & Ingram,2002; Alexander et al.,2006) Trenberth et al.,2007). As a result, several landslides, flash floods, and cloud bursts caused wide-scale destruction. Consequently, it may interrupt the fragile Himalayan people's life, livelihood, infrastructure, water supply, and subsistence agriculture economy on a vast scale (Wester,2019).

There is a significant knowledge gap in the understanding of increasing warming and its association with the rainfall intensity in the Himalayas, owning lack of adequate hydro-meteorological data, the Himalayan region has not been included in many essential research works (Wester et al.,2019) However, a few studies have been conducted to understand so far to analyse the trends and variability f temperature and rainfall intensity, particularly at Himalayan region. Bhutiyani et al.2007 did a study and suggested a rise in temperature in the north-western Himalayas during the twentieth century. Dimiri et al.,.2007 investigated the winter temperature and precipitation over the western Himalayas and initiated that temperature is under-estimate and precipitation is over-estimated in the Himalayas. IPCC 2007 pointed out that the average annual mean temperature over Asia including the Himalayas will increase by about 3^{0}C by the 2050s and about 5^{0}C by 2080s and average annual precipitation will increase by 10–30% by the 2080s (IPCC, 2007). Bhutiyani et al. (2009) interpreted the interlinkage between climate change and the precipitation variation in the north-western Himalaya. The study analysed the spatial and temporal patterns of rainfall using the long -term climatic data [1992-2005] of two meteorological stations located at Nainital and Almora districts in the state of Uttarakhand. Basistha et al. (2009) analyzed changes in rainfall pattern for 30 station during the twentieth century in Indian Himalayas and found that there was an increasing trend 1964, after which trends decreased during 1965-1980. Shrestha et al.2011 reported warming rate 0.6 ^{0}C/decade in Nepal central Himalaya during

1977-2002. Nandargi and Dhar (2011) analyzed the frequency of extreme one-day rainfall for 475 stations from 1871-2007 across the Indian Himalayan region. Joshi et al. (2013) examined rainfall trends by correlating it with different indices of extreme rainfall in Uttarakhand Himalaya. Moreover, in the Himalayas, the annual average temperature increased at the rate of 0.2°C per decade over the past five decades (Huggel et al. 2020; Dimri et al. 2021; Krishnan et al. 2019). Kotal et al., (2014) studied the observational aspects of catastrophic heavy rainfall event in the Great Himalayan Ranges in Uttarakhand occurred in June 2013. Xavier et al., (2018) analyzed the dynamic of an extreme rainfall event that triggered a devastating flood in the Greater Himalayan ranges in Uttarakhand. Nevertheless, the rate of increase in temperature has been remarkably high over the last decades, nearly equal to the global average increase in temperature (Dimri et al. 2021; ICIMOD 2012). Further, the annual mean temperature increased by almost 0.1°C across the Himalayan mountains over the last seventy years, and elevation-dependent warming will increase in the region in the coming decades (Dimri et al. 2021). Further, the annual mean temperature in the Himalayas is expected the rise between 0.3°C and 0.7°C at the end of the 21st century (Krishnan et al. 2019).

Given this, the present study aims to analyze the temperature and rainfall intensity trends and variability over the watershed level in the Himalayan ecosystem. The work presented in this paper is based on the explanation of ground observed daily temperature and rainfall data of the past fifty years (1971-2020) over the Ramgad Watershed, located in Kumaun Lesser Himalaya, Uttarakhand, India.

2. Study Area:

The specific study area selected for this paper is the Ramgad Watershed. The Ramgad Watershed is situated in the Lesser Himalayan ranges of Nainital, Uttarakhand. The Watershed lies between 29°24' to 29°29' N latitudes and 79°29' to 79°39'E longitudes and encompasses a geographical area of nearly 75.02 km^2 between 1025 and 2525 m altitude. Ramgad is one of the principal tributaries of River Kosi in its mountainous part. The site is characterised by diversified terrain and geomorphic landscape, which are reflected in varying magnitudes of slopes and their aspects, variety of soils, natural vegetation and hydrological parameters, and the climatic complexities of the region. Geologically, the area is very complex and constituted by several formations and shows evidence of displacement of rocks, slope failure and multi-cyclic river terraces. The total population of the headwater was 22085 persons in 2017, inhabited in 30 revenue villages. Since the Ramgad watershed is one of the most densely populated area of Kumaun Lesser Himalaya, it has been considered a representative watershed for the present study.

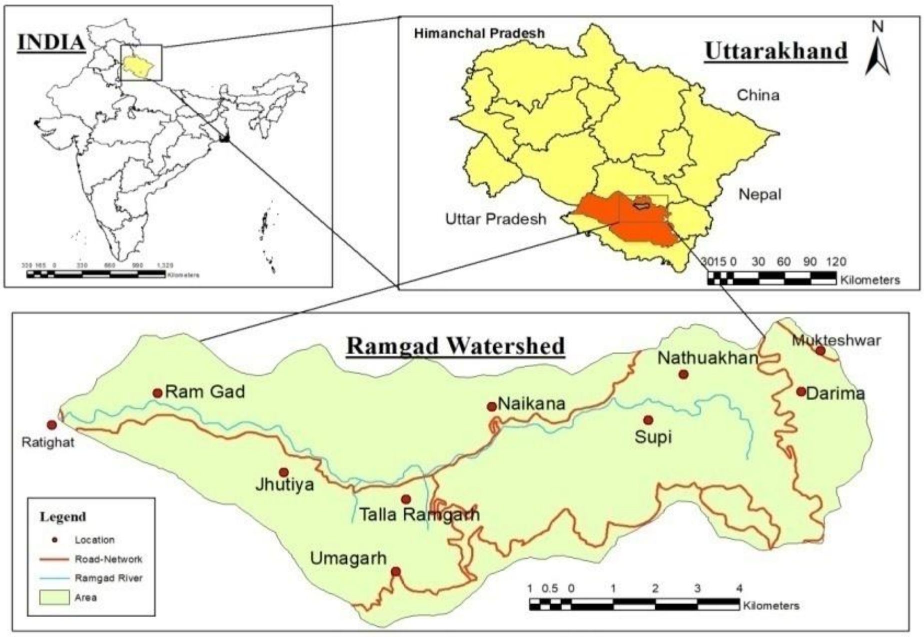

figure number 1: location map of Ramgad watershed

3. Data Source and Methodology:

To understand the changing temperature pattern in the Ramgad watershed, a comprehensive assessment has been carried out based on the ground-observed daily temperature data of the Automated Weather Station [AWS] of the Indian Meteorological Department situated in the Ramgad Watershed. IMD Dehradun collected the daily maximum and minimum temperature data from 1971 to 2020. since this section is comprised of an annual and seasonal analysis of maximum, minimum and mean temperature. The arithmetic average of daily maximum and minimum temperature data calculates the maximum and minimum temperature data. The mean temperature has been calculated by taking the arithmetic average of the daily maximum and minimum temperature. Similarly, the seasonal mean temperature was also calculated by averaging that particular season's daily minimum and maximum temperature. The high-intensity rainfall events have been divided into 'three' categories according to their intensity through the following criteria of IMD revised classification of high-intensity rainfall for 24-hour accumulation Forecasting Circular 5/2015(3.7) 2015. Mainly, the 'rainfall range in [mm]' and 'Percentile' parameters have been adopted for calculating high-intensity rainfall over the Watershed. This is as follows: [i] heavy rainfall ranges between 64.5mm and 115.5 mm/day (percentile ranges between 95 and 99) [ii] very heavy rainfall varies between 115.6 and 204.4 mm/day (percentile ranges between 99 and 99.9) [iii] extremely heavy rainfall, above 204.4 mm/day (percentile above 99.9). As per the approach of IITM (Indian Institute of Tropical Meteorology Pune), the season is divided into four parts [i] The cold and dry winter season (December-February), [ii] The hot and dry summer (March-May), [iii] The hot and wet rainy season (June-September) and [iv] The Retreating south-west monsoon (October-November), the same approach of IITM is followed here to examine the seasonal rainfall trends and distribution over Ramgad Watershed.

4. Result and Discussion

4.1 The Annual Mean Temperature Trends in Ramgad Watershed

The temperature is the most important physical quantity, determining the climatic system's fundamental properties. The temporal distribution of mean annual temperature trends over 1971-2020 in the Ramgad watershed is presented in Table 4.1. It has been shown to increase the mean annual temperature for 1971-2020 gradually. The annual mean temperature was recorded at 13.69^{0}C, with an increasing rate of 0.18^{0}C during the past fifty years Table no.4.1.2(Figure no.4.1.1). The annual mean maximum temperature exhibited a growing trend, with a mean maximum temperature of 18.85^{0}C and an rising rate of1^{0}C during the past fifty years Table no.4.1.2 (figure no.4.1.2). while the annual mean minimum temperature displayed significantly increasing trends of 5.84^{0}C with an increasing rate of 0.25^{0}C during the past fifty years Table no.4.1.2 (figure no.4.1.3). As evident from Table, the highest mean annual temperature (15^{0}C) was registered in 2010, and the mean annual temperature (12.5^{0}C) was recorded in 1992 in Ramgad Watershed during the last 50 years**.** Likewise, the annual mean maximum temperature was detected highest (20.36^{0}C) in 1987 and the lowest (17.65^{0}C) in 1971. Following 2009 and 2016 were the second and third hottest years when the annual mean maximum temperature rose to 20.2^{0}C and 20.32^{0}C in the region.

On the other hand, thee annual mean minimum temperature was highest (10.21^{0}C) in 2010, and the lowest (5.88^{0}C) was recorded in 1992. Similarly, 1989 and 1991 were the second and third coolest years when the mean annual minimum temperature dropped to 7.4^{0}C and 6.72^{0}C, respectively. Moreover, the extreme maximum temperature of 32.5^{0}C was recorded on 25 May 2012, and the extreme minimum temperature of -7.60^{0}C was recorded on 1registeredy 1992 during the last 50 years in Ramgad Watershed.

Table no. 4.1.1: The Annual Mean Temperature Trends in Ramgad Watershed

SI.No.	Years	Annual Mean Temperature (^{0}C)	Annual Mean Maximum Temperature (^{0}C)	Annual Mean Minimum Temperature (^{0}C)
1.	**1971**	12.98	17.65	8.31
2.	**1972**	13.71	18.72	8.71
3.	**1973**	13.49	18.33	8.66
4.	**1974**	14.13	19.97	8.3
5.	**1975**	13.28	18.49	8.07
6.	**1976**	13.38	18.52	8.29
7.	**1977**	13.3	18.35	8.25
8.	**1978**	13.08	18.19	7.97
9.	**1979**	13.47	19.09	7.86
10.	**1980**	13.6	19.12	8.11
11.	**1981**	13.1	18.53	7.72
12.	**1982**	13	18.24	7.85
13.	**1983**	12.6	17.72	7.53
14.	**1984**	13.54	18.85	8.23
15.	**1985**	13.5	18.64	8.41
16.	**1986**	12.9	18.28	7.64
17.	**1987**	14.64	20.36	8.92
18.	**1988**	13.89	19.05	8.73
19.	**1989**	12.54	17.67	7.41
20.	**1990**	12.55	18.07	8.08
21.	**1991**	12.7	18.33	6.72

22.	**1992**	12.05	18.04	5.88
23.	**1993**	12.91	18.82	7.01
24.	**1994**	NA	NA	NA
25.	**1995**	NA	NA	NA
26.	**1996**	NA	NA	NA
27.	**1997**	NA	NA	NA
28.	**1998**	12.75	18.71	7.89
29.	**1999**	14.7	19.91	9.69
30.	**2000**	13.75	18.58	9.12
31.	**2001**	14.4	19.01	9.67
32.	**2002**	14.2	18.87	9.41
33.	**2003**	13.95	18.98	9.26
34.	**2004**	14.45	19.55	9.45
35.	**2005**	14.3	18.35	9.29
36.	**2006**	14.8	19.67	9.97
37.	**2007**	14.2	19.38	9.18
38.	**2008**	13.8	18.76	8.81
39.	**2009**	14.7	20.2	9.34
40.	**2010**	15	19.9	10.21
41.	**2011**	13.9	19.02	9.67
42.	**2012**	13.85	18.7	9.41
43.	**2013**	13.7	17.75	9.26
44.	**2014**	14.4	19.47	9.45
45.	**2015**	14.1	18.37	9.29
46.	**2016**	14.35	20.32	9.97
47.	**2017**	14.80	19.77	9.18
48.	**2018**	14.55	19.87	8.81
49.	**2019**	13.9	18.48	9.34
50.	**2020**	14.45	18.69	10.21
Average Annual Temperature	**50 years**	**13.69**	**18.85**	**8.54**

Table no.4.1.2: Decadal changes in temperature trends in Ramgad Watershed.

Decades	Decadal Mean Temperature (^{0}C)	Change in Decadal Mean Temperature (^{0}C)	Decadal Mean Maximum Temperature (^{0}C)	Change in Decadal Mean Maximum Temperature (^{0}C)	Decadal Mean Minimum Temperature (^{0}C)	Change in Decadal Mean Maximum Temperature (^{0}C)
1971-1980	13.44	-	18.64	-	8.25	-
1981-1990	13.29	-0.15	18.54	-0.1	8.05	-0.2
1991-2000	13.22	-0.07	18.73	+0.19	7.71	-0.34
2001-2010	14.35	+1.13	19.26	+0.53	9.45	+1.74
2011-2020	14.17	-0.18	19.09	-0.17	9.26	-0.19
Average Temperature	**13.69**	**+0.18**	**18.85**	**+0.11**	**8.54**	**+0.25**

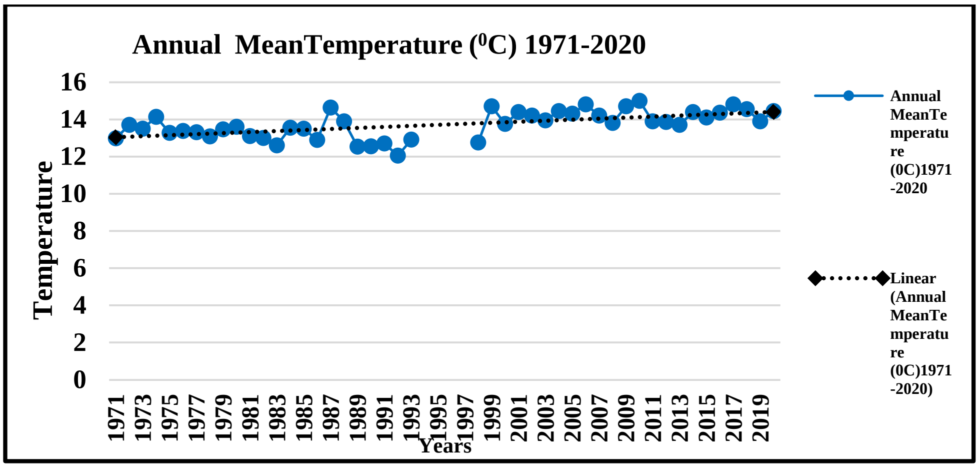

Figure no. 4.4.1 Annual Mean Temperature (^{0}C) 1971-2020

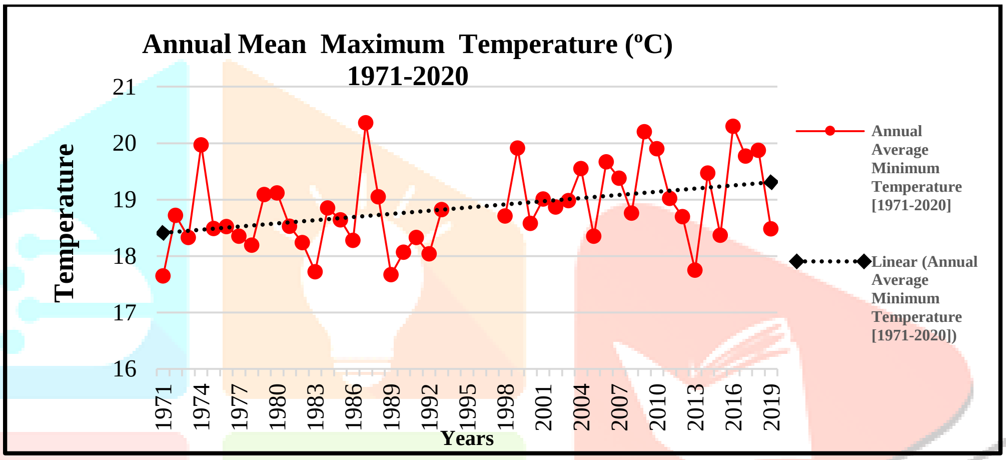

Figure no. 4.4.2 Annual Mean Maximum Temperature (^{0}C) 1971-2020

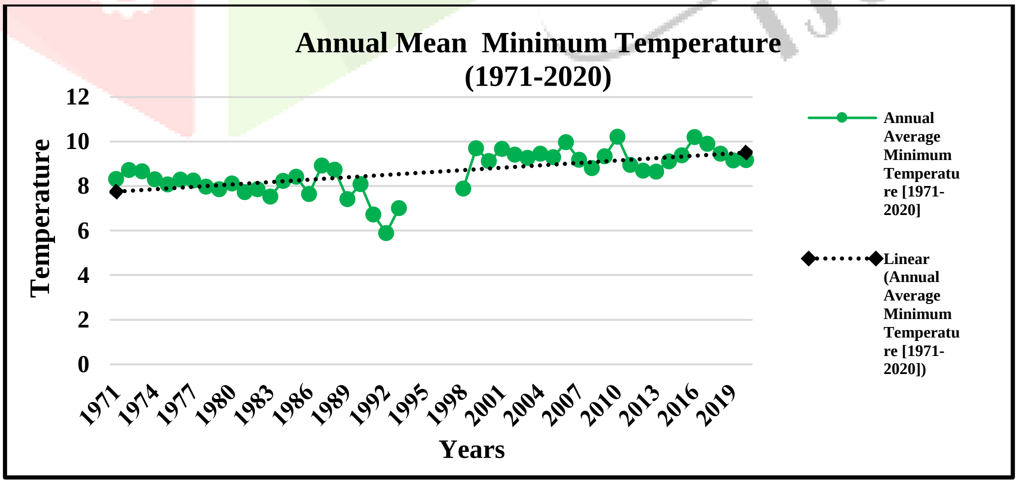

Figure no. 4.4.3 Annual Mean Minimum Temperature (1971-2020)

4.2. The Seasonal Temperature Trends in Ramgad Watershed

All four seasons show significantly increasing trends over 1971-2020 in the region. Therefore, the season-wise detailed analysis of the trends of temperature in the study area is as follows:

4.2.1 Winter Temperature Trends in Ramgad Watershed:

The winter temperature trends of Ramgad Watershed have been illustrated in **Table 4.2.1 and Figure 4.2.1;** The Table shows that the mean winter temperature has registered at 7.86^{0}C with an increasing rate of 0.19^{0}C during the past five decades. The mean winter temperature increased by 0.63^{0}C and 1.75^{0}C between 1981-1990 and 2001-2010; it declined by 0.7^{0}C between 1991-2000 and by 0.9^{0}C between 2011-2020. The winter mean maximum temperature was recorded at 13.34^{0}C with an increasing rate of 0.15^{0}C over the past five decades. The winter mean maximum temperature increased by 0.76^{0}C and by 1.18^{0}C respectively during the decades 1981-1990 and 2001-2010, while the winter mean maximum temperature has risen by 1.18^{0}C, respectively. The winter mean maximum temperature declined by 0.45^{0}C between 1991-2000 and by 0.87^{0}C between 2011-2020. The winter mean minimum temperature was recorded at 2.48^{0}C with an increasing rate of 0.23^{0}C during the past five decades. The winter minimum temperature increased by 0.46^{0}C and 2.23^{0}C respectively during 1981-1,990 and 2001-2010; while it declined by 0.95^{0}C and by 0^{0}C dur the remaining decades in the watershed.

Table no. 4.2.1: Winter Temperature Trends in Ramgad Watershed

Decades	Winter Mean Temperature (^{0}C)	Change in Winter mean Temperature (^{0}C)	Decadal Maximum Temperature (^{0}C)	Change in Tmax. (^{0}C)	Decadal Minimum Temperature (^{0}C)	Change in Tmin (^{0}C)
1971-1980	7.26	-	12.61	-	1.92	-
1981-1990	7.89	+0.63	13.37	+0.76	2.41	+0.49
1991-2000	7.19	-0.70	12.92	-0.45	1.46	-0.95
2001-2010	8.94	+1.75	14.10	+1.18	3.78	+2.32
2011-2020	8.04	-0.90	13.23	-0.87	2.85	-0.93
Average Winter Temperature	7.86	**+0.19**	13.24	**+0.15**	2.48	**+0.23**

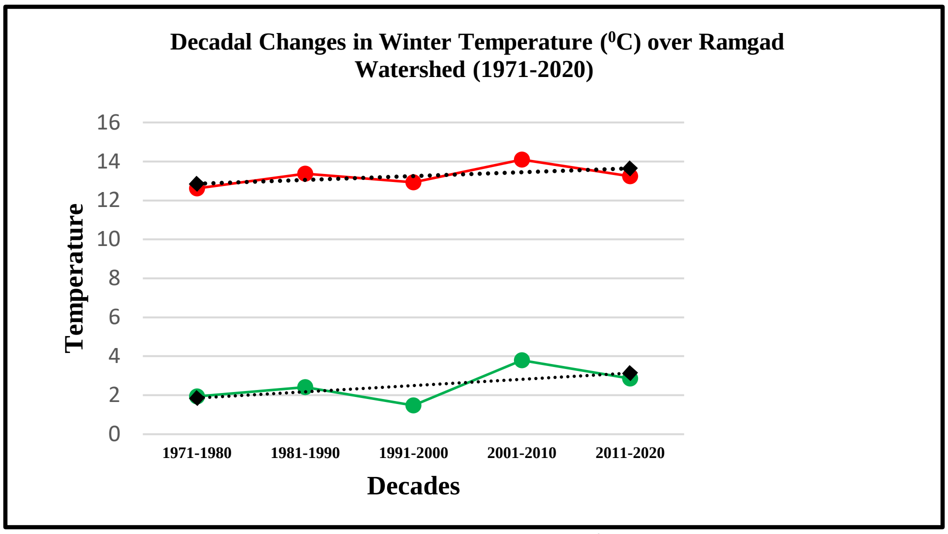

Figure no. 4.2.1 Decadal Changes in Winter Temperature (^{0}C) over Ramgad Watershed (1971-2020)

4.2.2 Summer Temperature Trends in Ramgad Watershed:

The summer temperature trends in Ramgad Watershed are presented in Tables **2 and Figure 4.2.2.** The Table shows that the mean summer temperature was recorded at 15.04^{0}C temperature with an increasing rate of 0.03^{0}C during the past five decades. The mean summer temperature increased respectively by 0.59^{0}C and 1.01^{0}C between 1991-2000 and 2001-2010; while it declined by 0.79^{0}C between 1981-1990 and 0.69^{0}C between 2011-2020. The summer mean maximum temperature was recorded 21.12^{0}C with an increasing rate of 0.05^{0}C during the past five decades. The maximum summer temperature has increased by 1.17^{0}C and by 0.21^{0}C respectively In the decades 1991-2000 and 2001-2010, while it declined by 0.73^{0}C between 1981-1990 and by 0.44^{0}C during 2011-2020. Similarly, the summer mean minimum temperature was recorded at 8.97^{0}C with an increasing rate of 0.06^{0}C during the past five decades. The summer mean minimum temperature increased by 0.86^{0}C and b.8^{0}C respectively during the decades 1981-1990 and 2001-2010, while it declined by 0.86^{0}C, 0.17^{0}C, 0.53^{0}C, during 1981-1990,1991-200 and 2011-2020 respectively the Watershed.

Table no. 4.2.2 Summer Temperature Trends in Ramgad Watershed

Decades	Mean Temperature (^{0}C)	Change in mean Summer Temperature (^{0}C)	Maximum Temperature (^{0}C)	Change in Tmax. (^{0}C)	Minimum Temperature (^{0}C)	Change in Tmin (^{0}C)
1971-1980	15.06	-	20.98	-	9.15	-
1981-1990	14.27	-0.79	20.25	-0.73	8.29	-0.86
1991-2000	14.86	+0.59	21.61	+1.17	8.12	-0.17
2001-2010	15.87	+1.01	21.82	+0.21	9.92	+1.8
2011-2020	15.18	-0.69	20.98	-0.44	9.39	-0.53
Average Winter Temperature	15.04	**+0.03**	21.12	**+0.05**	8.97	**+0.06**

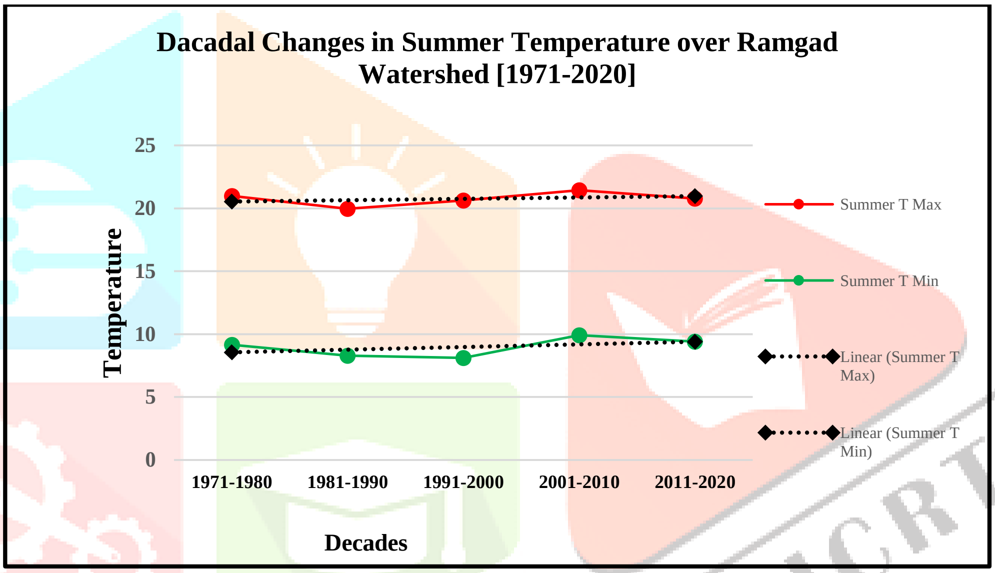

Figure No. 4.2.2 Decadal Changes in Summer Temperature over Ramgad Watershed (1971-2020)

4.2.3 Monsoon Temperature Trends in Ramgad Watershed:

The monsoon temperature trends of Ramgad Watershed have been presented in **Table 4.2.3 and Figure 4.2.3.** The table shows that the mean monsoon temperature has registered 17.39^{0}C with an increasing rate of 0.30^{0}C during the past five decades. The mean summer temperature increased by respectively by 0.18^{0}C,1.05^{0}C and 0.18 ^{0}C during the decades of 1981-1990, 2001-2010 and 2011-2020; while it declined by 0.20^{0}C between 1991-2000. The monsoon means the maximum temperature has been recorded 21.5^{0}C temperature with an increasing rate of 0.20^{0}C during the past five decades. Between the decades of 1981-1990 and 1991-2000, the monsoon maximum temperature has increased by 0.46^{0}C and by 0.03^{0}C respectively. Between the decades of 2001-2010 and 2011-2020, the monsoon means maximum temperature significantly increased by 0.33^{0}C and by 0.01^{0}C in the Watershed. Similarly, the monsoon means minimum temperature had recorded 13.28^{0}C and with an increasing rate of 0.30^{0}C with an increasing rate of 0.39^{0}C during the past five decades. Between the decades of 1981-1990 and 1991-2000, the monsoon means the minimum temperature has declined by 0.10^{0}C and by 0.43^{0}C respectively; while it increased by 1.76^{0}C and by 0.36^{0}C between 2001-2010 and 2011-2020 the watershed.

Table no. 4.2.3: Monsoon Temperature Trends in Ramgad Watershed

Decades	Mean Temperature (^{0}C)	Change in mean Monsoon Temperature (^{0}C)	Maximum Temperature	Change in Tmax. (^{0}C)	Minimum Temperature (^{0}C)	Change in Tmin (^{0}C)
1971-1980	16.91	-	20.98	-	12.85	-
1981-1990	17.09	+0.18	21.44	+0.46	12.75	-0.10
1991-2000	16.89	-0.20	21.47	+0.03	12.32	-0.43
2001-2010	17.94	+1.05	21.8	+0.33	14.08	+1.76
2011-2020	18.12	+0.18	21.81	+0.01	14.44	+0.36
Average Monsoon Temperature	17.39	**+0.30**	21.5	**+0.20**	13.28	**+0.39**

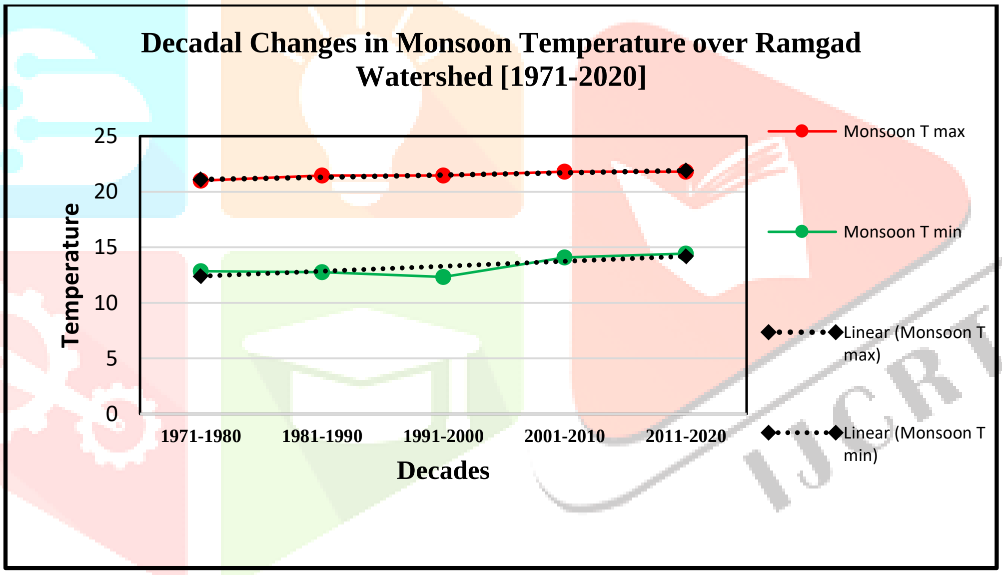

Figure no. 4.2.3 Decadal Changes in Monsoon Temperature over Ramgad Watershed {1971-2020)

4.2.4 Post-Monsoon Temperature Trends in Ramgad Watershed:

The Post-monsoon temperature trends of Ramgad Watershed have been presented in **Table 4.2.4 and Figure 4.2.4.** The Table shows that the mean post-monsoon temperature was registered at 13.04^{0}C with an increasing rate of 0.23^{0}C during the past five decades. The mean post-monsoon temperature increased respectively by 0.37^{0}C,0.76^{0}C, and 0.29 ^{0}C between 1991-2000, 2001-2010, and 2011-2020, while it declined by 0.50^{0}C between 1981-1990 in the watershed. The post-monsoon mean maximum temperature was recorded at 18.62^{0}C with an increasing rate of 0.04^{0}C during the past five decades. The post-monsoon means maximum temperature increased by 0.13^{0}C, 0.32^{0}C, and 0.58^{0}C between 1991-2000, 2001-2010 and 2011-2020, while it declined by 0.32^{0}C between 1981-1990 in the watershed. Similarly, the post-monsoon mean minimum temperature was recorded at 7.47^{0}C with an increasing rate of 0.28^{0}C during the past five decades. The post-monsoon means minimum temperature increased by 0.060C, 1.150C, and 0.060C between 1991-2000, 2001-2010, and 2011-2020, while it declined by 0.68^{0}C between 1981-1990 in the watershed.

Table no. 4.2.4 Post-Monsoon Temperature Trends in Ramgad Watershed

Decades	Mean Temperature (^{0}C)	Change in mean post-Monsoon Temperature (^{0}C)	Maximum Temperature	Change in Tmax. (^{0}C)	Minimum Temperature (^{0}C)	Change in Tmin (^{0}C)
1971-1980	12.87	-	18.56	-	7.19	-
1981-1990	12.37	-0.50	18.24	-0.32	6.51	-0.68
1991-2000	12.74	+0.37	18.37	+0.13	7.11	+0.6
2001-2010	13.50	+0.76	18.69	+0.32	8.26	+1.15
2011-2020	13.79	+0.29	19.27	+0.58	8.32	+0.06
Average Post-Monsoon Temperature	13.04	**+0.23**	18.62	**+0.04**	7.47	**+0.28**

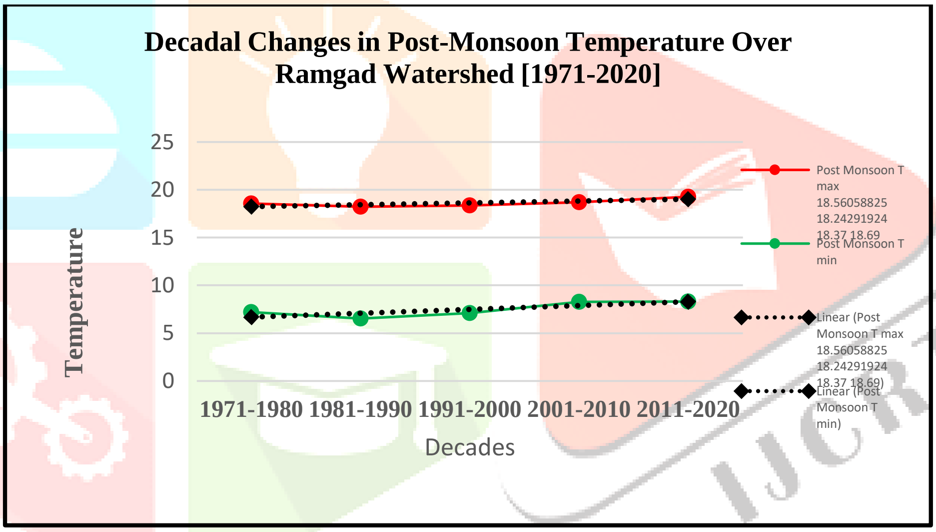

Figure no. 4.2.4 Decadal Changes in Post-Monsoon Temperature Over Ramgad Watershed (1971-2020)

4.3 Annual Trends of High-Intensity Rainfall Events in Ramgad Watershed:

The annual trends of high-intensity rainfall events in Ramgad Watershed over the past fifty years, 1971-202,0 have been presented in **Table 4.3.1 and Figure 4.3.1.** The Table shows that the Watershed observed a significant growing trend of high-intensity rainfall events over the past fifty years. The Table shows that the Watershed recorded the highest number of high-intensity rainfall events ranging between 4-7 events per year in 2007, 2005, 1980, 1985, 1993,1995,1998, 2000, 2005, 2009, 2010, 2013, 2014, and 2017, while the region experienced the lowest number of high-intensity rainfall events varying from 1 to 3 events per year in 1971, 1974, 1975, 1976, 1977, 1978, 1984, 1987, 1989, 1991, 1992, 1994, 1997, 1999, 2002, 2006, 2009 and 2015 over the past fifty years. As a result, the Ramgad watershed has recorded an overall 123 high-intensity rainfall events with an increasing rate of 0.11% in the past fifty years.

Table no. 4.3.1 Annual Trends of High-Intensity Rainfall Events in Ramgad Watershed

SI.No.	Years	Annual Number of Rainy Days	Number of High-Intensity Rainfall Events
1.	1971	83	1
2.	1972	61	4
3.	1973	81	0
4.	1974	62	1
5.	1975	91	3
6.	1976	75	2
7.	1977	82	1
8.	1978	75	1
9.	1979	60	0
10.	1980	84	4
11.	1981	73	2
12.	1982	81	2
13.	1983	77	3
14.	1984	60	1
15.	1985	88	4
16.	1986	54	3
17.	1987	34	1
18.	1988	71	0
19.	1989	51	2
20.	1990	78	3
21.	1991	56	1
22.	1992	64	1
23.	1993	63	6
24.	1994	72	2
25.	1995	73	5
26.	1996	60	0
27.	1997	79	2
28.	1998	72	6
29.	1999	66	1
30.	2000	81	4
31.	2001	64	0
32.	2002	64	2
33.	2003	72	3
34.	2004	65	3
35.	2005	77	5
36.	2006	68	2
37.	2007	71	3
38.	2008	81	2
39.	2009	55	4
40.	2010	72	5
41.	2011	77	3
42.	2012	76	3
43.	2013	70	4
44.	2014	68	7
45.	2015	75	2
46.	2016	68	3
47.	2017	71	4
48.	2018	66	0
49.	2019	79	0
50.	2020	67	1
Total		3513	**123**

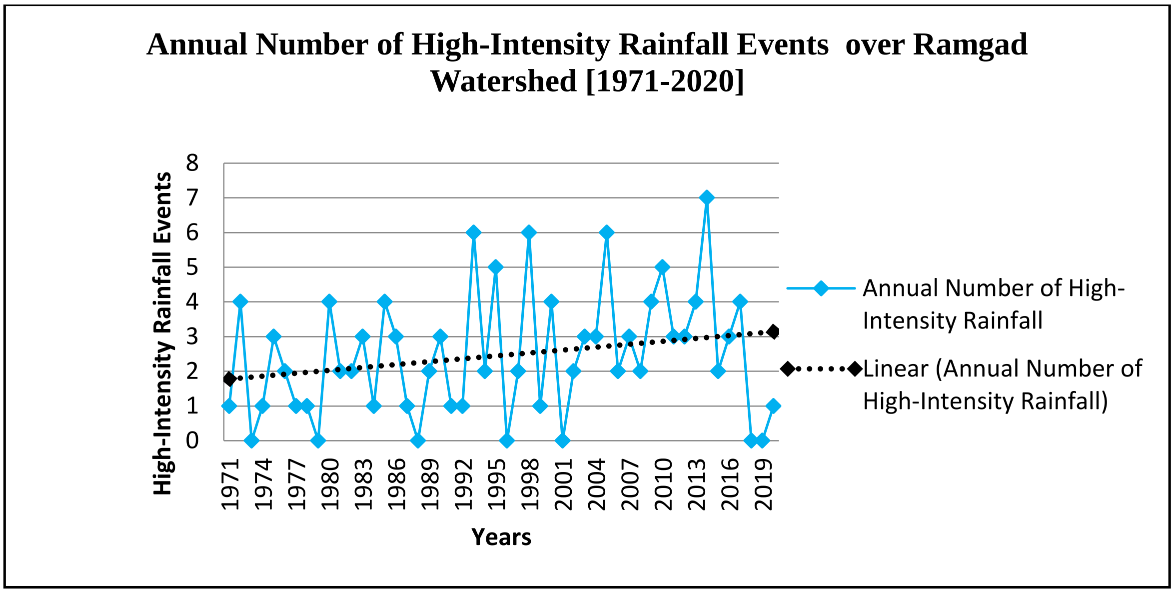

Figure no. 4.3.1 Annual Number of High-Intensity Rainfall Events over Ramgad Watershed (1971-2020)

4.3.2 Seasonal Trends of High-Intensity Rainfall Events in Ramgad Watershed:

The seasonal trends of high-intensity rainfall events in the Ramgad Watershed over 1971-2020 have been illustrated in **Table 4.3.2 and Figure 4.3.2.** The Table makes it clear that the watershed recorded the highest number of events (109) of high-intensity rainfall in the monsoon season, followed by winter (6), post-monsoon (6), and summer season (2) over the past 50 years. This indicates that the monsoon season is the most critical from the viewpoint of the incidences of high-intensity rainfall and their associated risks in the region. Out of the 10 -intensity rainfall events that occurred during the monsoon months, respectively 81, 25, and 3 have been characterized as heavy, very heavy, and extremely heavy rainfall events. Nevertheless, not a single event of extremely heavy rainfall was experienced in the region in the winter, summer, and post-monsoon seasons over the past fifty years.

Table No. 4.3.2 Seasonal Trends of High-Intensity Rainfall Events in Ramgad Watershed

Seasons	Total Rainfall (mm)	Days of High-Intensity Rainfall Events	Categories of High-Intensity Rainfall Events		
			Heavy Rainfall Events	Very Heavy Rainfall Events	Extremely Heavy Rainfall Events
Winter Season (December-February)	6370	6	4	2	0
Summer Season (March-May)	8259	2	1	1	0
Monsoon Season (June-September)	46009	109	81	25	3
Post-Monsoon Season (October and November)	1959	6	5	1	0
Total	**62596**	**123**	**91**	**29**	**3**

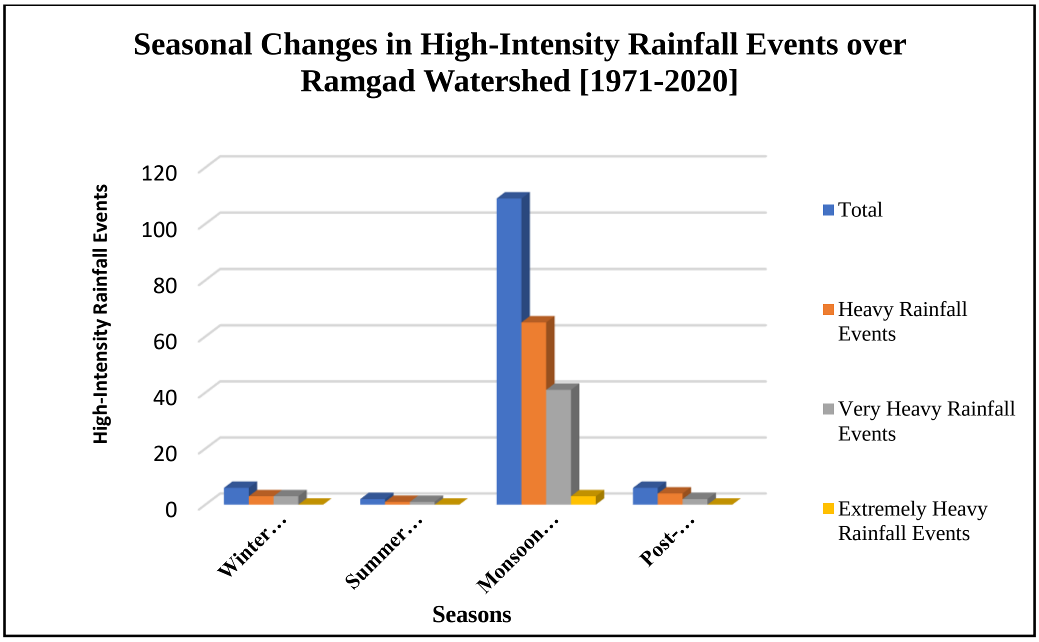

Figure no. 4.3.2Seasonal Changes in High-Intensity Rainfall Events over Ramgad Watershed (1971-2020)

5. Conclusion

The study examines that rainfall intensity has increased more strongly with rising temperatures in the Ramgad watershed over the past fifty years. The study has displayed that the annual mean temperature has increased at the rate of 0.18^{0}C, while high-intensity rainfall events increased by 0.11% in the Ramgad watershed during 1971-2020. The seasonal temperature trends also disclose the temperature variability in the watershed. The seasonal mean, maximum and minimum temperature increase significantly over the four seasons. The events of high-intensity rainfall are increasing not only during the monsoon months but also embellishing more severely. However, the Ramgad watershed experienced fewer quantities of high-intensity rain during the winter compared to the monsoon months. The increasing heavy rainfall events, in union with poverty and marginality, have increased the susceptibility of poor people in the watershed to climate change and climate change-induced risks across the Himalayan region. Given this, it is expected that the present study will contribute towards improving the understanding of how significantly increasing warming affects rainfall intensity and risk of flooding and the need for the Himalayas ecosystem adaptation at watershed levels.

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