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Trend Analysis of Rainfall over the Ramgad Catchment of Kumaun Himalaya

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Abstract: Rainfall is one of the most significant climatological elements and a crucial component of the hydrological cycle. The present research paper studies the variations in the trend of rainfall over the Ramgad Catchment of Kumaun Himalaya, Nainital district, Uttarakhand for the period of 50 years from 1969 to 2019. In the present study, standard statistical techniques, i.e., mean, standard deviation, coefficient of variation and median are applied for the trend analysis of rainfall data for the study region. Variations in monthly and seasonal rainfall are calculated, and the result indicates that the mean monthly rainfall in the Ramgad Catchment is increasing over time at a rate of about 2.38 mm. Further, the trend shows that the rainfall in the Ramgad Catchment is primarily seasonal; the month of July recorded the highest mean rainfall, while the month of November recorded the lowest mean rainfall. The variation of annual seasonal rainfall is also determined, and the findings indicate that the annual monsoon season rainfall peaked in 1980 with a total of around 1716.7 mm, while there was a minimal amount of rainfall in 1994 with 208.9 mm. Over the past few decades, the monsoon pattern in the study area has changed. The adverse effects of rainfall i.e. floods, droughts, etc. have been observed, which affects both natural and human resources. Therefore, analysis of long-term rainfall variability is very important to cope up with changing climatic conditions.

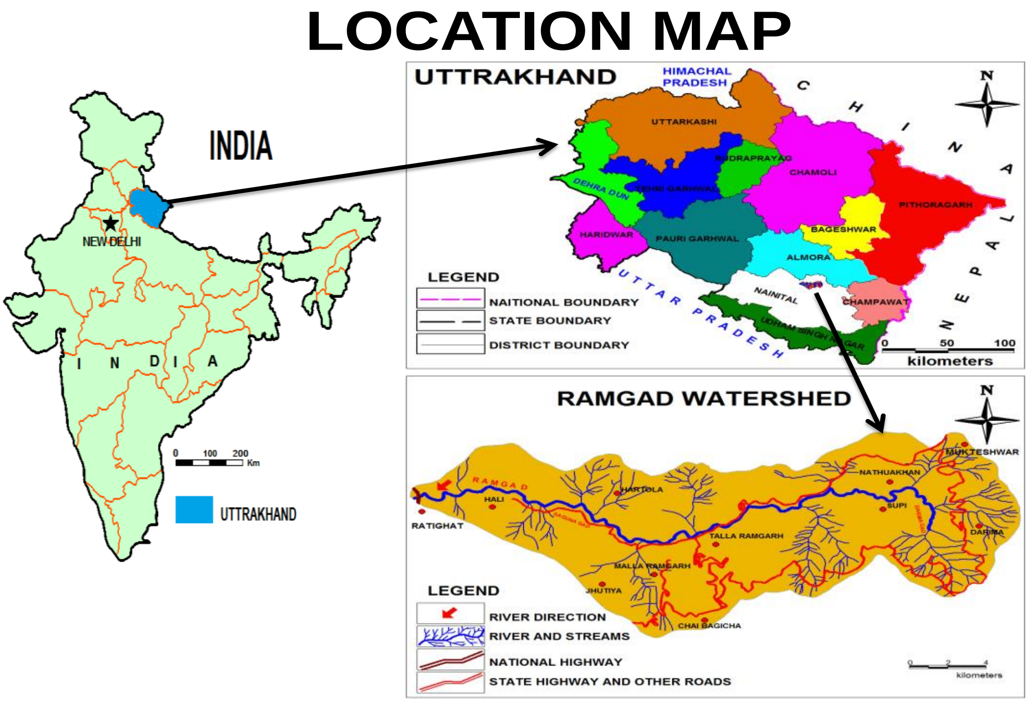
Key words: trend; rainfall; Kumaun Himalaya; Uttarakhand

Introduction: Climate change has become a global environmental phenomenon. It poses a serious threat to the social, economic, and political aspects of human life. Broadly, its impacts are likely to affect the well-being of mankind. Mountain ecosystems have a greater risk of climate change impacts. The Himalayan region is among the most fragile landscapes and is most vulnerable to climate change. During the last few decades, the Himalayas have experienced approximately two to three times greater atmospheric temperature warming than the global average (Xu J., et al., 2009). The region is warming faster than the global average, and during the past five decades, precipitation patterns vary widely, indicating both rising and declining trends. The changing pattern of rainfall in consequence of climate change is now concerning issues to water resource managers and hydrologists (Gajbhiye S., et al., 2015). The

Himalayan region's mountainous farming populations are among the most susceptible to climate change. Impact of climatic variability will be particularly considerable in rain-fed agriculture in fragile ecosystems like Himalaya where balance between the availability and demand exists at a very low level with a high vulnerability (IPCC, 2007) and rainfall variability have contributed to reduced food availability and increased food prices, threatening food and nutrition security (IPCC, 2022). The economy of India is based on agriculture, which heavily depends on rainfall. Significant spatial, temporal and inter-seasonal variations in the trends and variability of rainfall have been noticed in India (Ghosh S., et al., 2009). According to Zhang X., et al. 2007, it was estimated that the 20^{th} century anthropogenic forcing contributed significantly to observed changes in global and regional precipitation. The micro-level rainfall affects agricultural productivity, crop patterns, food security, livestock, water availability, irrigation systems, forest cover, soil fertility, and human health. Higher or lower rainfall, or changes in its spatial and seasonal distribution would influence the spatial and temporal distribution of runoff, soil moisture and groundwater reserves, and would affect the frequency of droughts and floods (Kumar V., et al., 2010). Rainfall anomalies have resulted in the frequency of extreme events such as floods, droughts, hailstorms and shifting patterns of snowfall. Consequently, it is of utmost importance to evaluate how climate change is affecting monsoon rainfall.

Study Area: The study area Ramgad Catchment is situated in the Nainital district of Uttarakhand. The Catchment lies in the Lesser Himalaya between 29^0 24’ and 29^0 29’ northern latitudes and 79^0 29’ and 79^0 39’ eastern longitudes. The geographical area of the Ramgad Catchment is about 77.8 square kilometers. The altitude of the region lies between 1025 and 2346 m above sea level. Ramgad is the principle tributary of Niglat Gad which constitutes part of the Kosi catchment in the Lesser Himalaya. The study area receives rainfall from the north-east monsoon (winter precipitation) and mostly (about 85-90%) from the south-west monsoon (summer precipitation).

Figure 1: Location map of the study region

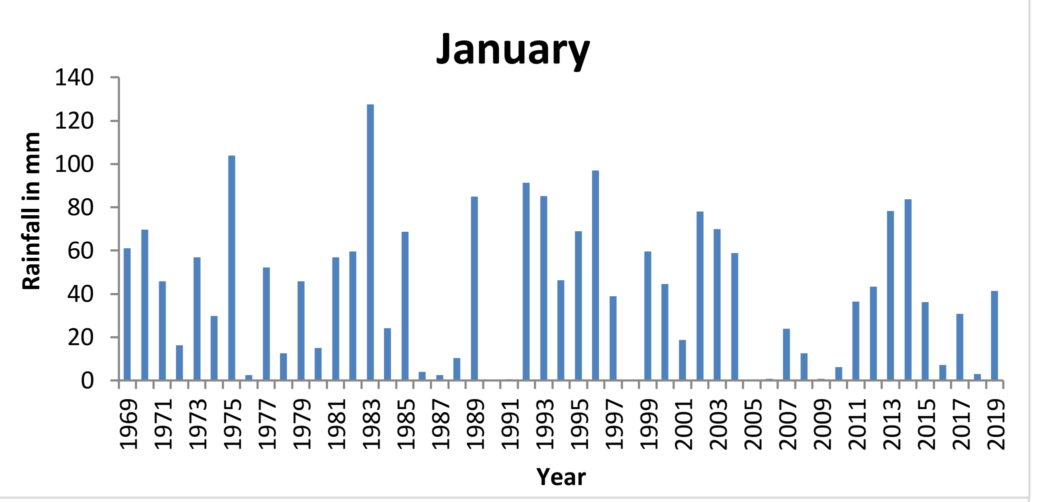


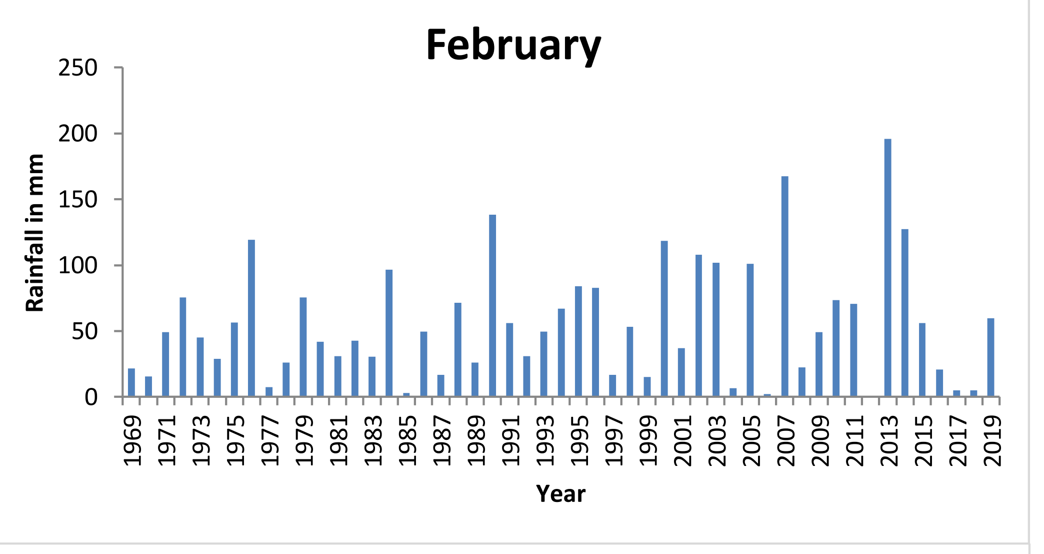
Data Sources and Methodology: The rainfall data for the period of 50 years, from 1969 to 2019, is collected from the Indian Meteorological Department (IMD), Dehradun, at the Mukteshwar observatory. The mean, standard deviation, coefficient of variation, and median are used in the present investigation for the trend analysis of rainfall data for the Ramgad Catchment.

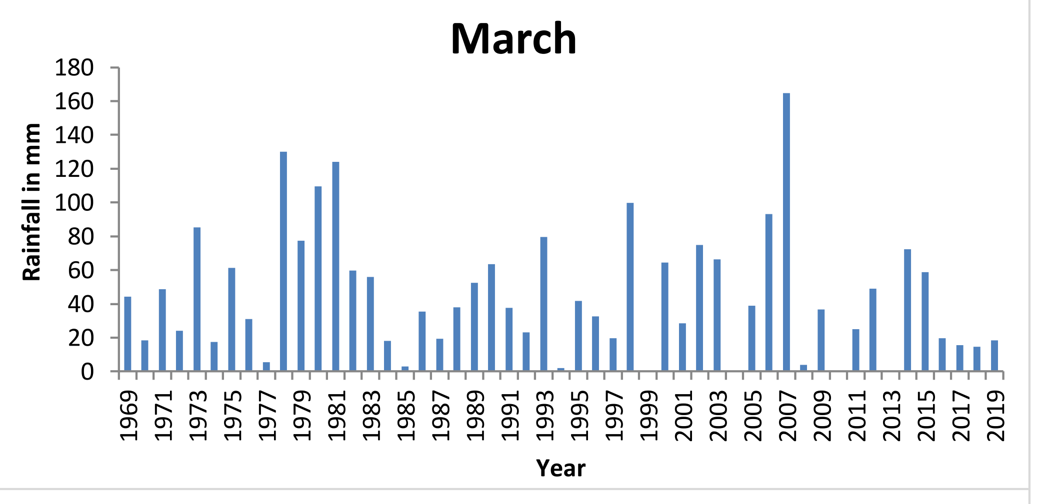
Results and Discussion: In order to detect any changes in rainfall patterns, monthly and seasonal rainfall data are analyzed. Tables and graphs are used to portray the logically quantified data.

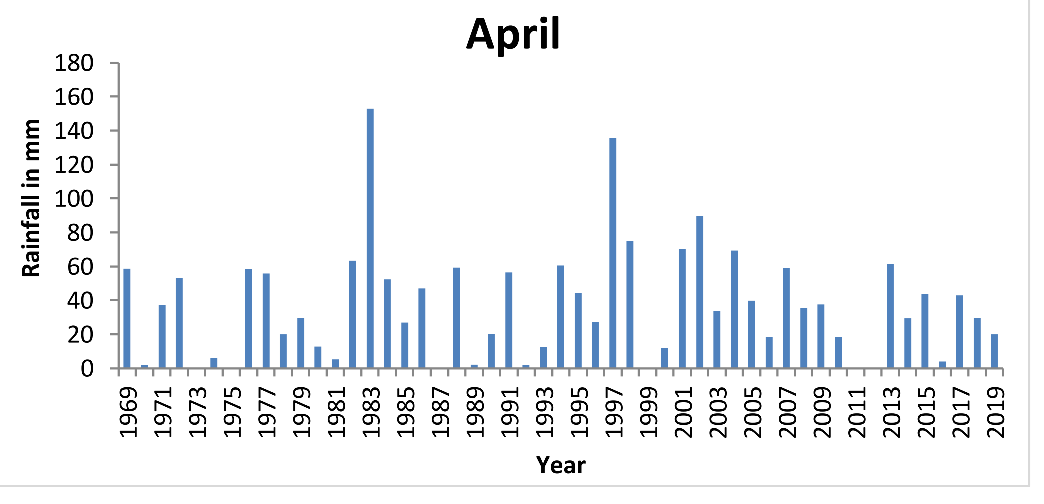
Monthly Variation of Rainfall: The daily rainfall data of the Ramgad Catchment for 50 years (1969–2019) is calculated on a monthly basis. Figure 1 shows the monthly variation of rainfall for individual months from January to December for the 50 year period of the study area. The maximum rainfall has occurred in the month of July with a total of about 14211.4 mm, followed by the months of August (13955.3 mm) and September (9181.5 mm), while the minimum rainfall has occurred in the month of November (400.1 mm), followed by the months of December (958.7 mm) and April (1890.9 mm).

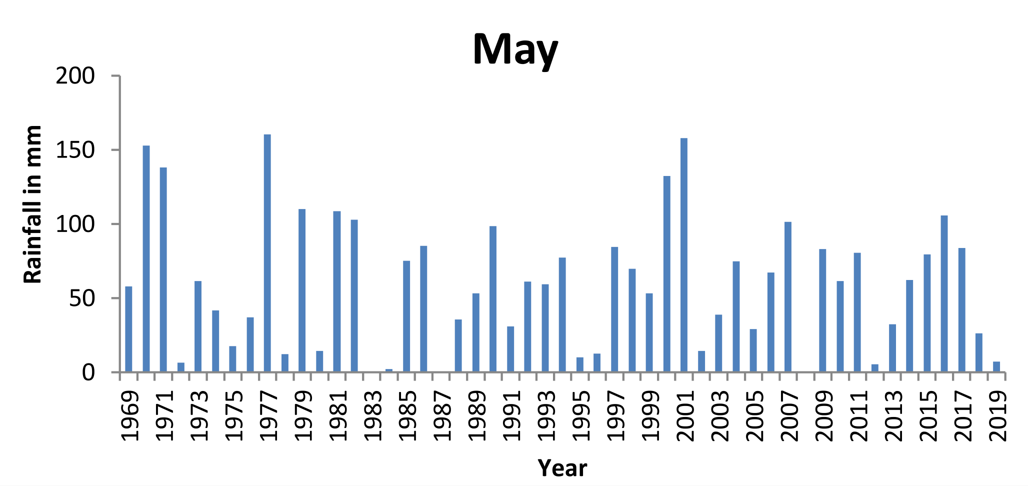
Figure 1 Variation of rainfall of each months of the Ramgad Catchment of 50 years from 1969-2019

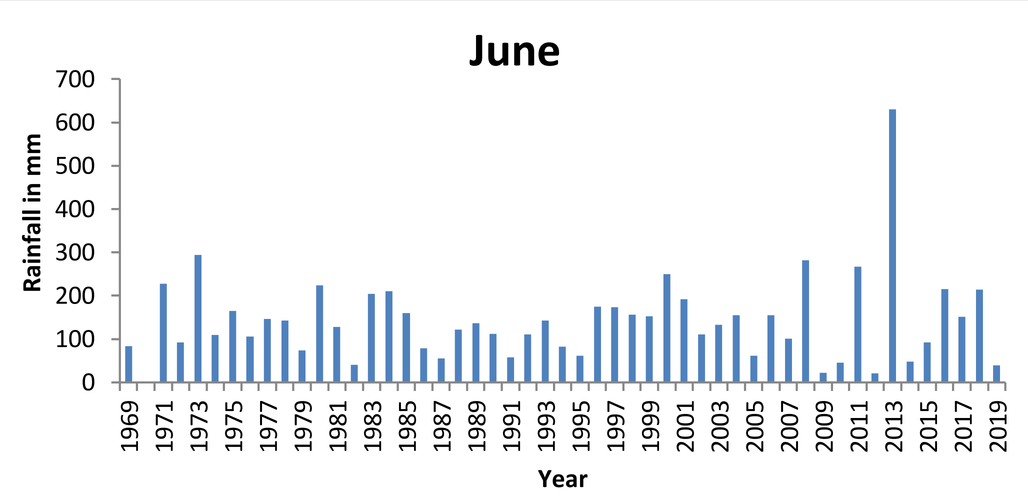

January
Rainfall in mm
Year

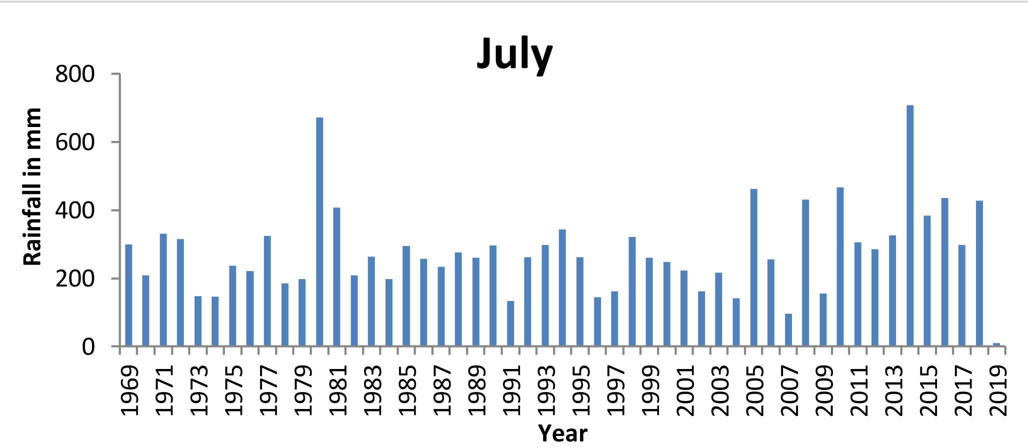

February
Rainfall in mm
Year

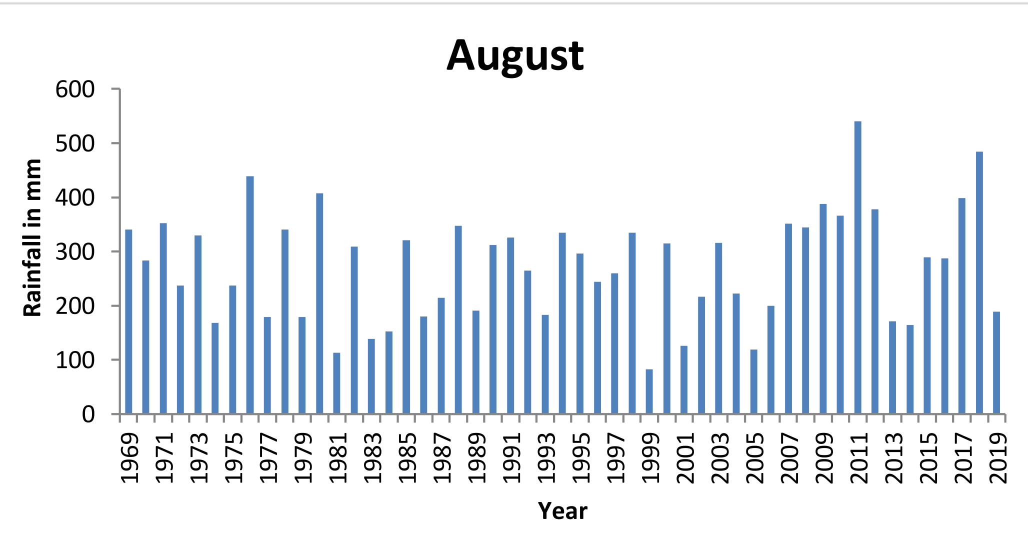

March
Rainfall in mm
Year

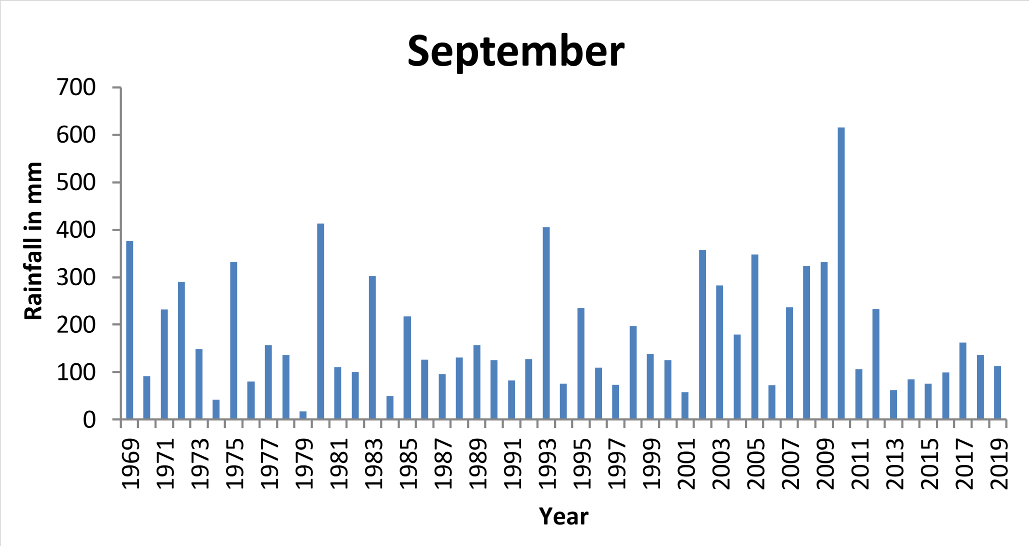

April
Rainfall in mm
Year

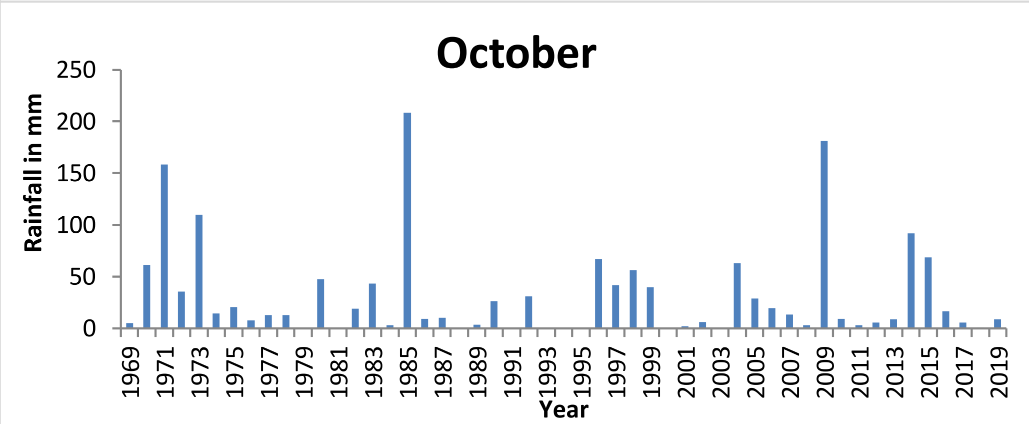

May
Rainfall in mm
Year
200
150
100
50
0
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
2019

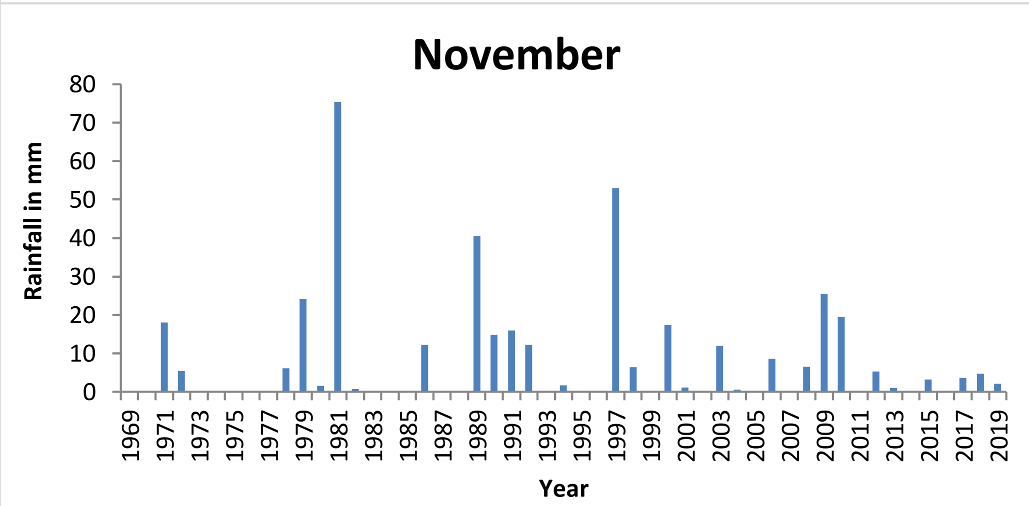

June
Rainfall in mm
Year
700
600
500
400
300
200
100
0

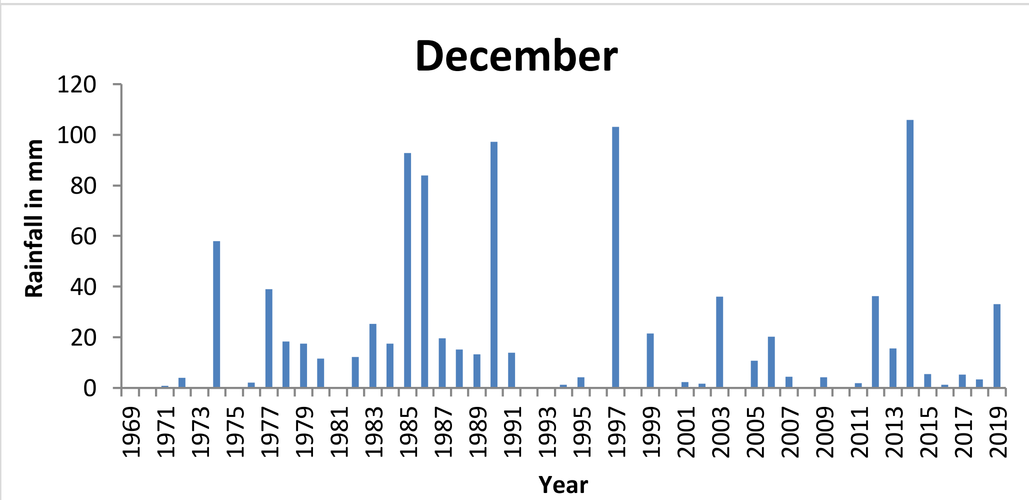

July
Rainfall in mm
Year
800
600
400
200
0


August
Rainfall in mm
Year
600
500
400
300
200
100
0


September
Rainfall in mm
0
100
200
300
400
500
600
700
Year


October
Rainfall in mm
0
50
100
150
200
250
Year


November
Rainfall in mm
0
10
20
30
40
50
60
70
80
Year


December
Rainfall in mm
0
20
40
60
80
100
120
Year

Monthly calculations are used to determine the daily rainfall data for the Ramgad Catchment during a 50-year period (1969-2019). Table 1 represents the results of these statistical techniques, namely the mean S, standard deviation SD, coefficient of variation CV, and median.

Table 1: Trends of rainfall in the Ramgad Catchment for different months from 1969-2019

Months	S	SD	CV (%)	MED
January	41.4	33	79.7	41.5
February	57	44	77.1	49.2
March	46	36.9	80.2	37.9
April	39.3	32.2	82	36.3
May	64	42.6	66.5	61.4
June	144.1	98.1	68	134.5
July	279	127.3	45.6	262.1
August	274	100.5	36.6	287
September	180	121.9	67.7	136
October	31.6	46.4	146.8	13
November	8	14.5	181.2	1.4
December	19.1	29	152	5.3

The means (standard deviation) for the months of January, February, March, April, May, June, July, August, September, October, November, December are 41.4 mm (33 mm), 57 mm (44 mm), 46 mm (36.9 mm), 39.3 mm (32.2 mm), 64 mm (42.6 mm), 144.1 mm (98.1 mm), 279 mm (127.3 mm), 274 mm (100.5 mm), 180 mm (121.9 mm), 31.6 mm (46.4 mm), 8 mm (14.5 mm) and 19.1 mm (29 mm), respectively. The maximum mean rainfall has been found in the month of July, whereas the month of November denotes the minimum amount of mean rainfall over the study area.

Figure 2: Mean monthly variation of rainfall for 50 years from 1969-2019

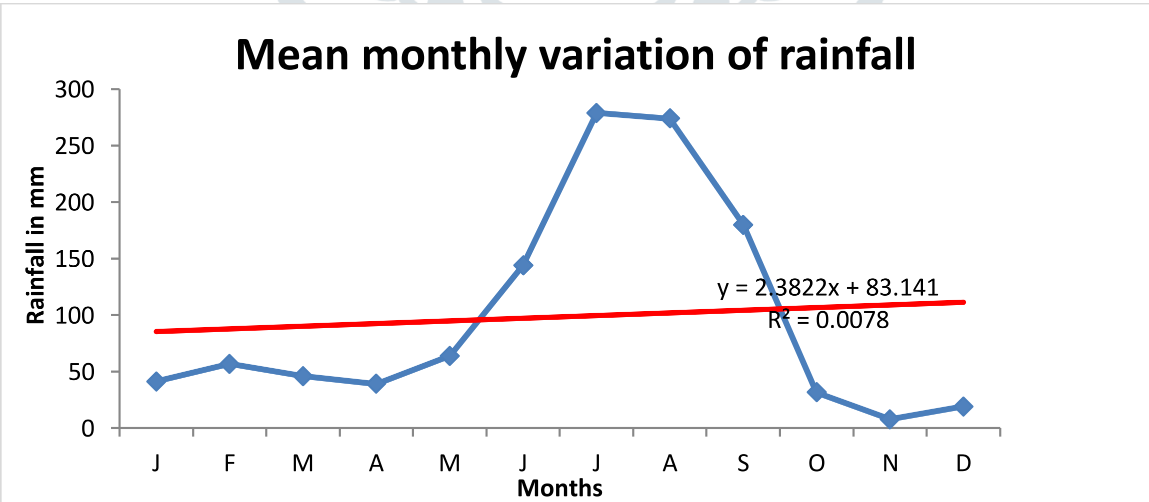
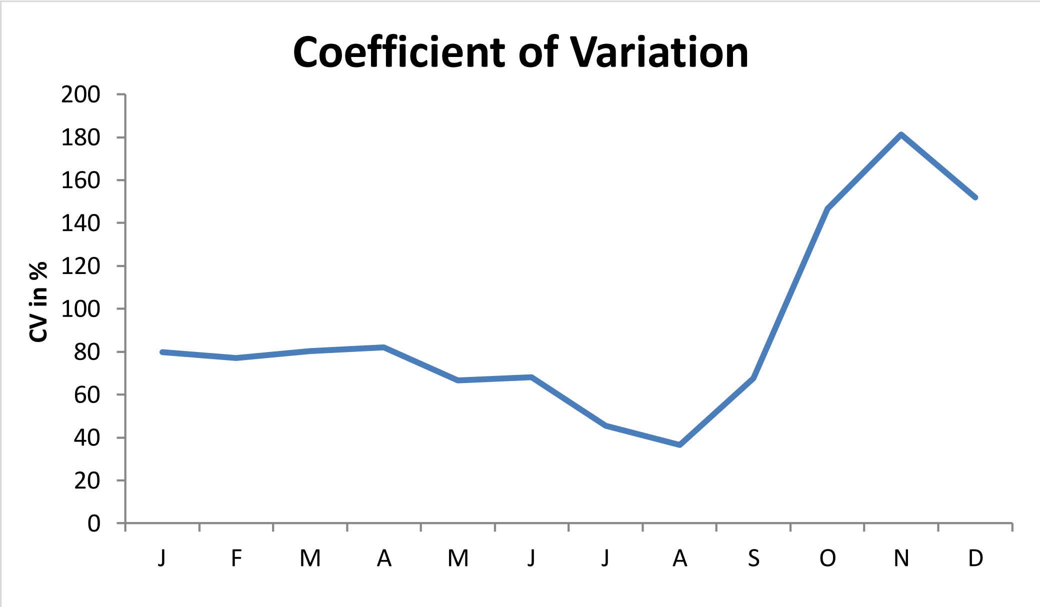


Figure 2 denotes that the curve of mean monthly rainfall data for the Ramgad Catchment. The mean monthly rainfall curve initially shows an increase that reaches to the highest value in the month of July which is about 279 mm followed by August (274 mm) and September (180 mm). It starts decreasing and attains the lowest value in the month of November (8 mm) followed by December (19.1 mm) and October (31.6 mm). As a result, the findings indicate that the Ramgad Catchment's mean monthly rainfall is rising at a rate of about 2.38 mm over time. The coefficient of variation (CV) is used to detect comparisons, and findings are obtained as percentages. According to literature, CV is used to classify the degree of variability as less (CV<20%), moderate (20<CV<30%), high (CV>30%), very high (CV>40%), and CV>70% indicate extremely high inter-annual variability of rainfall (Panda A. and Sahu N., 2019). The coefficients of variation (CV) for the months of January, February, March, April, May, June, July, August, September, October, November, and December are 79.7%, 77.1%, 80.2%, 82%, 66.5%, 68%, 45.6%, 36.6%, 67.7%, 146.8%, 181.2%, and 152%, respectively. As a result, it is determined from the collected data that every month has a CV above 30%, emphasizing the great variability of rainfall. Among all the months, November has the most rainfall variability, while August has the lowest. Figure 3 illustrates the CV values for the monthly variability of rainfall for 50 years (1969–2019).

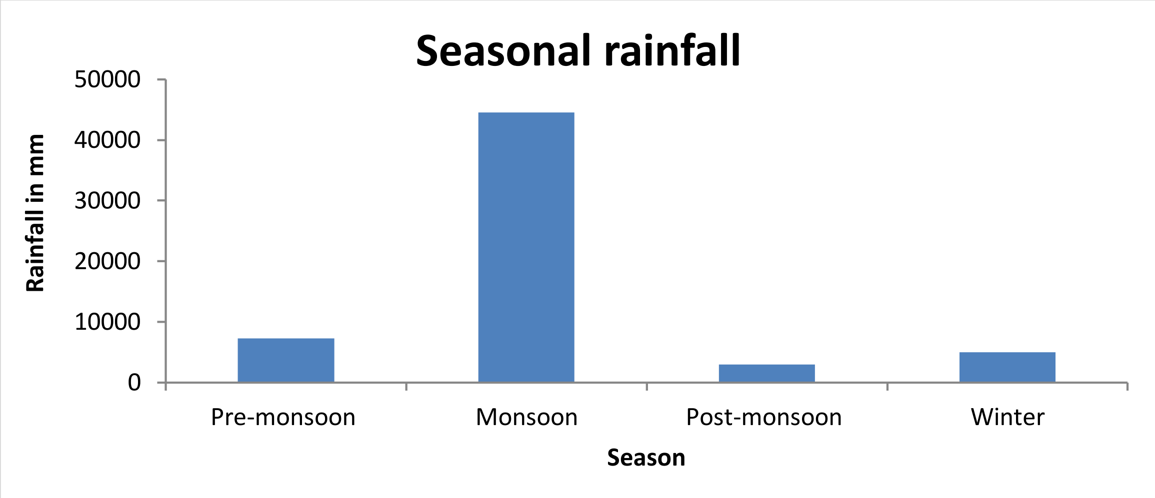
Figure 3: Monthly variability (Coefficient of Variation CV) of rainfall for 50 years



The median values for the months of January, February, March, April, May, June, July, August, September, October, November, and December are 41.5, 49.2, 37.9, 36.3, 61.4, 134.5, 262.1, 287, 136, 13, 1.4, and 5.3, respectively.

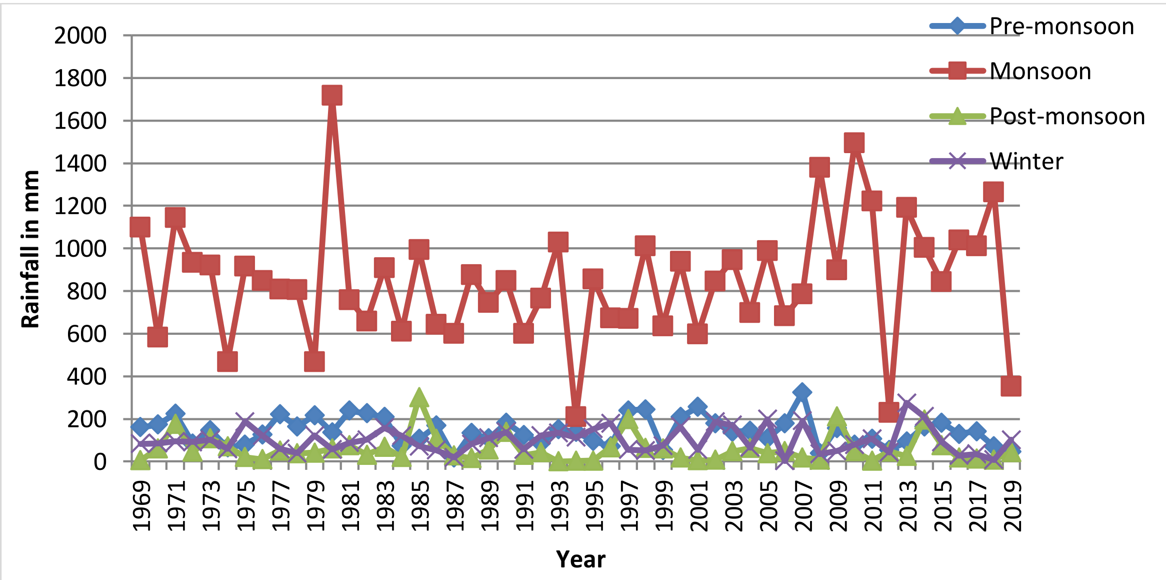
Seasonal variation of Rainfall: To identify trends and variability in rainfall over the Ramgad Catchment, a hydrological year is divided into four seasons: pre-monsoon, monsoon, post-monsoon, and winter. Based on the dynamics of rainfall, the pre-monsoon season (March, April, and May), monsoon season (June, July, August, and September), post-monsoon season (October, November, and December), and winter season (January and February) combinations of months have all been used. Out of the total rainfall of the study area which is about 59727 mm, the pre-monsoon season is received about 7269.2 mm (12.17 %) rainfall whereas maximum about 44554.6 mm (74.6 %) rainfall has occurred during the monsoon season. The winter season rainfall accounts for 4964.5 mm (8.31 %) and minimum rainfall has received in post-monsoon season which is about 2938.6 mm (4.92 %) out of the total rainfall. Thus, the trend reveals that the rainfall in the study area is highly seasonal (Figure 4).

Figure 4: Variation in seasonal rainfall of 50 years for 1969-2019



The annual seasonal rainfall for all four seasons is shown in Figure 5. The annual pre-monsoon season (March, April, and May) rainfall denotes the highest point in the year of 2007 (325.1 mm), followed by the years of 2001 (256.5 mm) and 1998 (244.4 mm), whereas pre-monsoon rainfall dropped down to 19.2 mm in the year of 1987, followed by the years of 2008 (39.4 mm) and 2019 (45.6 mm). Annual monsoon season (June, July, August, and September) rainfall attains the highest points in 50 years (1969–2019).The curve of annual monsoon season rainfall reaches its maximum value in the year 1980 with a total of around 1716.7 mm, followed by the years 2010 (1494.2 mm) and 2008 (1379.8 mm), while the minimum value of rainfall recorded in the year 1994 is about 208.9 mm, followed by the years 2012 (229.4 mm) and 2019 (350.9 mm). According to the analysis, the study area experienced abnormally dry conditions throughout the post-monsoon months of October, November, and December over two different time periods, namely 1993–1995 and 2000–2003. The year 1985 has the highest annual post-monsoon rainfall of all 50 (1969-2019) years, with 301 mm, followed by the years 2014 (210.8 mm), and 2009 (210.7 mm), while the year 1994 has the lowest annual post-monsoon rainfall of all, with only 3.1 mm, and the years 1995 (4.5 mm), and 2011 (4.6 mm) respectively. The annual winter season (January and February) rainfall approached 274.2 mm in the year of 2013, which attains the highest value in 50 years, followed by the years of 2014 (210.8 mm) and 2005 (194.2 mm), while the minimum rainfall of the winter season is 2.8 mm in the year of 2006, followed by the years of 1987 (19.3 mm) and 2008 (35.2 mm).

Figure 5: Variation of annual seasonal rainfall from 1969-2019



Conclusion: The present study uses the analysis of rainfall trends over the Ramgad Catchment of the Kumaun Himalaya for the period of 50 years from 1969 to 2019. Variations in monthly and seasonal rainfall are calculated, and the result indicates that the mean monthly rainfall in the Ramgad Catchment is increasing over time at a rate of about 2.38 mm. Further, the trend shows that the month of July recorded the highest mean rainfall, while the month of November recorded the lowest mean rainfall. The variation of annual seasonal rainfall is also calculated, and the results suggest that with a total of roughly 1716.7 mm in 1980, the annual monsoon season rainfall reached its highest point, while in 1994 there was a minimum amount of rainfall of 208.9 mm.

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