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RESEARCH ARTICLE

RAINFALL VARIABILITY AND CHANGE, AND ITS IMPACT IN THE WESTERN HIMALAYA

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ABSTRACT

The variability and change in rainfall conditions have become a potential future threat, manifesting several adverse impacts on nature and society. This study examines rainfall variability and change and its impact in the Western Himalaya. Rainfall data, obtained from the Indian Institute of Tropical Meteorology (Pune) for the period 1845-2006, has been analyzed by Mann-Kendall Test and descriptive statistics to describe the evolution of the minimum, maximum, and mean rainfall patterns for monthly, annual, decadal and seasonal periods. The Indian Institute of Tropical Meteorology has divided the Western Himalaya into four rain seasons – (1) January and February; (2) March, April, and May; (3) June, July, August, and September; and (4) October, November, and December. Therefore, the data were analyzed based on these seasons. This study depicts high rainfall variability and change in terms of average decadal, annual, seasonal, and monthly rainfall. Rainfall variability is high in the monsoon and winter seasons. The monsoon season spanning for five months now reduced to three months with high intensity of rain. It can be observed from the data that in 1901, the average annual rainfall was only 1000 mm whereas in 1950 it was 3600 mm. The similar situation was noticed in the recent past. Similarly, the rainfall by western disturbances in December and January has been shifted to February and March with low intensity. This has resulted in low crop production and productivity and high geo-hydrological disasters. Furthermore, it also has an impact on the types and distribution of biodiversity resources.

KEYWORDS

Rainfall variability, average rainfall, impact**,** trends, Western Himalaya.

1. INTRODUCTION

The observed variability and changes in rainfall patterns pose a significant threat to the environment, impacting people and livelihoods worldwide. Atmospheric circulation, the seasonal migration of the inter-tropical convergence zone, and the complexity of topography are identified as primary contributors to this variability (Adane et al., 2020). Numerous studies have delved into the implications of rainfall variability, yielding substantial results. Notably, the influence of climate change on cropping patterns and crop production is a prominent concern in various regions, particularly in Africa. In West Africa, researcher explored the effects of climate and habitat on the morphological characteristics and fruit production of Picralima nitida (Akabassi, 2023). The Mutirikwi River in Zimbabwe has experienced substantial impacts from climate change, prompting a study in 2024 on climate change responses and implications for sustainable development goals in the region (Ziti et al., 2024). In Ethiopia, rainfall variability is pronounced in terms of both amount and distribution at spatial and temporal scales (Reda, 2015). The adverse effects of rainfall variability on rainfed crop production, including delays in onset, early cessation, and dry spells throughout the growing season, have been extensively examined (Bahiru et al., 2020; Mugalavai et al., 2008).

The Western Himalayan Region – encompassing Jammu and Kashmir, Himachal Pradesh, and Uttarakhand – stands as one of the most fragile landscapes, highly susceptible to climate change and various natural and human-induced disasters (Shah and Malakar, 2014). This region receives approximately 80% of its annual rainfall during the four months of the monsoon season. Additionally, it receives rainfall from Western Disturbances during the winter, while minimal rain occurs for the rest of the year. Although seasonal and annual variability in rainfall has always been high, the past decades have witnessed an increase in rain intensity with greater variability.

Several studies have highlighted significant changes and variations in rainfall patterns in the Western Himalayan region. Researchers noted a decrease in the average annual number of rainy days during the period 1961-1989 (Kothyari and Singh, 1996). Similarly, researchers observed reduced precipitation in the Chinese part of the Himalaya from 1951 to 1980 (Nakawo et al., 1994). The monsoon rainfall in the Himalaya was described as trendless and random over the last four decades (Kumar et al., 2002). Researchers reported no distinct long-term trend in rainfall records from 1948 to 1994 in the Nepal Himalaya, despite significant variations at annual and decadal time scales (Shrestha et al., 2000). Conversely, the Kosi River basin in Nepal showed an increasing trend in rainfall (Sharma et al., 2001).

Several studies on temperature trends in the Western Himalaya were conducted for different phases of the monsoon (Dash and Hunt, 2007; Dash et al., 2007). These studies revealed significant differences in trends, particularly in minimum temperature and cloud cover during different seasons. Researchers reported India's mean annual temperature increased

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by 0.58°C between 1901 and 2003 (Kothawale and Kumar, 2005). However, another study indicated substantial inter-annual fluctuations in monsoon season mean precipitation data over the Central Himalaya (Shrestha et al., 2000). Notably, a recent observation highlights a shortening of the summer monsoon and an increase in the intensity of rainfall within a shorter period, primarily during the monsoon season.

Precipitation in the Western Himalaya has been decreasing over the last few decades. There has been a substantial reduction in snow cover in both winter and spring. Furthermore, snowmelt has accelerated from winter to spring since 1993, attributed to global warming, as observed by (Kripalani et al., 2003). Simultaneously, the southwest monsoon, a complex ocean-land-atmospheric system (Turner and Annamalai, 2012), exhibits significant spatial and temporal variations in precipitation. Several studies have explored the future evolution of Himalayan monsoon precipitation under warming scenarios (Palazzi et al., 2013, 2015; Pandey et al., 2015; Rajbhandari et al., 2016). These studies highlight observed climate change consequences in the region (Baidya et al., 2008; Karki et al., 2017). The reduction in snow cover, changing precipitation trends and increasing precipitation variability are indicative of the significant impact of climate change in the Western Himalaya (Ageta et al., 2001; Shrestha and Aryal, 2011; Wang et al., 2013; Panthi et al., 2015; Roxy et al., 2015; Duan et al., 2006).

The Himalayan region has been experiencing high variability in rainfall, exacerbating the occurrences of disasters, among which cloudburst-triggered debris flows, flash floods, landslides, and mass movements are prominent. Changes in land-use patterns, agriculture, cropping patterns, and decreasing production and yield of crops are major consequences of this high rainfall variability. Additionally, changing distribution patterns of fauna and flora and the increasing incidence of forest fires, attributed to the warming of river valleys and middle altitudes, are major adverse incidents taking place in this region (Deal et al., 2017).

Studies on climate change and its implications in the entire Himalayan region have been conducted by scholars worldwide. However, due to the unavailability of sufficient meteorological stations and consequently inadequate climate data, a comprehensive climate change study is yet to be undertaken. The scope of the present study is limited to the analysis of 161 years of rainfall data. This study examines rainfall variation and change in the Western Himalayan Region, encompassing Uttarakhand, Himachal Pradesh, and Jammu and Kashmir Himalayas as a whole. Furthermore, it analyses average monthly rainfall and its variation, average annual rainfall and its variation, average decadal rainfall and its variation, as well as season-wise annual and decadal rainfall and variation. The study also includes the analysis of annual and decadal minimum, maximum, and mean values of rainfall and their variation. Its aim is to examine trends in rainfall—decadal, annual, and seasonal—and to explore the impact of rainfall variability on ecology as shifting of pine trees towards the high altitudes, disappearing of oak forests from the temperate region, and declining of apples and citrus fruits. It also aims to examine the impact of rainfall variability on geo-hydrological hazards – such as flash floods, debris flows, and landslides.

2. STUDY AREA

The Western Himalayan region comprises Uttarakhand (53,483 km²), Himachal Pradesh (55,653 km²), and Jammu and Kashmir (222,236 km²) (Figure 1). It is a mountainous region, with about 90% of its total area being highly elevated, and approximately 20% covered in snow. The altitude varies from 500 m to over 7000 m, and the terrain is rough, rugged, and precipitous. Rainfall occurs in two distinct seasons—primarily during four months of the summer (June, July, August, and September) due to the Monsoon outbreak, and during the two months of winter (December and January) due to Western disturbances. The rainfall in the summer season is highly intensive and devastating, causing significant losses to life and property, often in the form of cloudbursts. The entire region is home to two major river systems in India—the Ganga system and the Sindhu system. All rivers and their numerous tributaries are glacial-fed and perennial, flowing above the danger mark during the monsoon season. While rainfall variability has been high, there has been a noticeable decrease in rainfall in the recent past.

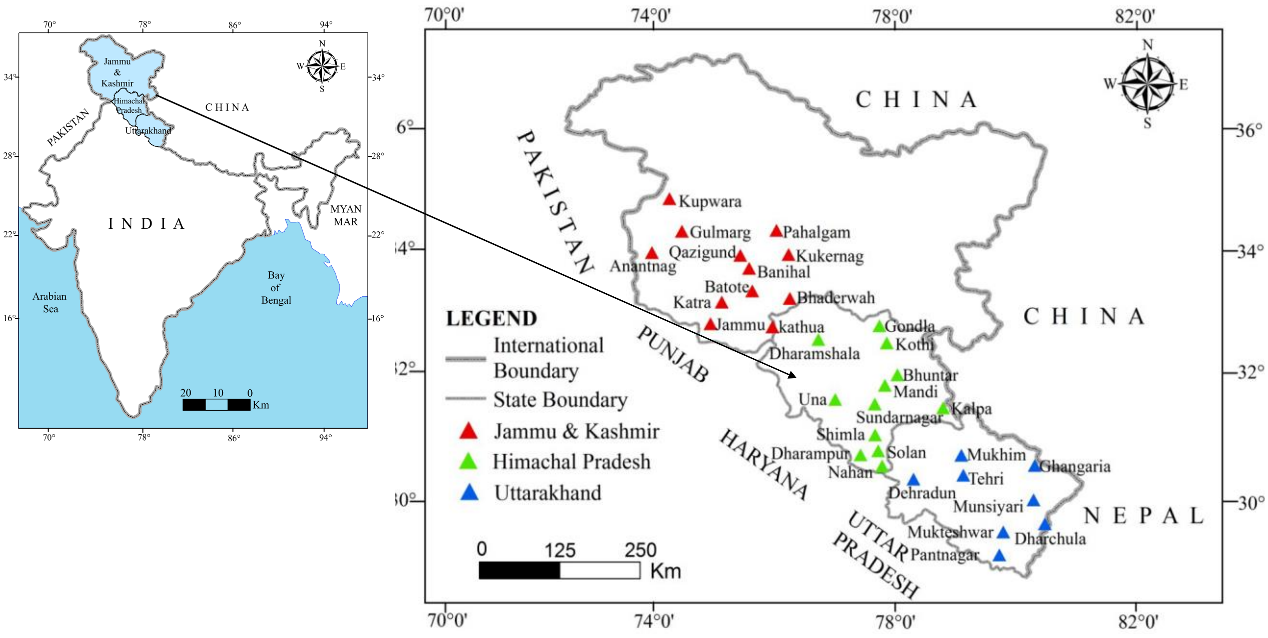

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Figure 1: Location map of the Western Himalaya showing the meteorological stations

3. MATERIALS AND METHODS

3.1 Data collection

Rainfall data from 1845 to 2006 (161 years) were collected from the Indian Institute of Tropical Meteorology (IITM) in Pune, Maharashtra for the Western Himalaya. Three states - Uttarakhand, Himachal Pradesh, and Jammu and Kashmir, are the part of the Western Himalaya. There are a total of 32 meteorological stations, which includes 12 in Jammu and Kashmir, 12 in Himachal Pradesh and 8 in Uttarakhand. The rainfall data were already averaged for all states and all meteorological stations by IITM as the Western Himalaya as a whole.

Data were also collected on changing patterns in agriculture and horticulture by analysing crop production and productivity at two different times from secondary sources. Additionally, the shifting of crop cultivars, such as apples and citrus fruits and floral species was observed. Intensive field visits of the Uttarakhand State in Dec-Jan 2022 were conducted to validate the secondary sources of data. During the field visits, it has been observed that pine trees have invaded the mixed-oak forest regime and therefore, oak forests have disappeared from many temperate regions. It has also been observed that apple and citrus fruits are shifted to the high altitudes. Furthermore, a study was conducted on the impact of rainfall variability on geo-hydrological disasters. A linear regression model was applied to determine the R² value of the trends in average annual and decadal rainfall.

3.2 Data analysis

The author analyzed the collected rainfall data as average monthly rainfall, average annual rainfall, and average decadal rainfall. Mann-Kendall Test, linear regression, and descriptive statistics were applied to analyze rainfall. The IITM categorized four rainfall seasons for the Western Himalaya: (1) January and February, (2) March, April, and May, (3) June, July, August, and September, and (4) October, November, and December, based on the rainfall characteristics in this region. Accordingly, the season-wise average annual and decadal rainfall was analyzed.

3.2.1 Mann-Kendall Test

The Mann-Kendall Test and Sen's slope estimator were used to identify trends in rainfall data in the Western Himalayan region, India. Furthermore, autocorrelation for all data series was assessed using the Lag-k autocorrelation function at a significance level of 0.05.

3.2.2 Descriptive statistics and regression models

Descriptive statistics were applied to analyze the seasonal minimum, maximum, and mean values of rainfall; decadal minimum, maximum, andmean values of rainfall; as well as, monthly minimum, maximum, and mean values of rainfall. The data were presented using graphs and the regression models. Additionally, rainfall variability and change were observed. Both SPSS and Excel Sheet were used to analyze data.

4. RESULTS

4.1 Trends of annual and seasonal average rainfall in the Western Himalaya

4.1.1 Mann-Kendall Test

The Mann-Kendall Test on rainfall in the Western Himalaya (Table 1) reveals both significant and insignificant increasing and decreasing trends in seasonal and annual average rainfall over the years 1845 to 2006. During the seasons – (1) March, April, and May and (2) October, November, and December, rainfall increased insignificantly with magnitudes of 0.31 mm/year and 0.15 mm/year, respectively. Conversely, an insignificant decrease in rainfall was noticed during June, July, August, and September, with very high magnitudes of -0.85 mm/year. In January-February, there was a significant decrease observed in rainfall at a rate of -0.02 mm/year. The annual average rainfall decreased insignificantly (-0.36 mm).

Table 1: Trends of annual and seasonal average rainfall in the Western Himalaya (1845-2006)

Seasons	Z	P	Q	Trend
January and February	-0.14	0.89	-0.02	Significant decrease
March, April, and May	2.43	0.02	0.31	Insignificant increase
June, July, August, and September	-2.15	0.03	-0.85	Insignificant decrease
October, November, and December	2.01	0.04	0.15	Insignificant increase
Annual	-0.87	0.39	-0.36	Insignificant decrease

Note: Z= Mann-Kendall/modified Mann-Kendall test statistics, P= Probability Value, Q= Sen's Slope; Level of significance is 0.05

4.1.2 Regression Model

4.1.2.1 Trends of annual average rainfall

The average annual rainfall data from 1845 to 2006 were analyzed (Fig. 2). The highest rainfall occurred in 1931, reaching 3223 mm, while the lowest rainfall was recorded in 1848, falling below 900 mm. Rainfall below 1200 mm occurred in several years, such as in 1847 (1172 mm), 1860 (1125 mm), 1902 (1159 mm), 1918 (1189 mm), 1965 (1187 mm), 1974 (1193 mm), and 1991 (1177 mm). Similarly, rainfall exceeding 2000 mm was observed in the years 1914 (2001 mm), 1917 (2181 mm), 1961 (2009 mm), and 1967 (2160 mm). The average annual rainfall and the mean value were recorded at 1573 mm. It has been observed that rainfall variability was very high, i.e., above 1600 mm and below 600 mm during the assessment period. In terms of the change in annual average rainfall, there was a slight decrease in overall rainfall during the period.

It has been observed that the average annual rainfall variability was high, ranging from <1000 mm to >3000 mm during the period. However, there is a declining trend, with an average decrease of 50 mm of rainfall over the entire 161-year period. From 1945 to 1980, the variability in average annual rainfall was 1000 mm, ranging from 1000 mm to 2000 mm, while after 1980, the average variability was 700 mm, ranging from 1100 mm to 1800 mm. The data indicate that average annual rainfall variability was high, whereas the changes in rainfall patterns were comparatively low.

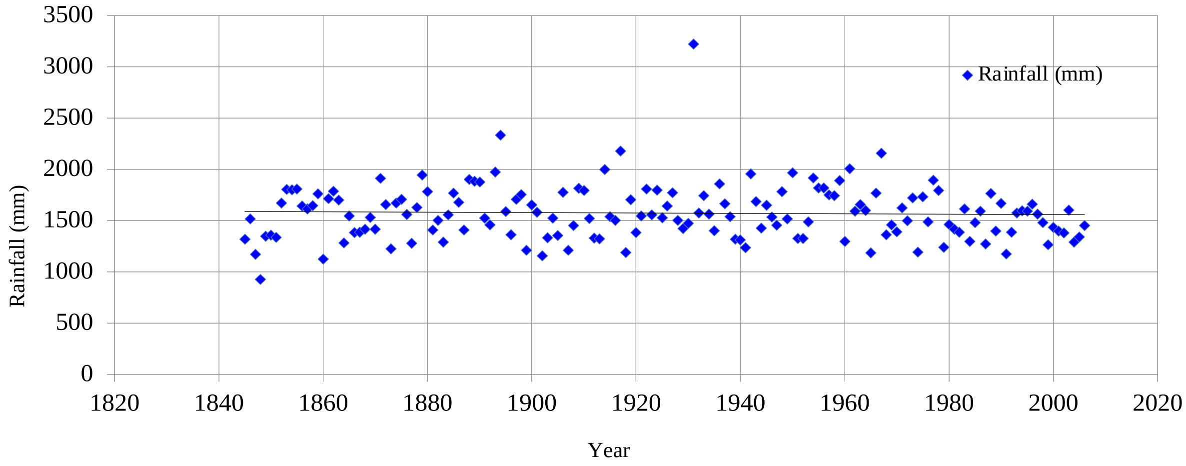

Figure 2: Annual average rainfall – the evolution of the average annual rainfall based on rainfall data recorded at 32 stations in the Western Himalaya from 1845 to 2006

4.1.2.2 Trends of seasonal average rainfall

The average seasonal rainfall variation was analyzed (Figure 3). In the first two months of January and February, there was a very small amount of rainfall with an almost stagnant R^2 value. However, the variability of rainfall was very high, ranging from 360 mm in 1960 to 20 mm in 1905. The following three months, March, April, and May exhibited increasing trends of rainfall with an R^2 value of 0.035. The variability observed during these months ranged from a minimum of 40 mm to a maximum of 380 mm. The highest rainfall occurred during the four months of June, July, August, and September, known as the monsoon season. The trend of rainfall during this period was observed to decrease with an R^2 value of 0.020. Furthermore, the variability was quite high, ranging from a minimum of 500 mm to a maximum of 1800 mm. In October, November, and December, a lesser amount of rain occurs in the Himalaya, making this season mainly dry. However, the trend of rainfall was noticed to increase with an R^2 value of 0.029. Meanwhile, rainfall variability was also high, ranging from 10 mm to 330 mm.

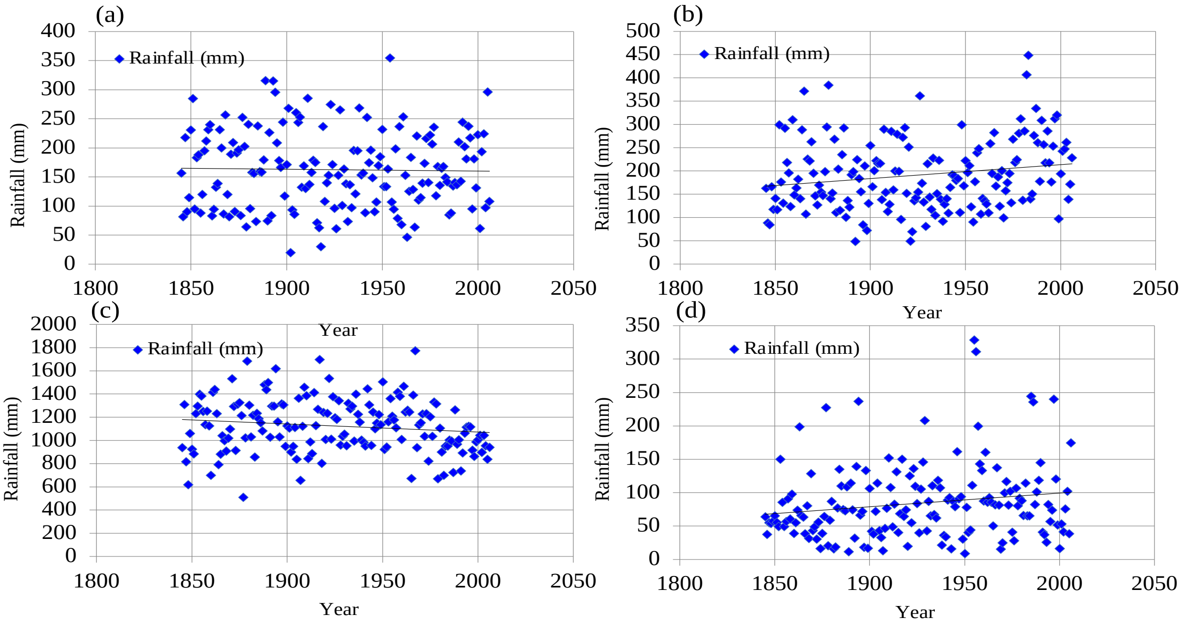

Figure 3: Seasonal average rainfall variability (a) January and February (b) March, April, and May (c) June, July, August, and September (d) October, November, and December

4.1.2.3 Change in annual average rainfall

The change in average annual rainfall was analyzed (Figure 4). It has been noticed that, although the change in average annual rainfall was highly variable throughout the 161 years, the highest decrease was observed in 1853, amounting to -3500 mm. This was followed by 1932, with a decrease of -1800 mm in rainfall. In 1917, the decrease in average annual rainfall was -1000 mm, and similarly, in many years, there was a decrease of -500 mm in rainfall. In terms of the increase in average annual rainfall, the highest was observed in 1931, at about 1800 mm. In other years, the rainfall increased simultaneously.

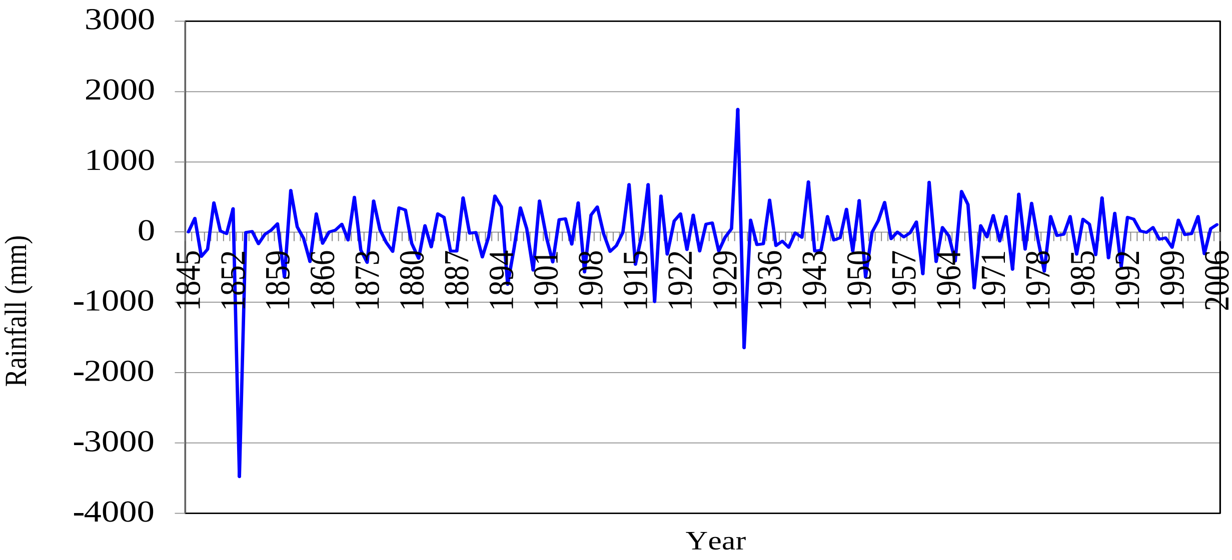

Figure 4: Change in the annual average rainfall in mm

4.2 Trends of decadal and seasonal average rainfall

4.2.1 Mann-Kendall Test

The Mann-Kendall Test and Sen's Slope analysis on trends of decadal and seasonal average rainfall in the Western Himalaya depict an insignificant decrease and increase during 1845-2006 (Table 2). Rainfall seasons (1) January and February and (2) June, July, August, and September received an insignificant decreasing trend with magnitudes of -5.09 and -102 per decade, respectively. Conversely, during March, April, and May; and October, November, and December, there was an insignificant increase in rainfall with magnitudes of 11.64 and 15.03 per decade, respectively. Moreover, the overall decadal trend for the entire study area showed an insignificant decrease during the recorded period, with an average magnitude of -61.45 per decade.

Table 2: Trends of decadal and seasonal average rainfall

Seasons	Z	P	Q	Trends
Jan and Feb	-0.50	0.62	-5.09	Insignificant decrease
Mar, Apr, and May	0.77	0.44	11.64	Insignificant increase
Jun, Jul, Aug, and Sept	-1.40	0.16	-102	Insignificant decrease
Oct, Nov, and Dec	1.85	0.06	15.03	Insignificant increase
Total	-1.31	0.19	-61.45	Insignificant decrease

Note: Z= Mann-Kendall/modified Mann-Kendall test statistics, P= Probability Value, Q= Sen's Slop; Level of significance 0.05

4.2.2 Regression Model

4.2.2.1 Trends of decadal average rainfall

The average decadal rainfall was observed to decrease with high variability. The rainfall was the highest in the 1930s, with an average decadal of 1700 mm, and the lowest in 2000 when the average decadal rainfall was 1400 mm (Figure 5).

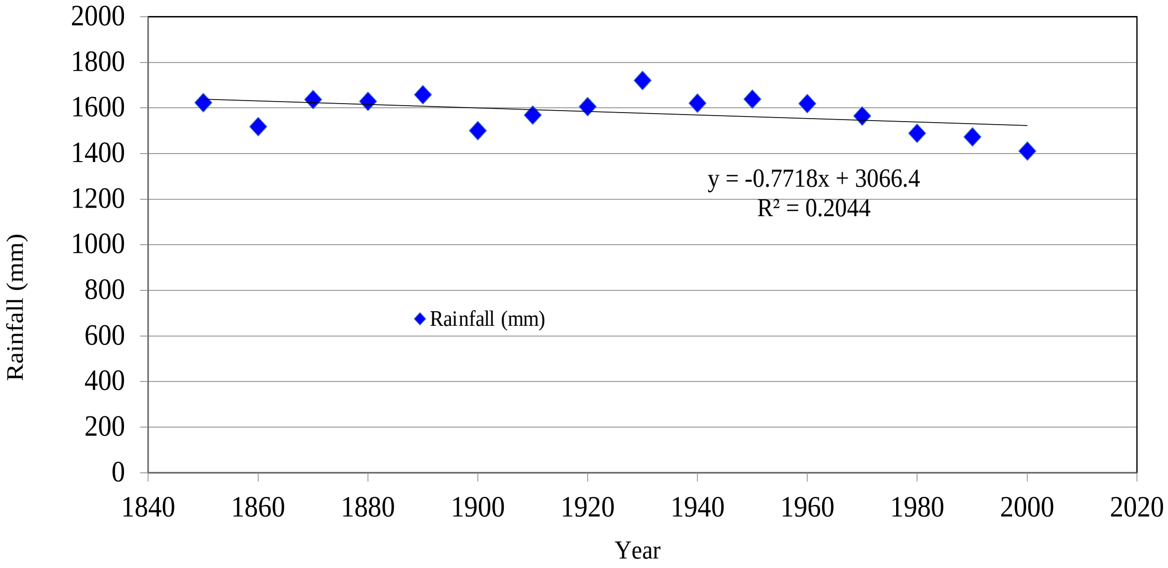

Figure 5: Decadal average rainfall

4.2.2.2 Trends of decadal-seasonal average rainfall

Similarly to the average annual seasonal rainfall, the average decadal-seasonal rainfall was analyzed (Figure 6). The entire year was divided into four seasons – January and February; March, April, and May; June, July, August, and September; and October, November, and December. The trend of the average decadal seasonal rainfall in January and February was noticed to decrease (averaging 10 mm). The variability remained high, with a maximum of 200 mm and a minimum of 140 mm. Meanwhile, the trend of the average decadal rainfall has been increasing in March, April, and May. During this period, the highest rainfall was noticed in 1980 with 280 mm, and the lowest was in 1940 (150 mm). The four months of the rainy season – June, July, August, and September – experienced decreasing trends. Although the variability of the average decadal rainfall was normal, it exhibited a decreasing trend, with an average decrease of 150 mm during the period. The average decadal rainfall was noticed to increase during the returning monsoon in October, November, and December. The increase was significant (40 mm) with high variability – ranging from 150 mm (highest) to 60 mm (lowest).

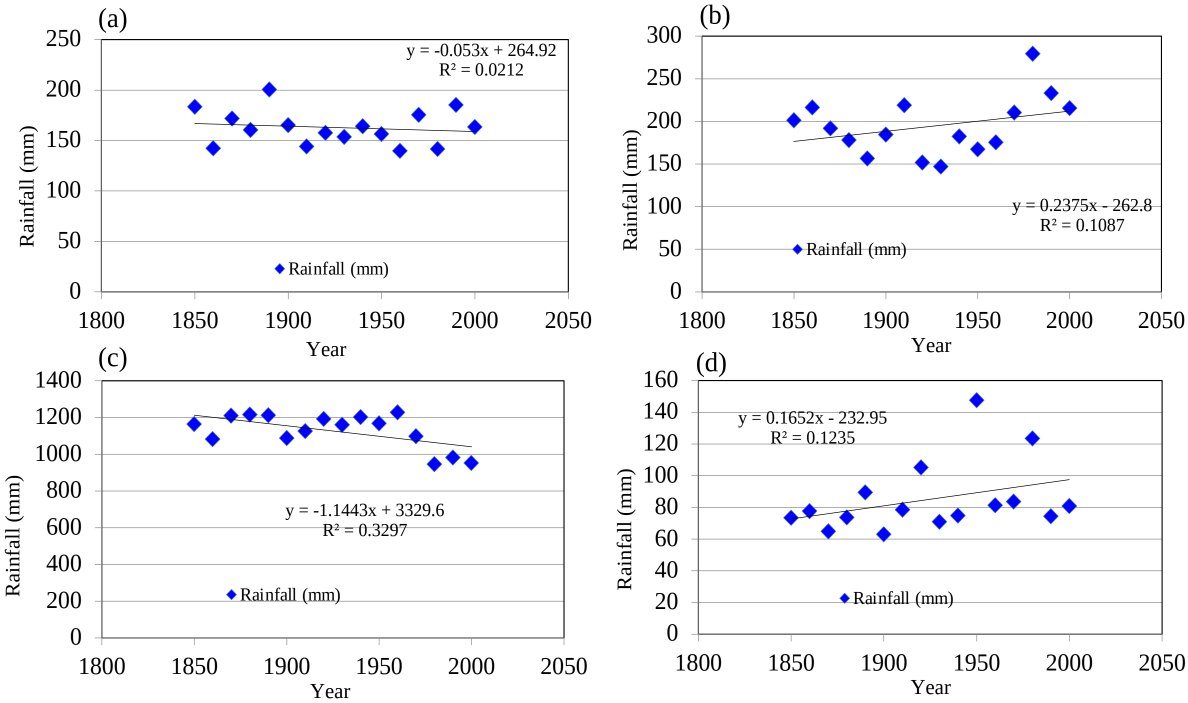

Figure 6: Decadal-seasonal Average rainfall (a) January and February (b) March, April, and May (c) June, July, August, and September (d) October, November, and December

4.2.2.3 Trends of decadal-seasonal mean, minimum, and maximum rainfall

Decadal mean, minimum, and maximum rainfall were analyzed (Fig. 7). The decadal mean and maximum rainfall have been decreasing. However, the decadal minimum rainfall has been increasing. The change and variability in decadal maximum rainfall were the highest, with a 400 mm decrease in rainfall. The variability ranged from 435 mm (highest) to 315 mm (lowest). Variability in decadal mean and minimum rainfall was noticed to be less.

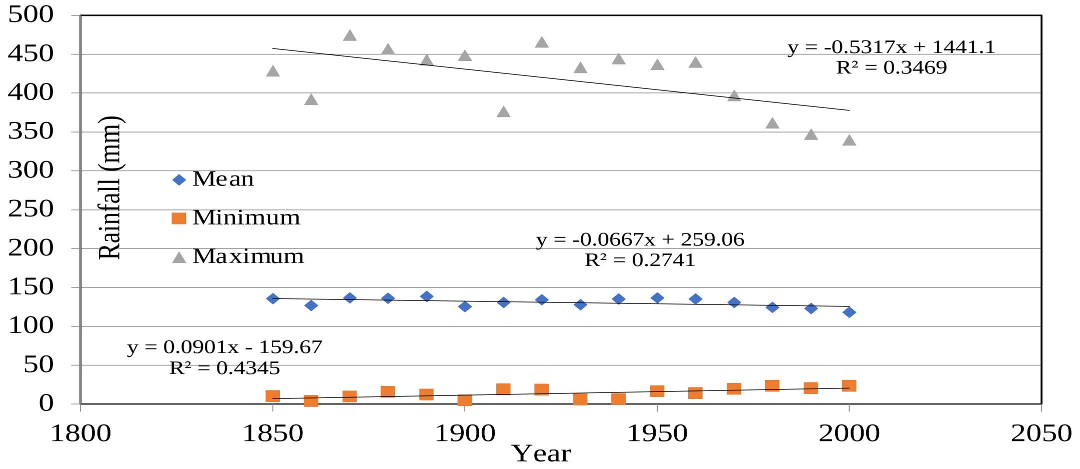

Figure 7: Decadal average mean, minimum, and maximum rainfall

4.2.2.4 Trends of decadal-monthly average rainfall

Data on the average decadal monthly rainfall were presented. The highest rainfall occurs in July and August. Meanwhile, these two months received a decrease in rainfall. Rainfall increased in September, whereas in June, it decreased. In February and November, rainfall increased. The other months experienced less rainfall and rainfall variability (Figure 8).

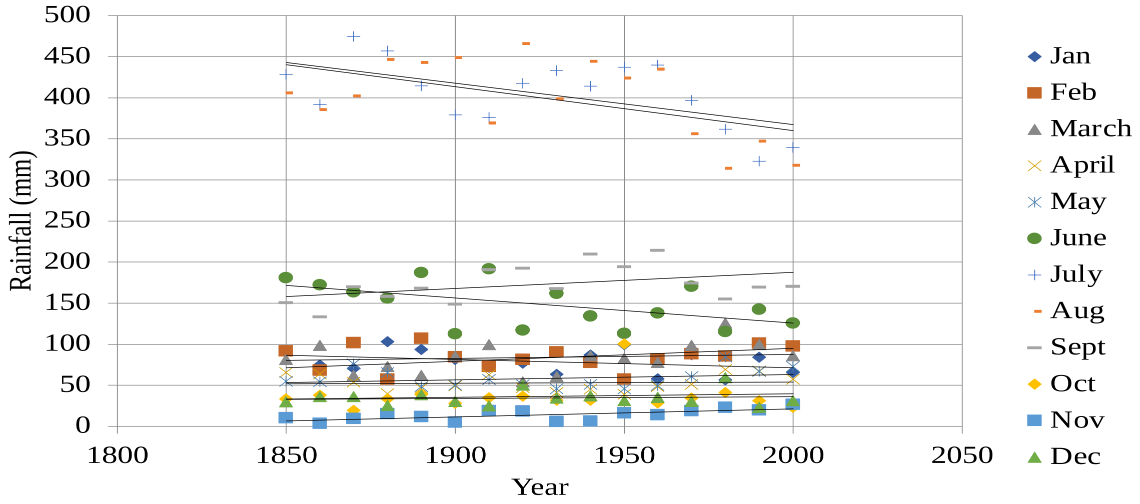

Figure 8: Monthly-decadal average variability in rainfall (n=161 years)

4.2.2.5 Change in decadal average rainfall

The average decadal rainfall during the period was 1581 mm. A total of 169 mm of rainfall decreased during this period. The highest decrease was noted in the decades of the 1900s, with more than 150 mm. About 100 mm of rainfall decreased in the 1860s and 1940s. In the 1980s, the decrease in rainfall was 75 mm. In terms of an increase in rainfall, the highest occurred in the 1870s and 1930s, with more than 100 mm. Above 50 mm of rainfall increased in the 1910s. The rainfall variability during the period of 161 years was very high (Figure 9).

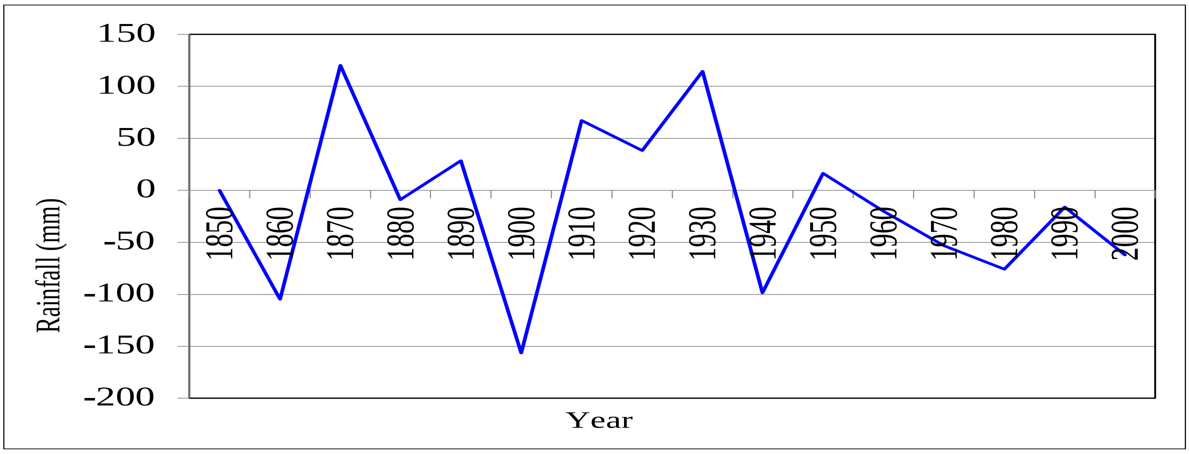

Figure 9: Change in decadal average rainfall

4.3 The impacts of the changing rainfall patterns on the crop production, vegetation and occurrence of geo-hydrological disasters

The impact of rainfall variability on different aspects in the Western Himalaya was noticed to be enormous, mainly on cropping patterns, distribution patterns of floral species, and the occurrences of geo-hydrological disasters. A study conducted by the author revealed that apples have disappeared from the areas where they were grown earlier. Similarly, citrus fruits have shifted to higher altitudes (Sati, 2019). The impact of rainfall variability on the area, production, and productivity

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(production/ha) has been noticed enormously in the past decades. The area of seven principal crops has decreased. Similarly, except for pulses, the production of all crops has decreased. In terms of productivity, a nominal increase was noted in some crops, whereas in a few crops, it decreased (Table 3). High rainfall variability and warming of the river valleys and middle altitudes have led to such situations in recent decades.

Table 3: Change (%) in the area, production, and productivity of principal crops

Food grains	Area	Production	Productivity
Rice	-6.43	-4.93	0.04
Wheat	-5.7	-0.36	0.13
Ragi	-9.6	-6.13	0.05
Pulses	+20	21.74	0.01
Oilseeds	+77.78	3	-0.77
Sugarcane	-5.56	1.66	4.13
Potato	0	-5.32	-0.92
Spices	+42.4	-43.18	-6.61
Total	-3.1	0.29	0.29

Source: State Agricultural Diary, Uttarakhand State (2022)

The phenomenon of rainfall variability and change has largely impacted either the disappearance of floral species or their shifting toward high altitudes. A study showed that pine trees are invading mixed oak forests (Fig. 10), and in many locations, mixed-oak forests have disappeared. This is because of the warming of the river valleys and the middle altitudes, as the study depicted (Sati 2023). There are several instances that showed several crop and floral races have disappeared, and several have shifted to high altitudes.

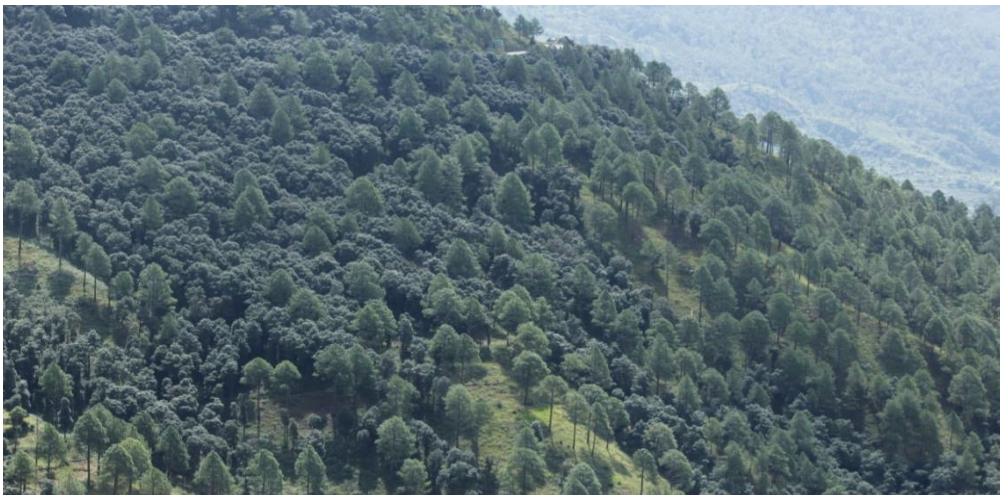

Figure 10: Pine trees are invading mixed-oak forests in the Paukhal area of the Tehri district.

The high variability and change in rainfall have resulted in several consequences. The high intensity of rain within very short duration, principally during the monsoon season, has led to increasing geo-hydrological hazards in the Western Himalaya. All three states of the Western Himalaya – Uttarakhand, Himachal Pradesh, and Jammu and Kashmir – are facing the problem of increasing geo-hydrological hazards, such as cloudbursts-triggered debris flows, flash floods, landslides, and mass movements (Table 4). The geo-hydrological incidents occurred in the past were due to high rainfall. The incidents of avalanches have also been increasing. It has been increasing for the past decades. Rainfall intensity and disasters have a significant correlation. It has been noticed that in years when rainfall intensity was higher (cloudbursts occurred), the damage caused by geo-hydrological disasters was enormous. Additionally, some of the recent cloudburst incidents were noticed in 2013, 2021, and 2022, resulting in the loss of many lives and significant property damage (Sati, 2022).

Table 4: Major geo-hydrological disasters in the Himalaya

S. No.	Year (Monsoon season)	Geo-hydrological disaster	Place of occurrence	Consequences
1.	1893	Flash floods	Birahi Ganga (Uttarakhand)	12 people died
2.	1970	Flash floods	Alaknanda valley (Uttarakhand)	400 people died
3.	1979	Avalanches	Lahaul Spiti (Himachal Pradesh)	237 people died
4.	1991	Cloudburst	Satluj valley (Himachal Pradesh)	32 people died
5.	1995	Landslides	Luggarbhati (Himachal Pradesh)	65 people died
6.	1995	Flash flood	Duling valley (J&K)	32 people died
7.	1995	Flash flood	Pabbar valley (Uttarakhand)	124 people died
8.	1998	Landslide	Malpa (Uttarakhand)	225 people died
9.	1998	Landslide	Ukhimath (Uttarakhand)	69 people died
10.	2007	Flash flood	Bhavi village (Himachal Pradesh)	58 people died
11.	2010	Flash floods	Leh, Ladakh (J&K)	255 people died
12.	2013	Flash flood	Kedarnath valley (Uttarakhand)	10,000 people died
13.	2015	GLOF	Zanskar, Ladakh (J&K)	300 people died
14.	2021*	Flash flood	Rishi and Dhauli Ganga (Uttarakhand)	+200 people died
15.	2022*	Flash floods	Vaishno Devi (J&K)	19 people died
16.	2022*	Flash flood	Bandal valley (Uttarakhand)	22 people died

Source: Sati, 2019; *2022

5. DISCUSSION

The study reveals that the average annual rainfall was highly variable from year to year in the Western Himalaya. In several years, the variability was >1000 mm. During the period, the rainfall variability was noticed as non-uniformed. The average decadal minimum rainfall increased, which was 10 mm. Meanwhile, the average decadal maximum and mean values of rainfall decreased largely after 1950, which were 100 mm and 20 mm, respectively. On average, duration of rainfall shortened, whereas the intensity of rainfall changed over time and space. A decreasing trend of rainfall was noticed, and the average 227 mm of rainfall decreased in the past five decades.

In terms of average decadal monthly rainfall, it decreased mainly in July and August, which is the prime monsoon season. About 150 mm of rainfall decreased in these two months. Rainfall also decreased in November, December, and January, whereas it increased in February and March. The shifting of winter rainfall from November, December, and January to February and March is the recent trend in the Western Himalayan region. Seasonal rainfall is also variable and has become scanty after 1980, mainly during the monsoon season. The average seasonal rainfall variability was the highest in October, November, and December, followed by January and February, and March, April, and May (three seasons). In the four months of the monsoon season, rainfall variability was comparatively less. It shows that rainfall variability was higher during the dry season in comparison to the wet season.

The trend of annual and seasonal average rainfall and decadal and seasonal average rainfall is insignificantly increasing and decreasing except for March, April, and May. Increase in annual average rainfall in these months increased significantly. The findings of this research is that there is high variability and change in rainfall. Rainfall has decreased during the monsoon season, whereas, during the summer season, rainfall has significantly increased.

In the past decades, the intensity of rainfall was noticed to be high within a short period and in a specific place. The duration of the monsoon season has shortened. The overall situation has led to changes in all spheres, such as agricultural systems, cropping patterns, distribution of floral species, and major crop races/cultivars, as well as geo-hydrological disasters. People in the Eastern Himalaya practice rain-fed agriculture. With increasing variability in rainfall, the production and productivity of crops have decreased. Furthermore, the warming of river valleys and mid-altitudes has led to the changing distribution of crop races/cultivars and floral species. Many crop cultivars and floral species have become extinct, and many are on the verge of extinction. In the last three decades, geo-hydrological events have increased multi-fold because of intensive and frequent rainfall.

6. CONCLUSIONS

This study reveals that the trend of annual and seasonal average rainfall in the Western Himalaya is significantly decreasing with high variations. For example, rainfall significantly decreased during the four-month monsoon season – June, July, August, and September; and January and February, which are the main cropping seasons, i.e., Kharif and Rabi, respectively. Therefore, crop production and productivity decreased during the last decades. However, rainfall significantly increased in two seasons - March, April, and May; and October, November, and December, which are mainly less rainy seasons. In terms of decadal-seasonal rainfall, it follows the same trend whereas, the increase and decrease were mainly insignificant. In both cases, overall rainfall decreased significantly. The occurrence of snowfall has observed a decrease. The high rainfall also impacted the shifting of pine trees towards higher elevations, leading to the disappearance of oak forests in many locations. Similarly, it has impacted the shifting of fruit trees, mainly apple and citrus, to high altitudes. Furthermore, the high intensity of rain in the form of cloudbursts resulted in increasing geo-hydrological disasters in the Western Himalaya. There are several examples, which depict that intensive rainfall has correlation with occurrences of geo-hydrological disasters. In the recent past, Kedarnath tragedy, Uttarkashi cloudbursts, and Bandal Valley disasters were the result of heavy rainfall. The rainfall data used in this study are averaged from all states and all meteorological centres and temperature data are unavailable. These are the limitations of the study. For further study, state-wise data can be obtained and analyzed, and similarly, temperature data are required for the overall evaluation of climate impact on agro-biodiversity and geo-hydrological disasters.

REFERENCES

Adane, G. B., Hirpa, B. A., Song, C., and Lee, W.-K., 2020. Rainfall characterization and trend analysis of wet spell length across varied landscapes of the upper Awash River Basin, Ethiopia. Sustainability, 12 (2). https://doi.org/10.3390/su12219221

Ageta, Y., Naito, N., Nakawo, M., Fujita, K., Shankar, K., Pokhrel, A.P., Wangda, D. ,2001. Study project on the recent rapid shrinkage of summer-accumulation type glaciers in the Himalayas, 1997–1999. Bull Glaciol Res, 18, Pp 45–49

Akabassi, G. C., Pandonou, E. A., Gbesso, G. H. F., Assogbadjo, A. E., Guede, N. Z., 2023. Effect of climate and habitat on morphological characteristics and fruit production of Picralima nitida (Stapf) in West Africa, Journal of Environmental Geography, 16 (1-4). https://doi.org/10.14232/jengeo-2023-44667

Bahiru, W., Wende, E., Mohammed, L., Mohammed, Y., Adem, H., & Demmisie, Y., 2020. Assessing the impact of rainfall variability on teff production and farmers perception at Gubalafto district, North Eastern, Ethiopia. International Journal of Earth Science and Geophysics, 6 (2), Pp. 042. https://doi.org/10.35840/2631-5033/1842

Baidya, S.K., Shrestha, M.L., Seikh, M.M., 2008. Trends in daily climatic extremes of temperature and precipitation in Nepal. J Hydrol Meteorol 5, Pp. 38–51

Dash, S.K. and Hund, J.C.R. 2007. Variability of climate change in India. Current Sci., 93 (6), Pp. 782–788.

Dash, S.K., Jenamani, R.K., Kalsi, S.R. and Panda, S.K. 2007. Some evidence of climate change in twentieth-century India. Climatic Change, 85 (3–4), Pp. 299–321.

Deal, E., Catherine, A., Braun, J., 2017. Rainfall variability in the Himalayan orogen and its relevance to erosion processes, Advancing Earth and Space Sciences, 53 (5), Pp. 4004-4021, https://doi.org/10.1002/2016WR020030

Duan, K., Yao, T., Thompson, L.G.. 2006. Response of monsoon precipitation in the Himalayas to global warming. J Geophys Res Atmos 111, D19110

Hamed, K. H., & Ramachandra Rao, A. 1998. A modified Mann-Kendall trend test for autocorrelated data. Journal of Hydrology, 204 (1), Pp. 182–196. https://doi.org/10.1016/S0022-1694(97)00125-X

Jayanta, D., Tapash, M., Piu, S., and Sudip Kumar, B., 2021. Variability and trends of rainfall using non-parametric approaches: A case study of semi-arid area. MAUSAM, 71(1), Pp. 33–44. https://doi.org/10.54302/mausam.v71i1.4

Karki, R., Hasson, S., Schickhoff, U., Scholten, T., Bohner, J., 2017. Rising precipitation extremes across Nepal. Climate (Basel) 5, Pp. 4

Kendall, M. G. 1948. Rank correlation methods. Griffin.

Kothawale, D.R. and Rupa, K. *2005*. On the Recent Changes in Surface Temperature Trends over India. Geophysical Research Letters, 32, L18714.

Kothyari, U.C. and Singh, V.P., 1996. Rainfall and temperature trends in India. Hydrological Processes. 10, Pp. 357-372.

Kripalani, R.H., Kulkarni, A. and Sabade, S.S. 2003. Western Himalayan snow cover and Indian monsoon rainfall: a reexamination with INSAT and NCEP/NCAR data. Theor. Appl. Climatol., 74 (1–2), Pp. 1–18.

Kumar, R., Krishna, K., Ashrit, A.G., Patwardhan, S.K. and Pant, G.B. 2002. Climate change in India: Observations and model projections. In: Climate change and India: Issues, Concerns and opportunities (Eds. Shukla et al.), Pp.25-76.

Mann, H. B. 1945. Nonparametric Tests Against Trend. Econometrica, 13 (3), Pp. 245. https://doi.org/10.2307/1907187

Mugalavai, E., Kipkorir, E. C., Raes, D., and Rao, M. S. 2008. Analysis of rainfall onset, cessation and length of growing season for western Kenya. Agricultural and Forest Meteorology, 148 (6–7), Pp. 1123–1135. https://doi.org/10.1016/j.agrformet.2008.02.013

Nakawo, M.K., Fujita, Y., Ageta, K., Shankar, A.P., Pokhrel and Tandong, Y. 1997. Basic studies for assessing the impacts of global warming on the Himalayan cryosphere, 1994-1996. In: Bulletin of Glacier Research 15, Datacenter for glacier research, Japanese society for snow and ice, Pp. 53-58.

Palazzi, E., von Hardenberg, J., Provenzale, A. 2013. Precipitation in the Hindu-Kush Karakoram Himalaya: observations and future scenarios. J Geophys Res Atmos 118, Pp. 85–100

Panday, P.K., Thibeault, J., Frey, K.E. 2015. Changing temperature and precipitation extremes in the Hindu KushHimalayan region: an analysis of CMIP3 and CMIP5 simulations and projections. Int J Climatol 35, Pp. 3058–307

Panthi, J., Dahal, P., Shrestha, M.L., Aryal, S. 2015. Spatial and temporal variability of rainfall in the Gandaki River basin of Nepal Himalaya. Climate (Basel)3, Pp. 210–22

Rajbhandari, R., Shrestha, A.B., Nepal, S., Wahid, S. 2016. Projection of future climate over the Koshi River basin based on CMIP5 GCMs. Atmos Clim Sci 6, Pp.190–204

Reda, A. T. 2015. SMHI-RCA model captures the spatial and temporal variability in precipitation anomalies over East Africa. Journal of Climatology & Weather Forecasting, 3 (03), Pp. 138. https://doi.org/10.4172/2332-2594.1000138

Roxy, M.K., Ritika, K., Terray, P., Murtugudde, R., Ashok, K., Goswami, B.N. 2015. Drying of Indian subcontinent by rapid Indian Ocean warming and a weakening land-sea thermal gradient. Nat Commun 6, Pp. 7423

Sati, V.P. 2023. Sustainable Forest Management in the Himalaya, Springer, Cham, Switzerland, ISBN: 978-3-031-21935-1.

Sati, V.P. 2022. Environmental and economic impact of cloudburst-triggered debris flows and flash floods in Uttarakhand Himalaya: a case study. Geoenvironmental Disasters. 9 (5), Pp, 1-11, https://doi.org/10.1186/s40677-022-00208-3.

Sati, V.P. 2019. Himalaya on the Threshold of Change. Springer International Publishers, Switzerland, ISBN 978-3-030-14179-0, Pp. 250, Advances in Global Change Research series, Scopus Indexed

Sen, P. K. 1968. Estimates of the Regression Coefficient Based on Kendall's Tau. Journal of the American Statistical Association, 63 (324), Pp. 1379–1389. https://doi.org/10.1080/01621459.1968.10480934

Shah, A. and Malakar, K. 2014. Climate-change-induced risk mapping of the Indian Himalayan districts using the latest IPCC framework, International Journal of Disaster Risk Reduction, Volume 102, 15 February 2024, 104283, https://doi.org/10.1016/j.ijdrr.2024.104283

Sharma, K.P., Moore, B. and Vorosmarty, C.J. 2000. Anthropogenic, Climatic and Hydrologic Trends in the Koshi Basin, Himalaya. In: Climatic Change 47, Kluwer Academic Publishers, Dordrecht, the Netherlands, Pp. 141-165.

Shrestha, A.B., Aryal, R. 2011. Climate change in Nepal and its impact on Himalayan glaciers. Reg Environ Change 11, Pp. 65–77

Shrestha, A.B., Wake, C.P., Dibb, J.E., Mayewski, P.A. 2000. Precipitation fluctuations in the Nepal Himalaya and its vicinity and relationship with some large-scale climatological parameters. Int J Climatol 20, Pp. 317–327

Turner, A.G., Annamalai, H. 2012. Climate change and the South Asian summer monsoon. Nat Clim Chang 2, Pp.587–595

Wang, S.Y., Yoon, J.H., Gillies, R.R., Cho, C. 2013. What caused the winter drought in western Nepal during recent years? J Clim 26, Pp. 8241–8256

Ziti, C., Chapungu, L., Nhamo, G., 2024. Climate Change Response Strategies and Implications on Sustainable Development Goals in Mutirikwi River Sub-Catchment of Zimbabwe, Journal of Environmental Geography, 17 (1-4). https://doi.org/10.14232/jengeo-2024-44881

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