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Short communication

Analysis seasonal rainfall trends in Himachal Pradesh by Mann-Kendall and Sen's Slope estimator test

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The Tibetan plateau and Indian subcontinent are heavily affected by Himalayan temperature. By blocking cold, dry northerly winds from flowing south, the range keeps the subcontinent warmer than other continents. This barrier prevents western disturbances from reaching Iran, causing snow in Kashmir, Himachal Pradesh, and Punjab and heavy rains in the Himalayan foothills. But unlike winter, Pant *et al.,* (1999) found a rising tendency in post-monsoon rainfall in the western Himalayan area. The Himalaya, a biodiversity hotspot and ecosystem service provider, is one of the few places facing more severe climate change consequences than others. Since there are no climate monitoring stations, the India Meteorological Department (Guhathakurta and Rajeevan, 2006) found that monsoon rainfall in Himachal Pradesh and Uttarakhand has dropped by 61 and 79 mm, respectively, indicating climate change over the past 100 years. Bhutiyani *et al.,* (2008) have conducted the study revealing an increase in high-magnitude flood episodes in the northwest Himalayas over the previous three decades. Especially in the Indo-Gangetic Plains and Western Ghats, India's summer monsoon precipitation has dropped by 6% between 1951 and 2015.

Global warming is causing diminishing snowfall, melting glaciers, and a northward temperate fruit belt in Himachal Pradesh. This disrupts rainfall, apple production, and rabi season. The hills receive significant snowfall except during the Southwest monsoon. Climate of Himachal Pradesh's (2010) climate in the Himalayan area, climate change is thought to affect the yearly and summer monsoon rainfall. Few studies have noted favourable trends in rainfall patterns for local areas, including Sharma *et al.,* (2000) in Nepal's Kosi basin and Kumar *et al.,* (2005) in India's Himachal Pradesh state. Swami (2024) analysed monsoon rainfall trend in Uttarakhand and reported that rainfall was decreasing in most parts of Uttarakhand while Singh *et al.,* (2021) analysed monthly and seasonal rainfall of western Maharashtra and related it with soybean productivity.

Study area and data

The state of Himachal Pradesh was selected for the study (Fig. 1). The long-term monthly rainfall data (1991- 2020) of 12 rain stations were collected from the Shimla Centre of the Indian Meteorological Department (IMD) in New Delhi, India. For seasonal analysis, each year was divided into four seasons: December–March (winter season), April–June (pre-monsoon season), July–September (monsoon season), and October–November (post-monsoon season) as per IMD Shimla centre according to IMD Shimla.

Mann-Kendall test and Sen's Slope estimator test

The Mann-Kendall Test is employed to ascertain whether a time series exhibits a monotonic upward or downward trend. It is not necessary for the data to be normally distributed or linear. It is necessary that there be no autocorrelation. Mann (1945) developed the Mann-Kendall test as a non-parametric test for trend detection. Kendall (1975) provided the test statistic distribution for testing non-linear trend and turning points. Sen (1968) developed a nonparametric technique for predicting the trend slope in a sample of n data pairs. The details of computation are given by Swami (2024) and Singh *et al.* (2021).

Monsoon season rainfall trends

Significant geographical disparities in monsoon rainfall patterns in Himachal Pradesh are revealed by the nonparametric Mann-Kendall test and Sen's slope estimator (Table 1). The Mann-Kendall test identified positive trends in Dharamshala, whereas negative trends were observed in Keylong and Bharmour. No significant trends were found in the remaining stations. The Sen's Slope test showed monsoon season patterns rising in Dharamshala (43.219mm), Nahan (4.08 mm), Shimla (0.21mm), Kalpa (0.80 mm),

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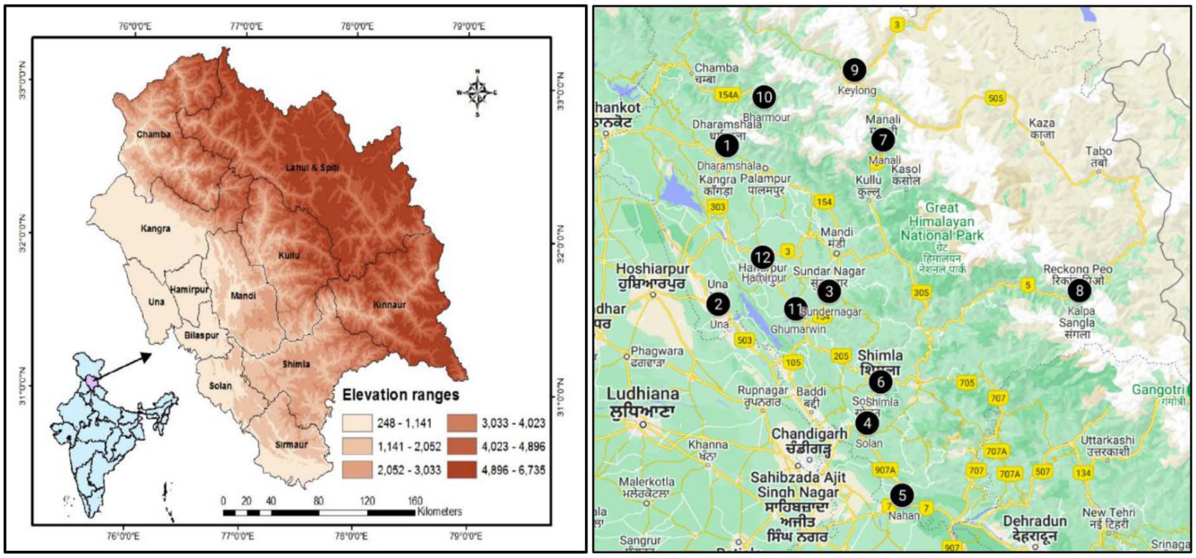

Fig. 1: Map of the study area

Table 1: Mann-Kendall and Sen's Slope estimator results of monsoon rainfall trends and p-value. Bold values indicate significance at p<0.05.

Area	Mann-Kendall statistic(S)	Kendall's tau	p-value (two tailed test)	Alpha	Sen slope	Test interpretation
Dharamshala	205	0.471	0.000	0.05	43.219	REJECT H0
Una	-77	-0.177	0.175	0.05	-7.637	ACCEPT H0
Sundernagar	-29	-0.067	0.617	0.05	-3.100	ACCEPT H0
Solan	77	0.177	0.175	0.05	4.079	ACCEPT H0
Nahan	-25	-0.057	0.669	0.05	-4.338	ACCEPT H0
Shimla	26	0.060	0.656	0.05	0.206	ACCEPT H0
Manali	-13	-0.030	0.830	0.05	-1.243	ACCEPT H0
Kalpa	31	0.071	0.592	0.05	0.800	ACCEPT H0
Keylang	-130	-0.299	0.021	0.05	-4.558	REJECT H0
Bharmour	-127	-0.292	0.025	0.05	-10.57	REJECT H0
Ghumarwin	57	0.131	0.318	0.05	6.717	ACCEPT H0
Hamirpur	-57	-0.131	0.318	0.05	-3.010	ACCEPT H0

and Ghumarwin (6.72 mm). Out of all the options, Dharamshala had the most significant upward tendency according to Sen's Slope, with a value of 43.22 mm. Conversely, Una had a decrease of -7.64 mm, Sundernagar a decrease of -3.10 mm, Nahan a decrease of -4.34 mm, Manali a decrease of -1.24 mm, Keylong a decrease of -4.56 mm, Bharmour a decrease of -10.57mm, and Hamirpur a decrease of -3.01 mm in their yearly trends. Bharmour had the most significant decline at Sen's Slope, at a rate of -10.57mm.

Winter season rainfall trends

Significant geographical variability in Himachal Pradesh winter precipitation patterns indicate the nonparametric Mann-Kendall test and Sen's slope estimator. No Mann-Kendall trends were seen at any location in Table 2. At Una (1.29 mm), Solan (1.28 mm), Nahan (0.25 mm), Manali (6.92 mm), and Ghumarwin (2.02 mm), the Sen's Slope test uncovered upward winter season rainfall trends. With a rate of increase of 6.93 mm, Manali exhibited the most pronounced upward trend among these. On the other hand, Dharamshala (-0.209mm), Sundernagar (-0.81 mm), Shimla (-1.86 mm), Kalpa (-2.19 mm), Keylong (-3.20 mm), Bharmour (-6.65 mm), and Hamirpur (-1.14 mm) showed decreasing winter season rainfall trends. Keylong had the highest decreasing trend at Sen's Slope (-6.65 mm).

A decline in monsoon rainfall has been observed in the northern high Himalayan regions, as indicated by this study. On the other hand, there has been an increase in rainfall in the regions of Dharamshala, Solan, and Ghumarwin. At five different stations, with Manali being located in the high mountain region and Una, Solan, Nahan, and Ghumarwin being located in the low mountain range, there has been an increase in the amount of winter precipitation that has been observed. Among the several stations, Bharmour, which is located in the northern high mountainous region, has experienced the least quantity of winter rainfall over the course of the past three decades in compared to the other stations.

Table 2: Mann-Kendall and Sen's Slope estimator results. Winter season rainfall trends and p-value. Bold values indicate significance at p<0.05

Area	Mann-Kendall statistic(S)	Kendall's tau	p-value (two tailed test)	Alpha	Sen slope	Test interpretation
Dharamshala	-7	-0.016	0.915	0.05	-0.209	ACCEPT H0
Una	23	0.053	0.695	0.05	1.292	ACCEPT H0
Sundernagar	-13	-0.030	0.830	0.05	-0.808	ACCEPT H0
Solan	39	0.090	0.498	0.05	1.280	ACCEPT H0
Nahan	13	0.030	0.830	0.05	0.254	ACCEPT H0
Shimla	-37	-0.085	0.521	0.05	-1.860	ACCEPT H0
Manali	85	0.195	0.134	0.05	6.925	ACCEPT H0
Kalpa	-45	-0.103	0.432	0.05	-2.189	ACCEPT H0
Keylang	-74	-0.170	0.193	0.05	-3.200	ACCEPT H0
Bharmour	-71	-0.163	0.212	0.05	-6.645	ACCEPT H0
Ghumarwin	33	0.076	0.568	0.05	2.017	ACCEPT H0
Hamirpur	-25	-0.057	0.669	0.05	-1.136	ACCEPT H0

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