Content is available at: CRDEEP Journals
Journal homepage: http://www.crdeepjournal.org/category/journals/ijes/

International Journal of Environmental Sciences
(ISSN: 2277-1948) (Scientific Journal Impact Factor: 6.043)

UGC Approved-A Peer Reviewed Quarterly Journal

Full Length Research Paper

Monsoon Season Temperature Trends Analysis by Mann-Kendall and Sen's Slope Estimator Test in Himachal Pradesh, India.

Aman Kumar[1] and Pawan K. Attri
School of Environmental Sciences, Department of Interdisciplinary Studies, Himachal Pradesh University, Summer Hill, Shimla-5 (H.P.) India.

ARTICLE DETAILS

Corresponding Author:
Aman Kumar

Key words:
Temperature trends; Climate variability, Mann-Kendall; Himachal Pradesh

ABSTRACT

This study will use the Mann-Kendall (MK) test and Sen's Slope estimator to examine monsoon season variability and trend of average maximum and lowest temperatures at twelve meteorological stations in twelve Himachal Pradesh (India) districts. Temperature, a fundamental climatic parameter, indicates climate change. Temperature changes must be carefully examined to see how climate change affects agriculture and other industries. Every location showed a similar monsoon season temperature pattern. Monsoon season variations were seen at all stations, with Keylong showing the greatest rise in temperature (Sen's slope values of 0.049°C). During the monsoon season, the average maximum temperature decreased at all locations, with the greatest decreases at Una, Ghumarwin, and Hamirpur (Sen's slope: -0.072›C). The study found that these temperature trends affect agriculture, food production, human health, fisheries, forestry, energy, and tourism. Trends, whether positive or unfavourable, may need planning to handle migratory patterns and forced displacement. To handle harmful climate changes, the public must be educated and support smart adaptation plans. These methodologies should use long-term series data to accurately assess their efficacy over time.

1. Introduction

At the present time, climate change presents major obstacles for our planet. For many years and perhaps even decades to come, this is a complete risk that will provide significant environmental, financial, social, and political problems. Because of its effect on the common atmosphere of the Earth, climate change has grown to be a global environmental issue of great interest. Climate, as defined by the WMO Technical Regulations (2020), is the prolonged period of meteorological variables including temperature, precipitation, humidity, wind speed, and direction that are unique to a certain geographical location (Linacre, 1992). Usually extending 30 years, Climate change is the continuous modification of climatic properties brought about by both natural and manmade activities. Having major effects on food and energy security, water resources, natural ecosystem dynamics and services, and human health among other sectors, climate change is the main environmental issue facing humans worldwide. Since the preindustrial era, the earth's climate system has undergone notable both global and regional changes (Mustafa Z., 2011). Supported by significant data (Houghton *et al.,* 2001), which is predicted to rise in the future, maybe at a quicker rate, human activities have been extensively acknowledged as the main source of the increasing trend (0.1°C/decade) observed over the previous 50 years. Rising human-caused concentrations of greenhouse gases (GHGs) are connected to the noted warming throughout the later half of the 20th century (IPCC 2007, 2012). By the year 2100, the IPCC has projected an increase in global temperature ranging from 1.4°C to 5.8°C; this would have major effects on the entire hydrological system, ecosystems, sea level, agricultural production, and other activities. Human-caused greenhouse gas emissions, aerosols, changes in land use and cover, and other factors account mostly for climate change. By lowering Earth's terrestrial radiation escaping to space, GHGs warm the surface. Ice core research indicates that quantities of atmospheric carbon dioxide, methane, and nitrous oxide are higher than they

---

[1] Author can be contacted at: *School of Environmental Sciences, Department of Interdisciplinary Studies, Himachal Pradesh University, Summer Hill, Shimla-5 (H.P.) India.*

Received: 20-Dec-2024; Sent for Review on: 25-Dec-2024; Draft sent to Author for corrections: 05-Jan-2025; Accepted on: 12-Jan-20225; Online Available from 16-Jan-2025
DOI: 10.13140/RG.2.2.15148.78723

have ever been in 800,000 years. Their mean annual growth rates during the past century are probably not matched in the prior 22,000 years (Stocker *et al.,* 2013). Precipitation trend analysis has become a key issue for a century attributable in great part to scientific attention to global climate change. While certain areas are negative, overall, it demonstrates a slight global positive trend (IPCC, 1996). Rainfall influences ecological changes and crop decisions; anticipating trends might strengthen the economics of a country. While global warming is accelerating at 0.74 ± 0.18 °C during 1906–2005, effective water resource management is vital for development, food production, and flood control (IPCC, 2007). With long term data, several studies have greatly advanced the knowledge on climate change (Dessens and Bucher, 1995; Serra *et al.,* 2001; Marengo, 2004). Time series data analysis exposes a clear trend of either dropping or increasing temperatures and rainfall. Human intervention—more especially, agricultural and irrigation practices affecting land useis blamed for this trend, which aggravates climate change (Kalnay and Cai, 2003).

Most indices around the west coast and north-western areas of the peninsula showed a clear rise when severe precipitation patterns in India between 1901 and 2000 were analysed (Joshi *et al.,* 2006). With a disproportionately impact on the water, agricultural, and food security sectors, the frequency of heat stress, drought, and floods disasters is expected to rise throughout the century (IPCC, 2012). Analysis of discharge data shows that during the past thirty years, high-magnitude flood episodes in the northwest Himalayas have increased (Bhutiyani*et al.,* 2008). Summer monsoon precipitation (Krishnan *et al.,* 2021) has dropped as human-caused aerosol forcing in the Northern Hemisphere has offset the expected rise in precipitation brought on by greenhouse gas warming. The unique climate of the Himalayan system is quite important for the Tibetan plateau as well as the Indian sub continence. The range serves as a barrier, preventing chilly, dry winds from the north from southerly travel and preserving a warmer temperature on the subcontinent than on other continents. This barrier also impedes monsoon winds, so preventing significant precipitation in the Himalayan foothill region and hindering the advance of western disturbances into Iran, so producing snowfall in Kashmir and Himachal Pradesh as well as rainfall in Punjab. Unlike the drop in the winter, post-monsoon precipitation in the western Himalayan area has been seen to be on increase (Pant *et al.,* 1999). From events like decreasing snowfall, diminishing glaciers, and the northward shift of the temperate fruit belt, global warming is obviously seen in Himachal Pradesh. These elements shorten the length of the rabi season, lower the yield of apple harvests, and create anomalies in rainfall patterns. With the exception of the Southwest monsoon season, the hills get significant annual snowfall. Except for the Southwest monsoon season, the hills get a lot of snow all year round. While the number of days with snowfall spans (2 to 23 Climate of Himachal Pradesh 2010), the range of winter snowfall is between 2 and 130 cm. In the Himalayan area, climate change is thought to affect the yearly and summer monsoon rainfall. Scholars have looked at the long-term rainfall distribution pattern in the Himalayan area including Pant and Borgaonkar 1984; Pant *et al.,* 1999; Sharma *et al.,* 2000; Singh and Sen-Roy 2002; Fowler and Archer 2006; Kumar *et al.,* 2005. The present adverse climate shifts need the discovery and understanding of prospective adaptation measures to capture the public's attention. Examining the data series over an extended period is used to forecast the impact of climatic variations. As awareness of the potential negative consequences of global climate change increases, the present study examines Monsoon Season Temperature (Maximum and minimum average temperature) Trends Analysis by Mann-Kendall and Sen’s Slope Estimator Test in Himachal Pradesh, India.

2. Materials and methods

2.1 Study area

The northernmost state in India, Himachal Pradesh has borders with Ladakh, Punjab, Haryana, Uttarakhand, Jammu & Kashmir, and a limited border with Uttar Pradesh. It also has a boundary internationally from the China's Tibet Region. Covering 55,673 square kilometres, the state is between 30°22′N and 33°12′N latitude and 75°47′E′ and 79°04′E longitude. An Indian state, Himachal Pradesh boasts a varied mountain range and temperature. Whereas the vast Himalayan range runs east and northernly, the Zanskar range runs in the northeast. The central mountains are the Dhaula Dhar and Pir Pranjal ranges; the Shivalik range covers southern and western Himachal Pradesh. Rising at 7,025 meters, Shilla is the tallest mountain summit. Rivers and glaciers make up the state's drainage system; Himalayan rivers run crisscrossing the whole mountain range. In the southern tracts, the temperature is hot and humid subtropical; in the northern and eastern mountain ranges, it is chilly, alpine, and glacial. Three seasons pass through the state: summer, winter, and a rainy season. Temperatures between 28 and 32°C (82 and 90°F) define summer, which runs from mid-April to the end of June.

2.2 Location of study area

Table 1: Location of the study area

S.N.	Area of Study	District	Direction	Latitude	Longitude	Average sea level height(m) for temperature data*
1	Dharamshala	Kangra	North-west Himachal	32.219 °N	76.323°E	1112.16m
2	Una	Una	West Himachal	31.468°N	76.270°E	485.47m
3	Sundernagar	Mandi	Central Himachal	31.529°N	76.888°E	1265.62
4	Solan	Solan	South Himachal	30.908°N	77.099°E	897.65m
5	Nahan	Sirmaur	South Himachal	30.559°N	77.295°E	832.97m
6	Shimla	Shimla	South-east Himachal	31.104°N	77.173°E	1887.45m
7	Manali	Kullu	Central Himachal	32.243°N	77.189°E	2281.73m

8	Kalpa	Kinnaur	East Himachal	31.537°N	78.275°E	3817.54m
9	Keylang	Lahaul and Spiti	North Himachal	32.571°N	77.032°E	3934.93m
10	Bharmour	Chamba	North Himachal	32.442°N	76.532°E	2350.50m
11	Ghumarwin	Bilaspur	West Himachal	31.449°N	76.704°E	485.47m
12	Hamirpur	Hamirpur	West Himachal	31.690°N	76.517°E	485.47m

* Maximum and minimum average temperature for 0.5° × 0.625° latitude/longitude region at a height of 2 metres on the surface of earth.

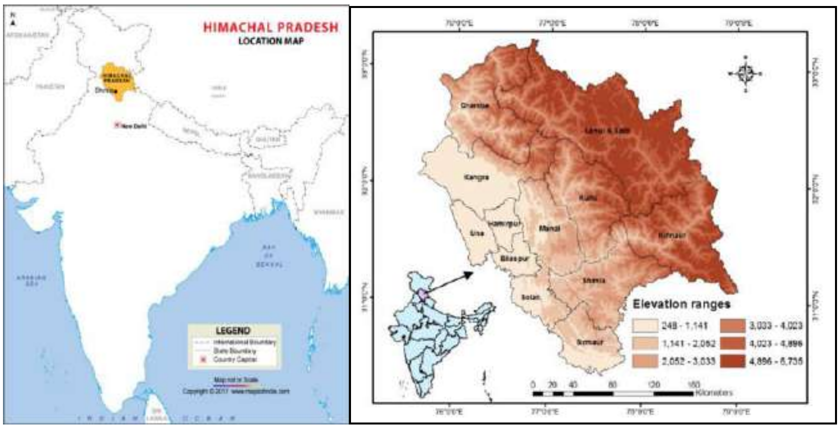


Fig. 1 (a) Map of India (b) District wise Location of study area in Himachal Pradesh.

2.3 Data base and sources

Trend analysis requires extended time-series data to show changes in climate patterns and temperature trends. Monthly minimum and maximum average monthly temperature data span from 1991-2020 obtained from 12 stations in Himachal Pradesh, India and data collected from NASA site https://power.larc.nasa.gov/data-access-viewer/ .

The seasonal study was conducted by dividing each year into four distinct periods: December–March (referred to as the winter season), April–May (known as the pre-monsoon season), June–September (referred to as the monsoon season), and October–November (referred to as the post-monsoon season), as per the IMD Shimla research centre.

2.4 Methodology

2.4.1 Mann-Kendall test

The Mann-Kendall Test is used to determine whether a time series has a monotonic upward or downward trend. It does not require that the data be normally distributed or linear. It does require that there is no autocorrelation. Mann-Kendall test had been formulated by *Mann (1945)* as non-parametric test for trend detection and the test statistic distribution had been given by *Kendall (1975)* for testing non-linear trend and turning point.

The null hypothesis for this test is that there is no trend, and the alternative hypothesis is that there is a trend in the two-sided test or that there is an upward trend (or downward trend) in the one-sided test. For the time series $x_1,..,x_n$, the MK Test uses the following statistic:

$$S = \sum_{i=1}^{n-1} \sum_{j=k+1}^{n} sign\left(x_j - x_i\right)$$

Note that if $S > 0$ then later observations in the time series tend to be larger than those that appear earlier in the time series, while the reverse is true if $S < 0$.

The variance of S is given by

$$var = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_t f_t(f_t - 1)(2f_t + 5)\right]$$

where t varies over the set of tied ranks and f_t is the number of times (i.e. frequency) that the rank t appears.

The MK Test uses the following test statistic:

$$z = \begin{cases} (S-1)/se, & S > 0 \\ 0, & S = 0 \\ (S+1)/se, & S < 0 \end{cases}$$

where se = the square root of var. If there is no monotonic trend (the null hypothesis), then for time series with more than 10 elements, $z \sim N(0, 1)$, i.e., z has a standard normal distribution.

2.4.2 Sen's Slope estimator test

Sen (1968) developed a nonparametric procedure for estimating the slope of trend in asample of n pairs of data. The usual method for estimating the slope of a regression line that fits a set of (x, y) data elements is based on a least-squares estimate. This approach is not valid when the data elements don't fit a straight line; it is also sensitive to outliers.

We now describe an alternative, more robust, nonparametric estimate of the slope, called Sen's slope, for the set of pairs (i, x_i) where x_i is a time series. Sen's slope is defined as

$$Sen's\ slope = Median\left\{\frac{x_j - x_i}{j - i} : i < j\right\}$$

A $1-\alpha$ confidence interval for Sen's slope can be calculated as (*lower, upper*) were

$N = C\,(n, 2)$ $k = se$ ▯ z_{crit}

$lower = m_{(N-k)/2}$ $upper = m_{(N+k)/2+1}$

Here, N = the number of pairs of time series elements (x_i, x_j) where $i < j$ and se = the standard error for the Mann-KendallTest. Also, m_h = the h^{th} smallest in the set $\{(x_j-x_i)/(j-i): i < j\}$ and z_{crit} = the $1-\alpha/2$ critical value for the normal distribution.

2.4.3 Simple Linear Regression Analysis

The "simple linear regression" model is in equation form of Y= mX + c, where, Y = rainfall, X = time in years, m = slope coefficients and c = least square estimates of the intercept. The sign of the slope defines the direction of trend variable: increasing if the sign is positive and decreasing if the sign is negative.

3. **Result and Discussion**

3.1 Monsoon Season Average Minimum Temperature

The nonparametric Mann-Kendall test and Sen's slope estimator indicate notable spatial variations in monsoon season minimum average temperature patterns in research stations. Table number 2 shows the result of the Man-Kendall test shows that there were positive trends in the stations of Sundernagar, Shimla Manali, Kalpa, Keylong and Bharmour. No significant trends were seen in the stations of Dharmshala, Una, Solan, Nahan, Ghumarwin, and Hamirpur. The Sen's Slope test revealed increasing annual maximum average temperature trends at Dharamshala (0.011°C), Una (0.004°C), Sundernagar (0.018°C), Solan (0.011°C), Nahan (0.016°C), Shimla (0.030°C), Manali (0.026°C), Kalpa (0.032°C), Keylong (0.049°C), Bharmour (0.028°C), Ghumarwin (0.004°C), and Hamirpur (0.004°C), in which Keylong had the highest increasing trends at Sen's Slope (0.049°C).Figure 2 presents the examination of temporal data during the monsoon season average minimum temperature. Twelve areas' average rainfall data from 1991 to 2020 were examined using Sen's slope estimator and basic linear trend analysis.

Table 2: Results of the Mann-Kendall test and Sen's Slope estimator test. Trends and p value for minimum monsoon average temperature,bold values are significant at p<0.05.

Area	**Observation**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**Mann-Kendall Statistic(S)**	**Kendall's Tau**	**Var(S)**	**p-value (two tailed test)**	**Alpha**	**Sen slope**	**Test Interpretation**
Dharamshala	30	21.29	22.88	22.01	0.416	85	0.195	3141.6	0.134	0.05	0.011	ACCEPT H0
Una	30	24.70	26.74	25.75	0.529	23	0.053	3141.6	0.695	0.05	0.004	ACCEPT H0
Sundernagar	30	19.80	21.67	20.54	0.429	113	0.260	3141.6	**0.046**	0.05	0.018	**REJECT H0**
Solan	30	21.67	23.78	13.50	0.472	79	0.182	3141.6	0.164	0.05	0.011	ACCEPT H0
Nahan	30	21.95	23.51	22.72	0.450	79	0.182	3141.6	0.164	0.05	0.016	ACCEPT H0
Shimla	30	15.42	17.00	16.14	0.461	163	0.375	3141.6	**0.004**	0.05	0.030	**REJECT H0**
Manali	30	13.33	14.99	14.16	0.395	179	0.411	3141.6	**0.001**	0.05	0.026	**REJECT H0**
Kalpa	30	3.53	5.79	4.67	0.540	155	0.356	3141.6	**0.006**	0.05	0.032	**REJECT H0**
Keylang	30	1.95	4.87	3.41	0.687	211	0.485	3141.6	**0.000**	0.05	0.049	**REJECT H0**
Bharmour	30	13.08	14.70	13.85	0.420	169	0.389	3141.6	**0.003**	0.05	0.028	**REJECT H0**
Ghumarwin	30	24.70	26.74	25.75	0.529	23	0.053	3141.6	0.695	0.05	0.004	ACCEPT H0
Hamirpur	30	24.70	26.74	25.75	0.529	23	0.053	3141.6	0.695	0.05	0.004	ACCEPT H0

3.2 Monsoon Season Average Maximum Temperature

Research stations indicate significant geographical differences in monsoon maximum average temperature patterns, as shown by the nonparametric Mann-Kendall test and Sen's slope estimator. Table number 3 shows the result of the Man-Kendall test reveals a decline in the stations of Dharmshala, Una, Sundernagar, Manali, Kalpa, Keylong, Bharmour, Ghumarwin, and Hamirpur. No notable patterns were seen in the Solan, Nahan and Shimla stations. The Sen's Slope test identified a decline in monsoon season maximum average temperatures at various locations in Himachal Pradesh. The locations with the most significant decreasing trends were Ghumarwin (-0.072°C), Hamirpur (-0.072°C), Una (-0.072°C) Dharamshala (-0.063°C), Kalpa (-0.063°C), Bharmour (-0.058°C) and Manali (-0.043°C).

Other locations such as, Keylong (-0.039°C), Solan (-0.048°C), Sundernagar (-0.048°C), Nahan (-0.036°C), and Shimla (-0.026°C) also experienced decreasing trends, although to a lesser extent.Figure 3 presents the examination of temporal data during the monsoon season average maximum temperature. Twelve areas' average temperature data from 1991 to 2020 were examined using Sen's slope estimator and basic linear trend analysis.

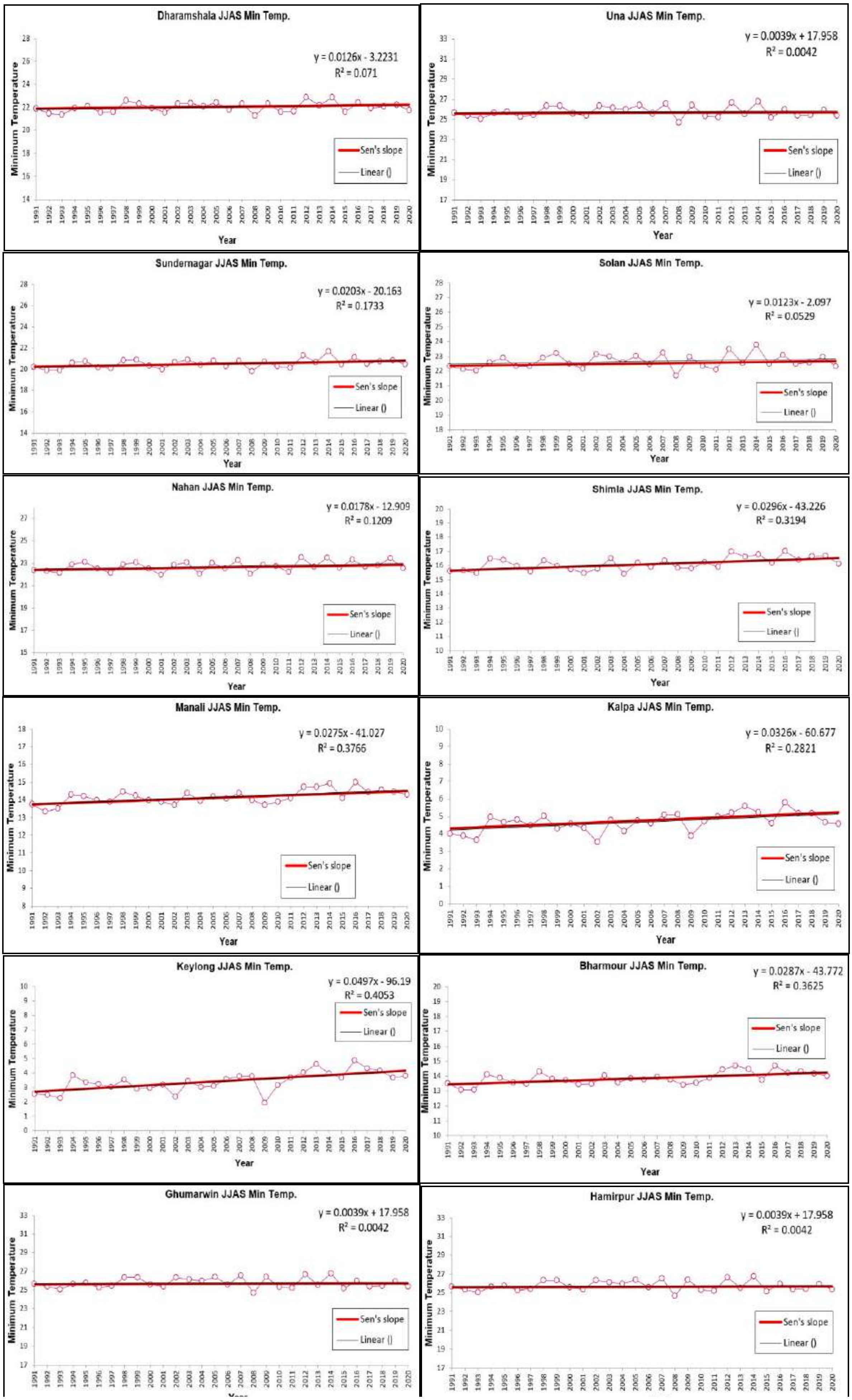
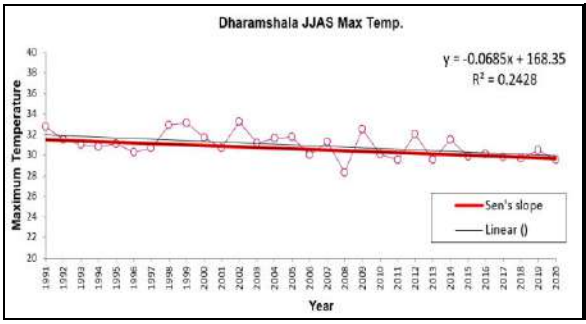
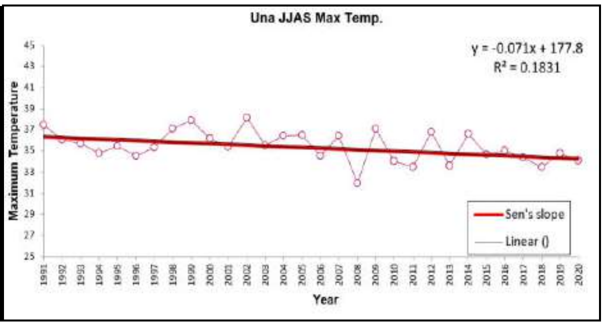


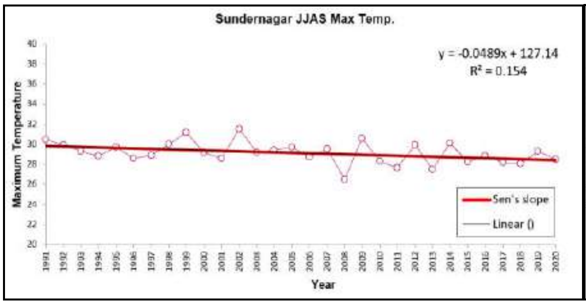
Fig 2: Time Series of the minimum monsoon average temperature for Sen's Slope Estimator and Simple Linear Trend Analysis of the Average Value of Rainfall From 1991–2020 in Twelve Stations.

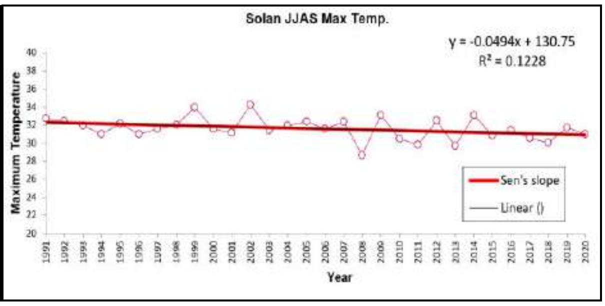
Table 3: Results of the Mann-Kendall test and Sen's Slope estimator test. Trends and p value for Maximum monsoon average temperature, bold values are significant at p<0.05.

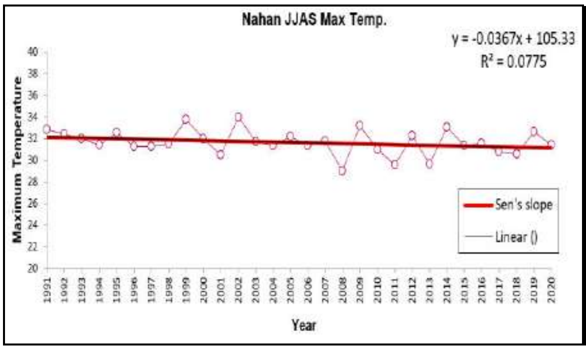
Area	Observation	Minimum	Maximum	Mean	Std. Deviation	Mann-Kendall Statistic(S)	Kendall's Tau	Var(S)	p-value (two tailed test)	Alpha	Sen slope	Test Interpretation
Dharamshala	30	28.32	33.23	30.95	1.224	-147	-0.338	3141.6	**0.009**	0.05	-0.063	**REJECT H0**
Una	30	31.9	38.1	35.4	1.460	-121	-0.278	3141.6	**0.032**	0.05	-0.072	**REJECT H0**
Sundernagar	30	26.48	31.52	29.13	1.096	-117	-0.269	3141.6	**0.038**	0.05	-0.048	**REJECT H0**
Solan	30	28.64	34.30	31.61	1.242	-105	-0.241	3141.6	0.064	0.05	-0.048	ACCEPT H0
Nahan	30	29.00	34.00	31.65	1.162	-79	-0.182	3141.6	0.164	0.05	-0.036	ACCEPT H0
Shimla	30	23.04	26.76	25.13	0.854	-79	-0.182	3141.6	0.164	0.05	-0.026	ACCEPT H0
Manali	30	21.10	24.59	22.97	0.854	-153	-0.352	3141.6	**0.007**	0.05	-0.043	**REJECT H0**
Kalpa	30	13.50	16.39	15.01	0.723	-227	-0.522	3141.6	**<0.0001**	0.05	-0.063	**REJECT H0**
Keylang	30	11.59	14.36	12.92	0.601	-221	-0.508	3141.6	**<0.0001**	0.05	-0.039	**REJECT H0**
Bharmour	30	21.43	25.11	22.95	0.961	-201	-0.462	3141.6	**0.000**	0.05	-0.058	**REJECT H0**
Ghumarwin	30	31.9	38.1	35.4	1.460	-121	-0.278	3141.6	**0.032**	0.05	-0.072	**REJECT H0**
Hamirpur	30	31.9	38.1	35.4	1.460	-121	-0.278	3141.6	**0.032**	0.05	-0.072	**REJECT H0**

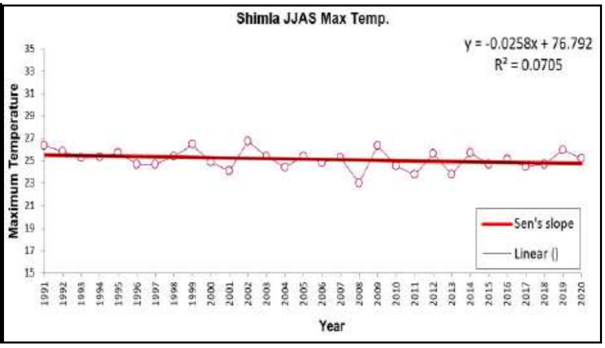


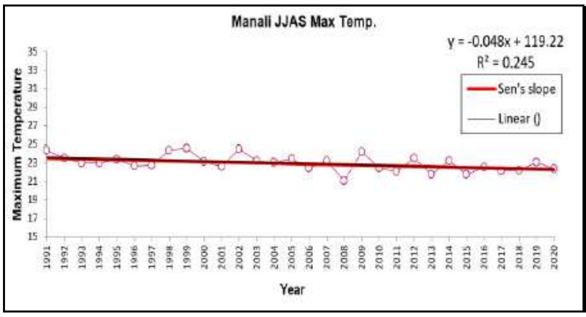


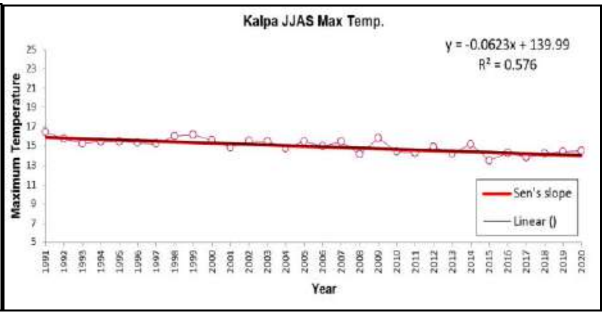












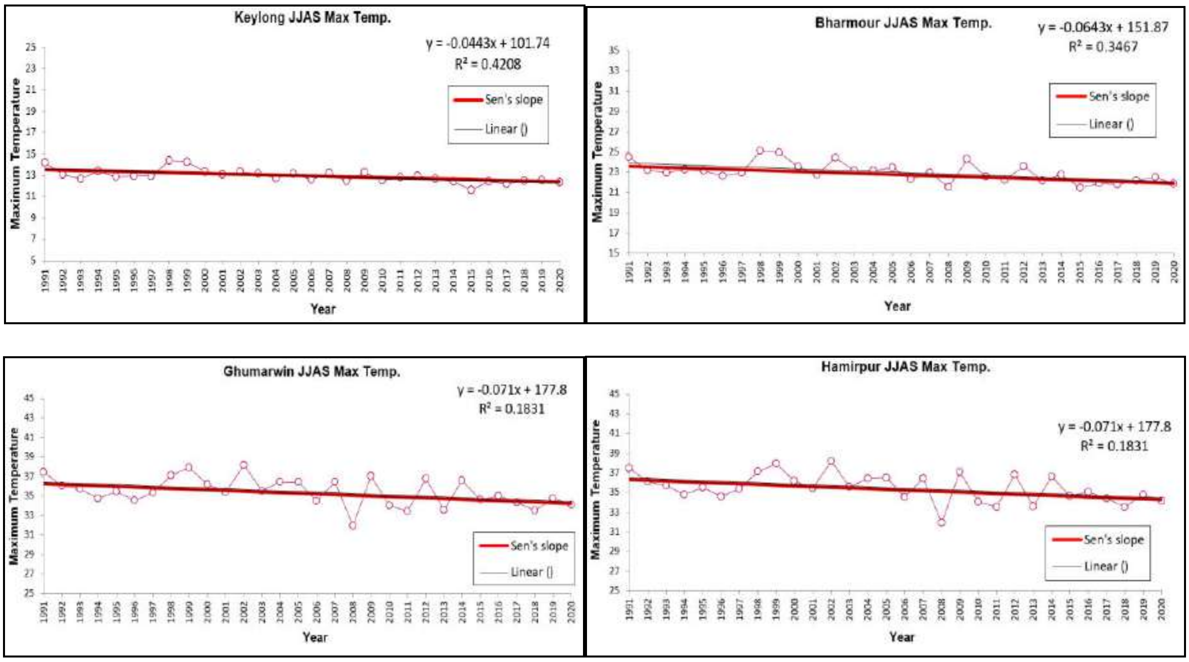


Fig 3: Time Series of the maximum monsoon average temperature for Sen's Slope Estimator and Simple Linear Trend Analysis of the Average Value of temperature from 1991–2020 in Twelve Stations.

4 Discussion

We calculated the mean, standard deviation, Mann-Kendall statistic (S), Kandell's tau, Var(S), p-value (two-tailed test), Alpha, Sen slope, and analysed the data in the temperature time series for each station during the monsoon periods as part of the preliminary analysis for this study. The findings are displayed in tables 2 and 3, correspondingly. Tables 2 and 3 present the statistical properties for the 30-year duration being studied, which covers the years 1991 to 2020. The study analyses the monsoon season maximum and minimum average temperature data collected from twelve locations in Himachal Pradesh to evaluate the patterns and fluctuations of temperature in monsoon season. Statistical analysis was performed using the Mann-Kendall test to evaluate the trends. The experiment was carried out with a confidence level of 95%. Changes were deemed unimportant if they were found to be statistically insignificant at a confidence level below 95%.

The Mann-Kendall test and Sen's slope estimator highlight significant spatial variations in the trends of monsoon season minimum and maximum average temperatures across research stations. The Mann-Kendall test identified positive trends in minimum temperatures for stations such as Sundernagar, Shimla, Manali, Kalpa, Keylong, and Bharmour, while others, including Dharmshala, Una, Solan, Nahan, Ghumarwin, and Hamirpur, showed no significant trends. Similarly, Sen's slope estimator revealed a rising trend in minimum temperatures, with Keylong showing the highest increase (0.049°C). In contrast, maximum temperature trends varied, with a consistent decline observed across most stations. Notably, Ghumarwin, Hamirpur, and Una exhibited the steepest decreases in maximum temperatures, further emphasizing geographical and seasonal variability. The statistical results underscore the nuanced climatic shifts in the region. Stations at higher altitudes, such as Keylong and Kalpa, demonstrate more pronounced trends in both minimum and maximum temperatures, possibly reflecting greater sensitivity to global warming. Meanwhile, lower-altitude stations like Dharamshala and Una exhibit milder changes. The findings highlight the importance of localized climate analyses, as regional climatic responses can differ significantly. These variations in temperature trends have profound implications for agricultural practices, water resources, and ecosystem dynamics, calling for targeted adaptation and mitigation strategies in these geographically diverse regions.

5. Conclusion

This article analysed the patterns in the monsoon season average maximum and minimum temperature at twelve different sites in Himachal Pradesh during a thirty-year period from 1991 to 2020. Both the Mann-Kendall (MK) and Sen's Slope estimator tests indicate a consistent declined in average maximum temperature across all regions but in case of minimum average temperature increasing all the stations. At a variety of sites, both positive and negative trends were detected simultaneously. The biggest negative trend in case of maximum monsoon average temperature may be seen in Una, Ghumarwin and Hamirpur, whereas the highest positive trend can be found in Keylang during the minimum average temperature in monsoon season. The rising minimum average temperature is a pressing global issue with cascading effects on the environment, ecosystems, and human society. From melting glaciers and biodiversity loss to health crises, food insecurity, and economic strain, the impacts are pervasive and interconnected. Urgent and coordinated action is essential to mitigate these challenges, protect vulnerable communities, and preserve Earth's natural systems for future generations.

6.References

Bhutiyani, M. R., Kale, V. S., & Pawar, N. J. (2008). Changing stream flow pattern in the rivers of north-western Himalaya: Implications of global warming in the 20th century. *Curr. Sci. India,* 95. 703-708. http://www.indiaenvironmentportal.org.in/files/Changing.pdf

Dessens, J., & Bucher, A. (1995). Changes in minimum and maximum temperatures at the Pic du Midi relation with humidity and cloudiness, 1882–1984. *Atmospheric Research* 37, 147–162. https://doi.org/10.1016/0169-8095(94)00075-O

Fowler, H.J., & Archer, D.R. (2006). Conflicting signals of climatic change in the upper Indus Basin. *Journal of Climate,* 19: 4276–4293. https://doi.org/10.1175/JCLI3860.1

Houghton J.T., Meira F, L.G., Callander B.A., Harris N., Kattenberg A., & Maskell K. (eds). Climate change. Cambridge University Press: New York. IPCC ;1996. The IPCC Second Assessment Report.

IPCC. (1996). Climate change. In The IPCC Second Assessment Report, Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A., Maskell, K. (eds). Cambridge University Press: New York. https://www.ipcc.ch/site/assets/uploads/2018/05/2nd-assessment-en-1.pdf

IPCC. (2007). Climate change 2007: climate change impacts, adaptation and vulnerability. Working Group II contribution to the Intergovernmental Panel on Climate Change Fourth Assessment Report. Summary for policymakers, 23. https://www.ipcc.ch/site/assets/uploads/2018/03/ar4_wg2_full_report.pdf

IPCC. (2012). A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. (Eds. C. B., Field, V., Barros, T. F., Stocker, D., Qin, D. J., Dokken, K. L., Ebi, M. D., Mastrandrea, K. J., Mach, G. K., Plattner, S. K., Allen, M., Tignor, P. M., Midgley). Cambridge University Press, Cambridge, United Kingdom; New York, USA.

Joshi, N.V., Ravindranath, N.H., & Sukumar, R. (2006). Impact of climate change on forests in India*. Curr. Sci.,* 90 (3), 354–361. https://www.researchgate.net/publication/2183030

Kalnay, E., & Cai, M. (2003). Impact of urbanization and land-use change on climate*. Nature,*423, 528–531. https://doi.org/10.1038/nature01675

Kendall, M.G. (1975). Rank Correlation Methods, 4th edition. Charles Griffin, London, U.K.

Kumar, V., Singh, P., & Jain, S. K., (2005), "Rainfall trends over Himachal Pradesh, Western Himalaya, India", *Conference on Development of Hydro Power Projects - A Prospective Challenge, Shimla,* 20-22 April, 2005.

Linacre, E. (1992) Climate Data and Resources: A Reference and Guide. Routledge, London.

Mann, H.B. (1945). Non-parametric test against trend. *Econometrica,* 13, 245–259. http://dx.doi.org/10.2307/1907187

Marengo JA. (2004). Interdecadal variability and trends of rainfall across the Amazon basin. *Theoretical and Applied Climatology,* 78, 79–96. http://dx.doi.org/10.1007/s00704-004-0045-8

Mustafa, Z. (2011). Climate change and its impact with special focus in Pakistan. In *Pakistan Engineering Congress, Symposium* (Vol. 33, p. 290). Lahore.

Office of the Addl. Director General of Meteorology (Research). Climate of Himachal Pradesh. Climatological Summaries of States Series - No.15. New Delhi: Controller of Publications, Government of India, Department of Publication, Civil Lines; 2010. https://imdpune.gov.in/library/public/Climate%20of%20Himachal%20Pradesh.pdf

Pant, G.B., Rupa Kumar, K., & Borgaonkar, H.P. (1999). Climate and its long-term variability over the western Himalaya during the past two centuries. In *The Himalayan Environment*, Dash SK, Bahadur J (eds). New Age International (P) Ltd., Publishers: New Delhi; 171–184.

Pant. G., & Borgaonkar, H. (1984). Climate of the hill regions of Uttar Pradesh. *Himal Res Dev,* 3:13–20

R. Krishnan, J. Sanjay, Chellappan Gnanaseelan, Milind Mujumdar, Ashwini Kulkarni & Supriyo Chakraborty. (2021). Assessment of Climate Change over the Indian Region. *A Report of the Ministry of Earth Sciences (MoES), Government of India*. https://doi.org/10.1007/978-981-15-4327-2

Sharma, K., Moore, B., & Vorosmarty, C. (2000). Anthropogenic, climatic and hydrologic trends in the Kosi Basin, Himalaya. *Clim Chang,* 47:141–165 http://dx.doi.org/10.1023/A:1005696808953

Sen, P.K. (1968) Estimates of the regression coefficient based on Kendall's tau. *J Am Stat As*, 63:1379–1389. doi:10.1080/01621459.1968.10480934

Serra, C., Burgueno, A., & Lana, X. (2001). Analysis of maximum and minimum daily temperatures recorded at Fabra observatory (Barcelona, NE Spain) in the period 1917–1998. *InternationalJournal of Climatology,* 21, 617–636. https://doi.org/10.1002/joc.633

Singh, R., & Sen-Roy, S. (2002). Climate variability and hydrological extremes in a Himalayan catchment. In: ERB and Northern European FRIEND Project 5 Conference. Slovakia. https://www.researchgate.net/publication/237123220_Climate_variability_and_hydrological_extremes_in_a_Himalayan_catchment

Shrestha, S., Yao, T., Kattel, D. B., & Devkota, L. P. (2019). Precipitation characteristics of two complex mountain river basins on the southern slopes of the central Himalayas. *Theoretical and Applied Climatology,138*(1–2), 1159–1178. https://doi.org/10.1007/s00704-019-02897-7

Shrestha, U. B., Gautam, S., & Bawa, K. S. 2012. Widespread climate change in the Himalayas and associated changes in local ecosystems. *PloS One*, *7*(5). https://doi.org/10.1371/journal.pone.0036741

Stocker, T.F., *et al.* (2013) IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Wigley, T. M., & Raper, S. C. (2001). Interpretation of high projections for global-mean warming. *Science (New York, N.Y.)*, *293*(5529), 451–454. https://doi.org/10.1126/science.1061604