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Short communication

Variability and trends of rainfall in past and future in Kumaon region of Uttarakhand

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The IPCC's report states that in the high-altitude region the variability in rainfall have increased due to climate change impact which have affected the mountain regions' ecosystems, food, agriculture, culture and tourism, and water resources in the region. Evaluating the impacts of both historical and projected climate change on both nature and society demands a broader perspective (Hedlund *et al.,* 2018). Several works have been reported across the India and in other parts of the world to study the trend and variability in rainfall (Al-Lami, *et al.,* 2024; Dharani *et al.,* 2022; Kale, 2020; Yadav *et al.,* 2014). View on this, an attempt has been made to study the rainfall patterns across the Kumaon region of Uttarakhand, based on historical data (1901–2022) and future projections under SSP 2-4.5 (intermediate greenhouse gas (GHG) emissions with CO_2 rising until 2050 and then declining by 2075) and SSP 5-8.5 (very high GHG emissions with CO_2 continuing to rise until 2075).

The study area encompasses the Kumaon region of Uttarakhand, which is situated between latitude 29.27º N and longitude 79.47º E. This region comprises six districts: Almora, Bageshwar, Champawat, Nainital, Pithoragarh and Udham Singh Nagar (Fig. 1). The futuristic meteorological data of rainfall as predicted by MIROC-6 model with resolution of 1.4°×1.4° (Tatebe *et al.,* 2019) were downloaded from the site (https://cds.climate.copernicus.eu) and downscaled from the year 2015-2100 for different locations in Kumaon region of Uttarakhand state by using Python3 at two SSPs (Shared Socioeconomic Pathway) i.e., SSP 2-4.5 and SSP 5-8.5.

The baseline model and IMD data (1985-2014) were used to bias correct the future projected data as predicted by the model. The historical IMD gridded (0.5º×0.5º) rainfall data from 1901-2022 were obtained (https://www.imdpune.gov.in) to analyze the uncertainties in these climatic parameters with the future projections at two SSPs. Different softwares like Weathercock, Rstudio and Applications like Spyder (Python) has been used to do statistical analysis like Average annual Rainfall and Mann Kendall test is performed to evaluate the trend in annual rainfall. The Z value is a standardized test statistic used to determine the significance of a trend in a time series. A very high positive value of Z is an indicator of an increasing trend and a negative value indicates a decreasing trend, when Z value lies between +1.96 to -1.96 then null hypothesis is accepted and when the value of $Z > +1.96$ or $Z < -1.96$ then null hypothesis (H0) is rejected at 95% confidence level. The trend magnitude is calculated by Sen's slope.

Rainfall variability in past and future

The historical mean rainfall (Table 1) varies across districts, with Pithoragarh receiving the highest rainfall (1929.8 mm) and Almora the lowest (1309.6 mm). Future rainfall deviations under SSP 2-4.5 and SSP 5-8.5 indicate an overall increase in rainfall, with significant variations across districts and time periods. For instance, Bageshwar shows a sharp rise in rainfall by the end of the century (904.7 mm under SSP 5-8.5), while Nainital exhibits relatively moderate changes (211.4 mm under SSP 5-8.5). The rainfall deviation in the Kumaon region is generally higher (Table 1) under SSP 5-8.5 than SSP 2-4.5 during the near future (2015-2044) and mid-century (2045-2074). For instance, in the near future, districts like Almora (331.3 mm), Champawat (509.5 mm), and Bageshwar (494.9 mm) exhibit higher deviations under SSP 5-8.5 compared to SSP 2-4.5 (267.2 mm, 378.8 mm, and 512.5 mm, respectively). A similar pattern continues into the mid-century, with districts such as Almora (355.2 mm under SSP 5-8.5 vs. 319.1 mm under SSP 2-4.5) and Pithoragarh (446.6 mm under SSP 5-8.5 vs. 406.8 mm under SSP 2-4.5) showing greater rainfall deviations.

However, by the end of the century (2075-2100), this trend reverses, and SSP 2-4.5 exhibits higher rainfall deviations than SSP 5-8.5 for all districts. For example, Almora's rainfall deviation is 413.6 mm under SSP 2-4.5 but reduces to 378.0 mm

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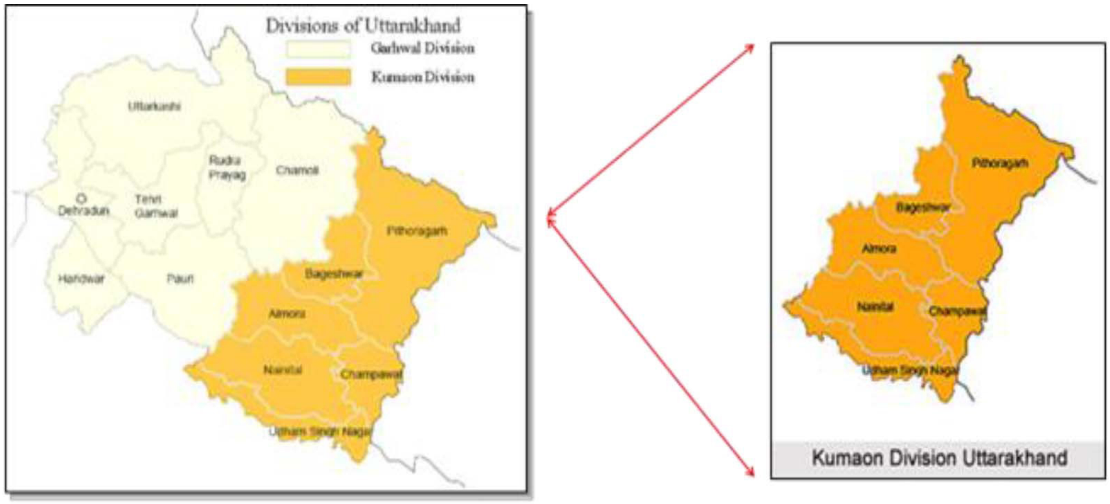

Fig. 1: Map showing different districts of Kumaon division

Table 1: Base line mean rainfall and deviations of projected rainfall under various scenarios in Kumaon region of Uttarakhand

District	Past (1901- 2022) (mm)	Deviation in the rainfall from the Past (mm)					
		Near future (2015-2044)		Mid century (2045-2074)		End century (2075-2100)	
		SSP 2-4.5	SSP 5-8.5	SSP 2-4.5	SSP 5-8.5	SSP 2-4.5	SSP 5-8.5
Almora	1309.6	267.2	331.3	319.1	355.2	413.6	378.0
Bageshwar	1774.9	512.5	494.9	14.6	406.8	904.7	564.5
Champawat	1472.5	378.8	509.5	491.2	521.9	625.7	605.2
Nainital	1454.3	125.1	228.5	311.1	278.8	294.1	211.4
Pithoragarh	1929.8	344.4	435.1	406.8	446.6	628.7	13.1
US Nagar	1398.4	262.8	387.1	456.2	439.2	481.3	390.9

under SSP 5-8.5 and Pithoragarh shows a drastic decline to only 13.1 mm under SSP 5-8.5 compared to 628.7 mm under SSP 5-8.5 by the end century. This suggests that while extreme warming under SSP 5-8.5 initially leads to a higher increase in rainfall, by the end of the century, changes in atmospheric circulation and precipitation patterns may result in a relative decline in rainfall under SSP 5-8.5 compared to SSP 2-4.5. This contrast between SSP 2-4.5 and SSP 5-8.5 underscores the variability introduced by extreme greenhouse gas concentrations, leading to potentially intensified climate impacts in certain districts. This could result from the interplay of increased temperatures and shifting monsoonal patterns, leading to drier conditions in these regions (Loo *et al.,* 2015).

Trends in annual rainfall

The trend equations that describe the annual rainfall trends for the past and future under different SSP scenarios as per Table 2. The past trends (1901-2022) indicate predominantly negative slopes, indicating declining rainfall trends in most districts due to weakened monsoon circulation, deforestation and shifting monsoon patterns caused by global warming, aerosols, and inter-annual variability like ENSO (El Niño-Southern Oscillation) as per (Sharma *et al.,* 2022), though variations exist as studied by Banerjee *et al.,* (2020). Champawat for instance, show a gradual increase in rainfall historically as driven by orographic effects, influenced by its elevation and transition between hill and plain regions while Pithoragarh and US Nagar exhibit relatively stable trends with minimal fluctuations. Almora's historical trend suggests a decreasing trend, while Pithoragarh's equation indicates a smaller but still negative trend. However, in the future (2015-2100), several districts exhibit positive slopes, suggesting an increasing rainfall trend. Almora transitions to a positive slope of 2.74 under SSP 5-8.5, while Bageshwar shifts from -1.79 to 8.21 under SSP 2-4.5. On the other hand, some districts, such as Nainital (-0.71 under SSP 5-8.5) and Pithoragarh (-5.20 under SSP 5-8.5), still show negative trends, indicating potential declines in rainfall towards the end of the century.

Comparing past and future rainfall trends based on the slopes of these equations provides insights into expected changes in rainfall magnitude. A positive shift in slope from the historical period to the future indicates a projected increase in rainfall, while a continued negative slope suggests persistent or worsening declines. The most notable increase occurs in Bageshwar, where the slope changes from -1.79 to 8.21 under SSP 2-4.5. Conversely, Pithoragarh's transition from -0.51 to -5.20 under SSP 5-8.5 suggests a significant reduction in annual rainfall, possibly due to shifting monsoon patterns and localized climate influences.

Mann-Kendall test and Sen's slope

The Sen's slope quantifies changes in annual rainfall, while the Z value from the Mann-Kendall test determines trend significance as depicted in Table 3. For Nainital, Pithoragarh, and

Table 2: Annual rainfall trend equations for past and future scenarios in Kumaon region of Uttarakhand

	Past (1901-2022)	SSP 2-4.5 (2015-2100)	SSP 5-8.5 (2015-2100)
Almora	y = -2.34x + 5899.2	y = 1.36x - 1337.3	y = 2.74x - 4116.5
Bageshwar	y = -1.79x + 1885.2	y = 8.21x + 939.85	y = 2.71x + 1780.3
Champawat	y = 0.60x + 1435.6	y = 4.23x - 6747.5	y = 1.36x + 1801.7
Nainital	y = -2.23x + 1587.4	y = 3.27x + 1184.3	y = -0.71x + 1806.6
Pithoragarh	y = -0.51x + 2924.8	y = 6.00x - 9945.6	y = -5.20x + 12942
US Nagar	y = -1.35x + 4045.3	y = 3.85x - 6130.5	y = -0.40x + 2616.6

Table 3: Mann Kendall test and Sen's slope of annual rainfall for past and future scenarios in Kumaon region of Uttarakhand

District	Past (1901-2022)			SSP 2-4.5 (2015-2022)			SSP 5-8.5 (2015-2022)		
	Sen's Slope (mm)	Z value	NS/S	Sen's Slope (mm)	Z value	NS/S	Sen's Slope (mm)	Z value	NS/S
Almora	-2.02	-2.97	S	2.60	1.98	S	3.50	0.00	NS
Bageshwar	-2.19	-1.80	NS	9.40	0.73	NS	2.79	0.31	NS
Champawat	0.48	0.47	NS	3.64	1.98	S	0.63	0.31	NS
Nainital	-2.22	-2.39	S	3.38	1.15	NS	-2.54	-1.15	NS
Pithoragarh	-0.95	-0.66	NS	6.10	1.15	NS	-5.71	-0.51	NS
US Nagar	-1.09	-1.09	NS	4.84	1.77	NS	-1.64	-0.94	NS

At 5% level of significance

Udham Singh Nagar (US Nagar), rainfall trends decline under SSP 5-8.5 compared to SSP 2-4.5. Specifically, Nainital's Sen's slope shifts from 3.38 mm in SSP 2-4.5 to -2.54 mm/yr in SSP 5-8.5, In the past (1901-2022), Nainital had a significant decreasing trend (Sen's slope: -2.22, Z: -2.39, S), while Pithoragarh (-0.95 mm/yr) and US Nagar (-1.09 mm/yr) showed non-significant decreasing trends. The lack of significance in most future trends indicates high variability in projected rainfall. The declining rainfall under SSP 5-8.5 is influenced by topographical variations, as Nainital and Pithoragarh's mid-to-high elevations rely on orographic lifting of monsoonal winds, which may weaken due to higher evapotranspiration and monsoon shifts under increased warming. US Nagar, a lowland district dependent on runoff from upper regions, may experience reduced moisture influx, explaining its negative trend in the high-emission scenario.

Overall, rainfall is expected to increase in the future, with notable deviations across districts. Bageshwar shows the highest increase (904.7 mm by the end of the century under SSP 5-8.5), while Nainital exhibits a moderate rise (211.4 mm). However, end-century projections reveal a reversal, with SSP 2-4.5 exhibiting higher rainfall deviations than SSP 5-8.5. Trend equations indicate a shift from historical declines to increasing future rainfall in some districts, though Nainital (-0.71 mm/yr), Pithoragarh (-5.20 mm/yr), and Udham Singh Nagar (-1.64 mm/yr) show decreasing trends under SSP 5-8.5. The Mann-Kendall test highlights significant past declines in Almora and Nainital with Z value of -2.97 and -2.39 respectively. These variations are attributed to topographical effects, weakened orographic lifting, and changing monsoonal patterns under extreme warming. The findings underscore the complexity of climate-induced rainfall variability in Himalayan regions.

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Data availability: The historical rainfall data are available Indian Meteorological Department portal (https://www.imdpune.gov.in) and The future MIROC 6 model data are available online at the link (https://cds.climate.copernicus.eu).

Author's Contribution: **S. Goel**: Methodology, Data analysis, Major editing, Writing original manuscript; **S. Kothiyal**: Discussion, Formal analysis; **R.K. Singh**: Guidance, Supervision, Visualization

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REFERENCES

Al-Lami, A.M., Al-Timimi, Y.K. and Al-Salihi, A.M. (2024). Innovative trend analysis of annual rainfall in Iraq during 1980-2021. *J. Agrometeorol.,* 26(2): 196-203.

https://doi.org/10.54386/jam.v26i2.2561

Banerjee, A., Dimri, A. P. and Kumar, K. (2020). Rainfall over the Himalayan foot-hill region: Present and future. *J. Earth Sys. Sci.,* 129: 1-16.

Dharani C., Maragatham, N., Geetalakshami, V., Ramanathan, S.P. and Kannan, B. (2022). Rainfall variability analysis and trend assessment in Theni District of Tamil Nadu, India: An implication for crop planning. *J. Agrometeorol.,* 24(3): 305-308. https://doi.org/10.54386/jam.v24i3.1797

Hedlund, J., Fick, S., Carlsen, H. and Benzie, M. (2018). Quantifying transnational climate impact exposure: new perspectives on the global distribution of climate risk. *Glob. Environ. Chang.,* 52(1): 75-85. https://doi.org/10.1016/j.gloenvcha.2018.04.006.

Kale, G. D. (2020). Trend analyses of regional time series of temperatures and rainfall of the Tapi basin. *J. Agrometeorol.,* 22(1): 48-51. https://doi.org/10.54386/jam.v22i1.121

Loo, Y. Y., Billa, L. and Singh, A. (2015). Effect of climate change on seasonal monsoon in Asia and its impact on the variability of monsoon rainfall in Southeast Asia. *Geosci. Front.,* 6(6): 817-823.

Sharma, A., Sharma, D. and Panda, S. K. (2022). Assessment of spatiotemporal trend of precipitation indices and meteorological drought characteristics in the Mahi River basin, India. *J. Hydrol.,* 605: 127314.

Tatebe, H., Ogura, T., Nitta, T., Komuro, Y., Ogochi, K., Takemura, T., Sudo, K., Sekiguchi, M. ……and Masahide Kimoto (2019). Description and basic evaluation of simulated mean state, internal variability, and climate sensitivity in MIROC6. *Geosci. Model Dev.,* 12(1): 2727-2765. https://doi.org/10.5194/gmd-12-2727-2019.

Yadav, R., Tripathi, S. K., Pranuthi, G. and Dubey, S. K. (2014). Trend analysis by Mann-Kendall test for precipitation and temperature for thirteen districts of Uttarakhand. *J. Agrometeorol.,* 16(2): 164-171. https://doi.org/10.54386/jam.v16i2.1507