Analysis of non-parametric trend and climatic parameter homogeneity tests in a data-scarce region: a spatio-temporal perspective in the Tawang River basin, Eastern Himalayas

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Abstract
This study is aimed at studying long-term historical and future (1950–2099) trends for the RCP 4.5 and RCP 8.5 on approximately 30-year timescale at annual and seasonal for precipitation and at annual, seasonal, monthly, and diurnal temperature ranges (DTR) for temperature maximum (T_max), temperature minimum (T_min) variations using statistical trend analysis techniques—Mann–Kendall test (MK) and Sen’s slope estimator (S) and the homogeneity test using Pettitt’s test. The study is carried out in three spatial points across the Tawang Chu in the district of Tawang, Arunachal Pradesh. The summer mean precipitation for RCP 4.5 (2006–2065) shows a positive trend with $Z=0.126$ (2006–2035), $Z=0.205$ (2036–2065) for point 1; $Z=0.080$ (2006–2035), $Z=0.200$ (2036–2065) at point 2 and $Z=0.048$ (2006–2035), $Z=0.205$ (2036–2065) at point 3, with a rise in precipitation between 1.56 and 9.94 mm in all the study points. The mean annual precipitation statistics for all the points show an increase for RCP 4.5 in 2006–2052 and 2053–2099 timescale. During the study, all points in both RCPs 4.5 and 8.5 display a uniform rise in mean annual T_min ($Z=0.260$ to 0.738) and T_max ($Z=0.329$ to 0.674). Still, the inter-decadal temperature statistical analysis shows that the increase in mean annual T_min is greater than the increase in T_max, indicating a decreasing trend in DTR. It is anticipated that this study’s outcomes will contribute to a better understanding of the relationship between change in climate and the regional hydrological behaviour. It can benefit the society to develop a regional strategy for water resource management and can serve as a resource for climate impact research scope-assessments, adaptation, mitigation, and disaster management strategies for India’s north-eastern region.

1 Introduction
Outside of the polar zone, the Himalayas have the highest concentration of glaciers. These glaciers provide a source of fresh water for millions of people downstream in countries. There is clear evidence that due to climate change, in recent decades, the Himalayan glaciers have melted at an unprecedented rate, causing dramatic fluctuations in freshwater flow regimes (Gurung et al. 2011). The Himalayas (Pamir Plateau) are a massive mountain range that stretches 2500 km east to west over several nations and encompassing about 67,028 glaciers with a total area of 120,162 km$^2$ in Bhutan, Nepal, Pakistan, Afghanistan, China, and India (IPCC 2014). The important features that define climate change are related to climate variables—precipitation and temperature. The elements of the two variables are increasing global temperature, cloud cover changes, abrupt changes in precipitation over land, seasonal variation in precipitation, and temperature patterns. The IPCC (2007) concluded that global temperature has been seen unequivocal warming trend since 1950. Multiple hydrological phenomena, as well as the availability of water, are altering in frequency and magnitude as greenhouse gas concentrations in the atmosphere increase (Bhave et al. 2016; Sharma and Goyal 2020; Shivam et al. 2017). According to the IPCC (2014), in the fifth assessment report (AR5), these ongoing warming trends are affecting the hydrology of the mountainous region leading to the occurrence of flash floods, drought, loss of life, and agricultural activities (Radinović and Ćurić
Significant impacts of warming trends will be on the snowpack and glaciers of the mountainous systems. With the increasing trend of air temperature across the globe, the Himalayan glaciers are retreating faster than normal (Scherler et al. 2011). Eventually, this will influence the regional hydrology and water resources. The relationship between global warming and anthropogenic activities is closely related to each other, threatening each other. Therefore, the assessment and detection of the historical trend, changes and variability, and futuristic projections became crucial for the regions at the regional and local level (Sharma et al. 2016; Shifteh Some’e et al. 2012).

To assess the historical trend of the climatic parameters, statistical analysis proved to be very useful. Numerous statistical tests, both parametric and non-parametric, are used to analyse trends in hydro-meteorological series data at global as well as in Indian region including observed positive and negative yearly precipitation trends (Dash et al. 2013; Duhan and Pandey 2013; Jain et al. 2013; Kumar et al. 2010, 2020; Milentijević et al. 2020; Shivam et al. 2018; Yürekli 2015) and rising patterns in T_max and T_min on both an annual and monthly scale (Bapuji Rao et al. 2014; Kothawale et al. 2010; Liu et al. 2019; Shivam et al. 2017). The rising number of studies on precipitation and temperature trend analysis in recent years, where the use of the non-parametric method, Mann–Kendall test, and Sen’s slope estimator is extensively applied (Kousari et al. 2013; Li et al. 2018; Mahjabin and Abdul-Aziz 2020; Malik et al. 2020; Milentijević et al. 2020; Mir et al. 2015).

Unlikely, various international and national studies on precipitation and temperature trends have been performed in mountain areas and projection using climate models; Eastern Himalayas (India) lack studies in the particular field at the spatial and temporal scales. Eastern Himalayas, covering the entire northeast part of India, are experiencing rising temperature and precipitation variables like maximum, minimum, mean, and prevailing ranges. Arunachal Pradesh, one of the major states falling in the eastern Himalayas, has glaciers and good seasonal snow cover at a higher elevation towards the northern part of the state inaccessible and has a minimal meteorological network. Due to changes in temperature and precipitation, this region is experiencing a change impact on the water resources. Only a few studies have been conducted in this large region, including temporal aspects of a few river basin boundaries, political boundaries (at the district and state levels), covering parts of the region’s mountain and plain areas (Deka et al. 2016; Soraisam et al. 2018; Jhajharia et al. 2012; Gupta et al. 2021; Srilakshmi et al. 2022; Shivam et al. 2017, 2018; Chakraborty et al. 2017) with no reported study in the present study area. Thus, the present study is aimed at studying long-term historical and future (1950–2099) annual and seasonal precipitation trend analysis, and temperature—temperature maximum (T_max), temperature minimum (T_min) variations—annual, seasonal, monthly, and diurnal temperature range (DTR) trend analysis using statistical trend analysis techniques—Mann–Kendall test (MK) and Sen’s slope estimator (S).

Further, the mean annual and monthly precipitation and T_min and T_max homogeneity tests are done using Pettitt’s test. It is anticipated that the findings of this study will aid in a better understanding of regional hydrological behaviour as well as the link between climate change and the hydrological cycle. Formulating a regional water resources management strategy will be beneficial. It might provide data for climate impact research, such as monitoring, adaptation, mitigation, and disaster management plans for the northeast Indian region.

2 Materials and methods

2.1 Study area

The northern part of the Himalayan state, Arunachal Pradesh in India, is mostly covered with snow and glacier across the year. Tawang is one of the 23 districts in Arunachal Pradesh. The Tawang River (Chu) basin (shown in Fig. 1) with a downstream area of 2596.78 km² covering the entire Tawang district of Arunachal Pradesh has been selected as the study area (a large part of the upstream Tawang Chu basin falls in the Tibetan region). This basin in its upstream is covered by snow cover. The Tawang Chu and Nyamjang Chu are the two main rivers in the basin. The Tawang Chu is the confluence of the Nyukcharong Chu and Mago Chu flowing from the eastern and north-eastern regions of the basin. This basin is a tourist attraction place due to its snow-covered mountains and pass, scenic beauty, waterfall, and culture.

The entire basin extends between latitudes 27° 27' N and 27° 54’ N and longitudes 91° 33’ E and 92° 19’ E, lies on the west of the state of Arunachal Pradesh. The study area is shared by national and international boundaries, surrounded by Tibet in the North, Bhutan in the West, and West Kameng district in the South-East. The entire basin ranges over 979–6443 m above mean sea level (msl). The climate is marked by elevation-related temperature variance at such varied altitudes. In winter, the temperature typically drops to the freezing point. The winter season’s lowest temperature is –3 °C in December, whilst the summer season’s highest temperature is 25 °C in July. The Tawang Chu basin experiences a monsoon climate, rainy or wet summers, and dry and cold winters. The monsoon season onsets at the end of May and continues till September or early October. The region experiences annual rainfall ranging from 1500 to 2000 mm. The winter season is dominant in October, November, December, January, and February.
The basin is found to be mountainous and mostly bare and uninhabited. Here, three location points given in Table 1 are used for the study. Point 1 is used for replicating the Central Water Commission data with the suitable ERA5-Land hourly reanalysis dataset, the Tropical Rainfall Measuring Mission (TRMM), and the Global Precipitation Measurement (GPM) for precipitation; and the ERA5-Land hourly reanalysis dataset for temperature maximum (T_max) and temperature minimum (T_min).
ERA5-Land hourly data is gridded from 1 January 1981 to 31 December 2019 with 0.1×0.1 spatial resolution in Network Common Data Form (NetCDF) format. The TRMM is a NASA-JAXA collaborative project that was launched in 1997 to research tropical rainfall. TMPA (TRMM) data, which were used for this investigation, have a spatial resolution of 0.25°×0.25° with a coverage range of 50°N–50°S and are accessible on a monthly basis. The latest version of the IMERG-GPM final-run product V06, released in April 2014, is also utilised. This product has a spatial resolution of 0.1×0.1 and a coverage of 60 N–60 N (https://disc.gsfc.nasa.gov/datasets).

2.2 Data source

2.2.1 Central Water Commission (CWC) India dataset

In this analysis, the Central Water Commission (CWC) meteorological data—precipitation and temperature (maximum and minimum) ground station data have been utilised. The study area in its downstream has several gauge stations with varied data collection start periods, and the nearest gauge CWC station discharge site—Muruga Bridge site (Lat 27° 37′ 4.8″ and Long 92° 0′ 0.28.8″) is used for the study location near the basin outlet. The limited daily temperature and precipitation CWC dataset for the station are available for two consecutive years 2017 and 2018 and are used in the study to replicate with the available satellite dataset or climate reanalysis dataset using statistical tests.

2.2.2 Climate dataset

The climatic data (air temperature—maximum and minimum) for the current study were collected from the NASA POWER (Prediction of Worldwide Energy Resources) project since ground data was insufficient for selecting a General Circulation Model (GCM) for trend analysis. The data for the POWER project comes from NASA’s World Climate Research Program (WCRP), Global Energy and Water Cycle Experiment (GEWEX), Surface Radiation Budget Project (NASA GEWEX SRB), and Clouds and the Earth’s Radiant Energy System (CERES) projects at NASA LaRC, as well as the Goddard Space Flight Center’s Global Modeling and Assimilation Office (https://power.larc.nasa.gov). The ERA5-Land hourly data from the European Centre for Medium-Range Weather Forecasts (ECMWF), the Tropical Rainfall Measuring Mission (TRMM), and the IMERG data from Global Precipitation Measurement (GPM), the global successor to TRMM data has been also used to imitate as the ground data for precipitation. The ERA5-Land hourly—a reanalysis dataset, comprises both temperature and precipitation datasets. The land component of the ECMWF ERA5 climate reanalysis has been replayed to create ERA5-Land. Reanalysis assimilates data from the model and observations from all across the world to create a global dataset that is both complete and consistent (Muñoz Sabater 2019). The ERA5-Land hourly data is gridded from 1 January 1981 to

| Location point | Latitude   | Longitude   | Altitude (m) |
|---------------|------------|-------------|--------------|
| Point 1       | 27° 37′ 04″ | 92° 00′ 28″ | 2401         |
| Point 2       | 27° 33′ 03″ | 91° 53′ 34″ | 1733         |
| Point 3       | 27° 29′ 59″ | 91° 41′ 07″ | 1081         |

2.2.3 GCM- NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset

The NEX-GDDP (General Circulation Model (GCM) carried out with the Coupled Model Intercomparison Project Phase 5 (CMIP5)) dataset that consists of global downscaled climate scenarios has been used. These datasets are developed supporting the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5). It contains two scenarios: range from moderate (RCP4.5) to extreme (RCP8.5) RCP scenarios from the four Representative Concentration Pathways scenarios for greenhouse gas emissions (RCPs) with 0.25×0.25 of spatial resolution (Melton 2015). Daily precipitation, maximum temperature, and minimum temperature are included in each of the climatic projections for the period from 1950 to 2005 as a retrospective run and from 2006 to 2099 as a prospective run (https://www.nccs.nasa.gov/services/data-collections/land-based-products/nex-gddp). These datasets offer a collection of global, high-resolution, bias-corrected climate change estimates that are used to assess the effects of climate change on processes that are susceptible to smaller-scale climatic gradients as well as the influence of local topography on climate conditions. The Bias-Correction Spatial Disaggregation (BCSD) method, which was designed expressly to overcome these existing constraints of global GCM outputs [Wood et al. 2002; Wood et al. 2004; Maurer and Hidalgo 2008; Thrasher et al. 2012], is used for bias-correct these datasets. The method makes adjustments to future climate estimates based on information obtained from comparing the GCM outputs with corresponding climatic observations over a common period. The programme additionally interpolates the GCM outputs to higher-resolution grids using the spatial detail offered by observationally derived datasets. The dataset used to create NEX-GDDP is known as the Global Meteorological Forcing Dataset (GMFD) for land surface modelling and is available from the Terrestrial Hydrology Research Group at Princeton University. These observed values are needed for bias correction and statistical downscaling (Sheffield et al. 2006). This dataset combines observational data with reanalysis data. The historical 0.25-degree data for daily maximum
temperature, daily minimum temperature, and daily precipitation from 1950 to 2005 are used to generate the NEX-GDDDP dataset.

The NEX-GDDDP temperature and precipitation data have been extensively used in several hydro-climatological investigations all around the world (Jose and Dwarakish 2022; Singh et al. 2019; Raghavan et al. 2018; Yu et al. 2018). Also, the highest resolution gridded data for climate change studies available in India is the NEX-GDDP data, which has been deemed to be the most accurate climate model data based on CMIP5 scenarios.

### 2.3 Methodology

#### 2.3.1 Validation process

Data scarcity is one of the main problems in study areas with high mountain regions. Our study area has very few data stations. For analysis or any validation process, relatively large ground data is valuable. Therefore, to meet the said demand, the small temporal scale CWC data of 2017–2018 meteorological data has been validated with the ERA5-Land hourly reanalysis dataset, the Tropical Rainfall Measuring Mission (TRMM) dataset, and the Global Precipitation Measurement (GPM) dataset for precipitation (mm); and the NASA POWER along with the ERA5-Land hourly reanalysis and the NASA POWER dataset for T\(_{\text{max}}\) and T\(_{\text{min}}\) using the same statistical method and resulted for T\(_{\text{max}}\) ’r’ value—0.80 and 0.79, Bias (%) value 7.83 and 2.40; and T\(_{\text{min}}\) ‘r’ value—0.88 and 0.87, Bias (%) value 10.23 and 4.99, respectively. From the statistical validation of CWC datasets with the ERA5 hourly, GPM, TRMM data, and NASA POWER data, the NASA POWER T\(_{\text{max}}\) and T\(_{\text{min}}\) and ERA5 precipitation is justifiable and can be replicated with the CWC dataset.

The second step considered for the study is validating the NASA POWER and ERA5 data with the NEX-GDDP dataset and selecting the GCM models that are suitable to the study area. The NEX-GDDP historical data for the year 1998–2005 of 11 GCMs, as shown in Table 2, has been used to validate an assortment of the suitable GCM for the trend analysis. The agreement and the Bias (%) between the NASA POWER and the NEX-GDDP GCM data for T\(_{\text{max}}\) and T\(_{\text{min}}\) and the ERA5 and the NEX-GDDP GCM data performances have been evaluated and compared using a few selected statistical methods—Bias (%), Pearson’s Correlation coefficient (\(r\)), root mean square error (RMSE), and mean absolute error (MAE) (Kanda et al. 2020; Tang et al. 2020; Zhang et al. 2020) as shown in Table 8. These statistical methods are used for the ranking of the best GCM to be used for further steps in the study. The weighted sum model is used to rank the GCM models. The two GCMs—GFDL-CM3 and CSIRO-Mk3-6–0—are ranked 1 for temperature and precipitation, respectively, and used in the trend analysis study. The final step in the

### Table 2 List of GCMs used for replicating ERA5-Land hourly reanalysis dataset

| S. no | GCM name               | Institution                                                                 | Source |
|-------|------------------------|------------------------------------------------------------------------------|--------|
| 1     | ACCESS1                | Australian Community Climate and Earth-System Simulator, version 1.0         | Australia |
| 2     | BNU-ESM                | Beijing Normal University Earth System Model                                | China  |
| 3     | CCSM4                  | National Center for Atmospheric Research                                    | United States |
| 4     | CESM1-BGC              | Community Earth System Model, version 1–Biogeochemistry, National Science    | United States |
|       |                        | Foundation, Department of Energy, & National Center for Atmospheric Research  |        |
| 5     | CNRM-CM5               | Centre National de Recherches Meteorologiques/Centre Europeen de Recherche    | France |
|       |                        | et Formation Avances en Calcul Scientifique                                 |        |
| 6     | CSIRO-Mk3-6–0         | Commonwealth Scientific and Industrial Research Organization in collaboration| Australia |
|       |                        | with Queensland Climate Change Centre of Excellence                         |        |
| 7     | CanESM2                | Second generation Canadian Earth System Model, Canadian Centre for Climate    | Canada |
|       |                        | Modelling and Analysis (CCGma) of Environment and Climate Change Canada       |        |
| 8     | GFDL-CM3               | NASA Geophysical Fluid Dynamics Laboratory                                   | United States |
| 9     | GFDL-ESM2G             | Geophysical Fluid Dynamics Laboratory Earth System Model with Generalized     | United States |
|       |                        | Ocean Layer Dynamics (GOLD) component                                        |        |
| 10    | GFDL-ESM2M             | Geophysical Fluid Dynamics Laboratory Earth System Model with Modular Ocean   | United States |
|       |                        | Model 4 (MOM4) component                                                     |        |
| 11    | IPSL-CM5A-LR           | L’Institut Pierre-Simon Laplace Coupled Model, version 5A,                   | France |
| 12    | IPSL-CM5A-MR           | L’Institut Pierre-Simon Laplace Coupled Model, version 5A                    | France |
study, i.e. The Mann–Kendall (MK) test, and Sen’s slope estimator are used to analyse trends in the data. The goal of this research is to investigate climate change in the study area using the appropriate bias-corrected GCM model from NEX-GDDP. Because this work only uses one GCM for one element at a time (GFDL-CM3 for temperature and CSIRO-Mk3-6–0 for precipitation), uncertainty in climate change projections induced by model uncertainty cannot be stated, as it is not recommended to perform uncertainty assessment when just one model is used (Sahany et al. 2019).

**Ranking the datasets** The weighted sum model (WSM)—a multiple criteria decision-making (MCDM) approach has been used for ranking the GCMs validated with ERA5. The WSM or simple additive weighting (SAW) (Eq. 1)
is one of the simplest and most commonly used MCDM techniques (Kolios et al. 2016; Mulliner et al. 2016; Triantaphyllou 2000) combines the criteria values for each alternative and applies the individual criteria weights.

\[ A_{\text{WSM}}^{*} = \max_{i} \sum_{j} a_{ij}w_{j} \]  

where \( i = 1, m \), \( A_{\text{WSM}}^{*} \) denotes the weighted sum score, \( a_{ij} \) denotes the score of the \( i \)-th option in relation to the \( j \)-th criterion, and \( w_{j} \) is the weight of the \( j \)-th criterion.

### 2.3.2 Mann–Kendall trend detection

The precipitation and temperature trend tests are done using the Mann–Kendall (MK) test (Kendall 1975; Mann 1945), a non-parametric statistical test identifying monotonic increasing or decreasing trends. This method is extensively used in climatic variable trend analysis and to know the existence of a trend in the climatic variables (Milentijević et al. 2020; Mir et al. 2015; Sharma and Goyal 2020; Sharma et al. 2016; Shivam et al. 2018). If the Mann–Kendall Z-value is larger than +1.96 for a significance threshold of 0.05, the test shows a significantly rising (positive) trend. If the Z-value is calculated lower than −1.96, the test shows a declining (negative) trend. The test’s null hypothesis (H0) says that there is no trend in the series. The alternate hypothesis (Ha) signifies the presence of an increasing or decreasing trend in the temporal data series. The magnitude of the trend or shift throughout the study is determined using Sen’s slope estimator. Here, the MK test is used for historical and futuristic time series analysis of precipitation and temperature trends. The definition of MK statistics (S) is as follows Eq. 2:
where $N$ is the number of data points, assuming $(x_j - x_i) = \theta$.

The value of $sgn(\theta)$ (Eq. 3) is computed as follows:

$$sgn(\theta) = \begin{cases} 
1 & \text{if } \theta > 1 \\
0 & \text{if } \theta = 1 \\
-1 & \text{if } \theta < 1 
\end{cases}$$ (3)

for all the differences evaluated, this statistic indicates the number of positive variations minus the number of negative variations. The statistic $S$’s (Eq. 4) variance is computed as follows:

$$Var(S) = \frac{N(N - 1)(2N + 5) - \sum_{k=1}^{n} t_k(t_k - 1)(2t_k + 5)}{18}$$ (4)

where $N$ represents the total number of data points in the data series, $n$ represents the number of tied groups in the set.
of data, and \( t_k \) represents the number of tied groups in the \( k \)th tied group, respectively. The “Z-statistic” of Mann–Kendall is calculated as follows in Eq. 5:

\[
Z = \begin{cases} 
\frac{S-1}{\sqrt{\text{Var}(S)}} & S > 0 \\
0 & S = 0 \\
\frac{S+1}{\sqrt{\text{Var}(S)}} & S < 0 
\end{cases}
\]  
(5)

The null hypothesis of no trend is accepted or rejected at a 95% confidence interval depending on the \( Z \)-statistics value.

**Sen’s slope estimator** Sen’s slope estimator (Eq. 6) is a non-parametric approach for determining the amplitude of a trend in a time series (Sen 1968). The Sen’s slope may be computed using the following formula:

\[
T_i = \frac{x_j - x_k}{j-k} \quad \text{for} \ i = 1, 2, 3, \ldots N 
\]  
(6)

where \( x_j \) and \( x_k \) are data values at time \( j \) and \( k \), respectively; Sen’s estimate of slope (\( \beta \)) is the median of these \( N \) values of \( T_i \). A positive value indicates an increasing trend in the time series, whereas a negative value suggests a downward trend.

**Homogeneity test using Pettitt’s test** A test for change point detection is a crucial strategy for determining when a major shift in a time series of variables occurred. In homogeneity in time series can lead to erroneous interpretations of exceptional occurrences and can be deceiving when interpreting time-series tendencies. Significant fluctuations in the mean are a common existence in time series data due to inhomogeneity. The Pettitt's test (Pettitt 1979) is a non-parametric test that does not make any assumptions about data distribution and is commonly employed in continuous data hydrological or climatic series to detect any significant change in the data series (Chakraborty et al. 2017; Ilori and Ajayi 2020; Kocsis et al. 2020; Liu et al. 2012). It compares the null hypothesis (\( H_0 \)) where the \( T \) variables follow one or more distributions with the same location parameter is compared to the alternative hypothesis (\( H_1 \)), which depicts the existence of a change point. The Pettitt’s test for change point (\( K_T \)) (Eq. 7) statistics is described as follows:

...
Historic 1950-1977
Historic 1978-2005
RCP 4.5 2006-2035
RCP 4.5 2036-2065
RCP 8.5 2006-2035
RCP 8.5 2036-2065
RCP 8.5 2066-2099
Analysis of non-parametric trend and climatic parameter homogeneity tests in a data-scarce…

3 Results and discussion

3.1 Validation of GCMs

For the three study points—point 1, point 2, and point 3 in the Tawang basin—the statistical method of validation and ranking of GCMs using the weighted sum model resulted in the selection of the two most suitable GCMs—GFDL-CM3 and CSIRO-Mk3-6–0—for temperature and precipitation data for further trend analysis, respectively. A boxplot is used to comprehend and evaluate the distribution and variability of datasets on a temporal scale as well as for various RCP scenarios. According to the World Meteorological Organization (2017), the standard time for averaging weather variables or elements such as temperature, precipitation, and wind for defining ‘climate’ is 30 years. Keeping these 30 years as reference period, this study uses a time scale of 30 years based on the definition and research in precipitation and temperature trend analysis (Rivera et al. 2019; Singh et al. 2015; Ruwangika et al. 2020; Dash et al. 2012; Shivam et al. 2017; Shivam et al. 2018). Temperature and precipitation datasets are divided into three categories: historical (1950–1977 and 1978–2005), RCP 4.5 scenario (2006–2035, 2036–2065, and 2066–2099), and RCP 8.5 scenario (2006–2035, 2036–2065, and 2066–2099). The boxplots of points 1, 2, and 3 for precipitation on a historical and futuristic scale of approximately 30 years are shown in Fig. 2. In both the historic and RCP scenarios, the plot distribution reveals an overall growing trend in the mean in both the lower and upper ranges of the datasets. The RCP 8.5 scenario for 2066–2099 shows a rise in the upper and lower limits of T_min at all study locations in the boxplot. Also, T_max at points 2 and 3 shows a similar temperature distribution pattern, with the mean steadily increasing and the minimum and maximum temperature limits for the T_max increasing. At point 1, a huge difference is observed between the historic 1978–2005 and RCP 2006–2035, which later shows a dramatic increase of 11.29 °C and 11.24 °C in the lower and upper limits T_max, respectively.

3.2 Precipitation trend analysis

Figure 4 shows the Mann–Kendall trend test results applied on mean annual and seasonal precipitation on a temporal scale using the GCM—CSIRO-Mk3-6–0—for the three selected study points. The three study points—point 1, point 2, and point 3—are studied on an annual scale and seasonal scale (winter, summer, monsoon, and post-monsoon) for the temporal scale—historical (1950–1977 and 1978–2005), RCP 4.5 scenario (2006–2035, 2036–2065, and 2066–2099), and RCP 8.5 scenario (2006–2035, 2036–2065, and 2066–2099).

At all the temporal scales and spatial scales, there is no significant trend found. Only at study point 3 with RCP 4.5 for the mean annual precipitation in the intra-decadal time scale 2066–2099, a significant declining trend was observed at a 95% confidence level. Table 3 also shows Sen’s slope magnitude of precipitation (annual) in all the basins. The maximum precipitation increase can be seen in all the study points as 9.14 mm, 0.08 mm, 9.94 mm, 2.34 mm, and 3.19 mm for the annual, winter, summer, and post-summer, respectively. The maximum precipitation decrease is as low as −22.15 mm (annual precipitation) at study point 2 for the time scale 2066–2099 at scenario RCP 4.5.

Figure 5 shows the trend test for the monthly precipitation at all three study points. There is a marked increasing trend observed in a few months for the various time scales—RCP 4.5 April (2036–2065) and October (2066–2095)—and a decreasing trend in August (2006–2035), June, and November (2066–2095) at point 1. A similar trend is also observed in the other 2 points for the same months. Across the months of a year, the maximum increase and maximum decrease in the magnitude of precipitation for study points 1, 2, and 3 are found in April and August—3.40 mm and −7.90 mm; 4.36 mm and −10.73 mm; 3.86 mm and −9.04 mm, respectively, as shown in Table 9. Although decreasing in mean annual precipitation in study point 1 is not in agreement with previous reports and studies (Government of Arunachal Pradesh 2011; Shivam et al. 2018), the increasing total precipitation in the later years of both RCPs in study point 2 and 3 looks in agreement with the report.
3.3 Temperature trend analysis

3.3.1 Mean maximum temperature (T$_{\text{max}}$)

Figure 6a shows the trend in all the study points for mean T$_{\text{max}}$ for all the seasons. At all the study points, the historic mean T$_{\text{max}}$ has shown a negative trend, but a positive trend was observed for the RCP scenarios at all the timescale. There is an overall increase in the annual, monsoon, and post-monsoon mean T$_{\text{max}}$ at all the points, with the RCP 8.5 scenario being the highest trend for T$_{\text{max}}$ at all the seasons. The mean T$_{\text{max}}$ positive trend can be seen in both the RCP 8.5 at all the seasons, the highest trend in the monsoon season at the intra-decadal (2066–2099).

At all the study points, for the RCP 8.5, the winter season is also showing a positive trend. The magnitude of increasing or decreasing in the mean annual and seasonal T$_{\text{max}}$ is shown in Table 4, where it can be observed that there is a maximum rise in T$_{\text{max}}$ is seen in the mean monsoon and post-monsoon season at study point 1 for RCP 8.5; and annual mean T$_{\text{max}}$, winter mean T$_{\text{max}}$ and summer mean T$_{\text{max}}$ at study point 2 for RCP 8.5—2066–2099. A maximum mean T$_{\text{max}}$ is observed as 0.161 °C in study point 2, and the minimum mean T$_{\text{max}}$ is observed as −0.060 °C at study points 1 and 2.

Similarly, the trend test for mean monthly T$_{\text{max}}$ in Fig. 7a is observed to increase positively for all the months and time scale at all the study points. The historical (1950–1977) mean monthly T$_{\text{max}}$ is observed to have a negative trend at all the study points for January, July, August, and September. Apart from historical (1950–1977), all other study points with change in RCPs and time scale observed a significant positive trend, a maximum trend observed in all the months except February, March, and April in the RCP 4.5 scenario. The T$_{\text{max}}$ magnitude in Table 10 also shows a maximum rise in mean monthly T$_{\text{max}}$ for all the months, the maximum
rise in April—\(-0.196\) °C (RCP 8.5 2066–2099)—and maximum fall in April at \(-0.023\) °C (RCP 4.5 2036–2065) in study point 1. Likewise, in study points 2 and 3, maximum rise and fall of mean \(T_{\text{max}}\) is observed in April—\(-0.184\) °C (RCP 8.5 2066–2099), 0.168 °C (RCP 8.5 2066–2099)—and \(-0.027\) °C (RCP 4.5 2036–2065), and \(-0.030\) °C (RCP 4.5 2036–2065), respectively.

### 3.3.2 Mean minimum temperature (\(T_{\text{min}}\))

Similar to mean annual and seasonal \(T_{\text{max}}\), the trend test for \(T_{\text{min}}\) also shows a significant negative trend in the historical time scale for both the RCPs at all the study points, as shown in Fig. 6b. A significant positive trend is observed in both annual and seasonal scales at all the study points for the two RCPs—RCP 4.5 and RCP 8.5—the latter showed the maximum positive trend at three intra-decadal time scale. The annual scale has shown a maximum positive trend in \(T_{\text{min}}\) for both the RCPs at all the time scale. The highest \(Z\) value of 0.738 is observed at study point 1 in the annual scale at the RCP 4.5 scenarios. The RCP 8.5 has shown a significant positive trend among all the study points for all the seasons—summer (\(Z=0.747\)), monsoon (\(Z=0.834\)), and post-monsoon (\(Z=0.651\))—winter maximum positive \(T_{\text{min}}\) trend is observed at study point 2 for RCP 4.5. The maximum negative trend in \(T_{\text{min}}\) is observed in the historical scale at all study points—the maximum lowest negative is as follows: \(-0.222\) at study point 1. Table 5 shows the maximum magnitude ranges between 0.138 °C at study point 2 and 0.073 °C at study point 1 in the mean annual and seasonal \(T_{\text{min}}\) for the RCP 8.5 summer season and RCP 4.5 monsoon season, respectively. The minimum decrease in \(T_{\text{min}}\) is between \(-0.031\) and \(-0.010\) °C for the post-monsoon (historical) at study point 2 and summer season (historical) at study point 1, respectively.

For the mean monthly \(T_{\text{min}}\), Fig. 7b shows a significant positive trend for all the 12 months at each study point, especially for May-December in both the RCP scenarios.

### Table 4 Mann–Kendall test Z-statistics and Sen’s slope (°C/year) for the study points (sub-basin level) of mean annual and seasonal \(T_{\text{max}}\) for historical (1950–2005) and futuristic (2006–2095) with RCP 4.5 and RCP 8.5 scenarios

| Station | Time Scale/Seasons | Annual | Winter | Summer | Monsoon | Post-Monsoon |
|---------|------------------|--------|--------|--------|---------|-------------|
|         |                  | \(Z\)  | \(Z\)  | \(Z\)  | \(Z\)  | \(Z\)        |
|         |                  | Slope  | Slope  | Slope  | Slope   | Slope       |
| SB 1    | Historical       | \(-0.360\) | \(-0.041\) | \(-0.196\) | \(-0.060\) | \(-0.217\) | \(-0.048\) | \(-0.540\) | \(-0.029\) | \(-0.228\) | \(-0.033\) |
|         | 1978–2005        | \(0.275\)  | \(0.029\)  | \(0.212\)  | \(0.060\)  | \(0.249\)   | \(0.059\)  | \(0.169\)  | \(0.013\)  | \(0.228\)  | \(0.038\)  |
| SB 2    | Historical       | \(-0.365\) | \(-0.040\) | \(-0.190\) | \(-0.060\) | \(-0.201\) | \(-0.044\) | \(-0.582\) | \(-0.029\) | \(-0.201\) | \(-0.031\) |
|         | 1978–2005        | \(0.254\)  | \(0.030\)  | \(0.190\)  | \(0.060\)  | \(0.249\)   | \(0.061\)  | \(0.122\)  | \(0.012\)  | \(0.249\)  | \(0.041\)  |
| SB 3    | Historical       | \(-0.349\) | \(-0.042\) | \(-0.190\) | \(-0.055\) | \(-0.222\) | \(-0.044\) | \(-0.561\) | \(-0.030\) | \(-0.228\) | \(-0.033\) |
|         | 1978–2005        | \(0.249\)  | \(0.027\)  | \(0.196\)  | \(0.059\)  | \(0.238\)   | \(0.062\)  | \(0.153\)  | \(0.015\)  | \(0.228\)  | \(0.041\)  |
| RCP 4.5 | 2006–2035        | \(0.434\)  | \(0.046\)  | \(0.218\)  | \(0.044\)  | \(0.223\)   | \(0.047\)  | \(0.623\)  | \(0.040\)  | \(0.453\)  | \(0.050\)  |
| RCP 8.5 | 2006–2035        | \(0.536\)  | \(0.067\)  | \(0.315\)  | \(0.099\)  | \(0.356\)   | \(0.068\)  | \(0.563\)  | \(0.049\)  | \(0.411\)  | \(0.053\)  |
| RCP 4.5 | 2006–2035        | \(0.646\)  | \(0.063\)  | \(0.269\)  | \(0.048\)  | \(0.241\)   | \(0.041\)  | \(0.720\)  | \(0.066\)  | \(0.591\)  | \(0.075\)  |

Bold numbers show a significant trend at 95% confidence level.
The mean monthly T_min with the maximum positive trend is observed for RCP 8.5 as 0.710 for September at study point 1 and 0.706 for June and September at study points 2 and 3, respectively. The maximum negative range for the minimum monthly T_min is observed as −0.238, −0.233, and −0.249 at all the study points for the historical timescale. Table 11 clearly shows the magnitude rise and fall of the mean monthly T_min in the study points. The maximum rise in the mean monthly T_min is observed in RCP 8.5 as 0.144 °C March month at the study point 1, 0.138 °C December month at study point 2, and 0.135 °C December month at the study point 3. Similarly, the maximum fall in mean monthly T_min is observed in historic timescale as −0.058 °C January at study point 1, −0.052 °C October at study point 2, and −0.051 °C January at study point 3.

3.3.3 Mean monthly diurnal temperature range (DTR)

Table 6 shows the trend test for the Diurnal temperature range for the two RCP scenarios at all the study points. The DTR is calculated by subtracting the minimum daily temperature from the maximum daily temperature data for RCP 4.5 and RCP 8.5 scenarios at each point. From Table 6, both significant positive and significant negative trend is observed. The negative maximum mean monthly DTR Z value falls to −0.499 (June) at study point 2 for RCP 4.5 scenario and a significant positive trend of $Z = 0.366$ (April) at study point 1 for RCP 8.5 scenario. The maximum magnitude rise and maximum fall in mean monthly DTR are different in all the study points. A maximum rise in mean monthly DTR at all the study points 1, 2, and 3 are—0.057 °C (April, RCP 8.5 = 2066–2099), 0.076 °C (February, RCP 4.5 = 2036–2065) and 0.062 °C (April, RCP 8.5 = 2066–2099), respectively. Similarly, the maximum fall in mean monthly DTR at all the study points falls for both the RCP 8.5 and RCP 4.5 scenarios: −0.055 °C (December, RCP 8.5 = 2036–2065), −0.079 °C (December, RCP 4.5 = 2066–2099) and −0.066 °C (December, RCP 8.5 = 2066–2099) at study point 1, 2, and 3, respectively. The inter-decadal temperature statistical analysis shows that the increase in mean annual T_min is greater than the increase in T_max, indicating a decreasing trend in DTR (Government of Arunachal Pradesh 2011; Shivam et al. 2017).
Table 5 Mann–Kendall test Z-statistics and Sen’s slope (°C/year) for the study points (sub-basin level) of mean annual and seasonal T_min for historical (1950–2005) and futuristic (2006–2095) with RCP 4.5 and RCP 8.5 scenarios

| Station | Time scale/seasons | Annual | Winter | Summer | Monsoon | Post-monsoon |
|---------|-------------------|--------|--------|--------|---------|-------------|
|         |                   | Z      | Slope  | Z      | Slope   | Z           | Slope  |
| SB 1    | Historical 1950–1977 | -0.222 | 0.025  | -0.058 | 0.020   | -0.010      | 0.025  |
|         | 1978–2005         | 0.233  | 0.021  | 0.090  | 0.025   | 0.238        | 0.029  |
|         | RCP 4.5 2006–2035 | 0.545  | 0.060  | 0.278  | 0.054   | 0.444        | 0.062  |
|         | 2036–2065         | 0.462  | 0.036  | 0.195  | 0.048   | 0.085        | 0.005  |
|         | 2066–2095         | 0.246  | 0.023  | 0.126  | 0.025   | 0.182        | 0.025  |
|         | RCP 8.5 2006–2035 | 0.591  | 0.059  | 0.320  | 0.070   | 0.490        | 0.051  |
|         | 2036–2065         | 0.738  | 0.080  | 0.366  | 0.084   | 0.499        | 0.078  |
|         | 2066–2099         | 0.669  | 0.090  | 0.338  | 0.093   | 0.747        | 0.137  |
| SB 2    | Historical 1950–1977 | -0.185 | 0.021  | 0.042  | 0.009   | -0.042       | 0.005  |
|         | 1978–2005         | 0.254  | 0.020  | 0.048  | 0.009   | 0.265        | 0.033  |
|         | RCP 4.5 2006–2035 | 0.646  | 0.057  | 0.444  | 0.070   | 0.411        | 0.053  |
|         | 2036–2065         | 0.503  | 0.032  | 0.251  | 0.035   | 0.067        | 0.007  |
|         | 2066–2099         | 0.260  | 0.024  | 0.177  | 0.033   | 0.223        | 0.031  |
|         | RCP 8.5 2006–2035 | 0.568  | 0.059  | 0.292  | 0.069   | 0.434        | 0.052  |
|         | 2036–2065         | 0.701  | 0.079  | 0.361  | 0.091   | 0.494        | 0.077  |
|         | 2066–2099         | 0.646  | 0.087  | 0.306  | 0.090   | 0.733        | 0.138  |
| SB 3    | Historical 1950–1977 | -0.201 | 0.023  | -0.032 | 0.009   | -0.037       | 0.006  |
|         | 1978–2005         | 0.228  | 0.020  | 0.095  | 0.016   | 0.243        | 0.029  |
|         | RCP 4.5 2006–2035 | 0.554  | 0.066  | 0.343  | 0.062   | 0.444        | 0.060  |
|         | 2036–2065         | 0.462  | 0.036  | 0.195  | 0.051   | 0.053        | 0.005  |
|         | 2066–2099         | 0.246  | 0.023  | 0.149  | 0.030   | 0.209        | 0.026  |
|         | RCP 8.5 2006–2035 | 0.591  | 0.059  | 0.297  | 0.075   | 0.467        | 0.056  |
|         | 2036–2065         | 0.720  | 0.081  | 0.384  | 0.091   | 0.490        | 0.078  |
|         | 2066–2099         | 0.664  | 0.090  | 0.329  | 0.090   | 0.733        | 0.137  |

Bold numbers show a significant trend at a 95% confidence level

3.4 Homogeneity test using Pettitt’s test

The homogeneity test using Pettitt’s test on mean annual and monthly precipitation, T_min, and T_max is done for the three study points in the Tawang river basin. The change point of the year is made on three-time scales: historical (1950–2005), RCP 4.5 (2006–2099), and RCP 8.5 (2006–2099). The RCP scenarios are further divided into near-future (2006–2052) and distant future (2053–2099). The statistically significant Pettitt’s test result is given in Table 7, which shows the change point year and shift direction in the continuous time-series datasets. A negative change in precipitation is likely to be observed in the historical time scale at study points 1 and 2 for October (1988). This decline in precipitation is observed in the (District Statistical Handbook of Tawang, Arunachal Pradesh 1989, 1989), where a sudden decline of precipitation can be noticed in October (1988). The RCP 4.5 and RCP 8.5 have also indicated an increasing precipitation pattern for April, August, and October and a decline in the pattern for January (RCP 8.5–2038) and July (RCP 4.5–2020), mostly observed in study point 1. Annual precipitation increasing change point is only likely to be observed for RCP 8.5 from the year 2065, from an annual mean of 1490 mm (1.6%) to 1902 mm (29.7%), 1996 mm (0.9%) to 2588 mm (30.8%), and 1622 mm (1%) to 2071 mm (29%) percent increase from historic precipitation for study points 1, 2 and 3, respectively.

Unlike precipitation, the change point year in the mean T_min and T_max is observed in all the months in both RCP scenarios. The historical data (from 1963) reveals a decrease in both T_min and T_max; however, validation is unattainable due to data unavailability. All of the months of the year, as well as the overall mean yearly change, demonstrate a positive change point in the future T_min and T_max. The majority of the mean T_min changes in both RCP scenarios are observed between
| Station | Time scale/months | 1950–1977 | 1978–2005 | RCP 4.5 2006–2035 | RCP 8.5 2006–2035 | RCP 4.5 2006–2035 | RCP 8.5 2006–2035 | 2006–2095 | 2036–2065 | 2066–2095 | 1950–1977 | 1978–2005 | RCP 4.5 2006–2035 | RCP 8.5 2006–2035 | 2006–2095 | 2036–2065 | 2066–2095 | 1950–1977 | 1978–2005 | RCP 4.5 2006–2035 | RCP 8.5 2006–2035 | 2006–2095 | 2036–2065 | 2066–2095 |
|---------|-----------------|-----------|-----------|-----------------|-----------------|-----------------|-----------------|-----------|-----------|-----------|-----------|-----------|-----------------|-----------------|-----------|-----------|-----------|-----------|-----------|-----------------|-----------------|-----------|-----------|-----------|
| SB 1    | Historical      | −0.159    | 0.159     | −0.163          | 0.117           | −0.085          | −0.016          | 0.117      | 0.177     | 0.218     | −0.228    | 0.143     | −0.131           | −0.343           | 0.126      | −0.011    | −0.177     | −0.180     | 0.143     | −0.131           | −0.343           | 0.126      | −0.011    | −0.177     |
|         |                 | −0.026    | 0.039     | −0.036          | 0.021           | 0.090           | 0.013           | 0.191      | 0.042     | 0.026     | −0.047    | 0.048     | −0.007           | −0.059           | 0.165      | −0.035    | −0.016     | −0.033     | 0.042     | −0.007           | −0.035           | 0.165      | −0.035    | −0.016     |
|         |                 | −0.090    | −0.085    | −0.071          | 0.186           | 0.076           | 0.076           | 0.191      | 0.063     | 0.057     | −0.201    | 0.058     | −0.140           | −0.114           | 0.191      | 0.063     | 0.057      | −0.201    | 0.058     | −0.140           | −0.114           | 0.191      | 0.063     | 0.057      |
|         |                 | −0.025    | −0.020    | −0.016          | 0.030           | 0.020           | 0.020           | 0.043      | 0.013     | 0.021     | −0.042    | 0.013     | −0.010           | −0.033           | 0.043      | 0.013     | 0.021      | −0.042    | 0.013     | −0.010           | −0.033           | 0.043      | 0.013     | 0.021      |
|         |                 | −0.095    | 0.159     | −0.048          | 0.053           | 0.053           | 0.053           | 0.020      | 0.042     | 0.085     | −0.074    | 0.032     | −0.032           | −0.085           | 0.020      | 0.042     | 0.085      | −0.074    | 0.032     | −0.032           | −0.085           | 0.020      | 0.042     | 0.085      |
|         |                 | −0.023    | 0.034     | −0.012          | 0.116           | 0.116           | 0.116           | 0.021      | 0.004     | 0.021     | −0.017    | 0.006     | −0.005           | −0.085           | 0.021      | 0.004     | 0.021      | −0.017    | 0.006     | −0.005           | −0.085           | 0.021      | 0.004     | 0.021      |
|         |                 | −0.259    | 0.217     | 0.039           | 0.039           | 0.039           | 0.039           | 0.021      | 0.006     | 0.079     | −0.116    | −0.012   | −0.034           | −0.085           | 0.021      | 0.006     | 0.079      | −0.116    | −0.012   | −0.034           | −0.085           | 0.021      | 0.006     | 0.079      |
|         |                 | −0.048    | 0.049     | 0.009           | 0.039           | 0.039           | 0.039           | 0.006     | 0.001     | −0.079   | −0.012    | −0.026   | −0.005           | −0.085           | 0.006     | 0.001     | −0.079   | −0.012    | −0.026   | −0.005           | −0.085           | 0.006     | 0.001     | −0.079   |
|         |                 | −0.196    | 0.132     | 0.246           | 0.168           | 0.168           | 0.168           | 0.132     | 0.022     | 0.103    | 0.117    | 0.117   | −0.025           | −0.013           | 0.132     | 0.022     | 0.103    | 0.117    | 0.117   | −0.025           | −0.013           | 0.132     | 0.022     | 0.103    |
|         |                 | −0.032    | 0.095     | 0.039           | 0.039           | 0.039           | 0.039           | 0.095     | 0.022     | 0.103    | 0.117    | 0.117   | −0.025           | −0.013           | 0.132     | 0.022     | 0.103    | 0.117    | 0.117   | −0.025           | −0.013           | 0.132     | 0.022     | 0.103    |
|         |                 | 0.053     | 0.032     | 0.009           | 0.009           | 0.009           | 0.009           | 0.053     | 0.001     | 0.007    | 0.011    | 0.011   | −0.025           | −0.004           | 0.053     | 0.001     | 0.007    | 0.011    | 0.011   | −0.025           | −0.004           | 0.053     | 0.001     | 0.007    |
|         |                 | 0.011     | 0.021     | 0.006           | 0.006           | 0.006           | 0.006           | 0.021     | 0.001     | 0.007    | 0.011    | 0.011   | −0.025           | −0.004           | 0.053     | 0.001     | 0.007    | 0.011    | 0.011   | −0.025           | −0.004           | 0.053     | 0.001     | 0.007    |
Table 6 (continued)

|       | Jul   |   | Aug   |   | Sep   |   | Oct   |   | Nov   |   | Dec   |   |
|-------|-------|---|-------|---|-------|---|-------|---|-------|---|-------|---|
|       | Z     | Slope | Z   | Slope | Z   | Slope | Z   | Slope | Z   | Slope | Z   | Slope |
| −0.076 | −0.006 | 0.154 | 0.015 | 0.140 | 0.019 | −0.071 | −0.013 | 0.030 | 0.003 | −0.168 | −0.028 |
| −0.153 | −0.019 | −0.386 | −0.028 | −0.228 | −0.025 | 0.037 | 0.011 | −0.037 | −0.008 | −0.190 | −0.058 |
| −0.153 | −0.016 | −0.005 | 0.000 | 0.228 | 0.029 | −0.005 | −0.002 | 0.005 | 0.002 | 0.206 | 0.035 |
| −0.016 | −0.002 | 0.117 | 0.009 | 0.343 | 0.030 | 0.195 | 0.026 | 0.016 | 0.001 | −0.071 | −0.011 |
| 0.053 | 0.002 | −0.030 | −0.002 | 0.126 | 0.022 | −0.048 | −0.004 | −0.080 | −0.011 | 0.191 | 0.038 |
| −0.154 | −0.009 | 0.007 | 0.001 | −0.136 | −0.021 | 0.025 | 0.003 | 0.062 | 0.011 | −0.283 | −0.079 |
| −0.080 | −0.008 | 0.131 | 0.022 | −0.228 | −0.029 | 0.122 | 0.016 | −0.021 | −0.002 | −0.057 | −0.017 |
| −0.044 | −0.003 | −0.117 | −0.009 | −0.090 | −0.013 | −0.057 | −0.009 | −0.333 | −0.055 | −0.343 | −0.072 |
| −0.030 | −0.002 | 0.131 | 0.012 | 0.136 | 0.017 | −0.044 | −0.007 | −0.011 | −0.003 | −0.067 | −0.008 |
| −0.153 | −0.018 | −0.392 | −0.030 | −0.249 | −0.023 | 0.000 | 0.000 | −0.101 | −0.018 | −0.175 | −0.063 |
| −0.143 | −0.014 | −0.011 | −0.001 | 0.233 | 0.027 | −0.005 | −0.001 | 0.021 | 0.004 | 0.217 | 0.039 |
| −0.080 | −0.009 | 0.136 | 0.015 | 0.191 | 0.016 | 0.011 | 0.001 | −0.090 | −0.018 | −0.168 | −0.025 |
| −0.002 | 0.000 | 0.044 | 0.003 | −0.011 | −0.003 | −0.177 | −0.026 | −0.007 | −0.002 | −0.011 | −0.005 |
| −0.145 | −0.012 | 0.048 | 0.005 | −0.228 | −0.026 | 0.140 | 0.018 | −0.011 | −0.002 | −0.159 | −0.032 |
| −0.090 | −0.007 | 0.136 | 0.022 | −0.232 | −0.028 | 0.136 | 0.019 | 0.039 | 0.004 | −0.030 | −0.006 |
| 0.030 | 0.001 | −0.136 | −0.012 | −0.094 | −0.009 | −0.076 | −0.013 | −0.347 | −0.058 | −0.352 | −0.066 |
| −0.080 | −0.007 | 0.136 | 0.013 | 0.145 | 0.022 | −0.039 | −0.002 | −0.025 | −0.003 | −0.122 | −0.016 |

Bold numbers show a significant trend at a 95% confidence level
Table 7 Changepoint analysis of mean monthly and annual precipitation, $T_{\text{min}}$, and $T_{\text{max}}$ over the three study points under historic, RCP4.5, and RCP8.5

| Month     | Study point 1 |        | Study point 2 |        | Study point 3 |        |
|-----------|---------------|--------|---------------|--------|---------------|--------|
|           | Precipitation | $T_{\text{min}}$ | $T_{\text{max}}$ | Precipitation | $T_{\text{min}}$ | $T_{\text{max}}$ | Precipitation | $T_{\text{min}}$ | $T_{\text{max}}$ |
|           | Change year   | Shift  | Change year   | Shift  | Change year   | Shift  | Change year   | Shift  | Change year   | Shift  |
| January   | 2033 (4.5)    | ↑      | 2065 (4.5)    | ↑      | 2033 (4.5)    | ↑      | 2065 (4.5)    | ↑      | 2033 (4.5)    | ↑      |
|           | 2038 (8.5)    | ↓      | 2055 (8.5)    | ↑      | 2051 (8.5)    | ↑      | 2055 (8.5)    | ↑      | 2055 (8.5)    | ↑      |
| February  | 1976 (Hist)   | ↑      | 2043 (4.5)    | ↑      | 2052 (8.5)    | ↑      | 2052 (8.5)    | ↑      | 2052 (8.5)    | ↑      |
| March     | 2044 (4.5)    | ↑      | 2060 (4.5)    | ↑      | 2059 (4.5)    | ↑      | 2060 (4.5)    | ↑      | 2059 (4.5)    | ↑      |
|           | 2052 (8.5)    | ↑      | 2064 (8.5)    | ↑      | 2050 (8.5)    | ↑      | 2067 (8.5)    | ↑      | 2050 (8.5)    | ↑      |
| April     | 2048 (4.5)    | ↑      | 2035 (4.5)    | ↑      | 2035 (4.5)    | ↑      | 2035 (4.5)    | ↑      | 2035 (4.5)    | ↑      |
|           | 2051 (8.5)    | ↑      | 2051 (8.5)    | ↑      | 2051 (8.5)    | ↑      | 2051 (8.5)    | ↑      | 2051 (8.5)    | ↑      |
| May       | 2052 (4.5)    | ↑      | 2052 (4.5)    | ↑      | 2052 (4.5)    | ↑      | 2052 (4.5)    | ↑      | 2052 (4.5)    | ↑      |
|           | 2051 (8.5)    | ↑      | 2051 (8.5)    | ↑      | 2051 (8.5)    | ↑      | 2051 (8.5)    | ↑      | 2051 (8.5)    | ↑      |
| June      | 2049 (4.5)    | ↑      | 2049 (4.5)    | ↑      | 2049 (4.5)    | ↑      | 2049 (4.5)    | ↑      | 2049 (4.5)    | ↑      |
|           | 2051 (8.5)    | ↑      | 2050 (8.5)    | ↑      | 2050 (8.5)    | ↑      | 2050 (8.5)    | ↑      | 2050 (8.5)    | ↑      |
| July      | 2020 (4.5)    | ↓      | 2051 (4.5)    | ↑      | 2051 (4.5)    | ↑      | 2051 (4.5)    | ↑      | 2051 (4.5)    | ↑      |
|           | 2051 (4.5)    | ↑      | 2053 (4.5)    | ↑      | 2053 (4.5)    | ↑      | 2053 (4.5)    | ↑      | 2053 (4.5)    | ↑      |
|           | 2052 (8.5)    | ↑      | 2050 (8.5)    | ↑      | 2050 (8.5)    | ↑      | 2050 (8.5)    | ↑      | 2050 (8.5)    | ↑      |
| August    | 2049 (8.5)    | ↑      | 2051 (4.5)    | ↑      | 2048 (4.5)    | ↑      | 2051 (4.5)    | ↑      | 2048 (4.5)    | ↑      |
|           | 2055 (8.5)    | ↑      | 2048 (4.5)    | ↑      | 2055 (8.5)    | ↑      | 2055 (8.5)    | ↑      | 2055 (8.5)    | ↑      |
| September | 2047 (4.5)    | ↑      | 2053 (4.5)    | ↑      | 2047 (4.5)    | ↑      | 2053 (4.5)    | ↑      | 2053 (4.5)    | ↑      |
|           | 2048 (8.5)    | ↑      | 2050 (8.5)    | ↑      | 2048 (8.5)    | ↑      | 2050 (8.5)    | ↑      | 2050 (8.5)    | ↑      |
| October   | 2057 (4.5)    | ↑      | 2051 (4.5)    | ↑      | 2057 (4.5)    | ↑      | 2051 (4.5)    | ↑      | 2057 (4.5)    | ↑      |
|           | 2059 (8.5)    | ↑      | 2052 (8.5)    | ↑      | 2057 (8.5)    | ↑      | 2052 (8.5)    | ↑      | 2057 (8.5)    | ↑      |
| November  | 2051 (4.5)    | ↑      | 2051 (4.5)    | ↑      | 2051 (4.5)    | ↑      | 2051 (4.5)    | ↑      | 2051 (4.5)    | ↑      |
|           | 2049 (8.5)    | ↑      | 2052 (8.5)    | ↑      | 2052 (8.5)    | ↑      | 2052 (8.5)    | ↑      | 2052 (8.5)    | ↑      |
| December  | 2048 (4.5)    | ↑      | 2048 (4.5)    | ↑      | 2048 (4.5)    | ↑      | 2048 (4.5)    | ↑      | 2048 (4.5)    | ↑      |
|           | 2045 (8.5)    | ↑      | 2054 (8.5)    | ↑      | 2054 (8.5)    | ↑      | 2054 (8.5)    | ↑      | 2054 (8.5)    | ↑      |
| Annual    | 1963 (Hist)   | ↓      | 2052 (4.5)    | ↑      | 2049 (4.5)    | ↑      | 2052 (4.5)    | ↑      | 2049 (4.5)    | ↑      |
|           | 2065 (8.5)    | ↑      | 2050 (8.5)    | ↑      | 2065 (8.5)    | ↑      | 2052 (8.5)    | ↑      | 2054 (8.5)    | ↑      |
|           | 2065 (8.5)    | ↑      | 2050 (8.5)    | ↑      | 2065 (8.5)    | ↑      | 2052 (8.5)    | ↑      | 2054 (8.5)    | ↑      |

Sign ↑ showing increasing change point and sign ↓ showing decreasing change point.
2033 and 2059 at the end of the near future and the early years of the distant future (Government of Arunachal Pradesh 2011). A drastic change is likely to be observed for T_min at study point 1 from the year 2052 with as high as 5–10 times in the near future and from 6 to 15 times in the distant future than the historical in both RCP 4.5 and RCP 8.5, respectively. The other study points for T_min also show an increasing change from 2052 with 14.1 to 74% to the historic T_min in both RCPs. Similarly, mean monthly (all 12 months) and annual T_max also show an increasing change point in the scenarios between 2037 and 2074. The mean annual T_max changes for all study points range from 6.6 to 14.9% and 8.7 to 36.4% to the historic mean T_max in RCP 4.5 and RCP 8.5, respectively.

4 Conclusions

Precipitation and temperature are two important variables in the weather system that define a region’s climate and vary according to the geographical features and time scale. This paper aims to investigate and quantify the trend and homogeneity in total precipitation, T_min, and T_max for the RCP 4.5 and RCP 8.5 from 1950–2099 using a class of approximately 30-year duration. The study carries three study points across the Tawang Chu in the district of Tawang, Arunachal Pradesh. The NEX-GDDP data is used to complete the study validated using a minimum set of meteorological acquired from the CWC. The historic precipitation trend analysis in the study reveals that there is no significant increasing trend in the annual and seasonal mean precipitation. The summer mean precipitation for RCP 4.5 (2006–2065) shows a positive trend with a positive rise in precipitation between 1.56 and 9.94 mm in all the study points, which is not observed in the RCP 8.5. The monthly mean precipitation at all study points, there is a clear increasing trend within 12 months for the various time scales—RCP 4.5 April (2036–2065) and October (2066–2095) and a clear downward trend in August (2006–2035), June, and November (2066–2095). The mean annual precipitation statistics show an increase of 10.2% and 10.7% than the historic precipitation for RCP 4.5 in 2006–2052 and 2053–2099 at study point 1, which declined for RCP 8.5 than the historical mean annual. Study points 2 and 3 show an increase in mean annual precipitation by 7.5 to 12.2% for RCP 4.5 and by 1.4 to 19.6% for RCP 8.5 as compared to the historic mean annual. The mean annual T_min statistics in the study reveal a significant increase against the normal increase of T_max in RCP 4.5, similar to the precipitation statistics and behaviour of study point 1. Both RCP scenarios show a uniform increase in T_min and T_max for study points 2 and 3. The results also show a consistent increase in mean annual T_min and T_max for the three study points. Only a few studies have been conducted in the eastern Himalayan region, particularly in India’s Arunachal Pradesh. The lack of similar studies in the Tawang region has resulted in a low comparison between study results and published data. The three study points fall in the Tawang river basin with a large area covered with snow and glacier, which plays an important role in the Tawang basin’s hydrology and downstream hydrology. Any change in temperature and precipitation can influence the region’s hydrology as glacier basins are more sensitive to temperature and precipitation changes. Thus, detailed temperature and precipitation studies can help understand and assess the changes in the basin hydrology and help related affairs (irrigation activities, agricultural, tourism sector, etc.) mitigate with changes.
## Appendix

### Table 8  List of the statistical method

| Statistical method                                      | Equation                                                                 | Optimal value |
|---------------------------------------------------------|--------------------------------------------------------------------------|---------------|
| Bias (%)                                                | \[
\text{Bias} = \frac{1}{n} \sum_{i=1}^{n} \frac{(\text{Obs}_i - \text{Est}_i)^2}{\text{Obs}_i} \times 100
\] | 0                          |
| Pearson’s correlation coefficient (r)                   | \[
\text{Pearson’s correlation coefficient} = \frac{\sum_{i=1}^{n} (\text{Obs}_i - \bar{\text{Obs}})(\text{Est}_i - \bar{\text{Est}})}{\sqrt{\sum_{i=1}^{n} (\text{Obs}_i - \bar{\text{Obs}})^2} \sqrt{\sum_{i=1}^{n} (\text{Est}_i - \bar{\text{Est}})^2}}
\] | 1                          |
| Root mean square error (RMSE)                           | \[
\text{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\text{Obs}_i - \text{Est}_i)^2}
\] | 0                          |
| Mean absolute error (MAE)                               | \[
\text{MAE} = \frac{1}{n} \sum_{i=1}^{n} |\text{Obs}_i - \text{Est}_i|
\] | 0                          |

Obs, and \( \bar{\text{Obs}} \) refers to observation and mean of observation and \( \text{Est} \), and \( \bar{\text{Est}} \) indicate to estimated value (derived from NEXGDDP data) and mean of estimated value, respectively.

### Table 9  Mann – Kendall test Z-statistics and Sen’s slope (mm/year) for the study points (sub-basin level) of mean monthly precipitation for historical (1950–2005) and futuristic (2006–2095) with RCP 4.5 and RCP 8.5 scenarios

| Station | Time scale/months | Jan | Feb | Mar | Apr | May | Jun |
|---------|-------------------|-----|-----|-----|-----|-----|-----|
| SB 1    | Historical        | 0.04| 0.00| 0.10| 0.00| 0.10| 0.00|
|         | 1978–2005         | -0.11| 0.00| -0.08| 0.00| 0.08| 0.16| 0.04| 0.25| 0.05| 0.78| -0.07| -2.42|
| RCP 4.5 | 2006–2035         | 0.09| 0.00| -0.08| 0.00| -0.02| -0.06| -0.04| 0.46| 0.10| 1.59| -0.10| -2.29|
|         | 2036–2065         | -0.12| 0.00| -0.06| 0.00| 0.19| 0.48| 0.26| 3.40| 0.07| 1.06| -0.15| -5.15|
|         | 2066–2095         | -0.22| 0.00| -0.08| 0.00| 0.13| 0.32| 0.03| 0.52| -0.18| -2.90| -0.26| -6.91|
| RCP 8.5 | 2006–2035         | 0.09| 0.00| -0.04| 0.00| 0.12| 0.31| -0.10| -1.01| -0.01| -0.33| 0.04| 0.66|
|         | 2036–2065         | -0.04| 0.00| 0.02| 0.00| 0.04| 0.14| 0.18| 2.97| -0.15| -2.95| -0.18| -4.49|
|         | 2066–2095         | 0.13| 0.00| -0.10| -0.01| -0.04| -0.21| -0.11| -2.04| 0.06| 1.23| -0.11| -3.29|
| SB 2    | Historical        | 0.13| 0.04| -0.07| -0.03| -0.11| -0.30| -0.06| -0.37| -0.08| -1.27| -0.17| -5.61|
|         | 1978–2005         | 0.02| 0.01| 0.10| 0.03| 0.04| 0.14| 0.02| 0.48| 0.05| 0.89| -0.05| -2.19|
| RCP 4.5 | 2006–2035         | 0.20| 0.02| -0.12| -0.02| -0.10| -0.35| -0.08| -1.15| 0.14| 3.44| -0.06| -5.18|
|         | 2036–2065         | -0.17| -0.04| 0.16| 0.06| 0.22| 1.00| 0.24| 4.36| 0.05| 1.27| -0.14| -4.66|
|         | 2066–2095         | -0.09| -0.02| -0.09| 0.00| 0.05| 0.17| 0.03| 0.66| -0.20| -4.46| -0.20| -9.31|
| RCP 8.5 | 2006–2035         | 0.13| 0.05| -0.02| 0.00| 0.13| 0.66| -0.09| -1.83| 0.01| 0.21| 0.05| 1.28|
|         | 2036–2065         | -0.06| 0.00| -0.12| 0.00| -0.03| -0.15| 0.13| 2.47| -0.14| -4.01| -0.16| -5.80|
|         | 2066–2095         | -0.20| -0.05| -0.08| 0.00| -0.10| -0.57| -0.16| -3.71| 0.03| 0.53| -0.09| -3.19|
| SB 3    | Historical        | 0.22| 0.00| -0.06| 0.00| -0.09| -0.17| -0.03| -0.14| -0.10| -1.04| -0.17| -6.24|
|         | 1978–2005         | -0.11| -0.02| 0.11| 0.01| 0.04| 0.07| 0.04| 0.20| 0.06| 1.80| -0.07| -1.95|
| RCP 4.5 | 2006–2035         | 0.06| 0.00| -0.14| -0.01| -0.10| -0.17| -0.08| -0.63| 0.07| 1.55| -0.09| -4.12|
|         | 2036–2065         | -0.06| 0.00| 0.08| 0.00| 0.22| 0.51| 0.25| 3.86| 0.07| 1.55| -0.15| -4.24|
|         | 2066–2095         | -0.13| 0.00| -0.05| 0.00| 0.09| 0.16| 0.03| 0.68| -0.18| -3.55| -0.24| -8.15|
| RCP 8.5 | 2006–2035         | 0.05| 0.00| 0.10| 0.00| 0.14| 0.40| -0.10| -1.28| 0.00| 0.07| 0.00| 0.05|
|         | 2036–2065         | -0.11| 0.00| -0.04| 0.00| -0.06| -0.13| 0.12| 2.30| -0.13| -2.39| -0.16| -4.05|
|         | 2066–2095         | -0.19| 0.00| -0.10| 0.00| -0.10| -0.41| -0.17| -3.56| 0.04| 0.61| -0.07| -1.97|

*Z* and *Slope* values are calculated for each month and year.
| Jul | Slope | Aug | Slope | Sep | Slope | Oct | Slope | Nov | Slope | Dec | Slope |
|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|
| -0.01 | -0.19 | 0.10 | 2.95 | -0.06 | -1.15 | **0.29** | 2.17 | -0.24 | -0.20 | -0.27 | 0.00 |
| -0.07 | -1.20 | -0.22 | -5.31 | -0.09 | -0.87 | -0.09 | -0.54 | -0.20 | -0.12 | -0.05 | 0.00 |
| 0.02 | 0.16  | 0.16 | 1.99 | 0.12 | 2.65  | 0.23 | 1.92  | 0.05 | 0.02  | -0.19 | 0.00 |
| 0.13 | 3.27  | 0.11 | 2.97 | -0.02 | -0.24 | -0.22 | -2.29 | 0.05 | 0.02  | 0.11  | 0.00 |
| -0.16 | -6.59 | -0.09 | -2.16 | -0.14 | -2.82 | -0.03 | -0.25 | 0.03 | 0.03  | 0.05  | 0.00 |
| -0.01 | -0.14 | -0.23 | -7.94 | 0.05 | 1.47  | -0.12 | -1.28 | 0.13 | 0.08  | 0.19  | 0.00 |
| 0.02 | 0.71  | **-0.36** | -10.73 | -0.07 | -2.09 | -0.02 | -0.45 | 0.18 | 0.14  | 0.11  | 0.00 |
| 0.08 | 1.46  | 0.01 | 0.22 | 0.05 | 1.57  | -0.04 | -1.42 | 0.08 | 0.08  | 0.08  | 0.00 |
| -0.03 | -1.52 | 0.08 | 2.37 | -0.06 | -1.52 | **0.24** | 2.79 | -0.32 | -0.56 | -0.01 | 0.00 |
| -0.04 | -0.95 | -0.21 | -7.03 | -0.04 | -0.92 | -0.12 | -1.12 | -0.24 | -0.31 | -0.05 | 0.00 |
| -0.03 | -0.66 | 0.10 | 2.84 | 0.05 | 0.87  | 0.24 | 3.05  | 0.02 | 0.02  | 0.18  | 0.00 |
| 0.02 | 0.81  | 0.10 | 3.78 | -0.10 | -2.34 | -0.21 | -1.96 | -0.02 | -0.05 | 0.00  | 0.00 |
| -0.14 | -4.97 | -0.06 | -1.32 | -0.16 | -2.65 | -0.03 | -0.19 | -0.01 | 0.00  | 0.05  | 0.00 |
| 0.04 | 0.81  | -0.22 | -5.82 | 0.06 | 1.43  | -0.12 | -0.89 | 0.15 | 0.06  | -0.05 | 0.00 |
| 0.01 | 0.41  | **-0.34** | -9.04 | -0.04 | -0.87 | -0.04 | -0.44 | 0.15 | 0.09  | -0.10 | 0.00 |
| 0.05 | 1.51  | 0.00 | 0.11 | 0.04 | 0.96  | -0.08 | -0.96 | 0.09 | 0.06  | 0.11  | 0.00 |
| -0.05 | -1.45 | 0.09 | 3.02 | -0.03 | -1.09 | **0.25** | 2.12 | -0.33 | -0.35 | -0.02 | 0.00 |
| -0.07 | -1.63 | -0.19 | -5.94 | -0.03 | -0.37 | -0.10 | -0.64 | -0.20 | -0.16 | -0.05 | 0.00 |
| -0.03 | -0.59 | 0.11 | 1.91 | 0.06 | 0.95  | 0.23 | 2.31  | 0.00 | 0.00  | 0.28  | 0.00 |
| 0.03 | 1.41  | 0.11 | 2.95 | -0.07 | -1.72 | -0.18 | -1.40 | -0.02 | 0.00  | -0.02 | 0.00 |

Bold numbers show a significant trend at a 95% confidence level.
| Station | Time scale/months | Jan Slope | Feb Slope | Mar Slope | Apr Slope | May Slope | Jun Slope |
|---------|------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| SB 1    | Historical       | 0.312     | -0.086    | -0.185    | -0.100    | -0.222    | -0.049    | -0.185    | -0.040    | -0.243    | -0.043    | -0.265    | -0.029    |
|         | 1978–2005        | 0.275     | 0.089     | 0.000     | -0.002    | 0.132     | 0.037     | 0.217     | 0.080     | 0.238     | 0.046     | 0.201     | 0.023     |
| RCP 4.5 | 2006–2035        | 0.324     | 0.054     | 0.218     | 0.094     | 0.223     | 0.050     | 0.177     | 0.038     | 0.310     | 0.053     | 0.457     | 0.034     |
|         | 2036–2065        | -0.067    | -0.009    | 0.246     | 0.092     | 0.145     | 0.046     | -0.094    | -0.023    | 0.283     | 0.056     | 0.467     | 0.054     |
|         | 2066–2095        | -0.126    | -0.020    | 0.011     | 0.001     | -0.080    | -0.019    | 0.090     | 0.020     | 0.480     | 0.079     | 0.301     | 0.024     |
| RCP 8.5 | 2006–2035        | 0.347     | 0.080     | 0.237     | 0.116     | 0.324     | 0.091     | 0.292     | 0.064     | 0.292     | 0.050     | 0.407     | 0.048     |
|         | 2036–2065        | 0.103     | 0.026     | 0.113     | 0.026     | 0.149     | 0.028     | 0.264     | 0.052     | 0.140     | 0.027     | 0.591     | 0.076     |
|         | 2066–2099        | 0.361     | 0.096     | 0.186     | 0.105     | **0.503** | 0.187     | **0.536** | 0.196     | **0.563** | 0.095     | **0.467** | 0.047     |
| SB 2    | Historical       | -0.307    | -0.091    | -0.169    | -0.080    | -0.222    | -0.045    | -0.169    | -0.036    | -0.228    | -0.044    | -0.228    | -0.026    |
|         | 1978–2005        | 0.280     | 0.090     | -0.026    | -0.012    | 0.175     | 0.040     | 0.243     | 0.079     | 0.228     | 0.044     | 0.116     | 0.014     |
| RCP 4.5 | 2006–2035        | 0.264     | 0.045     | 0.228     | 0.088     | 0.195     | 0.053     | 0.145     | 0.042     | 0.274     | 0.048     | 0.398     | 0.029     |
|         | 2036–2065        | -0.108    | -0.024    | 0.232     | 0.081     | 0.113     | 0.034     | -0.103    | -0.027    | 0.251     | 0.050     | 0.430     | 0.049     |
|         | 2066–2099        | -0.117    | -0.019    | 0.016     | 0.012     | -0.085    | -0.018    | 0.108     | 0.021     | 0.462     | 0.081     | 0.260     | 0.023     |
| RCP 8.5 | 2006–2035        | 0.324     | 0.079     | 0.255     | 0.118     | **0.329** | 0.094     | **0.297** | 0.066     | **0.297** | 0.048     | **0.343** | 0.036     |
|         | 2036–2065        | 0.053     | 0.014     | 0.085     | 0.028     | 0.108     | 0.019     | 0.191     | 0.052     | 0.080     | 0.015     | **0.536** | 0.070     |
|         | 2066–2099        | 0.430     | 0.106     | 0.137     | 0.079     | **0.458** | 0.148     | **0.544** | 0.184     | **0.633** | 0.107     | **0.462** | 0.044     |
| SB 3    | Historical       | -0.302    | -0.086    | -0.190    | -0.093    | -0.228    | -0.047    | -0.175    | -0.040    | -0.243    | -0.046    | -0.249    | -0.033    |
|         | 1978–2005        | 0.270     | 0.087     | -0.011    | -0.006    | 0.175     | 0.041     | 0.233     | 0.077     | 0.243     | 0.045     | 0.190     | 0.022     |
| RCP 4.5 | 2006–2035        | 0.333     | 0.058     | 0.223     | 0.097     | 0.228     | 0.056     | 0.177     | 0.042     | 0.329     | 0.056     | 0.457     | 0.034     |
|         | 2036–2065        | -0.076    | -0.018    | 0.237     | 0.083     | 0.103     | 0.038     | -0.131    | -0.030    | 0.264     | 0.051     | 0.434     | 0.054     |
|         | 2066–2099        | -0.131    | -0.021    | 0.007     | 0.002     | -0.085    | -0.021    | 0.108     | 0.018     | 0.471     | 0.079     | 0.269     | 0.023     |
| RCP 8.5 | 2006–2035        | 0.352     | 0.077     | 0.241     | 0.116     | **0.343** | 0.094     | **0.306** | 0.064     | **0.310** | 0.053     | **0.389** | 0.046     |
|         | 2036–2065        | 0.076     | 0.022     | 0.094     | 0.028     | 0.140     | 0.023     | 0.246     | 0.049     | 0.136     | 0.027     | **0.559** | 0.075     |
|         | 2066–2099        | **0.419** | 0.104     | 0.141     | 0.076     | **0.462** | 0.143     | **0.540** | 0.168     | **0.622** | 0.106     | **0.444** | 0.042     |
| Jul  | Aug  | Sep  | Oct  | Nov  | Dec  |
|------|------|------|------|------|------|
| **Z** | Slope | Z    | Slope | Z    | Slope |
| 0.577 | 0.009 | 0.380 | 0.063 | 0.090 | 0.034 |
| −0.326 | 0.042 | 0.002 | 0.000 | 0.004 | 0.000 |
| −0.513 | 0.045 | 0.002 | 0.000 | 0.004 | 0.000 |
| −0.338 | 0.043 | 0.002 | 0.000 | 0.004 | 0.000 |
| −0.180 | 0.043 | 0.002 | 0.000 | 0.004 | 0.000 |
| **Slope** | Z    | Slope | Z    | Slope | Z    |
| 0.632 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.619 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.619 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.619 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

Bold numbers show a significant trend at a 95% confidence level.
Table 11  Mann–Kendall test Z-statistics and Sen’s slope (°C/year) for the study points (sub-basin level) of mean annual T_min for historical (1950–2005) and future (2006–2095) with RCP 4.5 and RCP 8.5 scenarios

| Station | Time scale / months | Jan Z | Jan Slope | Feb Z | Feb Slope | Mar Z | Mar Slope | Apr Z | Apr Slope | May Z | May Slope | Jun Z | Jun Slope |
|---------|----------------------|------|-----------|------|-----------|------|-----------|------|-----------|------|-----------|------|-----------|
| SB 1    | Historical 1950–1977 | −0.238 | −0.058 | −0.095 | −0.039 | −0.138 | −0.031 | −0.037 | −0.008 | −0.005 | −0.001 | −0.153 | −0.024 |
|         | 1978–2005            | 0.169 | 0.032 | 0.048 | 0.025 | 0.053 | 0.010 | 0.206 | 0.042 | 0.190 | 0.027 | 0.286 | 0.043 |
| RCP 4.5 | 2006–2035            | 0.393 | 0.085 | 0.228 | 0.069 | 0.389 | 0.066 | 0.195 | 0.034 | 0.559 | 0.092 | 0.595 | 0.078 |
|         | 2036–2065            | 0.034 | 0.011 | 0.159 | 0.067 | 0.149 | 0.034 | −0.214 | −0.037 | 0.324 | 0.037 | 0.517 | 0.043 |
| RCP 8.5 | 2006–2035            | 0.264 | 0.043 | −0.021 | −0.005 | 0.076 | 0.013 | 0.062 | 0.019 | 0.356 | 0.057 | 0.333 | 0.024 |
|         | 2036–2065            | 0.228 | 0.058 | 0.246 | 0.091 | 0.246 | 0.047 | 0.274 | 0.047 | 0.508 | 0.078 | 0.568 | 0.071 |
| SB 2    | Historical 1950–1977 | −0.233 | −0.048 | −0.026 | −0.009 | −0.090 | −0.018 | 0.016 | 0.003 | 0.000 | 0.000 | −0.143 | −0.023 |
|         | 1978–2005            | 0.153 | 0.023 | 0.042 | 0.010 | 0.085 | 0.021 | 0.238 | 0.050 | 0.175 | 0.022 | 0.307 | 0.038 |
| RCP 4.5 | 2006–2035            | 0.287 | 0.065 | 0.356 | 0.089 | 0.306 | 0.051 | 0.159 | 0.023 | 0.549 | 0.088 | 0.614 | 0.070 |
|         | 2036–2065            | −0.002 | 0.000 | 0.205 | 0.063 | 0.122 | 0.025 | −0.200 | −0.037 | 0.338 | 0.040 | 0.526 | 0.042 |
| RCP 8.5 | 2006–2035            | 0.310 | 0.064 | −0.007 | −0.005 | 0.094 | 0.015 | 0.080 | 0.013 | 0.379 | 0.059 | 0.310 | 0.022 |
|         | 2036–2065            | 0.218 | 0.048 | 0.232 | 0.088 | 0.186 | 0.044 | 0.264 | 0.044 | 0.531 | 0.075 | 0.563 | 0.070 |
| SB 3    | Historical 1950–1977 | −0.249 | −0.051 | −0.079 | −0.040 | −0.127 | −0.029 | −0.032 | −0.004 | 0.005 | 0.001 | −0.153 | −0.024 |
|         | 1978–2005            | 0.159 | 0.029 | 0.058 | 0.026 | 0.058 | 0.011 | 0.217 | 0.042 | 0.164 | 0.021 | 0.280 | 0.043 |
| RCP 4.5 | 2006–2035            | 0.393 | 0.084 | 0.278 | 0.101 | 0.393 | 0.067 | 0.172 | 0.030 | 0.563 | 0.093 | 0.591 | 0.077 |
|         | 2036–2065            | 0.393 | 0.084 | 0.278 | 0.101 | 0.393 | 0.067 | 0.172 | 0.030 | 0.563 | 0.093 | 0.591 | 0.077 |
| RCP 8.5 | 2006–2035            | 0.278 | 0.054 | −0.007 | −0.002 | 0.085 | 0.011 | 0.071 | 0.017 | 0.361 | 0.058 | 0.333 | 0.023 |
|         | 2036–2065            | 0.301 | 0.064 | 0.205 | 0.071 | 0.306 | 0.064 | 0.439 | 0.081 | 0.384 | 0.083 | 0.674 | 0.084 |

| Jul | Z | Slope | Aug | Z | Slope | Sep | Z | Slope | Oct | Z | Slope | Nov | Z | Slope | Dec | Z | Slope |
|-----|---|-------|----|---|-------|-----|---|-------|-----|---|-------|-----|---|-------|-----|---|-------|
| −0.212 | −0.017 | −0.085 | −0.008 | −0.069 | −0.010 | −0.143 | −0.047 | −0.063 | −0.020 | 0.101 | 0.045 |
| 0.286 | 0.026 | 0.180 | 0.018 | −0.058 | −0.008 | 0.212 | 0.045 | 0.138 | 0.034 | 0.021 | 0.008 |
| 0.568 | 0.047 | 0.361 | 0.030 | 0.490 | 0.046 | 0.338 | 0.065 | 0.315 | 0.066 | 0.191 | 0.047 |
| 0.499 | 0.032 | 0.453 | 0.043 | 0.411 | 0.044 | 0.430 | 0.079 | 0.209 | 0.047 | 0.338 | 0.084 |
| 0.172 | 0.012 | −0.076 | −0.005 | 0.310 | 0.029 | −0.136 | −0.026 | 0.044 | 0.006 | 0.103 | 0.020 |
| 0.683 | 0.050 | 0.494 | 0.046 | 0.476 | 0.069 | 0.154 | 0.032 | 0.448 | 0.050 | 0.398 | 0.077 |
| 0.618 | 0.059 | 0.660 | 0.067 | 0.710 | 0.084 | 0.384 | 0.083 | 0.623 | 0.115 | 0.586 | 0.130 |
Bold numbers show a significant trend at a 95% confidence level.
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Author contribution Juna Prohba Devi: summarised the overall process involved in carrying out the study, data curation, and methodology, performed the calculation, compiled the figure, and wrote the manuscript. Chandan Mahanta: conceptualization, methodology, validation, supervision, writing—review and editing. Anamika Barua: conceptualization, methodology, validation, supervision, writing—review and editing.

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Data availability The data that support the findings of this study are available from the Central Water Commission Shillong and Itanagar, India but restrictions apply to the availability of these data, which were used under licence for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of the Central Water Commission Shillong and Itanagar, India.

Code availability There is no code used in this study. All the statistical formulas used in this study are available.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

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Conflict of interest The authors declare no competing interests.

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