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Long period trend analysis of precipitation and temperature of West Sikkim, India

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सार – वर्तमान अध्ययन का उद्देश्य भारत में सिक्किम के पश्चिमी जिले में वर्षण और तापमान की दीर्घ अवधि की प्रवृत्तिा का विश्लेषण करना है। इस उद्देश्य के लिए भारत मौसम विज्ञान विभाग, भारत सरकार द्वारा उपलब्ध कराए गए ग्रिडेड डाटासेट से 100 से अधिक वर्षों के दैनिक वर्षण और तापमान आंकडे निकाले गए। वर्षण और तापमान की दीर्घ अवधि की मासिक, वार्षिक और मौसमी प्रवृत्तिए का विश्लेषण किया गया है और परिणाम मॉनसून और वार्षिक वर्षा की कमी की प्रवृत्ति दिखाते हैं जबकि 1950 के दशक से तापमान की वृद्धि की प्रवृत्ति दिखाते हैं जैसा कि सेन स्लोप अनुमानक से स्पनष्ट है। 1901-2014 की अवधि के लिए औसत वार्षिक तापमान में परिवर्तन की दर 0.027 °से.प्रति वर्ष है।

ABSTRACT. The present study aims to analyse the long period trend of precipitation and temperature in West district of Sikkim, India. For this purpose daily precipitation and temperature data of more than 100 years were extracted from the gridded dataset provided by the India Meteorological Department, Government of India. Long-term monthly, annual and seasonal trend of precipitation and temperature have been analysed and results show declining trend of monsoonal and annual precipitation as revealed by Sen's slope estimator, whereas increasing trend of temperature since 1950s. Rate of change of mean annual temperature is 0.027 °C per year for the period of 1901-2014.

Key words – Sikkim, Long-term variability, Monsoon, Sen's slope.

1. Introduction

Intergovernmental Panel on Climate Change (IPCC, 2007) defines climate change as "any change in climate over time, whether due to natural variability or as a result of human activity". According to a report published by Food and Agriculture Organization of the United Nations (FAO, 2015), it was said that, "climate change threatens our ability to achieve global food security, eradicate poverty and achieve sustainable development". Climate change is a global phenomenon and is a natural event, but human activity has increased the rate of change. According to IPCC (2014) report, the global mean temperature (combined land and ocean) has increased 0.85 °C for the period 1880 to 2012. Many studies have shown that, in general, the frequency of intense rainfall events in many parts of Asia has decreased, while the number of rainy days and total annual precipitation has decreased (Jain *et al.*, 2012). PRECIS simulation 2071-2100 indicates the annual mean surface temperature over Indian sub continent rise by the end of this century under both A2 (3 °C-5 °C) and B2 (2.5 °C-4 °C) scenario. This warming seemed to be more pronounced in the northern parts of India. Annual and monsoon rainfall show similar increasing pattern under A2 and B2 scenario, except some states like Punjab, Rajasthan, Tamil Nadu etc (Kumar *et al.*, 2006). Government of India's report on climate change (2004) have identified a 0.4% increase in mean temperature and no clear trend was identified for monsoon rainfall over a long period of time in the country.

The climate of North Eastern Region of India (NER) is mainly humid subtropical with hot, humid summers, severe monsoons and mild winters. The NER is a part of Himalayan region and it is most vulnerable to climate change and variability. Precipitation trends show large variability in magnitude in NER for the period 1871-2008. Maximum, minimum and mean temperatures in the NER shows a rising trend during the period 1871-2008 (Jain *et al.*, 2012).

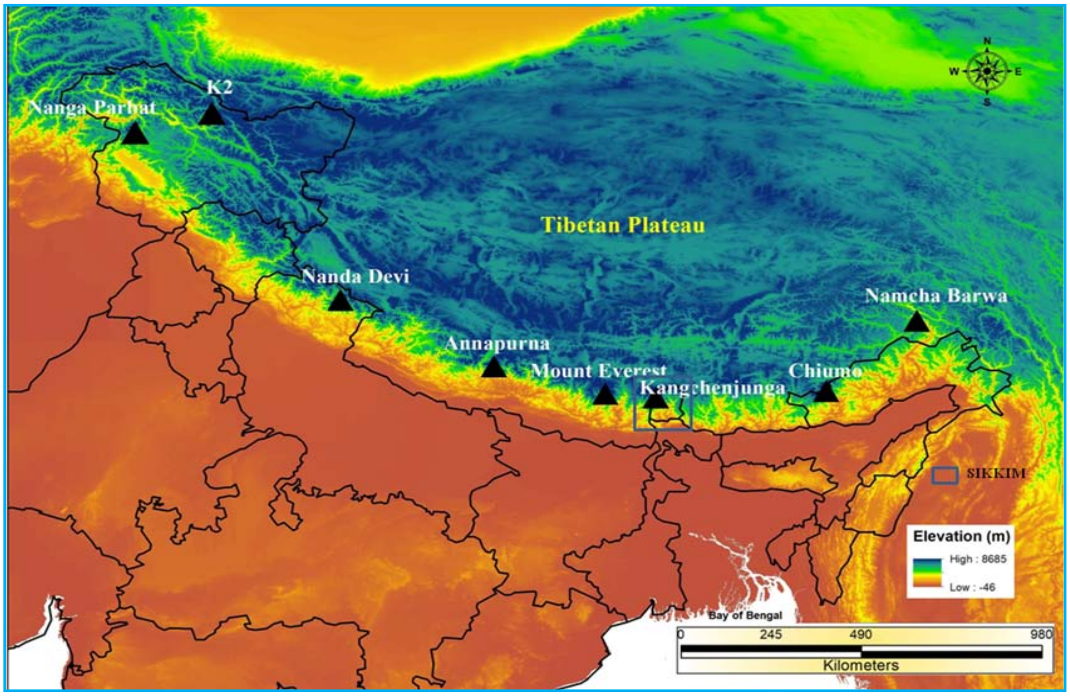

Fig. 1. The study area and surroundings

IPCC (2001) argued for considerable impact of climate change and variability over agricultural and other livelihood in Asian countries in future decades. Especially the endemic rich Himalayas include many plant species that may not respond successfully to the projected rate of climate change (Xu *et al*., 2009).

In Sikkim State Action Plan on Climate Change (2014) report, it was reported that the minimum temperature in the state had increased by almost 2.5 °C during 1957-2009 and total rainfall had decreased by around 250 mm during 1983-2009, however, there exists spatial variability. Changes in climate pose a threat to the production and productivity of crops and livestock products, which are significant from the point of view of the livelihoods it provides to the people. The present study therefore, aims to estimate the long term trend and variability of temperature and precipitation conditions in West district of Sikkim.

2. The study area

Sikkim (Fig. 1) is located in the Darjeeling and Sikkim Himalayas sections of the Eastern Himalayas (Karan and Jenkins, 1963). The geographical area of the state is around 7096 sq. km. Administratively, it has four districts namely, North district, East district, South district and West district. West Sikkim is predominantly rural in character and it consists of 55 gram panchayat units (highest in the state). Livelihood of the people of West Sikkim mainly depends on farming and tourism related activities, which are highly climate sensitive.

3. Data sources and methods

For the present analysis, daily precipitation and temperature data of 115 years (1901-2015) and 114 years (1901-2014) respectively were extracted from the gridded dataset provided by the India Meteorological Department (IMD).

3.1. *Analysis of climatic trends*

One of the widely used non-parametric tests for detecting trends in the time series is the Mann Kendall test (Mann, 1945; Kendall, 1975). The Mann-Kendall trend test is derived from a rank correlation test for two groups of observations proposed by Kendall (1975). In the Mann-Kendall trend test, the correlation between the rank order of the observed values and their order in time is considered. The null hypothesis for the Mann-Kendall test is that there is no trend or serial correlation structure among the observations (Hamed and Rao, 1998; Sam and Chakma, 2019a, b). The Mann-Kendall test statistic S is calculated as :

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

TABLE 1

Mann Kendall test statistics of mean monthly precipitation and Sen's Slope estimation of West district of Sikkim (1901-2015)

Month	Maximum	Minimum	Mean	SD	CV (%)	Z	Q
January	108.8	0	20.19	23.50	116.39	1.79	0.064
February	256.8	0	37.99	43.77	115.22	2.21*	0.142
March	325	0	71.40	61.78	86.53	4.04*	0.655
April	437.2	21.3	136.81	76.27	55.75	4.33*	0.907
May	505.1	69.3	236.99	98.54	41.58	1.56	0.356
June	1445.4	157.8	503.93	187.76	37.26	-3.23*	-1.511
July	1053.2	218.3	668.60	193.92	29.00	-3.59*	-2.064
August	1063.2	197.4	535.34	160.73	30.02	-5.58*	-2.249
September	1045.1	113.5	379.11	155.44	41.00	-1.99*	-0.753
October	679.1	7.3	124.37	115.70	93.03	1.74	0.392
November	263.8	0	21.22	34.43	162.30	1.81	0.053
December	173.5	0	9.44	20.75	219.73	2.67*	0.025

Source : IMD database. (Note: Q is Sen's slope; * indicates significant at ≤ 0.05)

where, n is the number of data points, x_i and x_j are the data values in time series i and j ($j > i$), respectively and $\mathrm{sgn}(x_j - x_i) = +1$ (when $x_j - x_i > 0$), $\mathrm{sgn}(x_j - x_i) = 0$ (when $x_j - x_i = 0$) and $\mathrm{sgn}(x_j - x_i) = -1$ (when $x_j - x_i < 0$).

If, sample size ≥ 8, the test statistics S is approximately normally and variance of S as follows:

$$V(S) = 1/18\,[n\,(n-1)\,(2n+5)] \quad (2)$$

where, n denotes the length of the time series and standardized statistical test Z is computed as:

$$Z = S\text{-}1 / \sqrt{V}(S) \text{ if, } S > 0;\ Z = 0, \text{ if } S = 0 \text{ and}$$
$$Z = S\text{+}1 / \sqrt{V}(S) \text{ if, } S < 0 \quad (3)$$

In this study, significance levels $\alpha = 0.05$ was used. At the 5% significance level, the null hypothesis (H0) of no trend is rejected if $|Z| > 1.96$ (Gocic and Trajkovic, 2013). Positive and negative values of Z indicates increasing or decreasing trend respectively in the time series data.

In the second phase of trend analysis, Sen's slope of non-parametric method (as proposed by Sen in 1968) was used to estimate true slope (magnitude) of an existing trend (change per year) in precipitation and temperature. The magnitude is predicted by the slope (Ti) from all data pair estimated as follows:

$$Ti = X_j - X_i / j\text{-}i \quad (4)$$

where, X_j and X_i are as rainfall values at the time of j and i ($j > i$). The median value of Ti represented as Sen's slope estimator and is calculated as Qmed = $T\,(N+1)/2$ if N is odd and Qmed = $[T\,(N+1)/2 + T\,(N+1)/2]/2$ if N is even. Thereafter, trend is tested 100 (1-α) % confidence interval.

In the third phase of trend analysis, linear regression (Mandal *et al*., 2013) was also used for the time series data of precipitation and temperatures.

The annual precipitation was classified as deficit, when the actual precipitation was < long period average (LPA) – 19% (1901-2015); normal, when actual precipitation is within the range of LPA ± 19% and

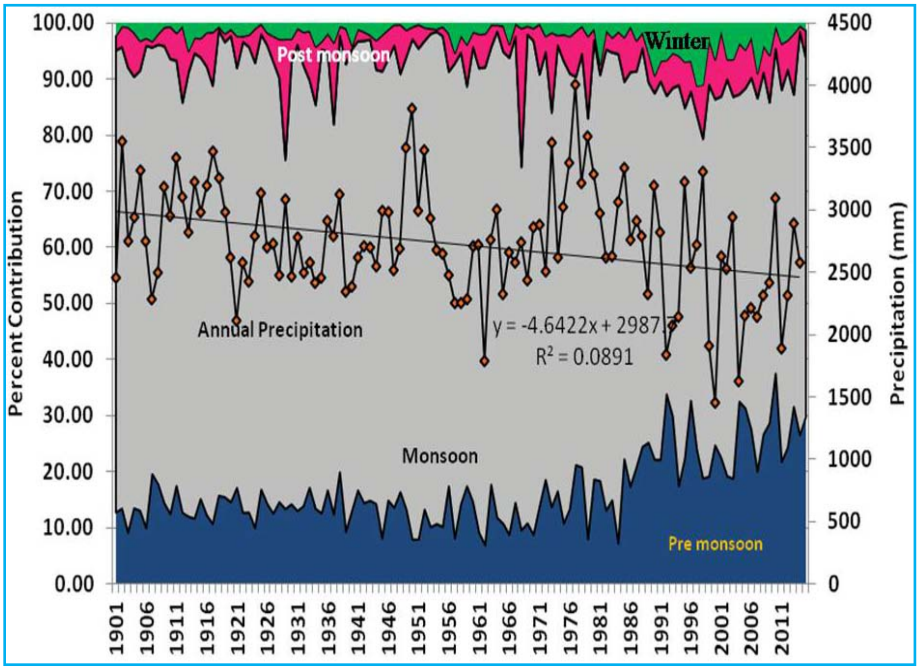

Fig. 2. Temporal variation in long period (1901-2015) annual and seasonal precipitation in West district of Sikkim

excess, when actual precipitation was >LPA + 20% of the corresponding year (as proposed by the IMD). Changing trends of annual and seasonal precipitation was detected in the time series data using Mann-Kendall test (MKT).

For the analysis, months/seasons are considered following IMD categorisation as: Winter (January-February), Pre Monsoon (March-May), Monsoon (June-September) and Post Monsoon (October-December).

All the calculations were done in Excel spreadsheet 2007 and Xlstat software.

4. Results and discussion

4.1. *Long period trend analysis of precipitation*

4.1.1. *Long period monthly distribution pattern of precipitation*

Mean Monthly precipitation varied significantly in West Sikkim (1901-2015) and July received the highest (668.60 ± 193.92 mm) while December (9.44 ± 20.75 mm) received the lowest precipitation (Table 1). In the past 115 years (1901-2015) highest monthly precipitation of 1445.40 mm was received in the month of June.

The trend analysis showed a significant (Z > 1.96) increasing trend during February, March, April and December (0.142, 0.655 mm, 0.907 mm and 0.025 mm per month) and non significant (Z < 1.96) increasing trend during January, May, October and November (0.064, 0.356, 0.392 and 0.053 mm per month respectively) while a significant (Z >1.96) declining trend were observed during the months of June, July, August and September (1.511, 2.064, 2.249 and 0.753 mm per month). The precipitation is declining during the Monsoon months whereas it is rising during other seasons in West district of Sikkim (Fig. 2).

4.1.2. *Long period seasonal distribution pattern of precipitation*

The analysis of long period average (1901-2015) precipitation dataset revealed that West Sikkim received an average annual precipitation of 2745.39 ± 452.16 mm (Table 2). Highest annual precipitation was recorded in the year 1977 (4009.1 mm), while the lowest precipitation was received during the year of 2000 (1448.9 mm). Monsoon received maximum precipitation of 2086.99 ± 448.88 mm with relatively less variability (CV = 21.52%) and winter received lowest precipitation of 67.62 ± 62.31 mm with maximum variability (CV = 92.14%).

The Mann-Kendall test confirmed a significant decreasing trend (Z > 1.96) of mean annual and monsoon precipitation (-3.071 mm/year and -6.526 mm/year respectively) in West district of Sikkim (1901-2015). Besides, significant (p < 0.05 however, Z > 1.96) increasing trend was recorded during the pre Monsoon and Winter

TABLE 2

Mann-Kendal test statistics and Sen's Slope estimation of long period seasonal precipitation and rainy days of West District of Sikkim (1901-2015)

Precipitation (mm)	Total annual precipitation (mm)	Pre monsoon	Monsoon	Post monsoon	Winter	Annual rainy days
Minimum	1448.90	122.00	893.00	11.70	2.40	122.00
Maximum	4009.10	1159.90	3409.90	679.10	361.30	234.00
Mean	2745.39	445.20	2086.99	145.59	67.62	154.74
SD	452.16	171.07	448.88	120.06	62.31	21.36
CV (%)	16.47	38.43	21.51	82.47	92.14	13.80
P-value	0.988387	< 0.0001	1.000	0.033	0.003	0.000109
Z	-2.27*	4.40*	-5.37*	1.84	2.77*	3.69*
Q	-3.071	2.123	-6.526	0.444	0.337	0.232

[*Source* : IMD database. (Note: Q is Sen's slope; * indicates significant at ≤ 0.05)]

TABLE 3

Seasonal mean precipitation in sub-periods (SPA) in West district of Sikkim

Sub periods	Sub-period analysis of Mean Precipitation (mm)				
	Pre monsoon	Monsoon	Post monsoon	Winter	Annual
1901-30	391.19	2289.83	142.05	52.12	2875.75
1931-60	360.41	2213.99	115.51	46.70	2735.78
1961-90	435.42	2220.01	168.39	63.01	2883.63
1991-2015	623.48	1531.55	158.56	119.98	2434.62
Long period average (1901-2015)	445.20	2086.99	145.59	67.62	

Source : IMD database, 1901-2015

season at the rate of 2.123 and 0.337 mm per year respectively.

4.1.3. *Rainy days and precipitation extreme events*

The average rainy days (precipitation ≥ 2.5 mm/day) was 154.74 ± 21.36 with minimum of 122 days in the year 1962 and highest of 234 days in the year 1998. The trend analysis showed a significant ($p < 0.05$, $Z > 1.96$) increasing trend (0.232 days/year) during the whole period of 1901-2015.

4.1.4. *Excess, normal and deficit precipitation*

The whole period (1901-2015) was divided into four sub periods (1901-1930; 1931-1960; 1961-90 and 1991-2015) of 30 years duration (except the last period is of 25 years duration). Normal, excess and deficit precipitation was calculated for both sub-period average (SPA) and long period average (LPA) basis for the whole period. On an average 14 years experienced excess precipitation, 11 years received deficit precipitation while 90 years received normal precipitation as per LPA basis for the

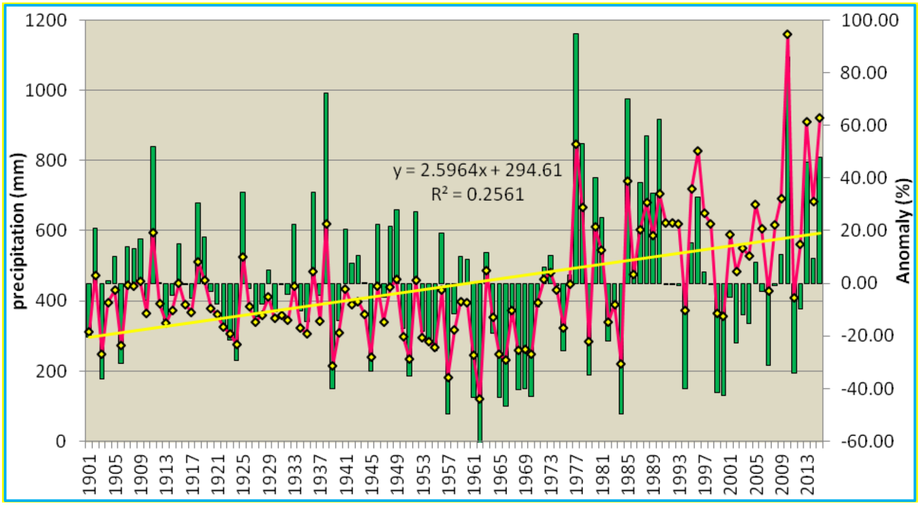

Fig. 3. Pre-monsoon precipitation, anomaly from sub-period analysis, with linear trend (1901-2015) in West district of Sikkim

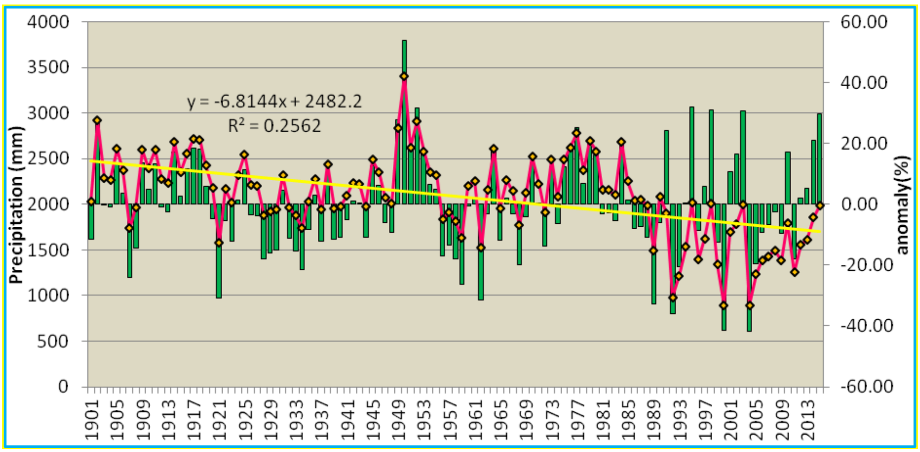

Fig. 4. Monsoon precipitation, anomaly from sub-period analysis, with linear trend (1901-2015) in West district of Sikkim

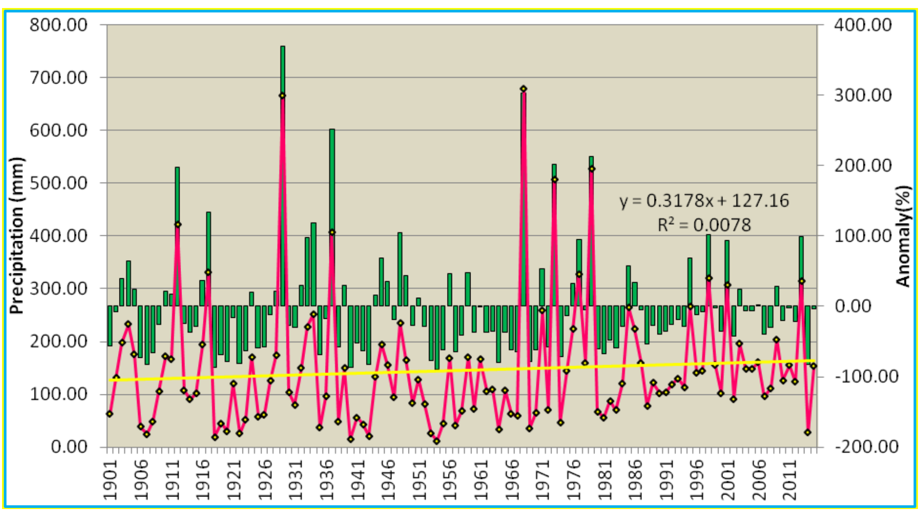

Fig. 5. Post-monsoon precipitation, anomaly from sub-period analysis, with linear trend (1901-2015) in West district of Sikkim

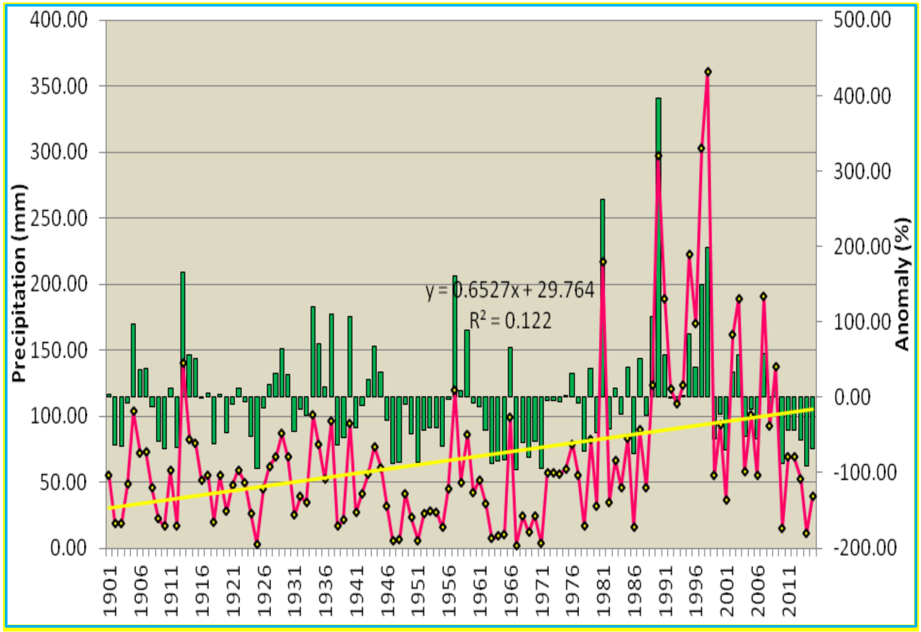

Fig. 6. Winter precipitation, anomaly from sub-period analysis, with linear trend in West district of Sikkim. [*Note* : For figures 3-6 : Green bars shows anomaly from sub-period analysis, red line with yellow markers represents actual seasonal precipitation and the yellow line indicates linear trend line]

whole period. On the other hand, when calculated sub period average, 14 years experienced excess precipitation, 9 years received deficit precipitation while 92 years received normal precipitation. It is found that, fluctuation in annual precipitation was highest in the last sub-period with respect to sub period average. The range of normal precipitation (SPA ± 19%) varied considerably (showing an oscillating pattern) during the whole period of 1901-2015.

4.1.5. *Long period average analysis of seasonal precipitation*

Monsoon months contributed 75.78% with an average variability of 11.80% to the annual precipitation (2745.39 ± 447.04 mm), whereas Pre-Monsoon, Post-Monsoon and winter months contributed 16.38%, 5.27% and 2.57% respectively. Seasonal precipitation distribution showed wide variability, especially during the winter and post monsoon (CV > 75%) periods and pre monsoon variability was also high (CV = 39.64%). The contribution of monsoon precipitation to annual precipitation showed a decreasing trend (0.156 mm per year) while pre-monsoon, post-monsoon and winter precipitation showed an increasing trend. The annual precipitation also showed a decreasing trend (-3.071 mm per year and a linear decreasing trend with r^2 of 0.065) over the period of 1901-2015.

Average monthly maximum temperature (T_{max}) was found to be at highest in the month of August (26.69 °C) and the lowest monthly minimum temperature (T_{min}) was recorded in the month of February (3.88 °C) while average mean monthly temperature (T_{mean}) was 20.66 °C during the period of 1901-2014 in West district of Sikkim. Mann-Kendall test exhibited a significant ($p < 0.05$ and $Z > 1.96$) increasing trend of average monthly maximum, minimum and mean temperature in all the months (0.019-0.043 °C/month). Average annual mean temperature (20.66° ± 1.08 °C) increased significantly ($p < 0.05$ and $Z > 1.96$) at the rate of 0.027 °C per year for the whole period 1901-2014.

4.1.6. *Sub-period average (SPA) analysis of seasonal precipitation*

Sub-period average (SPA) analysis of pre-monsoon precipitation was estimated at 391.19 mm, 360.41 mm, 435.42 mm and 623.48 mm for the periods of 1901-1930, 1931-60, 1961-90 and 1991-2015 respectively (Table 3), while long-period average was 445.2 mm with an linear increasing trend ($r^2 = 0.256$) over the whole period (1901-2015). In the past 115 years (1901-2015) highest pre-Monsoon precipitation of 1159.9 mm was received during 2010, while lowest precipitation of 122 mm received in the year of 1962 with high variability of 38.49%. The anomaly for pre monsoon from SPAs also showed high

TABLE 4

Seasonal anomaly (1901-2015) from respective seasonal sub-period analysis of precipitation in West district of Sikkim

Precipitation	Anomaly in precipitation (%)			
	Pre-monsoon	Monsoon	Post-monsoon	Winter
Minimum	-71.98	-41.69	-89.87	-95.99
Maximum	94.62	54.02	368.78	396.71
SD	30.13	16.68	80.40	76.49

Source : IMD database, 1901-2015

TABLE 5

Long period analysis of seasonal and annual mean temperature in West district of Sikkim

Temperature (°C)	Pre-monsoon (March-May)	Monsoon (June-September)	Post-monsoon (October-December)	Winter (January-February)	Annual Temperature (°C)
Minimum	18.52	23.37	18.57	11.44	18.73
Maximum	24.17	26.17	22.71	16.92	22.35
Mean	21.72	24.65	20.49	14.38	20.66
SD	1.42	0.81	1.08	1.43	1.08
CV(%)	6.53	3.27	5.28	9.96	5.22
P	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
Z	7.76*	9.91*	8.75*	8.19*	9.23*
Q	0.031	0.021	0.026	0.032	0.027

Source : IMD database. Note: Q is Sen's slope; * indicates significant at ≤ 0.05)

variation with a minimum of -71.98% to a maximum of 94.62% (Table 4). Yearly anomaly from respective SPA was low during 1901-1930 while it was maximum during the last phase of 1991-2015, indicating erratic precipitation in the last period. Also, in the first three periods, the anomalies were mostly negative whereas mostly positive anomalies were recorded in the last period from respective SPAs (Fig. 3).

Sub period average for Monsoon precipitation remained almost similar during the first three periods (2289.83 mm, 2213.99 mm and 2220.01 mm in the periods of 1901-1930, 1931-60, 1961-90 respectively) while declined to 1531.15 mm in the last period of 1991-2015. The long period average was 1086.99 mm with a variation of ± 443.89 mm and showed a linear decreasing trend (r^2 = 0.256) over the whole period (1901-2015). In the past 115 years (1901-2015) highest monsoon precipitation (3409.90mm) was experienced during 1950 while lowest precipitation of 893.0 mm received in the year of 2004 and the variability (CV = 21.27%) was lowest amongst all the seasons. The anomaly of monsoon season from SPAs also showed considerable variation with a minimum of -41.69% during the year 2004 to a maximum of 54.02% in the year 1950. Yearly anomalies from respective sub period averages were observed to be much greater in the last period (1991-2015) in comparing to other periods, indicating erratic and fluctuating Monsoon precipitation in the last period (Fig. 4).

During post Monsoon season, the long period average was 145.59 mm ± 120.33 mm with a very high variability (82.65% of LPA) for the whole period of 1901-2015 (Table 2). Post Monsoon precipitation showed an increasing linear trend (r^2 = 0.007) at the rate of 0.337 mm per year. The sub period average were estimated at 142.05 mm, 115.51 mm, 168.39 mm and 158.56 mm for the periods of 1901-30, 1931-60, 1961-90 and 1991-2015 respectively. Highest precipitation 679.10 mm was received in the year 1968 and lowest precipitation was received during the year (11.70 mm) 1954. Yearly anomalies were mostly negative throughout the whole period from respective sub period averages and some years showed very high positive anomalies (Fig. 5).

During Winter season, the observed long period average was 67.42 mm ± 62.40 mm with highest variability (92.28% of long period average) for the whole period of 1901-2015 amongst other seasons. Trend of winter precipitation showed an increasing pattern (r^2 = 0.122) at the rate of 2.123 mm per year. The sub period average were estimated at 52.12 mm for the period 1901-30 and then decreased to 46.70 mm in the next period of 1931-60, then increased in the two successive periods as 63.01 mm and 119.98 mm in the periods of 1961-90 and 1991-2015 respectively. Highest winter precipitation 361.30 mm was received in the year 1998 and lowest precipitation was received during the year (2.40 mm) 1967. Winter anomalies were very high throughout the whole period with highest anomaly of 396.71% and lowest anomaly was -95.99% as compared to other seasons (Fig. 6).

4.2. *Long period analysis of annual and seasonal Mean Temperature (Tmean) of West Sikkim*

Average monthly maximum temperature (T_{max}) was highest in the month of August (26.69 °C) and lowest monthly minimum temperature (T_{min}) was recorded in the month of February (3.88 °C), while average mean monthly temperature (T_{mean}) was 20.66 °C during the period of 1901-2014. Mann Kendall test exhibited a significant ($p < 0.05$ and $Z > 1.96$) increasing trend of average monthly maximum, minimum and mean temperature in all the months (0.019-0.043 °C/month). Average annual mean temperature (20.66 ± 1.08 °C) increased significantly ($p < 0.05$ and $Z > 1.96$) at the rate of 0.027 °C per year for the whole period 1901-2014.

Seasonal mean temperature was highest during Monsoon (24.65 ± 0.81 °C) with lowest variability (CV = 3.27%), while it was lowest in the winter months (14.38 ± 1.43°C) with highest variability (CV = 9.96%) for the period 1901-2014 (Table 5). Mann-Kendall test confirmed a significant ($p < 0.05$ and $Z > 1.96$) increasing trend of mean temperature during all the seasons (20.021 to 0.032 °C per year). Increase of mean temperature was higher during the Monsoon and pre Monsoon seasons, while relatively low in the Winter and post Monsoon seasons.

5. Conclusions

It may be concluded that, the overall climate of West Sikkim is becoming warmer and drier during the whole period of analysis. Rate of change of mean annual temperature is 0.027 °C per year for the period of 1901-2014. Conversely, a declining trend in precipitation was observed during the Monsoon, which in turn resulted in less annual precipitation in West Sikkim as revealed by Sen’s slope estimator. Quite the opposite, Winter, pre-Monsoon and post-Monsoon precipitations have increased a little. However, persistent increase in temperature was observed in all the seasons and this change was more notably observed since 1950s. In a nutshell, Monsoon has become warmer and drier, while other seasons have become warmer and wetter during past 100 years. However, proper planning and policy need to be executed by the respective authorities to combat with the changeability of climatic situation in the district as well as in the state.

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