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Climatic variability of Eastern Himalayan Indian state, Sikkim during last Century

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ABSTRACT
In this present study, trend analysis of temperature and rainfall were performedfor Sikkim state at district level during last century(1901-2002). For trend analysis, MK Test was employed. The long term trend analysis showed that during early half of last century all the districts exhibited a significantly increasing trend on yearly scale.However the latter half of century remained trendless. An increasing trend was found in min temperature for most of the seasons and at yearly scales. Rainfall mostlyremains trendless with an exception of Monsoon season during 1901-51, where an increasing trend was observed.The increasing trend of temperature can disturb the fragile ecosystem that exists in Sikkim. Results of this study can be employed in research of water resources development and management plan in the Sikkim state.
Key words: Rainfall, Temperature, Trend analysis, Eastern Himalaya, MK Test

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INTRODUCTION

Climate change is the most discussed subject in the recent times. Wider impact of the global climate changes on the existing eco-cultural landscape has been observed due to anomalies in climatic parameters at the global level since 20th century. The fourth and fifth assessment reports of the IPCC reported that the global mean surface temperature had increased by 0.74°C (33.3°F) and 0.80°C(33.5°F), respectively [3]. Change in climate over the India by southwest monsoon causes drastic change in hydrological parameters such as precipitation, evaporation and stream flow, which leads to serious implication of drought and floods in different regions and cause damage to overall economy of the country [10]. The Alpine environment has been under-represented in the global climatic prediction because of restricted accessibility, remoteness and scarcity of the instrumental climatic data. It is notable that alpine environments inherit diverse environmental settings and mostly prone to diverse impacts of climate change. Due to existence of large population in the forefeet of the Himalaya, climatic studies in different part of this mountain have been pivotal. Countries with poor economy are more prone to climate change with grave affect on billions of people so more studies are required to be done. The available limited climatic studies show warming trends at diverse rate, have extensively focused on the western and central Himalayas [6].
Detection of trends in long-term series of climatic data is of paramount importance and is of practical significance [10, 4]. Studies of change are also of importance because of our need to understand the impact thatman is having on the 'natural' world [12].
Sikkim, a part of the Eastern Himalaya, is effected by tri-junction of climatic systems mostly by SW monsoon and receive limited rain from the Mediterranean westerly, and north east monsoon, gives a best location to get aware about the complex responses of the climatic variations. There are few studies conducted to understand the climatic variations at different scale on Sikkim. Archisman *et al.,* [1] investigated the trend of temperature in recent past and in future time periods over the Gurudongmar area, North Sikkim. They found an increasing trend of temperature during winter season. Patle *et al.,* [9] analyzed trends in major climatic parameters and sensitivity of evapotranspiration to climatic

parameters of Sikkim. They found a increasing trend of minimum temperature and mean temperature during1985–2013. Kumar *et al.,* [7] conducted a study on Gangtok and Tadong weather observatories in Sikkim to understand long-term trends in the temperature and precipitation during 1961–2017. They reported an accelerated warming with an increase in the probability of extreme events of temperatures (minimum, maximum, average) at the higher end. Precipitation was found to be more variable across the observed period and suggested no trend in both stations. In India, district administration plays an important role in managing natural resources. Information on climatic parameters of the area at the local scale is of utmost important for the planning and development [6]. Keeping in view, the present study is conducted to understand the trend of seasonal and annual precipitation and temperature of Sikkim during last century (1901-2002)at district scale.

Study Area

Sikkim (27º04'46" to 28º07'48" North latitudes and 88º00'58" to 88º55'25" East longitudes) is part of north-eastern India and lies in the western flank of eastern Himalaya (Figure 1). This hilly state of India is surrounded by Tibetan Plateau in the North, Chumbi Valley of Tibet and the kingdom of Bhutan in the east, West Bengal in the south and the kingdom of Nepal in the west with elevations ranging from 300 to 8583 m above means sea level. The total geographical area of Sikkim is 7096 Km^2. The major river system of Sikkim areTeesta and Rangeet Rivers which flow throughout the state. The mean annual temperature of Sikkim is 18˚C and mean annual rainfall is about 2552 mm. The Sikkim Himalaya is a part of the biodiversity hotspot. Agriculture and tourism are main economic activities of most of the rural population. About 100 glaciers around this region play significant role in water resources of Sikkim. Administratively, Sikkim state is divided in four districts viz. east, west, north and south Sikkim.

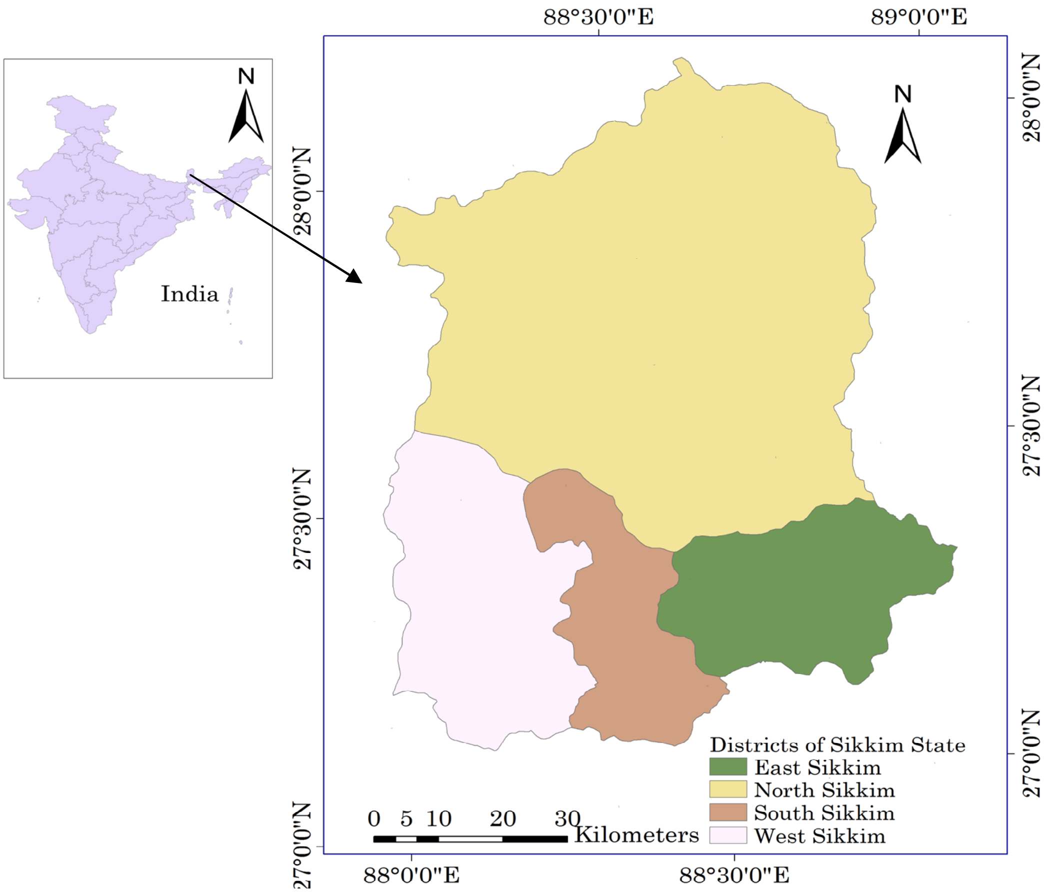

Figure 1: Study area map

MATERIAL AND METHODS

To study the temporal changes in climate of the Sikkim state,trend analysis of rainfall (annual and seasonal) and minimum and maximum temperature (annual and seasonal) were considered. Daily precipitation and temperature data were obtained for 102 years (1901–2002) from website of India Water Portal (www.indiawaterportal.org). For better understanding, the study was divided into two time frames ie: 1901-1951 and 1952-2002.For seasonal analysis, the water year (i.e., 1 June to 31 May) was classified into three seasons, each of 4 months' duration. Season 1 corresponds to the monsoon season (June to September); season 2 corresponds to the winter season (October to January), and season 3 corresponds to the summer season (February to May).

The Mann-Kendall Test

The Mann-kendall trend test is a rank correlated test between the rank of observation and there time order. This method has been widely used to test for randomness against trend detection in a time series in climatology and hydrology [5, 8]. This test is found to be an excellent tool for trend detection by other researchers in similar application [2, 10].

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} a_{ij} \qquad \text{Eq. (1)}$$

Where,

$$a_{ij} = \operatorname{sgn}(x_j - x_i) = \begin{Bmatrix} 1 x_j < x_i \\ 0 \quad x_j = x_i \\ 1 \quad x_j > x_i \end{Bmatrix} \qquad \text{Eq. (2)}$$

and$R_i$andR_j are the ranks of observations x_i and x_j of the time series, respectively.

It has been documented that when n ≥10, the statistic S is approximately normally distributed with the mean zero and a variance is

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \qquad \text{Eq. (3)}$$

Where n is the number of data points, m is the number of tied groups (a tied group is a set of sample data having the same value), and $t_i$is the number of data points in the i^{th} group. A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend.

The standardized test statistic Z is computed as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} \text{ if } S > 0 \\ 0 \text{ if } S = 0 \\ \frac{S+1}{\sqrt{VAR\,(S)}} \text{ if } S < 0 \end{cases} \qquad \text{Eq. (4)}$$

The null hypothesis, H0, meaning that no significant trend is present, is accepted if the test statistic Z is not statistically significant, i.e. $-Z_{\alpha/2} < Z < Z_{\alpha/2}$, where $Z_{\alpha/2}$ is the standard normal deviate. This study is conducted at 1% and 5% significance levels.

RESULTS

Trend of Max Temperature

The seasonal maximum temperature of 4 stations (i.e. east, north, south, west Sikkim) was analyzed for a period 1901 to 1951, 1952 to 2002 and from 1901 to 2002. MK z value and significant level of trends are presented in Table 1 to 3.

Table: 1 – **Trend of Max Temperature during 1901-1951**

	Season 1		Season2		Season3		Yearly	
	zmk	sig	zmk	sig	zmk	sig	zmk	sig
east sikkim	1.388898	0	1.301308	0	2.017568	1	2.910031	1
north sikkim	0.932135	0	1.251089	0	2.09597	1	2.526292	1
south sikkim	0.666021	0	1.257322	0	1.87478	0	3.531704	1
west sikkim	0.739121	0	1.283093	0	1.861996	0	3.041725	1

Table: 2, **Trend of Max Temperature during 1952-2002**

	Season1		Season2		Season3		Yearly	
	zmk	sig	zmk	sig	zmk	sig	zmk	sig
east sikkim	1.868109	0	1.088376	0	-1.80313	0	0.228942	0
north sikkim	1.884353	0	1.185843	0	-2.34468	-1	0.178689	0
south sikkim	2.570888	1	1.007154	0	-2.01431	-1	0.119229	0
west sikkim	2.242363	1	1.072132	0	-2.01431	-1	0.133617	0

Table: 3,**Trend of Max Temperature during1901-2002**

	Season1		Season 2		Season 3		Yearly	
	zmk	sig	zmk	sig	zmk	sig	zmk	sig
east sikkim	1.51634	0	3.793466	1	3.924968	1	5.91749	1
north sikkim	1.14296	0	3.579505	1	3.094442	1	4.785484	1
south sikkim	1.631006	0	3.761661	1	3.433303	1	6.044651	1
west sikkim	1.639171	0	3.787683	1	3.427452	1	5.317355	1

During 1901 to 1951, the monsoon season (season 1) and winter season (season 2)were found trendless in nature. However in summer season (season 3), east and north Sikkim districts exhibited a significantly increasing trend. However, on the yearly scale,all district exhibited an increasing trend during 1901-1951.Similarly, during 1952 to 2002, no significant trend was observed in monsoon season in part of east and north Sikkim, whereas increasing trends were observed in part of south and west Sikkim. However no trend was observed in winter season in this period. In the same time period east Sikkim does not show any trend in maximum temperature whereas decreasing trend has been observed in north south and west Sikkim. When the analysis was done for the year 1901 to 2002 monsoon season does not show any trend for all the district whereas increasing trend of winter, summer and annual maximum temperature has been observed.

Trend of Min temperature

Table 4, **Trend of Min Temperature during1901-1951**

	Season 1		Season 2		Season 3		Yearly	
	zmk	sig	zmk	sig	zmk	sig	zmk	sig
east sikkim	2.264483	1	1.868109	0	2.996629	1	2.652101	1
north sikkim	2.011774	1	1.945881	0	3.092404	1	2.655649	1
south sikkim	2.341337	1	1.754398	0	2.978863	1	2.493888	1
west sikkim	2.320555	1	1.697542	0	2.99117	1	2.500349	1

Table 5, **Trend of Min Temperature during1952-2002**

	Season 1		Season 2		Season 3		Yearly	
	zmk	sig	zmk	sig	zmk	sig	zmk	sig
east sikkim	2.24173	1	7.350775	1	2.557456	1	6.336279	1
north sikkim	2.234783	1	3.608567	1	2.176944	1	5.578584	1
south sikkim	2.160508	1	3.08644	1	2.530921	1	3.626585	1
west sikkim	2.006186	1	3.029585	1	2.434242	1	3.634443	1

Table 6, **Trend of Min Temperature during1901-2002**

	Season 1		Season 2		Season 3		Yearly	
	zmk	sig	zmk	sig	zmk	sig	zmk	sig
east sikkim	1.084033	0	4.3179	1	7.978208	1	6.336279	1
north sikkim	0.900211	0	3.655323	1	8.72982	1	5.578584	1
south sikkim	0.947979	0	3.782227	1	7.455041	1	3.626585	1
west sikkim	0.992844	0	3.823365	1	7.619453	1	3.634443	1

The seasonal minimum temperature of 4 stations (i.e. east, north, south, west Sikkim) was analyzed for a period 1901 to 1951, 1952 to 2002 and from 1901 to 2002. The MK z value and significant level of trends are presented in Table 4 to 6.

For the period 1901 to 1951 the monsoon season (season 1) and summer season (season 3) exhibited increasing significant trend. However in summer season (season 3) no station showed any trend however yearly max temperature was found to be significant increasing trend in this period. Similarly, for the year 1952 to 2002 significant increasing trend was observed in monsoon, winter, summer as well as annual season. When the analysis was done for the year 1901 to 2002 monsoon season did not show any trend whereas winter, summer and annual minimum temperature showed increasing trend for all the stations.

Trend of Rainfall

Table 7, **Trend of rainfall during 1901-1951**

	Season 1		Season 2		Season 3		Yearly	
	zmk	sig	zmk	sig	zmk	sig	zmk	sig
east sikkim	1.249036	0	2.615352	1	-0.97467	0	1.461998	0
north sikkim	3.029594	1	0.893443	0	-1.59404	0	6.245056	1
south sikkim	2.9893	1	1.283309	0	-1.36908	0	2.674407	1
west sikkim	3.07771	1	1.267065	0	-1.4369	0	2.703471	1

Table 8, **Trend of rainfall during 1952-2002**

	Season 1		Season 2		Season 3		Yearly	
	zmk	sig	zmk	sig	zmk	sig	zmk	sig
east sikkim	0.078632	0	1.335704	0	1.348287	0	0.471088	0
north sikkim	-0.79598	0	1.234576	0	2.729063	1	0.406111	0
south sikkim	-0.4652	0	1.627498	0	2.599108	1	0.032853	0
west sikkim	-0.52812	0	1.553663	0	2.517885	1	0.03314	0

Table 9, **Trend of rainfall during 1901-2002**

	Season 1		Season 2		Season 3		Yearly	
	zmk	sig	zmk	sig	zmk	sig	zmk	sig
east sikkim	-2.14253	-1	3.541003	1	0.283353	0	-0.24574	0
north sikkim	-2.74044	-1	-0.34696	0	0.086741	0	-1.79338	0
south sikkim	-1.54325	0	0.323832	0	0.12722	0	-1.17277	0
west sikkim	-1.50093	0	0.25444	0	0.086741	0	-1.15552	0

The seasonal and annual rainfall of 4 stations (i.e. east, north, south, west Sikkim) were also analyzed for a period 1901 to 1951, 1952 to 2002 and from 1901 to 2002. Lag 1 serial correlation coefficient, the MK z value and significant level of trends is presented in Table 7 to 9.

For the period 1901 to 1951 the monsoon season (season 1) east Sikkim did not show any significant trend whereas north, south and west Sikkim showed the significant increasing trend. For the winter season only east Sikkim showed increasing trend whereas other station did not show any trends. In summer season no any station showed any significant trend. Annual rainfall of north, south and west showed significant increasing trend however, no any trend was observed in east Sikkim.

For the period 1952 to 2002 no significant trend was observed in monsoon and winter season whereas in summer season increasing trend of rainfall has been observed in north, south and west Sikkim. In east Sikkim no any trend has been observed. In annual (yearly) rainfall no station showed any significant trend. Analysis for the period of has also been conducted and come with conclusion that monsoon season of east and north Sikkim showed decreasing trend whereas south and west Sikkim does not showed any trend. In winter season only east Sikkim showed significant increasing trend. Summer and yearly season for all the station showed no trend of rainfall.

CONCLUSIONS

The following conclusions can be drawn from the study:

1. The seasonal max temperature during early half of last century (1901-51) remains significantly trendless. However during the same time period, all the districts exhibited a significantly increasing trend on yearly scale.
2. During later half of last century (1952-2002), for max temperature, a significantly decreasing trend was found in North, South and West Sikkim districts during winter season. However, the annual max temperature remained trendless.
3. An increasing trend was observed for max temperature for all districts of Sikkim during 1901-2002 at various seasonal and at yearly scales.
4. An increasing trend was found in min temperature for most of the seasons and at yearly scales during 1901-51, 1952-2002 and 1901-2002.
5. During 1901-51, an increasing trend was observed in Monsoon season in North, South and West districts.

6 The rainfall almost remained trendless during 1952-2002 and 1901-2002.

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