Analysis of Trend of Spatial and Temporal Characteristics of Temperature: A Case Study of Teesta-Dikchu Watershed, Sikkim

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Abstract

The glacial and monsoon dependent flow of the river Teesta in Sikkim makes the flow very climate sensitive. The trend analysis of the temperature of the watershed becomes essential to keep a record of the any behavioural change in temperature and its impact on the flow of the Teesta river. The study analyses the trend in mean monthly temperature and mean seasonal temperature using Mann-Kendall test, Sen's slope estimation and Pettitt's test for the period 1985-2015 for Gangtok and Tadong and Pettitt's test from 2005 to 2015 for Majitar and Mangan. The trends of temporal and spatial characteristics of temperature along the watershed show much variation. Gangtok and Tadong, the eastern district of Sikkim shows a rise in temperature while the temperature in Sikkim's northern region has fallen.

Introduction

Weather elements such as rainfall and temperature hold a direct relation to the hydrological regime of any watershed. Understanding the trend of spatial and temporal behaviour of rainfall and temperature therefore becomes essential for purposes of water resource use and management. The burden of the anthropogenic activities on water resources, caused by unplanned urbanization along lakes, rivers and water bodies, now results into the drying up of water bodies and block the recharging of ground water. Further seasonal variation in the volume of spring water available is another crisis frequently reported owing to climate change led weather variability, including erratic, untimely, and unpredictable rainfalls and temperature variations (Rai 2014).

As it is understood, the contribution of the climatic parameters is significant to the health of a watershed and its vulnerabilities to climate change, there is a need to understand the catchment flow regime of the Teesta- Dikchu watershed in relation to the trend of the weather elements in the catchment. The Dikchu River originates from the glaciers, while the volume of the discharge is hugely contributed by rainfall. The study will essentially analyse the climatic pattern of the watershed. Using data for thirty years, the work consists of developing a trend analysis of temperature of the watershed area.

Weather elements and its relation to Hydrology

Climatic parameters which regulate the water cycle have a direct relation to the hydrological regime of any watershed. Hydrologic models applied to understand the hydrologic cycle in various watersheds provide an understanding of the influence of the weather elements on the watershed hydrology. In Upper Colorado River Basin, Haw River Watershed in North Carolina, and Boise and Spokane River Basins show that an increase in temperature leads to an increase in the average annual evapotranspiration and an increasing snowmelt corresponding to changes in the magnitude and timing of annual peak flows (Chattopadhyay and Edwards 2015). The Dhuliel catchment in north-east Jordan shows a high unpredictability of temporal and spatial rainfall, flash floods, absence of base flow, and high rates of evapotranspiration (Abushandi 2011). Modelling the Upper Mississippi River Basin, through the SWAT hydrological model, revealed the impact of climate change on temperature, precipitation, and CO_2 levels. Furthermore, the river hydrology is particularly prone to imminent climate change, causing greater episodes of both flooding and drought (Jha 2004). The analysis of mean annual temperature and precipitation 225 meteorological observations over Turkey reveals spatial distribution of mean annual precipitation and temperature and shows a positive correlation of the weather elements to discharge (Bostan and Akyürek 2009).

Trends in Air Temperature

As the Himalayan climate and water atlas key messages indicates, temperatures across the mountainous Hindu Kush Himalayan region are likely to increase by about 1–2°C (in places by up to 4–5°C) by 2050 (ICIMOD 2013). The analysis of the spatial trends and patterns of temperature in sub-regions around the Himalayan region therefore becomes important. Addisu et al, (2015) calculated a time series trend of temperature and precipitation in Lake Tana Sub-basin in Ethiopia, and concluded that the mean, maximum, and minimum temperature showed an increasing trend. This was confirmed by CSAG (2012)'s seasonal Mann-Kendall trend analysis in the Ethiopian region, Dire Dawa, Belg and Kiremit for 1953–1999, which found cooling of Dire Dawa and significant warming at Belg and Kiremit temperatures over the same period. An increase in the temperature in Eastern China by 1.52°C over the last 100 years, Sweden's increasing temperature trend for 1959–2008, and the increasing temperature trend in Florida is affirmed by Chattopadhyay and Edwards' (2015) study. The analysis of historical (1971–2005) and future episodes (2011–2099) of temperature trends in the inner catchment of Sutlej river basin in India shows a fluctuating trend of increase and decrease in temperature (Singh et.al 2015). Jain et.al (2013) studied the rainfall and temperature trends in northeast India by using the Mann-Kendal analysis technique. From this, they understood that the temperature data for all the four temperature variables (maximum, minimum, and mean temperatures and temperature range) showcased a rising trend.

These studies indicate that there is a huge regional variability of temperature in different time and a need for the analysis of the spatial and temporal trends and behavioural pattern of different weather parameters.

Objective

The study will analyse the climatic pattern of the Teesta-Dikchu watershed In Sikkim, using data for thirty years (1985-2015), this work will consist of developing a trend analysis of temperature of the watershed area. The main objective of this study is therefore, to evaluate trends in air temperature for the state of the Teesta-Dikchu Watershed, Sikkim.

Study Area

The study area is a sub-catchment of the river Teesta river basin in the Indian state of Sikkim. The Teesta is the main rivers in Sikkim and originates from the glaciers of in North Sikkim at an elevation of about 5,280 m. The present work is in the Teesta-Dikchu watershed (name given for the present study).. The Teesta- Dikchu watershed has an total area of 4657 Sq. km and is located 88°13'E, 28°12N' to 88°51' E to 27°20'N.

Fig.1: Teesta-Dikchu Watershed

Data Base and Methodology

The present study required a set of secondary data on land use and weather. Table 1.1 details the meteorological Database -Daily values for maximum and minimum temperature used in the study. Data of daily temperature of the catchment were collected for 30 years from a number of stations of the India Meteorology Department Sikkim, namely Mazitar, Tadong, Gangtok, and Mangan.

Table 1.1: Temperature data from different stations

Station Name	Parameter	Period from	Period to
Gangtok	Daily Maximum & Minimum Temperature	01.01.1985	31.12.2015
Tadong		01.01.1985	31.12.2015
Mangan		01.01.2005	31.12.2015
Magitar		01.01.2005	31.12.2015

Methodology

Statistical test for trend analysis

A trend analysis of a time series data consists of the magnitude of a trend and its statistical significance. In general, the magnitude of a trend in a time series is determined by either using regression analysis (parametric test) or by using Sen's estimator method (non-parametric test) (Sen, 1968). In addition, a change point in the time series climatic data can be determined with the Pettitt's test. This study uses both trend analysis methods; it uses non-parametric (Mann-Kendall and Sen's Slope) and the change point detection Pettitt's test method on temperature (minimum and maximum) records from weather stations of the Teesta Dikchu watershed for the period ranging from 1985-2015 for the Gangtok and Tadong stations, and a ten year period Pettitt's test for Mangan, Chungthang and Majitar stations due to the unavailability of long term data for these stations. Pettitt's test is used for these stations because Mann-Kendall's test can only be applied to a long-term time series data of about 30 years. The study analyses the temperature trend on a monthly, seasonal and annual timescale.

Findings

Climate and Rainfall

Sikkim's great elevation range from 260m to 7700m in less than 100 km causes abrupt changes in climatic conditions. Orographic lift, and its interaction with the monsoonal climate, results in major difference in rainfall and temperature profiles across the Teesta river basin in Sikkim. The month of April marks the onset of summer and the monsoon with a rise in temperature accompanied by hails and thunderstorms. "The rainfall in Sikkim, decreases with elevation after a certain limit. Rainfall at Chungthang (1,600 m) is 2,650 mm and at Lachen situated at a distance of only about 20 km north of Chungthang is 1,680 mm, whereas Thangu (3,800 m), located about 20 km further north receives only 840 mm of rain annually" (CISMHE,DU 2006). Thus, through the different altitudinal gradient of the basin the southern and middle valleys are hot, humid and wet, and the north relatively drier and colder. Four distinct seasons can be observed in Sikkim with winter from mid-November to mid-April, spring from mid-April to mid-June, the monsoon from mid-June to mid-September, and the autumn from mid-September to mid-November (CISMHE, DU 2006). The section that follow provides a trend analysis of the spatial and temporal variation of the temperature maximum and minimum of the Gangtok and Tadong for the past thirty years in the Teesta Dikchu Watershed.

Trend of Maximum, Minimum Temperature at Gangtok

Mann–Kendall's Temperature trend analysis (monthly, seasonal and annual)

A trend analysis using the Mann–Kendall method and Sen slope estimator was applied for Teesta Dikchu watershed using monthly, average annual, and seasonal (pre-monsoon, monsoon, post-monsoon and winter) temperature data. A positive *z*-statistic value indicates an increasing trend in temperature, while a negative *z*-statistic value indicates a decreasing trend in temperature.

Table 1.2: Trends of maximum temperature in Gangtok 1985-2015

Place	Month	SEN Slope	z statistics	Significance	Trend at 95%
Gangtok	Jan	.035	1.25	A	no trend
	Feb	.073	1.62	non-significant	no trend
	Mar	.054	2.30	non-significant	Positive
	Apr	-.014	-.61	non-significant	no trend
	May	.011	.70	non-significant	no trend
	June	0.000	-.16	non-significant	no trend
	July	.019	1.72	non-significant	no trend
	Aug	-.006	-.56	non-significant	Negative
	Sept	.025	1.59	non-significant	no trend
	Oct	.019	1.07	significant	no trend
	Nov	.008	.30	non-significant	no trend

	Dec	.018	.77	non-significant	no trend
	Pre Monsoon	0.044	0.8	non-significant	no trend
	Monsoon	.014	1.23	non-significant	Negative
	Post Monsoon	.013	1.38	non-significant	no trend
	Winter	.067	1.14	significant	no trend
	Annual	.044	1.37	significant	Negative

While the Z-statistics of the maximum temperature of Gangtok from 1985-2015 show an increasing trend with all seasons and nine months of the year showing a positive value, including the winter months of December, January and February. Only the months of April, June and August show a negative value, indicating a drop of temperature in these months. Sen's slope shows the magnitude of change in any given time series data. A decreasing trend with the Sen's slope magnitude of -.014 and -.006 is observed in the months of April and August, while all other months show an increasing trend with highest magnitude of .073 in the month of February and .067 magnitude in winters of 1985-2015.

Table 1.3: Trends of minimum temperature in Gangtok 1985-2015

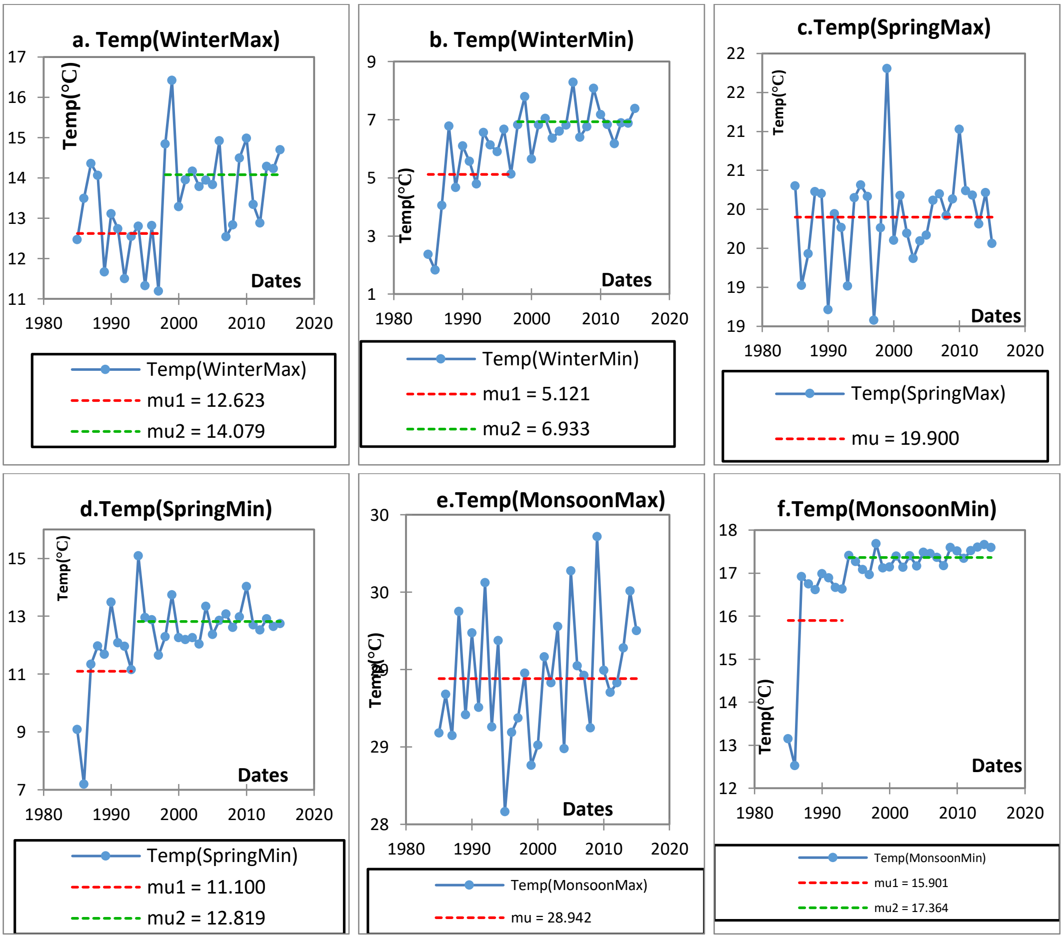
Place	month	SEN Slope	z statistics	Significance	Trend at 95%
Gangtok	Jan	.092	1.28	significant	no trend
	Feb	.133	3.14	non-significant	Positive
	Mar	.078	2.92	non-significant	Positive
	Apr	.075	.99	significant	no trend
	May	.050	2.47	non-significant	Positive
	June	.038	1.86	significant	no trend
	July	.035	1.28	significant	no trend
	Aug	.040	.79	significant	no trend
	Sept	.036	1.03	significant	no trend
	Oct	.054	.77	significant	no trend
	Nov	.067	1.14	significant	no trend
	Dec	.060	1.60	significant	no trend
	Pre Monsoon	.087	.88	significant	no trend
	Monsoon	.050	1.14	significant	no trend
	Post Monsoon	.036	2.08	significant	Positive
	Winter	.059	.90	significant	no trend
	Annual	.217	.32	significant	no trend

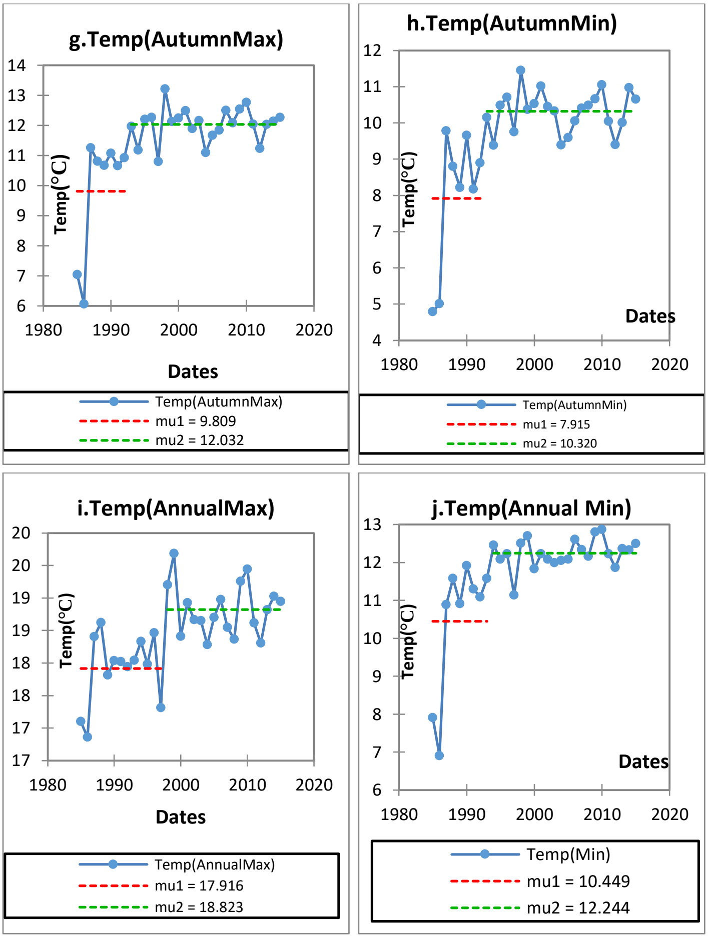
While the Z-statistics of the minimum temperature of Gangtok from 1985-2015 show an increasing trend with all seasons and twelve months of the year showing positive values, including all the winter months of December, January and February. The Sen's slope describes the magnitude of change in minimum time series data of Gangtok and indicates no decreasing trend with all the Sen's slope magnitude of observing positive values in all the months and seasons of the years. All other months show an increasing trend with highest magnitude of .133 in the month of February and .087 magnitude in winters of 1985-2015.

Pettitt's Temperature trend analysis (seasonal and annual) test Gangtok

Pettitt's test, as discussed earlier, indicates the change point in any time series data. The following analysis is derived from a test performed in the four different seasons in the Teesta Dikchu watershed.

Fig 2: Seasonal and annual temperature trend analysis of Gangtok





The winter maximum 12.623 degrees and minimum 5.121 degrees show a similar trend with a lower average observed till the year 1998 when the change occurs and a rise of an avarage of 14.079 degrees maximum and 6.933 degrees minimum is observed. The Spring Temperature does not show a very significant change over the years, except for the year 2000 with a high point of 22 deegrees, while the avarage temperature remains 19.9 degrees throughout 1985-2015. The minimum spring temperature shows a rise after 1995 with a rise from 11.1 degrees to 12.819 degrees after 1995.

The Annual avarage maximum temperature shows a rise in temperature from 17.916 to 18.823 degrees with the change occuring during 1998. The minimum avarage temperature also rises from 10.449 to 12.244 degrees with the change occuring in 1995.The maximum temperature during the monsoon, though fluctuating, has remained the same with an average of 28.942 degrees, with no change point, while the minimum temperature shows a rise from 1988 from 15.901 degrees to 17.364 degrees. The autumn maximum average temperature rises after 1988 from 9.809 to about 12.032. Similarly, the minimum average temperature rises from

7.915 to 10.320 degrees. The temperature patterns in Gangtok shows a rising trend with an average annual increase of a maximum rise of 1 degree, while the minimum annual temperature has raised by about 2 degrees. The winter maximum and minimum temperature was raised by about 2 degrees. The spring and the monsoon seasons also saw the rise in the minimum temperature of about 1 degree, while in the autumn season the temperature has been high with a rising temperature of about 2 degrees.

Trend of Maximum, Minimum Temperature at Tadong

Mann–Kendall's Temperature trend analysis (monthly, seasonal and annual)

While the Z-statistics of the maximum temperature of Tadong from 1985-2015 show a decreasing temperature trends with a negative Z-Statistics observed in the months of January -.95, June -.04, August -.11 -2,31 and -3.70 in November and December respectively, an increasing trend is observed in all seasons and other months. The Sen's slope shows the magnitude of change in Tadong's maximum temperature, which is a decreasing trend with the Sen's slope magnitude of -.030, -.050 and -.067 being observed in the winter months of January, November and December, while all other months show an increasing trend with highest magnitude of .047 in the month of March of 1985-2015.

Table 1.4: Maximum Temperature Trends at Tadong 1985-2015

Place	month	SEN Slope	z statistics	Significance	Trend at 95%
Tadong	Jan	-.030	-.95	non-significant	no trend
	Feb	.037	.88	non-significant	no trend
	Mar	.047	2.07	non-significant	Positive
	Apr	.000	.13	non-significant	no trend
	May	.018	.99	non-significant	no trend
	June	.000	-.04	non-significant	no trend
	July	.024	1.77	non-significant	no trend
	Aug	.000	-.11	non-significant	no trend
	Sept	.033	1.64	non-significant	no trend
	Oct	.014	.86	non-significant	no trend
	Nov	-.050	-2.31	non-significant	Negative
	Dec	-.067	-3.70	non-significant	Negative
	Pre Monsoon	.000	.13	non-significant	no trend
	Monsoon	.027	1.93	non-significant	no trend
	Post Monsoon	.012	1.44	non-significant	no trend

	Winter	-.027	-1.66	non-significant	no trend
	Annual	.009	1.04	non-significant	no trend

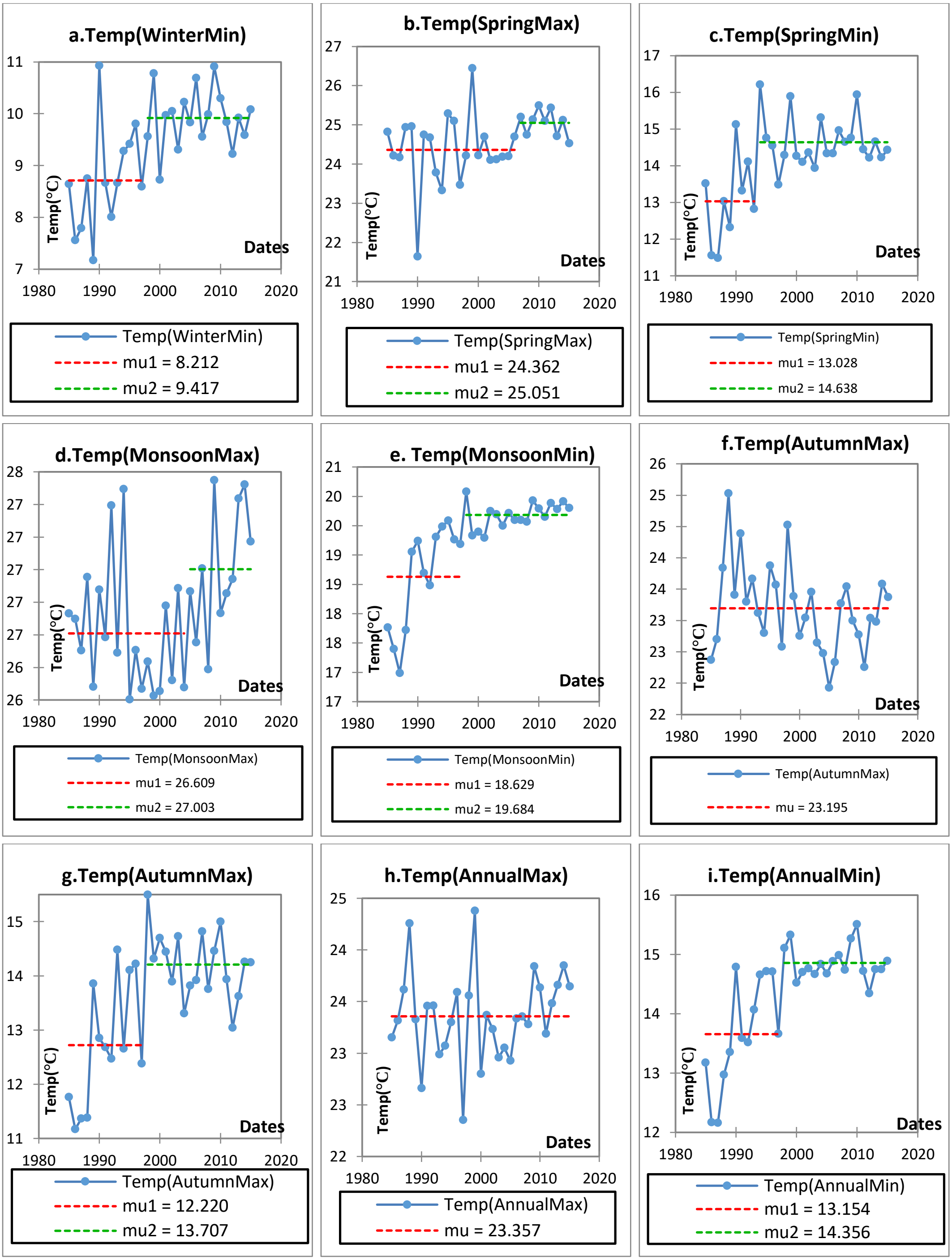
Table 1.5 Minimum Temperature Trends at Tadong 1985-2015

Place	month	SEN Slope	z statistics	Significance	Trend at 95%
Tadong	Jan	.058	2.93	non-significant	Positive
	Feb	.081	2.68	non-significant	Positive
	Mar	.057	1.93	non-significant	no trend
	Apr	.080	1.82	Significant	no trend
	May	.075	2.12	Significant	Positive
	June	.071	1.75	Significant	no trend
	July	.057	1.37	Significant	no trend
	Aug	.050	1.39	Significant	no trend
	Sept	.98	1.64	Significant	no trend
	Oct	.068	2.54	non-significant	Positive
	Nov	.082	1.33	Significant	no trend
	Dec	.074	1.63	Significant	no trend
	Pre Monsoon	.069	3.33	non-significant	Positive
	Monsoon	.057	2.04	Significant	Positive
	Post Monsoon	.046	.94	Significant	no trend
	Winter	.070	1.56	Significant	no trend
	Annual	.064	1.01	Significant	no trend

The Z-statistics of the minimum temperature of Tadong from 1985-2015 show an increasing trend with all seasons and twelve months of the year showing positive values, including all the winter months of December, January and February. The Sen's slope shows the magnitude of change in minimum time series data of Tadong, and, similar to the Z-statistics, it shows no decreasing trend with all the Sen's slope magnitude of observing positive values in all the months and seasons of the years. All other months show an increasing trend with highest magnitude of .98 in the month of September and .070 magnitude in winters of 1985-2015.

Pettitt's Temperature trend analysis (seasonal and annual) test Tadong

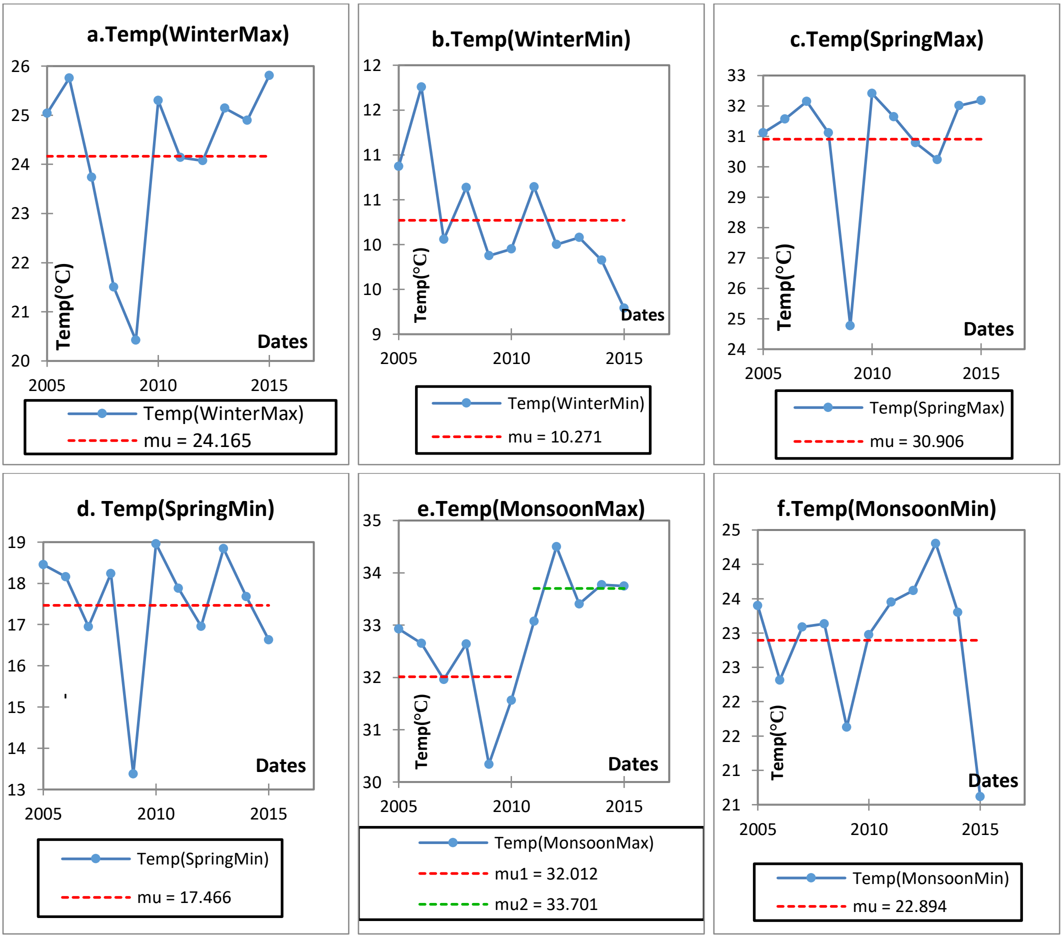
Fig 3: Seasonal and annual temperature trend analysis of Tadong.

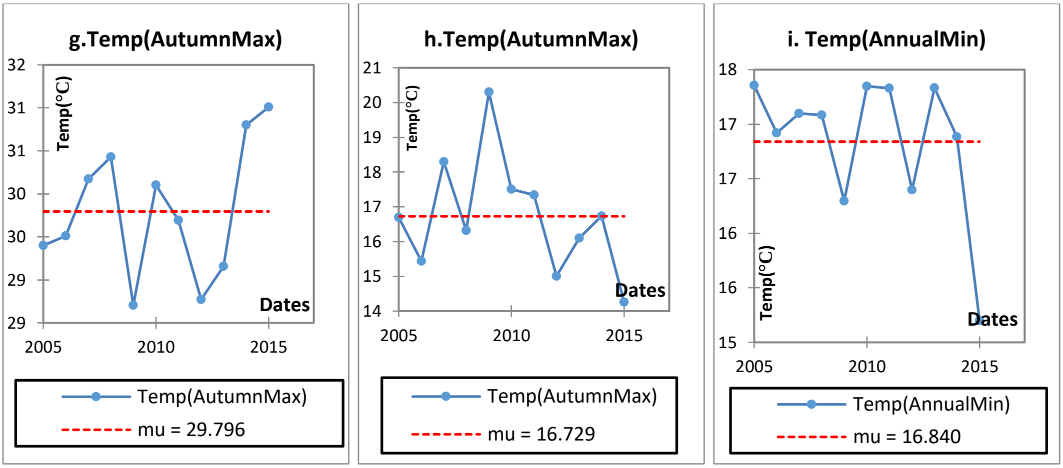


The winter average minimum temperature at Tadong station shows a change point in the year 1998 with a rise from 8.212 to 9.417 degrees, while the change in the avarage maximum temperature emerges only in 2005 with a rise from 24.362 to 25.051 degrees. The avarage spring minimum temperature shows a change point in the year 1995 with a rise from 13.02 degrees to 14.628 degrees. Simalarly, the rise in avarage maximum temperature of 26.609 degrees to 27.003 degrees is witnessed with the change point in 2004. The monsoon minimum average temperature also shows a rise from 18.629 to 19.684 degrees with the change point year being 1998, while the maximum average temperature remains 23.195. The annual avarage maximum temperature remains 23.357 degrees, while the minimum changes aat1998 from 13.154 degrees to 14.356 degrees. The trend in the maximum and minimum temperature pattern in the Tadong area has been rising with an annual minimum temperature rise of about 1 degree. Rise in minimum temperature of about 1 degree is seen in all seasons, while the maximum temperature also rise by 1 degree in winter and spring season.

Pettitt's Temperature trend analysis (seasonal and annual) test Magitar

Fig 4: Seasonal and annual temperature trend analysis of Magitar.

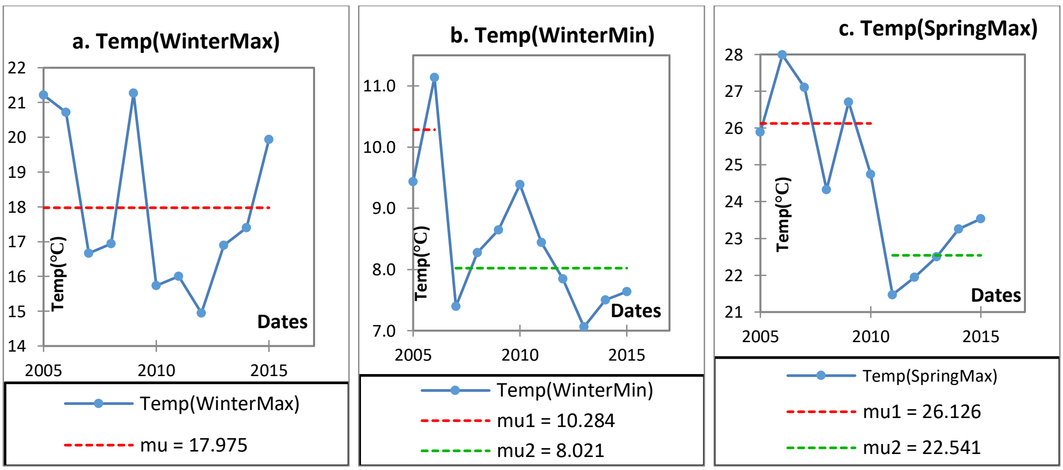


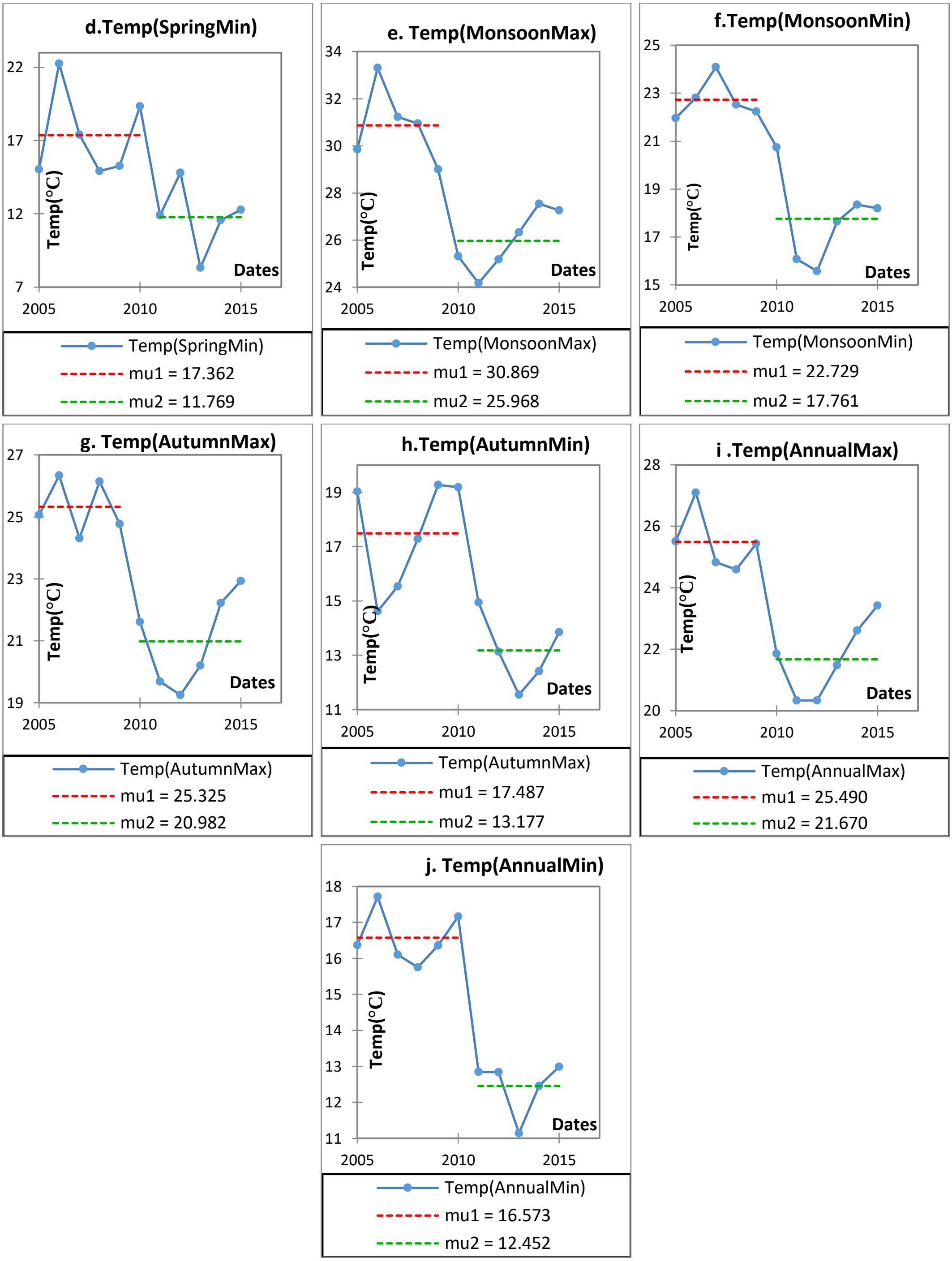


The maximum minimum winter temperature is 24.165 degrees and 10.271 degrees and 30.906 and 17.466 degrees in spring. The monsoon shows a change point in 2010 with the rise from 33.701 to 32.012 degrees. The minimum average remains 22.894 degrees. The autumn and annual maximum and minimum show no change with the annual maximum remaining 29.412 and the minimum 16.40 degrees. The maximum minimum winter temperature is 24.165 degrees and 10.271 degrees and 30.906 and 17.466 degrees in spring. The monsoon shows a change point in 2010 with rise from 33.701 to 32.012 degrees. While the minimum average remains 22.894 degrees.

Pettitt's Temperature trend analysis (seasonal and annual) test at Mangan

Fig 5: Seasonal and annual temperature trend analysis of Mangan.





The maximum and minimum temperatures of the Magitar is fluctuating and does not reveal a rising or a falling trend, except for the monsoon maximum temperature in Magitar in which there was a 1 degree rise in temperature. In Mangan a constant overall fall of about 4 degree is observed in all the months with both maximum and minimum temperature falling from an average 25.5 to 21.7 degrees maximum temperature to a decrease of 16.6 to 12.5 degrees minimum temperature.

Conclusion

The behavioral pattern of monthly, seasonal and annual series of temperature data of Mazitar, Tadong, Gangtok, and Mangan stations of the Teesta Dikchu Watershed were analyzed using two techniques, which were a non-parametric Mann-Kendall test together with Sen's Slope Estimator and Z statistics and Pettitt's test for the data period 1985-2015 for Gangtok and Tadong. The Pettitt's test was used from 2005 to 2015 for Majitar and Mangan.

The results of the Mann-Kendall test's Z-statistics of the maximum temperature of Gangtok from 1985-2015 show an increasing trend with all seasons including the winter months of December, January and February. An increasing trend with highest magnitude of .073 in the month of February and .067 in winters of 1985-2015 is recorded. Z-statistics of the minimum temperature of Gangtok from 1985-2015 also shows an increasing trend in all the seasons and months of the year while the Sen's slope series data of Gangtok also shows no decreasing trend.

While the Z-statistics of the maximum temperature of Tadong from 1985-2015 shows a decreasing temperature trends with a negative Z-Statistics observed in the months of January -.95, June -.04, August -.11 November and December -2,31 and -3.70 respectively, an increasing trend is observed in all seasons and other months. A decreasing trend of the Sen's slope magnitude of -.030, -.050 and -.067 is observed in the winter months of January, November and December, while all other months show an increasing trend with highest magnitude of .047 in the month of March of 1985-2015. Z-statistics of the minimum temperature of Tadong from 1985-2015 show an increasing trend in all seasons and twelve months with a highest magnitude of .98 in the month of September and .070 magnitude is observed in winters of 1985-2015.

The analysis of the trends of Temporal and Spatial Characteristics of temperature along the watershed by the Pettitt's test show much variation along the watershed. In the eastern district, the temperature has risen, while the temperature (maximum) in the northern part, especially the Mangan region, shows a falling trend.

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