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Research Article

Seasonal Spatio-Temporal Variability in Temperature over North Kashmir Himalayas Using Sen Slope and Mann-Kendall Test

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ABSTRACT

The present paper is an attempt to assess seasonal spatio-temporal variability of temperature in order to get an insight into nature of climate variability and its effects on various ecosystem services offered by the region. Mann-Kendall and Sen Slope statistic is a simple but a robust method of detecting trends in time series data. The rising temperature has affected the discharge pattern of the catchments. Moreover, the winter-time warming of the region leaves little scope for snow accumulation consequently, affecting the extent and distribution of snow/glacial cover. The temperature trends seem altitude dependent as is the case with eastern part of the North Kashmir Himalayas. The winter time warming has negatively affected the snow/glacier mass balance which in turn, has reduced the availability of water for rest of the seasons particularly, in the last couple of decades. The region shows some increasing trend in average temperature for all the four seasons from 1996 to 2015 against the average temperature calculated from 1977 to 1995. The highest maximum temperature has revealed an increasing trend at all the stations for almost, all the seasons.

Keywords: Himalayas; Mann-Kendall; Sen Slope; Pahalgam

INTRODUCTION

In recent times, the debate of climate change has found way into the political discourses apart from being the highly focused theme of scientific research. The increasing temperature has endangered the livelihood of many people who survive by exploiting the services offered by the Himalayan region. A large number of studies have reported a never before like warming trend of the earth's atmosphere. The Indian sub-continent is no exception to this warming of climate system. The Indian Himalayas have registered an increasing trend in the various temperature variables including the Tibetan plateau region [1-5]. Various other studies have also found evidence of warming, particularly in the last few decades, on the same pattern [2,5,6-9]. The human induced warming: on account of GHG's emissions, has been reported as the strong climate forcing scenario in the recent decades [2,4,5,10-12]. The warming trend in Himalayas has been reported widely in the scientific literature available on the topic. However, the trend shows some degree of asymmetry in its distribution and magnitude across the entire length and breadth of the region. The current rate of warming in Himalayas is unprecedented in the last century. The Himalayan and the Tibetan Plateau region registered an increasing trend in the maximum temperature from 1971-2005 at the rate of 0.5°C, annually compared to 1901 to 1960 time period [13,14]. Various studies have reported different rate of warming in Himalayas, a result obtained using time series data over different time scales. The western Himalayas have recorded a warming phase in maximum temperature up to the magnitude of 1.1°C to 2.5°C. Bhutiynai et al. while analyzing the temperature data for the previous century in western Himalayas have also reported a decadal increase of 0.16°C in their study [2]. The mountainous landscapes are characterized as fragile ecosystems owing to topography of these regions. Western Himalayas have shown a strong response to the processes involved in changes in climate system. An upward trend in the Tmax at the rate 0.9°C is reported in a study done by Dash et al. [15]. The increasing decadal trend in Tmax during winter season across different segments of Indus basin has been reported. The decadal winter time warming found during 1967 to 2005, is at a magnitude of 0.45°C for Upper Indus basin while as the middle part of the basin has shown an increase of 0.42°C. The lowest increase is found in the lower reaches of the basin [16]. In a study conducted by Fowler and Archer, using a time series data from 1961-2006 also reported a winter time warming in the upper Indus basin [17]. They registered a decadal increase of 0.07°C to 0.51°C in the mean annual temperature and an increase of 0.1°C to 0.55°C in the Tmax in the study area. An increasing trend in northwest Himalayas particularly in lower Indus basin in daily

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average maximum temperature on seasonal basis and maximum temperature is reported in a study done by Singh et al. [18]. Except monsoon season, the trend is prominent in all the other seasons. Mountainous landscapes have shown a strong response to varying climatic variables and hence act as valid indicators of indicators of climate change [19-21]. The retreat of Himalayan glaciers in the last couple of decades [22-26] and the formation of glacial lakes in the region increase the risk of disasters in the form of glacial lake outburst floods [27]. Himalayas have always been as a source of livelihoods to millions of people living both upstream and the downstream of some of the world's largest catchments. Avoiding looking into the consequences of climate change may deteriorate the natural systems beyond redemption. Spatio-temporal analysis of temperature trends is one such approach to get insight into the working of natural ecosystems and their response to climate change.

STUDY AREA

The North Kashmir River catchment region lies in the North Kashmir range which splays out from Greater Himalayas near Zoji-La Pass and takes a westerly direction. The range forms the main water divide between Kishanganga and Jhelum rivers. The location of the study area is shown in the Figure 1.

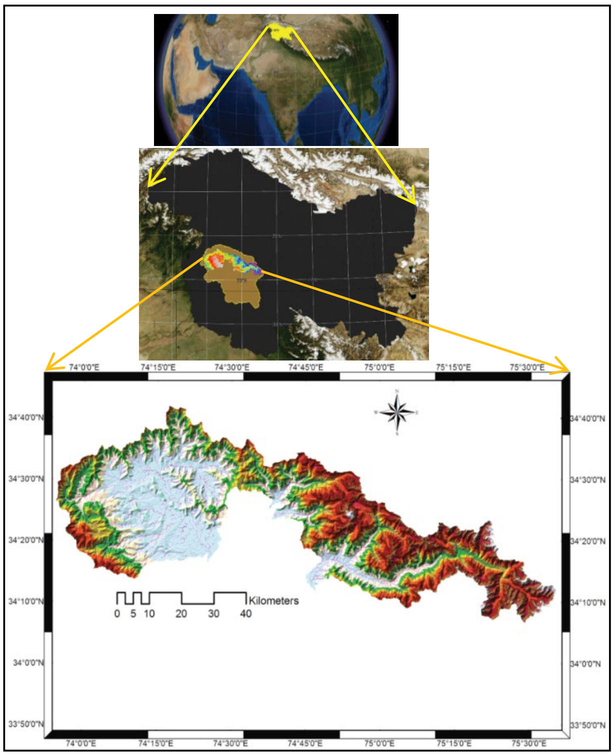

Figure 1: Location of the study area.

The maximum altitude in the range is found at the Zoji-La. Many peaks rise above the snowline creating favorable conditions for the formation of glaciers as region receives good amount of snowfall during the months of December to February. The glaciers and snowfields of the region play an important role in the Hydrology of the river system. The study area is located between 34°12'09"N to 34°41'55"N latitude and 73°54'37"E to 75°35'10"E longitude. The region is highly rugged owing to its mountainous nature. There is a general decrease of slope and altitude from east to west. The central and western catchments are rain-fed, thus, having a strong seasonal effect on the water flow. Four major tributaries of river Jhelum and Wular Lake namely Sind, Erin, Madhumati and Pohru make up the North Kashmir River catchment region. Sind and Pohru being the largest streams cut their course through high mountains and finally debouch into river Jhelum. Erin and Madhumati have, comparatively, smaller catchment size and find their way into Wular Lake. The highest point with approximately 5500 meters height above mean sea level is located in the eastern part of the study area. The lowest point with an altitude 1600 meters is found in Pohru catchment. The location of meteorological stations used in the study, are shown in the Figure 2.

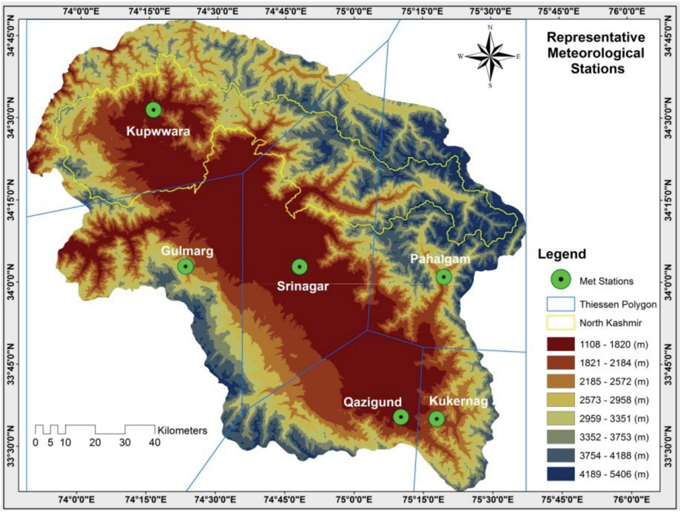

Figure 2: Distribution of meteorological stations used for the study.

MATERIALS AND METHODS

The stations are situated in the different altitudinal zones. The Kupwara station is located in Pohru catchment and covers the western part of the study area at an altitude of 1723 meters above mean sea level. It is the only station which is located within the study area. Pahalgam and Srinagar stations cover the eastern and the central part of the study area, respectively. Pahalgam station, which is situated at an altitude of 2292 meters above mean sea level, has been taken as the representative station for the eastern part of the study area. The climatic data at the Srinagar station has been further extended to represent the central part of the study area.

The meteorological data has been acquired from India Meteorological Department. The rainfall data had many gaps at the time of acquisition. Before performing any analysis, the missing data was filled using the Normal Ratio Method given as under:

$$P_x = \frac{N_x}{n}\left(\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} \ldots + \frac{P_n}{N_3}\right) \quad \text{(Equation 1)}$$

Where,

px: Missed rainfall of station x to be filled,

Nx: Average annual rainfall of station x,

p_1, p_2 p_3 and p_n and N_1, N_2, N_3 and N_n corresponding rainfall values of stations 1, 2, 3...n and annual average rainfall values of stations 1, 2, 3...n, respectively,

N: Number of stations for which rainfall data is available.

The trend analysis has been performed using non-parametric Mann-Kendall test along with Sen Slope Estimator. The Mann-Kendall test identifies only the trend but Sen Slope is a good estimator of magnitude of the trend. The statistical tests were carried out using VBA Macro 'MAKESENS' developed by Finnish Meteorological Institute, Finland.

Mann-Kendall test

The Mann-Kendall test can be viewed as a non-parametric test for zero slope of the linear regression of time-ordered data versus time as illustrated by Hollander and Wolfe. The test is applicable if the time series obeys the linear model:

$$x_i = f(t_i) + \varepsilon_i \quad \text{(Equation 2)}$$

Where f (t) is a continuous monotonic increasing or decreasing function of time and the residuals εi can be assumed to be from the same distribution with zero mean. It is therefore, assumed that the variance of the distribution is constant in time.

If n is 40 or less, the following procedure may be used. When n exceeds 40, the normal approximation test is used (Gilbert, 1987). The following procedure is applied when only one datum per time unit is taken which may be a day, week, month, and so on.

Let $Sgn\left(x_j - x_k\right)$ be an indicator function that takes on the values 1, 0 or -1 according to the sign:

$$\text{sgn}(x_j - x_k) = \begin{bmatrix} 1 & \mathit{If}\,(x_j - x_k) > 0 \\ 0 & \mathit{If}\,(x_j - x_k) = 0 \\ -1 & \mathit{If}\,(x_j - x_k) < 0 \end{bmatrix} \quad \text{(Equation 3)}$$

The Mann-Kendall statistic is computed as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k=1}^{n} \text{sgn}(x_j - x_k) \quad \text{(Equation 4)}$$

Where x_j and x_k are the annual values in years j and k, j>k, respectively.

When n is greater than 40, the normal approximation test described as under is used. Actually, Kendall (1975) proposes that this method may be used for n as small as 10 unless there are many tied groups. In order to apply normal approximation test to the time series data, the first step is to compute the variance of S which is done through the following equation:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \quad \text{(Equation 5)}$$

Here q is the number of tied groups and tp is the number of data values in the p^{th} group

The values of S and VAR(S) are used to compute the test statistic Z as follows:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} \mathit{If} & S > 0 \\ 0 \quad \mathit{If} & S = 0 \\ \dfrac{S+1}{VAR(S)} \mathit{If} & S < 0 \end{cases} \quad \text{(Equation 6)}$$

The presence of a statistically significant trend is evaluated using the Z value. A positive/negative value of Z indicates an upward/downward trend. The statistic Z has a normal distribution. To test for either an upward or downward monotonic trend (a two-tailed test) at α level of significance, H_0 is rejected if the absolute value of Z is greater than Z_1-α/2, where Z_1-α/2 is obtained from the standard normal cumulative distribution tables. The statistical testes used in the macro computes the trend at 0.001, 0.01, 0.05 and 0.1 significance levels of α.

Sen's method

Sen Slope is a non-parametric method that gives magnitude of slope (Change per unit time). It is used in cases where trend is assumed to be linear. This means that *f (t)* in equation (2) is equal to

$$f(t) = Qt + B \quad \text{(Equation 7)}$$

Where Q is the slope and B is a constant.

To get the slope estimate Q in equation (7) we first calculate the slopes of all data value pairs using the formula:

$$Q_i = \frac{x_j - x_k}{j - k} \quad \text{(Equation 8)}$$

Where x_j and x_k are data values at times (or during time periods) j and k, respectively and where j>k and N is the number of data pairs for which j>k. The median of these N values of Q is Sen's estimator of slope. If there is only one datum in each time period, then N'=n (n -1)/2, where n is the number of time periods.

If there are *n* values x_j in the time series we get as many as N=n (n-1)/2 slope estimates (Q_i). The Sen's estimator of slope is the median of these *N* values of Q_i. The *N* values of Q_i are ranked from the smallest to the largest and the Sen's estimator is:

$$Q = Q_{[(N+1)/2]} \; if \quad N \quad is \quad Odd$$

$$Q = \frac{1}{2}\left(Q_{[N/2]+Q[(N+2)/2]}\right) if \quad N \quad is \quad even \quad \text{(Equation 9)}$$

The procedure in VB macro computes the confidence interval at two different confidence levels; α=0.01 and α=0.05, resulting in two different confidence intervals. A 100 (1-α)% two-sided confidence interval about the true slope may be obtained by the non-parametric technique given by Sen (1968). The procedure given above is based on the normal distribution which is valid for n as small as 10 unless there are many ties. This procedure is a generalization of that given by Hollander and Wolfe (1973) when ties and/or multiple observations per time period are present.

At first, we compute:

$$C_\alpha = Z_{1-\alpha/2}\sqrt{VAR(S)} \quad \text{(Equation 10)}$$

Where *VAR(S)* has been defined in equation (4) and $Z_{1\text{-}\alpha/2}$ is obtained from the standard normal distribution.

Next $M_1 = (N\text{-}C_\alpha)/2$ and $M_2 = (N+C_\alpha)/2$ are computed. The lower and upper limits of the confidence interval, Q_{min} and Q_{max} are the M_1^{th} largest and the $(M_2+1)^{th}$ largest of the N ordered slope estimates Q_i. If M_1 is not a whole number, the lower limit is interpolated. Correspondingly, if M_2 is not a whole number, the upper limit is interpolated.

The spatial interpolation maps for rainfall and temperature data were prepared by running the Inverse Distance Weighting function from the Geostatistical Analyst module from ArcGIS toolbox. The Inverse Distance Weighting is simple and deterministic interpolation method based on principle that sample values closer to the prediction location have more influence on prediction value than sample values farther apart.

RESULTS AND DISCUSSION

The data collected at Pahalgam station shows an increasing trend in, almost, all the temperature parameters for all the seasons as can be seen from the Table 1. The winter highest maximum temperature reveals a positive trend with a Z value of 2.98. The trend is significant at α=0.01 which means the data has a positive linear trend at 99 % of confidence level. The annual rate of increase in the highest maximum temperature is 0.09°C. Spring and the summer seasons also show an increasing trend at 99% of confidence level. The Z value for spring and summer season, as calculated by the Mann-Kendall test, is 2.86 and 2.02, respectively. The Sen Slope test estimates an annual increase of 0.07°C for the spring season and 0.02°C for the summer season. Autumn season shows a positive trend at 99.9% confidence level and the magnitude of trend is 0.04°C, annually. Figures 3, 4, 5 and 6 shows the trend in highest maximum temperature for winter, spring, summer and autumn season, respectively. The winter and the spring mean maximum temperature shows an increasing trend at 99.9% of confidence level. The magnitude of the trend is very steep for the winter and spring season as shown in Figures 7 and 8, respectively. Sen Slope shows an increase in the mean maximum temperature by a value of 0.14°C and 0.16°C for the winter and spring season, respectively. The spring temperature shows less deviation from the estimated values. Summer mean maximum temperature shows an increasing trend but with a small magnitude of 0.06°C. Figure 9 shows a trend in mean maximum temperature for summer season. Like winter and spring season, autumn season also reveals an increasing trend with a steep slope at 90% of confidence level as shown in the Figure 10. The temperature in autumn season is showing a positive trend at an annual rate of 0.12°C.

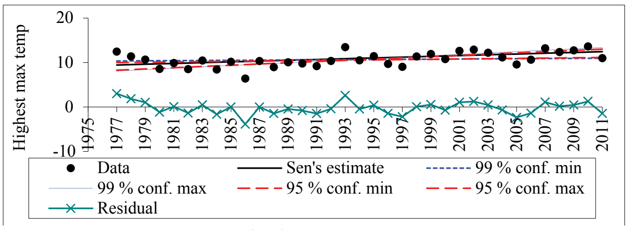

Figure 3: Winter highest maximum temperature.

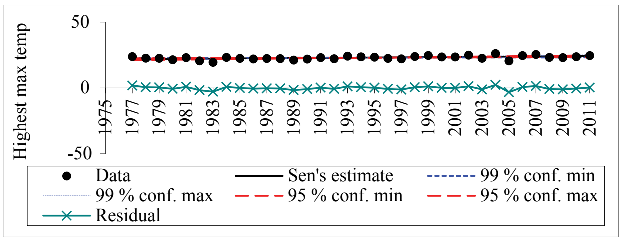

Figure 4: Spring highest maximum temperature.

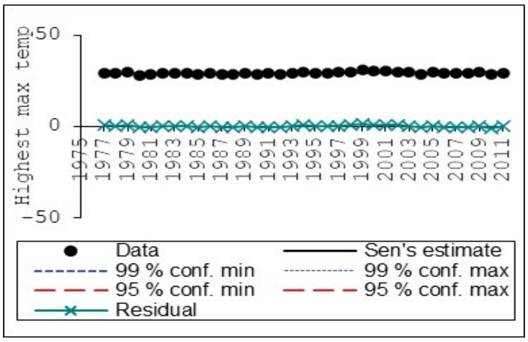

Figure 5: Summer highest maximum temperature.

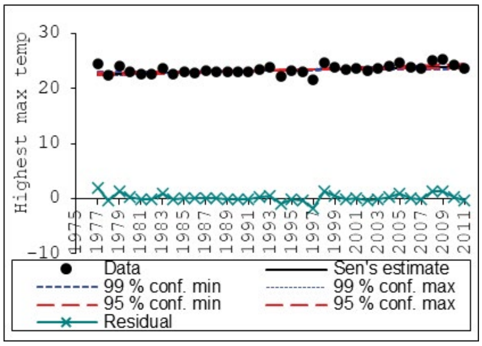

Figure 6: Autumn highest maximum temperature.

Table 1: Test statistics for Pahalgam, Srinagar and Kupwara stations.

Station	Season	Highest maximum temperature				Mean maximum temperature				Mean minimum temperature			
		Data Available	Z Value	Level of Significance	Sen Slope	Data Available	Z Value	Level of Significance	Sen Slope	Data Available	Z Value	Level of Significance	Sen Slope
Pahalgam	Winter	1977-2011	2.98	0.01	0.09	1977-2015	3.17	0.01	0.14	1977-2015	3.17	0.01	0.05
	Spring	1977-2011	2.86	0.01	0.07	1977-2015	2.65	0.01	0.16	1977-2015	1.85	0.1	0.02
	Summer	1977-2011	2.03	0.05	0.02	1977-2015	1.72	0.1	0.06	1977-2015	1.98	0.05	0.03
	Autumn	1977-2011	3.55	0.001	0.04	1977-2015	2.86	0.01	0.12	1977-2015	2.41	0.05	0.02
Srinagar	Winter	1977-2011	2.68	0.01	0.05	1977-2015	2.84	0.01	0.06	1977-2015	1.55	Nil	0.01
	Spring	1977-2011	2.29	0.05	0.05	1977-2015	1.56	Nil	0.04	1977-2015	2.25	0.01	0.02
	Summer	1977-2011	-0.58	Nil	-0.01	1977-2015	-0.85	Nil	-0.01	1977-2015	0.79	Nil	0.01
	Autumn	1977-2011	2.5	0.05	0.04	1977-2015	0.48	Nil	0.01	1977-2015	1.46	Nil	0.02
Kupwara	Winter	1977-2011	2.7	0.01	0.05	1977-2015	2.24	0.05	0.04	1977-2015	-0.45	Nil	-0.01
	Spring	1977-2011	3.41	0.001	0.08	1977-2015	2.01	0.05	0.06	1977-2015	2.85	0.01	0.03
	Summer	1977-2011	1.61	Nil	0.03	1977-2015	1.1	Nil	0.02	1977-2015	1.27	Nil	0.01
	Autumn	1977-2011	3.84	0.001	0.06	1977-2015	0.68	Nil	0.02	1977-2015	1.57	Nil	0.02

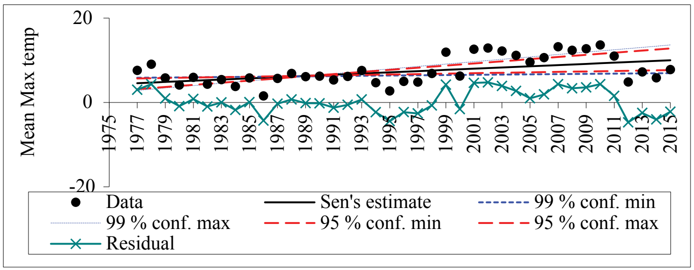

Figure 7: Winter mean maximum temperature.

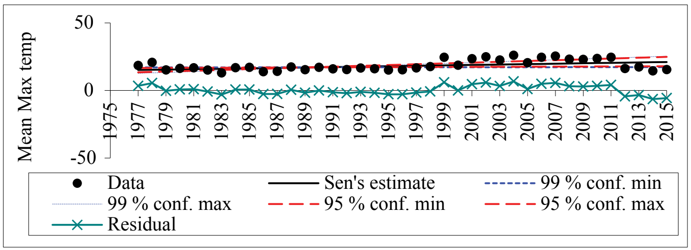

Figure 8: Spring mean maximum temperature.

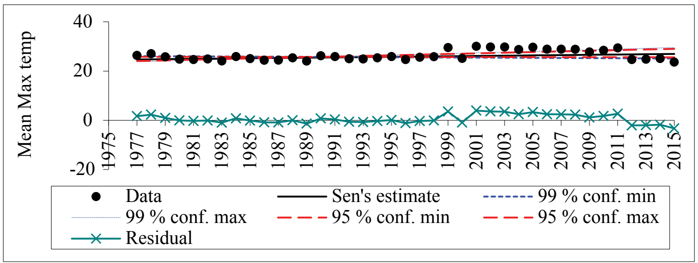

Figure 9: Summer mean maximum temperature.

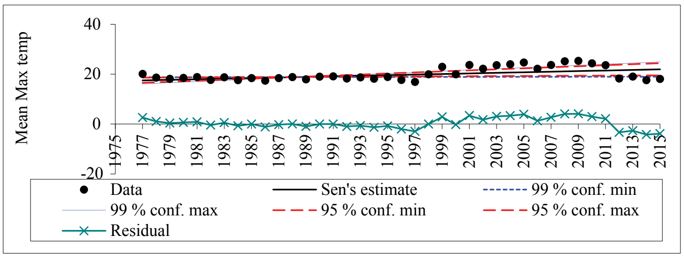

Figure 10: Autumn mean maximum temperature.

The mean minimum temperature has also shown an increasing trend for all the seasons of the year. The winter mean minimum temperature is revealing an increasing trend at 99% confidence level with a slope of 0.05 as shown in the Figure 11. The winter mean minimum temperature has increased by 0.05°C, annually.

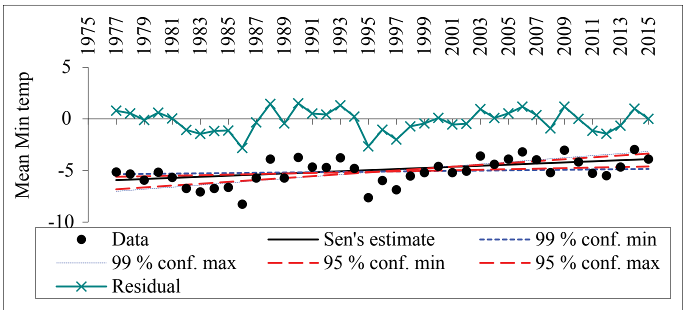

Figure 11: Winter mean minimum temperature.

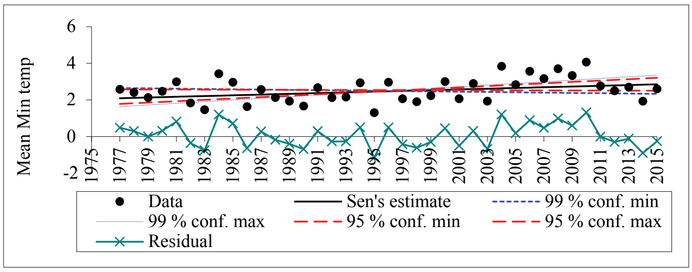

Figure 12: Spring mean minimum temperature.

Rest of the seasons also shows an increasing trend but with a lesser confidence level and magnitude of the trend is also comparatively, low. The mean minimum temperature has increased at an annual rate of 0.02°C, 0.03°C and 0.02°C for spring, summer and autumn season as shown by Figures 12, 13 and 14, respectively. Mann-Kendall test has calculated an increasing trend for the spring mean minimum temperature at 90% of confidence level. Summer and the autumn season also show a similar trend at 95% of confidence level with a small slope value. The winter mean minimum temperature data observed at Pahalgam station is showing an increasing trend with a Z value of 3.17. The trend is significant at α=0.01. There is higher degree of certainty in the trend calculated by Mann-Kendall test. The slope of the trend is steep as compared to other seasons. The data points are randomly distributed along the trend line. The narrow angle between the confidence limits also suggests an increasing trend with a higher confidence level. Spring season does follow an increasing trend but with a very gentle slope.

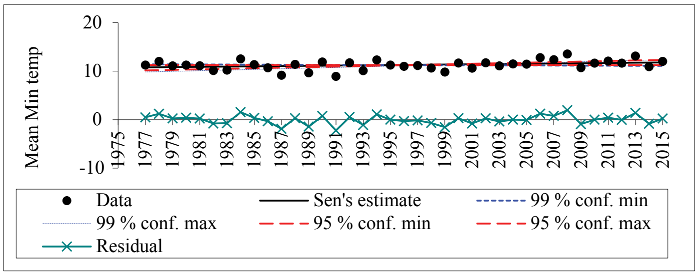

Figure 13: Summer mean minimum temperature.

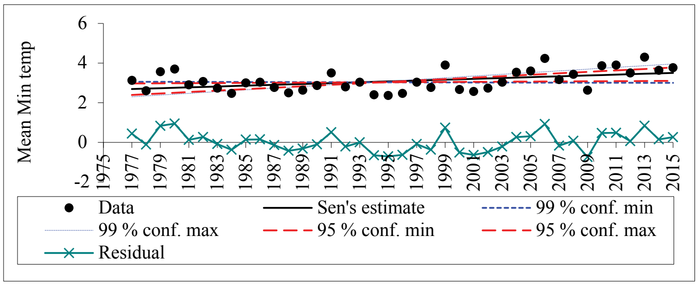

Figure 14: Autumn mean minimum temperature.

The winter highest maximum temperature has revealed an increasing trend from 1977 to 2011 as shown by the Figure 15. The data observed at the Srinagar station for winter season shows an increasing trend with a confidence level of 99%. The Figure 15 clearly shows that the absolute values of highest maximum temperature have increased during later part of the time series. The test has calculated a trend with a slope of 0.05 which means an increase of 0.05°C, annually with respect to time. The Figure 16 shows the trend in highest maximum temperature for spring season.

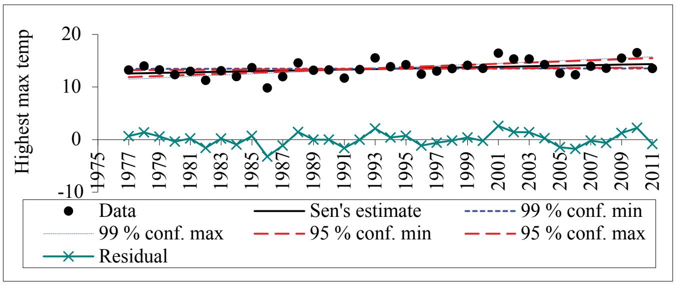

Figure 15: Winter highest maximum temperature.

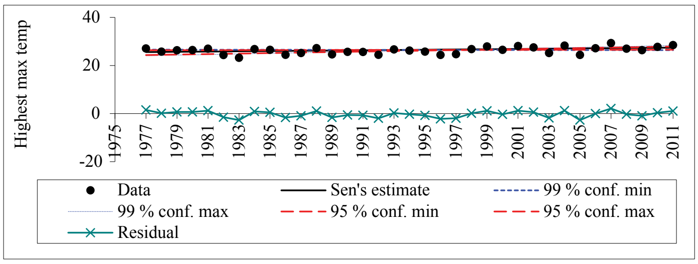

Figure 16: Spring highest maximum temperature.

Spring season also reveals an increasing monotonic trend at 95% of confidence level with a slope of 0.05. The trend is missing in summer season (Figure 17) but the autumn season shows up an increasing trend at 95% of confidence level with a slope of 0.04. Spring and autumn seasons have witnessed an increase in the highest maximum temperature at an annual rate of 0.05°C and 0.04°C as shown in the Figure 16 and 18, respectively.

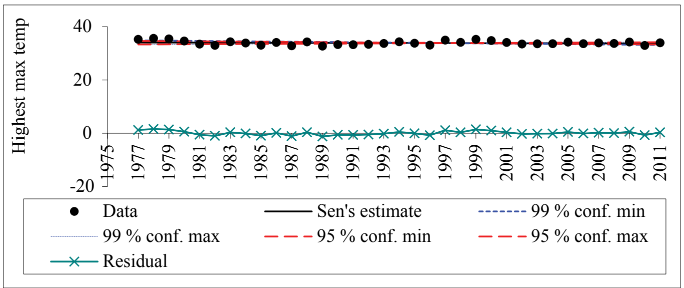

Figure 17: Summer highest maximum temperature.

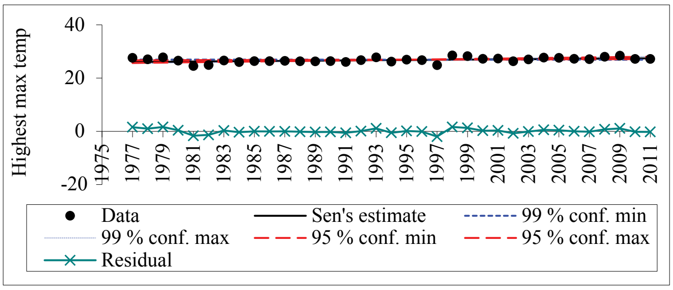

Figure 18: Autumn highest maximum temperature.

The mean maximum temperature has not varied much in Srinagar as there is no trend in data except for the winter season which shows an increasing trend at 99% confidence level. The slope of the trend is steep given the slope values of other seasons. The mean maximum temperature at Srinagar station has increased by a magnitude of 0.06°C annually from 1977 to 2015 for the winter season.

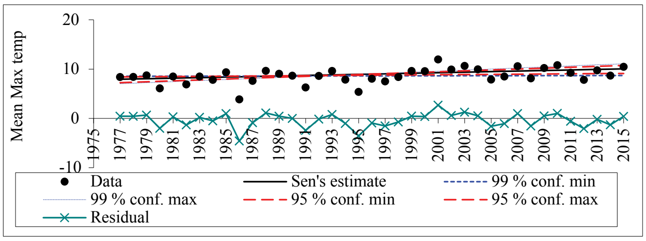

Figure 19: Winter mean maximum temperature.

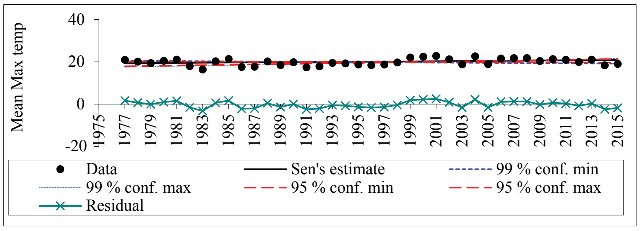

Figure 20: Spring mean maximum temperature.

The winter season shows, comparatively, much randomness in data distribution as can be seen from the Figure 19. Figures 20, 21 and 22 shows trend in the mean maximum temperature for spring, summer and autumn season, respectively.

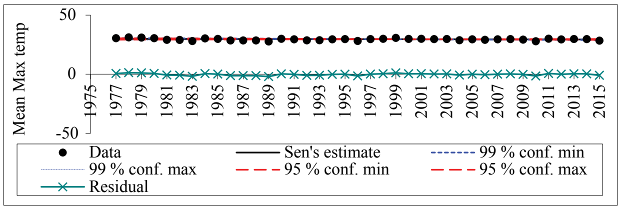

Figure 21: Summer mean maximum temperature.

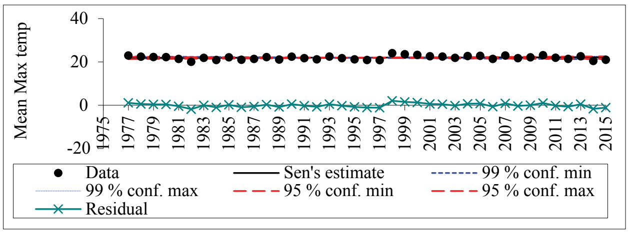

Figure 22: Autumn mean maximum temperature.

The data points fall close to or on the trend line for all the three seasons indicating a less randomness. The Sen Slope test has calculated a positive trend for spring and autumn season and a negative trend for summer season but the trend is not significant at any statistical level of confidence.

Figures 23 and 24 shows trend in the mean minimum temperature for winter and spring season, respectively. The spring mean minimum temperature shows an increasing trend with a Z statistic of 2.25 which means the trend is significant at 99% level of confidence but the magnitude of trend is very gentle with a slope value of only 0.02.

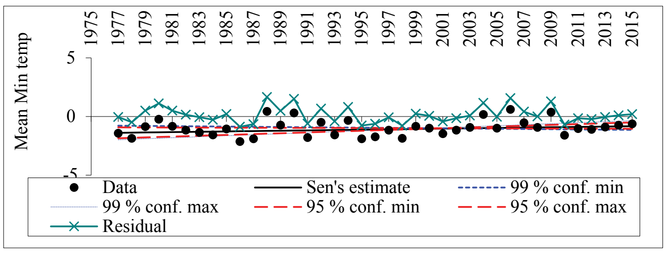

Figure 23: Winter mean minimum temperature.

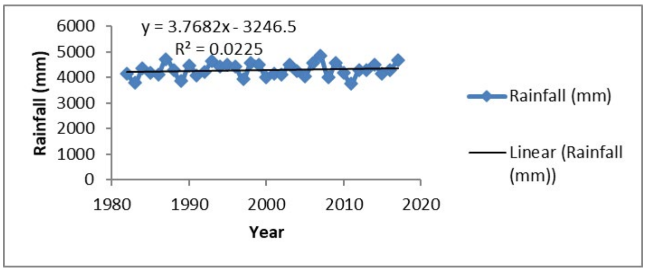

Figure 24: Spring mean minimum temperature.

The summer mean minimum temperature does not follow any trend, at all (Figure 25). Though, winter, summer and autumn seasons reveal a trend but it is statistically insignificant. The winter mean minimum temperature shows much randomness as compared to other seasons which is clear from the Figure 23 but the trend is missing at any statistical level of significance.

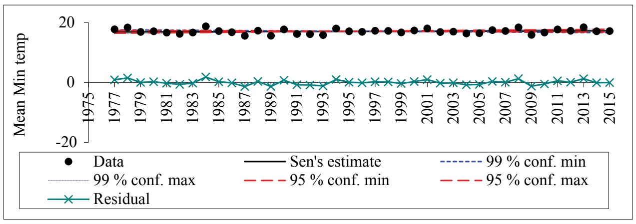

Figure 25: Summer mean minimum temperature.

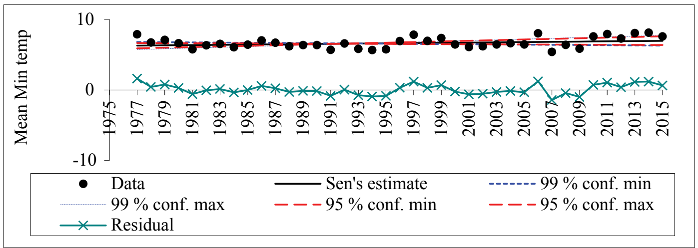

Figure 26: Autumn mean minimum temperature.

The statistics calculated from the Mann-Kendall and Sen Slope is given in the Table 1 for Kupwara station. The highest maximum temperature in the winter season is showing an increasing trend with a Z value of 2.70 and slope value of 0.05. The temperature is increasing at 0.05°C, annually. The trend is increasing at 99% level of significance. The narrow angle between the confidence limits at 95% and 99% also confirms the fact that the trend is increasing at the statistical level of significance (Figure 27).

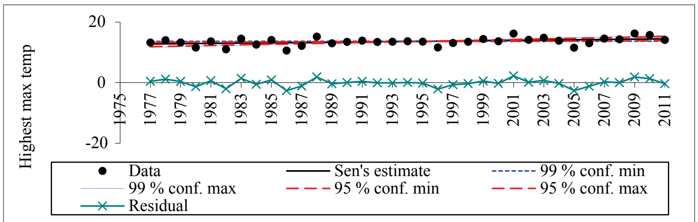

Figure 27: Winter highest maximum temperature.

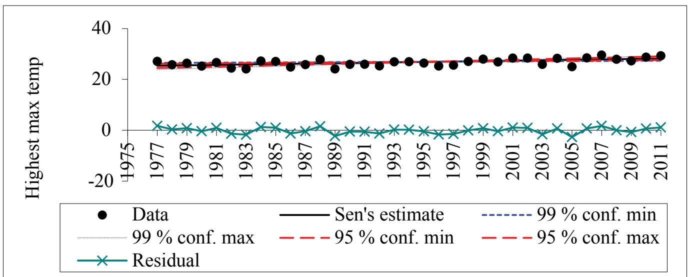

Figure 28: Spring highest maximum temperature.

The spring season indicates an increasing trend in the highest maximum temperature at the Kupwara station from 1977 to 2011 (Figure 28). The trend is positive at α=0.001. The statistical tests have calculated an increasing trend at the 99.9 % of confidence level. The temperature has been increasing from 1977 to 2011 with an annual rate of 0.08°C for the spring season.

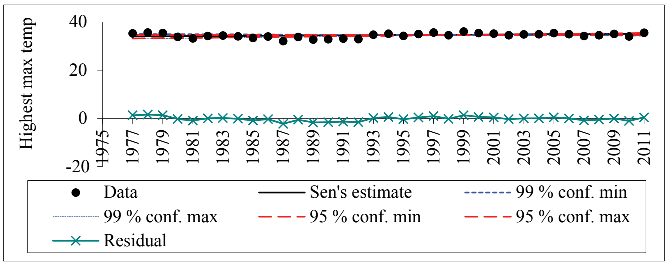

Figure 29: Summer highest maximum temperature.

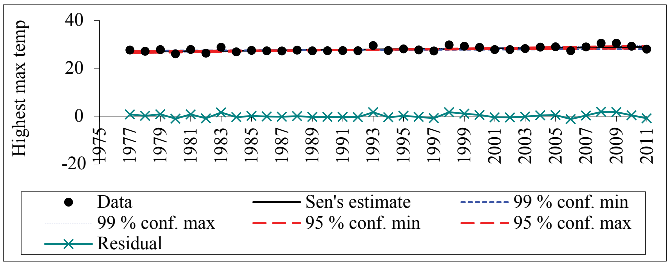

Figure 30: Autumn highest maximum temperature.

Though, the summer highest maximum temperature shows an increasing trend but it is not statistically significant (Figure 29). The Z value is 1.61 which is very close to the normal distribution value of 1.64 at 90% confidence level. The autumn season also shows an increasing trend with a Z value of 3.84. The trend is significant at α=0.001. The temperature has increased by a magnitude of 0.06°C, annually as shown in the Table 1 and Figure 30.

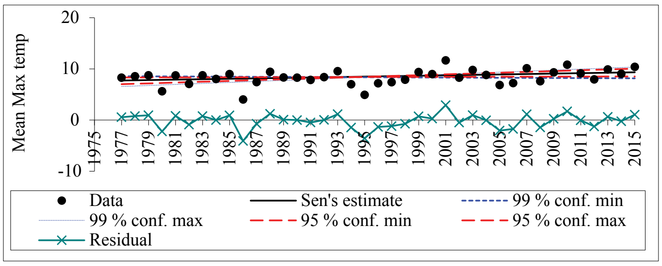

Figure 31: Winter mean maximum temperature.

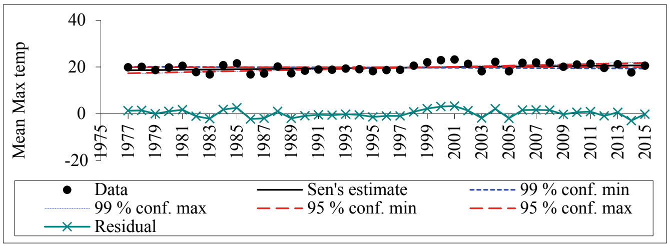

Figure 32: Spring mean maximum temperature.

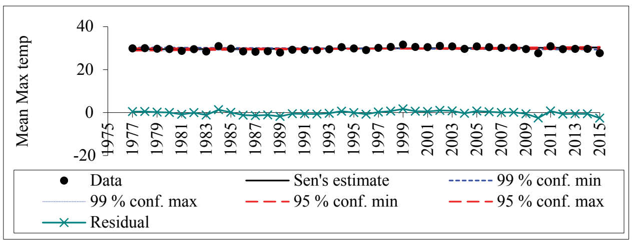

Figure 33: Summer mean maximum temperature.

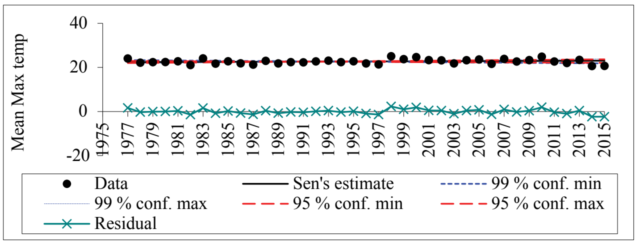

Figure 34: Autumn mean maximum temperature.

The winter mean maximum temperature is showing an increasing trend at the 95% level of confidence. The absolute Z value is 2.24 which clearly signify an increasing trend at α=0.05. Most of the data points fall within or close to the confidence limits which means there are no outlier values in the time series (Figure 31). The slope value for this trend is 0.05 which means an annual increase of 0.05°C in the mean maximum temperature from 1977 to 2015. Similarly, the spring mean maximum temperature indicates an upward trend with a Z value of 2.01 at α=0.05 (Figure 32). Though, Sen Slope estimates a slight positive trend in the mean maximum temperature for summer and autumn season as shown in the Figure 33 and 34, respectively, but the is not significant at any statistical level of significance as shown in the Table 1. The winter mean minimum temperature does show a downward trend with the Z value of -0.45 but the trend is statistically insignificant. The slope line runs almost parallel to the abscissa with a slope value of -0.01 (Figure 35).

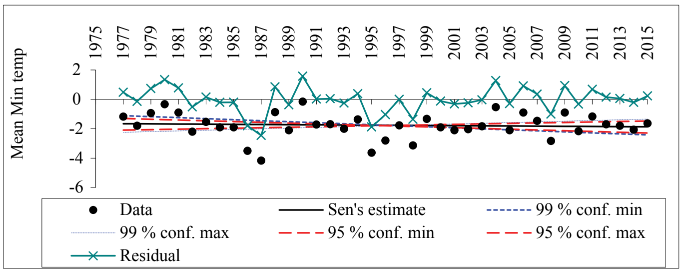

Figure 35: Winter mean minimum temperature.

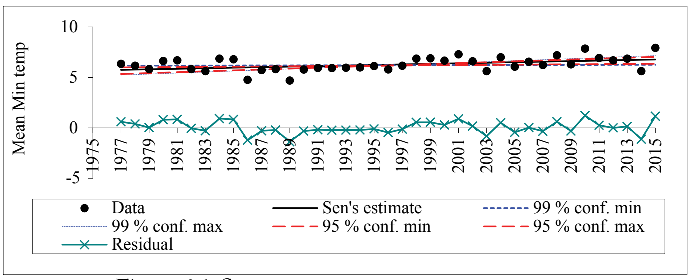

Figure 36: Spring mean minimum temperature.

Spring season shows a significant increasing trend (Figure 36) with a Z value of 2.85 which is significant at α=0.01 which means the trend is true at the 99% of confidence level.

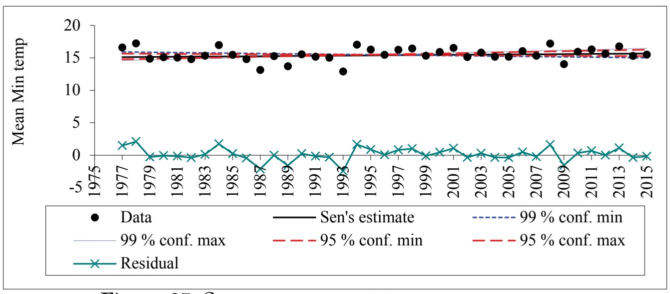

Figure 37: Summer mean minimum temperature.

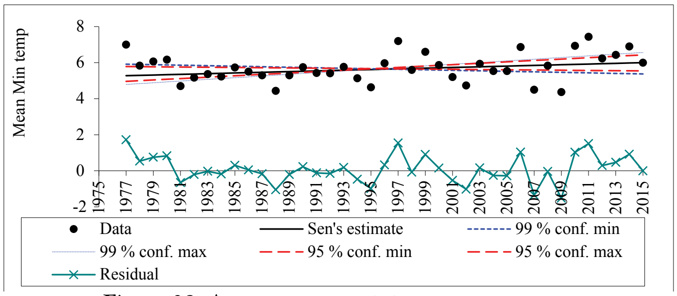

Figure 38: Autumn mean minimum temperature.

There is small increment of 0.03°C annually in the mean minimum temperature in spring season. Though, the summer and the autumn season reveals some slight increasing trend, however, the trend is insignificant as suggested by the Z value shown in the Table 1 and Figures 37 and 38, respectively.

Spatial distribution of temperature in North Kashmir river catchment region

The distribution of average winter temperature shows some spatial trend. The study area has experienced a change in the spatial distribution of average winter temperature. The highest average winter temperature estimated in the study area is 3°C from 1977 to 1995. The higher reaches of Pohru catchment have experienced the highest average winter temperature from 1977 to 1995. The extreme eastern part has recorded the lowest temperature as interpolated by the tool. The temperature shows an increasing spatial trend from the east to west (Figure 39). The average value of winter temperature has increased from 1996 to 2015. Though, the lower reaches of Pohru catchment should experience higher temperature than the upper reaches but this incongruity arises due to the fact that Gulmarg station, which has been used to interpolate the temperature distribution in this area, is a high-altitude station that experiences very low average annual temperature.

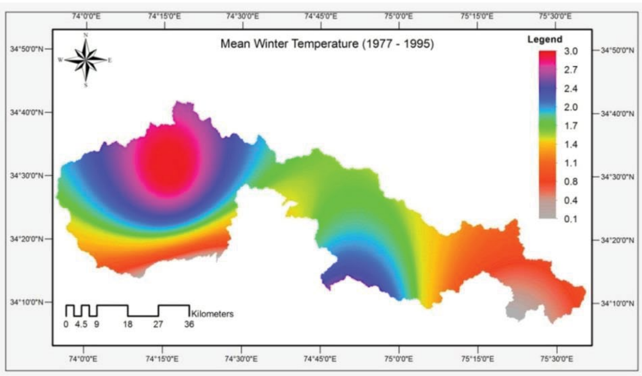

Figure 39: Temperature shows an increasing spatial trend from the east to west.

The lower part of Sind and the upper reaches of Pohru catchment have been the hotter regions with the same temperature distribution. The Erin, Madhumati and the upper part of Sind catchment show the same temperature distribution without any spatial trend as against the average winter temperature from 1977 to 1995 (Figure 39 and 40).

The spatial distribution of average temperature in spring season shows a little variation in the study area. The average temperature ranges from 8.8°C to 12.5°C from 1977 to 1995 while as it ranges from 9.9°C to 13.7°C from 1996 to 2015 as shown in the Figures

41 and 42. The extreme eastern part of Sind catchment has experienced the lowest average temperature. The middle portion of Sind and Madhumati catchment including, almost, the entire area of Erin catchment has experienced the same average temperature from 1977 to 1995. The extreme downstream part of the Sind catchment and the upper reaches of Pohru have been the hottest areas in terms of temperature distribution. Pohru catchment does not have much relief as compared to the eastern part of the study area. As a result, it records comparatively, the higher temperature. The lower reaches of Sind experience the highest temperature owing to its close proximity to Srinagar station.

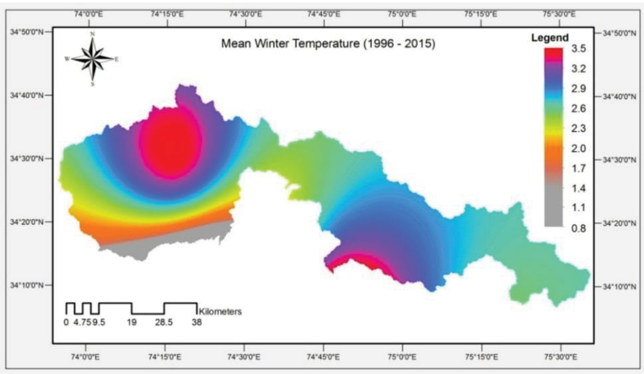

Figure 40: Erin, Madhumati and the upper part of Sind catchment show the same temperature distribution without any spatial trend as against the average winter temperature from 1977 to 1995.

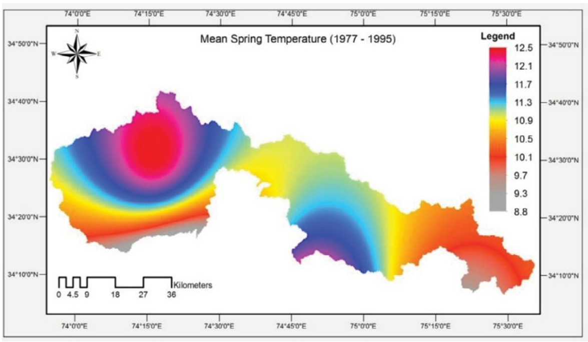

Figure 41: Average temperature ranges from 8.8°C to 12.5°C from 1977 to 1995.

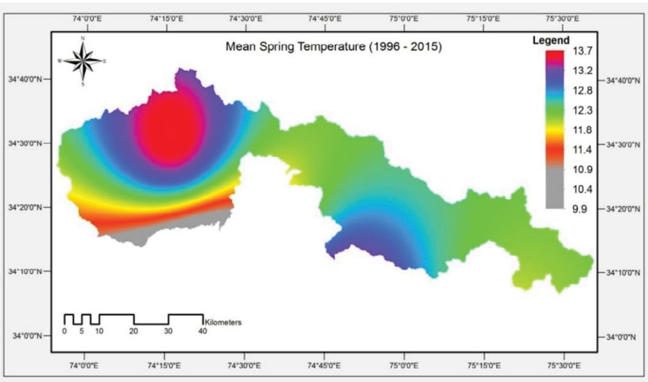

Figure 42: Average temperature ranges from 9.9°C to 13.7°C from 1996 to 2015.

The average summer temperature ranges from 18.5°C to 22.3°C as shown in the Figure 43. The temperature in the extreme eastern part of the study area has been interpolated using the data observed at Pahalgam station. The lowest temperature has been recorded at the Pahalgam and Gulmarg. Both these stations are located at an altitude of approximately 2500 meters. As a result, these locations experience relatively low temperatures in any season. There is spatially increasing trend in the mean summer temperature while going from east to west. The Pohru catchment has all the five temperature zones and the Sind catchment has four. The temperature shows a decreasing trend while moving from the lower to higher reaches of Sind catchment. The Erin and Madhumati catchments have two different temperature zones each. The Pohru catchment shows the same characteristics in terms of spatial distribution of twenty-year average temperature. There is a general increasing trend in temperature from the lower to upper reaches of Pohru catchment but the magnitude of temperature increases in not that high. Sind catchment also shows the similar trend in mean summer temperature distribution from lower to higher reaches as shown in the Figure 44.

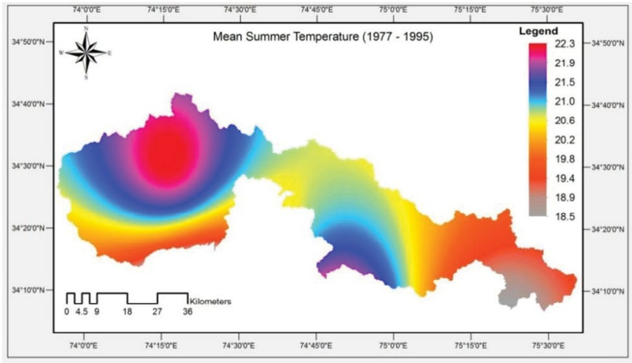

Figure 43: Average summer temperature ranges from 18.5°C to 22.3°C.

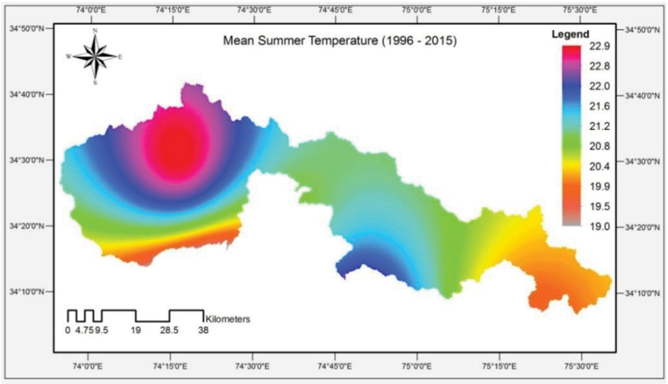

Figure 44: Sind catchment showing mean summer temperature distribution from lower to higher reaches.

The upper portion of Pohru catchment and the lower section of Sind catchment experienced the same average temperature from 1977 to 1995. The IDW tool has calculated different average temperature value (1996 to 2015) for the same area. The Erin and Madhumati fall within a single temperature zone.

The first two decadal (1977-1995) average of mean autumn temperature ranges from 11°C to 14°C. The lowest of the average temperature has been recorded at Gulmarg and Pahalgam stations owing to their high-altitude location. The temperature starts increasing from Gulmarg to Kupwara but it shows a decreasing trend while moving from Srinagar towards north (Figure 45). Sind catchment can be divided into four temperature zones based on the interpolation data while as Erin and Madhumati have largely experienced the same temperature distribution. The lower reaches of Sind catchment experience the highest temperature as it happens to be very near to Srinagar which is hottest of all the stations in any season. The IDW tool has calculated somewhat different results for the mean autumn temperature from 1996 to 2015 as shown in the Figure 46. The average temperature in the recent two decades (1996-2015) has increased by 0.5°C. Pohru catchment has all the five temperature zones with same areal extent but the magnitude of temperature for each zone has increased by a small fraction. Sind catchment can broadly be divided into two temperature zones as against the four zones from 1977 to 1995.

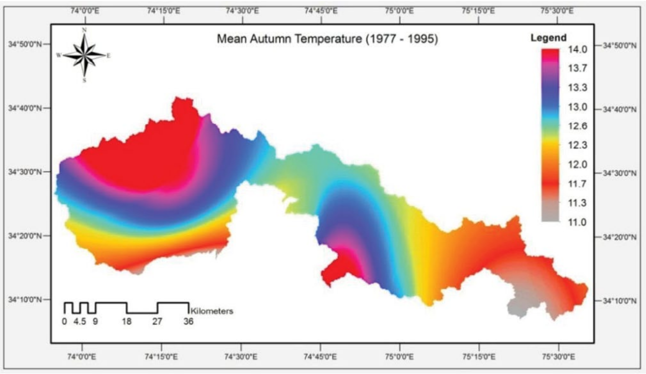

Figure 45: Temperature starts increasing from Gulmarg to Kupwara but it shows a decreasing trend while moving from Srinagar towards north.

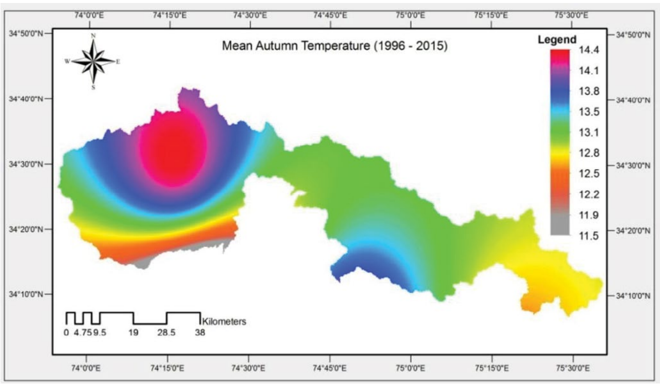

Figure 46: IDW tool has calculated different results for the mean autumn temperature from 1996 to 2015.

CONCLUSION

The magnitude and distribution of increasing temperature variables found in North Kashmir Himalayan region is asymmetrical in nature. The increase in highest maximum, mean maximum and the mean minimum temperature has been found in Pahalgam station for all the four seasons. Being a high-altitude area, this region is experiencing a warming phase in its climatic setting. Srinagar and Kupwara stations also reveal an increasing trend in all the temperature variables for winter and spring seasons. The analysis suggests a sharp and clear upward trend in temperature maximums. The mean temperature has also increased from 1996 to 2015 compared to the mean temperature for the region from 1977 to 1995. The decade of 1990's has witnessed some of the hottest years in the earth's climate. This increasing trend in the temperature is an evidence of connection of Himalayan warming with the global changing climate. The winter time warming is a recipe for disaster for such region where snow/glacial cover has the major role to play in the catchment hydrology of many rivers. As the area faces a warming phase, the uncertainty of availability of water in different seasons has triggered a shift in the land use practices since couple of decades. North Kashmir region is home to about two million people where agriculture is the mainstay of the economy. There has been an accelerated shift from paddy cultivation to plantation agriculture. Further insights are needed in order to assess the nature of climate variability in Northwest Himalayas. Lacking long term time series data in the northwest Himalayas has been a problem in projecting the exact climatic setup attributed to the region. The data is missing on smaller time scales even for the recent decades which further limit our understanding of the changing climatic pattern in Himalayas as a precise and meaningful climate assessment relies on it.

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