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Assessment of recent temperature trends in Mangla watershed

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Abstract

Climate change in the region in terms of changes in temperatures may seriously affect snow melting rates in the watershed and hence flows at dam. The main source of flows is snowmelt and rainfall that varies with temporal and spatial scale. So, understanding of spatial and temporal variability of climatic parameters is most important for the management of water resources. The present study was conducted to test the existence of monotonic trends and relative change (step change) in the annual and seasonal regional maximum, minimum, and mean and diurnal temperature data produced by thiessen polygon method from a meteorological network of stations in Mangla watershed for the period 1971-2010. Significant trends were detected by applying the student t test, Mann Whitney U, Spearman and Mann Kendall tests in time series of temperature for Mangla catchment and its sub-basins (Kanshi, Poonch, Kunhar and Neelum).

The results of this study revealed that Climate change is occurring more severe with warming trends in lower part of Mangla catchment whereas cooling trends were in higher part. The prevailing trends, caused by climate change, have an effect on the flows that should be considered by the water managers for better water management in a water scarcity country like Pakistan.

Keywords: Mangla watershed; Climate change; Trends; Temperatures; Regional.

1. Introduction

Scientific evidence indicates that due to increased concentration of greenhouse gases in the atmosphere, the climate of the Earth is changing; temperature is increasing and the amount and distribution of rainfall is being altered (Yue and Hashino, 2003; Andrighetti et al., 2009). The IPCC Scientific Assessment suggests that global average temperature may increase between 1.5 and 4.5°C, with a 'best estimate' of 2.0°C, in the next century with a doubling of the CO_2 concentration in the atmosphere. Global warming induced changes in temperature and rainfall are already evident in many parts of the world, as well as in Pakistan (IPCC AR4, 2008, Bates et al., 2008; Fowler and Archer, 2006). According to International Panel on Climate Change (IPCC, 2008), the global temperature has been increased by 0.13 °C (± 0.03°C) per decade over the last 50 years due to changing climate. Climate change over the last century has been a subject of great topical interest. The potential adverse impact due to climate change worries the scientific community, as it could have a major impact on natural and social systems at local, regional and national scales. The climatologists (Parker and Horton, 1999; IPCC, 2001; Jones and Moberg, 2003) agree that there has been a large-scale warming of the Earth's surface over the last one hundred years or so. The globe is warming due to anthropogenic factors such as emission of greenhouse gases. The climate is changing due to global warming in the Hindukush-Karakoram-Himalaya (HKH) region. The warming in the higher Himalaya of HKH is greater than the global average temperature. For instance warming in Nepal was 0.6°C per decade between 1977 and 2000 (Shrestha et al., 1999). Another recent study indicate that warming is undergoing in major part of eastern HKH and increasing trend in the temperature was found at the rate of 0.01°C pear year (Shrestha and Devkota, 2010).

Pakistan's economy is based on agriculture that is highly dependent on Indus Basin Irrigation system (IBIS). The Indus Basin Irrigation System serves an area of 22.2 million hectares and irrigated land accounts for 85% of all crop/food production (Khan et al., 2002). Pakistan has three major reservoirs (Tarbela, Mangla and Chasma), which have original storage capacity of 19.43 BM^3. The Mangla reservoir has original storage capacity 6.6 BM^3 (34% of total storage) and installed capacity of 1000 MW (WRM, 2008). Its command area is about 6 million hectares). In Pakistan future water resources assessment under climate change is essential for planning and operation of hydrological installations (Akhtar et al., 2008). Seasonal flow forecasting with respect to the climate change would be an efficient tool for the management of water resources for national power management, by providing an early indication of surplus or shortfall in hydropower, further it will be helpful for planners (Fowler and Archer, 2005). As seen in some recent studies, due to wide variation in topographic and meteorological parameters, different trends has been observed in different climatic regions of the country (Chaudhry and Sheikh, 2002; Chaudhry and Rasul, 2007; Afzal et al., 2009). Keeping in view, temperature changes have to be analyzed regionally in Mangla watershed by using different techniques in order to understand the variation in temperature.

Traditionally, climate patterns have been investigated using trend analysis on a point-by-point basis. Temperature and precipitation trends from one location have been compared with surrounding locations. This is appropriate when large distances separate monitoring locations. However, advanced spatial analysis is possible when monitoring locations are clustered in a local region. The use of regional average, in general, provides a time series that is a better representation of large-scale climatic processes, and it is easier to deal with one index series that is a spatially averaged series in a region.

This study focuses on trend detection in annual and seasonal maximum, minimum, mean and diurnal temperature for the Mangla catchment and its sub-catchments. The study was conducted to assess the effect of climate change at spatio-temporal scale for Mangla catchment and its four sub catchments (Kunhar, Neelum, Kanshi and Poonch) on a regional data for the period (1971-2010). In addition, the trend-free pre-whitening (TFPW) approach was used to eliminate the influences of significant lag-1 serial correlation trend tests. Thus for better management and planning, suitable studies related to climate change is necessary for this region. These results can be used for local and regional planning of water resources sections and helps governors for selecting optimum strategies related to water management. In fact the goal of the study is to determine trends in temperature series and these results will be suitable for better water management in the Mangla catchment.

2. The study area

The Mangla watershed is located between latitudes 33˚ to 35˚12′ N and longitudes 73˚ 07′ to 75˚40′ E. The elevation of this catchment varies from 300m to 6282 m above mean sea level (a.m.s.l). The catchment area at the dam site is around 33425 km^2. There are five main tributaries/rivers i.e. Jhelum, Poonch, Kanshi, Neelum/Kishan Ganga and Kunhar which contribute water to Mangla reservoir as shown in (Fig. 1). The Mangla Watershed and its tributaries drain the southern slopes of the Himalaya and parts of the Pir Panjal Range in Jammu and Kashmir. The catchment area of this watershed is divided by the line of control between India and Pakistan. Although monsoon rainfall affects the lower part of the catchment, runoff from the melting of winter snow makes a significant contribution to river flow during the summer season; vital for irrigation and hydropower production in the region. About 55% of the catchment area lies in Indian held Kashmir and 45% lies in Pakistan including Azad Kashmir. Due to unavailability of data in Indian held catchment, so study area was confined in catchment carrying within Pakistan boundary as marked in (Fig.1). The mean monthly maximum and minimum temperature in Mangla catchment varies from 10.4°C to 31.6°C and 4°C to 25°C respectively. The mean monthly maximum and minimum temperature in high altitude basins (Kunhar and Neelum) of Mangla catchment varies from 4°C to 28°C and -6°C to 25°C whereas in low altitude basin (Kanshi and Poonch) varies 16°C to 38°C and 4°C to 25°C respectively.

3. Data set

Thirteen climate stations were selected for this study and their characteristics are given in Table 1. The geographical distribution of these stations is shown in (Fig. 1). The daily data were collected from Surface Water Hydrology Project (SWHP), WAPDA and Pakistan Meteorological Department (PMD) for the period 1971-2010. The mean monthly maximum T_{max}, minimum T_{min} and mean T_m temperatures were computed from the daily maximum, daily minimum and daily mean temperatures. Mean daily temperatures are based on the arithmetic average of daily maximum and minimum temperatures. The seasonal mean temperatures were calculated by averaging the monthly values. The three month seasons are as winter (December, January, and February), spring (March, April and May, pre-monsoon), summer (June, July and August, monsoon) and autumn (September, October and November, post-monsoon). Annual mean is the average of January to December monthly means. Similarly, annual and seasonal diurnal temperature range (DTR) data were computed by subtracting the minimum temperature from maximum temperature. The missing data were also substituted by the average between the data of the previous and the following year. The regional seasonal and annual temperature time series for the study area and as well as for all sub-basins from these 13 climatic stations were computed using the thiessen polygon method. Distribution of mean monthly maximum and minimum temperature in Mangla catchment and sun-basins is shown in (Fig. 2).

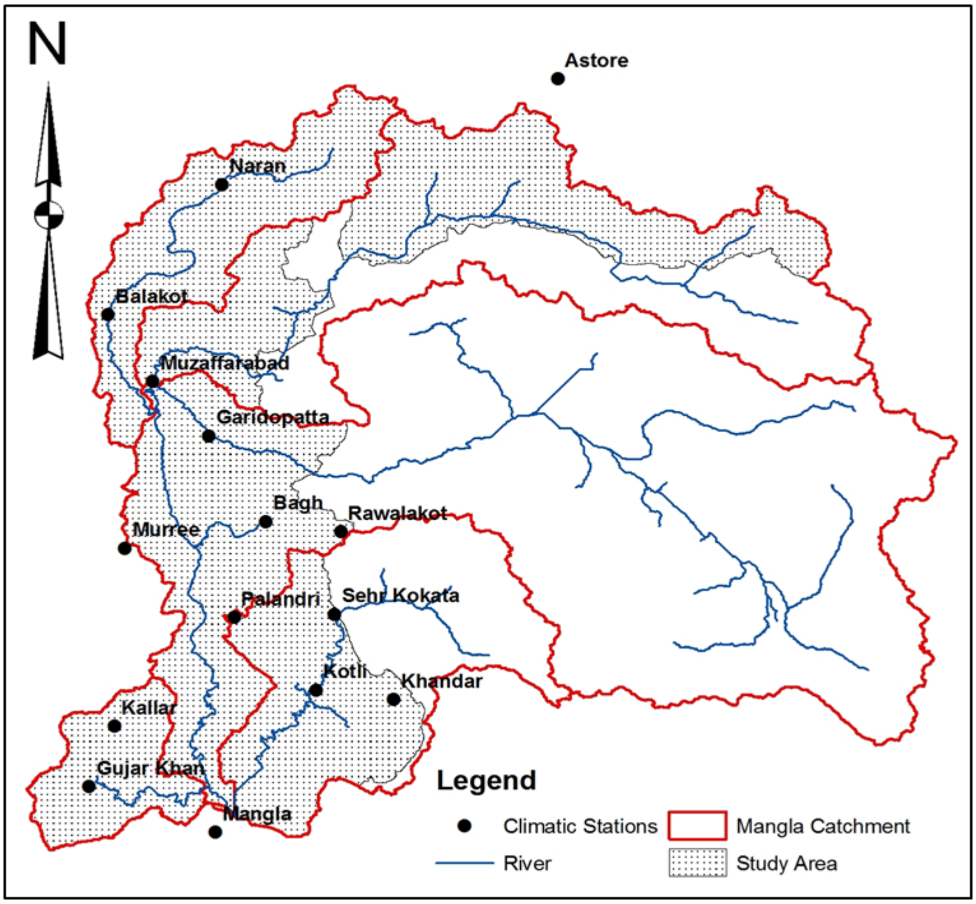

Fig. 1. The Mangla basin showing climatic stations, sub-basins and catchment area laying in Pakistan (shaded).

Table 1. List of climatic stations used in the present study and their characteristics.

Sr.No.	Station	Lat (dd)	Lon (dd)	Elevation (m.a.s.l)	Basin	Mean Annual Temperature (C°)			
						Max.	Min	Mean	DTR
1	Astore	35.2	74.5	2168	Astore	15.7	4.1	9.9	11.6
2	Balakot	34.6	73.4	995.5	Kunhar	25.1	12.2	18.6	12.9
3	Garidopatta	34.2	73.6	813.5	Jhelum	26.0	12.5	19.2	13.5
4	Kotli	33.5	73.9	610	Poonch	28.4	15.3	21.9	13.1
5	Murree	33.9	73.4	2206	Jhelum	17.3	8.6	12.9	8.7
6	Muzaffarabad	34.4	73.5	702	Neelum	27.6	13.6	20.6	14.0
7	Bagh	34.0	73.8	1067	Jhelum	25.1	12.0	18.5	13.1
8	Gujar Khan	33.3	73.3	457	Kanshi	28.5	14.9	21.7	13.6
9	Kallar	33.4	73.4	518	Kanshi	28.5	16.4	22.5	12.0
10	Mangla	33.1	73.6	282	Mangla	29.7	17.1	23.4	12.6
11	Narran	34.9	73.7	2363	Kunhar	12.0	2.5	7.2	9.4
12	Palandri	33.7	73.7	1402	Jhelum	22.9	12.1	17.5	10.9
13	Rawalakot	34.0	74.0	1677	Jhelum	20.6	9.2	14.9	11.4

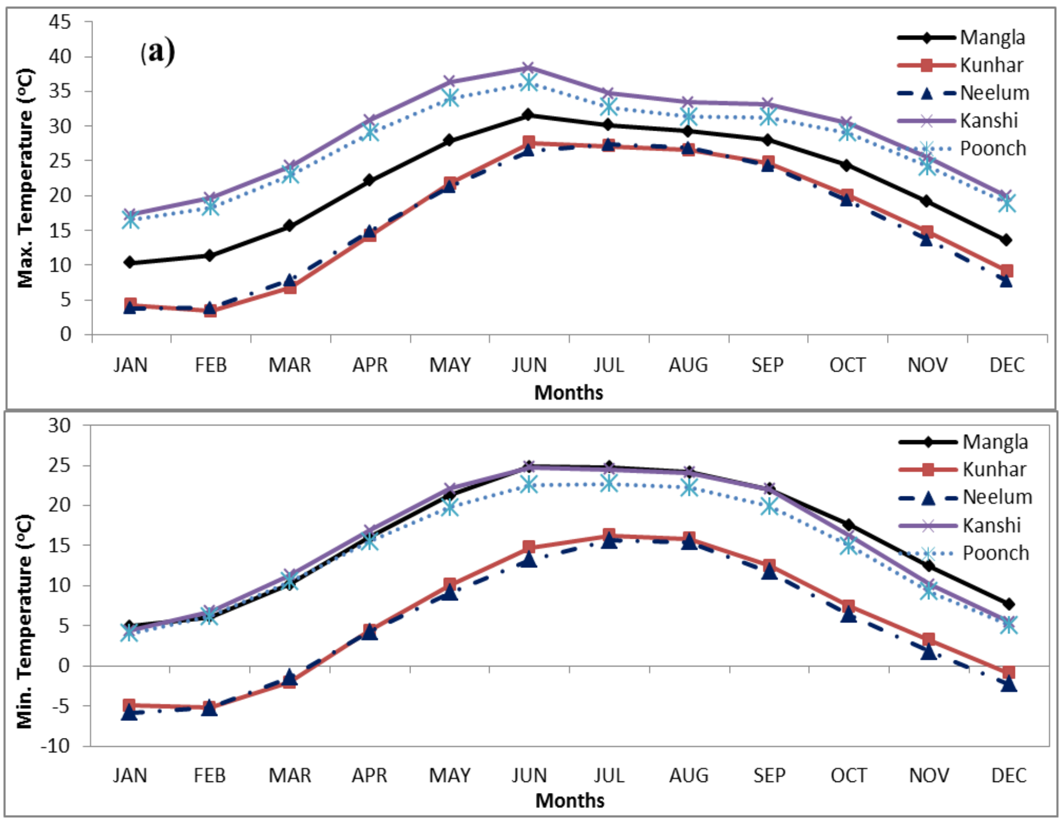

Fig. 2. Mean monthly maximum (a) and minimum (b) temperature in Mangla basin and its sub-basins.

4. Methodology

In this study we perform two analyses; first we assess relative changes in temperature, to evaluate if patterns in relative change can be identified. Second, trend analysis is performed to evaluate if trends are statistically significant and if patterns in trends across the basin area can be identified.

4.1. Assessment of relative change

The relative change in annual and seasonal time series was carried out in two equal data sets. Statistical tests were used to determine whether the 2nd data period differed from the 1st data period. The tests used are the t-test for differences between means, the variance ratio (F)-test, and Mann-Whitney (non-parametric) test (Robson et al., 2000).

4.1.1. Student t-test

Student t-test was used to determine whether two sets of data are significantly different from each other. Before applying t-test on data a variance F test was applied to determine whether the variance is equal or not. If the variance was equal in two data period then the t-statistic to test whether the means are different can be calculated as follows:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{S_p\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}} \tag{1}$$

Where S_p is the pooled standard deviation and can be computed as follow:

$$S_p = \sqrt{\frac{(n_1-1)S_1^2+(n_2-1)S_2^2}{n_1+n_2-2}} \tag{2}$$

The calculated value of t was compared with the table value. If the computed value was higher than the table value for a given significant level the null hypothesis was rejected and therefore it could be concluded that there was significant difference between the two means. For significance testing, the degree of freedom for this test is $2n - 2$ where n is the number of participants in each group. If the variance was unequal in two data period then the t statistic to test whether the means are different can be calculated as follows

$$T = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S_1^2}{n_1}+\frac{S_2^2}{n_2}}} \tag{3}$$

4.1.2. Mann–Whitney U

In statistics, the Mann–Whitney U test (Wilcoxon, 1945) (also called the Mann–Whitney–Wilcoxon (MWW), Wilcoxon rank-sum test, or Wilcoxon–Mann–Whitney test) is a non-parametric test of the null hypothesis that two sample are the same against an alternative hypothesis especially that a particular sample tends to have larger values than the other. The test statistic is the sum of the ranks of the elements in each sub-set. The p-value can be calculated exactly by considering all possible combinations or approximated by a normal distribution for large sample sizes. The two sub-sets need not have identical lengths, as was pointed out by Mann and Whitney (1947).

4.2. Detection of trends

The purpose of trend testing is to determine if the values of a random variable generally increase or decrease over some period of time in statistical terms (Haan, 1977). Parametric or Non-parametric statistical tests can be used to decide whether there is a statistically significant trend.

The analysis was carried out for the time series of the regional averages; these steps essentially involve: (i) testing the serial correlation effect; (ii) Trend detection by applying the Mann–Kendall test, spearman test and linear trend methods; (iii) Estimate the trend value by applying Sen's estimator

4.2.1. Serial correlation effect

In time series analysis it is essential to consider autocorrelation or serial correlation, defined as the correlation of a variable with itself over successive time intervals, prior to testing for trends. Specifically, if there is a positive serial correlation (persistence) in the time series, then the non-parametric test will suggest a significant trend in a time series that is, in fact, random more often than specified by the significance level (Kulkarni and Van Storch, 1995). For this, Von Storch and Navarra (1999) suggest that the time series should be 'pre-whitened' to eliminate the effect of serial correlation before applying the Mann–Kendall test or any trend detection test. Yue and Wang (2002) showed that removal of serial correlation by pre-whitening can effectively remove the serial correlation and eliminate the influence of the serial correlation on the MW test. Yue et al. (2002) modified the pre-whitening method as the trend-free pre-whitening to the series in which there was a significant serial correlation. The TFPW method has been applied in many of the recent studies to detect trends in hydrological and meteorological parameters (e.g., Yue et al., 2002, 2003; Aziz and Burn 2006; Novotny and Stefan 2007; Kumar et al., 2009; Oguntunde et al., 2011). This study incorporates this suggestion, and thus possible statistically significant trends in a temperatures observation (x_1, x_2. . . x_n) are examined using the following procedures:

1. For a given time series of interest, the slope of the trend (β) is estimated by using the Sen's robust slope estimator method. Then the time series is de-trended by assuming a linear trend as:
$$Y_i = x_i - (\beta \times i) \quad (4)$$
2. Compute the lag-1 serial correlation coefficient (designated by r_1).
3. If the calculated r_1 is not significant at the 5% level, then the statistical tests are applied to original values of the time series. If the calculated r_1 is significant, prior to application tests, then the 'pre-whitened' time series were obtained as:
$$\bar{Y}_i = Y_i - rY_{1-i} + (\beta \times i) \quad (5)$$

4.2.2. Tests for trend detection

The following tests were used to detect the monotonic trends in annual and seasonal temperature time series:

a) Pearson t-test (linear trend test)

The classical Student's t-test evaluates the significance of the correlation between the values of the temperatures and their years of observation. Pearson's correlation coefficient is calculated from the covariance and standard deviation of both variables. Student's t-test is then used to test the p-value of the test statistic.

b) Spearman's rank test

This test is the non-parametric analog of the Pearson t-test. The test statistic is Spearman's rank correlation coefficient r_s, which is the correlation between the ranks of the temperatures and their years of observation. Because of the use of ranks instead of the absolute values, the sampling distribution of r_s for a stationary process can be calculated without the assumption of a distribution function. For short series, the P-value can be calculated analytically.

c) Mann Kendall test

Mann originally used this test and Kendall subsequently derived the test statistic distribution (Kendall, 1975). Mann Kendall test is a statistical test widely used for the analysis of trend in climatologic (Tabari et al., 2012, Caloiero et al., 2011, Mavromatis and Stathis, 2011, Bhutiyani, 2007, Rio del et al., 2005,) and in hydrologic time series (Yue and Wang, 2004).There are two advantages of using this test. First, it is a non-parametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series (Tabari et al., 2011). This test was found to be an excellent tool for trend detection.

The number of annual values of the data series is denoted by *n*. The differences of annual values *x* were determined to compute the Mann-Kendall statistics. The Mann-Kendall statistic, S was computed using equation 4:
$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_k) \quad (6)$$

Where $sgn\ (x_j - x_k)$ is an indicator function that takes on the values 1, 0 or -1 according to sign of difference ($x_j - x_k$), where $j > k$:
$$sgn(x_j - x_k) = \begin{cases} 1 & if\ x_j - x_k > 0 \\ 0 & if\ x_j - x_k = 0 \\ -1 & if\ x_j - x_k < 0 \end{cases} \quad (7)$$

The values x_j and x_k are the annual values in the year j and k respectively.
The variance *S* was computed by the following equation:
$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \quad (8)$$

Where *q* is the number of tied groups and t_p is the number of data in the *p* group. Before computing *VAR(S)* the data was checked to find all the tied groups and number of data in each tied group.

S and *VAR(S)* were used to compute the test statistic Z as follows:

$$Z = \begin{cases} \frac{S-1}{[VAR(S)]^{1/2}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{[VAR(S)]^{1/2}} & if\ S < 0 \end{cases} \quad (9)$$

The trend was evaluated using *Z* values. A positive value of *Z* indicates an upward (warming) trend while negative value shows downward trend (cooling trend). The statistics *Z* has a normal distribution. The null hypothesis, Ho is true if there is no trend and thus uses the standard normal table to decide whether to reject H_o. To test for either upward or downward trend (a two-tailed test) at a level of significance H_o is rejected if the absolute value of *Z* is greater than $Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$, was obtained from standard normal tables.

In this study the existence and significance of trend was evaluated with α values that is $\alpha \leq 0.1$.

4.2.3. Sen's estimator slope

If a linear trend is present in a time series, then the slope (change per unit time) can be estimated by using a simple nonparametric procedure developed by Sen (1968). The slope estimates of N pairs of data were first computed by the formula:

$$Q_i = \frac{x_j - x_k}{j-k} \qquad \text{If } j > k \quad (10)$$

Where x_j and x_k are the annual values in the year j and k respectively. The Sen's estimator of slope is the median of these N values of Q. The median of the N slope estimates was obtained in the usual way. N values of Q_i were ranked from smallest to largest and the Sen's estimator was computed as follow:

Sen's estimator =

$$Q_{[(N+1)/2]} \qquad \text{if } N \text{ was odd and} \quad (11)$$

$$\frac{1}{2}\left(Q_{N/2} + Q_{[(N+2)/2)]}\right) \quad \text{if } N \text{ was even} \quad (12)$$

Finally, Q_{med} was tested by a two-sided test at the 100(1-α) % confidence interval and the true slope was obtained by the non-parametric test. Data were processed using an Excel macro named MAKESENS created by Salmi et al. (2002).

5. Results and discussions

5.1. Relative change in temperature

Table 2 demonstrates that more significant serial correlation coefficient was observed in whole data period. The annual and seasonal temperature series at 48% of time series have the positive lag-1 serial correlation whereas 6% and 16% were found in 1st and 2nd data periods. As mentioned earlier, the existence of positive serial correlation will increase the possibility of rejecting the null hypothesis of no trend in the MK test and reduces the power of the MW test for detecting a shift.

Table 3 shows the results of relative change of maximum, minimum, mean and diurnal temperature. These results reveal that annual maximum and minimum temperature has decreased significantly in Mangla catchment upto 1.6% and 2.6% respectively whereas the mean and DTR has increased upto 2.1% and 1.3% respectively. The spatial analysis of temperature showed that the annual maximum temperature and DTR has decreased in upper sub-basins i.e. in Kunhar and Neelum whereas has increased in lower sub-basins (Kanshi and Poonch). The minimum and mean temperature has decreased significantly in all sub-basins. The values of changes are given in Table 3. Less annual maximum and minimum temperature was observed in last three decades with respect to 1st decade (1971-1980) in Mangla catchment and all sub-basins as shown in (Fig. 3). Mean and diurnal temperature has increased in last three decade respect to 1st decade. The seasonal maximum and minimum temperature has also decreased in Mangla catchment in all seasons expect the autumn whereas the mean and diurnal temperature has increased. It was also noted that minimum temperature in winter and autumn has increased significantly at 95% confidence level in Kunhar and Neelum basins. This indicated that there will be less water-mass balance in form of snow covered and glacier due to early melting of snow in this season.

Table 2. Results of lag-1 serial correlation coefficient using TFPW technique.

Basins	**Maximum Temperature**			**Minimum Temperature**			**Mean Temperature**			**Diurnal Temperature Range**		
	1971-2010	**1971-1990**	**1991-2010**	**1971-2010**	**1971-1990**	**1991-2010**	**1971-2010**	**1971-1990**	**1991-2010**	**1971-2010**	**1971-1990**	**1991-2010**
Annual (J-D)												
Mangla	0.28	0.04	0.42	**0.36**	-0.06	0.53	**0.45**	0.02	**0.77**	0.14	0.41	-0.14
Kunhar	**0.63**	0.04	0.40	**0.37**	-0.06	**0.46**	**0.55**	-0.02	**0.44**	**0.63**	0.16	0.31
Neelum	**0.42**	-0.06	**0.48**	0.30	0.10	0.40	**0.37**	0.00	**0.48**	**0.44**	0.14	0.15
Kanshi	**0.43**	0.37	0.37	**0.41**	0.16	0.40	0.30	0.26	0.33	**0.56**	**0.52**	0.43
Poonch	0.23	0.15	0.27	**0.50**	0.42	0.60	**0.39**	0.18	**0.59**	**0.31**	**0.60**	-0.03
Winter(DJF)												
Mangla	0.21	0.19	0.10	0.26	0.17	0.09	**0.42**	0.29	**0.52**	0.06	-0.10	0.11
Kunhar	**0.50**	-0.04	0.13	**0.32**	0.17	0.20	**0.48**	0.09	0.18	**0.32**	-0.12	-0.02
Neelum	**0.36**	0.04	0.10	0.21	0.25	-0.03	**0.33**	0.19	0.05	0.20	-0.15	0.05
Kanshi	**0.38**	0.51	0.23	-0.04	-0.31	0.05	0.14	0.15	0.12	**0.36**	0.24	0.24
Poonch	0.19	0.29	0.12	0.11	-0.12	0.36	0.13	0.12	0.17	0.19	0.06	0.24
Spring (MAM)												
Mangla	0.28	0.01	0.43	**0.34**	0.11	**0.46**	0.24	-0.12	**0.60**	0.06	-0.01	0.19
Kunhar	**0.66**	0.09	0.17	**0.49**	0.11	0.09	**0.60**	0.09	0.13	**0.51**	0.09	0.16
Neelum	**0.46**	-0.04	0.33	**0.33**	0.04	0.10	**0.43**	-0.02	0.25	**0.31**	0.06	0.28
Kanshi	0.30	0.29	0.25	**0.41**	0.19	**0.44**	**0.36**	0.28	0.41	0.28	0.22	0.16
Poonch	0.29	0.08	0.38	**0.43**	0.13	**0.64**	**0.33**	0.06	**0.54**	**0.44**	0.36	0.16
Summer (JJA)												
Mangla	0.00	-0.20	0.02	0.07	-0.34	0.09	0.25	0.13	0.16	0.10	-0.04	0.07
Kunhar	**0.36**	0.13	0.12	-0.02	-0.34	0.22	0.17	-0.13	0.26	0.16	-0.09	0.00
Neelum	0.11	0.05	0.04	0.13	0.01	0.23	0.13	0.06	0.20	0.05	-0.20	-0.04
Kanshi	0.24	-0.20	0.39	0.11	-0.08	0.05	-0.07	-0.22	-0.01	**0.49**	-0.01	0.53
Poonch	-0.10	-0.23	-0.05	0.00	0.19	-0.29	-0.11	-0.14	-0.16	0.01	0.13	-0.13
Autumn (SON)												
Mangla	0.04	0.18	-0.08	0.19	0.29	0.14	**0.45**	-0.06	0.40	0.03	0.34	-0.18
Kunhar	**0.32**	0.22	0.40	**0.42**	0.29	0.31	**0.36**	0.25	0.42	0.30	0.17	0.23
Neelum	0.12	0.06	0.18	**0.39**	0.22	0.28	0.22	0.08	0.28	0.11	0.20	-0.07
Kanshi	**0.41**	**0.48**	0.30	**0.47**	0.08	**0.59**	0.23	0.25	0.20	**0.55**	0.45	**0.48**
Poonch	0.13	0.19	0.00	**0.36**	0.37	0.36	**0.37**	**0.46**	0.13	0.03	-0.01	0.04

Bold values indicate significant serial correlation at 90% confidence level

Table 3. Relative change (%) in annual and seasonal temperatures during 2nd period (1991-2010) compared to 1st period (1971-2010).

Basins	Annual	Winter	Spring	Summer	Autumn
Maximum Temperature, T_{max}					
Mangla	**-1.6***	**-3.2**	**-4.8**	-0.5	0.5
Kunhar	**-12.5***	**-19.3***	**-27.0***	**-4.5***	-1.6
Neelum	**-6.5***	**-13.6***	**-15.4***	**-3.2***	1.4
Kanshi	1.1*	**2.4***	-0.2	1.2	1.4
Poonch	0.6	1.8	1.5	0.5	**-1.1**
Minimum Temperature, T_{min}					
Mangla	**-2.6***	**-5.7***	**-6.9***	-1.4	0.5
Kunhar	**-16.5***	**21.3***	**-11.5**	-2.7	**4.9***
Neelum	**-12.8***	**15.5**	**-25.5***	-4.8	**3.1***
Kanshi	-3.1*	**-7.3***	-4.5	**-2.5***	-0.5
Poonch	-3.3*	-4.3	-5.6	-2.7*	-1.7*
Mean Temperature, T_m					
Mangla	**2.1***	7.8	-1.0	**1.3***	**4.5***
Kunhar	**-13.6***	**-21.*7**	**-23.4***	**-3.9***	0.2
Neelum	**-8.0***	**-23.*0**	**-20.2***	-3.7	1.8
Kanshi	-0.4	0.1	-1.7	-0.3	0.7
Poonch	-0.8	0.4	-1.1	-0.8	**-1.3**
Diurnal Temperature Range, DTR					
Mangla	1.3	-0.3	1.0	3.2	0.5
Kunhar	**-10.2**	**-16.6***	**-13.5**	**-7.0***	**-5.5***
Neelum	**-3.3**	**-7.9***	**-6.1***	-1.2	0.5
Kanshi	**6.5***	**6.7***	**5.5***	**10.0***	3.6
Poonch	**5.4***	4.4	**10.3***	7.5	-0.4

Bold, underline and * showed significant trend with Student t-test, F- test and Mann Whitney U test respectively at 95% confidence level.

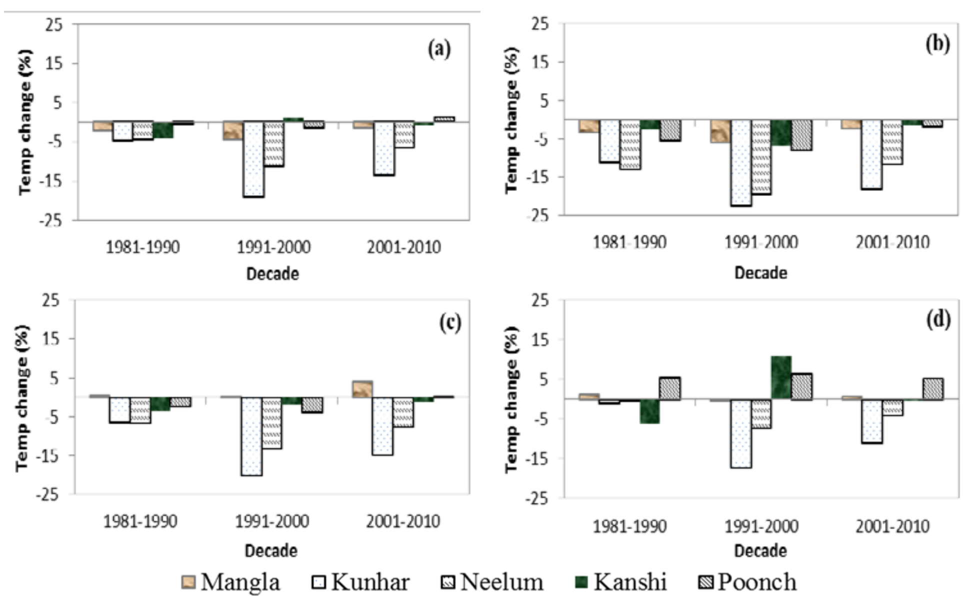

Fig. 3. Decadal Relative change (%) in annual Temperature compared (1971-1980) decade, (a) maximum, (b) minimum, (c) mean and (d) diurnal temperature range.

5.2. Trends in annual temperatures

Table 4 presents the results of trends analysis in Mangla watershed and its sub-basins using parametric and non-parametric statistical test and Sen's slope method. These results demonstrated a negative trend in annual maximum, minimum and mean temperature for Mangla catchment at the rate of 0.06°C, 0.06°C and 0.14°C per decade respectively for the whole period. Trends in sub-catchment of Mangla catchments were observed positive in maximum temperature for Poonch and Kanshi catchments whereas Kunhar and Neelum catchments showed the negative trends. In Kanshi basin, the minimum and mean temperature is decreasing at the rate of 0.08°C and 0.02°C per decade whereas maximum is increasing at the rate of 0.04°C per decade. In Poonch basin, trends in T_{max} & T_m were found positive at the rate of 0.18, and 0.05°C per decade with statistically significant. Trend in Kunhar and Neelum catchments were found negative in all temperatures. Trends in 2nd data period were found positive in annual temperature for the whole catchment and as well as sub-catchments except in Kanshi catchment. Time series of annual temperatures for Mangla catchment and its sub-basins are shown in (Fig. 5). These results reveal that climate change is occurring more severe and was observed warming trends in lower part of Mangla catchment whereas in higher part of catchment cooling trends were observed.

Warming in mean annual temperature in the Mangla catchment (0.14°C decade^{-1}) has a good agreement with the finding of Afzal et al. (2009) in which he reported that the mean temperature of Pakistan in increasing with the rate of 0.06°C decade^{-1} from the analysis of last century data. The minimum temperature has decreased in upper sub-catchments for the whole data period is comparable with the finding of Fowler and Archer (2006). The minimum temperature has also decreased in surrounding part of UIB.

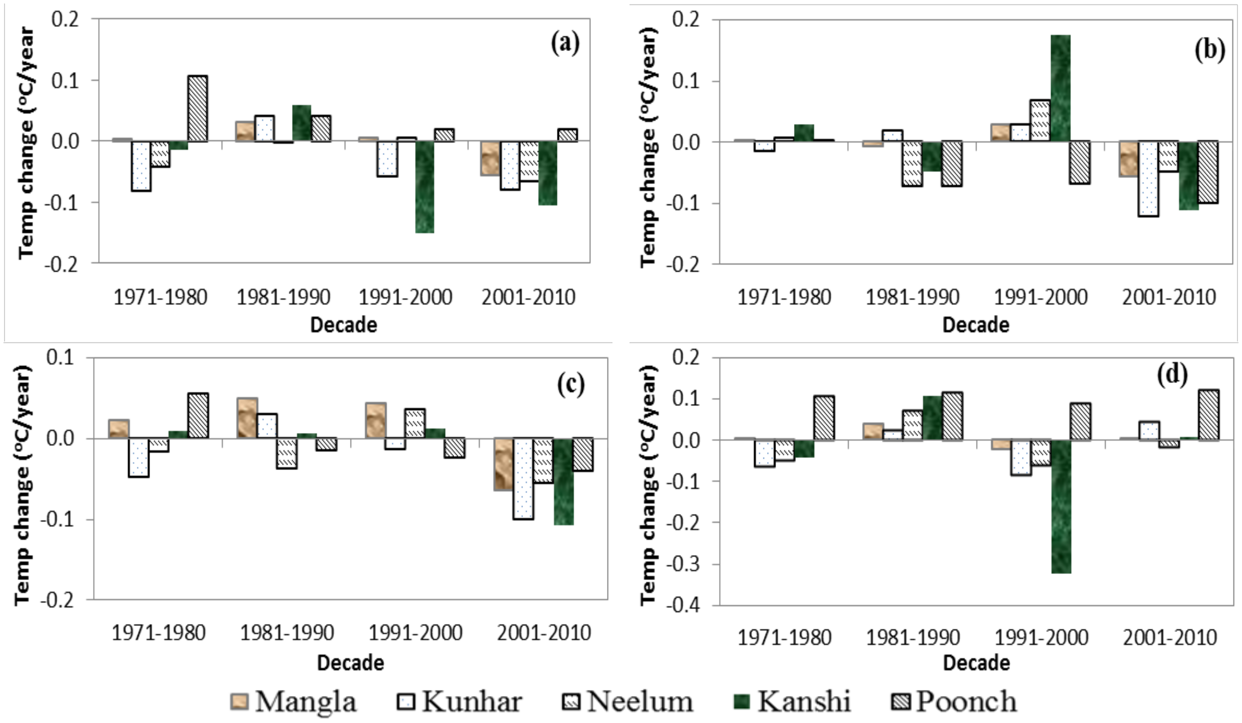

Fig. 4. Decadal change in annual (a) maximum, (b) minimum, (c) mean and (d) diurnal temperature range.

Table 4. Trends in annual and seasonal temperatures for the different periods showing change in °C decade $^{-1}$ analysis in study area.

Basins	Maximum Temperature			Minimum Temperature			Mean Temperature			Diurnal Temperature Range		
	1971-2010	1971-1990	1991-2010	1971-2010	1971-1990	1991-2010	1971-2010	1971-1990	1991-2010	1971-2010	1971-1990	1991-2010
Annual (J-D)												
Mangla	-0.06	-0.07	**<u>0.63*</u>**	-0.06	-0.29	0.22	**<u>0.14*</u>**	0.26	0.16	0.03	**<u>0.14*</u>**	0.1
Kunhar	-0.21	-0.92*	**1.02***	**<u>-0.26*</u>**	-0.49	0.15	**<u>-0.24*</u>**	<u>-0.80*</u>	<u>0.59*</u>	-0.12	-0.3	**<u>0.90*</u>**
Neelum	-0.18*	-0.56	0.49	**<u>-0.15</u>**	**<u>-0.66*</u>**	<u>0.43*</u>	-0.14	**<u>-0.59*</u>**	0.38	-0.07	0.11	**<u>0.48*</u>**
Kanshi	0.08	-0.75*	-0.54	-0.08	**<u>-0.52*</u>**	**<u>0.58*</u>**	-0.02	**<u>-0.43*</u>**	0.07	0.06	0.14	**<u>-0.96</u>**
Poonch	<u>0.18*</u>	0.25	**<u>0.71*</u>**	-0.02	**<u>-0.49*</u>**	0.23	0.05	-0.18	0.28	**<u>0.27*</u>**	0.09	0.39
Winter(DJF)												
Mangla	-0.12	0.09	0.33	-0.13	-0.12	0.2	0.10	**<u>0.44*</u>**	0.11	0.02	0.26	0.16
Kunhar	**<u>-0.63</u>**	-0.3	<u>0.22</u>	**<u>-0.37*</u>**	-0.7	-0.56	**<u>-0.48*</u>**	-0.52	-0.04	**<u>-0.27</u>**	-0.02	0.63
Neelum	**<u>-0.38*</u>**	-0.16	0.21	-0.26	-0.44	0.09	-0.25	-0.33	0.06	**-0.39***	0.2	0.04
Kanshi	0.18	-0.06	-0.63	-0.16	0.04	0.14	0.00	-0.21	-0.24	0.23	-0.48	<u>-1.19*</u>
Poonch	0.23	0.43	0.84	-0.01	-0.03	0.29	0.13	0.19	**<u>0.55</u>**	0.28	**0.94**	0.8
Spring (MAM)												
Mangla	-0.21	-0.44	**<u>1.2</u>**	-0.11	-0.66	0.72	0.15	0.20	0.38	0.05	0.16	0.08
Kunhar	**-0.41**	**-1.5**	1.5	**<u>-0.65*</u>**	**<u>-1.52*</u>**	0.33	**<u>-0.51*</u>**	**<u>-1.21*</u>**	0.97	<u>-0.26*</u>	-0.29	**<u>1.03*</u>**
Neelum	-0.33*	-0.95	**<u>1.63*</u>**	**<u>-0.39*</u>**	**<u>-1.26*</u>**	0.63	**<u>-0.35*</u>**	**<u>-1.07*</u>**	**<u>1.16*</u>**	-0.17	-0.01	**<u>0.70*</u>**
Kanshi	0.08	-0.96	-0.12	-0.02	**<u>-1.00*</u>**	0.67	0.01	**<u>-1.04*</u>**	0.49	0.14	0.03	**<u>-1.48*</u>**
Poonch	<u>0.55*</u>	-0.54	**<u>1.72*</u>**	0.01	**<u>-0.99*</u>**	**0.7**	0.20	-0.66	<u>1.06*</u>	**<u>0.29*</u>**	0.66	0.29
Summer (JJA)												
Mangla	-0.03	0.13	0.03	-0.09	-0.15	0.13	**<u>0.19*</u>**	**<u>0.45*</u>**	**0.16**	0.03	**<u>0.26*</u>**	-0.08
Kunhar	**<u>-0.19*</u>**	-0.28	**0.79***	0.03	-0.01	0.32	-0.13	-0.11	<u>0.53*</u>	**<u>-0.36*</u>**	-0.19	0.34
Neelum	-0.19	-0.4	0.44	-0.08	**-0.68**	0.36	-0.11	-0.38	0.42	-0.12	0.3	0.02
Kanshi	-0.11	-0.27	**<u>-0.49*</u>**	**<u>-0.23*</u>**	**<u>-0.47*</u>**	0	<u>-0.19*</u>	-0.42	<u>-0.39*</u>	0.03	0.24	-0.21
Poonch	**0.09**	0.33	0.22	<u>-0.18*</u>	<u>-0.39*</u>	0.01	-0.06	-0.01	0.15	0.26	**<u>0.78*</u>**	0.27
Autumn (SON)												
Mangla	0.09	-0.4	**<u>0.71*</u>**	0.1	**<u>-0.34</u>**	**<u>0.50*</u>**	**<u>0.23*</u>**	0.36	**<u>0.40*</u>**	0	0.14	0.17
Kunhar	0.12	<u>-1.34*</u>	**2.41***	**0.19**	**<u>-0.77*</u>**	0.40*	0.14	**<u>-0.89*</u>**	**<u>1.43*</u>**	-0.25	-0.75	**<u>1.91*</u>**
Neelum	0.23	-0.59	**<u>1.42*</u>**	**<u>0.19*</u>**	**<u>-0.70*</u>**	**<u>0.46*</u>**	**0.23***	<u>-0.57*</u>	**<u>0.95*</u>**	-0.03	-0.01	**<u>1.01*</u>**
Kanshi	0.02	-0.33	-0.49	0.04	0.12	0.22	0.09	-0.27	0.07	-0.02	-0.04	-0.73
Poonch	**-0.11**	-0.06	0.23	-0.07	-0.34*	0.15	-0.08	-0.04	0.19	0.01	0.39	0.11

Bold, underline and * showed significant trend with Pearson t-test, Spearman test and Mann Kendall respectively at 95% confidence level.

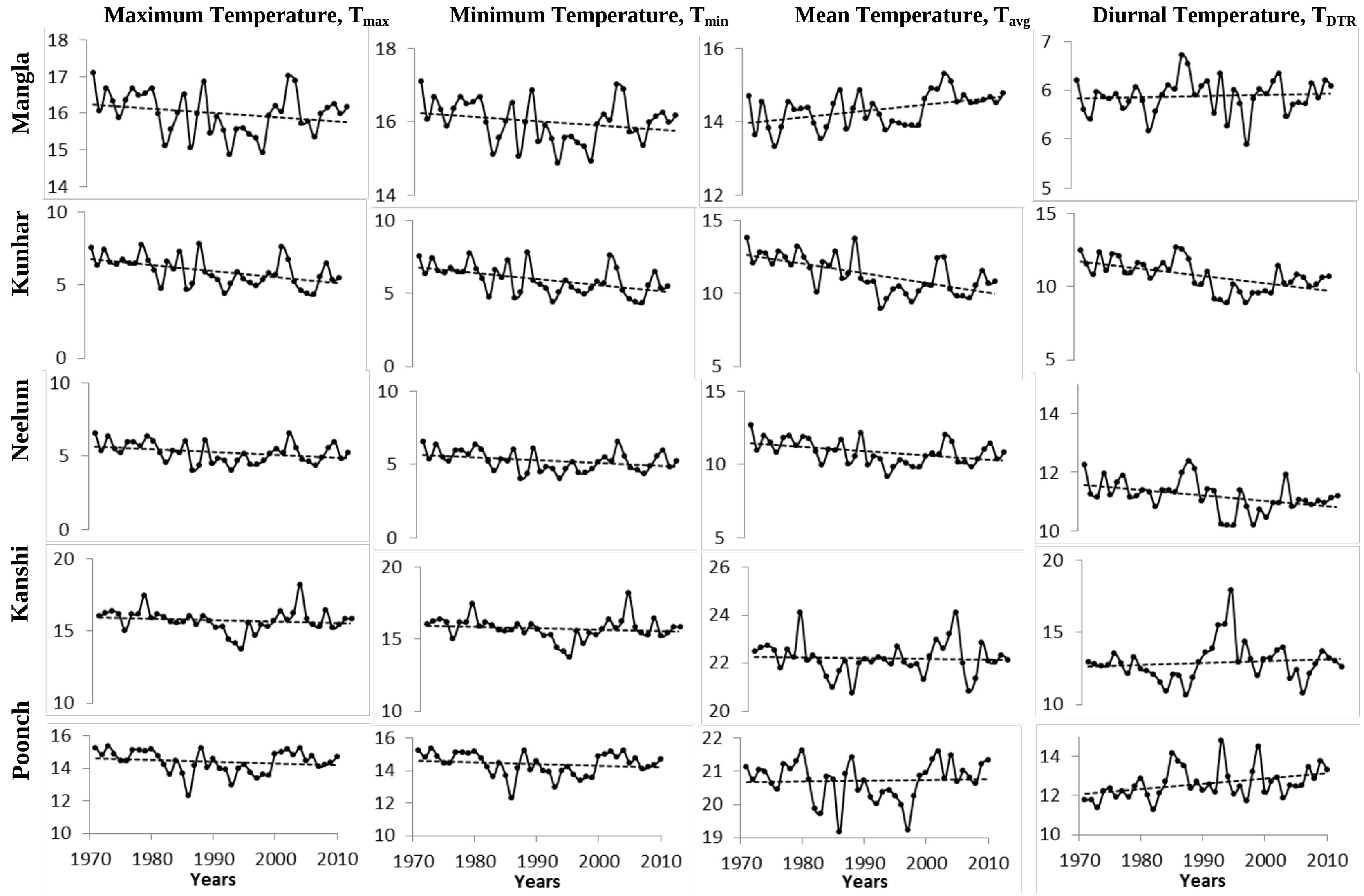

Fig. 5. Time series of annual T_{max}, T_{min}, T_{avg} & T_{DTR} for Mangla basin and its sub-basin between 1971 and 2010 showing temperature in ^{o}C.

As the results of two periods showed that different types of trends were observed in most of the cases as given in Table 4. To ascertain whether the warming rate in particular catchments were uniform throughout the last decades or not, decade-to-decade rates (season-wise) were computed. (Fig. 4) depicts that 1st and 3rd decades have warming trends with a modest rate whereas the last decade has highest cooling rate in case of maximum, minimum and mean temperature. The rate of change from short period revealed that rate of change was high in lower altitude catchments which are deviating the finding of other studies in Himalayas (Liu and Chen, 2000; Bhutiyani et al., 2007).

5.3. Trends in seasonal temperatures

Analysis of seasonal meteorological variable (Temperature and Precipitation) provided a better understanding of climate change. The analysis of trends for winter temperatures depicts that maximum and minimum temperature in Mangla catchment is decreasing at the rate of 0.12°C and 0.13°C per decade respectively where mean and DTR is increasing with the rate of 0.1°C and 0.02°C per decade respectively but statistically are non-significant as given in Table 4. Maximum, DTR and mean winter temperature in Poonch basin also increasing at the rate of 0.23°C, 0.28°C and 0.21ºC per decade at 99% respectively. In Kanshi basin only minimum temperature decreasing at the rate of 0.16°C per decade whereas maximum and DTR is increasing at the rate of 0.18°C and 0.23°C per decade respectively but are not statistically significant. The Kunhar and Neelum catchments have different trends as compared to Kanshi and Poonch catchments. In these catchments the winter temperatures are decreasing. Significant Trends in maximum, minimum, mean and DTR temperature for Kunhar basin were observed negative at the rate of 0.63°C , 0.37°C 0.48°C and 0.27°C per decade respectively. Cooling trends in maximum, minimum and mean temperature for Neelum basin were observed with the rate of 0.38°C, 0.26°C and 0.25°C per decade respectively.

As Khattak et al. (2011) analyzed the 39 year data spanning 1967-2005 and reported that maximum temperature for winter, spring and autumn seasons has strong warming trend in upper, medium and lower region of Upper Indus Basin (UIB) but in case of Mangla catchment maximum temperature for these seasons has cooling trend in upper region and warming trend for lower region for the period 1971-2010. In last two decade period analysis, warming trends were observed in whole region expect in minor lower part of Kanshi for the all these seasons. The maximum, minimum and mean temperatures have decreased in whole region (all basins) for the summer season which supports the results of Khattak et al. (2011). Table 2 also represents results of two period’s analysis that more warming trends were observed in last period (1991-2010) and more cooling trends in 1st period (1971-1990).

6. Conclusions

The present study analyses the investigation of annual and seasonal maximum, minimum, mean and diurnal temperatures in Mangla watershed and its sub-basins (Kanshi, Poonch, Kunhar and Neelum) for period (1971-2010) by student t test, Mann Whitney U, Spearman and Mann Kendall tests in time series of temperature for Mangla catchment and its sub-basins (Kanshi, Poonch, Kunhar and Neelum) on spatially distributed temperature data produced by thiessen polygon method. The overall results of this study reveal that climate change is being observed. The warming trends were observed in lower part of study area whereas in higher part cooling trends were found. The following specific conclusions from this study are:

1. Annual maximum, minimum and mean temperature for Mangla catchment have the cooling trends at the rate of 0.06°C , 0.06°C and 0.14°C per decade respectively for the whole period and indicates that annual maximum and minimum temperature has decreased significantly in Mangla catchment upto 1.6% and 2.6% respectively.
2. Warming trends were observed in annual maximum and mean temperature for Poonch and Kanshi basins whereas Kunhar and Neelum catchments showed the cooling trends. Minimum temperature has decreased in all catchment for annual and all seasons except autumn.
3. Trends for winter temperatures depict that maximum and minimum temperature in Mangla catchment is decreasing at the rate of 0.12°C and 0.13°C per decade respectively

where mean and DTR is increasing with the rate of 0.1°C and 0.02°C per decade respectively.

4. Warming trends were found in annual temperature for the whole catchment as well as in all sub-catchments except in Kanshi catchment for the 2nd data period.

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