

Assessment of Climate Change at Spatio-Temporal Scales and its Impact on Stream Flows in Mangla Watershed

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Abstract

The Mangla reservoir was built for irrigation as well as power generation. The variability in climatic variables (temperature and precipitation) at spatial and temporal scales affects the streamflows. To consider the hydro-climatic unpredictability, 50 years (1961-2010) record was scrutinized. The time series were divided in two periods of 25 years each (1961-1985, 1st and 1986-2010, 2nd). Results of the current investigation revealed that the mean temperature in annual as well as in spring, winter and autumn seasons has been increased however the summer temperature has decreased for the period 1961-2010. Declining trends were observed in annual temperature for the 1st period whereas 2nd period showed more warming. The results of annual and seasonal precipitation indicate that trends in the 1st period were not consistent while in the 2nd period trends were decreasing in all basins. The annual streamflows in rivers Kanshi, Poonch, Kunhar, Neelum, and Jhelum (at Azad Pattan) have decreased upto 41, 5, 34, 24 and 45% respectively with increase of 1 °C annual mean temperature for the period 1961-2010. On the other hand, trends in annual mean temperature showed cooling trends for the 1st period and this yield increased streamflow for rivers Kanshi, Kunhar, Neelum and Jhelum upto 21, 11, 4 and 10% respectively. In 2nd period, the annual mean temperature has increased in all the basins. The annual streamflows in rivers Kanshi, Poonch, Kunhar, Neelum, and Jhelum have decreased upto 46, 32, 43, 43 and 51% respectively. In 2nd period the streamflows in rivers Kanshi, Poonch, Kunhar, Neelum, and Jhelum have decreased upto 35, 37, 5, 11 and 11 % in spring season with increase of 1 °C temperature. Divergent to this, there was a reverse situation in the 1st period for the spring season. The summer mean temperature has been decreased upto 1°C and the streamflows in rivers Poonch, Kunhar, Neelum and Jhelum have decreased upto 2, 11, 11 and 33% per decade respectively for the whole period. Similarly in the 2nd period the streamflows have reduced upto 29, 32, 12, 46 and 36% in rivers Kanshi, Poonch, Kunhar, Neelum and Jhelum respectively. The trends, caused by climate change, have impacts on the streamflows that should be considered by the water managers for the better water management in a water scarce country like Pakistan.

Key Words: Mangla Watershed; Climate Change; Trends; Streamflows

1. Introduction

Pakistan's economy is based on agriculture that is highly dependent on Indus Basin Irrigation system (IBIS). The IBIS serves an area of 22 Million Hectares (MHa) and irrigated land accounts for 85% of all food production in the country [1]. Mangla reservoir has water storage capacity 5.34 MAF (34% of total storage) and installed capacity of 1000 MW.

The area of 6 MHa is employed by this watershed. Change in climate will revise the hydrological cycle and water balance of the area. For instance, changes in temperature and precipitation directly influence on processes of runoff generation. Consequently, any change in the spatial and temporal availability of water resources upsets agriculture, industry and urban development. Climate change is expected to have

adverse impacts on socio-economic development in all nations although the degree of the impact may differ. The monsoon rainfall affects the lower part of the catchment, runoff from melting of winter snow and perennial ice make a significant contribution to river flow during the summer season.

The impacts of climate change on water resources are high on the research agenda worldwide [2]. Future changes in flow magnitude, variability and timing of the flow events are among the most frequently cited hydrologic issues [2] and [3]. These changes may have a great impact on trans-boundary river basins where contest for water disputes by water patrons from different economic, political and social credentials while changing runoff variability of upstream countries can affect the downstream countries. 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 and it will be helpful for planners [5].

Many studies conducted in Upper Indus Basin (UIB) state that streamflows are seriously changing [6], [4], [5] and [7]. The findings of [8] states that the annual runoff for rivers Shoyk (at Yogu), Shigar (at Shigar) Indus (at Kachura) has increased upto 9%, 7% and 5 % respectively due to warming trend of annual temperature upto 5% (1°C) whereas the annual and summer streamflows in river Kabul at Nowshera have decreased to upto 22% and 11% by increasing 4% and 1% temperature respectively.

[9] and [10] found that the river flows have decreased, with an estimated decrease of 9% for a 1°C rise in temperature for the Sutlej basin in the western Himalayas. [11] found in a sub-basin of Yellow River for the period 1950–2000 that the decrease in percentage change of run-off due to climate change impact is found to be 89% followed by 66% and 56% in 1970s, 1980s and 1990s, respectively. [12] claimed a 4% increase in global total runoff per 1°C rise in temperature during the 20th century.

In Pakistan changes in flow magnitudes are likely to raise tensions among the provinces, in particular with the downstream areas (Sindh

province), regarding reduced water flows in the dry season as well as higher flows in wet season and resulting flood problems. The future water resources estimation under changing climate is essential for planning and operation of hydrological installations [13]. To quantify climate change's impacts on water resources planning and management in the basin, an analysis of possible changes in climate in multiple aspects of water resources under changing climatic conditions is required. In Pakistan some studies on climate change have been done in the upper region but there is no such kind of investigation has been carried out in the lower part. The objective of this study is to examine the existing changes in temperature and precipitation over the Mangla watershed and its impacts on the streamflows at spatio-temporal scales. Results of this study serve decision makers to develop strategies for planning and development of water resources for future.

2.1 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 ranges from 300 m to 6282 m above mean sea level (a.m.s.l). The catchment area at the dam site is around 33425 km². About 57.3% of the catchment area lies in Indian held Kashmir and 42.3% lies in Pakistan including Azad Kashmir (extracted from dem). 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. Although monsoon precipitation affects the lower part of the basin, runoff by melt water from glaciers and winter snowfall makes a significant contribution to river flow during the summer season.

2.2 Data

Streamflows measurement in Mangla watershed is carried out by the Water and Power Development Authority—Surface Water Hydrology Project (WAPDA-SWHP) with the earliest records commencing in 1960. The streamflow gauges are installed in all sub-basins of Mangla watershed at different locations which are shown in Fig.1. From these gauges, eight gauges were selected in all the sub-basins. Two gauges namely Naran and Garhi-Habibullah (now Talhata Bridge) were selected in

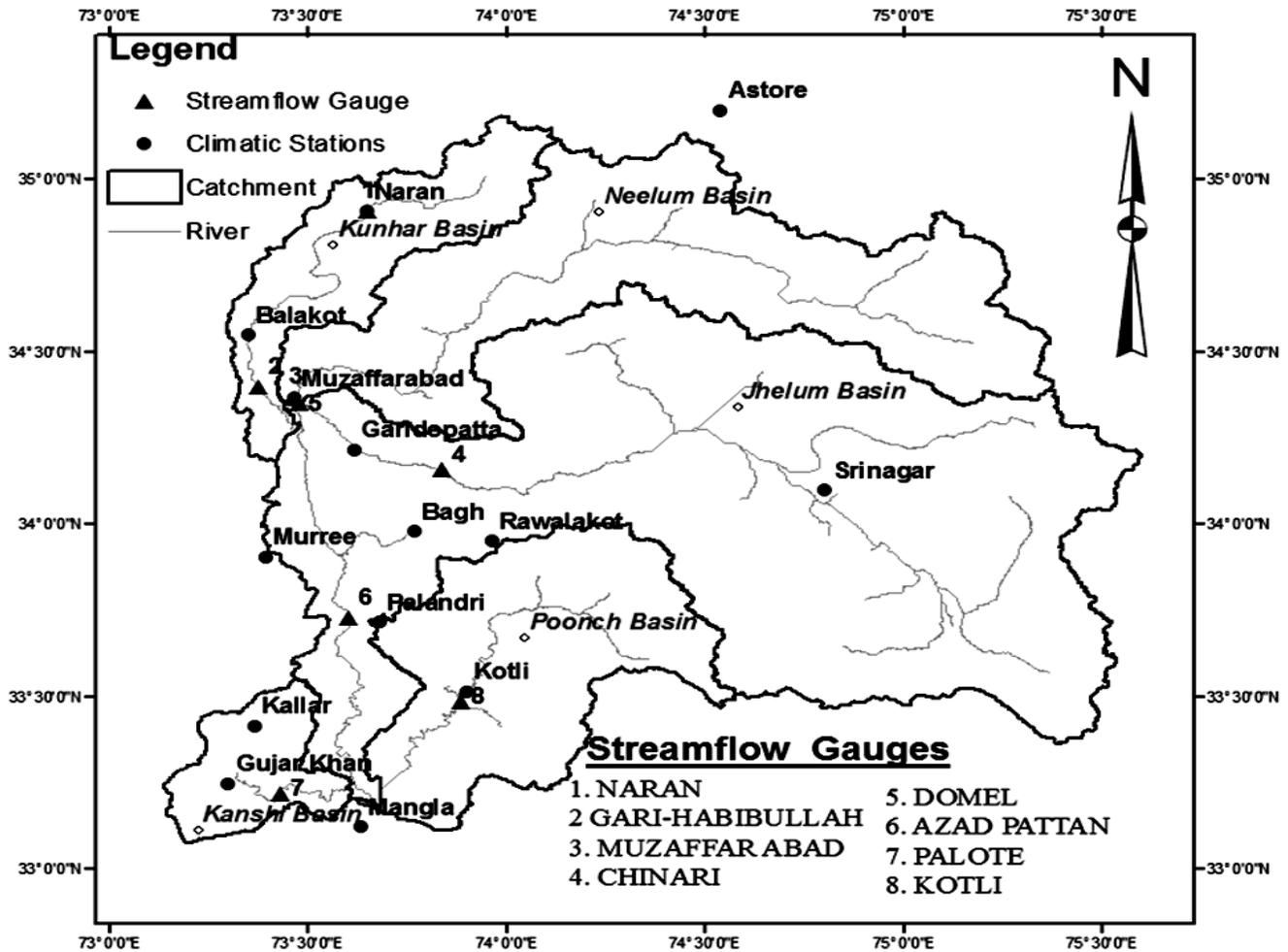


Fig.1 The Mangla Watershed showing sub-basins, river network, climatic stations and stream gauging stations.

River Kunhar whereas three gauges Chinari (Now Hattian Bala), Domel and Azad Pattan in River Jhelum were selected. Streamflows in Neelum, Kanshi and Poonch basins are measured at Muzaffarabad, Palote and Kotli respectively. The characteristics/information of selected flow gauges/sites are given in Table 1. The flow data of these sites were collected from WAPDA-SWHP for period 1961-2010. The monthly mean streamflows for each year were calculated from daily mean flows.

Fourteen climatic stations were selected and their locations are shown in Fig.1. The data of these stations were collected from WAPDA-SWHP and Pakistan Meteorological Department (PMD) for the period 1961-2010. Mean daily temperatures are based

on the arithmetic average of daily maximum and minimum temperatures. The monthly mean were computed from the daily mean temperature. The total monthly precipitation was computed from the daily precipitation. Monthly records were summed to get seasonal and annual totals for each year.

The following statistics and time scales analysis of temperature, precipitation and streamflow were performed to examine the impact of climate change on streamflows in the study area:

- i. Annual Mean Analysis
- ii. Three Month Seasonal Analysis
 - a) Winter Season, DJF (December, January and February)
 - b) Spring Season, MAM (March, April & May)

- c) Summer Season, JJA (June, July and August)
- d) Autumn Season, SON (September, October and November).

2.3 TIME Intervals Analyzed

The overall period from 1961 to 2010 was subdivided into two 25 years periods and the complete measurement period as follow:

- i. 1961-1985
- ii. 1986-2010
- iii. 1961-2010

2.4 Delineation of Snow Covered Area

The impact of climate change on water resources in the Mangla watershed may be considered in terms of two hydrological regimes: a nival regime depending on melting of winter snow and a rainfall regime depending on concurrent rainfall. The data used for the snow cover delineation is MODIS Terra Snow with spatial resolution of 500m by 500m dated 1st Jan, 5th Feb, 2nd Mar, 1st Apr, 5th May, 11th Jun, 5th Jul, 2nd Aug and 1st Sep in 2010 that was acquired from USGS website (<http://nsidc.org>). The snow covered area for all the sub-basins of Mangla watershed were delineated from these satellite images using the GIS software (Fig.2). The snow-covered area in whole Mangla watershed is ranging from 45 to 20% in months of January to March as given in Table 2. The month-wise distribution of snow covered area all in the sub-basins and different locations of Mangla watershed is shown in Figure 3. This figure clearly illustrates that Kunhar and Neelum basins have more percentage of snow-covered area as compared to other basins. Poonch basin has little snow cover whereas Kanshi has no snow cover. This figure also showed that snow is depleting with increasing in temperature. In summer (JJA) season, all snow has been depleted.

2.5 Tests for Trend Detection and Estimation of Slope

The purpose of trend testing is to determine whether the values of a random variable changes (increases or decreases) over some period of time in statistical terms [14]. Parametric or Non-parametric statistical tests can be used to decide whether there is a statistically significant trend.

Non-parametric tests are widely used in trend analysis of climatic and hydrological data, which are

robust with respect to missing values. The times series of all the meteorological variables were analysed using the Mann-Kendall non-parametric test for trend. Mann originally used this test and Kendall subsequently derived the test statistic distribution [15]. The Mann-Kendall test is a non-parametric test for identifying trends in time series data. This test was found to be an excellent tool for trend detection. One of the reasons to use this test is that the data does not require conformation to any particular distribution. The time series were pre-whitened to eliminate the effect of serial correlation before applying the Mann-Kendall test using the trend free pre-whitening technique (TFPW). The slope (change per unit time) was estimated by using a simple nonparametric procedure developed by Sen [16]. All three analyses are common to detect trends in time series and reference is made to studies by [17], [18], [19] and [20].

3. Results and Discussion

3.1 Changes in Temperature

a) Annual Temperature

The annual mean temperature has been increased in almost all the regions of the Mangla watershed except in Balakot, Gujar Khan, Mangla and Naran. Warming trends in Astore, Balakot, Garidopatta, Murree, Muzaffarabad, Srinagar, Bagh, Kallar, Palandri and Rawalakot were observed at the rate of 0.14, 0.06, 0.16, 0.10, 0.24, 0.15, 0.41, 0.01 and 0.66 °C per decade respectively for the data period 1961-2010. Only at Bagh and Palandri, trends were found insignificant. The declining trends were observed at Balakot, Gujar Khan, Mangla and Naran at the rate of 0.13, 0.21, 0.06 and 1.11°C per decade respectively for the whole data period as given in Table 2.

Trends analyses were also performed by segmented the whole data period (1961-2010) into two equal periods (1961-1985) and (1986-2010). The analysis of annual mean temperature within the two periods reveals that trends in 1st data period (1961-1985) were experienced most cooling in most of the region and percentage of temperature change as a data period is shown in Fig.4a whereas the 2nd period (1986-2010) showed the more warming trends as shown in Fig.3b. The change in temperature at (difference of 1st period and 2nd period) is shown in Fig.4d.

Table 1 Snow covered area in sub-basins of Mangla watershed.

Basin & Flow Gauge	Basin Area (Km ²)	Snow-covered Area (Km ²)							
		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG
Kanshi at Palote	867	0	0	0	0	0	0	0	0
Poonch at Kotli	3210	706	579	553	112	127	79	0	0
Kunhar at Naran	1107	1080	957	744	613	443	387	19	22
Kunhar at Gari-Habibullah	2433	1678	1495	1563	1460	1212	709	29	41
Neelum at Muzaffarabad	7412	5175	4683	4077	3335	3235	2197	28	22
Jhelum at Chinari	13652	4192	3413	2556	2730	2044	1756	43	3
Jhelum at Domel	14396	5183	4031	3167	2879	2051	1757	43	3
Jhelum at Azad Pattan	25967	12984	12665	5926	5713	5193	4663	100	77
Mangla Watershed	33425	14707	13277	8356	6685	6667	4779	101	77

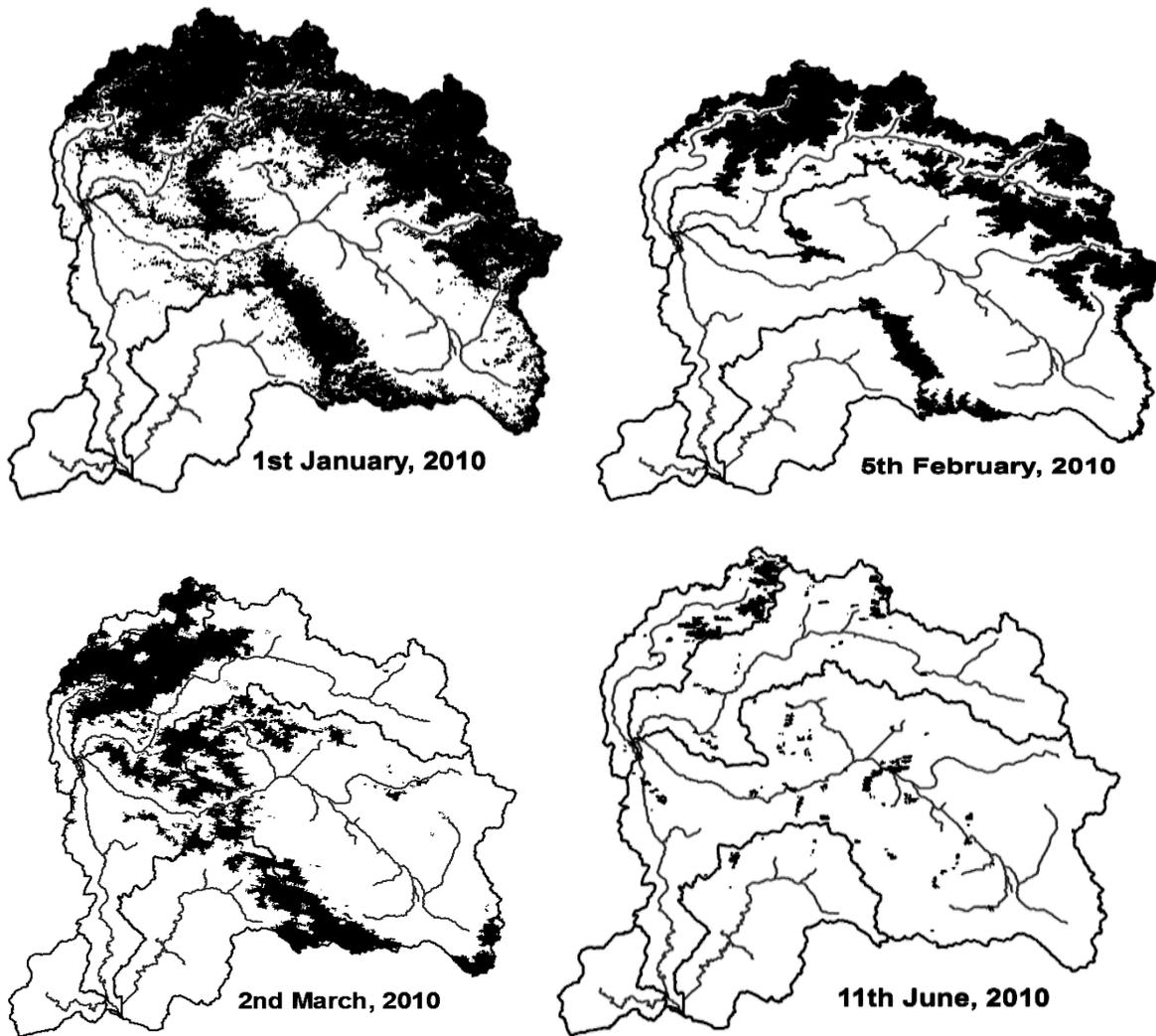


Fig.2 Snow covered areas in Mangla watershed on different dates in 2010.

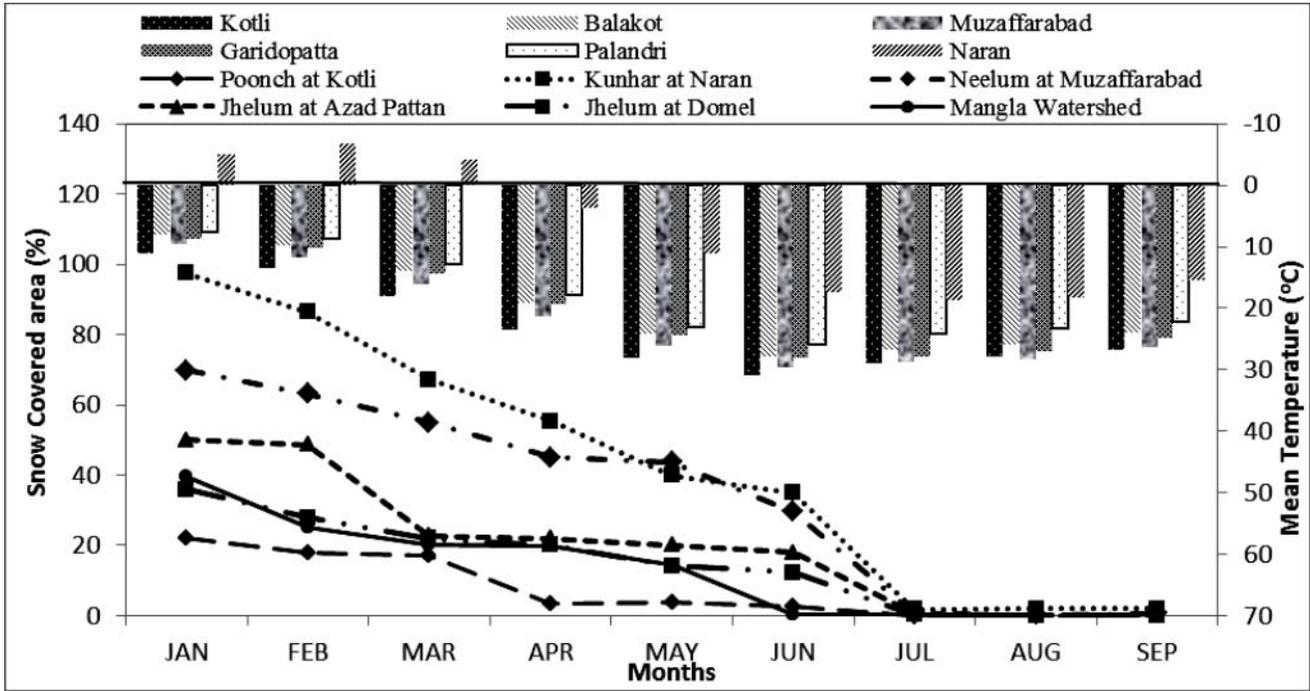


Fig. 3 Month-wise distribution of snow covered area and mean temperature in sub-basins of Mangla watershed.

b) Seasonal Temperature

Analysis of seasonal temperature provided a better understanding of climate change in the study area. Trends in seasonal mean temperature are given in Table 2 and percentage of change (as a % of data period average) is shown in Fig.5. This table and figure showed that the mean temperature in spring, winter and autumn has been increased whereas the summer temperature has decreased for the period 1961-2010.

Warming trends in winter were observed at all sites except Kotli, Murree, Gujar Khan, Mangla and Naran for the period 1961-2010. The trends in winter season for 1st period were experienced in downward direction (cooling trends) at all the sites except Murree and Srinagar whereas in 2nd period most of trends were positive as given Table 2.

In spring season, the behavior of trends was the same as were in winter season. The warming trends were observed in whole period (1961-2010) and the 2nd period where in 1st period nine sites showed the cooling trends. Only Naran showed the cooling trend for the 2nd period at the rate of 2.28 °C per decade at 99.9% significance level. The spatial distribution of

trends in spring season for period (1961-2010) is shown in Fig.5b. Table 2 reveals the slope of trends in 2nd period was quite high than the 1st and whole period.

In summer season, the behavior of temperature trends was not consistent. Eight and five sites showed the warming trends in whole and 2nd period respectively whereas nine sites showed the cooling trends for the 1st period. Garidopatta, Murree, Bagh and Kallar showed cooling trends in the 1st period whereas these stations have changed the nature of trends (into positive) in the 2nd period. Fig.5c clearly shows that the summer temperature has increased 2-6% of mean temperature per decade in the region of Garidopatta, Rawalakot and its surrounding whereas rest of Mangla watershed, the summer temperature has reduced upto 6% per decade.

3.2 Changes in Precipitation

a) Annual Precipitation

Trends in annual precipitation for the period 1961-2010 showed non-consistent trends. Only three significant trends out of five decreasing trends were found at Garidopatta, Kotli and Palandri that have

Table 2 Trends and changes in annual and seasonal mean temperature, precipitation and stream-flows for periods (1961-2010), (1961-1985) and (1986-2010).

River & Flows Station	Climatic Station	Precipitation Changes (% of Data Period average)			Temperature Changes (% of Data Period average)			Runoff Changes (% of Data Period average)		
		61-10	61-85	86-10	61-10	61-85	86-10	61-10	61-85	86-10
Annual Analysis										
Kanshi at Palote	Kallar	-15	15***	-19***	9**	3	3	-41	21	-46
Poonch at Kotli	Kotli	-2*	3	-12***	1*	-8	2	-5	-1	-32
Kunhar at Naran	Naran	15***	0	-21***	-16***	-14**	-12+	0.0	-7	1
Kunhar at Garhi-Habibullah	Balakot	1	18**	-7	-2+	-0.1	3+	-34	11	-43
Neelum at Muzaffarabad	Muzaffarabad	3*	-7*	-4*	2+	-3+	5*	-24	4	-43
Jhelum at Chinari	Garidopatta	-6***	19***	-8*	6***	-2	-9***	-24	2	-32
Jhelum at Domel	Domel	-13	-7	-35	1	2	-4**	-16	-4	-25
Jhelum at Azad Pattan	Palandri	-7**	7+	-20***	-1	6	-4*	-45	10	-51
Spring Analysis										
Kanshi at Palote	Kallar	-3	19	-37**	20***	5	8	-19	9	-35
Poonch at Kotli	Kotli	-4	18	-26***	2	-17*	2**	-22	-7	-37
Kunhar at Naran	Naran	14*	-18**	-34***	-8***	-24*	-16***	-2	-15	-3
Kunhar at Garhi-Habibullah	Balakot	-7**	9	-29***	5*	1	9*	0	5	-5
Neelum at Muzaffarabad	Muzaffarabad	0	-5	-32***	6*	-1	11**	-6	2	-11
Jhelum at Chinari	Garidopatta	-13***	-19+	-38***	-9**	1	-17***	-14	11	-16
Jhelum at Domel	Domel	5	24	-42	3**	-5***	4**	-17	9	-22
Jhelum at Azad Pattan	Palandri	-13**	-8	-47***	3	-2	16**	-10	8	-11
Summer Analysis										
Kanshi at Palote	Kallar	-3	11	-2	1	-1	3+	-51	-6	-58
Poonch at Kotli	Kotli	-1	14	-7*	-1***	-2***	-1	21	16	-32
Kunhar at Naran	Naran	8	29**	-12*	-2**	-2+	-1	7	-16	-20
Kunhar at Garhi-Habibullah	Balakot	4+	27	5	-1	0	-1	-11	4	-12
Neelum at Muzaffarabad	Muzaffarabad	3	7	1	-1 ⁺	-4***	2+	-11	-17	-76
Jhelum at Chinari	Garidopatta	-5***	-17**	-4	-1 ⁺	-2*	-4*	-19	-43	-17
Jhelum at Domel	Domel	29***	-16	-38***	1	1**	0.3	7	-26	-11
Jhelum at Azad Pattan	Palandri	-9***	6	-13***	-1	1 ⁺	-6***	-33	8	-36

***Significance level <= 99.9%, **Significance level <= 99%. *Significance level <= 95%. +Significance level <= 90%. Bold = Negative trend.

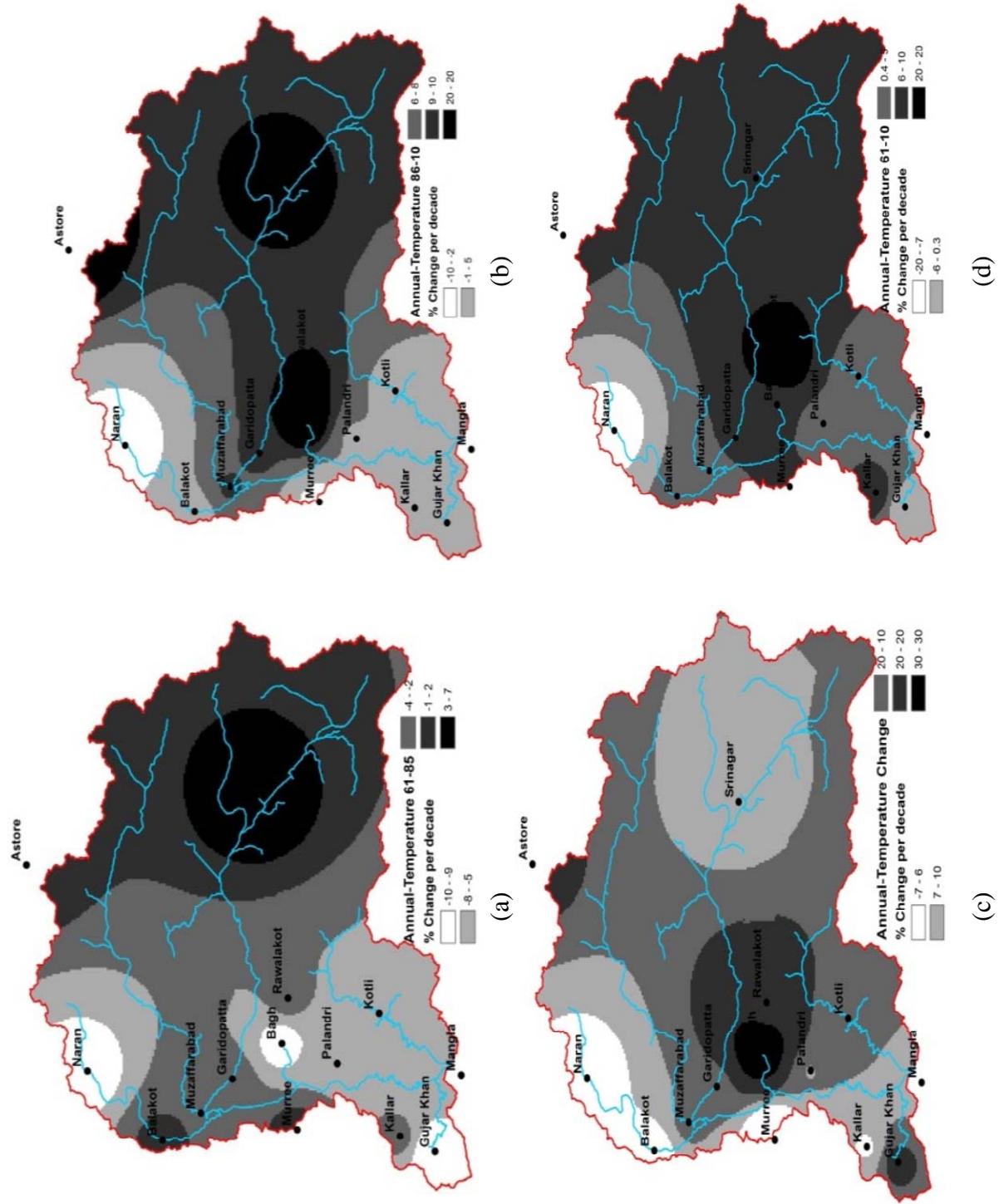


Fig.4 Spatial distribution of trends in annual mean temperature for different periods in climatic stations of Mangla Watershed showing % change per decade as a % of data period average (a) for period 1961-1985, (b) for period 1986-2010, (c) for period 1961-2010 and (d) % change per decade in difference of 1st and 2nd period.

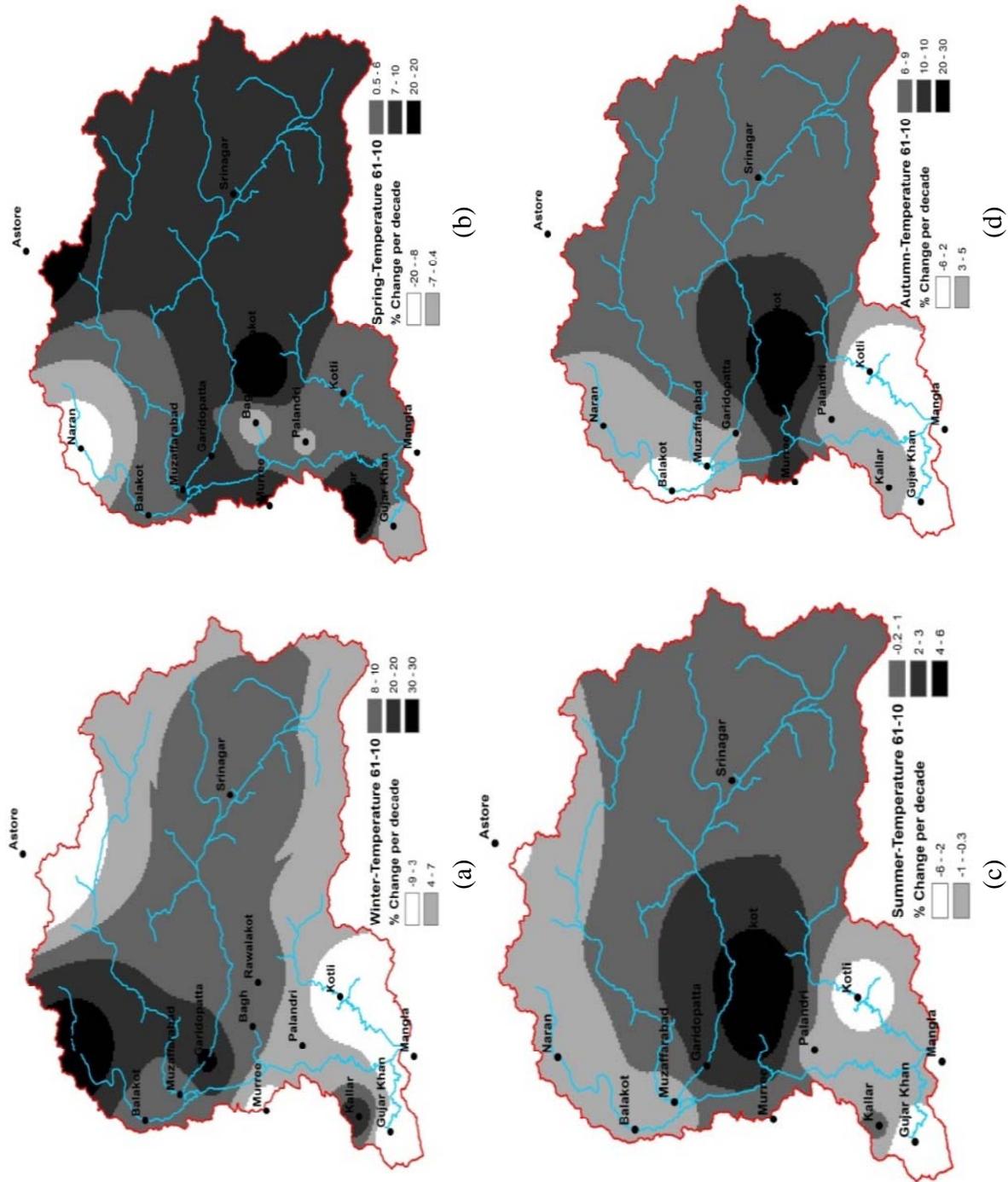


fig. 5 Spatial distribution of trends in seasonal mean temperature in climatic stations of Mangla Watershed showing % change per decade as a % of data period average (a) winter (DJF), (b) Spring (MAM), (c) Summer (JJA) and (d) Autumn (SON).

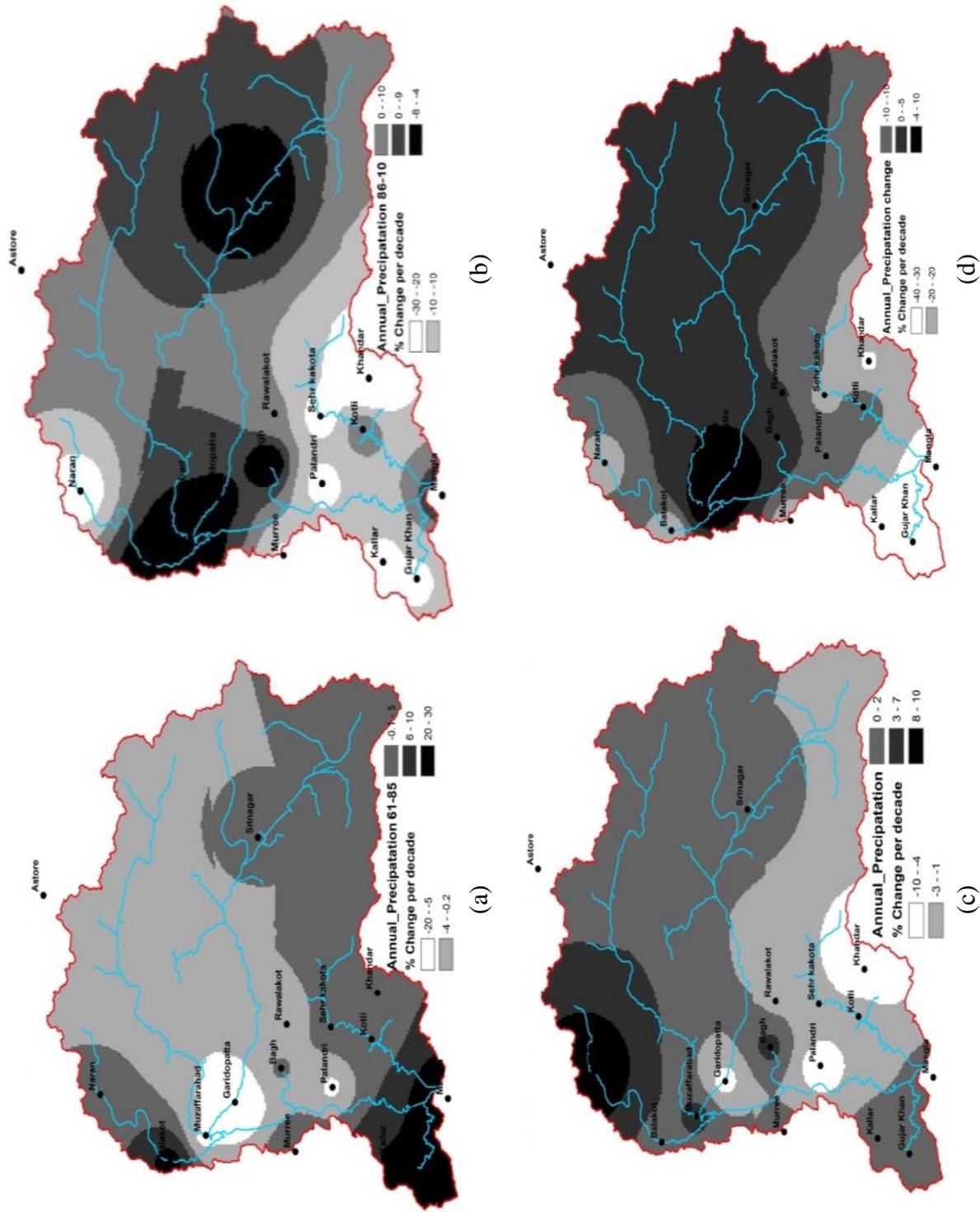


Fig. 6 Spatial distribution of trends in annual Precipitation for different periods in climatic stations of Mangla Watershed showing % change per decade as a % of data period average (a) for period 1961-1985, (b) for period 1986-2010, (c) for period 1961-1985 and (d) % change per decade in difference of 1st and 2nd period.

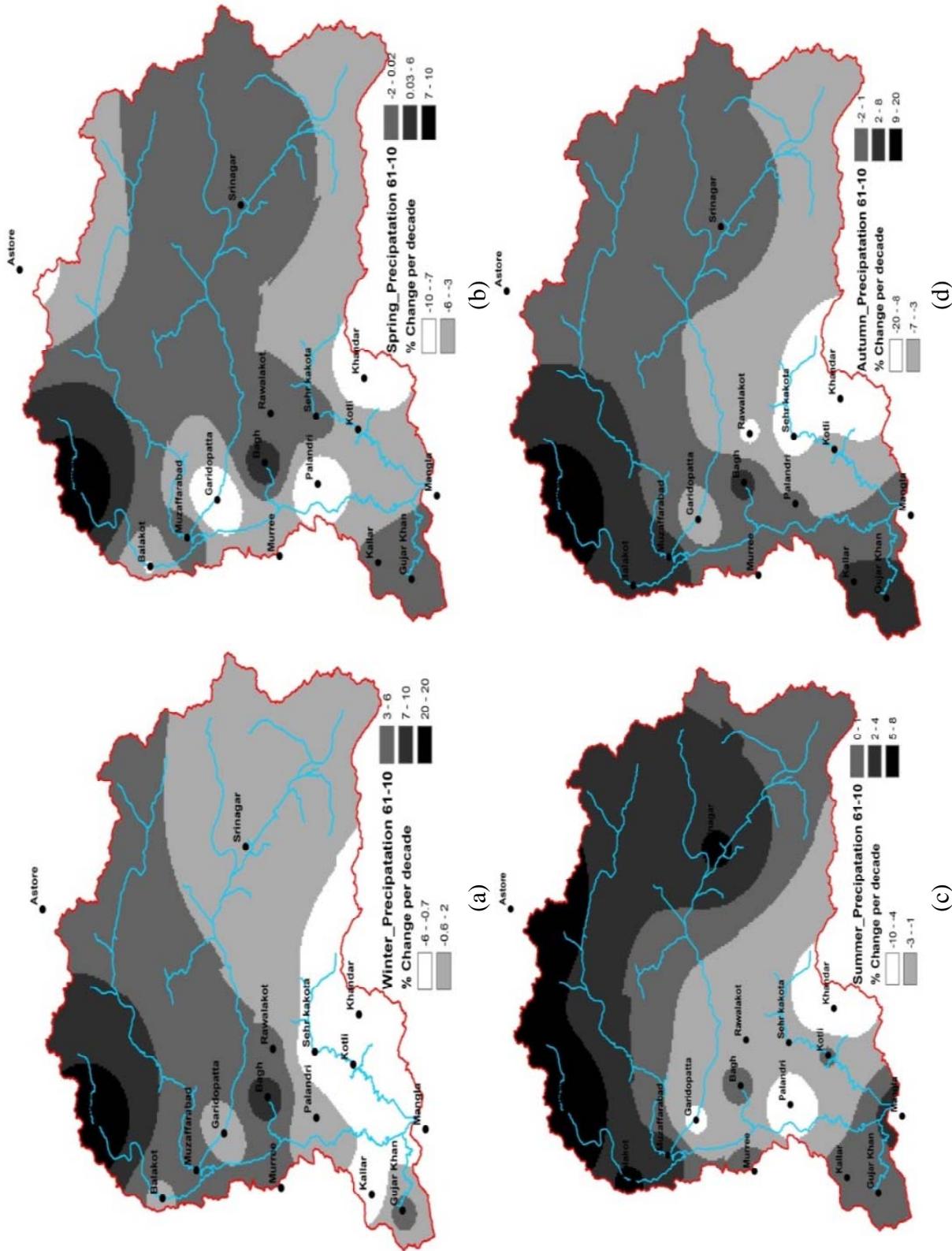


Fig.7 Spatial distribution of trends in seasonal Precipitation in climatic stations of Mangla Watershed showing % change per decade as a % of data period average (a) winter (DJF), (b) Spring (MAM), (c) Summer (JJA) and (d) Autumn (SON).

decreased up-to 6, 2 and 7% of their average precipitation respectively whereas have increased significantly at Muzaffarabad, Bagh and Naran at the rate of 3, 3 and 15% per decade respectively. Spatial distribution of annual trends for period 1961-2010 is shown in Fig.6c. From this figure it can be seen that annual rainfall has increased upto 2% per decade in the Kanshi and Neelum basins whereas it has decreased in the Poonch basin upto 10% of its average rainfall per decade. In the Kunhar basin, highest increasing trend in annual rainfall was found upto 10% per decade for the period 1961-2010.

When the analysis was performed in two periods, an alarming situation was found that decreasing trends were found at all the sites for the 2nd period (1986-2010) whereas only three significant decreasing trends were found in the 1st period as represented by Table 2 and shown in Fig.6a & b. The results of this analysis showed that rainfall has decreased upto 40% of its mean value per decade in Kanshi basin as shown in Fig.6d. The rainfall also decreased in Poonch and Kunhar basins ranging from 10-20% per decade from 1st period to 2nd period whereas in Neelum and remaining other part of Jhelum basin the rainfall has increased upto 10% of their mean rainfall per decade.

b) *Seasonal Precipitation*

The interpolated linear slopes for winter (Fig. 7a) show negative slopes in the Poonch and Kanshi basins for the whole (1961-2010) and 2nd (1986-2010) periods whereas for the 1st period (1961-1985) these basins showed positive slopes. Increasing trends of precipitation was seen in Neelum, Kunhar and higher part/region of Jhelum basins for the whole period while for the 2nd period these showed the negative slopes.

For the spring season, the falling trends in the Kanshi and Poonch basins were found over the whole and 2nd period while for the first period it was found in increasing trend in Kunhar, Neelum and higher part/region of Jhelum basins. Rainfall has decreased for the 1st and 2nd periods while it has increased over the whole period.

Based on the interpolated surface of summer slopes positive slopes were generally present in the Kunhar, Neelum and higher region of Jhelum basins over the whole and 1st period (Fig. 7c) whereas for

the 2nd period it has increased. Only in small part of Poonch and Jhelum at Garidopatta, Bagh and Rawalakot, the rainfall has decreased in the 1st period while in the remaining region it has increased. But for the 2nd period rainfall has declined over the whole watershed except in Balakot region up-to 18% per decade of the mean rainfall.

3.3 Impact of Climate Change in Stream Flows

Regression analysis has been performed between annual & seasonal streamflow, mean temperature and precipitation for the eight sites of Mangla watershed.

3.3.1 Annual Analysis

Correlation coefficients between annual streamflow & temperature, streamflow & precipitation and temperature and precipitation for three periods 1961-2010, 1961-1985 and 1986-2010 are shown in Fig.9. The correlation coefficient (r) between the annual streamflow and temperature was negative at all river sites apart from only for River Kunhar at Naran as shown in Fig.8 for period 1961-2010. The mean temperature in all sub-basins except Naran of Mangla watershed has the positive trends and temperature has been increased for the period 1961-2010 and 1986-2010 and impact of this increased temperature leads to the decreased streamflows as given in Table 2.

The annual streamflow in River Kanshi, Poonch, Kunhar, Neelum, and Jhelum at Chinari, Domel and Azad Pattan has decreased up-to 41, 5, 34, 24, 24, 16 and 45% respectively with increased in 1 °C annual mean temperature for the period 1961-2010. On the other hand, trends in annual mean temperature showed cooling trend for the period 1961-1985 and yield increased streamflow for River Palote, Kunhar at Talhata, Neelum and Jhelum at Chinari, Domel and Azad Pattan up-to 21, 11, 4, 2, 4, and 10% respectively. In 2nd period, the annual mean temperature and precipitation has increased in all basins and the annual streamflows in River Kanshi, Poonch, Kunhar, Neelum, and Jhelum at Chinari, Domel and Azad Pattan have decreased up-to 46, 32, 43, 43, 32, 25 and 51% respectively. The comparison of trends and % changes in annual mean average temperature & streamflows for periods (1961-2010), (1961-1985) and (1986-2010) are shown in Fig.9.

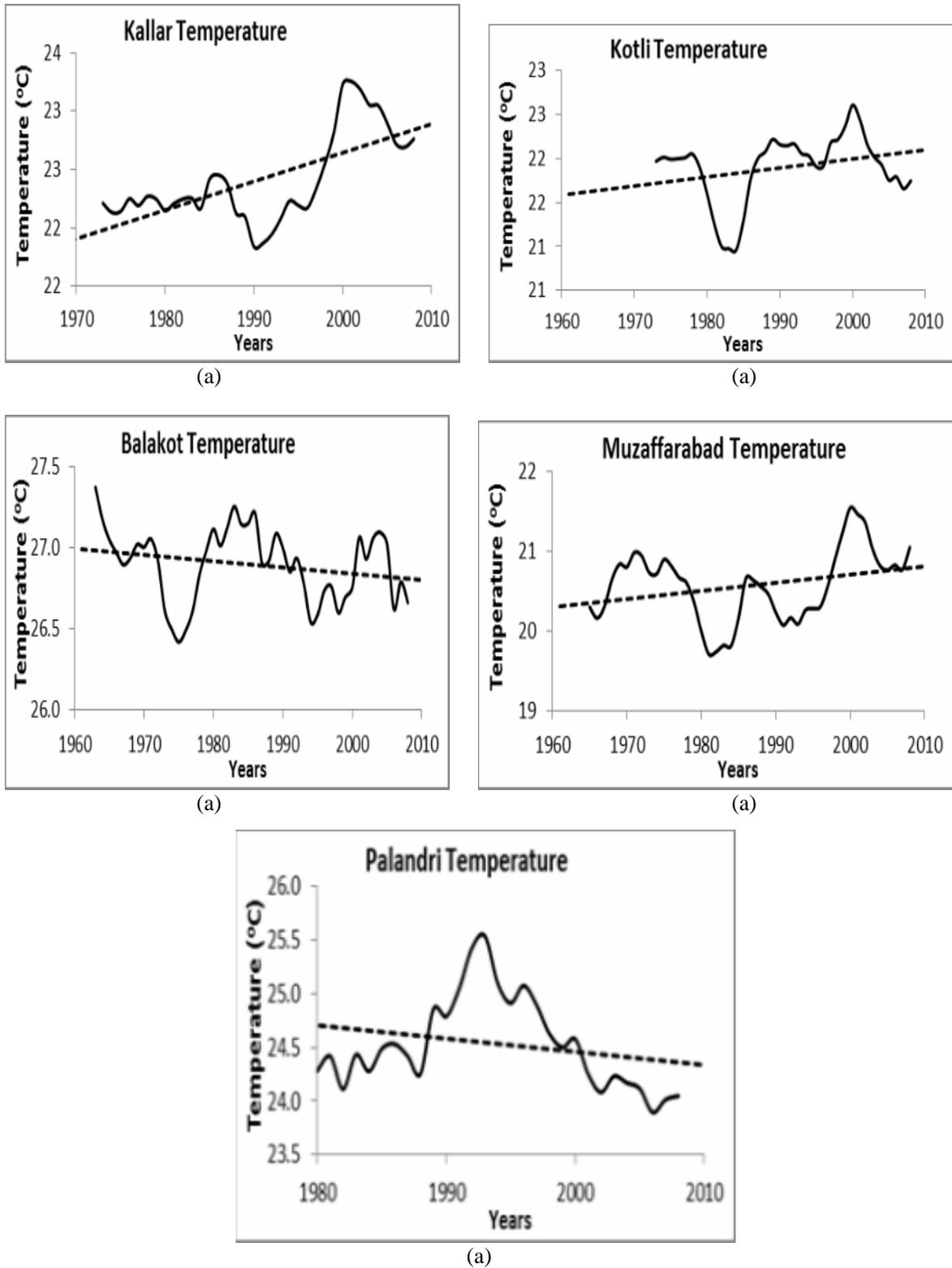
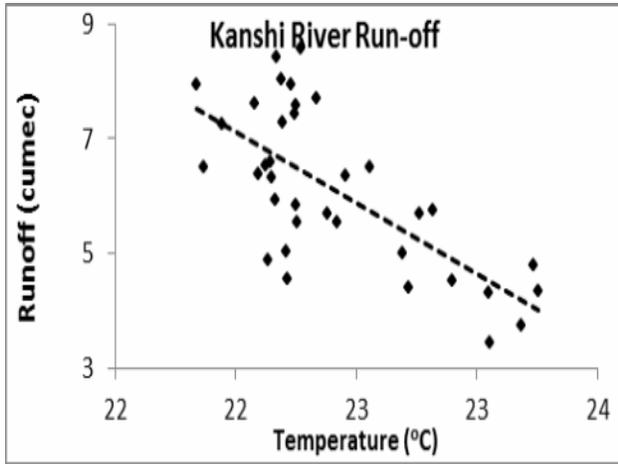
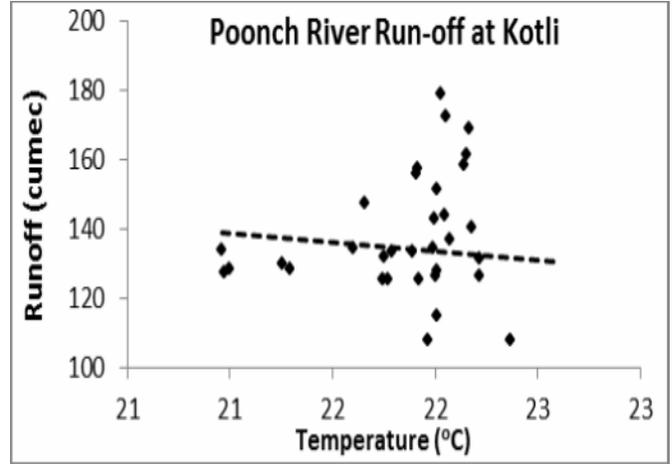


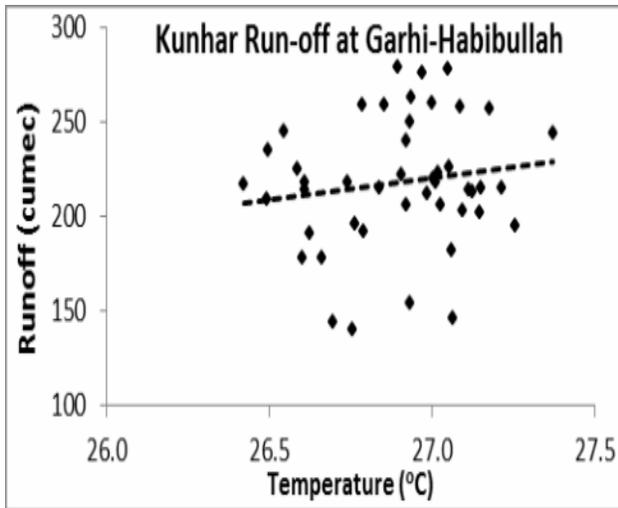
Fig.8 Relationship between annual mean temperature and run-off in sub-basins of Mangla watershed (a) temperature trend; (b) relationship between annual temperature and streamflow (cumec); and (c) time series of annual streamflow.



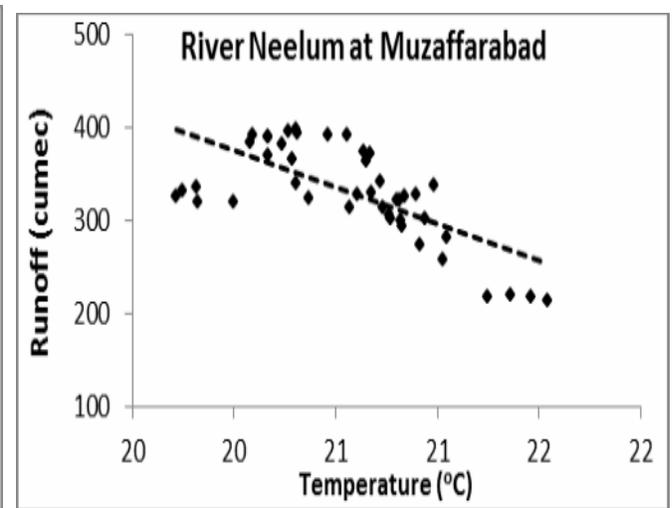
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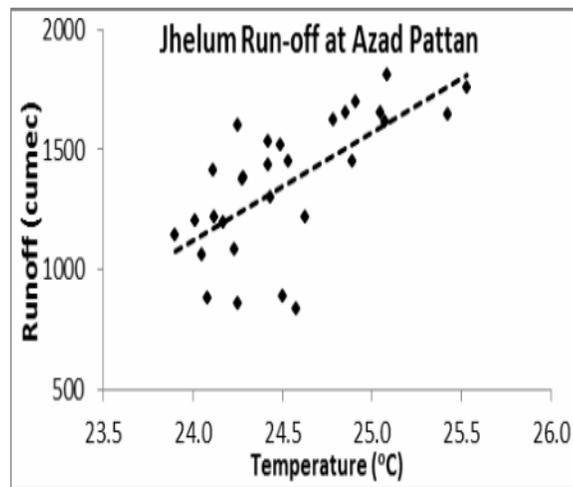
(b)



(b)

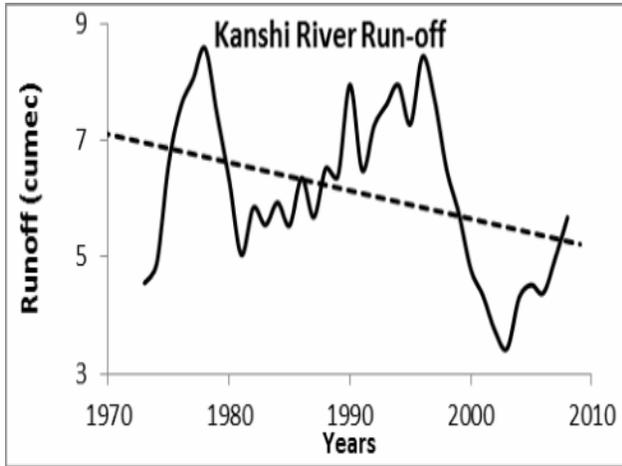


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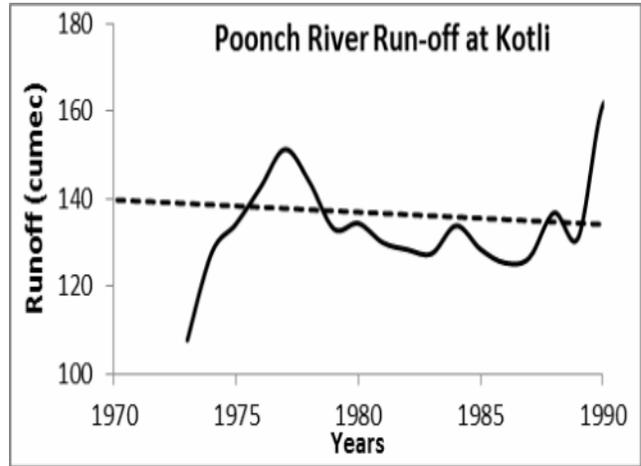


(b)

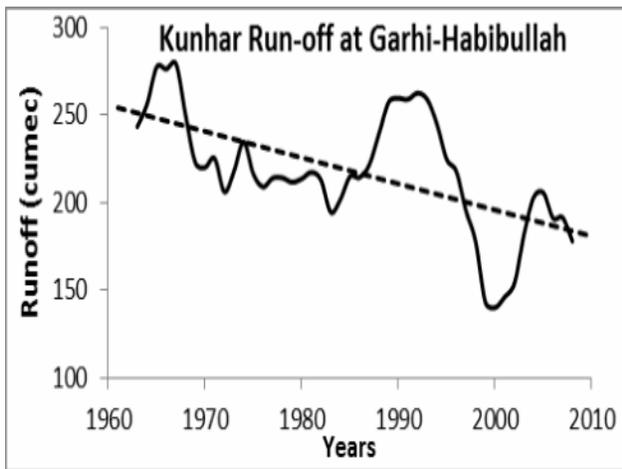
Fig. 8 (Continue)



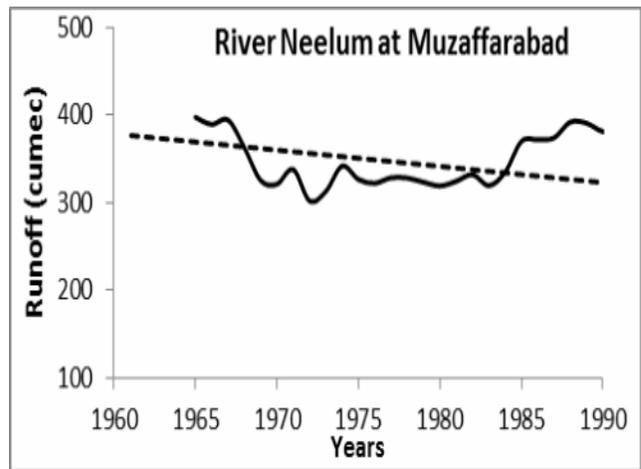
(c)



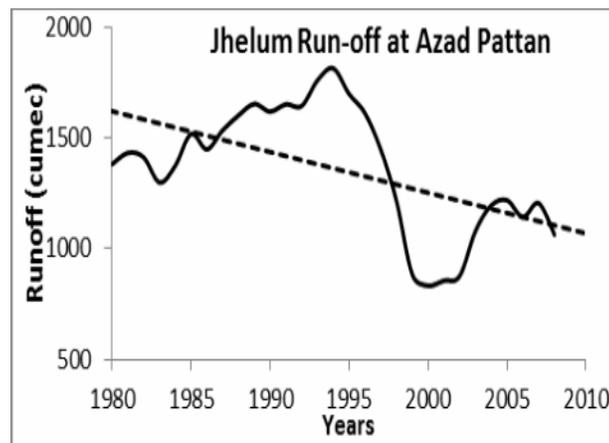
(c)



(c)



(c)



(c)

Fig. 8 (Continue)

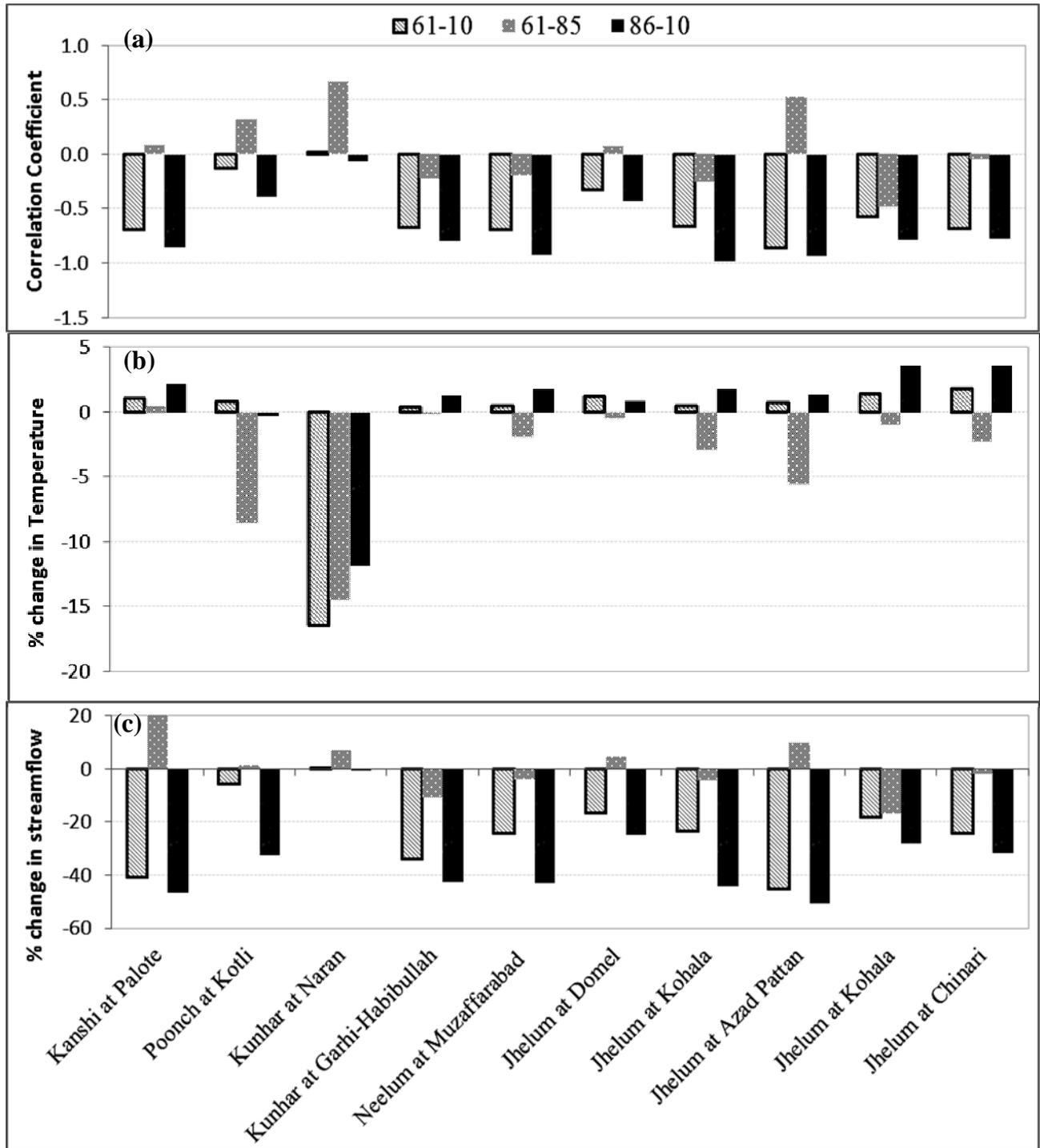


Fig. 9 Comparison of (a) correlation coefficient between temperature and streamflow, (b) % changes in annual mean temperature & (c) % changes in annual streamflow for periods (1961-2010), (1961-1985) and (1986-2010).

3.3.2 Seasonal Analysis

Spring seasonal correlation coefficient between mean temperature and streamflows has negative correlation in all sub-basins of Mangla watershed except in Naran for the whole 2nd period. In spring season, the mean temperature has increased upto different percentage of mean stations temperature and the precipitation has decreased for the whole and the 2nd period and this leads to decrease the streamflows for these periods as given in Table 2. On an average assumed that 1 °C temperature has increased in the study area and this impact on the streamflows as: the streamflow in Rivers Kanshi, Poonch, Kunhar (at Naran), Neelum and Jhelum (at Azad-Pattan) has reduced upto 19, 22, 2, 6 and 10% respectively for the whole period.

For 2nd period, the streamflow in Rivers Kanshi, Poonch, Kunhar (at Garhi-Habibullah), Neelum, and Jhelum (at Azad-Pattan) has been reduced upto 35, 37, 5, 11 and 11% in spring season by warming of 1 °C temperature. On the other hand, there was a reverse situation for the 1st period in the spring season. Mean temperature was in warming position in all sub-basins of the Mangla watershed. Only the Poonch basin showed the decreased flows for this period upto 7% per decade with decreased temperature of 17% per decade. Streamflow in Rivers Kanshi, Kunhar (at Garhi-Habibullah), Neelum, Jhelum at all sites (Chinari, Domel and Azad Pattan) was in increasing order at the rate of 9, 5, 2, 11, 9 and 8% per decade with decreased of 1 °C mean temperature. From these results it is clearly implicit that climate change is occurring in warming nature in the 2nd period and this yields the decreased streamflows.

In summer season, the mean temperature has increased in Kanshi basin upto 1% (0.01 °C per decade) of mean temperature and this effect on the streamflow that flows has decreased upto 25% per decade for the whole period. But in the other basins the mean temperature has decreased upto 1°C per decade and the stream flows in Rivers Poonch, Kunhar (at Garhi-Habibullah), Neelum and Jhelum (at Azad Pattan) has decreased upto 2, 11, 11 and 33% per decade respectively for the whole period. Similarly in the 2nd period the streamflows has decreased upto 29, 32, 12, 46 and 36% per decade in

Rivers Kanshi, Poonch, Kunhar, Neelum and Jhelum (at Azad Pattan) respectively.

Table 2 illustrates that the trends of temperature in spring season were warming in all-over the basin and this yields to lesser decreased runoff as compared to summer season. The comparison of % change in summer (JJA) & spring (MAM) mean average temperature and streamflows for period 1961-2010 is shown in Fig.10.

4. Conclusions

Overall conclusion of this investigation is that climate is changing in warming term in the last period and this yields decreased streamflows. Specific conclusions of this study are as follow:

- The snow-covered area in Mangla watershed is ranging from 45 to 20% in months of January to March whereas Kunhar and Neelum basins have more percentage of the snow-covered area as compared to other basins.
- The annual mean temperature has increased in most of the region for the period (1961-2010). The analysis of the two periods reveals that trends in 1st data period (1961-1985) were experienced more warming in most of the region whereas the 2nd period (1986-2010) showed more cooling trends.
- The mean temperature in spring, winter and autumn has been increased whereas the summer temperature has been decreased for the period 1961-2010.
- Trends in annual precipitation for the period 1961-2010 were not consistent. A distressing situation has noticed that decreasing trends were found at all sites for the 2nd period (1986-2010) whereas only three significant decreasing trends were found in 1st period.
- The annual streamflows in rivers Kanshi, Poonch, Kunhar, Neelum, and Jhelum at Chinari, Domel and Azad Pattan have reduced upto 41, 5, 34, 24, 24, 16 and 45% respectively with increased of 1°C annual mean temperature for the period 1961-2010. On the other hand, trends in annual mean temperature showed cooling trend for the first period and this yield

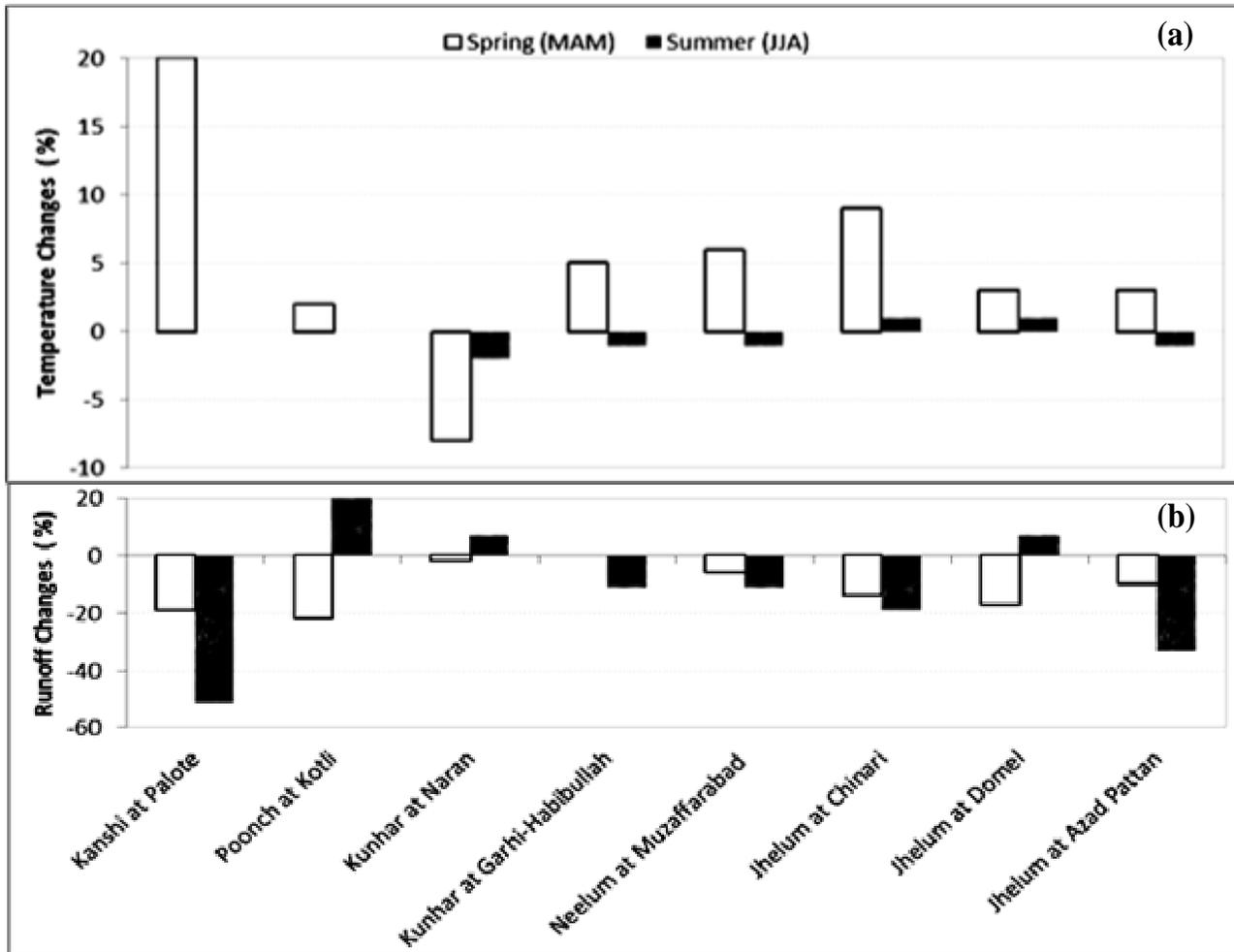


Fig. 10 Comparison of % change in summer & spring (a) mean temperature and (b) run-off for the period 1961-2010.

- increased streamflows for rivers Palote, Kunhar at Talhata, Neelum and Jhelum at Chinari, Domel and Azad Pattan upto 21, 11, 4, 2, 4, and 10% respectively. In the 2nd period, the annual mean temperature has increased in all basins and the annual streamflows in rivers Kanshi, Poonch, Kunhar, Neelum, and Jhelum at Chinari, Domel and Azad Pattan have reduced upto 46, 32, 43, 43, 32, 25 and 51% respectively.
- In 2nd period the streamflows in rivers Kanshi, Poonch, Kunhar (at Garhi-Habibullah), Neelum, and Jhelum (at Azad-Pattan) have reduced upto 35, 37, 5, 11 and 11 % in spring season by

warming of 1 °C temperature in Mangla watershed. On the other hand, there was a reverse situation in the 1st period (1961-1985) for the spring season.

- The summer mean temperature has decreased upto 1°C per decade and the streamflows in rivers Poonch, Kunhar (at Garhi-Habibullah), Neelum and Jhelum (at Azad Pattan) have decreased upto 2, 11, 11 and 33% per decade respectively for the whole period. Similarly in the 2nd period the streamflows have reduced upto 29, 32, 12, 46 and 36% in Rivers Kanshi, Poonch, KunhSar, Neelum and Jhelum (at Azad Pattan) respectively.

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